In the Matter Of:

REGENTS OF THE UNIVERSITY OF MINNESOTA

-vs-

LSI CORPORATION, ET AL.

EMINA SOLJANIN

May 09, 2018

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Exhibit #

UMN Exhibit 2008

06/12/20 - AB

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UMN EXHIBIT 2008
LSI Corp. et al. v. Regents of Univ. of Minn.
IPR2017-01068

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF CALIFORNIA
SAN JOSE DIVISION
Civil Action No. Civ. 5:18-cv-00821-EJD-NMC
---x
REGENTS OF THE UNIVERSITY OF MINNESOTA,

Plaintiff,

-against-

LSI CORPORATION and AVAGO
TECHNOLOGIES U.S. INC.,

Defendants.
---x

May 9, 2018
8:58 a.m.

Deposition of EMINA SOLJANIN taken by Plaintiff pursuant to Notice, held at the offices of K&L Gates LLP, 599 Lexington Avenue, New York, New York, before Frank J. Bas, a Registered Professional Reporter, Certified Realtime Reporter and Notary Public of the State of New York. Job WDC-170935

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A P P E A R A N C E S:

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MR. VERDINI: Chris Verdini and Mark Knedeisen of K&L Gates on behalf of the plaintiff, Regents of the University of Minnesota.

MR. SIPIORA: David Sipiora and Ted Mayle from Kilpatrick Townsend. We represent the defendant LSI and Avago.

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E M I N A S O L J A N I N,
called as a witness, having been first duly sworn, was examined and testified as follows:

EXAMINATION BY
MR. VERDINI:

Q. Good morning, Professor.
A. Good morning.
Q. Can you state your full name for the record?
A. Emina Soljanin.
Q. What is your residential and business address?
A. My residential address is 26 Britten Road, Green Village, New Jersey 07935.

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USA.
Q. And your business address?
A. It's 94 Brett Road, Piscataway, New Jersey, Rutgers University.
Q. Professor, you understand that you're under oath today, correct?
A. Yes.
Q. And are you represented by counsel?
A. Am I represented?
Q. Yes.
A. No.
Q. Is there any reason that you can't be truthful and accurate in your testimony today?
A. No.
Q. Are you on any medications that would affect your memory or your ability to give testimony today?
A. No.
Q. Have you ever been deposed before?
A. No.
Q. All right. So this your first time so I'll go over a little bit of ground

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rules. The court reporter who is sitting to your left is writing down everything that we say, okay?
A. (Nodding head affirmatively.)
Q. So that's going to be the first rule. He can't take down shakes of the head, so all of your answers have to be verbal. Okay?
A. Yes.
Q. And because he's writing down what is said, when appropriate answer yes or no as opposed to "uh-huh" or "uh-uh," because that's not entirely clear when it's written down. Okay?
A. I understand.
Q. If you don't understand a question that I've asked can you let me know so that I can try to rephrase. Okay?
A. Yes.
Q. And if you don't, I will assume you understand the question. Okay?
A. Yes.
Q. The other thing in normal conversation sometimes you know where my question is headed and you may want to talk

over me, that makes it very difficult for the court reporter. So if you could let me finish my question first before you answer, and I'll let you answer before I ask my next question so that the transcript is clear. Okay?
A. Yes.
Q. And lastly, if you need a break at any time just let me know. If there's a question pending I may ask you to answer that question before we take the break, but we'll accommodate your break request as soon as we can. All right?
A. Yes.
Q. What did you do to prepare for today's deposition?
A. I reviewed the documents and I met with Mr. Mayle and Mr. Sipiora.
Q. What documents did you review?
A. I reviewed original patent, '601. I reviewed my declaration. I looked into court cases.
Q. When you say you looked --
A. Case histories. Sorry.
Q. Sorry. Go ahead?
A. Case histories, I think they're

called.
Q. Case histories.
A. Right.
Q. When you say you looked at case histories, what are you referring to specifically?
A. This was a file that included my previous declaration and description of -- of the background material for the patent, and also the provisional application, and the declaration of Professor McLaughlin.
Q. Who prepared the case history?
A. Mr. Sipiora and Mr. Mayle.
Q. Did you have any input into what was put into the case history that you reviewed in preparation for today?
A. No.
Q. You also said you met with Mr. Mayle and Mr. Sipiora, is that correct?
A. Yes.
Q. When was that?
A. Yesterday.
Q. And for how long?
A. From 10 a.m. until 3 p.m.
Q. You've been retained in this

case to provide expert testimony on behalf of the defendants LSI and Avago, is that your understanding?
A. Correct.
Q. Do you know when you were retained?
A. I believe it was the fall of 2016. I don't remember exact day.
Q. And in connection with your work for LSI and Avago in this case have you worked with anybody else?
A. No.
Q. Have you ever been retained by LSI or Avago to provide expert testimony in any other case?
A. No.
Q. What about a company called Broadcom Limited?
A. No.
Q. And have you provided expert testimony in any other patent case prior to this one?
A. No.
Q. All right.
MR. VERDINI: I am going to

introduce just a few exhibits so that you'll have them in front of you, the ones that we'll be referring to.

(Deposition Exhibit 1, U.S. patent number 5,859,601 was marked for identification)

BY MR. VERDINI:
Q. I am going to hand you what has been marked as exhibit 1.
Professor, do you recognize exhibit 1 as U.S. patent number 5,859,601?
A. I do.
Q. And you understand that this is the patent that's being asserted by the university against LSI and Avago in this case?
A. I do.

(Deposition Exhibit 2, joint claim construction and prehearing statement was marked for identification)

BY MR. VERDINI:

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Q. I hand you what has been marked as exhibit 2. Professor, do you recognize exhibit 2?
A. I do.
Q. And what do you understand it to be?
A. It's my signed declaration.
Q. Almost. Exhibit 2 is the joint claim construction and prehearing statement that the parties filed without the exhibits.
A. Oh, I see.
Q. One of the exhibits is your declaration. Have you seen just the main document, the joint claim construction and prehearing statement before today?
A. Yes.

(Deposition Exhibit 3, declaration of Professor Emina Soljanin was marked for identification)

BY MR. VERDINI:
Q. And last one for now, I am going to show you what has been marked as

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exhibit 3. Professor, do you recognize exhibit 3 as your declaration that you submitted in connection with the joint claim construction and prehearing statement that was marked as exhibit 2?
A. The first part of it, yes. And then there are appendices, it seems.
Q. Pardon?
A. There is declaration followed by an appendix.
Q. Right. And your declaration incorporates the appendices that are attached or part of exhibit 3, correct?
A. Yes.
Q. If you turn to page 15 of your declaration. On page 15, is that your signature at the bottom of the page?
A. Yes, it is.
Q. And in paragraph 60 you declared under penalty of perjury that what you identified in the, or what you stated in the declaration was true and correct, right?
A. Yes.
Q. On exhibit 3, if you would turn to paragraph 1. In the introduction you wrote

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(as read):
I have been engaged as an expert on behalf of LSI corporation and Avago Technologies U.S. Inc. (collectively, defendants or LSI) in the above referenced case and in the inter partes review, IPR proceeding involving the in patent-in-suit.
Is that an accurate statement, that you have been engaged not only for the district court litigation but also for the IPR proceeding?
A. Yes.
Q. And is it correct that you submitted a declaration in that IPR proceeding?
A. Yes.
Q. And in that declaration your opinion was that certain prior art references invalidated the claims of the '601 patent, correct?
A. Yes.

(Deposition Exhibit 4, declaration of Professor Emina Soljanin regarding U.S. patent No. 5,859,601 was marked for identification)

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BY MR. VERDINI:
Q. I am going to hand you what has been marked as exhibit 4. Professor, do you recognize what's been marked as exhibit 4 as the declaration that you submitted in the IPR proceeding referenced in paragraph 1 of your declaration in this district court litigation?
A. Yes.
Q. And on page 2 of that declaration, using the numbers in the bottom right, that's your signature at the bottom, correct?
A. Yes.
Q. It's dated March 9, 2017, correct?
A. Yes.
Q. So that was before the joint -- the declaration that you submitted in connection with claim construction in the district court litigation, correct?
A. Correct.

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Q. And on page 2 above your signature you declare and state that the statements in the declaration are true to the best of your information and belief, and made under penalty of perjury, correct?
A. Correct.
Q. Let's go back to -- we're going to look at exhibit 4 throughout today so you can put it to the side for now, but let's go back to exhibit 3. And if you would turn to paragraph 3. And does paragraph 3 reflect the opinion that you are giving in the district court litigation in connection with claim construction?
A. Yes.
Q. And your opinion is that the asserted claims, which are claims 13, 14 and 17, are indefinite under 35 USC section 112(b), correct?
A. Yes.
Q. Now if you would turn to exhibit 2, and go to page 3, please. In the paragraph that states LSI intends to rely on, do you see that?
A. Yes.

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Q. Is it your understanding that your testimony will be offered only on the issue of indefiniteness and not for purposes of general claim construction?
MR. SIPIORA: Well, that's really a question for counsel, and I can confirm that's the case.
MR. VERDINI: Okay. And I'll ask it, and you can confirm.
BY MR. VERDINI:
Q. You are not providing any testimony on any of the alternate constructions that LSI has offered to the extent that a claim identified by you as indefinite, determines that it's not indefinite, is that correct?
MR. SIPIORA: Professor Soljanin is only offering opinions that are in her report and she does not opine on those subjects.
MR. VERDINI: Okay.
MR. SIPIORA: In her report. Obviously later in the case --
MR. VERDINI: Correct. In connection with claim construction --

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MR. SIPIORA: Today's deposition, yes.
MR. VERDINI: And the claim construction briefing, she'll be limited --
MR. SIPIORA: Correct.
MR. VERDINI: -- to the indefiniteness opinions that are in her declaration that's been marked as exhibit 3?
MR. SIPIORA: That's accurate.
BY MR. VERDINI:
Q. So go back to exhibit 3, which is your declaration in the district court litigation of claim construction, and turn to paragraph 5 which is on page 2. In paragraph 5 you write I am being compensated at a rate of $420 per hour for my consulting services, including the preparation of this declaration.
Is that an accurate statement?
A. Yes.
Q. And is $420 per hour a regular rate for your consulting services?
A. I cannot -- I don't have anything else to compare with.

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Q. This is the first time that you've consulted in this forum, is that correct?
A. Correct, yes.
Q. How many hours did you spend on preparing the declaration that we've marked as exhibit 3?
A. I don't remember exactly how many hours.
Q. Can you approximate?
A. Not more than ten.
Q. And approximately how many hours did you spend drafting the declaration in the IPR that's attached -- or that we've marked as exhibit 4?
A. This was the declaration that was submitted a year ago?
Q. Yes.
MR. SIPIORA: So I'm going to object, outside the scope. Not relevant to this deposition. And really taking discovery in the IPR. So I object; outside the scope. I can't instruct not to answer, but I'm going to object. Any inquiry that

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looks like discovery in the IPR is not appropriate here. So outside the scope; object.
MR. VERDINI: I think it connects to her declaration in this case, so ...
BY MR. VERDINI:
Q. Can you approximate how many hours you spent on the declaration submitted in the IPR that's been marked as exhibit 4?
A. Not more than ten.
Q. And leaving aside anyone, any lawyer for LSI or Avago, has anyone assisted you with drafting the declaration that's been marked as exhibit 3 in the district court litigation?
A. No.
Q. And the same question with respect to the declaration you submitted in the IPR?
A. No.
MR. SIPIORA: The same objection, outside the scope.
BY MR. VERDINI:
Q. Professor, you were employed by

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Bell Labs from approximately 1995 to 2015, is that right?
A. From September '94 until the end of 2015.
Q. Can you give a brief description of what Bell Labs is?
A. Bell Labs is research arm of -- well, there are four companies that I went through, and Bell Labs is the research arm of all four.
Q. And what were the four companies that were a part of Bell Labs?
A. First parent company was AT&T. The second parent company was Lucent Technologies. The third parent company was Alcatel Lucent. And the last one was Nokia.
Q. Does Bell Labs currently exist today, to your knowledge?
A. Yes.
Q. And is Nokia still the parent company of Bell Labs?
A. Yes.
Q. Can you describe at a high level what your responsibilities were over the course of the 20 -- about 20 years you were at

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Bell Labs?
A. I was in general conducting research on information theory and coding.
Q. Your declaration refers to some teaching that you did also while you were at Bell Labs, is that correct?
A. Yes.
Q. Can you give me a sense of percentage of the time that you were teaching versus working at Bell Labs?
A. So I worked at Bell Labs for 21 years, and I taught at Brooklyn Poly one semester. At Columbia two-and-a-half semesters. Everything else was less than a week, at a conference, tutorial, something like that.
Q. So a small percentage of your work?
A. Very small.
Q. Do you know Professor Steven McLaughlin?
A. I do.
Q. How long have you known him?
A. I don't know exact date that we met, but I do believe that I know -- I knew

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him very early when I started working at Bell Labs.
Q. And in the course of that time have you ever worked on any research with him?
A. On a research problem, no.
Q. Are you familiar with his research work?
A. Not anymore.
Q. There was a time when you were?
A. There was a time when I heard him give talks, which I don't remember at the moment.
Q. What were the general subject matters, if you recall, of the talks?
A. It was in recording. Information recording.
Q. Have you ever used Professor McLaughlin's research in your work?
A. Not that I remember.
Q. Would you consider him someone skilled in the art in coding and detection?
A. Yes.
Q. And do you respect his work?
A. Yes.
Q. You are currently a professor

at Rutgers?
A. Yes.
Q. What do you teach?
A. Since I started I taught coding theory and probability theory.
Q. To what types of students?
A. Coding theory is a graduate class. Probability theory is an undergraduate class. Sophomore.
Q. Do you still conduct research?
A. Yes.
Q. What percentage of your time now is dedicated to research versus teaching?
A. It's about equally split. At least for the paid hours.
Q. What, generally speaking, is the research that you are currently doing?
A. Generally I work on distributed systems.
Q. Can you say that again? I am sorry?
A. Distributed systems.
Q. What are distributed systems?
A. It can be distributed storage. Distributed computing. Whatever is not done

at the single computer, single machine, but multiple machines.
Q. If you would look at paragraph 12 of your declaration which has been marked as exhibit 3. In paragraph 12 you write -- you are discussing your employment with Bell Labs, correct?
A. Yes.
Q. And you refer to, in the second sentence, that the projects that you worked on include (as read):
Designing the first distance enhancing codes to be implemented in commercial magnetic storage devices.
When you say "distance enhancing codes" what do you mean?
A. These are codes which would cause the distance between the possible sequences that can be received, at the output of the channel to be larger than if it didn't have the code.
Q. And what is the scope of --
MR. VERDINI: Strike that.
BY MR. VERDINI:
Q. You identify specific distance

enhancing code in paragraph 12. What is it? Does it have a name?
A. It did have a name. I don't remember the name that we used.
Q. And you wrote that that distance enhancing code was implemented in commercial magnetic storage devices, correct?
A. Yes.
Q. What commercial magnetic storage devices was it implemented in?
A. That was the late '90s. There were channel chips that we produced. But that's about all I remember.
Q. And you said that "we produced."
When you say we, who are you referring to?
A. Lucent Technologies.
Q. Can you describe -- you said you couldn't name it. Can you describe what the first distance enhancing code was that you are referring to there?
A. It was a code that removed certain strings from all possible sequences.
Q. What strings did it remove?

A. I don't remember which strings were in the first code removed.
Q. The distance enhancing codes that you were working on, were they relevant to peak detectors?
A. No.
Q. Why not?
A. Because at that time peak detectors were not in use anymore.
Q. And so what were the systems that were in use at the time of the distance enhancing codes that you were designing?
A. These were sequence detectors.
Q. And again what was the time frame?
A. The late '90s.
Q. And when you say late '90s, is it '97, '98?
A. So I started working on these codes since I came in '94, and I believe that the first chips were made in about '98. That's to the best of my recollection. I don't claim that to be exact dates.
Q. Moving to paragraph 13 you write (as read):

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According to the University's allegations in the first amended complaint in this case, the alleged invention of the '601 patent is, quote, maximum transition run, end quote, MTR, code featuring a, quote, j constraint, which, quote, imposes a limit on the maximum number of consecutive transitions, end quote, in a binary system.

Is that correct?

A. Yes.

Q. When you say in a binary system what are you referring to?

A. That means that the symbols that are used in sequences are 0's and 1's.

Q. In your opinion what sorts of systems are binary systems?

A. All systems that can either transmit and receive or record, what corresponds to 0's and 1's.

Q. Magnetic storage is a binary system?

A. Yes.

Q. If you turn to exhibit 4, which

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is your IPR declaration. At page -- I am going to use the numbers of the actual declaration as opposed to the numbers that are in the bottom right. So page 4 of your declaration paragraph 13. Do you see that?

A. Yes.

Q. In paragraph 13 you write (as read):

According to the patent owner, the alleged invention of the '601 patent is, quote, maximum transition run, end quote, MTR code, featuring a quote, j constraint, end quote, which, quote, imposes a limit on the maximum number of consecutive transitions that are written to the disk, end quote, of a hard disk drive.

Did I read that correctly?

A. You read correctly.

Q. Yes? You said? I'm sorry. I didn't hear you.

A. I have the same text.

Q. Okay. You would agree comparing what you wrote in paragraph 13 in the IPR declaration to paragraph 13 in your

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claim construction declaration, you changed the word "hard disk drive" to binary system, correct?

A. Changed? I did not have this in mind when I was writing the -- this opinion.

Q. So why did you describe it as being an invention of a hard disk drive in the IPR declaration and change it to -- and describe it as a binary system in paragraph 13 of your claim construction declaration?

MR. SIPIORA: Objection as to form. But you can go ahead and answer. This is a legal thing.

A. I believe here I was looking at the system, at storage, and here I was thinking about mathematics, probably.

Q. You were thinking about?

A. Mathematics, about 0's and 1's.

Q. You used "this" so let's try to be -- and I know you're looking at two different things. When you said you were referring to the system, you were saying in paragraph 13 of your IPR declaration, correct?

A. IPR declaration is this one

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(indicating).

Q. The one that says hard disk drive?

A. Yes.

Q. Okay. And so why did you use hard disk drive in paragraph 13 of the IPR declaration?

A. Because it was about to describe. The invention is about to describe.

Q. And in your mind is hard disk drive the same thing as binary system?

A. Binary systems are a more general form.

Q. So why did you use the more general form in your declaration in connection with claim construction in the district court litigation?

A. That I don't know.

Q. Did you change that language?

A. No. I did not have this in front of me (indicating) when this was done (indicating).

Q. So in connection with drafting your declaration in the claim construction --

MR. VERDINI: Strike that.

BY MR. VERDINI:
Q. In connection with drafting your declaration in the district court litigation relating to claim construction you did not look at your IPR declaration, is that correct?
A. I did not look into this sentence when this sentence was written (indicating).
Q. Do you recall writing the description of the invention in paragraph 13 of your claim construction declaration, which is marked as exhibit 3?
A. I recall discussing this with Mr. Mayle, who made the draft.
Q. And what did you discuss about the reference to binary system?
MR. SIPIORA: Objection; instruct not to answer.
(Instruction not to answer.)
MR. SIPIORA: Attorney work product.
MR. VERDINI: I think she's relied upon it in connection with drafting her opinion. So it should be

something underlying why it's there. So I think that's not privileged.
MR. SIPIORA: I think you're wrong.
MR. VERDINI: You're instructing her not to answer?
MR. SIPIORA: I just did.
BY MR. VERDINI:
Q. Are you going to accept your counsel's instructions?
A. Yes.
Q. Did you rely on counsel to describe the invention as being in a binary system in connection with exhibit 3?
MR. SIPIORA: Professor, I'll just instruct you that any communication you had with counsel in connection with preparing any of the legal documents in this case is covered by the work product doctrine and the rules of the court as not discoverable. So any answer you give, please don't delve into or describe or characterize communications you had with counsel. So I'll just give you

that general instruction.
Can we have the question back, please?
(The reporter read back as follows:
"Question: Did you rely on counsel to describe the invention as being in a binary system in connection with exhibit 3?)"
A. No.
Q. But you did testify that that was something that you discussed with counsel, correct?
MR. SIPIORA: Objection; instruct not to answer.
MR. VERDINI: I think she testified she talked to counsel about it, so that's a yes-or-no question.
MR. SIPIORA: I still am instructing not to answer.
(Instruction not to answer.)
BY MR. VERDINI:
Q. Did you have a discussion with counsel about describing the invention as being in a binary system in connection with

drafting your IPR declaration that's been marked as exhibit 4?
MR. SIPIORA: The same instruction. Instruct not to answer based on attorney work product.
(Instruction not to answer.)
BY MR. VERDINI:
Q. While we're talking about describing the invention of the '601 patent, I am going to show you what has been marked as exhibit 5.

(Deposition Exhibit 5, book entitled Coding and Signal Processing For Magnetic Recording Systems was marked for identification)

BY MR. VERDINI:
Q. Professor, do you recognize what has been marked as exhibit 5?
A. I can read what it is.
Q. Are you familiar with a book entitled Coding and Signal Processing For Magnetic Recording Systems?
A. What do you mean by "familiar"?

Q. I think you wrote a chapter in it. Do you recall that?
A. Yes.
Q. If you turn to the fourth page of exhibit 5. One more page, I think. There you go. This version of the book is, there's a copyright date of 2005, do you see that towards the bottom of the page?
A. Yes.
Q. Do you know when this book was first published?
A. No.
Q. Who would you identify as the audience that this book is intended for?
A. The people in the academia industry who are interested in coding and single processing for magnetic recording systems.
Q. Would it be someone of skill in the art, who would be the intended audience?
A. Yes.
Q. We copied the beginning part of the book and if you turn about three-quarters of the way back you should reach chapter 11. It starts with 11-1 on the bottom right. Are

you there?
A. Yes.
Q. This chapter is entitled modulation codes for storage systems, correct?
A. Yes.
Q. And you and a Brian Marcus are identified as the authors, is that correct?
A. Yes.
Q. Who is Brian Marcus?
A. He's a professor at the University of British Columbia.
Q. And have you worked with him on research before?
A. No.
Q. Have you written chapters about modulation codes for storage systems with him other than this chapter 11?
A. I don't remember correct, completely, but there may have been an earlier book that we -- that we were asked to write the survey together. I don't remember.
Q. And am I correct that you and Mr. Marcus wrote this chapter together?
A. Yes.
Q. And you reviewed it before it

was published?
A. Yes.
Q. And you believed it to be accurate, correct?
A. At the time, yes.
Q. And do you recall any edits to this chapter between, how about from the time that it was published in 2005 to current?
A. I don't remember edits.
Q. And do you recall any edits --
MR. VERDINI: Strike that.
BY MR. VERDINI:
Q. If you would pull out exhibit 3, which is your declaration in this case and go to your CV. The easiest way to get there, at the top there's pages numbers that say of 49. If you would go to page 45. There's a section entitled books, book chapters and editing. Do you see that?
A. Mm-hmm.
Q. And this is a CV that you put together?
A. Yes.
Q. Number 5 is identified as B. Marcus and E. Soljanin, "Modulation codes for

storage systems," in The Computer Engineering Handbook, and it's a date of 2002. Do you see that?
A. Yes.
Q. Now that's the same title of the chapter 11 that's referenced in exhibit 5, correct?
A. (Nodding head affirmatively.)
Q. Verbal? Sorry, is that --
A. The same title, yes.
Q. Is it the same chapter?
A. I don't remember if we did any edits between 2002 and 2005.
Q. What is the computer engineering handbook?
A. CRC Press used to, maybe they still do, have books of collected papers on a particular topic.
Q. If you know, who was the intended audience for the computer engineering handbook?
A. Computer engineering handbooks are covering many topics, so it would cover many areas of engineering.
Q. You referred to exhibit 5 as

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being intended for those who do research and those in industry. Is the computer engineering handbook similarly intended for that group of people?
A. I believe it's more read by industry.
Q. Why did you include the chapter from the computer engineering handbook in your CV?
A. Why I included -- why I put my publication in my CV?
Q. Mm-hmm. Why did you identify that one as one to include in your CV?
A. I'm not sure I understand.
Q. Well, let me ask it this way. You do not identify what has been marked as exhibit 5 in the books and book chapters that you identify in 1 through 6, correct?
A. Because I believe that that was a similar paper, so I put only one.
Q. Okay. Is 1 through 6 that you've identified as books, books chapters and editing the entirety of books, books chapters and editing that you've done in the course of your career?

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A. I wrote a CV hoping that that would be the case, that I don't miss anything.
Q. Okay. No other books or book chapters that you can think of while we're sitting here today? And it's not a trick question. I'm just curious as to whether you selected these or if this is the entirety.
A. No, this is the entirety that I could recall, so it was not on purpose, selected, like the next title.
Q. Okay. So let's go back to exhibit 5. Exhibit 5 is the chapter. Sorry.
A. Yes.
Q. And you're at chapter 11?
A. Yes.
Q. And if you turn to page 11-2. In the third full paragraph you wrote (as read):

During the past few years, significant progress has been made in defining high capacity distance enhancing constraints for high density magnetic recording channels.

A. Yes.
Q. And that was accurate at the

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time you wrote it, correct?
A. Yes.
Q. And then you go on to --
A. The time would be 2002.
Q. Okay. So even though this particular chapter that's exhibit 5 is dated 2005 your belief is that this was written in or around 2002?
A. I cannot recall -- I cannot recall how many -- how much editing we did.
Q. Between 2002 and 2005?
A. Exactly.
Q. Let me ask you this: if it was published in 2002 when would you have started writing the chapter with Mr. Marcus? And I don't need an exact date. But generally how long does it take to write a chapter like this?
A. Usually less than papers, so maybe a year earlier.
Q. Okay. So you believe that the statement "during the past few years significant progress has been made in defining high capacity distance enhancing constraints for high density magnetic recording channels"

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was accurate in or around the time that you wrote it, correct?
A. Yes.
Q. And in the next sentence you write (as read):

One of the earliest example of such a constraint is the maximum transition run, paren (MTR), end paren, constraint, bracket [28], end bracket, which constrains the maximum run of 1s.

Is that correct?

A. Yes.
Q. And that was accurate when you wrote it, correct?
A. Yes.
Q. If we look at the last page of the exhibit, which is 11-11. Are you there?
A. Yes.
Q. Reference 28, do you see that?
A. Yes.
Q. What is reference 28?
A. It's the Moon and Brickner, maximum transition run codes for data storage.
Q. And it's from the IEEE -- an

IEEE article dated September 1996, correct?
A. Yes.
Q. Professor Moon and Mr. Brickner are the inventors of -- the named inventors on the '601 patent, correct?
A. Correct.
Q. Now go back to the last page again. Reference number 30, do you see that?
A. Yes.
Q. That's a paper that you wrote, correct?
A. Yes.
Q. Entitled on-track and off-track distance properties of class 4 partial response channels. Correct?
A. Yes.
Q. And that's from an October 1995 symposium?
A. Yes.
Q. Going back to 11-2. When you are describing the earliest examples of MTR constraint you don't identify reference 30, correct?
MR. SIPIORA: Objection to the form. Misstates the document. It

says one of the earliest examples of such constraint. Not the earliest example.
MR. VERDINI: That wasn't really my question.
BY MR. VERDINI:
Q. My question is: you don't identify as one of the earliest examples of such a constraint the reference number 30, is that correct?
A. It doesn't show here.
Q. Go back to 11-1 of exhibit 5. Which is the chapter. Are you on page 11-1?
A. Exhibit 5. Page 11-1?
Q. Yes. It should be on the bottom right. Not figure 11-1. I'm sorry. Just back a page. The beginning chapter.
A. Oh, I see.
Q. Yes. So that's 11-2. So I want to get you to 11-1. Thanks.
In the first paragraph, in the third sentence you wrote (as read):
Perhaps the most widely known constraints are the runlength limited, paren RLL, paren (d,k), end paren

constraints, in which 1s are required to be separated by at least d and no more than k 0s.
Was that an accurate statement at the time you wrote it?
A. Yes.
Q. Next you wrote (as read):
Such constraints are useful in data recording channels that employ peak detection; waveform peaks -- colon waveform peaks, corresponding to data ones, are detected independently of one another.
Again is that an accurate statement of the usefulness of the (d,k) constraint?
A. They are useful for peak detectors.
Q. And then in the last sentence of that paragraph you wrote (as read):
The d-constraint helps to increase linear density while mitigating intersymbol interference, and the k-constraint helps to provide feedback for timing and gain control.
Is that an accurate description

of the purposes of the d-constraint and k-constraint?
A. For peak detectors, yes.
Q. Is it different for other detectors?
A. For other detectors peak constraint can offer beneficial -- additional benefits.
Q. First what other detectors are you referring to?
A. In sequence detectors, peak constraints can offer, can be beneficial.
Q. And how so?
A. What would be a good way to describe? It would eliminate some sequences which the detector can confuse easily one for the other.
Q. Is the help for the k-constraint that you identify in chapter 11, does it provide the same help to a sequence detector?
A. K-constraints, constraint, is important for timing for any detector.
Q. If we go to paragraph 3 of section 11.1 of exhibit 5. You write (as

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read):
Broadly speaking, two classes of constraints are of interest in today's high density recording channels: (1) constraints for improving timing and gain control and simplifying the design of the Viterbi detector for the channel, and (2) constraints for improving noise immunity. Some constraints serve both purposes.
How would you classify the MTR constraint that you described on page 2 of this chapter with respect to the classes that you identified on page 1?
A. Depending on the channel, it can serve both purposes.
Q. And when you say it depends upon the channel, what about the channel determines whether it's one class or both?
A. Could you rephrase that?
Q. You said depending on the channel --
A. Right.
Q. -- an MTR constraint would be

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classified under both of the classes that you've identified. What is it about the channel that makes a difference?
A. The channel transfer function.
Q. And what do you mean by that?
A. That is at the end of the second paragraph. h(D).
Q. So what is the transfer function that would, in your mind, make the MTR constraint that you described in this chapter -- that would make it serve both purposes, as you had identified in paragraph 3?
A. I didn't get it.
Q. Sorry. That was a long question.
A. Yes.
Q. What about the transfer function in your mind would make the MTR constraint serve both purposes that you identified in paragraph 3? I hope that's a little better question.
A. If h(D) here, if N is 2, maybe there are some other N's that I don't know, but this would be one example, an MTR

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constraint would simplify a Viterbi detector and help improve noise immunity if the detector is implemented to take into account the constraint; it would not -- MTR by itself would not do anything about timing and gain.
Q. That's the k-constraint, correct?
A. Right.
Q. And when you say MTR constraint are you referring to the j constraint?
A. The constraint that limits the transitions between 0's and 1's, and 1's and 0's.
Q. If you would turn to page 3 of -- well, 11-3 of exhibit 5. The last full paragraph that starts "translation of constrained sequences."
Do you see that?
A. The last paragraph, right.
Q. Yes. In the second sentence you wrote (as read):
Saturation recording of binary information on magnetic medium is accomplished by converting an input stream of data into a spatial stream

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of bit cells along a track where each cell is fully magnetized in one of two possible directions, denoted by 0 and 1.
Was that accurate -- is that an accurate statement as of the time of this chapter?
A. Yes.
Q. And would that have been accurate as of in or around 1996?
A. Yes.
Q. And when you wrote input stream of data, what were you referring to?
A. Sequences of 0's and 1's.
Q. And then what is a spatial stream of bit cells?
A. This is in the magnetic medium.
Q. When you say this is in the magnetic medium, what do you mean by "this"?
A. A bit cell in the magnetic medium.
Q. And what is the spatial stream of bit cells that you are referring to in the magnetic medium?
A. It's a sequence of bit cells.

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Q. And the track that you're referring to in the sentence is what?
A. Sorry. I don't see the track.
Q. It says --
A. Along the track?
Q. Yes. What is "the track"?
A. The track is a spatial part of disk -- the disk is round, it would be a part, between two concentric circles, would be a full track.
Q. In the third sentence of that paragraph you wrote (as read):
There are two important modulation methods commonly used on magnetic recording channels, colon, non-return-to-zero, paren NRZ, end paren, and modified non-return-to-zero, paren NRZI.
And that was an accurate statement as of the time of this chapter?
A. Yes.
Q. And that was accurate as of 1996, correct?
A. Yes.
Q. Next you wrote (as read):

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In NRZ modulation, the binary digits 0 and 1 in the input data stream corresponds to 0 and 1 directions of cell magnetizations, respectively.
Again, that was an accurate statement at the time of this chapter?
A. Yes.
Q. And it was accurate as of 1996 correct?
A. Yes.
Q. And then next you write (as read):
In NRZI modulation the binary digit 1 corresponds to a magnetic transition between two bit cells and the binary digit 0 corresponds to no transition.
Again that was accurate as of the time of the chapter?
A. Yes.
Q. And accurate as of 1996, correct?
A. Yes.
Q. If you turn to the next page.

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This section is called Constraints For ISI Channels. What is ISI?
A. Intersymbol interference.
Q. Can you describe what intersymbol interference means?
A. That means that data which is transmitted or recording at different points in time or space add up -- may add up to the same output of the channel.
Q. When you say may add up to the same output of the channel, what do you mean?
A. I mean what is described by equation 11-1 where data is Am, and output is Yn. So the output reflects a sum, weighted sum of several data symbols. We say that this data symbols interfere with each other.
Q. In the introductory paragraph on section 11.3 you wrote (as read):
We discuss a class of codes known as codes which avoid specified differences.
And you italicized "codes which avoid specified differences." What does that mean? Sorry. What does "codes which avoid specified differences" mean?

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A. That means that -- so a code is a set of sequences, and codes which avoid specified differences are codes where the sequences which are in the code cannot differ from each other in the way that is specified.
Q. And when you say in the way that is specified, you mean in the way in which it's specified in --
MR. VERDINI: Strike that.
BY MR. VERDINI:
Q. The sequences that cannot differ from one another are sequences that are ultimately written to the disk, is that right?
A. Written or transmitted.
Q. In the next sentence in that first paragraph you wrote (as read):
This is the only class of distance enhancing codes used in commercial magnetic recording systems.
And that was accurate at the time that you wrote it?
A. At the time that we wrote it the first time. I am not sure if in 2005 there were no introduction of different codes for distance enhancement.

Q. But at least as of 2002 it was that class of codes that were used in commercial magnetic recording systems, is that correct?
A. To the best I can recall.
Q. And then you identify two -- in your mind, two reasons for that, correct, in the next sentence in this chapter?
(The witness reviews document.)
A. Where do you see two?
Q. Well, let me just read --
A. I see two.
Q. You say (as read):
There are two main reasons for this, colon. These codes simplify the channel detectors relative to the uncoded channel and even high rate codes in this class can be realized by low complexity encoders and decoders.
A. Yes.
Q. Was that accurate as of at least 2002?
A. Yes.
Q. Was it accurate in 2005 as well?

A. It's hard for me to say what's accurate after year 2000, because Lucent Technologies spun off the division that was introducing these chips.
Q. What were the chips? Did they have a name?
A. Read channel chips they're called.
Q. Any special sort of trade name or anything that you know?
A. Not that I remember.
Q. And then in 11.3.1 of this section entitled Requirements, do you see that?
A. Yes.
Q. You wrote (as read):
A number of papers have proposed using constrained codes to provide coding gain on channels with high ISI.
Correct?
A. Yes.
Q. And again you identify as one of the references reference 28, which is the paper by Professor Moon and Brickner, correct?

A. Yes.
Q. And again you do not identify reference 30 which was your paper in connection with the Philadelphia presentation in '95, correct?
A. My paper proposed the constraint. Not the code.
Q. But you didn't identify it there, correct?
A. Not as using constrained codes. Let me just check these other papers. I'm just curious. 4, 10, 20.
(The witness reviews document.)
A. Yeah, so my paper is paper 20, which was more recent paper than '95, and in publications kind of supersedes the ...
Q. The reference number 20 is a paper that you wrote with R. Karabed and P. Siegel, correct?
A. Yes.
Q. And it's dated September 1999?
A. Yes.
MR. VERDINI: I don't know if you want to take a break at this point? We've been at it about an

hour.
MR. SIPIORA: Sure.

(Recess from 10:02 to 10:14.)

BY MR. VERDINI:
Q. Professor, we're back on the record. Did you have any conversations with counsel about the substance of your testimony during the break?
A. No.
MR. SIPIORA: I'm just going to say for the record that conversations we have off the record are not discoverable, so ...
MR. VERDINI: That's the position that you are taking in this case?
MR. SIPIORA: Yeah. With experts, sure. Yes. Experts, it's not discoverable. Fact witness is a different story.
MR. VERDINI: Okay.
MR. SIPIORA: But experts, yes, it should be off the record.

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BY MR. VERDINI:

Q. You can put away exhibit 5 and let's go to exhibit 3, which is your declaration in connection with claim construction. I think we're done with exhibit 5, so you can probably put it away. Just off to the side.

A. Okay.

Could you say the number again?

Q. Exhibit 3, which is your declaration in claim construction. Will you turn to page -- paragraph 16, which is on page 4. And in paragraph 16 you are referring to your 1995 paper related to the presentation in Philadelphia, correct?

A. Yes.

Q. And in the last sentence you say that the first named inventor on the '601 patent, Professor Moon, attended my presentation given at the above referenced conference, as described in LSI's counterclaim for inequitable conduct.

Correct?

A. Is that something I'm reading here?

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Q. Yes. At the last sentence in paragraph 16.

A. The first-named inventor of the '601 patent ...

(The witness reviews document.)

A. Yes.

Q. Have you contacted anyone to ask whether Professor Moon was at the conference that you referred to there?

A. No.

Q. And who ran the conference?

A. Who ran the session or the conference?

Q. The conference. Who was responsible for the conference?

A. SPIE.

Q. Have you contacted SPIE for a list of attendees at the '95 conference?

A. No.

Q. Do you recall whether Professor Moon presented any -- did any presentations at that 1995 conference?

A. No.

Q. Was anyone else there when you and Professor Moon had a conversation that is

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identified in LSI's counterclaim?

A. No.

Q. Can you tell me what you remember about that conversation?

A. About the conversation.

(Pause.)

MR. SIPIORA: I'm going to object; outside the scope. But you can go ahead and answer.

MR. VERDINI: She talks about it being described in LSI's counterclaim for inequitable conduct and references 31 paragraphs in that counterclaim. So I don't think it's outside the scope.

BY MR. VERDINI:

Q. So what do you recall about the conversation with Professor Moon that's identified in LSI's counterclaim?

MR. SIPIORA: Well, if you are going to ask about the counterclaim you should give her the counterclaim to see.

BY MR. VERDINI:

Q. Do you recall a conversation

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with Professor Moon at that conference?

A. I recall a conversation with Professor Moon. I don't remember the conference actually. It was in connection with this paper.

Q. So where was that -- where did that conversation take place?

A. That I don't remember.

Q. What time of the day did it take place?

A. I don't remember.

Q. Do you remember what Professor Moon was wearing?

A. Absolutely not.

Q. And no one else was there?

A. No.

Q. And you don't recall whether it was actually at this conference?

A. Correct.

Q. Did it happen before or after the conference?

A. It happened after this paper.

Q. When you say "this paper" was the paper -- the paper was presented at a conference in Philadelphia in October of '95?

A. The paper was submitted earlier that year.
Q. Correct. So was the conversation with Moon before or after the conference in October?
A. That I don't remember.
Q. Where did the conversation take place?
A. I don't remember.
Q. What city?
A. I don't remember the city.
Q. Was it in person?
A. Yes.
Q. And what was the context that you and Professor Moon were in the same place?
A. There was either a conference or a meeting.
Q. You don't know whether it was a conference or a meeting?
A. I don't remember at this point.
Q. But you remember that the conversation -- do you remember what Professor Moon told you?
A. Yes.
Q. But you don't remember where it

was?
A. No.
Q. Or when it was?
A. No.
Q. And other than in LSI's counterclaim for inequitable conduct have you ever discussed that conversation with anyone else?
A. This conversation? Probably with my husband, but no one else.
Q. And when would you have discussed that with your husband?
A. After I came back from the trip.
Q. And what did you tell your husband about the conversation?
A. That I was offered the joint patent application based on my work.
Q. And why didn't you take the joint patent application if it was offered?
A. Because I thought that -- I was post-doctoral researcher at that time. I didn't know what my rights are within the company, that was something new for me, and in the paper it just appeared that something very

clear to me, and I wouldn't even think it would be patentable.
Q. What didn't you think would be patentable?
A. Limiting the sequences of symbols to 4, for example. It just came out of mathematics easily.
Q. You didn't work with Professor Moon on any research, did you?
A. No.
Q. So how would you be a joint inventor with him?
A. How would I be a joint inventor?
Q. Yes.
A. I wouldn't know at that time.
Q. And did he tell you why -- tell me everything you recall about what Professor Moon told you in that conversation, specifically?
A. He specifically said that he did some similar work, and that he would like to patent it, and asked if I would be interested to do it jointly.
Q. And what did you say in

response?
A. That I would think about it.
Q. And did you ever get back to Professor Moon?
A. No.
Q. And is that the way the conversation ended?
A. Yes.
Q. That was the only thing that you guys spoke about during that conversation?
A. Yes. That I remember.
Q. Did he reach out to you or did you reach out to him?
A. I didn't reach out to him. I wasn't aware of his work.
Q. No, the conversation. How did it start. Did he come over to you?
A. Yes.
Q. And did you know him before that?
A. I knew of him, we may have been together at some other meetings, it's a small community. But I don't remember when I first met him.
Q. Have you ever had a

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conversation with him prior to this conversation where you say he offered you to be a joint inventor on a patent?
A. It's possible.
Q. Do you recall any conversations with Professor Moon before that?
A. No. Not a conversation.
Q. Do you recall any conversations with Professor Moon after that time?
A. I don't.
Q. Have you had any conversations with the other named inventor on the patent, Brickner?
A. Not that I remember at all.
Q. Let's move to paragraph 19 of exhibit 3. In paragraph -- well, why don't you tell me. What is paragraph 19?
A. What it reads, or ...
Q. You can read it and tell me what you intended when you wrote paragraph 19.
(The witness reviews document.)
A. That I believe I have research experience and enough material to write what I wrote next.
Q. So those are the documents that

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you reviewed in connection with providing the declaration that's in exhibit 3, is that correct?
A. Yes.
Q. Did you review your declaration submitted in the IPR before you submitted the declaration that's marked as exhibit 3?
A. Did I review it immediately?
Q. Did you review it -- let me ask it this way.
Did it inform your opinions in any way --
MR. VERDINI: Strike it.
BY MR. VERDINI:
Q. Did your IPR declaration inform your opinions in any way that you recite in exhibit 3, which is your claim construction declaration?
MR. SIPIORA: Objection as to form.
THE WITNESS: Excuse me?
MR. SIPIORA: I just objected. So I object to form procedurally because I think the way the question is posed has a problem and it gives

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him a chance to rephrase it, if he wants to. He doesn't have to. But it's up to him. But that's not an instruction not to answer. You need to go ahead and answer.
BY MR. VERDINI:
Q. I'll re-ask the question with that.
A. Okay.
Q. So did you rely on any opinions in your IPR declaration in connection with your opinions in exhibit 3, which is your claim construction declaration?
A. They were very different opinions in my opinion, I mean that I was asked to provide.
Q. Why were they different in your opinion?
A. This one at hand was about the, how claims are, are they definite, how they're understood. And the previous was about code construction.
Q. The previous was about what?
A. Code construction.
Q. When you say code construction,

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what do you mean?
A. I mean constructing codes that are -- that eliminate or prohibit certain differences between sequences that we just discussed.
Q. Didn't you have to be reasonably certain as to what the claims meant to make the opinions in the IPR declaration?
A. Yes.
Q. Did you review Dr. McLaughlin's declaration prior to submitting your claim construction declaration?
A. Just prior to submitting, yes.
Q. And did anything in that declaration, did you rely on anything in that declaration in making your opinions that you set forth in exhibit 3?
A. No.
Q. In paragraph 19 you drop a footnote. Do you see that?
A. Mm-hmm.
Q. And you say that you may rely upon additional, quote, additional materials to respond to arguments raised by the university or its experts, and that you also

might consider additional documents and information in forming any necessary opinions, including documents that may not have yet been provided to you.
Have there been any documents provided to you since you signed the declaration in exhibit 3 that you are relying on for your opinions?
A. Since I signed which one?
Q. Exhibit 3.
A. Since I signed this one? To which opinion, then? This is my latest opinion.
Q. Exhibit 3 is your claim construction declaration.
A. Opinion. Yes.
Q. And I'll call it your claim construction declaration and try to reference exhibit 3 just so we're clear. So have there been any documents that have been provided to you since you signed your claim construction declaration that you are relying on in connection with your claim construction opinions?
A. It looks to me like a

chicken/egg.
Q. I'm not trying to be tricky. Let me ask it this way.
A. No, I'm probably not understanding. So this is the opinion I provided.
Q. Correct.
A. So now you are saying has -- and I signed it.
Q. On April 13.
A. Right. So you are saying since April 13 is there something that's provided that influenced this?
Q. Correct.
A. But this was before I wrote that.
Q. Correct. Is there anything else that you've been provided that you would rely upon to support your opinions in this --
A. To support this, in addition?
Q. Correct.
A. So yesterday I had a file with documents that I've seen before. So I don't remember anything in addition. I cannot be hundred percent sure if -- to me they all look

similar.
Q. So sitting here today there is not any other information that you can specifically identify that you would rely upon for your claim construction opinions, is that correct?
A. To be more certain about this, correct.
Q. In footnote 1 you also reserve the right to revise, supplement or amend your opinions.
A. Yes.
Q. Sitting here today is there any reason, any revision, supplement or amendment to your opinions that you are going to provide?
A. Not at the moment.
Q. In addition to the documents that you have reviewed did you have any conversations with any other experts retained by LSI and Avago in connection with forming your claim construction opinions?
A. No.
Q. Have you had any conversations with anyone at LSI?

A. No.
Q. Anyone at Avago?
A. No.
Q. Other than counsel for defendants, have you had any discussions with anyone else relating to your declaration?
A. No.
Q. And again these questions are excluding counsel. Any discussions with anyone relating to the '601 patent?
A. No.
Q. And anyone -- any discussions with anyone other than counsel about the case?
A. No.
Q. Let's move to paragraph 23, which is on page 6. Paragraph 23, am I correct that that's your description of a person having ordinary skill in the art?
A. Yes.
Q. Anything that you need to change, sitting here today?
A. No.
Q. And are you a person of ordinary -- having ordinary skill in the relevant art under your definition?

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A. Yes.
Q. The same page, section IV is entitled claim construction standard. Do you see that?
A. Yes.
Q. And it goes on from paragraphs 26 to 32, is that correct?
A. Yes.
Q. Can you tell me what your understanding of section IV is?
A. It's about the legal standard of claim construction.
Q. And did you apply those standards as you have laid them out in paragraphs 26 through 32 in connection with your claim construction opinion in this case?
A. To the best of my ability, yes.
Q. Did you apply those same standards in connection with your IPR declaration?
A. It was a different opinion. It was different nature.
Q. That wasn't my question. My question was did you apply the same claim construction standards in connection with your

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IPR declaration?
A. Did I -- I don't remember saying discussing standards in the IPR.
Q. Let's turn to exhibit 4, and if you go to page 25. Are you there?
A. Yes.
Q. And on page 25 you have a section VI entitled claim construction, correct?
A. Yes.
Q. And in paragraph 63 you wrote I understand that in this IPR proceeding, the claim terms are construed as understood by persons of skill in the art.
Correct?
A. Yes.
Q. And that's the same understanding that you have in connection with your claim construction opinion, correct?
A. Which paragraphs should I be comparing?
Q. Paragraph 26?
A. Paragraph 26 with paragraph which ...
Q. Of exhibit 3, which is your

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claim construction declaration.
A. And the paragraph here?
Q. 63 in exhibit 4.
(The Witness reviewing documents.)
A. Yes.
Q. And in paragraph 64 of your IPR declaration, if you would take a look at it.
A. 64, yes.
Q. And you would agree that's the standard you used to provide your opinions in the IPR, correct?
A. Yes.
Q. And in your mind is that any different from the standard that you used for claim construction in connection with your claim construction opinion?
A. For the claim construction -- I was not -- I was providing opinion about claim construction, and ...
(The witness reviews document.)
A. I was looking how claims are written here (indicating), and -- in the most recent declaration -- and the one that was a year ago, I don't remember exactly. I

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remember I was looking at codes more. Because the sequences that were eliminated were similar in the prior art. So ...
Q. So let's stay with your IPR declaration then, in light of that testimony. Turn to page 8, please?
A. Page 8 in the bottom or in the middle?
Q. In the middle. So you should be looking at paragraph 25, 26, and -- are you there?
A. Yes.
Q. Okay. So in paragraph -- or in section IV of your IPR declaration you identify, it's entitled the standards of anticipation and obviousness, correct?
A. Mm-hmm.
Q. And that was what you were providing an opinion on in connection with the IPR declaration, right?
A. Yes.
Q. So turn to page 11 of exhibit 4. Paragraph 35. You wrote you understand that determining anticipation of a patent claim requires a comparison of the properly

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construed claim language to the prior art on an element-by-element basis.
And that's what you did in the IPR declaration, correct?
A. Yes.
Q. And so you needed properly construed claim language to perform your opinion in the IPR declaration, correct?
A. I understand that determining the anticipation of a patent claim requires a comparison of properly construed claim language of the prior art. I have more knowledge than -- more prior knowledge about the area here than a person of ordinary skill would look at this.
Q. But fundamentally you had to have the properly construed claim language in your mind to compare whether the prior art anticipated the claims of the '601 patent in the IPR declaration, correct?
A. That was a year ago.
Q. Doesn't this first sentence --
A. That is what it says, yes.
Q. And that's what you did in the IPR, correct?

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A. Yes.
Q. And in paragraph -- in fact you swore to it under oath that's what you did, right?
A. Yes.
Q. And in paragraph 36 you have, the last sentence says (as read):
Additionally, the description provided in the prior art must be such that a person of ordinary skill could, based on the reference, practice the invention without undue experimentation.
A. Yes.
Q. The reference to "practice the invention" is the invention that's claimed in the '601 patent, correct?
A. Yes.
Q. And so you would have to be reasonably certain of the scope of the invention to form an opinion whether the prior art could teach a person of ordinary skill in the art to practice the invention without undue experimentation, correct?
A. Yes.

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Q. And again, that's what you did in the IPR declaration, right?
A. Yes.
Q. So let's go back to exhibit 3, which is your claim construction declaration, and paragraph 27. In the first sentence you reference highly technical patents. Do you see that?
A. Yes.
Q. What do you mean by a highly technical patent?
A. Highly technical patents, if more than -- if very technical skills are required for understanding.
Q. When you say technical skills, what are you referring to?
A. In the research -- in the technical area. Technical expertise.
Q. And what do you mean when you say technical? What constitutes technical expertise in your opinion?
A. Familiarity with the area of research. I mean to a high degree. To an expert level degree.
Q. What distinguishes, in your

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mind, a highly technical patent from one that's not highly technical?
A. The highly technical would have more -- would be -- not many experts would be familiar with it, and then the level of mathematics, if it's a mathematical patent, would be higher.
Q. Do you consider the '601 patent to be highly technical?
A. I consider it to be very specific. Not many -- not a widely understood area.
Q. So would that be a highly technical patent as you have written --
A. Yes.
Q. -- in paragraph 27?
A. (Nodding head affirmatively.)
Q. All right. If you would look at paragraph 28. You write that regarding the intrinsic evidence -- what do you mean when you say intrinsic evidence?
A. Something that is connected with the patent itself, as opposed to provided by an outside expert.
Q. So regarding the intrinsic

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evidence you say you understand that the claims themselves provide substantial guidance as to the meaning of particular claim terms.
A. Yes.
Q. What do you mean by "substantial guidance"?
(The witness reviews document.)
A. I mean that not much is left to imagination, and it's mostly guided.
Q. It's mostly ...
A. Guided.
Q. Mostly guided.
A. Instructions, right, are given.
Q. The claims themselves are mainly -- mainly guide the interpretation of the particular claim terms, is that what you mean?
A. No, substantial guidance to the meaning of a particular claim terms, right. So they're not open to interpretation.
Q. What isn't it open to interpretation?
A. Meaning of particular claim terms.
Q. So what do you mean when you

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say that means that particular claim terms are not open to interpretation? I'm not understanding the answer.
So let's go back to the sentence. It says "I understand that the claims themselves provide substantial guidance as to the meaning of particular claim terms."
A. Mm-hmm.
Q. So what do you mean when you say they provide substantial guidance as to the meaning of particular claim terms?
A. The claim term should not be subject to interpretation and there is enough information in the claim itself to know, to guide the reader to interpret the term.
Q. And did you apply that standard in connection with providing your claim construction opinions in this case?
A. Yes.
Q. And did you apply that same standard in connection with providing your opinions in the IPR declaration?
A. No.
Q. Why not?
A. Because I was asked to provide

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opinion about the technical content, to the best I understood it.
Q. And you are a person of ordinary skill in the art, correct?
A. Much higher than ordinary skills.
Q. I did not mean that to be pejorative. You are an extraordinary person of ordinary skill in the art.
In the next sentence you write (as read):
For example, the context in which a term is used in the asserted claim can be highly instructive.
What do you mean by -- when you say highly instructive, what does that mean to you?
A. That again is not subject to the interpretation.
Q. The claim term is not subject to interpretation?
A. Yes.
Q. That's what you mean?
A. That's how it reads, right.
Q. And that's the standard that

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you think the claim terms have to be written --
A. Yes.
Q. -- in relation to?
A. Yes. That I understand is the legal standard.
Q. And counsel for defendants provided you that legal standard?
MR. SIPIORA: Well, again, whatever you know in terms of your memory of knowledge of the basis of what you testified. But any conversations with counsel are out of bounds.
BY MR. VERDINI:
Q. Yeah, I don't want specific -- you reference to your understanding. Your understanding is based on conversations you had with counsel for the defendants, correct?
A. Yes.
Q. Did you have the same types of discussions with counsel for defendants before you submitted your IPR declaration?
MR. SIPIORA: Objection. I instruct you not to answer.

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(Instruction not to answer.)
BY MR. VERDINI:
Q. Did you rely upon counsel in connection with how claims should be construed in connection with your IPR declaration?
A. No.
Q. But you did rely on counsel in connection with how claims should be construed in your claim construction declaration?
A. Yes.
Q. Why the difference?
A. Because these were two expert opinions that I was asked to provide. That was my understanding.
Q. But you were interpreting the same claims of the '601 patent, correct?
A. Yes.
Q. And you had to know what those claim terms meant, correct?
A. Yes.
Q. In both the IPR declaration and in your claim construction declaration?
A. Yes.
Q. If you would turn to page 8 of your declaration -- your claim construction

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declaration. Do you see section V is called the Indefiniteness Standard. Do you see that?
A. Yes.
Q. In paragraph 35 you write (as read):
I understand that the United States Supreme Court relaxed this test... And you're referring to the indefinite test, in 2014.
What do you mean by "relaxed"?
A. The -- the paragraph before says that until recently, the legal standard for indefiniteness was determining whether a claim is amenable to construction, and the claim, as construed, is not insolubly ambiguous, and that was to certain extent relaxed.
Q. And how was it relaxed, in your view?
A. As the paragraph says, that the Federal Circuit formulation tolerates some ambiguous claims but not others. It does not satisfy the statute's definiteness requirement.
Q. So what was the difference in

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your mind between the test before the 2014 United States Supreme Court decision and after?
A. I cannot be precise about that.
Q. Can you be general about it?
A. In general, yes. That what is considered, let's say some less precision is allowed after 2014.
Q. And 2014 is before the date you signed your IPR declaration, correct?
A. Yes, correct.
Q. Okay. Let's move to page 9 of exhibit 3. Section VII is titled The Asserted Claims Are Indefinite. Correct?
A. Yes.
Q. And in paragraph 37 you identify five claim terms or claim phrases that you opine in this declaration are indefinite, correct?
A. Yes.
Q. All right. We're going to walk through each one of them. Paragraph 39. So let's go to the encoded waveform, which is one of the claim terms that you opine is indefinite, correct?

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A. Yes.
Q. So paragraph 39 you write (as read):
The phrase encoded waveform renders claim 13 indefinite (as well as all claims depending from it) because the claim, read in light of the specification of the '601 patent and the prosecution history, fails to inform, with reasonable certainty, those skilled in the art about the scope of the purported invention.
Correct?
A. Yes.
Q. You were reasonably certain at the time that you submitted your IPR declaration under oath the meaning of encoded waveform, weren't you?
A. Yes.
Q. And in fact you identified an encoded waveform in both Okada and Tsang, in the Okada patent and the Tsang patent that are the subjects -- part of the subject of your IPR declaration, right?
A. Yes.

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Q. So let's go to that -- the IPR declaration. So let's turn to page 25. We were already there. This is the section entitled Claim Construction.
In looking at that entire section am I correct that paragraph --
MR. VERDINI: Strike that.
BY MR. VERDINI:
Q. Looking at section VI, the claim construction, which runs from paragraphs 63 through paragraph 75. Go ahead and look at that. And I am going to ask you is it correct that the purpose of section VI is to identify anything that you believed needed to be construed --
MR. VERDINI: Strike that.
BY MR. VERDINI:
Q. It identifies anything in the '601 patent claims that you believe needed to be construed to provide your opinions in the IPR declaration?
A. Yes.
Q. And in paragraph 75 you conclude unless it was addressed in paragraphs 63 through 74 no express constructions of any

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additional term is believed to be needed to resolve the challenges herein, correct?
A. What is the question? That it says --
Q. So my question is, and I'll rephrase it: in paragraph 75 you write (as read):
Unless otherwise addressed herein, no express construction of any additional term is believed to be needed to resolve the challenges herein.
Correct?
A. Yes.
Q. And the reference to "otherwise addressed herein" is the paragraphs that precede paragraph 75 numbered paragraph 65 through 74, correct?
A. Yes.
Q. And when you say "no express construction is necessary," if you look to paragraph 64, that means that in your mind the meaning of the other claim terms involved little more than the application of widely accepted meaning of commonly understood words,

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correct?
A. No.
Q. So then why didn't you construe any of the other terms?
A. Because this was the interpretation I adopted in connection with the patent claims. I did not say that no other interpretation is possible.
Q. To have an interpretation of the claim terms, though, you would need to know what they mean, correct?
A. Yes.
Q. And you were able to do that in connection with your IPR declaration, right?
A. I can always have an interpretation. It may or may not be correct. Or it may or may not be the same as someone else's.
Q. But you, as a person of extraordinary skill in the art were reasonably certain you knew what the claims meant when you did your IPR declaration, right?
A. I said that if they're interpreted in this way, which would make sense, then there is a prior art.

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Q. Okay.
A. Could I go to the rest room before you ask this question, or no?
Q. Yes. Absolutely.
MR. VERDINI: Let's take a break.

(Recess from 10:58 to 11:06.)

BY MR. VERDINI:
Q. Professor, welcome back from the break. Did you discuss the substance of your testimony with counsel?
MR. SIPIORA: The same instruction as previous. I instruct you not to answer.
MR. VERDINI: The yes or no question?
MR. SIPIORA: Yeah, you can't -- the substance of testimony? You can't ask about what we talked about.
MR. VERDINI: No. I want to know whether in the break -- it's just yes or no -- you talked with counsel

about the substance of your testimony. I don't want to know what the substance was. I want to know, the first question I want to ask is whether it happened.

MR. SIPIORA: It goes into the subject matter of our conversation, whether we conversed at all. So I am going to instruct her not to answer. You can't ask about what we talked about.

MR. VERDINI: I didn't ask what you talked about. I asked whether you talked about the substance of your testimony.

MR. SIPIORA: You did. You asked about a topic, the substance of this testimony.

MR. VERDINI: Correct.

MR. SIPIORA: And that's a topic of conversation. So I'm not going to let her answer that. Conversations between counsel and a witness who is an expert are off limits.

MR. VERDINI: The substance of them, sure.

MR. SIPIORA: Right.

MR. VERDINI: But I'm not asking about the substance of them.

MR. SIPIORA: Right. So if you want to ask her if she spoke to me during the break you can ask her that. But then after that anything having to do with what the substance was, the subject matter, that's out of bounds.

MR. VERDINI: I'll ask the question.

BY MR. VERDINI:

Q. Did you talk to counsel during the break?

MR. SIPIORA: You can answer yes or no.

A. I am instructed not to answer the question?

MR. SIPIORA: No, you can answer that one.

A. Sorry.

Q. That's okay. Did you talk to counsel for the defendants during the break?

A. Yes.

Q. And did you talk about the substance of your testimony?

MR. SIPIORA: Object and instruct not to answer.

(Instruction not to answer.)

BY MR. VERDINI:

Q. You're not going to answer that question?

A. Correct.

Q. And counsel doesn't represent you, correct?

A. Correct.

MR. SIPIORA: I represent this witness. I'm standing here --

MR. VERDINI: I asked her if she was represented by counsel and she said no.

MR. SIPIORA: Well, I'm your counsel.

THE WITNESS: All right.

MR. VERDINI: I didn't know if there was some arrangement that I was unaware of, but I was taking her for her testimony.

MR. SIPIORA: Misunderstanding. Our law firm has retained her. We actually are paying for her services on behalf of our client. But the relationship is between our firm and this expert. And there's work product between us.

MR. VERDINI: That's fine.

MR. SIPIORA: All right.

MR. VERDINI: We reserve the right to challenge the privilege calls today, if necessary.

MR. SIPIORA: By the way, it's work product I'm relying upon. Not attorney-client privilege. I'm not -- she's not my client in the sense of like Broadcom.

MR. VERDINI: So how is it work product to know whether -- for the objection on the record, what is the basis for a work-product claim of whether you talked about the substance of her testimony? Not what you talked about, but whether you talked about it.

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MR. SIPIORA: Well, because you say the substance -- you see we're missing each other on this, but the substance of her testimony is a topic of conversation. And anything we talked about is off limits.
MR. VERDINI: I'm not asking about what you talked about; the things you talked about. I want to know whether you talked about her testimony. How is that work product?
MR. SIPIORA: Anything that we talked about is off limits, including the topics that we talked about, and --
MR. VERDINI: How is that work product? What mental impressions am I getting by asking her whether or not you talked about her testimony? What is the impressions that I am obtaining from you?
MR. SIPIORA: I don't know what impressions you will form. That's for you to decide. But anything that I consult with, with an expert during

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the case, until they get on the stand at trial, is off limits.
MR. VERDINI: All right. I'll ask a different question, and you can object if you want.
BY MR. VERDINI:
Q. Did you talk about your testimony in any way during the break?
MR. SIPIORA: I object and instruct not to answer.
(Instruction not to answer.)
BY MR. VERDINI:
Q. And you are going to accept that instruction, correct?
A. Yes.
Q. All right.
MR. VERDINI: We reserve the right to follow up on any instructions not to answer based on work product as to whether -- whether there was a discussion about her testimony during the break. So let's move on.
BY MR. VERDINI:
Q. Before the break we were talking about encoded waveform, correct?

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A. (Nodding head affirmatively.)
Q. So let's go to your IPR declaration, which is exhibit 4, page 29 and section VII. In paragraph 76 you opine that claims 1, 2, 8 through 10 and 13 through 17 of the '601 patent are anticipated by Okada. Correct?
A. Yes.
Q. And when you say Okada, you are referring to U.S. patent number 5,392,270, where one of the named inventors is Okada, correct?
A. Yes.
Q. Am I saying that correctly, is it Okada? Is that how you say it?
A. I don't know. Okada [Oh-KAY-da] or Okada [Oh-KAH-da], because it's Japanese, I guess.
Q. You don't know Mr. Okada?
A. I don't.
Q. All right. So let's turn to page 34 of the IPR declaration. We're in exhibit 4. And there's a subheading that is 4, do you see that?
A. Mm-hmm.

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Q. And it identifies claim 1, bracket D. Now the bracket there, you broke up the claim terms in connection with your IPR declaration, correct?
A. Yes.
Q. So claim 1 has different sections and one of the sections you identify is claim 1[D], correct?
A. Yes.
Q. And you would agree with me that claim 1[D] contains the claim term encoded waveform, correct?
A. Yes.
Q. And in paragraph 85 you determined that claim 1[D] as you've identified it with the term encoded waveform needed no construction for your opinions, correct?
A. I have adopted certain interpretation.
Q. You write that it needs no construction, correct?
A. Where is that?
Q. In paragraph 85.
(The witness reviews document.)

A. That's what it says, yes.
Q. So let's move to paragraph 87. Are you there?
A. Yes.
Q. In paragraph 87 you write in the first sentence (as read):
Rule (1) and Rule (2) of Okada each imposes a, quote, maximum number of consecutive transitions allowed on consecutive clock periods in the encoded waveform, end quote, as recited in claim limitation 1[D]. Correct?
A. Yes.
Q. So you were reasonably certain at that time that you knew what the encoded waveform was in the '601 patent claim 1[D] as you've broken it up, right?
A. Yes, I adopted a certain interpretation I felt comfortable with.
Q. In fact in the middle of paragraph 87 you identified --
MR. VERDINI: Well, strike that.
Q. You write in the middle of

paragraph 87 (as read):
More specifically, none of the encoded datawords from tables 1 through 7 -- and that's referring to Okada, correct?
A. Mm-hmm.
Q. -- that form the claimed encoded waveform have more than two - a finite number - such consecutive transitions, correct?
A. Yes.
Q. So for you the encoded datawords from tables 1 through 7 formed the claimed "encoded waveform," right?
A. That's what it says.
Q. And that's what you meant when you wrote it, right?
A. The claimed, quotation marks, "encoded waveform" under my interpretation, yes.
Q. And then at the end of paragraph 87 you're referring to tables 8 and 9 in Okada, correct?
A. Yes.
Q. And you write (as read):

In particular, these sequences each include a section consisting of, quote, "01010" - encoded waveforms in tables 8 and 9 and thus have exactly two consecutive transitions from 0 to 1 or from 1 to 0, correct?
A. Yes.
Q. And so again you're identifying what you believe you're reasonably certain to be the encoded waveforms in claim 1[D] as you've defined it of the '601 patent?
MR. SIPIORA: Objection as to form.
BY MR. VERDINI:
Q. Correct?
A. Yes.
Q. If you turn to page 40 of your IPR declaration. Your paragraph 92 reads (as read):
Okada thus discloses the imposition of a constraint on the encoded waveform data - through either Rule (1) or Rule (2) - to facilitate the reduction of a probability of a detection error in said receiver

means, which limitation is recited in claim limitation 1[D], correct?
A. Yes.
Q. And that was your opinion as to what Okada disclosed, correct?
A. Yes.
Q. And if you turn to page 46 of your IPR declaration, paragraph 109 relates to what you've identified as claim 13, bracket [D], end bracket, correct?
A. Yes.
Q. And that's the claim term imposing, or the claim phrase imposing a pair of constraints j and k on the encoded waveform that appears in claim 13, correct?
A. Yes.
Q. And in your mind --
MR. VERDINI: Strike that.
BY MR. VERDINI:
Q. In your opinion, as per paragraph 109 of your IPR declaration, you explained why Okada disclosed imposing a pair of constraints on the encoded waveform incorporating your analysis from claim element 1[D], correct?

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A. Yes.
Q. And in paragraph 89 you say that Okada -- Okada's 8-to-13 bit converter is what imposes a pair of constraints on the encoded waveform output from the converter, correct?
MR. SIPIORA: 89?
MR. VERDINI: What did you say?
MR. SIPIORA: 89.
MR. VERDINI: Paragraph 109. If I said 89, I apologize.
BY MR. VERDINI:
Q. Paragraph 109.
MR. VERDINI: So strike that and let me redo the question.
BY MR. VERDINI:
Q. In paragraph 109 your opinion in the IPR declaration was that Okada discloses an 8-to-13 bit converter that imposes a pair of constraints, j and k, on the encoded waveform output from the converter. Correct?
A. Yes.
Q. And in connection with the opinions on Okada, at no point in your

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declaration, your IPR declaration did you say you didn't know what encoded waveform meant, correct?
A. I adopted certain interpretation in the beginning of encoded waveform and proceeded with it.
Q. Where is that identified in your declaration?
A. Where is what identified?
Q. What you adopted as the definition of encoded waveform.
A. I don't think it's expressly identified.
Q. So what was your definition?
A. So my definition was that that means the outputs of -- of the converter.
Q. And you were reasonably certain that's what you believed encoded waveform meant in connection with that term as it's used in the '601 patent, right?
A. I was certain that that was a reasonable interpretation.
Q. Now in your IPR declaration, if you turn to page 48 you also opined that claims 1, 2, 8 through 10 and 13 through 17 of

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the '601 patent were anticipated by Tsang, correct?
A. Yes.
Q. And when you refer to Tsang you're referring to U.S. patent number 5,731,768, where one of the identified inventors is an individual named Tsang, correct?
A. Yes.
Q. And at paragraph 136, which is on page 55, again in connection with claim 1[D] --
MR. VERDINI: Well, strike that.
Q. You have identified claim 1[D] as a phrase that includes the term encoded waveform, correct?
A. Yes.
Q. And your opinion in the IPR declaration was that Tsang discloses claim 1[D], correct?
A. Yes.
Q. Now in these paragraphs there isn't a specific reference to an encoded waveform?

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A. In where?
Q. In paragraphs 136 through 142? I looked through it and didn't see any reference to an encoded waveform.
A. Explicit reference.
Q. Yes.
A. All right.
Q. Is it your opinion that Tsang discloses an encoded waveform?
A. As interpreted as the output of the converter.
Q. Why is that your interpretation of encoded waveform?
A. Because that would be, precisely should be called encoded symbols.
Q. As you read the entire '601 patent?
A. As it's usually called in the information theory and coding theory that would be encoded symbols which come out of the converter. I wasn't sure that encoded waveform is, corresponds to the signal and that square waves or something after NZI or something like that. But if it's interpreted as encoded symbols, then it can be compared

with Tsang and Okada.

Q. And you thought that that was the appropriate interpretation of that term?

A. I thought that's one possible interpretation.

Q. Did you think of any other interpretations?

A. Of encoded waveform?

Q. Mm-hmm.

A. Yes. I thought that that could possibly be also something after NRZI is applied. That would be one.

Q. And why didn't you adopt that construction?

A. Because this was actually sufficient to show the existence of prior art. If NRZI construction was adopted, the wording would be different but the prior art would be there as well.

Q. So my question was, though, why didn't you adopt the other reasonable interpretation that you thought encoded waveform would have?

A. Because I had one working definition which was sufficient for me to make

claims -- not claims -- opinion that I had.

Q. And if you turn to page 63 of your IPR declaration. And in paragraph 161, similar to what you did with Okada you opined that in light of your opinions as to claim elements 1[D], [E] and [F], that Tsang disclosed the claim element imposing a pair of constraints on the encoded waveform as it's stated in claim 13, correct?

A. Yes.

Q. So in your opinion what you did for claim 1 was sufficient for claim 13, is that right?

A. Yes.

Q. Okay. Let's go back now to exhibit 3, which is your claim construction declaration. And if you would turn to page 10.

A. Yes.

Q. Are you there?

A. Yes.

Q. All right. So let's start with paragraph 40. In paragraph 40 you say (as read):

First, there is no antecedent

basis --

MR. VERDINI: Well, strike that. Let me ask a foundational question.

BY MR. VERDINI:

Q. Paragraphs 40 through 45, what do those reflect?

A. Not definiteness of terms encoded waveform and recorded waveform.

Q. Are those paragraphs that you wrote to explain the basis for your opinion?

A. Yes.

Q. All right. So let's start with the first one. In paragraph 40 you write (as read):

First, there is no antecedent basis for the phrase the encoded waveform in the claim. The phrase begins with the word, quote, "the," which, according to counsel, is understood to be used in patent claims, paren and as I understand in normal English usage, end paren, to refer back to an element that was recited earlier in the same claim or

in an independent claim from which the claim at issue depends.

Correct?

A. Yes.

Q. When you say "according to counsel," who are you referring to?

A. Mr. Mayle.

Q. And when did Mr. Mayle inform you of the way in which patent claims are to be understood?

A. In which patent claims are to be understood, or this particular?

Q. When did Mr. Mayle inform you about the, what I'll call the antecedent basis principle that you're referring to in paragraph 40?

A. When he first time asked for my opinion about definite or indefiniteness of claims.

Q. And you didn't have that conversation with -- you weren't informed of that by counsel when you did your IPR declaration?

A. I expressed my doubts that -- that I don't know what encoded waveform is,

and in particular that I'm not certain what recorded waveform is, but there is a way to understand possibly encoded waveform as encoded symbols in connection with IPR.
Q. That wasn't my question. So my question is: did counsel inform you of the antecedent basis principle that's in paragraph 40 before you drafted and opined in the IPR?
A. I don't remember one way or the other.
Q. You didn't apply any antecedent basis principle in connection with your IPR declaration, correct?
A. Not that I remember.
(Reporter clarification.)
Q. I think you were referring to recorded. I should have asked.
A. Yes.
Q. I wanted to make sure that you weren't actually saying recoded. I think you were saying recorded?
A. Recording, yes.
Q. Now you know how magnetic recording systems are designed, correct, based on your work and experience?

A. The magnetic recording system of the time, yes, I'm familiar with that.
Q. Do you have an understanding of what LSI has proposed for the construction of recorded waveform?
A. No.
Q. Their construction, and I can show it to you if you need to see it, is the sequences of n-bit codewords that are recorded as symbols or patterns in a medium.
A. Mm-hmm.
Q. Do you follow that?
A. (Nodding head affirmatively.)
Q. My question for you is in a magnetic recording system n-bit codewords have encoded data in them, correct?
A. Codewords consist of encoded symbols.
Q. What is the difference, in your mind, between encoded symbols and encoded data? Because I use the phrase "data" is why I am asking.
A. Encoded data is fine.
Q. Okay. In paragraph 41 you wrote in the first sentence (as read):

I am informed that the University's expert, Professor McLaughlin, agrees that the, quote --
MR. VERDINI: Strike that, let me start over.
BY MR. VERDINI:
Q. In paragraph 41 of your claim construction declaration you write (as read):
I am informed that the University's expert, Professor McLaughlin, agrees that the word, quote, "the" signals that the following phrase, quote, "encoded waveform," must have an antecedent basis in the claim.
Do you see that?
A. Yes.
Q. Who were you informed by?
A. Mr. Mayle.
Q. Why didn't you just read Professor McLaughlin's declaration?
A. At that time I had that page.
Q. So did you read Professor McLaughlin's declaration?
A. Yes.

Q. So why was paragraph 41 started with "I am informed that the university's expert"? Why didn't you just say I've read Professor McLaughlin's declaration and see X?
A. Because this is a more precise description of -- I have read it, but it was -- the declaration was accessed through Mr. Mayle.
Q. So I think you have mentioned something about it being more precise. What did you mean when you said that?
A. I mean the declaration was being accessed through Mr. Mayle.
Q. What do you mean when you say the declaration -- what declaration are you referring to?
A. Of professor McLaughlin, page 46.
Q. Oh, you received that from Mr. Mayle, is that what you're saying?
A. Yes.
Q. Did you receive the whole declaration from Mr. Mayle?
A. I don't remember whether I received the whole declaration at this point

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or at a later point.
Q. Do you recall whether you reviewed Professor McLaughlin's entire declaration before you submitted your claim construction declaration?
A. Before I made the final pass through -- through the document. Final read through the document, yes.
Q. Let me ask it this way. Did you review Professor McLaughlin's full declaration before you signed your claim construction declaration?
A. Yes.
Q. Did you make any changes to your declaration, your claim construction declaration based on anything you reviewed in Professor McLaughlin's full declaration?
A. No.
Q. All right. Later in paragraph 41 -- I am going to use the numbers on the side there, line 18.
A. Mm-hmm.
Q. You say (as read):
The claim uses different words to mean different things.

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Why do you say that?
A. Because for me encoded waveform, I could interpret as encoded symbols, or encoded data, relatively reasonably, plus, minus, NRZ, and NRZI. However, recorded waveform, I don't know what it is.
Q. You opined that Okada had a recorded waveform, correct?
A. I don't remember recorded waveform in Okada.
Q. Okay. Let's look at exhibit 4 which is your IPR declaration. And turn to page 40, paragraph 94. Do you see that?
A. Yes.
Q. And in the second sentence you say imposition -- you're discussing Okada again, correct?
A. Mm-hmm.
Q. And you say (as read):
Imposition of the first rule, Rule (1), results in a maximum of one consecutive transition allowed on consecutive clock periods, not just in the encoded waveform output from the

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block converter, but also later in the recorded waveform that is, quote, recorded to an optical disk, end quote, following NRZI modulation.
So you knew what recorded waveform meant when you opined that Okada had a recorded waveform, right?
A. The recorded to an optical disk following an NRZI modulation.
Q. Okay. You had to know what a recorded waveform was to know that Okada had a recorded waveform, right?
A. Oh, I am not familiar with optical recording, and I don't know whether there is such thing as recorded waveform in the optical recording.
Q. But you opined that there was, in paragraph 94, didn't you?
A. I assumed that there was an optical recording, yes.
Q. You just assumed it?
A. Yes. This entire IPR declaration was under certain reasonable assumptions. I thought would be reasonable assumptions or interpretation.

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Q. Okay. Well, then let's go to paragraph 58 in your IPR declaration. Are you there?
A. Yes.
Q. And in paragraph 143 -- now we're talking about Tsang again, correct?
MR. VERDINI: Page 58, paragraph 143.
Q. You're describing Tsang again, correct?
A. I don't see Tsang in 58.
Q. Page 58, paragraph 143, I'm sorry.
A. Page 58, paragraph ... ?
Q. Paragraph 143. Are you there?
A. Yes.
Q. And in paragraph 143 you are discussing your opinion on what Tsang discloses, correct?
A. Yes.
Q. And in the last sentence -- or in the second to the last sentence you say a value of j equals 2 ensures that the recorded waveform, quote, avoids three or more consecutive transitions, end quote. Correct?

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A. Yes.
Q. So again you have now identified the recorded waveform in Tsang, right?
A. Yes.
Q. So you knew what the recorded waveform was that was being claimed in the '601 patent to know -- let me finish?
A. I'm sorry.
Q. -- to know that Tsang disclosed it, right?
A. Could you say that again?
Q. Yes. You had to know --
MR. VERDINI: Strike that.

BY MR. VERDINI:
Q. It would be reasonably certain what the recorded waveform was that was disclosed in the '601 patent to know, or to opine, that Tsang disclosed such a recorded waveform, right?
A. Yeah, I adopted that interpretation.
Q. What was the interpretation that you adopted?

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A. That it's -- that the recorded and encoded can differ only if NRZ or NRZI is applied in between.
Q. And you thought that that was a reasonable interpretation of the claim language, right?
A. That's reasonable -- that was a reasonable interpretation, yes.
Q. All right. So let's go back to paragraph 41 of your claim construction declaration, which is exhibit 3. And I think we ended up talking about encoded waveform because my question asked you on line 18 of page 10 you wrote the statement "the claim uses different words to mean different things."
Right?
A. There is encoded and recorded.
Q. So what was the basis for you to say that the claim uses different words to mean different things? What was your basis for that?
A. The encoded and recorded -- let's see.
(The witness reviews document.)

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A. I don't think I can say this differently than is here. "If the encoded waveform was the same as the recorded waveform, then the claim would use the phrase the recorded waveform in step 3."
Q. Let me ask it a different way. Were you relying on any legal principle provided to you by counsel to say that the claim used different words to mean different things?
A. No.
Q. That was your opinion --
A. Yes.
Q. -- based on reading the patent?
A. Yes.
Q. Okay. all right. You reviewed the file history in connection with rendering your claim construction opinions, correct?
A. (Nodding head affirmatively.)
Q. I am going to hand you what has been marked as exhibit 6.

(Deposition Exhibit 6, excerpt of the file history that reflects the Office Action dated September 16, 1997

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was marked for identification)

BY MR. VERDINI:
Q. And exhibit 6 is an excerpt of the file history that reflects the Office Action dated September 16, 1997 and then contains the University's response to the Office Action. Okay?
A. Mm-hmm.
Q. What did you understand to be the rejection that the examiner identified in the Office Action?
A. So one of the rejections referred to the d-constraint, which also limits the number of transitions in this Iketani.
Q. And you understand that the university responded to that Office Action prior to the '601 patent being granted, correct?
A. Yes.
Q. And if you turn -- I am going to use the little numbers on the bottom right. If you turn to the page that ends in 745. Do you recognize this as the University's

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response to the September 16, 1997 Office Action?
A. Yes.
Q. And it runs from 745 to 757, correct?
A. Yes.
Q. And that's the entire response, as far as you know?
A. Yes.
Q. All right. If you would turn to the page that's identified as 750. Do you see that?
A. Yes.
Q. The first full paragraph, do you understand that to be the University's attempt to distinguish the claims of the '601 patent from Iketani?
A. I need to read this. Could you say that again?
Q. Sure. Do you understand that paragraph to be part of the University's response to distinguish Iketani from the invention that they were claiming?
A. I understand that this entire document is the response?

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Q. Yes. I am asking you to focus on paragraph 750.
A. Yes.
Q. The first full paragraph.
A. Mm-hmm.
Q. And my question just is as you read that, is that, in your understanding, the University's -- one of the university's arguments to distinguish Iketani from the invention of the '601 patent?
MR. SIPIORA: Why don't you go ahead and take a moment and read it, please.
A. Sure. You mean if it stands out of the others, or something?
Q. Yes. You can read as much of the document as you need to.
(The witness reviews document.)
BY MR. VERDINI:
Q. Have you finished reading?
A. Yes.
Q. Okay. I want to direct your attention to the middle of that paragraph, where it starts with "in sharp contrast to Iketani," correct? At the top. I'm sorry. I screwed you up.
A. Yes.

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Q. So let's start at the top. That paragraph starts in sharp contrast to Iketani, the present invention provides, and it goes on to provide the University's description of what the invention provides, correct?
A. Yes.
Q. And in the middle of that paragraph it says, in the fifth line down, it reads means for imposing a pair of constraints (j;k) on the waveform. Right?
A. Yes.
Q. It doesn't say the recorded waveform or the encoded waveform, right?
A. Yes.
Q. And there's only one waveform, right?
A. In this paragraph it says "the waveform."
Q. Did you consider this paragraph when you opined that different words means different things?
A. Not this paragraph.

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Q. Doesn't this paragraph provide support for the fact that there is just one waveform that's referred to in the invention?
A. No. It's just mention "the waveform."
Q. Is there more than one waveform in a magnetic system, recording system?
A. Yes. Yes, there is encoded -- actually I wouldn't call it waveform. There are encoded symbols. There is a waveform that read head produces. And there is a waveform that -- sorry, the write head produces, that would be referring to the encoding side, so the writing side.
And then on the reading side there is also a waveform which consists of series of pulses, where transitions are, which would be the read waveform.
Q. And here -- my point here is that this paragraph only refers to the means for imposing the constraints on "the waveform."
Right?
A. That's what it says, "the waveform" in this line.

Q. And based on your understanding, and having read the prosecution history, the waveform that's being referred to there, is that on the read side or on the write side?
MR. VERDINI: And that's W-R-I-T-E.
A. It's on the read side.
Q. It's on the read side?
A. They seem to be concerned with read side. And it says encoded waveform four lines down.
Q. So you're saying you imposed the pair of constraints on the waveform that's on the read side?
A. Yes. On the -- sorry. Oh, right. On the write side. Yes. The read you cannot impose anything.
Q. Okay.
A. I may have switched that a few times.
Q. Let's make the record clear. The waveform, on page 750 of exhibit 6, it says means for imposing a pair of constraints on the waveform. The waveform there, is it on

the read side or the write side?
A. On the write side.
Q. Let's go back to exhibit 3, which is your claim construction declaration. And we're still on page 10 but now we're going to move to paragraph 42.
A. Mm-hmm.
Q. Would you agree that there is nothing in the terms of claim 13 that require the steps to be performed sequentially?
A. Which steps?
Q. The steps that are --
MR. VERDINI: Well, strike that.
BY MR. VERDINI:
Q. In paragraph 42 you identify steps of claim 13, correct?
A. Yes.
Q. And my question to you is: there's nothing express in claim 13 that requires those steps to be performed in a certain order, correct?
A. I have to see the claim 13. Usually in encoding order matters.
(The witness reviews document.)

A. You need to receive a binary dataword in order to produce anything.
(Reporter clarification.)
A. You need to receive a binary dataword in order to produce a codeword.
Q. Okay. Paragraph 42 relates to what you've identified steps 3, 4 and 5, correct?
A. It refers in 5, starting with imposing.
Q. Yes.
A. Generating --
Q. And my question to you is, is there anything express in claim 13 that requires those steps to be performed in a certain sequence?
A. Is there anything in the claim that requires?
Q. Correct.
A. A recorded waveform would come after encoded waveform, so nothing can happen in the recorded -- if we want to understand as it was understood in the IPR case, then the encoded has to be before recorded. Which would put 3 before 4.

Q. And that's the way in which you are interpreting the words of the patent, correct?
A. Not in connection with this declaration.
Q. Why didn't you interpret the claim that way in connection with -- when you say "this declaration," what declaration were you referring to?
A. The more recent one.
Q. And why do you say that wasn't the interpretation that you made in the claim construction?
A. Because here I was -- I was only looking into definiteness of the claims, and in the previous one I adopted certain interpretation.
Q. So you construed the claims differently when you were trying to find whether the prior art anticipated or rendered them obvious versus when you were trying to determine whether they were definite?
MR. SIPIORA: Objection as to form.
A. Sorry?

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MR. SIPIORA: I just objected as to form. You can still answer the question.
THE WITNESS: All right.
A. So there are terms that I had to interpret in order to write the last declaration, and I made some what seemed to me reasonable assumptions. I was asked to provide opinion about similarity with the prior art. In the more recent declaration I only looked in the, whether terms themselves are definite or not, regardless of how they appear in claims.
Q. When you say -- what do you mean regardless of how they appear in the claims?
A. So if the claim may be indefinite if the -- if it's not clear what the term is, but if someone asked me encoded and recorded waveform, even if I wasn't aware of this entire case, I would have the same doubts.
Q. You would have the same?
A. Doubts.
Q. But you didn't have those doubts when you did your IPR declaration; you interpreted --

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A. I did. I did. I made -- I adopted a certain interpretation.
Q. You adopted it assuming that it was correct, right?
A. I adopted it assuming that it can be correct, yes.
Q. Is it your opinion, in connection with paragraph 42, that the imposing step has to be done at one place in the system and nowhere else?
A. Yes.
Q. You don't believe that the constraint could be imposed by multiple components in the system?
A. Well, it depends how you define a component. It's imposed in the encoder.
Q. How would you define the component -- what are the options of the components that could make up the encoder, in your opinion?
A. So I consider encoder a component of the system.
Q. Okay.

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A. And that's the place where constraints are imposed.
Q. What would you identify as -- there are components of the encoder?
A. In some realizations there can be components of the encoders.
Q. In those instances can you identify for me what the components of the encoder would be?
A. A component would be component which maps M into N, so that's sort of a minimum component. And then there can be another component which would then worry how to string these n-bit sequences, so that the constraint is also satisfied in the sequence of n-bit strings.
Q. The sequence that is encoded is the same that is recorded, is that correct?
A. So when you say the sequence that is encoded, we take M, as in Mary, bits, and we encode them into N, Nancy, and something corresponding to this N will be eventually recorded.
So M are encoded -- M, as in Mary, are encoded, and N are -- eventually something corresponding to the N will be encoded.

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Q. What is the "something" that is recorded?
A. If it's magnetic recording it would be the strings of little magnets and how that corresponds to the sequence depends on whether NRZ or NRZI is used.
Q. If the constraint is imposed on the encoded sequence -- that's what you said, correct? That the imposition of the constraint is on the encoded data?
A. Yes.
Q. Is it fair to say then that the constraint is also imposed when that data is recorded?
A. Yes.
Q. Because if it wasn't, it would defeat the purpose of having the constraint, right?
A. Yes. Some counterpart to that constraint. It depends on the modulation that is imposed, yes. Exactly.
Q. Let's go to paragraph 43.
A. That's before --

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Q. Page 11.
A. That's just next page.
Q. Yes. In paragraph 43 you say consideration of claims other than claim 13 bolster your opinion that the encoded waveform is indefinite. Correct?
A. Which line are you reading?
Q. The first sentence of paragraph 43.
(The witness reviews document.)
BY MR. VERDINI:
Q. Have you read the paragraph?
A. Yes, I have.
Q. All right. So in paragraph 43 you say that consideration of claims other than claim 13 bolster your opinion that encoded waveform is indefinite, correct?
A. Yes.
Q. Is that fair?
A. Mm-hmm.
Q. And one of the claims that you identify is claim 18, correct?
A. Yes.
Q. Exhibit 1 is the patent. If you would look at claim 18. It's on the very

last page, claim 18 is.
A. Yes.
Q. While you're reading claim 18, the question is: does claim 18 say in express terms that it's imposing any constraints?
(The witness reviews document.)
A. Claim 18 relies on claim 14 and then also removes binary words that contain more than j consecutive 1's.
Q. So in your opinion that is the imposition of the j and k-constraint as you understand it as claimed in the '601 patent?
A. The -- yes. Or at least part of it.
Q. Why do you say part of it?
A. Because it relies on claim 14.
Q. Okay. So then going back to paragraph 43 of your exhibit. You say that claim 18 -- let me do it this way.
In paragraph 43, in the last sentence you say (as read):
This is consistent with my conclusion about the distinction between the recorded waveform and the encoded waveform in claim 13.

When you say "this" what is it that you are referring to?
A. Because, now to the best of my recollection, is that in 13 you're mapping M into N, and calling this N encoded. And in 18 you are doing some additional things before recording. So is now encoded where claim 13 stops, or would you call encoded where claim 18 stops after which recording happens.
Q. So you have claim 18 in front of you.
A. Yes, I can get it.
Q. What are the additional things that you have just testified about in claim 18?
A. These are these paragraphs in indentation. Removing binary words, removing, removing -- yeah.
Q. Did why did you describe those as additional things?
A. Because that's what it does. It removes binary words that contain more than j consecutive 1's.
Q. In addition to what are you referring to?

A. The previous claims.
Q. 14 and 13?
A. Yeah.
Q. And so how does that support that there's some difference between the recorded waveform and the encoded waveform?
A. So in the claim 13 the encoded waveform refers to a certain step, and then some other encoding like operations happen, and then the recording happens. So is the encoded waveform before 18 or -- before these removing, or after.
Q. So can you answer your own question? So is it before or after --
MR. VERDINI: Strike that.
BY MR. VERDINI:
Q. In paragraph 44 of your declaration, your claim construction declaration, that is, page 11, in the third sentence of paragraph 44 you say (as read):
In addition, the phrase encoded waveform has no standard or industry-specific definition.
Correct?
A. Yes.

Q. What investigation, if any, did you do in forming your opinion that encoded waveform has no standard or industry-specific definition?
A. I don't remember ever using before these patents encoded and recorded waveform.
Q. You are referring to your use?
A. Using or seeing before --
Q. Okay.
A. -- this case.
Q. Are you familiar with MATLAB?
A. Yes.
Q. Is it something that you use?
A. No, but I'm familiar with it.
Q. And what is it?
A. It's a program for computation.
Q. And is it used in data coding field?
A. No, that's a computer programming, which people refer as coding, but it's not error correction coding. It's programming, MATLAB.
Q. Is it --
A. Sometimes I have people in my

class thinking they're programming, but it's coding.
Q. Say that again?
A. Sometimes people register for my coding class thinking they would use MATLAB or programming, which is not coding. So they call coding programming, which is not this coding.
Q. Got it. Can you use MATLAB to simulate what's done in data coding?
A. Yes I believe so. I haven't, but I believe you can.
Q. I am going to show you what has been marked as exhibit 7.

(Deposition Exhibit 7, printout from www.mathworks.com referring to a Manchester receiver was marked for identification)

BY MR. VERDINI:
Q. Exhibit 7 is a printout from www.mathworks.com referring to a Manchester receiver. Do you see that?
A. Yes.

Q. Do you know what a Manchester receiver is?
A. No.
Q. You've never heard that before?
A. No.
Q. Under the encoding section, before the table --
A. Uh-huh.
Q. -- you would agree that the author of this uses the phrase in the table encoded waveform, correct?
A. Yes, I can see that.
Q. And would you agree that the encoded waveform is a continuous signal?
A. It's a signal in time. This may be -- this continues points, these squares. That's mathematical precision.
MR. SIPIORA: I'm just going to note for the record this document doesn't appear to be in any of the intrinsic record that we've been provided previous to this, so to the extent you try to bring this in through this testimony we're going to move to strike. We're just objecting

to the use of this exhibit and any questioning around it. Just so you know that. If you try to reuse it we'll move to strike.
MR. VERDINI: Objection noted, and we will respond if you do.
BY MR. VERDINI:
Q. Let me show you what's been -- what we will mark as exhibit 8.

(Deposition Exhibit 8, U.S. patent number 5,608,397 was marked for identification)

BY MR. VERDINI:
Q. Do you recognize exhibit 8?
A. Yes.
Q. Exhibit 8 is U.S. patent number 5,608,397, correct?
A. Yes.
Q. And you are the sole named inventor, right?
A. Yes.
Q. If you turn to column 1 of the patent?

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A. Yes.
Q. So we are in column 1. If you go down to line, approximately, 23.
A. Oh, sorry, that's a different page.
Q. Yes. Column 1 of the patent. Are you there?
A. Yes.
Q. So if you go to line, approximately, 23, the patent reads (as read):
Error correcting codes introduce additional symbols to a signal, paren, e.g. to a digital representing compressed information, end paren, to form an encoded signal.
Do you see that?
A. Yes.
Q. And what do you mean -- what were you referring to when you wrote encoded signal?
A. The sequence -- additional symbols, the encoded signal is a redundant or encoded version of the original symbols. So the original symbols and then additional symbols are added. Actually it's more like a

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map from N to M, to form an encoded set of symbols.
Q. Why do you call it a signal if it's just symbols?
A. That -- I don't know why we called it signal at that point. I think it could be either way.
Q. Either way, meaning what? It could be a --
A. It could be symbols and it could be -- yeah, it could be signal.
Q. Your testimony is that you're using those two terms interchangeably?
A. I don't remember, this patent was 25 years ago, but it does appear from this sentence that they're used interchangeably.
Q. And if you go down to line 32, you write (as read):
The encoded signal, comma, comprising the codewords, comma, may then be either transmitted over the communications channel or recorded on a medium. Correct?
A. Yes.
Q. So the encoded signal, as you

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wrote, is recorded, correct?
A. Can be recorded.
Q. Is there an instance when it's not recorded?
A. It can be transmitted. It can be preceded by an NRZI.
Q. In connection with a magnetic recording, it's recorded on a medium, the encoded signal, correct?
A. Unless it's preceded by NRZI.
Q. What happens if it's preceded by NRZI?
A. You change -- what's recorded on the medium is, there is a recorded pattern on the medium.
Q. But it's a one-on-one correspondence between what was NRZ into NRZI, right?
A. There is a correspondence, yes.
Q. And in column 2 of your patent you are -- at line 8 --
A. Yes.
Q. -- you are describing the background of the invention that you are describing here as being applicable to

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magnetic recording, correct?
A. Yes.
Q. All right. The last paragraph in this section, paragraph 45 of your claim construction declaration. So we're going back to exhibit 3.
A. Mm-hmm. Oh, sorry.
Q. That's okay.
A. 45 you said? Or 43?
Q. Correct. Paragraph 45.
A. 45, yes.
Q. I'm now over to page 12 of paragraph 45. So it goes to the next page. At line 2 you say binary codewords are not a waveform. Correct?
A. Binary codewords are not a waveform, yes.
Q. If you turn to the IPR declaration, exhibit 4. Page 40, paragraph 94.
A. Yes.
Q. Your opinion is that the output from the block converter is the encoded waveform in Okada. Correct?
A. Correct.

Q. What is the output of the converter?
A. It's output strings of bits.
Q. Isn't that inconsistent with saying in your claim construction declaration that binary codewords are not a waveform?
A. Binary codewords mathematically are not a waveform. This is the interpretation I adopted for the IPR.
Q. And again in the IPR you were intending to be truthful and accurate in your interpretation of the claims of the '601 patent, right?
A. That's correct.
Q. Okay.
MR. VERDINI: Let's go off the record.
(Lunch recess taken at 12:25 p.m.)

A F T E R N O O N S E S S I O N
(1:32 p.m.)
_ _ _

E M I N A S O L J A N I N,
resumed as a witness, having been previously sworn by the Notary Public, was examined and testified further as follows:
EXAMINATION BY
MR. VERDINI:
Q. Welcome back from the lunch break. Did you talk to counsel during the break about your testimony?
MR. SIPIORA: Objection and instruct not to answer based on work product.
(Instruction not to answer.)
BY MR. VERDINI:
Q. And you're going to obey your counsel's instruction on work product basis, correct?
A. Yes.
Q. Before we broke, I had one last question I wanted to ask you. You testified

that binary codewords mathematically are not a waveform and that's the interpretation that you adopted for the IPR, is that an accurate statement of your testimony?
A. That is not the interpretation -- that is why it's confusing, in the later -- in the this year declaration. For IPR I considered them the encoded waveform.
Q. And that's different than what you stated in the claim construction declaration where you say binary codewords are not a waveform, right?
A. Yes.
Q. All right. Let's move to exhibit 3, which is your claim construction declaration. Before we move there. You haven't submitted any supplemental declarations in the IPR, have you?
A. Not that I remember.
Q. And you haven't amended your opinions in any way in the IPR, is that correct?
A. Not that I remember, no.
Q. And sitting here today you

still believe your opinions in the IPR declaration are accurate, correct?
A. About the existence of prior art, yes.
Q. And the way in which you interpreted the '601 patent, correct?
A. That was an interpretation there.
Q. Okay. All right. Let's move to exhibit 3, page 12. We're moving now on to the claim phrase "generating no more than j consecutive transitions of said sequence in the recorded waveform such that j is greater than or equal to 2."
Okay?
A. Yes.
Q. And it's your opinion that that phrase is indefinite, is that correct?
A. Yes.
Q. In the IPR declaration were you reasonably certain what that phrase meant?
A. I had an interpretation -- a possible interpretation there that I followed.
Q. Was that a reasonably certain interpretation?

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A. It was a reasonable interpretation. I had doubts.
Q. Was it reasonably certain?
A. Does that have some other meaning?
Q. I'm just using the term reasonably -- do you have an interpretation of what reasonably certain means?
A. Because I hear there's reasonable doubts on TV.
Q. That's criminal trial. We're not there. What does the term reasonably certain mean to you?
A. So I had an interpretation which I thought was reasonable, and I thought there were other interpretations.
Q. Okay. Does that make your interpretation for you reasonably certain in the IPR declaration?
A. Well, if -- (Pause.) The interpretation I thought was reasonable. The possibility of other interpretations were there. Then no, because the probability -- no.
Q. You were not reasonably

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certain?
A. (Nodding head affirmatively.)
Q. So then why did you give your opinions in the IPR declaration if you weren't reasonably certain what the '601 patent meant?
A. I had an interpretation which I thought was reasonable.
Q. I didn't ask -- that's not the question I asked. I said why did you provide opinions under oath in the IPR declaration if you were uncertain as to what the '601 patent meant?
MR. SIPIORA: Objection as to form.
A. Because I --
MR. SIPIORA: Objection as to form. Misstates testimony. Go ahead.
A. Yeah, because I thought that my interpretation was reasonable, and assuming my interpretation I thought I could proceed.
Q. In your mind, does the fact that a claim term could have multiple interpretation make it not reasonably certain?
A. If I associate some kind of percentage to reasonably certain, then the --

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just the existence of multiple interpretations makes it not reasonably certain.
Q. Is that the standard that you applied in your claim construction declaration?
A. For which ...
Q. Your claim construction declaration.
A. In ...
Q. Is that the definition of reasonably certain that you applied in your claim construction declaration when you opined --
A. That is the most recent declaration?
Q. Correct.
A. Yes.
Q. That's the definition? You had multiple interpretations, it wasn't reasonably certain, is that your testimony?
A. Yes.
Q. All right. So now let's move to generating no more than j consecutive transitions of said sequence in the recorded waveform such that j is greater than or equal

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to 0.
Your opinion in the claim construction declaration is that that phrase is indefinite, correct?
A. Yes.
Q. And in the IPR declaration you identified in Okada where that reference discloses a generating no more than j consecutive transitions of said sequence in the recorded waveform such that j is greater than or equal to 2, correct?
A. Yes.
Q. And you did that without opining that there was any construction that was necessary for this claim phrase, correct?
A. Yes.
Q. And you didn't anywhere in your IPR declaration mention that you weren't reasonably certain as to what generating no more than j consecutive transitions of said sequence in the recorded waveform such that j is greater than 2 meant, right?
A. I did not consider reasonable certainty. Only reasonable interpretation of text.

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Q. And my question is: you did not state anywhere in the IPR declaration that you were not reasonably certain what that claim phrase meant, correct?
A. As far as I remember that was a year ago declaration.
Q. And as far as you remember it's not in there, right?
A. If I remember correctly, it's not there, yeah.
Q. And you have it in front of you if you want to check, but --
A. Yes. It's just little bit long, but yeah.
Q. So let's go to exhibit 4, which is your IPR declaration. If you would turn to page 40. And on page 40 there's a section 5 that you've identified as claim 1[E], correct?
A. Yes.
Q. And in that claim 1[E] there is a reference -- the claim phrase that you are opining on is said sequences generating no more than j consecutive transitions in the recorded waveform such that j is an integer equal to or greater than 2, correct?

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A. Yes.
Q. And that's slightly different wording than claim 13, isn't it?
A. Let me just check.
(The witness reviews document.)
A. Yes.
Q. And in paragraph 94 you describe what you call Rule (1) that's disclosed in Okada, correct?
A. Yes.
Q. And if you turn to page -- let's start on the bottom of page 40. You say (as read):
Imposition of the first rule, Rule (1), results in a maximum of one consecutive transition allowed on consecutive clock periods, not just in the encoded waveform output from the block converter, but also later in the recorded waveform that is, quote, recorded to an optical disk following NRZI modulation. Correct?
A. Yes.
Q. And based on that analysis you concluded that Okada discloses that there is

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no more than two consecutive transitions in the recorded waveform, right?
A. Yes.
Q. And in your opinion does that Rule (1) meet the claim limitation?
A. Yes.
Q. And then in paragraph 95 you say (as read):
Similarly, imposition of Rule (2) results in a maximum of two consecutive transitions allowed on consecutive clock periods, both in the encoded waveform before NRZI modulation, paren, as seen in tables 8 and 9, and in the recorded waveform after NRZI modulation, paren, as shown in Exhibit 1011.
Correct?
A. That's what it says, yes.
Q. And you conclude that that Okada, Rule(2), illustrates that there are no more than exactly two consecutive transitions in the recorded waveform following NRZI modulation, correct?
A. Yes.

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Q. And in doing so you are opining that Okada discloses the said sequences generating no more than j consecutive transitions claim phrase, correct?
A. Yes.
Q. Turn to page 46 of your IPR declaration. And in paragraph 110 am I correct that to opine that Okada discloses the way in which the generating no more than j consecutive transitions phrase is used in claim 13, all you did was incorporate your analysis of the claim element as it appears in claim 1?
A. Yes.
Q. And again you opine that Okada discloses the generation of no more than two consecutive transitions in the recorded waveform as required in claim 13[E] as you've identified it on page 46, correct?
A. Yes.
Q. Now go back to your claim construction declaration, and page 12 at paragraph 48. Do you see that?
A. Yes.
Q. Are you there?

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A. Yes.
Q. In paragraph 48 is it the case that you are relying on the differences in claim 13 and claim 1 to support your opinion that the generating no more than j consecutive transitions phrase is indefinite?
A. Yes.
Q. How is that consistent with your opinion in the IPR declaration whereby you identify no differences in claim 13 and claim 1 that were relevant to your opinion?
A. I believe that in IPR I wasn't aware of the level of the difference between 13 and 1.
Q. Why weren't you aware of the difference when you submitted your IPR declaration?
A. That was to the best of my knowledge at the moment.
Q. So what knowledge did you gain between your IPR declaration and your claim construction declaration -- let me finish -- when the patent's words never changed?
A. Patent's words never changed. It's my reading that understood -- I

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understood better.
Q. Why did you understand better? What did you do between -- let me ask it this way.
What did you do between your IPR declaration and your claim construction declaration that allowed you -- or that gave you a better understanding?
A. Read over once again.
Q. How many times did you read over once again between the time that you did your IPR declaration and your claim construction declaration?
A. Within that year? Several times, probably.
Q. How many is several?
A. Four, five.
Q. How many times did you talk to counsel between your IPR declaration and your claim construction declaration?
A. Actually, from the -- I don't remember. There was some period that we did not talk.
Q. But how many times? Not the period, but how many times?

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A. I wouldn't be able to say without looking at my calendar.
Q. More than ten?
A. No.
Q. More than five?
A. Probably not more than five.
Q. Did you contact counsel when you had a new understanding of the claim terms in the patent?
A. No.
Q. Did counsel contact you?
A. Not in connection with this particular interpretation.
Q. What do you mean by "this particular interpretation"?
A. I mean I had contacts, but they were not let's discuss paragraph 48, or ...
Q. My question is you testified that you, in reading between the IPR declaration and the claim construction declaration you had a new interpretation of the patent, right?
A. Yes.
Q. When you had that new interpretation of the patent did you reach out

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to counsel?
A. No.
Q. How did that get communicated, that you had a new interpretation of the patent?
A. Later I was asked to provide opinion about -- what was this called? Definiteness of the claims. So that was a general question.
Q. And after you were asked that question, is that when you formed a different opinion on what the claim terms meant in the '601 patent?
A. After I was asked that question I looked into a number of -- I looked over all the claims, actually, and then whatever I adopted as a possible interpretation that had other possible interpretations, I tried to address.
Q. And that's how you came to your opinion on indefiniteness?
A. Yes.
Q. Let's go back to your IPR declaration. In paragraph 95, that's your opinion as to how Rule (2) of Okada discloses

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the said sequences generating no more than j consecutive transition phrase that you've identified as claim 1[E], correct?
A. Yes.
Q. Take your time and read paragraph 95. And if you need Okada, I have it, I can give it to you.
My question is: would you agree that if transitions is defined as a switch from a binary 1 to a binary 0, or vice versa, Okada would not have two consecutive transitions?
A. That I don't remember at this point, because it took lots of work actually to look into Okada and write everything down and realize that yes, and write this paragraph.
Q. I am asking you a hypothetical. Assume that "transitions" is defined as a switch from a binary 1 to a binary 0 or vice versa. Looking at paragraph 95 in your analysis, and in the IPR declaration, if that's the definition of "transitions" how many consecutive transitions does Okada Rule (2) disclose?

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A. So that was my assumption, not hypothetical, that transitions are from 0 to 1, and 1 to 0.
Q. Okay.
A. And after going through Okada patent and writing tables of sequences, et cetera, I wrote what is in here. So I didn't make that as a hypothesis, but that was the assumption.
Q. Looking at paragraph 95, am I correct that you were counting consecutive 1's as consecutive transitions to --
A. In NRZI, yes.
Q. Yes.
-- to conclude that there are no more than exactly two consecutive transitions disclosed in Okada, is that correct?
A. Yes.
Q. You not only opined in the IPR declaration that Okada discloses the said sequences generating no more than j consecutive transitions in claim 13; you did the same thing with regard to the Tsang reference, right?

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A. I didn't get that.
Q. Let me just direct you. Turn to paragraph 143 of your declaration. IPR declaration.
A. Mm-hmm.
Q. That's on page 58. Are you there?
A. Mm-hmm.
Q. And in paragraph 143 you opine that Tsang discloses apparatuses having an MTR("j"), end paren, value of 2. And a value of j equals 2 ensures that the recorded waveform, quote, avoids three or more consecutive transitions. Correct?
A. If the value of j -- if there are -- let's see.
(The witness reviews document.)
A. Yes.
Q. And then in paragraph 162, again you just incorporate your analysis as to claim element 1[E] to opine that claim element 13[E], which is the generating no more than j consecutive transitions of said sequence in the recorded waveform such that j is greater than 2, is disclosed in Tsang, correct?

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A. Yes.
Q. So in the IPR declaration you concluded and opine that Okada and Tsang disclosed the generating no more than j consecutive transitions of said sequence in the recorded waveform such that j is greater than 2 as claimed in claim 13, correct?
A. Yes.
Q. And to determine that you had to be reasonably certain what it meant to generate no more than j consecutive transitions of said sequence in the recorded waveform such that j is greater than 2 as claimed in claim 13, right?
MR. SIPIORA: Objection as to form.
BY MR. VERDINI:
Q. J is greater than or equal to 2, right?
MR. SIPIORA: Objection as to form.
A. Under the interpretation I adopted, that's correct.
Q. And you stand by that interpretation, right?

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A. That was the interpretation I had -- I adopted throughout the IPR.

Q. And my question is do you stand by that interpretation?

A. The --

MR. SIPIORA: Objection as to form.

A. What does it mean to stand by? I mean that was what I adopted, and there were other possibilities.

Q. My question then -- I'll ask it a different way. You're not disavowing that opinion in today's deposition, are you?

A. I am not disavowing that opinion as a possible interpretation.

Q. Let's go back to exhibit 3, and we're going to go to page 13, which is, and I want to -- we're going to do the second half of paragraph 48. Right at the top. If you look back --

A. Oh, yes.

Q. Okay. In the first full sentence that starts on 1 you write (as read):

Moreover, the specification teaches that the minimum distance

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pairs shown in figure 1 must be eliminated and that, quote, in accordance with the present invention, this can be accomplished using the existing RLL, paren (1,k) end paren code, which does not allow consecutive transitions.

Correct?

A. Yes.

Q. And you refer to part of the specification in the patent at column 4 lines 8 through 12, correct?

A. Yes.

Q. And then the next sentence after you quote the language from the specification, you say (as read):

This adds up to a lack of reasonable certainty as to the meaning of the claim limitation.

Do you see that?

A. Yes.

Q. What is the "this" that adds up to the lack of reasonable certainty, in your opinion?

A. The consideration that RLL

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(1,k) code, which will not allow consecutive transitions. Meaning it would be a transition followed by a non-transition.

Q. Your opinion is that the RLL code in practice does not allow consecutive transitions?

A. Yes. With this parameters, (1,k).

Q. How many consecutive transitions are there if j equals 1?

A. One transition.

Q. How many consecutive transitions?

A. The j is interpreted as the maximum number of transitions, right?

Q. Mm-hmm.

A. Yeah. So j is 1 -- the maximum number of allowable transitions is j, which is 1.

Q. All right. So let's look at the patent, exhibit 1, column -- let's go to the column that you cite, which is column 4, and let's start at line 8. And the first sentence says (as read):

To obtain a coding gain, paren

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improvement in minimum distance due to coding, the minimum distance pairs shown in figure 1 must be eliminated.

Correct?

A. Yes.

Q. So let's turn to figure 1.

A. Where is figure 1? Yes.

Q. So you can understand figure 1 based on your reading of the patent and your experience in the field, correct?

A. Let me just see. Is this reading current -- what is the -- I have to be reminded. What does this represent? What's on the disk, or ...

Q. So column 3 --

A. Uh-huh.

Q. -- describes figure 1 at line 20?

A. So when it says write patterns, that is what is on the disk, 00, and then -- so the first one has 0101. And the other one has 010. So from this delimiters here, it would be in the upper part, 101, and in the lower part 010. So if I interpret that as 101 and 010, this would be the minimum distance error event. A minimum distance error event.

Q. Are there consecutive transitions reflected in those write patterns?

A. There are two consecutive transitions, yes.

Q. What are the two consecutive transitions?

A. So if you'll look when this delimiter starts within this, this is the, in the middle of the figure there are transitions.

Q. Okay. And are you looking -- there's four different pairs there. Are you looking at a particular one?

A. So the minimum distance event is this central part, actually. 101 and 010. And the rest is irrelevant --

Q. Because this is being transcribed and we can't see your hands, that you're doing --

A. All right. So what I'm looking is in the middle of the picture of the figure 1, and I have 101, if there are two levels of this square train, and underneath I have -- so this starts with, after the delimiters, these

vertical lines, and then the bottom one has 010.

Q. And you are looking at the pairs that are designated as 1 under figure 1, correct?

A. Under figure 1, one can look at, yes, as this is -- if this is what is recorded it would be 101 and 010.

Q. I am sorry. I'm just asking for clarification purposes.

A. Yes.

Q. The figure 1 has pairs identified as 1, 2, 3 and 4, correct?

A. I am only looking at the first pair at the moment. Yes.

Q. Got it. Okay. And are there any consecutive transitions in pair 1?

A. Two consecutive transitions.

Q. You're saying between the delimiters, right?

A. Yes. The rest is irrelevant.

Q. So go back to column 4. The first sentence -- I'll read the first two sentences. It says -- starting at line 8 -- (as read):

To obtain a coding gain (improvement in minimum distance due to coding), the minimum distance pairs shown in figure 1 must be eliminated. In accordance with the present invention, this can be accomplished using the existing RLL (1,k) code, which does not allow consecutive transitions.

Do you agree with that statement?

A. Yes.

Q. You stop there in connection with your opinion in paragraph 48, right?

A. Yes.

Q. If you read the remainder of column 4 lines 13 through 30 you would agree that the inventors are distinguishing their invention from the RLL codes that are referred to in lines 8 through 13, correct?

(The witness reviews document.)

A. The inventors are saying that their code is superior.

Q. Does RLL code allow dibit patterns to survive in the recorded sequence?

A. It does not.

Q. And that's why IPR code is improvement, correct, in part?

A. Yes.

Q. And so do you still believe that lines 8 through 12 add up to a reasonable certainty as to what the claim phrase generating no more than j consecutive transitions of said sequence in the recorded waveform such that j is greater than or equal to 2?

MR. SIPIORA: Objection as to form. Misstates testimony.

MR. VERDINI: I am sorry. Let me rephrase the question.

BY MR. VERDINI:

Q. Based on reading column 4 lines 8 all the way down to 30, do you still believe that lines 8 through 13 add up to a lack of reasonable certainty as to the meaning of the claim limitation?

A. If one reads the claim by itself then what is written here I stand by it, yes.

Q. But you don't read the claim --

to do claim construction on indefiniteness you don't just read the claim by itself, right?
A. What else would I read?
Q. You didn't read anything else in making your opinion?
A. For the claims?
Q. Mm-hmm.
A. Only how I -- I concentrated to understand what the claims as they are written say. But given all of my expertise and the outside literature, it's different issue.
Q. What is a different issue?
A. Whether one can come with a number of possible interpretations.
Q. You're saying as you did in the IPR declaration, correct?
A. I adopted one interpretation there, yes.
Q. Now in the claim construction declaration in paragraphs 49 and 50 you also identify that you have some --
MR. VERDINI: Strike that.
BY MR. VERDINI:
Q. In your claim construction declaration, in paragraph 49 you recite the

phrase "transitions of said sequence" and opine that this makes the claim ambiguous, is that correct?
A. Well, transitions are, as you pointed out between 0's and 1's, and 1's and 0's, so I did not understand "transitions of said sequence." Is that between sequences, or ...
Q. In your IPR declaration, page 46, in paragraph 110 am I correct that you didn't identify any ambiguity in determining that Okada has transitions of said sequence, is that right?
A. This 110?
Q. Correct.
A. He said "consecutive transitions within the recorded waveform." I don't see transitions between sequences here.
Q. But didn't you determine that Okada practiced the claim element 13[E]?
A. Yes.
Q. And that includes transitions of said sequence, correct?
A. I adopted the interpretation, which is here, that there are no more than two

consecutive transitions within the sequence, which consists of strings of codewords.
Q. So you interpreted said sequence to be strings of codewords, correct?
A. Yes.
Q. And you did the same thing with Tsang, right?
A. Yes.
Q. And again in interpreting Okada and Tsang as it applies to the '601 patent you didn't identify anywhere in your IPR declaration that you were uncertain about what the phrase "transitions of said sequence" meant, correct?
A. The interpretation I adopted was the one which exactly says these consecutive transitions, in the string of sequences.
Q. Okay. Thanks, but that -- let me ask my question again and I'll ask you to answer it.
In interpreting Okada and Tsang as it applies to the '601 patent you didn't identify anywhere in your IPR declaration that you were uncertain about the phrase

"transitions of said sequence" as it is written in the '601 patent, correct?
A. I didn't discuss uncertainty and certainty in that IPR at all.
Q. Let's move to, back to your claim construction declaration, page 13. And we'll move on to section 3, which is the generating no more than k consecutive sample periods of said sequences without a transition in the recorded waveform element of claim 13. Okay? Are you there?
A. Generating no more than k consecutive sample periods of said sequences ... yeah, now I am even more confused. Yeah.
Q. And your opinion is, in the claim construction definition, is that that phrase is indefinite, correct?
A. Yes.
Q. And again in your IPR declaration you didn't identify any uncertainty as to what that phrase meant when opining that Okada and Tsang disclosed that element, correct?
A. Yes.

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Q. And if we turn to your IPR declaration, page 41 -- are you there?
A. Yes, I am.
Q. -- you describe the sequences that you believe were disclosed by Okada, correct?
A. Yes.
Q. In fact, on page 42 you expressly opine that the sequences generated by Okada have no more than k consecutive sample periods without a transition in the recorded waveform as recited in claim 1[F], correct?
A. Yes.
Q. And you opine that to a person of -- of someone skilled in the art k has to be a finite number, right?
A. K has to be a finite number.
Q. That's what you opined, correct?
A. Yes.
Q. And you base that on your opinion that as someone skilled in the art you know that there can never be a codeword consisting of all 0's or all 1's, right?

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A. Oh, there are always codewords consisting of all 0's and all 1's.
Q. You opine at the end of paragraph 97, (as read):
In any case -- this is a quote from yours -- in any case, there can never be a codeword consisting of all 0's or all 1's.
A. Oh, there can never be a codeword within, if these rules are imposed.
Q. Correct.
A. That's correct.
Q. All right. So k -- and based on that you opine that k is a finite number, correct?
A. Yes.
Q. And again you didn't identify any claim construction --
MR. VERDINI: Strike that.
BY MR. VERDINI:
Q. In opining as to what Okada disclosed you didn't identify any need to construe any of the claim terms in the '601 patent, correct?
A. I adopted the interpretation

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that a sample is done once per symbol for these. That was my interpretation for sampling. For IPR. So that was one possibility to the sampling, yes.
Q. And why isn't that your interpretation of the '601 patent in connection with your claim construction?
A. It is one possible interpretation. There can be more than one sample per symbol in general.
Q. And again, as with the other claim 13 terms in Okada, if you turn to page 46 at paragraph 111 there was nothing in your opinion that distinguished claim 13 from claim 1 in terms of your opinion that Okada disclosed what you've identified as claim 13[F] and which you now say is indefinite, right?
A. Yes.
Q. And if you turn to page 1 -- or paragraph 144 of your IPR declaration.
A. I'm there.
Q. In paragraph 144 you opine that Tsang discloses apparatuses having a constraint k of 9, which ensures generation of

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no more than 9 consecutive sample periods without a transition in the recorded waveform. Correct?
A. Yes.
Q. So you were able to understand what sample periods were identified in claim 1[F] of the '601 patent, correct?
A. I adopted the most common sampling strategy, as an interpretation.
Q. That was your opinion as to how to construe the term "sample periods" as it appears in claim 1 and claim 13, correct?
A. Yes.
Q. And again you're not changing that opinion here today, right?
A. That is a possible interpretation. There are others. I am not changing this as a possibility.
Q. And if someone of skill in the art adopted that as a construction, would you say that they were wrong?
A. To adopt this interpretation?
Q. Yes.
A. No, it's a valid interpretation. It's just one of several.

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Q. What are the other ones?
A. People have done, for the sake of recovering timing a multiple -- sampling more than once per bit period.
Q. And how would that be a definition of sample periods?
A. So the bit period is the area of the disk where magnetization is in one direction, and if a read head is such that it senses transitions, then you would like the sample at the highest point, if you are able to sample more than once, there are proposals like that, there are advantages, with respect to noise, with respect to timing, et cetera. So there can be more frequent sampling than once per period. Bit period.
Q. And that would be a reasonable interpretation of sampling as well?
A. That would be another reasonable interpretation, absolutely, yes.
Q. Any others that you have?
A. For sampling? At the moment, these are either one or more than bit period, yes.
Q. And someone of ordinary skill

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in the art would understand those definitions, correct?
A. Yes.
MR. SIPIORA: Objection as to form. I'm not sure what definition you're referring to.
MR. VERDINI: The two definitions of sample periods she just gave.
A. It's not two. You are sampling at rate of at least one or higher. Per bit period.
Q. I'm sorry. What did you say at the end. Per bit period?
A. Per bit period.
Q. Okay. And in connection with Tsang you don't identify that you were unclear about what the sample periods were as claimed in the '601 patent, correct?
A. Correct. Through the entire IPR I made some -- picked one of a number of possible choices, and I upheld it through the end.
Q. I am going to ask a general question, then. Nowhere in the IPR

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declaration do you say you were uncertain about what any of the claim terms meant in the '601 patent, right?
A. I didn't say anything like that in the IPR.
Q. And you didn't say that you were providing interpretations, one of many possibilities, right?
A. I did not say that.
Q. You just construed the claim as you thought you should do it and applied it to Okada and Tsang and the other prior art references, right?
A. Actually, I expressed my doubts about how this was written, from the very beginning.
Q. Not in your IPR declaration, did you?
A. Not in the IPR declaration, no.
Q. Who did you express those doubts to?
A. To Mr. Mayle.
Q. When?
A. When we first discussed this patent.

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Q. Why didn't that doubt appear in your IPR declaration?
A. Because I adopted something that at the moment was one of reasonable interpretation.
Q. So why did you do that?
A. To be able to have something which is not indefinite in order to compare it with the prior art.
Q. And that's what you did; you took a not indefinite construction of the '601 patent and applied it to the prior art, right?
A. I took one possible interpretation and compared it with the prior art, yes.
Q. You just said you had to do something to be able -- you wanted to have something which was not indefinite in order to compare it to the prior art, right?
A. I cannot compare something indefinite to prior art.
Q. Right. And in fact you did then compare the '601 -- claim terms of the '601 patent to not only Tsang and Okada, but other prior art, right?

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A. Yes.
Q. All right. Let's go to the last phrase in your claim construction declaration. Now we're moving to the phrase wherein the binary sequence produced by combining codewords have no more than one of j consecutive transitions from 0 to 1 and from 1 to 0, correct?
A. Sorry. This is page 13, or --
Q. 14, I'm sorry. If I said 13.
A. No, you didn't say any page. 14 at the bottom?
Q. Yes, section 4 of your claim construction opinion.
A. I'm sorry.
(The witness reviews document.)
Q. And that claim term appears in -- or that claim phrase appears in claim 17, correct?
A. Yes.
Q. In your IPR declaration it's true that you opined that both Tsang and Okada disclose the elements of claim 17, correct?
A. Yes.
Q. And if you go to page 48 of

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your IPR declaration.
A. Yes.
Q. Paragraph 116, you quote the claim language of 17, correct?
A. Yes.
Q. You don't identify any claim terms there that require any express construction, correct?
A. I adopted an interpretation that both are transitions, not either/or or one not the other. But that all of the transitions.
Q. You thought that that was a reasonable interpretation?
A. Yes.
Q. And again you answered a question, but you didn't answer the one that I asked. So you don't identify in paragraphs 116, 117 or 118 any claim terms that you believed required any express construction, correct?
A. I don't identify this here, yes.
Q. And in those same paragraphs you didn't identify any claim terms that you

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thought were uncertain to you, right?
A. I did not identify any that had other interpretations in the IPR.
Q. So in paragraph 117 of your opinion in the IPR declaration you refer to your opinion as it respects claim 10, correct?
A. Yes.
Q. And you say for the reasons discussed previously with respect to claim 10, your opinion was that Okada discloses claim 17, right?
A. Yes.
Q. So let's look to claim 10. Sorry, let's stay with the IPR declaration. And let's look at your opinion with respect to claim 10.
A. And that was --
Q. It's page 43.
(The witness reviews document.)
A. Yes.
Q. So your opinion in paragraphs 102 and 103 as to what Okada discloses, that's inconsistent with the confusion that you identified in paragraphs 58 and 59 of your claim construction declaration, isn't it?

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A. So here it says transitions from 0 to 1 and from 1 to 0. Whereas in claim 17 -- I mean in section 4 it says no more than one of j consecutive transitions from 0 to 1 and from 1 to 0. So it's one of what can cause ambiguity is transitions from 0's and 1 treated separately than transitions from 1 to 0.
Q. But in paragraph 103 of your IPR declaration you expressly opine that Okada discloses no more than one of two consecutive transitions from 0 to 1 and from 1 to 0 in the NRZ format. You didn't have any confusion there, right?
A. He said and from 1 to 0. Oh --
Q. It's the same language, right?
A. No more than one or j consecutive transitions from zero to 1 and from 1 to 0. Yes, if you adopt that they both count together. If you adopt interpretation that from 0 to 1 and 1 to 0 -- that's together. It's funny, actually they just needed 1 and they would have had a better code.
Q. Say that again? It's funny

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that what?
A. From 0 to 1, that -- forget about it. I was just thinking whether we patented something. Forget about it. It might have been even better that -- yeah.
Q. When you say "we patented," who are you referring to?
A. Lucent Technologies, later.
Q. Later?
A. Yes.
Q. And what specific patent were you thinking of?
A. I don't remember now. It was late '90s.
Q. Do you remember what it was called?
A. No.
Q. And what did you recall about it that sort of brought it to your mind in connection with your opinion in paragraph 103 of your IPR declaration?
A. That there are different interpretations.
Q. What about the Lucent patent made you think there were different

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interpretations?
A. I was just thinking whether we had yet another interpretation of this, I cannot say for sure if we did. Because it was long time ago.
Q. When you say different interpretation of this, what is the "this"?
A. Of j consecutive transitions from 0 to 1 versus 1 to 0.
Q. So that's something that, at a minimum, was in some Lucent patent that you were recalling?
A. I don't know if this was in the Lucent patent, but there are various interpretations from 0 to 1 and 1 to 0.
Q. What interpretation did you use in the IPR declaration?
A. That they adopt that they're equivalent from 0 to 1 and 1 to 0.
(Reporter clarification.)
A. That the transitions are either from 0 to 1 or from 1 to 0.
Q. You made the same opinion with the same construction to opine in your IPR declaration that Tsang disclosed the elements

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of claim 17, correct?
A. Yes.
Q. Going to your claim construction declaration. In paragraph 58 -- are you there?
A. Yes.
Q. In paragraph 58 you identify -- you use as an example a simple bit string of 0 to 1, correct?
A. Yes.
Q. How many consecutive transitions are there in that simple bit string?
A. It's one transition from 0 to 1.
Q. How many consecutive transitions?
A. There is only one transition.
Q. So there cannot be any consecutive transitions, correct?
A. Right.
Q. Okay. The claim 17 requires consecutive transitions, though, correct?
A. The claim 17 talks about j consecutive transitions.

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Q. Correct. And your example has no consecutive transitions, right?
A. Correct.
Q. In paragraph 59 of your claim construction declaration you provide an example and then you ask the question how does one evaluate the claimed k plus 1 parameter, correct?
A. I have to remember that.
(The witness reviews document.)
A. Yeah, that's what it said. No more than k plus 1 consecutive 0's and k plus 1 consecutive 1's.
Q. And in paragraph 59 you provide an example and you say how does one evaluate the claimed k plus one parameter, correct?
A. Yes. Is k plus 1 referring to 0's or to 1's.
Q. But you did evaluate the claimed k plus 1 parameter in connection with the IPR declaration, right?
A. Yes. I made the interpretation that k plus 1 would be non-transitions, essentially.
Q. And why did you make that

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interpretation?
A. Because it's a -- it's one possibility, if it's referring to k plus 1 consecutive alike symbols.
Q. And that's how you interpreted the claim?
A. Yes.
Q. And again you would disagree with someone who interpreted the claim like that, right?
MR. VERDINI: Strike that.
BY MR. VERDINI:
Q. You wouldn't disagree with a person of skill in the art who interpreted the claim like that, right?
A. I would agree that that's a possible interpretation.
Q. And that interpretation is how you came to conclude in the IPR declaration that Okada and Tsang disclosed the elements of claim 17, correct?
A. Yes.
Q. What are the other possible interpretations of k plus 1?
A. So you -- it's hard to know

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whether you refer to 0's or 1's. Do you refer to any of them? A minimum, or a maximum?
Q. How did you decide which to use in the --
MR. SIPIORA: Were you done with your answer?
MR. VERDINI: Oh, I'm sorry. I didn't mean to cut her off. I thought she was.
A. Yes, I am.
Q. Sorry. So how did you determine what interpretation to use in your IPR declaration?
A. It's just that if instead of going with a more complex interpretation, which would involve separate constraints in 0's and 1's I decided to have identical constraints in 0's and 1's.
Q. But you could have --
A. These are non-transitions.
Q. But you could have interpreted the claim using that more complex construction and still have done your IPR opinion, right?
A. I don't know about that. I'm not sure about that.

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Q. So by definition that wouldn't be a reasonable construction, would it?
A. A reasonable ...?
Q. Construction.
A. Of what?
Q. K plus 1.
A. It's not a construction. It's an interpretation. What do you mean by construction of k plus 1?
Q. That's what we are construing the claims. So -- construing is interpreting the claims?
A. Right. So the way I interpreted the claim is there are no more than k plus 1 transitions.
Q. Yes.
A. And that's a reasonable interpretation. And as such is present in prior art. I did not, for IPR, have to come with additional interpretation which would also make this claim preceded by prior art. My understanding was one was enough.
Q. Right. But you did, sitting here today, say that there could be a more complex interpretation of the k plus 1, right?

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A. Yes, as in the paragraph.
Q. Okay. And my question is well, why didn't you use that interpretation of k plus 1 in your IPR declaration?
A. Because I didn't have a reason to use other. I was asked for an opinion under certain interpretation which was reasonable to adopt.
Q. When you say you were asked under a certain interpretation, how was the, quote-unquote, "certain interpretation" formed?
A. What I thought would be reasonable to interpret as being said by the claim.
MR. VERDINI: Let's take a break.

(Recess from 2:41 to 3:00.)

MR. VERDINI: Welcome back, Professor.
BY MR. VERDINI:
Q. If you would pull out what we marked as exhibit 6, which is the portion of

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the file history.
A. Yes.
Q. And turn to page 750. Professor, if you would read to yourself the bottom -- the very last paragraph that bleeds on to page 751 for me. And let me know when you're done.
A. The paragraph that starts "one of the ..."
Q. Yes.
(The witness reviews document.)
A. Just the one paragraph?
Q. Yes. Would you agree with me that that paragraph describes the j constraint that's disclosed in the '601 patent?
A. It talks about how restrictive j is. It says that -- it describes what it means, that j is greater or equal than 2, or what it means that j is 3. So it gives a few examples.
Q. And did you consider that description of the constraint in connection with forming any of your opinions in the claim construction declaration?
A. Did I consider this particular

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paragraph?
Q. Yes.
A. I considered the -- sorry. In claim interpretation?
Q. Correct?
A. The most recent one?
Q. Yes.
A. I considered it on claims language, but I considered all the material around.
Q. Do you recall specifically reading the description of the constraint on page 750 and 751 of the file history?
A. I don't remember any specific, but I remember going through the entire file.
Q. And on the bottom of page 750 referring to the j constraint, it says (as read):
Because the constraint prevents only transition runs with more than j consecutive transitions in consecutive clock periods, patterns with j or fewer consecutive transitions can be permitted.
A. Yes.

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Q. Is that consistent with your understanding of the j constraint as disclosed in the '601 patent?
A. Yes.
Q. And then it reads (as read):
For example, if j equals 3 the encoder can to -- which I think is a typo -- produce sequences with isolated transitions, two consecutive transitions on two consecutive clock periods, and three consecutive clock periods.
Correct?
A. Yes.
Q. And again is that your understanding of how the constraint -- the j constraint disclosed in the '601 patent would operate when j equals 3?
A. In the '601 patent the j constraint has a little bit different definitions in claim 1 and claim 13.
Q. Okay. My question was is j equals 3 under the claimed method of 13, is it your understanding that the encoder could produce sequences with isolated transitions,

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two consecutive transitions on two consecutive clock periods, and three consecutive clock periods, as described in the file history?
(The witness reviews document.)
A. It says generating no more than j consecutive transitions of said sequences in the recorded waveform such that j is greater or equal to 2. And that means that if j is equal to 2 then you cannot have -- oh, sorry. If j is equal to 3 then you cannot have -- then having j equals -- number of transition two is allowed.
(Reporter clarification.)
A. If j is 3 then having a sequence with two transitions would be alright.
(Reporter clarification.)
A. if j is 3 then having a sequence with two transitions is possible.
Q. And that's what's described in the file history paragraph we just looked at, right?
A. Yes.
MR. VERDINI: Subject to reservation on any of the instructions

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not to answer I don't have any further
questions other than potential
responsive questions if Mr. Sipiora
asks questions.
MR. SIPIORA: Okay. Let's take
a break and then we'll come back.

(Recess from 3:09 to 3:44.)

EXAMINATION BY
MR. SIPIORA:
Q. Good afternoon, Dr. Soljanin.
I just have a few questions.
Did you apply the same
principles of claim construction in your
declaration relating to indefiniteness as you
applied in your declaration relating to the
inter partes review?
MR. VERDINI: Object to the
form.
A. Yes.
Q. If you could turn to exhibit 3,
paragraph 26, where it says Claim Construction
Standard.
Did you apply, where

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appropriate, the claim construction principles
described in paragraphs 26 through 32 in
connection with your declaration in the
inter partes -- in connection with
indefiniteness?
A. Yes.
Q. And if you could turn to
exhibit 4, paragraphs 63 and 64, under the
section Claim Construction.
A. I am there.
Q. Did you apply the principles
described in these paragraphs 63 and 64 in
your indefiniteness declaration? I am sorry.
In your IPR declaration?
A. Yes.
Q. There's also paragraphs in
here, paragraphs 27 through 48, if you could
take a look at those.
A. I didn't get the numbers?
Q. 27 --
A. In which one?
Q. The same declaration. If you
would go to paragraph 27 of exhibit 4?
A. Which paragraphs?
Q. Paragraph 27. It's on page 8.

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A. Yes.
Q. Beginning on page 8 and
continuing for a number of pages there are
standards of anticipation and obviousness.
Did you apply these standards
in connection with exhibit 4, your
declaration, regarding the inter partes
review?
MR. VERDINI: Object to the
form.
A. Yes.
Q. In connection with the
inter partes review were you asked to evaluate
the question of indefiniteness with respect to
any of the claim terms?
A. Of the IPR?
Q. Correct.
A. No.
Q. Now you were asked -- if you
could go back to exhibit 3 now, if you could
turn to page 8. And on page 8 at paragraph 35
there's a quotation from the Supreme Court
case called Nautilus versus Biosig
Instruments. Do you see that?
A. Yes.

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Q. And in that the court said (as
read):
We hold that a patent is
invalid for indefiniteness if its
claims, read in light of the
specification delineating the patent,
and the prosecution history, fail to
inform, with reasonable certainty,
those skilled in the art about the
scope of the invention.
Is that the standard that you
applied in connection with evaluating
indefiniteness with respect to the '601
patent?
A. Yes.
Q. Earlier today you were asked
questions concerning that standard, and in
particular you were asked how you interpreted
the phrase "reasonable certainty."
Do you recall that?
A. I remember discussing this
paragraph.
Q. Did you consider, when you
evaluated the five claim terms that you
identified as indefinite, whether or not those

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claim terms could be construed by one of ordinary skill in the art with reasonable certainty?
MR. VERDINI: Object to the form.
A. I am not sure I understand. I can try to answer. I believe that there are more than one reasonable interpretation, as actually we discussed, of the terms that we discussed by a person skilled in art.
Q. Earlier you were specifically asked how you interpreted that phrase, "reasonable certainty," and you said something to the effect that if it had multiple interpretations, that therefore there was, by one of ordinary skill in the art, that there would be -- there would not be reasonable certainty surrounding the term. Do you recall that testimony?
MR. VERDINI: Object to the form and mischaracterizes the testimony.
A. I remember discussing this, and saying something to the effect that if person skilled in art would find a reasonable

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interpretation that is different than me, that one I adopted or there are in that sense multiple interpretations which are all reasonable to a person skilled in art, then there is no reasonable certainty.
Q. With respect to the five claim terms at issue, did you come to the conclusion that there were multiple reasonable interpretations with respect to each of them?
MR. VERDINI: Object to the form.
A. I believe I stated examples of multiple reasonable interpretation in a number of places that we discussed.
Q. And with respect to the interpretations that you consider reasonable, in the IPR did you select in each instance at least one of those interpretations and rely upon that consistently in the inter partes review as you did your work there?
MR. VERDINI: Object to the form.
A. Yes.
Q. I am going to switch gears now to the last topic.

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Do you recall you answered certain questions earlier about constraints being imposed with respect to the j and k elements of the '601 patent? Do you recall that?
A. Yes.
Q. All right. The constraints, the j and k constraints, where are they imposed in the '601 patent?
A. In the.
Q. Are they imposed in more than one place?
MR. VERDINI: Object to the form.
A. If encoder consists of multiple parts.
Q. That which is the encoder would be the place, whether it be multiple parts or one part, is that where the j and k constraints are imposed?
MR. VERDINI: Object to the form.
A. J and k constraints are imposed, so you would have incoming sequence then you would have an encoder which may be

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one or multiple parts, and after that you would have encoded symbols.
Q. Once the j and k constraints are imposed can they be imposed again?
MR. VERDINI: Object to the form.
MR. SIPIORA: Let me rephrase the question.
BY MR. SIPIORA:
Q. Once the j and k constraints are imposed by the encoder in the '601 patent are they imposed again?
MR. VERDINI: Object to the form.
A. Again? I mean once when they're imposed and encoded symbols are formed, then they are there. There is no -- no, they're not imposed again.
Q. According to your understanding of the '601 patent are the j and k constraints imposed again at the level, at the platter or on the optical surface in connection with what you consider the recorded waveform?
MR. VERDINI: Object to the form.

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A. Between the encoded symbols and the pattern in the disks there is NRZ and NRZI, which are maps. They don't impose anything.
Q. So is it the case that once the j and k constraints are imposed on the encoder there is no further imposition of those constraints on the quote-unquote "recorded waveform"?
MR. VERDINI: Object to the form and asked and answered.
A. Sorry, ask --
MR. SIPIORA: He's just making noise. You can answer the question.
A. Could you repeat the question?
Q. Yes, sure. Is it the case, in the '601 patent, that once the j and k constraints are imposed by the encoder, that they are not imposed again at the place that's known as the recorded waveform?
MR. VERDINI: The same objections.
A. They're not imposed again.
Q. In connection with the testimony you gave earlier you talked about a

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counterpart, there's some counterpart with respect to the imposition of the j and k constraints, do you recall that?
A. So for each encoded sequence of symbols, there is a counterpart of the disk of patterns of bit magnetizations --
(Reporter clarification.)
A. I mean cell magnetizations.
Q. What does that mean when you say there's a counterpart?
A. That means that between -- there is a correspondence which is 1-to-1, which depends how -- the nature of the correspondence is determined whether we have NRZ and NRZI. But there is a 1-to-1 correspondence and that's why I called it a counterpart.
Q. And the counterpart is in the recorded waveform, or in the magnetization, let's just say in this context, or on the optical disk, whatever was imposed previously with respect to j and k constraints, it's reflected in whatever that recording is?
MR. VERDINI: Object to the form.

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A. Maybe I used the term upheld or something. That whatever it's imposed should not be ruined, otherwise you should not be imposing it to begin with. But it's not imposed again.
MR. SIPIORA: Thank you. No further questions.
MR. VERDINI: I think probably two follow-up questions.
EXAMINATION (Cont'd)
BY MR. VERDINI:
Q. You were directed to paragraphs 26 through 32 in exhibit 3 regarding claim construction standard.
A. Paragraphs ...
Q. 26 through 32 of your claim construction declaration.
A. Yes.
Q. And then you were also directed to exhibit 4, paragraphs 63 and 64. So if you can have them both out. Right?
A. Yes.
Q. You would agree with me that the claim construction standard in exhibit 3, which runs from 26 through 32 has more words

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than the claim construction standard that you applied in the IPR declaration, right?
A. It has more words. It looks it has more words.
Q. In your view, though, was there a difference in the standards of claim construction that you used in the indefinite claim construction declaration and that which you used in the IPR declaration?
A. I think you asked me about principles. I believe I was just asked about principles --
Q. Yes.
A. -- which is --
Q. So let's use the word principles, then, instead of standards.
A. Okay.
Q. Even though there are more words --
A. It's a similar approach.
Q. -- you used the same approach in both, isn't that right?
A. Approach, yes.
Q. Okay. And you applied the same -- there wasn't a different claim

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construction standard that you were applying in one versus the other, was there?

A. No.

Q. And then in paragraph 35 of your claim construction declaration, your counsel referred you to the quote from the Supreme Court, right?

A. (Nodding head affirmatively.)

Q. And I just want to make sure we're clear. You read the patent in connection with your IPR declaration, correct?

A. Yes.

Q. You read the specification, correct?

A. (Nodding head affirmatively.)

Q. You read the prosecution history, correct?

A. Yes.

Q. And you did so as a person of ordinary skill in the art, correct?

A. Yes.

Q. And nowhere in there did you make any indication that any of the claims were not reasonably certain --

MR. VERDINI: Strike that.

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BY MR. VERDINI:

Q. And in your IPR declaration you didn't make any mention that any of the claim terms of the '601 patent were anything other than reasonably certain to you, correct?

A. I did not mention. I did not.

MR. VERDINI: I have no further questions. Thank you, Professor.

MR. SIPIORA: Thank you.

(Time noted: 4:00 p.m.)

____

EMINA SOLJANIN

Sworn and subscribed to before me, this _________day of ____________________, 2018, in the jurisdiction aforesaid.

____

NOTARY PUBLIC

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ACKNOWLEDGMENT OF DEPONENT

I,______________________________, do hereby acknowledge that I have read and examined the foregoing testimony, and the same is a true, correct and complete transcription of the testimony given by me, and any corrections appear on the attached Errata sheet signed by me.

__________________ ____________________

(DATE) (SIGNATURE)

Page 221

C E R T I F I C A T E

STATE OF NEW YORK)

COUNTY OF NEW YORK)

I, FRANK J. BAS, a Registered Professional Reporter, Certified Realtime Reporter and Notary Public within and for the State of New York, do hereby certify:

That prior to being examined, the witness named in the foregoing deposition was duly sworn to testify the truth, the whole truth and nothing but the truth;

That said deposition was taken down by me in shorthand at the time and place therein named and thereafter reduced by me to typewritten form and that the same is a true, correct, and complete transcript of said proceedings.

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I further certify that I am not interested in the outcome of this matter.

Witness my hand this 11th day of May, 2018.

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ERRATA SHEET
May 21, 2018

IN RE: Regents of the University of Minnesota v. LSI Corporation, et al.
DEPOSITION DATE: May 9, 2018
DEPONENT/AFFIANT: Emina Soljanin
REPORTER: Frank Bas
RETURN BY: June 23, 2018
JOB NO.: WDC-170935

PAGE	LINE	CORRECTION AND REASON
NUMBER		
29	8, 9	“to describe” should be “a disk drive”
34	17	“single” should be “signal”
136	14	“n-bit” should be “N-bit” for consistancy

6/7/2018 [signature]
(DATE) (SIGNATURE)

* * *

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6/7/2018 ____________________ [signature] ____________________

(Date) (Signature)

Job No.: WDC-170935

UMN EXHIBIT 2008
LSI Corp. et al. v. Regents of Univ. of Minn.
IPR2017-01068

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* * *

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6/7/2018 ____________________ [signature] ____________________

(Date) (Signature)

Job No.: WDC-170935

US005859601A

United States Patent [19]

Moon et al.

[11] **Patent Number: 5,859,601**

[45] **Date of Patent: Jan. 12, 1999**

[54] **METHOD AND APPARATUS FOR IMPLEMENTING MAXIMUM TRANSITION RUN CODES**

[75] Inventors: **Jaekyun Moon**, Plymouth; **Barrett J. Brickner**, Minneapolis, both of Minn.

[73] Assignee: **Regents of the University of Minnesota**, Minneapolis, Minn.

[21] Appl. No.: **730,716**

[22] Filed: **Oct. 15, 1996**

Related U.S. Application Data

[60] Provisional application No. 60/014,954 Apr. 5, 1996.

[51] **Int. Cl.**[6] **H03M 7/00**

[52] **U.S. Cl.** **341/59**; 341/94

[58] **Field of Search** 341/58, 59, 61, 341/94

[56] **References Cited**

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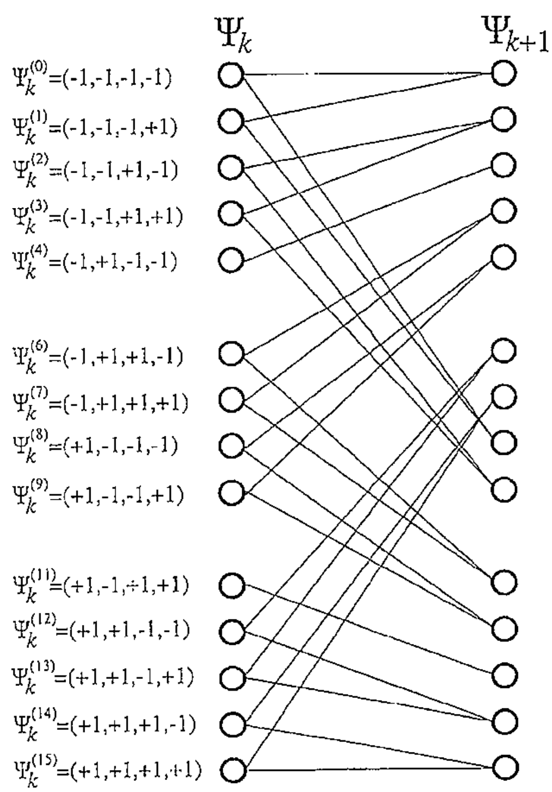
Primary Examiner—Jeffrey A. Gaffin
Assistant Examiner—Jason L. W. Kost
Attorney, Agent, or Firm—Patterson & Keough

[57] **ABSTRACT**

Apparatus and method for coding to improve the minimum distance properties of sequence detectors operating at high densities in storage systems is presented. The coding scheme of the present invention is referred to as maximum transition run (MTR) code and eliminates data patterns producing long runs of consecutive transitions while imposing the usual k constraint necessary for timing recovery. The code has a distance gaining property similar to an existing (1,k) runlength-limited (RLL) code, but can be implemented with considerably higher code rates. When the MTR code is used with fixed delay tree search (FDTS) or high order partial response maximum likelihood (PRML) detectors, the bit error rate performance improves significantly over existing combinations of codes and detectors.

21 Claims, 14 Drawing Sheets



DEPOSITION EXHIBIT 1 PENGAD 800-631-6989

UMN_0002896

Fig. 1

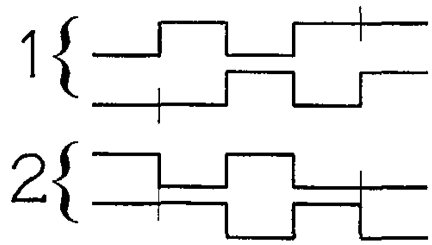


Fig. 2

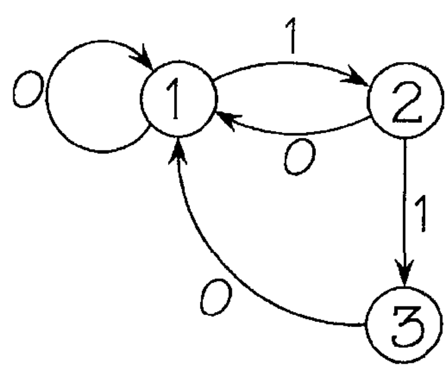


Fig. 3

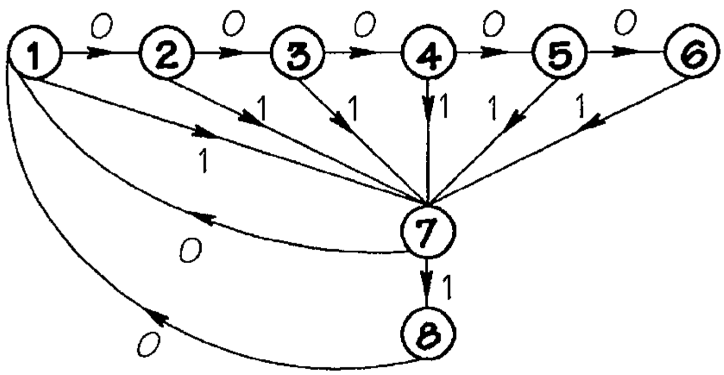


Fig. 4

RLL *k* Constraint	Capacity with MTR $j = 2$
∞	0.8791
10	0.8782
9	0.8774
8	0.8760
7	0.8732
6	0.8680
5	0.8579
4	0.8376
3	0.7947

Fig. 5

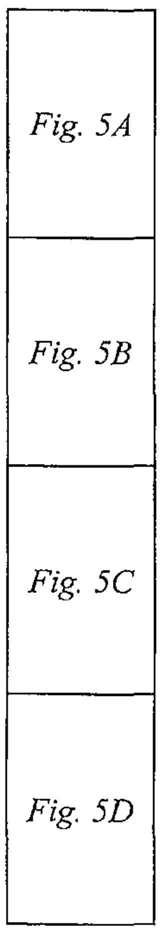


Fig. 6

DATAWORD	CODEWORD
0000	10000
0001	00001
0010	00010
0011	10001
0100	00100
0101	00101
0110	00110
0111	10110
1000	01000
1001	01001
1010	01010
1011	10010
1100	01100
1101	01101
1110	10100
1111	10101

Fig. 11

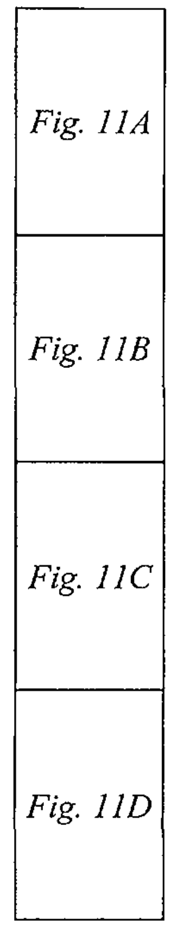


Fig. 5A

n	k	m	rate	efficiency	---- codewords ---- available	required
4	4	2	0.5000	0.5969	6	4
4	5	2	0.5000	0.5828	7	4
4	6	3	0.7500	0.8640	8	8
5	4	3	0.6000	0.7163	12	8
5	5	3	0.6000	0.6994	13	8
5	6	3	0.6000	0.6912	14	8
5	7	3	0.6000	0.6871	15	8
5	8	4	0.8000	0.9133	16	16
6	4	4	0.6667	0.7959	20	16
6	5	4	0.6667	0.7771	23	16
6	6	4	0.6667	0.7680	26	16
6	7	4	0.6667	0.7634	27	16
6	8	4	0.6667	0.7611	28	16
6	9	4	0.6667	0.7598	29	16
6	10	4	0.6667	0.7591	30	16
7	4	5	0.7143	0.8527	36	32
7	5	5	0.7143	0.8326	41	32
7	6	5	0.7143	0.8229	46	32
7	7	5	0.7143	0.8180	49	32
7	8	5	0.7143	0.8154	52	32
7	9	5	0.7143	0.8141	53	32
7	10	5	0.7143	0.8133	54	32
8	4	6	0.7500	0.8954	66	64
8	5	6	0.7500	0.8742	75	64
8	6	6	0.7500	0.8640	84	64
8	7	6	0.7500	0.8589	89	64
8	8	6	0.7500	0.8562	94	64
8	9	6	0.7500	0.8548	97	64
8	10	6	0.7500	0.8540	100	64
9	4	6	0.6667	0.7959	116	64
9	5	7	0.7778	0.9066	137	128
9	6	7	0.7778	0.8960	154	128
9	7	7	0.7778	0.8907	163	128
9	8	7	0.7778	0.8879	172	128
9	9	7	0.7778	0.8864	177	128
9	10	7	0.7778	0.8856	182	128
10	4	7	0.7000	0.8357	208	128
10	5	7	0.7000	0.8159	247	128
10	6	8	0.8000	0.9216	282	256
10	7	8	0.8000	0.9161	299	256
10	8	8	0.8000	0.9133	316	256
10	9	8	0.8000	0.9117	325	256
10	10	8	0.8000	0.9109	334	256

Fig. 5B

11	4	8	0.7273	0.8682	372	256
11	5	8	0.7273	0.8477	448	256
11	6	9	0.8182	0.9426	514	512
11	7	9	0.8182	0.9370	549	512
11	8	9	0.8182	0.9340	580	512
11	9	9	0.8182	0.9325	597	512
11	10	9	0.8182	0.9316	614	512
12	4	9	0.7500	0.8954	664	512
12	5	9	0.7500	0.8742	812	512
12	6	9	0.7500	0.8640	938	512
12	7	9	0.7500	0.8589	1005	512
12	8	10	0.8333	0.9513	1066	1024
12	9	10	0.8333	0.9497	1097	1024
12	10	10	0.8333	0.9489	1128	1024
13	4	10	0.7692	0.9183	1188	1024
13	5	10	0.7692	0.8966	1471	1024
13	6	10	0.7692	0.8862	1712	1024
13	7	10	0.7692	0.8809	1841	1024
13	8	10	0.7692	0.8781	1956	1024
13	9	10	0.7692	0.8767	2017	1024
13	10	11	0.8462	0.9635	2074	2048
14	4	11	0.7857	0.9380	2122	2048
14	5	11	0.7857	0.9159	2667	2048
14	6	11	0.7857	0.9052	3124	2048
14	7	11	0.7857	0.8998	3372	2048
14	8	11	0.7857	0.8970	3590	2048
14	9	11	0.7857	0.8955	3705	2048
14	10	11	0.7857	0.8947	3814	2048
15	4	11	0.7333	0.8755	3792	2048
15	5	12	0.8000	0.9325	4834	4096
15	6	12	0.8000	0.9216	5702	4096
15	7	12	0.8000	0.9161	6176	4096
15	8	12	0.8000	0.9133	6588	4096
15	9	12	0.8000	0.9117	6807	4096
15	10	12	0.8000	0.9109	7010	4096
16	4	12	0.7500	0.8954	6778	4096
16	5	13	0.8125	0.9471	8760	8192
16	6	13	0.8125	0.9360	10408	8192
16	7	13	0.8125	0.9305	11313	8192
16	8	13	0.8125	0.9275	12090	8192
16	9	13	0.8125	0.9260	12505	8192
16	10	13	0.8125	0.9252	12886	8192
17	4	13	0.7647	0.9129	12112	8192
17	5	13	0.7647	0.8914	15877	8192
17	6	14	0.8235	0.9487	18996	16384

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Fig. 5C

17	7	14	0.8235	0.9431	20723	16384
17	8	14	0.8235	0.9401	22188	16384
17	9	14	0.8235	0.9386	22972	16384
17	10	14	0.8235	0.9377	23686	16384
18	4	14	0.7778	0.9285	21646	16384
18	5	14	0.7778	0.9066	28776	16384
18	6	15	0.8333	0.9600	34670	32768
18	7	15	0.8333	0.9543	37960	32768
18	8	15	0.8333	0.9513	40720	32768
18	9	15	0.8333	0.9497	42202	32768
18	10	15	0.8333	0.9489	43536	32768
19	4	15	0.7895	0.9425	38684	32768
19	5	15	0.7895	0.9202	52153	32768
19	6	15	0.7895	0.9095	63278	32768
19	7	16	0.8421	0.9644	69534	65536
19	8	16	0.8421	0.9613	74732	65536
19	9	16	0.8421	0.9597	77529	65536
19	10	16	0.8421	0.9589	80024	65536
20	4	16	0.8000	0.9551	69132	65536
20	5	16	0.8000	0.9325	94523	65536
20	6	16	0.8000	0.9216	115492	65536
20	7	16	0.8000	0.9161	127369	65536
20	8	17	0.8500	0.9703	137152	131072
20	9	17	0.8500	0.9687	142429	131072
20	10	17	0.8500	0.9679	147092	131072
21	4	16	0.7619	0.9096	123548	65536
21	5	17	0.8095	0.9436	171314	131072
21	6	17	0.8095	0.9326	210790	131072
21	7	17	0.8095	0.9270	233309	131072
21	8	17	0.8095	0.9241	251708	131072
21	9	17	0.8095	0.9226	261658	131072
21	10	18	0.8571	0.9760	270370	262144
22	4	17	0.7727	0.9225	220794	131072
22	5	18	0.8182	0.9537	310489	262144
22	6	18	0.8182	0.9426	384724	262144
22	7	18	0.8182	0.9370	427366	262144
22	8	18	0.8182	0.9340	461946	262144
22	9	18	0.8182	0.9325	480694	262144
22	10	18	0.8182	0.9316	496970	262144
23	4	18	0.7826	0.9343	394584	262144
23	5	19	0.8261	0.9629	562732	524288
23	6	19	0.8261	0.9517	702180	524288
23	7	19	0.8261	0.9460	782831	524288
23	8	19	0.8261	0.9431	847784	524288
23	9	19	0.8261	0.9415	883087	524288
23	10	19	0.8261	0.9406	913484	524288

Fig. 5D

24	4	19	0.7917	0.9451	705168	524288
24	5	19	0.7917	0.9228	1019898	524288
24	6	20	0.8333	0.9600	1281584	1048576
24	7	20	0.8333	0.9543	1433958	1048576
24	8	20	0.8333	0.9513	1555892	1048576
24	9	20	0.8333	0.9497	1622325	1048576
24	10	20	0.8333	0.9489	1679082	1048576
25	4	20	0.8000	0.9551	1260216	1048576
25	5	20	0.8000	0.9325	1848466	1048576
25	6	21	0.8400	0.9677	2339084	2097152
25	7	21	0.8400	0.9619	2626666	2097152
25	8	21	0.8400	0.9589	2855444	2097152
25	9	21	0.8400	0.9573	2980384	2097152
25	10	21	0.8400	0.9565	3086334	2097152
26	4	21	0.8077	0.9643	2252152	2097152
26	5	21	0.8077	0.9415	3350167	2097152
26	6	22	0.8462	0.9748	4269182	4194304
26	7	22	0.8462	0.9690	4811419	4194304
26	8	22	0.8462	0.9660	5240442	4194304
26	9	22	0.8462	0.9643	5475284	4194304
26	10	22	0.8462	0.9635	5673012	4194304
27	4	21	0.7778	0.9285	4024856	2097152
27	5	22	0.8148	0.9498	6071855	4194304
27	6	22	0.8148	0.9387	7791902	4194304
27	7	23	0.8519	0.9755	8813360	8388608
27	8	23	0.8519	0.9725	9617500	8388608
27	9	23	0.8519	0.9708	10058681	8388608
27	10	23	0.8519	0.9700	10427604	8388608
28	4	22	0.7857	0.9380	7192882	4194304
28	5	23	0.8214	0.9575	11004651	8388608
28	6	23	0.8214	0.9463	14221398	8388608
28	7	23	0.8214	0.9407	16143951	8388608
28	8	24	0.8571	0.9785	17650478	16777216
28	9	24	0.8571	0.9769	18478872	16777216
28	10	24	0.8571	0.9760	19167054	16777216

Fig. 7

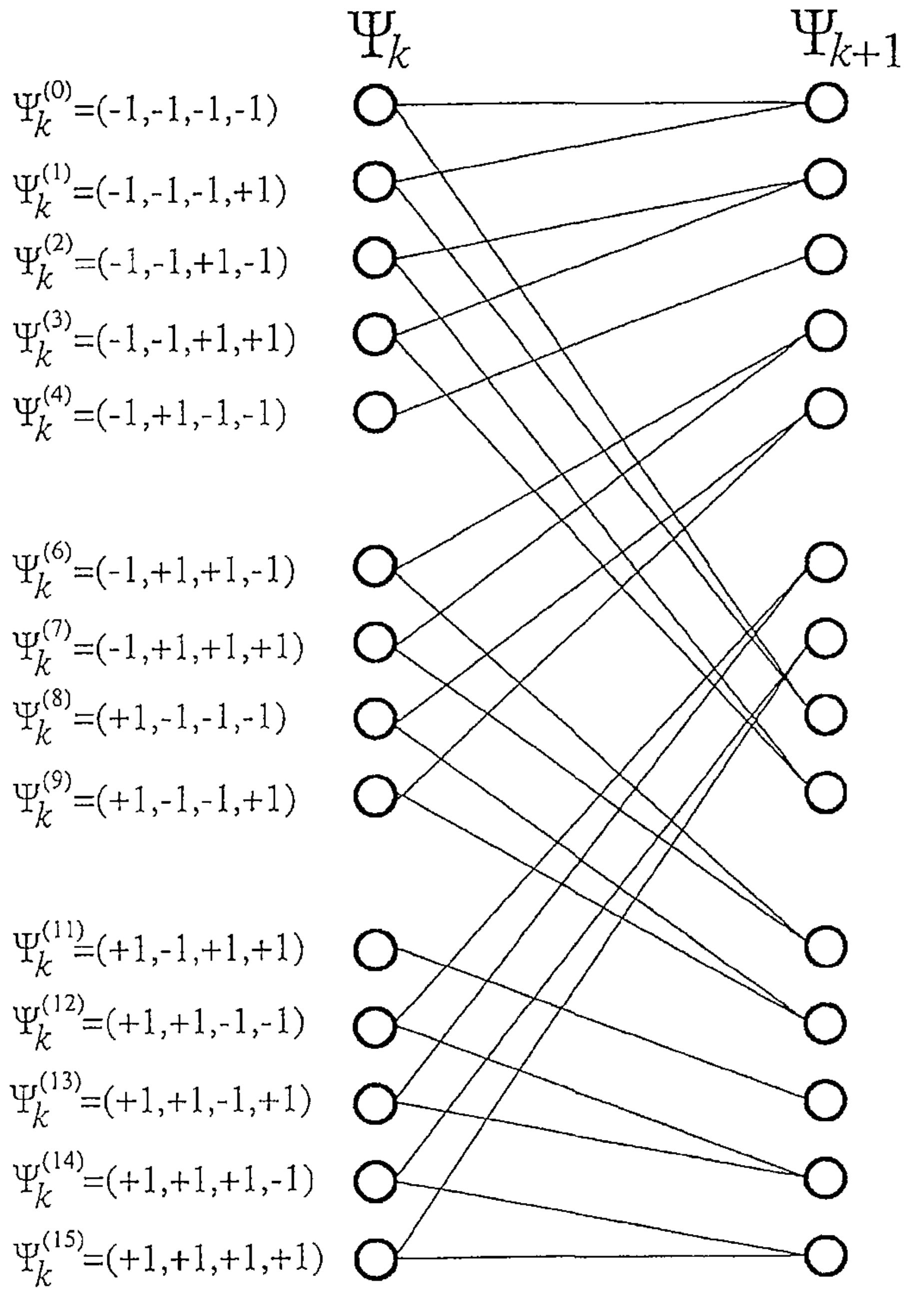

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Fig. 8

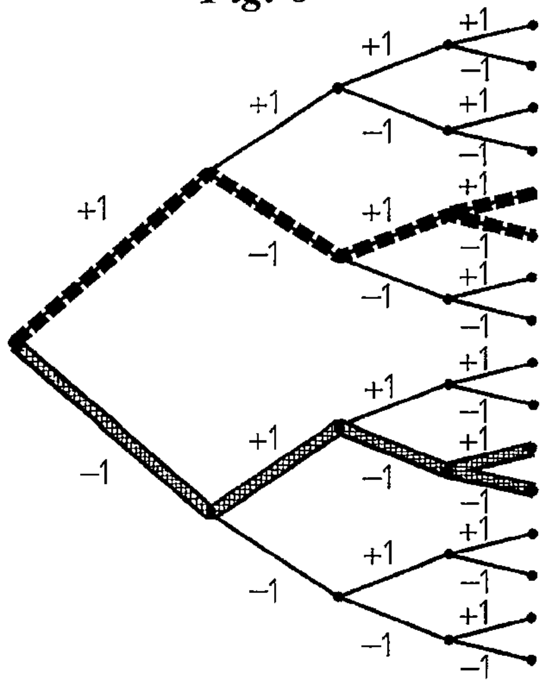

Fig. 9

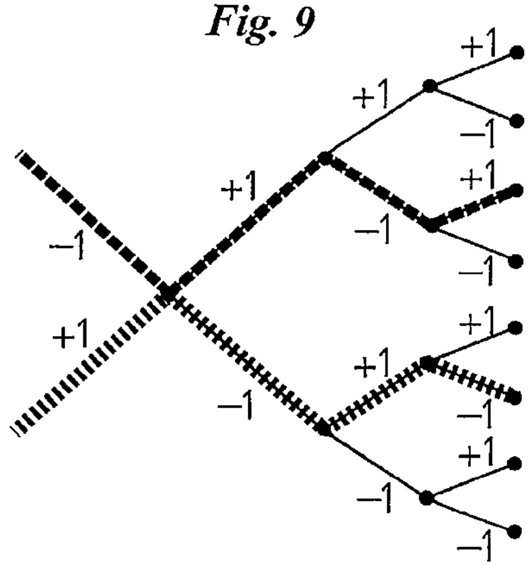

Fig. 10

C = 0				C = 2			C = 4		C = 6
219	795	3171	3651	247	998	3553	503	3555	1015
222	798	3174	3654	251	1004	3556	507	3558	3319
231	807	3180	3657	439	1009	3611	887	3564	3323
238	819	3185	3660	443	3127	3614	891	3569	3511
243	822	3192	3681	446	3131	3623	894	3576	3515
246	825	3207	3684	475	3134	3635	951	3639	3518
249	828	3214	3777	478	3175	3638	955	3643	3547
252	867	3219	3780	487	3182	3641	958	3646	3550
311	870	3225	3784	494	3187	3644	987	3687	3559
315	876	3228	3843	499	3190	3655	990	3694	3566
318	881	3267	3846	502	3193	3662	999	3699	3571
411	888	3270	3849	505	3196	3683	1006	3702	3574
414	903	3273	3852	631	3227	3686	1011	3705	3577
435	910	3276	3857	635	3230	3692	1014	3708	3703
438	915	3288	3864	638	3271	3697	3191	3783	3707
441	921	3297	3873	823	3278	3704	3195	3790	3710
444	924	3300	3876	827	3289	3779	3198	3801	3803
455	945	3459		830	3292	3782	3291	3804	3806
462	952	3462		871	3299	3785	3294	3811	3815
473	963	3465		878	3302	3788	3303	3814	3822
476	966	3468		883	3308	3800	3310	3820	3827
483	969	3473		886	3313	3809	3315	3825	3830
486	972	3480		889	3320	3812	3318	3832	3833
492	984	3521		892	3463	3847	3321	3867	3836
497	993	3524		923	3470	3854	3324	3870	3895
504	996	3528		926	3475	3859	3483	3879	3899
567	3099	3591		947	3481	3865	3486	3891	3902
571	3102	3598		950	3484	3868	3507	3894	3943
574	3111	3603		953	3505	3875	3510	3897	3950
615	3123	3609		956	3512	3878	3513	3900	3955
622	3126	3612		967	3523	3889	3516	3939	3958
627	3129	3619		974	3526	3896	3527	3942	3961
630	3132	3622		985	3529	3937	3534	3948	3964
633	3143	3633		988	3532	3940	3545	3953	
636	3150	3640		995	3544		3548	3960	

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Fig. 11A

n	k	m	rate	Max C	---- codewords ---- available	required
6	4	2	0.3333	2	5	4
7	4	3	0.4286	3	9	8
7	5	3	0.4286	3	10	8
8	4	4	0.5000	2	19	16
8	5	4	0.5000	2	24	16
8	6	5	0.6250	6	32	32
9	4	4	0.4444	3	24	16
9	5	5	0.5556	3	33	32
9	6	5	0.5556	3	39	32
9	7	5	0.5556	3	42	32
10	4	5	0.5000	2	47	32
10	5	6	0.6000	4	79	64
10	6	6	0.6000	2	75	64
10	7	6	0.6000	2	82	64
10	8	6	0.6000	2	84	64
11	4	6	0.5455	3	70	64
11	5	6	0.5455	3	97	64
11	6	7	0.6364	5	144	128
11	7	7	0.6364	3	129	128
11	8	7	0.6364	3	137	128
11	9	7	0.6364	3	142	128
12	4	7	0.5833	2	135	128
12	5	8	0.6667	6	263	256
12	6	8	0.6667	4	296	256
12	7	8	0.6667	4	328	256
12	8	8	0.6667	2	264	256
12	9	8	0.6667	2	274	256
12	10	8	0.6667	2	277	256
13	4	7	0.5385	3	200	128
13	5	8	0.6154	3	296	256
13	6	8	0.6154	3	364	256
13	7	9	0.6923	5	514	512
13	8	9	0.6923	5	556	512
13	9	9	0.6923	5	583	512
13	10	9	0.6923	5	601	512
14	4	9	0.6429	6	524	512
14	5	9	0.6429	2	562	512
14	6	10	0.7143	6	1046	1024
14	7	10	0.7143	4	1038	1024
14	8	10	0.7143	4	1114	1024

Fig. 11B

14	9	10	0.7143	4	1163	1024
14	10	10	0.7143	4	1195	1024
15	4	9	0.6000	3	578	512
15	5	10	0.6667	5	1119	1024
15	6	10	0.6667	3	1130	1024
15	7	10	0.6667	3	1274	1024
15	8	11	0.7333	9	2108	2048
15	9	11	0.7333	7	2136	2048
15	10	11	0.7333	7	2221	2048
16	4	10	0.6250	2	1086	1024
16	5	11	0.6875	4	2258	2048
16	6	11	0.6875	2	2153	2048
16	7	12	0.7500	10	4113	4096
16	8	12	0.7500	6	4164	4096
16	9	12	0.7500	6	4378	4096
16	10	12	0.7500	6	4531	4096
17	4	11	0.6471	5	2060	2048
17	5	11	0.6471	3	2737	2048
17	6	12	0.7059	5	4607	4096
17	7	12	0.7059	5	5312	4096
17	8	12	0.7059	3	4372	4096
17	9	12	0.7059	3	4575	4096
17	10	12	0.7059	3	4712	4096
18	4	12	0.6667	6	4545	4096
18	5	13	0.7222	8	8255	8192
18	6	13	0.7222	4	9135	8192
18	7	13	0.7222	4	10489	8192
18	8	13	0.7222	2	8272	8192
18	9	13	0.7222	2	8644	8192
18	10	14	0.7778	10	16747	16384
19	4	12	0.6316	3	4836	4096
19	5	13	0.6842	3	8379	8192
19	6	14	0.7368	7	16626	16384
19	7	14	0.7368	5	17111	16384
19	8	14	0.7368	5	18821	16384
19	9	14	0.7368	5	19849	16384
19	10	14	0.7368	5	20579	16384
20	4	13	0.6500	2	8985	8192
20	5	14	0.7000	4	21308	16384
20	6	15	0.7500	6	33829	32768
20	7	15	0.7500	4	33557	32768
20	8	15	0.7500	4	36775	32768
20	9	15	0.7500	4	38703	32768
20	10	15	0.7500	4	40032	32768
21	4	14	0.6667	5	17857	16384

Fig. 11C

21	5	15	0.7143	5	33597	32768
21	6	15	0.7143	3	35236	32768
21	7	16	0.7619	9	68427	65536
21	8	16	0.7619	7	71495	65536
21	9	16	0.7619	7	76019	65536
21	10	16	0.7619	5	67153	65536
22	4	15	0.6818	4	34683	32768
22	5	16	0.7273	4	65732	65536
22	6	16	0.7273	2	66307	65536
22	7	17	0.7727	8	140771	131072
22	8	17	0.7727	6	143015	131072
22	9	17	0.7727	6	151640	131072
22	10	17	0.7727	6	157756	131072
23	4	15	0.6522	3	40949	32768
23	5	16	0.6957	3	79430	65536
23	6	17	0.7391	5	149570	131072
23	7	17	0.7391	3	131932	131072
23	8	18	0.7826	11	264682	262144
23	9	18	0.7826	9	273403	262144
23	10	18	0.7826	9	286841	262144
24	4	16	0.6667	2	75344	65536
24	5	18	0.7500	10	263893	262144
24	6	18	0.7500	4	290571	262144
24	7	18	0.7500	4	346562	262144
24	8	19	0.7917	10	546228	524288
24	9	19	0.7917	8	553812	524288
24	10	19	0.7917	8	579307	524288
25	4	17	0.6800	5	154995	131072
25	5	18	0.7200	5	326028	262144
25	6	19	0.7600	7	558253	524288
25	7	19	0.7600	5	578589	524288
25	8	19	0.7600	5	648508	524288
25	9	19	0.7600	5	690244	524288
25	10	19	0.7600	5	719462	524288
26	4	18	0.6923	4	296598	262144
26	5	19	0.7308	4	629996	524288
26	6	20	0.7692	6	1110146	1048576
26	7	20	0.7692	4	1117761	1048576
26	8	20	0.7692	4	1250283	1048576
26	9	20	0.7692	4	1328833	1048576
26	10	21	0.8077	12	2110651	2097152
27	4	19	0.7037	9	540881	524288
27	5	20	0.7407	7	1175593	1048576
27	6	20	0.7407	3	1127331	1048576
27	7	21	0.7778	7	2229237	2097152
27	8	21	0.7778	5	2117392	2097152

Fig. 11D

27	9	21	0.7778	5	2260957	2097152
27	10	21	0.7778	5	2361027	2097152
28	4	20	0.7143	8	1085033	1048576
28	5	21	0.7500	6	2327099	2097152
28	6	22	0.7857	12	4234345	4194304
28	7	22	0.7857	6	4398507	4194304
28	8	22	0.7857	6	4985834	4194304
28	9	22	0.7857	4	4339268	4194304
28	10	22	0.7857	4	4525346	4194304

METHOD AND APPARATUS FOR IMPLEMENTING MAXIMUM TRANSITION RUN CODES

This application claims the benefit of U.S. provisional application No. 60/014,954, filed Apr. 5, 1996.

FIELD OF THE INVENTION

The present invention relates in general to digital storage systems. More specifically, the invention pertains to an improved coding technique involving data recovery channels utilizing sequence detection methods.

BACKGROUND OF THE INVENTION

Channel codes, sometimes called modulation codes, are mappings of data bits into the symbols that are either transmitted in a communication system or recorded onto a medium in a storage device. The purpose of these codes is to prevent certain characteristics in the stream of symbols that make their recovery difficult. Runlength limited (RLL) codes are commonly used in magnetic recording. These codes impose a (d,k) constraint on the recorded data sequence. With the Non-Return-to-Zero (NRZ) recording format, where the binary "1" represents a positive level in the magnetization waveform and the binary "0" negative level in the same waveform, d+1 is the minimum number of consecutive like symbols and k+1 is the maximum number of consecutive like symbols in the binary sequence With the Non-Return-to-Zero-Inversion (NRZI) recording format, where a magnetic transition is represented by 1 and no transition by 0, d and k are the minimum and maximum number of consecutive 0's between any two 1's, respectively as described in P. H. Siegel, "Recording codes for digital magnetic storage," *IEEE Transactions on Magnetics*, vol. MAG-21, no. 5, pp. 1344–1349, September 1985. The d constraint is used to increase the minimum physical spacing between transitions. The k constraint guarantees that a change in the readback waveform will occur at regular intervals for the purpose of synchronizing a phase locked loop to the data. A (1,7) code is a common example of an RLL code; see U.S Pat. No. 4,337,458. Also popular is the (0,4/4) code, where d=0 and k=4 both for the data sequence and for the sequence that results if every other symbol is considered; see U.S. Pat. No. 4,707,681. Additional constraints, such as a limitation on the total number of NRZI 1's in a codeword for the purpose of improving timing and gain control can be applied to these codes; see U.S. Pat. No. 5,196,849. A DC-free constraint as described in U.S. Pat. No. 4,499,454 can be used to reduce the low frequency spectral content of the readback signal. Codes for data storage typically assume a binary symbol set such as the polarity of the write signal or the presence and absence of a transition, but it is possible to conceive systems that use more than two distinct symbols. For example, the ternary 3PM code uses three distinct symbols and places a lower bound on the distance between symbols in the same way that the RLL d constraint is applied to the binary case. See G. V. Jacoby, "Ternary 3PM magnetic recording code and system," *IEEE Transactions on Magnetics*, vol. MAG-17, no. 6, pp. 3326–3328, November 1981. In optical data storage, a special type of RLL constraint is applied to guarantee the minimum size of the written mark on the medium as described in R. Karabed and P. H. Siegel, "Even mark modulation for optical recording," International Conference on Communications, June 1989. While RLL (1,k) coding has many useful properties, the required code rate, given by the number of data bits per channel bit, is typically low, forcing the channel to operate at a considerably higher speed than the actual data rate. On the other hand, (0,4/4) or more generally (0,G/I) coding offers a much higher rate, but does not provide any coding gain. Also, (0,G/I) codes are designed specifically for interleaved systems such as class IV partial response (PR4) systems, and are not optimal for other detectors such as fixed-delay tree search (FDTS) systems.

Sequence detectors are data recovery devices that examine multiple received samples to recover the input data sequence. Methods such as Viterbi detection, FDTS/DF, and PRML are all sequence detectors. In magnetic data storage devices, the response of the channel to an input symbol typically extends over several sample periods. Sequence detectors can outperform sample-by-sample decision rules such as peak detection by using information about the data to be detected contained in adjacent samples. Errors in sequence detectors arise mostly from difficulty in distinguishing minimum distance patterns. For a sequence detector that uses M samples to make a decision, all possible noiseless sample sequences can be plotted as points in an M-dimensional space, where each sample corresponds to a coordinate in this space. The minimum distance patterns are those patterns corresponding to different decisions that have the minimum Euclidean distance from one another. The Euclidean distance is the geometric distance between two points and refers to the square root of the sum of the squares of the differences between the coordinates of two points. The performance of sequence detectors such as E^2PRML can be improved by coding to remove the patterns that cause minimum distance error events, thereby increasing the minimum distance. This increase in the minimum distance as a result of coding is termed coding gain. See R. Karabed and P. H. Siegel, "Coding for higher order partial response channels," *Proceedings of the International Society for Optical Engineering*, vol. 2605, pp. 115–126, 1995.

SUMMARY OF THE INVENTION

The present invention relates to a channel coding technique to improve data storage devices such as magnetic computer disk drives and professional and consumer tape recorders. The coding scheme, which is referred to herein as the maximum transition-run (MTR) coding, eliminates certain error-prone binary data patterns from the allowable set of input data patterns that are to be recorded in the storage medium. As a consequence, the final bit error rate is improved significantly when the original data bits are reproduced. This improvement in the bit error rate can be traded for an increase in storage density if the error rate performance is already satisfactory. See B. Brickner and J. Moon, "Coding for increased distance with a d=0 FDTS/DF detector," Seagate Internal Report, May 1995; also presented at the Annual Meeting of the National Storage Industry Consortium, Monterey, Calif., June 1995, and J. Moon and B. Brickner, "Maximum transition run codes for data storage systems," presented at Intermag '96, Seattle, Washington, April 1996.

More specifically, the MTR code imposes a limit on the maximum number of consecutive transitions that can occur in the written magnetization pattern in magnetic recording. Analysis indicates that the performance improvement is most significant for the bit densities anticipated for products in the near future when the maximum number of consecutive transitions is limited to two. The MTR code with a constraint length of j=2 will allow "dibit" transitions in the magnetization pattern, but will not permit "tribit" or longer runs of

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consecutive transitions. Unless indicated otherwise, our discussion of the MTR code relating to the present invention will be focused on the constraint of j=2 hereafter. When the MTR coding scheme is combined with a certain class of sequence detectors to recover written data in high density recording, the bit-error-rate (BER) performance is improved significantly over existing code/detector combinations such as (0,G/I) code/partial response maximum likelihood (PRML) and (1,7) RLL code/peak detector combinations. Computer implemented simulations show a large performance advantage with the MTR code combined with high order PRML systems and fixed delay tree search with decision feedback (FDTS/DF) systems over the existing code/detector combinations. With the NRZI format, the MTR code constraint is equivalent to limiting the maximum runlength of 1's. To facilitate timing recovery, the usual maximum runlength constraint is also imposed on 0's.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows pairs of write patterns causing most errors in sequence detection at high user densities.

FIG. 2 is the state diagram for the MTR code with j=2.

FIG. 3 is the state diagram for an MTR (2;6) code.

FIG. 4 gives the capacities for the MTR j=2 codes with different RLL k constraints.

FIG. 5 is a table showing the code parameters for MTR j=2 block codes with different RLL k constraints and different block sizes.

FIG. 6 shows a mapping of datawords to codewords for the rate 4/5 MTR (2;8) code.

FIG. 7 is the E^2PR4-VA trellis modified for use with an MTR j=2 code.

FIG. 8 illustrates a FDTS τ=3 detector modified for use with an MTR j=2 code.

FIG. 9 illustrates a FDTS τ=2 detector modified for use with an MTR j=2 code.

FIG. 10 lists a decimal representation of the valid codewords corresponding to different values of C for the 8/12 DC-free MTR j=2 code.

FIG. 11 lists code parameters for DC-free MTR j=2 block codes with different RLL k constraints and different block sizes

DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention pertains to an improved coding technique to enhance the minimum distance properties of sequence detectors. The invention is advantageously used in storage and similar systems operating at high data densities.

Prior art experience indicates that the primary source of errors in optimal and near-optimal sequence detectors operating at high data densities is the detector's inability in the presence of noise to distinguish the minimum distance patterns. FIG. 1 is an exemplary depiction of pairs of write patterns which cause most errors in sequence detection. These four pairs correspond to an NRZ input error (or difference) pattern of $e_k=\pm\{2\text{-}2\ 2\}$, assuming input data take on +1's and −1's.

The present state of the art approach to attenuate these errors is to remove data patterns allowing this type of error pattern through coding. The potential improvement in the FDTS detection performance using this approach can be estimated by computing the increase in the minimum distance between two diverging look ahead tree paths after removing the paths that allow the $\pm\{2\text{-}2\ 2\}$ error events. A simple minimum distance analysis for PRML systems reveals that this is also a critical error pattern in high order PRML systems such as E^2PR4ML. Low order PRML systems are not dominated by these errors because they force the channel to respond like a low density system where the minimum distance error event is different.

To obtain a coding gain (improvement in minimum distance due to coding), the minimum distance pairs shown in FIG. 1 must be eliminated. In accordance with the present invention, this can be accomplished using the existing RLL (1,k) code, which does not allow consecutive transitions. The minimum requirement for producing a coding gain in this situation is to remove one pattern from each pair of minimum distance sequences. RLL (1,k) codes eliminate both patterns associated with all the minimum distance pairs and thereby result in fewer patterns available to the encoder. Consequently this imposes the need to map input data to a small set of patterns resulting in a lower code rate (the ratio of the number of input bits to output bits). Further, this increases the speed and bandwidth at which the detector must operate to produce data bits at a particular speed. An increase in noise bandwidth translates to increased noise in the system, which works against the coding gain. The idea of MTR coding is to eliminate all sequences with three or more consecutive transitions, but allow the dibit pattern to survive in the recorded sequence. Thus, with MTR coding, the dominant error events will be prevented as with (1,k) coding, but the required code rate is much better than that of the typical (1,k) RLL code.

Referring now to FIG. 2, the MTR j=2 code based on the NRZI recording convention, where 1 and 0 represent the presence and absence, respectively, of a magnetic transition is shown Specifically, FIG. 2 depicts a state diagram defining all possible channel input sequences. For example, a sequence can be found by starting at any state and moving along the arrows. In the alternate, a sequence can also be found by taking each arrow label as the channel input. The capacity of the code can be obtained by finding the largest eigenvalue of the adjacency matrix A, which describes the transitions between states for the given state diagram and computing:

$$\text{Capacity}=\log_2\lambda_{max}(A). \qquad (1)$$

To more compactly describe the code constraints, the MTR parameters are written as (j;k) where j is the MTR constraint and k is the usual RLL constraint. For practical codes, the RLL k-constraint must be included for timing recovery. This constraint can be incorporated into the state diagram as in the case of the MTR(j;k)=(2;6) code shown in FIG. 3. The capacities for MTR(2;k) codes for different k constraints are given in FIG. 4. The capacity is the upper bound on the code rate for the given set of parameters. Most codes will have a rate less than capacity because typically the code complexity will become very large as the code rate approaches capacity. For example, a code with a rate of 7/8 is possible for k≧8; however, it is likely to be extremely complex. Lower rates such as 4/5, 5/6 and 6/7 will require less complexity, while still improving on the 2/3 rate of RLL(1,7) codes.

While state-dependent encoders and sliding block decoders can be designed for the MTR constraint, simple fixed-length block codes can be realized with good rates and reasonable k values. A computer search is utilized to find the 2^m n-bit codewords required to implement a rate m/n block code. First, all binary words that contain the NRZI string of "111" or more than k consecutive NRZI 0's are removed

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from the list of 2^n n-bit binary words. Then, in order to meet the MTR constraint at the codeword boundaries, words that start or end with a "11" string are removed. Also, the k constraint is satisfied at the boundary by removing the words with k_1+1 leading 0's or k_2+1 trailing 0's where $k_1+k_2=k$. FIG. 5 shows code parameters for representative block codes obtained through computer search for various combinations of n and k. The efficiency is defined as the ratio of the code rate, m/n, to the capacity computed for the given value of k and the MTR constraint. Thus, the efficiency is a measure of how close the rate is to the upper bound

As an example of a MTR block code, the rate 4/5, MTR(2;8) block code is given in FIG. 6. The pairing of user data blocks and codewords were chosen so that the second bit in the codeword corresponds to the second bit in the user data. Many other pairings are possible; the one chosen is reasonable, but not necessarily optimal in terms of minimizing the logic implementation. Note that the k=8 constraint comes into effect when the codewords 10000 00001 occur in sequence. If the user data and codeword pairs are represented by

$$X=[X_0X_1X_2X_3]\longleftrightarrow Y=[Y_0Y_1Y_2Y_3Y_4]. \quad (2)$$

then the equations for the encoder are:

$$M=\bar{X}_0+\bar{X}_1$$

$$Y_0=\bar{X}_1\bar{Y}_1\bar{Y}_3\bar{Y}_4+X_2\bar{Y}_3X_2X_3$$

$$Y_1\_X_0\bar{X}_1\bar{X}_3+X_0\bar{X}_2 \quad (3)$$

$$Y_2=X_1$$

$$Y_3X_2\bar{Y}_4M$$

$$Y_4=\bar{X}_0\bar{X}_1X_3+X_3\bar{M}+\bar{X}_2X_3.$$

The corresponding decoder is

$$X_0=\bar{Y}_2\bar{Y}_4X_3+Y_0Y_2\bar{Y}_3+Y_1$$

$$X_1=Y_2$$

$$X_2=Y_0X_3+Y_0X_0+Y_3 \quad (4)$$

$$X_3=Y_0Y_3+Y_4.$$

These logic rules are representative of those that could be developed for any of the MTR codes using industry standard design packages.

Block codes with short block lengths tend to have low efficiencies because many potential codewords are eliminated by the boundary conditions. State-dependent encoders can use more codewords and achieve higher efficiencies because the state carries information about the previously used codeword(s). A shortcoming of codes that use a state-dependent encoder is that, in general, they require a sliding-block decoder that examines the codeword and other codewords adjacent to it. This mechanism can cause detection errors in adjacent codewords to affect the decoding of other codewords, an effect known as error propagation. It is possible to conceive state-depended encoders that use block decoders, thereby eliminating error propagation in the decoder. To this end, a two-state encoder can be formed in which the two states correspond to the last bit of the previous codeword. Knowledge of the most recent bit allows codewords to be added for both cases. In this manner, the mapping from dataword to codeword is dependent on the previously used codeword, but if the mapping from codeword to dataword is unique, a block decoder can be used.

An application of this technique is the reduction of the k constraint for a particular block code. The block code boundary condition eliminates all codewords that begin with "11", but if the last bit is known to be a 0, these codewords are valid. For small block sizes, the k constraint usually comes into effect when codewords beginning and ending with 0 are joined. By replacing the codewords with a long run of NRZI 0's with a codeword beginning with "11" when the previous bit is a 0, the k constraint can be reduced. To illustrate this, consider the rate 4/5 MTR(2,8) code. The RLL k=8 condition exists only when the codewords 10000 and 00001 are put together. Similarly, k=7 occurs when 10000 and 00010 or 01000 and 00001 are combined. All three cases can be eliminated if, following a codeword with $Y_4=0$, the codewords 00001 and 00010 are replaced by codewords where $Y_0=1$. This is not possible for a block code because all the available codewords are used; however, codewords beginning with 110 are valid if the preceding bit is a 0. In the case of codewords with length n=5, three such words exist, they are 11000, 11001, and 11010. To reduce the required k constraint to 6, the following conditional mappings are used:

$$Y(X=0001)=\left\{\frac{11001, Z=0}{00001, Z=1}\right\} \quad (5)$$

and

$$Y|(X=0010)=\left\{\begin{array}{l}11000\ Z=0\\ 00010, Z=1\end{array}\right. \quad (6)$$

where Z is the value of Y_4 in the previous codeword. All other pairings are unchanged from Table I. In effect, the conditional mappings creates a state dependent encoder with two states. Unlike most state dependent encoders, there is only one possible data word for each codeword; therefore, a block decoder can be used. Boolean equations for the resulting encoder is given by

$$Y_0=\bar{X}_1\bar{Y}_1\bar{Y}_3\bar{Y}_4+X_2\bar{Y}_3+\bar{X}_0Y_1+X_2X_3$$

$$Y_1=\bar{X}_1X_2\bar{X}_3\bar{Z}+\bar{X}_1\bar{X}_2X_3\bar{Z}=X_0\bar{X}_1\bar{X}_3+X_0\bar{X}_2$$

$$Y_2=X_1 \quad (7)$$

$$Y_3=X_1X_2\bar{X}_3Z+X_0\bar{X}_1X_2+X_0X_1X_2$$

$$Y_4=X_3\bar{Y}_3$$

The corresponding block decoder is

$$X_0=Y_2Y_4X_3+Y_2\bar{Y}_3X_2+Y_0Y_1$$

$$X_1=Y_2$$

$$X_2=Y_0Y_1\bar{Y}_4+Y_0\bar{Y}1Y_4+Y_0Y_2+Y_3 \quad (8)$$

$$X_3=Y_0Y_3+Y_4.$$

MODIFIED DETECTION AND DISTANCE GAIN

To realize the coding gain at the detector output, the detector has to be modified. In the case of PRML systems, this amounts to removing those states that correspond to the illegal data patterns from a trellis. A Viterbi trellis corresponding to an E^2PR4 system modified for use with MTR (2;k) coding is shown in FIG. 7. For uncoded or RLL(0,k) systems, all 16 states would be present along with two state transitions corresponding to the two binary inputs. The state labels are $\Psi_k=(a_k, a_{k-1}, a_{k-2}, a_{k-3})$ where a_k are the NRZ write current symbols taking on values from {-1,+1}. The states labeled 5 and 10, corresponding to (-1,+1,-1,+1) and

(+1,−1,+1,−1), respectively, have been removed because they represent three consecutive transitions in the NRZ data. Similar modifications can be performed on higher order PRML detectors. For the FDTS/DF detector, the code-violating look ahead paths must be prevented from being chosen as the most-likely path, a technique similar to the one used in the RLL(1,7) coded FDTS/DF channel. To illustrate the idea, consider FIG. 8 that shows a τ=3 look ahead tree utilized in FDTS/DF detection. The shaded paths in the tree correspond to the input data patterns with three consecutive transitions, and are considered illegal. For the τ=2 tree shown in FIG. 9, the past decision must be used to determine an illegal path, which is either the third path or the sixth path, as indicated by the marked paths. The complexity in the signal space formulation of the FDTS/DF detector is also reduced greatly with the MTR code. See, for example, B. Brickner and J. Moon, "A high dimensional signal space implementation of FDTS/DF," presented at Intermag '96, Seattle, Wash., April 1996. For a more detailed description of FDTS/DF detection, see U.S. Pat No. 5,136,593.

With this modification in FDTS/DF detection, the squared minimum Euclidean distance between any two diverging paths, denoted by β_{min}, is typically given by $4(1+f_1^2+f_2^2+\ldots+f_\tau^2)$ for τ greater than or equal to 2, where $f=(1, f_1, f_2, \ldots, f_{1-1})$ represents the 1 sample equalized dibit response (at the output of the forward equalizer) normalized so the first sample is 1. The effective SNR gain of the τ=2 FDTS/DF over the DFE, assuming the MTR j=2 code, is given by $10\log_{10}(1/1+f_1^2+f_2^2)$dB.

The distance gain with MTR coding is also significant for high order PRML systems such as E^2PR4. When the critical NRZ error pattern is ±{2−2 2}, the minimum distance for the E^2PR4 response {1 2 0−2−1} is $6\sqrt{2}$. With MTR coding, the worst case error pattern becomes a single bit error pattern of ±{2}, and the corresponding channel output distance is simply the square root of the energy in the equalized dibit response, or $10\sqrt{2}$. This increase in the minimum distance is equivalent to an SNR gain of 2.218 dB. If the code rate penalty is small, the overall coding gain is significant.

DC-FREE MTR CODES

Other useful constraints can be imposed on the MTR code at the expense of lowering the code rate. There exist storage systems where the recorded square waveform cannot have a DC component. In such applications, a DC-free constraint is necessary on the written data. The MTR code can be designed to have a DC-free property. A DC-free constraint is satisfied by bounding the running digital sum (RDS) of the binary sequence. The RDS at a given time is defined to be the excess number of 1's over 0's in the binary sequence up to that time, assuming the NRZ recording format is used (a negative RDS means there has been more 0's than 1's).

The following method can be used to design DC-free MTR codes. Assume an NRZ recording format. Starting from a list of 2^n n-bit binary words, first remove all binary words that contain either "0101" or "1010" as well as any words that contain more than k+1 consecutive like symbols. Then, to satisfy the MTR j=2 constraint at the codeword boundaries, remove all words that start with "01" or "10" and remove all words that end with "101" or "010". The same effect can be achieved by removing all words that end with 01 or 10 as well as the words that start with "101" or "010". The k constraint can be satisfied at boundaries by eliminating all words that either start with k_1 consecutive like symbols or end with k_2 consecutive like symbols, where k_1 and k_2 are preselected numbers such that $k_1+k_2=k+1$. The remaining codewords in the list now satisfy the MTR constraint as well as the k constraint. Investigation of the remaining codewords reveals that for every codeword, there exists another codeword which is a bit-by-bit complement of the first codeword. Now define charge C to be the number of 1's in the codeword minus the number of 0's in the same codeword. If a codeword has a charge C, its bit-wise complement will have a charge−C. This property is used to design a DC-free code. The final list of the valid DC-free MTR codewords is obtained by further removing either all the words with negative charges or all the words with positive charges. The final list now contains codewords with either zero-charge or charges with the same polarity. When a dataword is mapped to a zero-charge codeword, the mapping is one-to-one as usual But when a dataword is mapped to non-zero-charge codeword, either the codeword itself or its bit-wise complement is released by the encoder output, depending of the RDS value at the end of the last codeword. By choosing the codeword with a polarity which is opposite to the polarity of the present RDS value, the RDS is always kept bounded. FIG. 10 shows a decimal representation of codewords corresponding to different values of C for the 8/12 DC-free MTR code. The k-constraint in this case is equal to 8. FIG. 11 lists the code parameters for various DC-free MTR block codes obtained using the method described above.

While the preferred embodiments of the invention have been shown and described, it will be obvious to those skilled in the art that changes, variations and modifications may be made therein without departing from the invention in its broader aspects and, therefore, the aim in the appended claims is to cover such changes and modifications as fall within the scope and spirit of the invention.

What is claimed is:

1. Apparatus for encoding m-bit binary datawords into n-bit binary codewords, in a recorded waveform, where m and n are preselected positive integers such that n is greater than m, comprising:

receiver means for receiving the dataword;

encoder means coupled to the receiver means, for producing sequences of fixed length codewords;

means for imposing a pair of constraints (j;k) on the encoded waveform wherein the j constraint is defined as the maximum number of consecutive transitions allowed on consecutive clock periods in the encoded waveform to facilitate the reduction of a probability of a detection error in said receiver means;

said sequences generating no more than j consecutive transitions in the recorded waveform such that j is an integer equal to or greater than 2; and

said sequences generating no more than k consecutive sample periods without a transition in the recorded waveform.

2. Apparatus as in claim 1 wherein the j consecutive transition limit is defined by the relationship 2≦j<10.

3. Apparatus as in claim 2 wherein the encoder means produces a codeword, in response to each dataword sequentially, based on a predetermined word-by-word mapping of 2^m m-bit datawords to one of N n-bit codeword sets, wherein N may be written as $N=2^i$ and i is a positive integer and further that a selection of one of said N n-bit codeword sets is determined by a state of the encoder wherein said state is a predetermined function of a previous state and the encoder input and each set contains 2^m codewords wherein, a particular codeword may appear more than once in a given set and further a particular codeword may also appear in more than one set.

4. Apparatus as in claim 3 wherein the encoder means produces a codeword in response to each dataword sequentially, based on a predetermined word-by-word mapping of 2^m m-bit datawords to one of two n-bit codeword sets, where each particular codeword set contains 2^m different codewords, some of which may also be used in the other set and the set mapped to the encoder is chosen based on the last binary symbol of the previous codeword.

5. Apparatus as in claim 4 wherein, a first set (A) is chosen when a last binary symbol of a previous codeword (Z) is a 0 and a second set (B) is chosen when Z is a 1 and valid codewords for sets A and B are by the steps of:

removing binary words that contain more than one of j consecutive 1's and more than k consecutive 0's from each of two lists of 2^n possible codewords for sets A and B, respectively;

removing words that end with two consecutive 1's from both lists;

removing words from the list for set B that begin with two consecutive 1's;

selecting $k_1+k_2=k$;

removing words from the list for set A that begin with one of k_1+1 0's and end with k_2+1 0's;

removing words from the list for set B that end with consecutive 0's and k_2+1; and

selecting the 2^m codewords used in each of set A and set B from the respective lists, each of which contains at least 2^m codewords.

6. Apparatus as in claim 2 wherein the sequences of codewords also satisfy a DC-free constraint.

7. Apparatus as in claim 6 wherein the encoder means produces a codeword in response to each dataword sequentially, based on a predetermined word-by-word mapping of 2^m m-bit datawords to 2^m n-bit codewords, where the codewords are preselected using a selection method comprising the steps of:

removing binary words that contain either "0101" or "1010" from a list of 2^n possible n-bit binary words;

removing words that contain more than k+1 consecutive like symbols;

removing all words that begin with "01" or "10" and those that end with "101" or "010" having an equivalent effect of removing all words that begin with "101" or "010" and all words that end with "01" or "10";

removing one and combinations thereof of words that begin with k_1+1 consecutive like symbols and words that end with k_2+1 consecutive like symbols where $k_1+k_2=k$;

forming a set (A) of codewords with the number of 1's not less than the than number of 0's;

forming a set (B) of codewords with the number of 0's not less than the than number of 1's;

selecting codewords from set A if the number of 0's in all the previous encoder outputs exceeds the number of 1's; and

selecting codewords from set B if the number of 0's in all the previous encoder outputs does not exceed the number of 1's.

8. Apparatus as in claim 2 wherein the consecutive transition limit is defined by the relationship j=2.

9. Apparatus as in claim 2 wherein the binary sequences produced by combining codewords have no more than j consecutive 1's and no more than k consecutive 0's when used with a NRZI recording format.

10. Apparatus as in claim 2 wherein binary sequences produced by combining codewords have no more than one of j consecutive transitions from 0 to 1 and from 1 to 0 and no more than one of k+1 consecutive 0's and k+1 consecutive 1's when used in conjunction with a NRZ recording format.

11. Apparatus as in claim 2 wherein the encoder means produces a codeword in response to each dataword sequentially, based on a predetermined word-by-word mapping of 2^m m-bit datawords to 2^m n-bit codewords, wherein the codewords are preselected using a selection method comprising the steps of:

removing binary words that contain more than one of j consecutive 1's and more than k consecutive 0's from a list of 2^n possible n-bit binary words;

removing one of binary words that begin and end with two consecutive 1's;

removing one of binary words that begin with k_1+1 consecutive 0's and end with k_2+1 consecutive 0's where $k_1+k_2=k$; and

choosing 2^m codewords remaining in the list, which contains at least 2^m valid codewords.

12. Apparatus as in claim 2 wherein the receiver means incorporates means for removing certain code-violating patterns from the detection process wherein the detection process comprises at least one of the steps of:

removing states and state transitions corresponding to more than j consecutive transitions from a Viterbi trellis;

removing branches from a fixed delay tree search corresponding to more than j consecutive transitions;

removing branches from a fixed delay tree search corresponding to more than j consecutive transitions when the previous decision is considered part of the sequence;

forming boundaries for a signal space formulation such that points in the signal space constellation corresponding to sequences containing more than j consecutive transitions are not considered; and

selecting boundaries in a signal space formulation based on a constellation that does not include points corresponding to sequences containing more than j consecutive transitions when the previous decision is considered part of the sequence.

13. A method for encoding m-bit binary datawords into n-bit binary codewords in a recorded waveform, where m and n are preselected positive integers such that n is greater than m, comprising the steps of:

receiving binary datawords; and

producing sequences of n-bit codewords;

imposing a pair of constraints (j;k) on the encoded waveform;

generating no more than j consecutive transitions of said sequence in the recorded waveform such that $j \geqq 2$; and

generating no more than k consecutive sample periods of said sequences without a transition in the recorded waveform.

14. The method as in claim 13 wherein the consecutive transition limit is defined by the equation $2 \leqq j < 10$.

15. The method as in claim 14 wherein the consecutive transition limit is j=2.

16. The method as in claim 14 wherein the binary sequences produced by combining codewords have no more than j consecutive 1's and no more than k consecutive 0's when used with the NRZI recording format.

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17. The method as in claim 14 wherein the binary sequences produced by combining codewords have no more than one of j consecutive transitions from 0 to 1 and from 1 to 0 and no more than one of k+1 consecutive 0's and k+1 consecutive 1's when used in conjunction with the NRZ recording format.

18. The method as in claim 14 wherein the encoder means produces a codeword in response to each dataword sequentially, based on a predetermined word-by-word mapping of 2^m m-bit datawords to 2^m n-bit codewords, where the codewords are preselected using a selection method comprising the steps of:

removing binary words that contain more than j consecutive 1's and words that contain more than k consecutive 0's from a list of 2^n possible n-bit binary words;

removing one of binary words that begin and end with two consecutive 1's;

removing one of words that begin with k_1+1 consecutive 0's and end with k_2+1 consecutive 0's where $k_1+k_2=k$;

choosing 2^m codewords from the remaining list, which contains at least 2^m valid codewords.

19. The method as in claim 14 wherein the encoder means produces a codeword in response to each dataword sequentially, based on a predetermined word-by-word mapping of 2^m m-bit datawords to one of N n-bit codeword sets, wherein N may be written as $N=2^i$ where i is a positive integer and the selection of one of N codeword sets is determined by the state of the encoder and said state is a predetermined function of the previous state and encoder input and that each set contains 2^m codewords and further that a particular codeword may appear more than once in a given sets and may also appear in more than one set.

20. The method as in claim 14 wherein the sequences of codewords also satisfy a DC-free constraint.

21. The method as in claim 13 wherein the method of receiving data incorporates the removal of certain code-violating patterns from the detection process wherein the detection process comprises at least one of the steps of:

removing states and state transitions corresponding to more than j consecutive transitions from a Viterbi trellis;

removing branches from a fixed delay tree search corresponding to more than j consecutive transitions;

removing branches from a fixed delay tree search corresponding to more than j consecutive transitions when the previous decision is considered part of the sequence;

forming boundaries for a signal space formulation such that points in the signal space constellation corresponding to sequences containing more than j consecutive transitions are not considered; and

selecting boundaries in a signal space formulation based on a constellation that does not include points corresponding to sequences containing more than j consecutive transitions when the previous decision is considered part of the sequence.

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DEPOSITION EXHIBIT 2
PENGAD 800-631-6989

UNITED STATES DISTRICT COURT

NORTHERN DISTRICT OF CALIFORNIA

SAN JOSE DIVISION

REGENTS OF THE UNIVERSITY OF MINNESOTA, Plaintiff, vs. LSI CORPORATION and AVAGO TECHNOLOGIES U.S. INC., Defendants.	Case No.: 5:18-cv-00821-EJD-NMC **JOINT CLAIM CONSTRUCTION AND PREHEARING STATEMENT UNDER PATENT L.R. 4-3** *Markman* Hearing: July 12, 2018 Time: 1:30 p.m. Location: San Jose, Courtroom 4, 5th Floor

Plaintiff Regents of the University of Minnesota ("University") and Defendants LSI Corporation and Avago Technologies U.S. Inc. (jointly, "LSI" or "Defendants") jointly submit this Joint Claim Construction and Prehearing Statement in accordance with Patent L.R. 4-3 and this Court's Standing Order for Patent Cases. The sole asserted patent in this case is U.S. Patent 5,859,601 ("'601 Patent"), a copy of which is provided as **Exhibit A** hereto. The Asserted Claims are claims 13, 14, and 17. A copy of the complete prosecution history for the '601 Patent is available to the Court upon request, and was previously filed on March 15, 2018 as Document 190-3.

I. CONSTRUCTION OF THOSE TERMS ON WHICH THE PARTIES AGREE

The parties agree to the constructions set forth below for certain claim terms in the Asserted Claims of the '601 Patent.

Claim Language	Agreed-Upon Construction
m-bit binary datawords '601 Patent, claim 13	bit sequences of length m
binary datawords '601 Patent, claim 13	bit sequences of length m
n-bit binary codewords '601 Patent, claim 13	bit sequences of length n
n-bit codewords '601 Patent, claim 13	bit sequences of length n

II. DISPUTE TERMS AND IDENTIFICATION OF MOST SIGNIFICANT TERMS

The parties dispute the construction of ten (10) terms in the Asserted Claims. Each party's proposed constructions and identified support therefor are presented in **Exhibit B** hereto.

The most significant terms are the terms appearing below in claims 13 and 17. The parties propose that the disputed terms be argued in the following order at the hearing:

(1) "transitions" in claim 13;

(2) "producing sequences of n-bit codewords" in claim 13;

(3) "recorded waveform" in claim 13;

(4) "imposing a pair of constraints (j;k)" in claim 13;

(5) "encoded waveform" in claim 13;

(6) "generating no more than j consecutive transitions of said sequence in the recorded waveform such that $j \geq 2$" in claim 13;

(7) "generating no more than k consecutive sample periods of said sequences without a transition in the recorded waveform" in claim 13;

(8) "wherein the binary sequences produced by combining codewords have no more than one of j consecutive transitions from 0 to 1 and from 1 to 0" in claim 17; and

(9) "wherein the binary sequences produced by combining codewords have no more than one of j consecutive transitions from 0 to 1 and from 1 to 0" and "no more than one of k+1 consecutive 0's and k+1 consecutive 1's" in claim 17.

(10) NRZ/NRZI recording format in claim 17 and claim 16.

III. ANTICIPATED LENGTH AND TIME NECESSARY FOR THE CLAIM CONSTRUCTION HEARING

The Claim Construction Hearing is currently scheduled for July 12, 2018, with the Case Tutorial starting at 1:30 p.m. Dkt. 197. The parties anticipate needing no more than three (3) hours (1.5 hours per side) for the hearing, including the tutorial.

IV. IDENTIFICATION OF WITNESSES FOR CLAIM CONSTRUCTION HEARING

Neither party intends to present any witnesses live at the Claim Construction Hearing.

The University expects to rely on testimony (in the form of a declaration and/or deposition) from Prof. Steven W. McLaughlin, Dean of the College of Engineering at the Georgia Institute of Technology in support of its claim construction arguments. A copy of Prof. McLaughlin's declaration that the University served Defendants with on March 14, 2018 as part of the University's Patent L.R. 4-2 disclosures is attached hereto as **Exhibit C**. The University also currently intends to have Prof. McLaughlin available for the Case Tutorial.

LSI intends to rely on testimony (in the form of a declaration and/or deposition testimony) from Professor Emina Soljanin, Professor of Electrical & Computer Engineering at Rutgers University, on the issue of indefiniteness under 35 U.S.C. § 112 for five disputed claim terms. *See* Declaration of Professor Emina Soljanin, Ph.D., attached as **Exhibit D**. Professor Soljanin's testimony will be offered only on the issue of indefiniteness and not for purposes of general claim construction. If the Court determines that the five disputed-as-indefinite claim terms are not indefinite, then for three of the terms, LSI has offered alternative constructions that are based on intrinsic evidence and do not rely on Professor Soljanin's testimony. *See* Exhibit B. LSI contends that two of the disputed claim terms, both in dependent claim 17, cannot be construed, and will not offer proposed constructions for those two terms. Other than with respect to the issue of indefiniteness as to the five challenged terms, LSI will not rely on expert testimony. LSI believes that expert testimony is unnecessary for the Case Tutorial, but may have Prof. Soljanin in attendance if the Plaintiff brings its expert.

V. IDENTIFICATION OF FACTUAL FINDINGS REQUESTED FROM THE COURT RELATED TO CLAIM CONSTRUCTION

The parties have a dispute as to whether the Court should make factual findings with respect to claim construction. The parties' positions are set forth below:

The University's Identification

Pursuant to Patent Local Rule 4-3(f) which requires the parties to identify "any factual findings requested from the Court related to claim construction," the University requests that the Court make factual findings with respect to Defendants' indefiniteness arguments for claims 13 and 17 of the '601 Patent. *See, e.g.*, *Berkheimer v. HP Inc.*, 881 F.3d 1360, 1363 (Fed. Cir. 2018) (district court's indefinite determination included "subsidiary factual findings" based on expert declaration); *Teva Pharm. USA v. Sandoz, Inc.*, 135 S. Ct. 831, 841 (2015) (recognizing "factual finding" by court with regard to dispute between experts as to whether "a certain term of art had a particular meaning to a person of ordinary skill in the art at the time of the invention"); *Eli Lilly and Co. v. Teva Parenteral Medicines, Inc.*, 848 F.3d 1357, 1371 (Fed. Cir. 2017) ("[T]he district court's underlying determination, based on extrinsic evidence, of what a person of ordinary skill would understand 'vitamin B12' to mean in different contexts is a question of fact."). The University's requested factual findings will relate to the knowledge and understanding that a person of ordinary skill in the art would have concerning the scope and meaning of the following phrases when read in the context of the intrinsic record:

- "the encoded waveform" in claim 13;
- "generating no more than j consecutive transitions of said sequence in the recorded waveform such that $j \geq 2$" in claim 13;
- "generating no more than k consecutive sample periods of said sequences without a transition in the recorded waveform" in claim 13;
- "wherein the binary sequences produced by combining codewords have no more than one of j consecutive transitions from 0 to 1 and from 1 to 0" in claim 17; and
- "no more than one of k+1 consecutive 0's and k+1 consecutive 1's" in claim 17.

In particular, the University requests that the Court find that each of identified claim terms has an objective meaning to those skilled in the art, which objective meaning informs, with reasonable certainty, those skilled in the art about the scope of the claimed invention.

The University further requests that the Court find that the evidence cited by the University and Defendants, including the testimony of Prof. McLaughlin, supports the University's claim construction proposals and do not support Defendants' proposals. *See Teva Pharm.*, 135 S. Ct. at 837-38("Claim construction is a question of law with underlying questions of fact."). For example, the University requests that the Court find that:

- A person skill in the art would understand that a "transition" referred to in the '601 Patent, including the claims, is a magnetic transition, i.e., a reversal in the magnetic orientation of adjacent bit regions;
- Imposing a constraint in a magnetic recording system that limits the number of consecutive "transitions" in the record waveform to j, where $j \geq 2$, reduces the probability of bit errors of the magnetic recording system by removing error-prone write patterns; and
- A person skill in the art would understand that the j and k constraints are separate constraints, where the j constraint reduces the bit error probability of the magnetic recording system by removing error-prone write patterns and the k constraint ensures timing recovery.

LSI's Position: Factual Findings Are Not Required

The Court need not make any factual findings. Instead, the Court should construe all of the disputed claim terms as a matter of law, in light of the intrinsic evidence (*i.e.*, the patent's claims, specification, and its prosecution history). *See Markman v. Westview Instr., Inc.*, 517 U.S. 370, 372 (1996) ("We hold that the construction of a patent, including terms of art within its claim, is exclusively within the province of the court"); *see also Phillips v. AWH Corp.*, 415 F.3d 1305, 1314-24 (Fed. Cir. 2005) (*en banc*); *id.* at 1320 (overruling Circuit precedent that had "placed too much reliance on extrinsic sources such as dictionaries, treatises, and encyclopedias and too little on intrinsic sources, in particular the specification and the prosecution history"). The Supreme Court has made clear that indefiniteness may be resolved as a matter of law. *See Nautilus v. Biosig Instr.*, 134 S. Ct. 2120, 2124 (2014) ("[W]e hold that a patent is invalid for indefiniteness if its claims, read in light of the specification delineating the patent, and the prosecution history, fail to inform, with reasonable certainty, those skilled in the art about the scope of the invention.").[1] In this case, with respect to five disputed claim terms, intrinsic evidence alone is sufficient to conclude that the terms are indefinite.

Regardless of whether the proper analysis is characterized as purely legal (LSI's position) or requires the Court to make "factual findings" (Plaintiff's position), LSI requests that the Court find that claims 13 and 17 are indefinite under 35 U.S.C. § 112(b). *See Nautilus*, 134 S. Ct. at 2124. Specifically, LSI contends that the following phrases (each of which is case and/or claim dispositive), when read in the context of the intrinsic record, are indefinite because they cannot be construed with reasonable certainty:

- (1) "the encoded waveform" in claim 13;
- (2) "generating no more than j consecutive transitions of said sequence in the recorded waveform such that $j \geq 2$" in claim 13;
- (3) "generating no more than k consecutive sample periods of said sequences without a transition in the recorded waveform" in claim 13;
- (4) "wherein the binary sequences produced by combining codewords have no more than one of j consecutive transitions from 0 to 1 and from 1 to 0" in claim 17; and
- (5) "no more than one of k+1 consecutive 0's and k+1 consecutive 1's" in claim 17.

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[1] *See also Teva Pharm. USA v. Sandoz, Inc.*, 135 S. Ct. 831, 841 (2015) ("As all parties agree, when the district court reviews only evidence intrinsic to the patent (the patent claims and specifications, along with the patent's prosecution history), the judge's determination will amount solely to a determination of law[.]").

If, however, the Court finds that the first three terms can be construed with reasonable certainty, then LSI requests that the Court adopt LSI's proposed alternative constructions. *See* Exh. B. Regarding the fourth and fifth challenged terms, LSI offers no alternative constructions.

As to all other disputed claim terms, LSI requests that the Court adopt LSI's proposed constructions as set forth in Exhibit B, and reject the Plaintiff's proposed constructions and the opinions offered by Plaintiff's expert, Prof. McLaughlin, as to all nine disputed terms.

Dated: April 13, 2018

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CERTIFICATE OF SERVICE

I hereby certify that a true and correct copy of the above and foregoing document has been served on all counsel of record via the Court's ECF system on April 13, 2018.

/s/ Ranjini Acharya
Ranjini Acharya

CERTIFICATION PURSUANT TO CIV. L. R. 5-1(i)(3)

Pursuant to Civil Local Rule 5-1(i)(3), I hereby certify that concurrence in the filing of this document has been obtained from the signatories for whom a signature is indicated by a conformed signature (/s/). I have on file records to support this concurrence for production for the Court if so ordered.

Dated: April 13, 2018

/s/ Ranjini Acharya
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Attorneys for Defendants LSI Corporation and Avago Technologies U.S. Inc.

UNITED STATES DISTRICT COURT

FOR THE NORTHERN DISTRICT OF CALIFORNIA

SAN JOSE DIVISION

REGENTS OF THE UNIVERSITY OF MINNESOTA, Plaintiff, v. LSI CORPORATION AND AVAGO TECHNOLOGIES U.S. INC., Defendants.	Civil Action No. 18-cv-00821-EJD-NMC **DECLARATION OF PROFESSOR EMINA SOLJANIN**

I, Professor Emina Soljanin, declare as follows:

I. INTRODUCTION AND QUALIFICATIONS

A. Introduction.

1. I have been engaged as an expert on behalf of LSI Corporation and Avago Technologies U.S. Inc. (collectively, Defendants or "LSI") in the above-referenced case and in the *Inter Partes* Review ("IPR") proceeding involving the patent-in-suit (U.S. Patent and

Trademark Office Trial and Appeal Board, IPR2017-01068). The patent at issue in both proceedings is U.S. Patent No. 5,859,601 ("the '601 Patent").

2. I understand that ownership of the '601 Patent is claimed by the Regents of the University of Minnesota ("the University"). I understand that the University sued LSI in the U.S. District Court for the District of Minnesota on August 25, 2016, and that the '601 Patent expired on October 15, 2016. I understand that the District of Minnesota subsequently transferred this case to the U.S. District Court for the Northern District of California, San Jose Division.

3. In this Declaration, I offer my opinions regarding, among other things, certain terms in claims 13, 14, and 17 ("the Asserted Claims") of the '601 Patent. It is my opinion that the Asserted Claims are indefinite under 35 U.S.C. § 112(b) because the claims, read in light of the patent's specification and its prosecution history, fail to inform, with reasonable certainty, a person having ordinary skill in the art at the time of the invention the scope of the alleged inventions. The reasons for this opinion are set forth more fully below.

4. I also disclose below my understanding of certain legal principles regarding claim construction and 35 U.S.C. § 112(b) provided to me by counsel, as well as my view of the level of ordinary skill in the art at the time of the alleged inventions of the Asserted Claims.

5. I am being compensated at a rate of $420 per hour for my consulting services, including the preparation of this Declaration. I have no stake in the outcome of this civil action or the related IPR proceedings concerning the '601 Patent.

B. Expert Qualifications.

6. I am currently a professor of electrical and computer engineering at Rutgers University. My research interests are broad, but mainly concern theoretical understanding and practical solutions that enable efficient, reliable, and secure operation of communications networks. I also have expertise and interest in power systems and quantum computation.

7. My research has been funded by the National Science Foundation, the Center for Discrete Mathematics and Theoretical Computer Science (DIMACS), DARPA, and other

funding agencies.

8. All of my degrees are in electrical engineering. I earned a European Diploma degree from the University of Sarajevo, Bosnia, in 1986, and M.S. and Ph.D. degrees from Texas A & M University in 1989 and 1994, respectively.

9. Between my studies at the University of Sarajevo and my graduate studies, from 1986 to 1989, I worked in industry developing optimization algorithms and software for power system control.

10. Upon earning my Ph.D., I joined Bell Laboratories in Murray Hill, NJ, where I was a Member of the Technical Staff in the Mathematics of Networks and Communications research department. Over a dozen alumni of Bell Labs have won the Nobel prize in physics, with several more having been awarded the Turing Award, the highest distinction in computer science. In 2004 I was elevated to Distinguished Member of the Technical Staff.

11. During my time at Bell Labs, I was also an adjunct professor, guest lecturer, or visiting professor at various academic institutions around the world including, Columbia University, ENSE in Cergy-Pontoise, France, the University College Dublin, and others. I also mentored many students, interns, and postdoctoral researchers during that time.

12. In the course of my twenty year employment with Bell Labs, I participated in a wide range of research and business projects. These projects include designing the first distance enhancing codes to be implemented in commercial magnetic storage devices. Other projects that I worked on at Bell Labs included the first forward error correction for Lucent's optical transmission devices, color space quantization and color image processing, quantum computation, link error prediction methods for the third generation wireless network standards, and anomaly and intrusion detection. Some of my most recent activities are in the area of network and application layer coding.

13. According to the University's allegations in the First Amended Complaint in this case, the alleged invention of the '601 Patent is a "maximum transition run" ("MTR") code featuring a "j constraint" which "imposes a limit on the maximum number of consecutive transitions" in a binary system. I was conducting research in this area before the

application that matured into the '601 Patent was filed.

14. The named inventors of the '601 Patent, Professor Jaekyun Moon and his then-graduate student Dr. Barrett Brickner, published a paper in 1996 entitled "Maximum Transition Run Codes for Data Storage Systems," which paper is attached to the First Amended Complaint as Exhibit 3, and referred to therein by the University as "the Moon 1996 IEEE Paper." (*See* First Amended Complaint, Dkt. No. 40, at ¶¶ 49-52; attached hereto as Appendix A.)

15. The University alleges that this Moon 1996 IEEE Paper is "substantially similar to the '601 Patent." (*See id.*) This is noteworthy because Dr. Moon and Dr. Brickner confirmed in their 1996 IEEE Paper that I, in my "independent study," had disclosed that "removing long runs of consecutive transitions" can improve the performance of data storage systems. (*See* Moon 1996 IEEE Paper, Appendix A, right column of first page, citing reference [6].) Reference [6], cited by Dr. Moon and Dr. Brickner in their 1996 IEEE paper, relates to my conference presentation in October 1995. (*See* Appendix A, Reference [6] listed as "E. Soljanin, 'On-track and off-track distance properties of class4 partial response channels,' SPIE Conference, Philadelphia, PA, Oct. 1995.").

16. Additionally, my work was published in a 1995 paper entitled "On-track and off-track distance properties of class4 partial response channels," which paper is attached as Appendix B. This paper discloses that digital storage systems can be improved "by limiting the length of subsequences of alternating symbols to four," and that in the NRZI recording format, "this can be achieved by a code that limits the runs of consecutive ones to three" and discloses a "simple and inexpensive implementation" for such a code. (*See* Appendix A, at Section 4.2.) The first-named inventor on the '601 Patent, Prof. Moon, attended my presentation given at the above-referenced conference, as described in LSI's counterclaim for inequitable conduct. (Dkt. No. 62 at p. 23 *et seq.*, ¶¶ 18-49.)

17. Further, one of my own patents, U.S. Patent No. 5,608,397, is cited on the face of the '601 Patent. During prosecution, the examiner found that my U.S. Patent No. 5,608,397 (among others) "is considered pertinent to applicant's disclosure." (*See* File

History, Office Action dated Sept. 16, 1997.)

18. In addition to U.S. Patent No. 5,608,397, cited by the patent examiner and listed on the face of the '601 Patent, I am the inventor of additional patents and pending patent applications. I have authored numerous peer-reviewed journal and conference publications, as well as books and book chapters. Among other professional recognitions, I was elected an IEEE Fellow for my "contributions to coding theory and coding schemes for transmission and storage systems." My curriculum vitae includes additional details about my experience and professional background. It is attached as Appendix C.

II. MATERIALS REVIEWED

19. My opinions are based on years of education, research and experience, as well as investigation and study of relevant materials. In forming my opinions, I have considered the materials identified in this declaration, including the '601 Patent's claims (both the Asserted Claims and the non-asserted claims), its specification (including the figures and all of the written disclosure), and the prosecution history of the application that matured into the '601 Patent. I have also reviewed the documents discussed in Section I.B above.[1]

III. THE HYPOTHETICAL PERSON OF ORDINARY SKILL IN THE ART

20. I have been informed that patent claims are to be interpreted the way a hypothetical person having ordinary skill in the art would have interpreted the claims at the time of the invention. For shorthand, I may refer to such a person herein as a "POSITA."

21. The application resulting in the '601 Patent was filed on October 15, 1996. The face of the patent claims priority to "Provisional application No. 60/014,954" filed April 5, 1996. Merely for argument's sake, therefore, I will assume that the Asserted Claims are entitled to a priority date of April 5, 1996. As mentioned above, I was conducting research

[1] I may rely upon these materials and/or additional materials to respond to arguments raised by the University or its expert(s). I may also consider additional documents and information in forming any necessary opinions—including documents that may not yet have been provided to me. My analysis of the materials produced in this investigation is ongoing and I will continue to review any new material as it is provided. This report represents only those opinions I have formed to date. I reserve the right to revise, supplement, and/or amend my opinions stated herein based on new information and on my continuing analysis of the materials already provided.

and publishing my work in the relevant technological field prior to April 5, 1996.

22. In determining the characteristics of a person of ordinary skill in the art at the time of the claimed invention, I considered several things, including the factors discussed below, as well as (1) the levels of education and experience of the inventor and other persons actively working in the relevant field; (2) the types of problems encountered in the field; (3) prior art solutions to these problems; (4) the rapidity in which innovations are made; and (5) the sophistication of the relevant technology. I also placed myself back in the relevant time period and considered the individuals that I had worked with in the field.

23. It is my opinion that a person having ordinary skill in the relevant art at the time of the invention would have been someone with at least an undergraduate degree in electrical engineering or similar field, and three years of industry experience in the field of read channel technology.

24. I am prepared to testify as an expert in this field and also as someone who had at least the knowledge of a POSITA, and someone who worked with other POSITAs at the time of the alleged invention.

25. Unless otherwise stated, my statements below refer to the knowledge, beliefs, and abilities of a POSITA at the time of the claimed invention of the '601 patent.

IV. CLAIM CONSTRUCTION STANDARD

26. I understand that the Asserted Claims are construed as understood by a POSITA. Counsel informs me that sometimes the meaning of claim terms are readily apparent even to lay judges, and that, in such scenarios, claim construction involves little more than the application of widely accepted meaning of commonly understood words.

27. Otherwise, especially in highly-technical patents, courts look to the "intrinsic evidence" (*i.e.*, the words of the claims themselves, the specification and figures, and the prosecution history), and in some circumstances resort to consideration of extrinsic evidence concerning relevant scientific principles, the meaning of technical terms, and the state of the art to interpret a patent.

28. Regarding the intrinsic evidence, I understand that the claims themselves

provide substantial guidance as to the meaning of particular claim terms. For example, the context in which a term is used in the asserted claim can be highly instructive. Other claims of the patent in question, both asserted and un-asserted, can also be valuable sources of enlightenment as to the meaning of a claim term.

29. The claims do not stand alone, as they must be read in view of the specification, of which they are a part. I understand that the specification is always highly relevant to the claim construction analysis and is usually the single best guide to the meaning of a disputed term. I understand that the importance of the specification in claim construction derives from its statutory role, as the close kinship between the written description and the claims is enforced by the statutory requirement that the specification describe the claimed invention in "full, clear, concise, and exact terms." 35 U.S.C. § 112(a).

30. I understand further that the specification may reveal a "special definition" given to a claim term by the patentee that differs from the meaning it would otherwise possess. In such cases, the inventor's "lexicography" governs. In other cases, the specification may reveal an "intentional disclaimer, or disavowal, of claim scope by the inventor." In that instance as well, the inventor's intention governs.

31. In addition to consulting the claims and the specification, I understand that a court should also consider the patent's prosecution history. The prosecution history is a part of the intrinsic evidence and consists of the complete record of the proceedings before the Patent Office and includes the prior art cited during the examination of the patent. Like the specification, the prosecution provides evidence of how the Patent Office and the inventor understood the patent. Furthermore, like the specification, the prosecution history was created by the patentee in attempting to explain and obtain the patent. Yet because the prosecution history represents an ongoing negotiation between the Patent Office and the applicant, rather than the final product of that negotiation, it often lacks the clarity of the specification and thus is less useful for claim construction purposes.

32. I further understand that while extrinsic evidence (*e.g.*, expert testimony, dictionaries, learned treatises) can shed useful light on the relevant art, it is less significant

than the intrinsic record in determining the legally operative meaning of claim language. I understand further that the United States Court of Appeals for the Federal Circuit has viewed extrinsic evidence in general as less reliable than the patent and its prosecution history in determining how to read claims.

V. INDEFINITENESS STANDARD

33. A provision in the Patent Act states that "[t]he specification shall conclude with one or more claims particularly pointing out and distinctly claiming the subject matter which the inventor or joint inventor regards as the invention." 35 U.S.C. ¶ 112(b). I understand that a claim that does not comply with this provision is said to be "indefinite," and is invalid for that reason.

34. I understand that until recently, the legal standard for definiteness was determining whether a claim is "amenable to construction," and the claim, as construed, is not "insolubly ambiguous." If a claim could be construed and was not "insolubly ambiguous," then it was definite under 35 U.S.C. ¶ 112(b).

35. I understand that the United States Supreme Court relaxed this test in 2014. Counsel informs me that the Court, in a case called *Nautilus, Inc. v. Biosig Instruments, Inc.*, ("*Nautilus*") stated as follows:

> "We conclude that the Federal Circuit's formulation, which tolerates some ambiguous claims but not others, does not satisfy the statute's definiteness requirement. In place of the 'insolubly ambiguous' standard, we hold that a patent is invalid for indefiniteness if its claims, read in light of the specification delineating the patent, and the prosecution history, fail to inform, with reasonable certainty, those skilled in the art about the scope of the invention."

VI. THE ASSERTED CLAIMS

36. The text of the Asserted Claims is listed below:

<u>Claim 13</u>

[Preamble:] A method for encoding m-bit binary datawords into n-bit binary codewords in a recorded waveform, where m and n are preselected positive integers such that n is greater than m, comprising the steps of:

[Step 1:] receiving binary datawords; and

[Step 2:] producing sequences of n-bit codewords;

[Step 3:] imposing a pair of constraints (j;k) on the encoded waveform;

[Step 4:] generating no more than j consecutive transitions of said sequence in the recorded waveform such that $j \geq 2$; and

[Step 5:] generating no more than k consecutive sample periods of said sequences without a transition in the recorded waveform.

Claim 14

The method as in claim **13** wherein the consecutive transition limited is defined by the equation $2 \leq j < 10$.

Claim 17

The method as in claim **14** wherein the binary sequences produced by combining codewords have no more than one of j consecutive transitions from 0 to 1 and from 1 to 0 and no more than k+1 consecutive 0's and k+1 consecutive 1's when used in conjunction with the NRZ recording format.

VII. THE ASSERTED CLAIMS ARE INDEFINITE

37. It is my opinion that the claim terms below are indefinite: (1) "the encoded waveform" (claim 13); (2) "generating no more than j consecutive transitions of said sequence in the recorded waveform such that j≥2" (claim 13); (3) "generating no more than k consecutive sample periods of said sequences without a transition in the recorded waveform" (claim 13); (4) "wherein the binary sequences produced by combining codewords have no more than one of j consecutive transitions from 0 to 1 and from 1 to 0" (claim 17); and (5) "wherein the binary sequences produced by combining codewords have … no more than one of k+1 consecutive 0's and k+1 consecutive 1's" (claim 17).

38. My opinions are explained further below.

1. "The Encoded Waveform" (Claim 13)

39. Step 3 of claim 13 recites "imposing a pair of constraints (j;k) on the encoded waveform." The phrase "encoded waveform" renders claim 13 indefinite (as well as all

claims depending from it) because the claim, read in light of the specification of the '601 Patent and the prosecution history, fails to inform, with reasonable certainty, those skilled in the art about the scope of the purported invention.

40. First, there is no antecedent basis for the phrase "the encoded waveform" in the claim. The phrase begins with the word "the," which, according to counsel, is understood to be used in patent claims (and as I understand in normal English usage) to refer back to an element that was recited earlier in the same claim or in an independent claim from which the claim at issue depends. However, there is no earlier reference to "encoded waveform" in claim 13. The term is indefinite for at least this reason.

41. I am informed that the University's expert, Prof. McLaughlin, agrees that the word "the" signals that the following phrase "encoded waveform" must have an antecedent basis in the claim. (*See* McLaughlin Declaration at ¶ 46.) Professor McLaughlin confirms that no such antecedent basis exists in the claim, stating that "[t]he ***only*** waveform previously referred to in the claim is the '***recorded*** waveform' referred to in the claim preamble, which recorded waveform has encoded data as described above." (*Id.* at ¶ 46) (emphasis added). Unable to find antecedent basis for "the encoded waveform," Professor McLaughlin simply concludes that "the encoded waveform" is exactly the same as the "recorded" waveform. I do not agree; the claim uses different words to mean different things. If "the encoded waveform" was the same as the "recorded waveform," then the claim would use the phrase "the recorded waveform" in step 3. Instead, it uses a different phrase—"the encoded waveform."

42. Second, the structure of claim 13 supports the conclusion that "the encoded waveform" (recited in step 3) is not the same thing as the "recorded waveform" (recited in the preamble and in "generating" steps 4 and 5.) In particular, each of the five method steps recited in claim 13 begin with a verb ending in "ing": receiving, producing, imposing, generating, and generating, and logically they proceed in sequential order. A "recorded waveform" does not exist until steps 4 and 5 are completed. In a digital storage device, the "generating" steps would happen on the recording medium, not in the "encoder." In contrast,

the "imposing" step, *i.e.,* step 3 of claim 13, would happen in an encoder, which is typically a discrete electrical component separate from the recording medium, such as a system on a chip. The j and k constraints are "imposed" by the encoder on the sequence of n-bit codewords, which are not "the recorded waveform."

43. Third, consideration of claims other than claim 13 bolster my opinion. For example, see claim 18, which depends from claim 14, which in turn depends from claim 13. Claim 18 states that "the encoder" (as opposed to a recording medium or a component that can record on a medium) is the thing that "produces a codeword in response to each dataword sequentially," and the encoder imposes the j and k constraints by selecting the n-bit codewords according to certain specified steps. This is consistent with my conclusion about the distinction between the "recorded waveform" and "the encoded waveform" in claim 13.

44. Fourth, because the term "encoded waveform" does not appear earlier in claim 1, or in any other claim of the '601 Patent, one naturally would look to the specification for guidance. But the phrase does not appear in the specification. In addition, the phrase "encoded waveform" has no standard or industry-specific definition. In fact, the phrase "encoded waveform" was inserted during prosecution via a claim amendment and was introduced into amended claim 1 (which is not asserted here) and amended claim 13. However, neither the inventors nor the patent examiner provided a definition of this new phrase, even though the inventors stated that Claims 1 and 13 had been amended "to better define the invention." (*See* Response to Office Action at 3.) The patent examiner did not explain the meaning of "the encoded waveform" in the Notice of Allowability or elsewhere. (*See* File History (Dkt. No. 165-2).) This prosecution history underscores the fact that this term – "the encoded waveform" -- not only lacks an antecedent basis in claim 13, but lacks a foundation in the patent itself.

45. Fifth, it is not clear what is meant by a "waveform" in Step 3 of claim 13. In particular, Step 3 is listed prior to Steps 4 and 5. A waveform (in particular, a "recorded waveform") is said to be "generated" in Steps 4 and 5. The phrase "the encoded waveform" is used in Step 3, which is where the pair of constraints are "impos[ed]." According to the

specification, the step of "imposing" occurs in the production of binary codewords. *See, e.g.*, '601 Patent at Fig. 6 and 5:12-47 (providing "equations for the encoder"). Binary codewords are not a "waveform." (*See, e.g.*, Response to Office Action, Appendix A ("[C]ode bits are indicated above the appropriate waveform")); *see also* Claims 16, 17, 18 (showing that the j and k constraints are "imposed" at the binary level, *i.e.*, on sequences of 1's and 0's, and not on the recorded waveform). This lack of clarity further would leave a POSITA uncertain as to the meaning of the phrase "encoded waveform" in claim 13 of the '601 Patent.

46. For each of these reasons, taken alone or viewed together, claim 13 is indefinite under Section 112.

2. "Generating No More Than j Consecutive Transitions of Said Sequence in the Recorded Waveform Such That j≥2." (Claim 13)

47. Step 4 of claim 13 recites "generating no more than j consecutive transitions of said sequence in the recorded waveform such that j≥2." This phrase renders claim 13 indefinite (as well as all claims depending from it) because the claim, read in light of the specification of the '601 Patent and the prosecution history, fails to inform, with reasonable certainty, those skilled in the art about the scope of the purported invention.

48. First, take the case of j = 2. If only 1 (one) consecutive transition is generated, does this satisfy the limitation of Step 4? The claim disallows "*more than*" 2 consecutive transitions. Because 1 is less than 2, 1 consecutive transition meets the claim language "no more than j consecutive transitions." Yet the claim states that j≥2, which suggests that 1 consecutive transition would not satisfy the claim. In prosecution, its response to the patent examiner's rejection of the claims in view of prior art, the applicant attempted to explain what was being claimed and how it was different than the prior art (*see* File History), but note that claim 13 is written in terms of what is ***disallowed*** (*i.e.*, "***no more than***") instead of what is allowed. *Compare* independent method claim 13 ("generating ***no more than*** j consecutive transitions") *with* independent apparatus claim 1 ("wherein the j constraint is ***defined*** as the maximum number of consecutive transitions ***allowed*** on consecutive clock periods") (emphasis added). The "definition" in claim 1 is not recited in claim 13, even though claims 1

and 13 were amended at the same time, in response to the same Office Action. Moreover, the specification teaches that "the minimum distance pairs shown in FIG. 1 must be eliminated" and that "[i]n accordance with *the present invention*, this can be accomplished using the existing RLL (1,k) code, *which does not allow* consecutive transitions." '601 Patent at 4:8-12 (emphasis added). This adds up to lack of reasonable certainty as to the meaning of this claim limitation.

49. Second, Step 4 recites the phrase "transitions of said sequence." The "said sequence" appears to refer to n-bit codewords, but it does not make sense to speak of a transitions "of codewords." It does however make sense to think of transitions in terms of transitions between binary bits – 1 to 0 or 0 to 1. (*See e.g.*, claims 16 and 17.) This language is unclear. Moreover, a waveform does not have binary bits, making the claim ambiguous on multiple levels.

50. Third, Step 2 recites "sequences" (plural) while Step 4 recites "said sequence" (singular) and Step 5 recites "said sequences" (plural). There is no antecedent basis for the phrase "said sequence."

51. For each of these additional reasons, taken alone or viewed together, claim 13 is indefinite under Section 112.

3. "Generating No More Than k Consecutive Sample Periods of Said Sequences Without a Transition in the Recorded Waveform." (Claim 13)

52. Step 5 of claim 13 recites "generating no more than k consecutive sample periods of said sequences without a transition in the recorded waveform." This phrase renders claim 13 indefinite (as well as all claims depending from it) because the claim, read in light of the specification of the '601 Patent and the prosecution history, fail to inform, with reasonable certainty, those skilled in the art about the scope of the purported invention.

53. What is meant by the phrase "k consecutive sample periods" of "said sequences"? The phrase "said sequences" may refer to n-bit codewords because it does not make sense to speak of a transitions of sequences. Transitions refers to transitions between

binary bits – 1 to 0 or 0 to 1. Moreover, a waveform does not have binary bits, making the claim ambiguous on multiple levels.

54. Also, what "sample periods" are being referred to? Sampling is done, for example, when recorded data is read, not when data is being written. The ''601 patent at 2:10-37 discloses sampling the context of "sequence detectors" for "data recovery devices," i.e., reading previously-recorded data from a storage medium. But claim 13 addresses only a "writing" function, and is not directing to "reading" or recovery of stored data.

55. Further, as noted above, Step 2 recites "sequences" (plural) while Step 4 recites "said sequence" (singular) and Step 5 recites "said sequences" (plural). This adds to the ambiguity of the claim.

56. For each of these additional reasons, taken alone or viewed together, claim 13 is indefinite under Section 112.

4. "Wherein the Binary Sequences Produced by Combining Codewords Have No More Than One of j Consecutive Transitions from 0 to 1 and from 1 to 0." (Claim 17)

57. Claim 17 depends from claim 14, which depends from claim 13. Claim 17 recites "wherein the binary sequences produced by combining codewords have no more than one of j consecutive transitions from 0 to 1 and from 1 to 0." This phrase renders claim 17 indefinite because the claim read in light of the specification of the '601 Patent and the prosecution history, fails to inform, with reasonable certainty, those skilled in the art about the scope of the purported invention.

58. The meaning of "j consecutive transitions" in this claim is unclear. Consider the simple bit string 01. There is one (1) transition "from 0 to 1" but zero (0) transitions "from 1 to 0." So what is the value of j in this simple example? The claim does not specify that one would take the *maximum* of the two choices, or the *sum of both choices*, but it instead says that j is evaluated as "no more than ***one of***" two options that are not necessarily the same.

Which one? Claim 17 is indefinite under Section 112 for at least these additional reasons.

5. "Wherein the Binary Sequences Produced by Combining Codewords Have … No More Than One of k+1 Consecutive 0's and k+1 Consecutive 1's." (Claim 17)

59. Claim 17 is indefinite because the phrase "no more than one of k+1 consecutive 0's and k+1 consecutive 1's" is indefinite. Consider the simple bit string 00111. There are two (2) consecutive 0's and three (3) consecutive 1's. How does one evaluate the claimed "k+1" parameter? The claim does not specify that one would take the *maximum* of the two choices, but it instead says that k+1 is evaluated as "no more than one of" two options. Claim 17 is indefinite under Section 112 for at least these additional reasons.

VIII. CONCLUSION

60. I declare under 28 U.S.C. § 1746 and under penalty of perjury that the foregoing is true and correct.

Dated: April 13, 2018

By [signature]
Emina Soljanin, Ph.D.

APPENDIX A

Maximum Transition Run Codes for Data Storage Systems

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Abstract **– A new code is presented which improves the minimum distance properties of sequence detectors operating at high linear densities. This code, which is called the maximum transition run code, eliminates data patterns producing three or more consecutive transitions while imposing the usual k-constraint necessary for timing recovery. The code possesses the similar distance-gaining property of the (1,*k*) code, but can be implemented with considerably higher rates. Bit error rate simulations on fixed delay tree search with decision feedback and high order partial response maximum likelihood detectors confirm large coding gains over the conventional (0,*k*) code.**

I. INTRODUCTION

In this paper, we present a new code designed to improve the distance properties of sequence detectors operating at relatively high linear densities. The basic idea is to eliminate certain input bit patterns that would cause most errors in sequence detectors. More specifically, the code eliminates input patterns that contain three or more consecutive transitions in the corresponding current waveform, and, as a result, the performance of any near-optimal sequence detector improves substantially at high linear densities [1][2]. This code constraint, designated the maximum transition-run (MTR) constraint, can be realized with simple fixed-length block codes with rates only slightly lower than the conventional (0,*k*) code. Bit error rate (BER) simulation results with fixed delay tree search with decision feedback (FDTS/DF) detection and high order partial response maximum likelihood (PRML) detection confirm a large coding gain of the MTR codes over the conventional (0,*k*) code.

II. CODING METHODS

Investigation of high density error patterns in FDTS/DF detection reveals that errors arise mostly due to the detector's inability to distinguish the minimum distance transition patterns, four pairs of which are shown in Fig. 1. These pairs of magnetization waveforms give rise to an NRZ input error pattern of $e_k = \pm\{2\ -2\ 2\}$, assuming input data take on +1's and -1's. The proposed approach is to remove data patterns allowing this type of error pattern through coding. The potential improvement in the FDTS detection performance using this approach can be estimated by computing the increase in the minimum distance between two diverging lookahead tree paths after removing the paths that allow the $\pm\{2\ -2\ 2\}$ error events [3]. A simple minimum distance analysis for PRML systems reveals that this is also a critical error pattern in high order PRML systems such as E^2PR4ML. Note that a traditional (1,*k*) runlength limited (RLL) code eliminates all eight transition patterns shown in Fig. 1 [4][5], but the rate penalty is typically too large to see any coding gain unless the linear density is very high. The idea of MTR coding is to eliminate three or more consecutive transitions, but allow the dibit pattern in the written magnetization waveform. Thus, with MTR coding, the error events of the form $\pm\{2\ -2\ 2\}$ will still be prevented as with (1,*k*) coding, but the rate penalty is significantly smaller than that of the typical (1,*k*) RLL code. Notice that with the MTR constraint, the write precompensation efforts can be directed mainly on dibit transitions, unlike in conventional (0,*k*) coded systems. An independent study also suggests that removing long runs of consecutive transitions improves the offtrack performance in some PRML systems [6]. There exist other types of code constraints that can offer similar distance-enhancing properties for high order PRML systems [7].

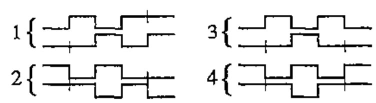

Fig. 1: Pairs of write patterns causing most errors in sequence detection at high linear densities.

Fig. 2 shows the state diagram of the MTR code based on the NRZI convention, where 1 and 0 represent the presence and absence, respectively, of a magnetic transition. Also included is the usual *k*-constraint for timing recovery. The capacity of the code can be obtained by finding the largest eigenvalue of the adjacency matrix for the given state diagram [8]. The capacities for different *k* values are given in Table 1.

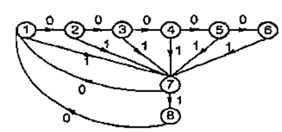

Fig. 2: State transition diagram for the MTR code with *k*=6.

k	capacity	k	capacity
4	.8376	8	.8760
5	.8579	9	.8774
6	.8680	10	.8782
7	.8732	∞	.8791

Table 1: Capacities for MTR codes.

While state-dependent encoders and sliding-block decoders can be designed for the MTR constraint (which can be easily generalized to limit any runs of consecutive transitions), we observe that simple fixed-length block codes can be realized with

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good rates and reasonable k values. A computer search is utilized to first find all n-bit codewords that are free of an NRZI 111 string or k+1 consecutive NRZI 0's. Then, in order to meet the MTR constraint at the codeword boundaries, words that start or end with an NRZI 11 string are removed. Also, the k constraint is satisfied at the boundary by removing the words with k_1+1 leading 0's or k_2+1 trailing 0's, where $k_1+k_2=k$. Finally, if the number of the remaining codewords is greater than or equal to 2^m, then those codewords can be used to implement a rate m/n block code. Table 2 shows important code parameters for representative block codes obtained through computer search. The efficiency was found by dividing the code rate m/n by the capacity computed for the given value of k and the MTR constraint. As an example of an MTR block code, 16 codewords required to implement the rate 4/5 code with k=8 are given in Table 3.

m	n	k	eff.	No. avail. codewords	No. needed codewords
4	5	8	.91	16	16
8	10	6	.92	282	256
9	11	6	.94	514	512
10	12	8	.95	1,066	1,024
14	17	6	.95	18,996	16,384
16	19	7	.96	69,534	65,536
24	28	8	.98	17,650,478	16,777,216

Table 2: Parameters for MTR block codes.

00001	00110	01100	10010
00010	01000	01101	10100
00100	01001	10000	10101
00101	01010	10001	10110

Table 3: A rate 4/5 MTR block code with k=8.

III. MODIFIED DETECTION AND DISTANCE INCREASE

To realize the coding gain at the detector output, the detector has to be modified. In the case of PRML systems, this amounts to removing those states and state transitions that correspond to the illegal data patterns from the trellis diagram. For the FDTS/DF detector, the code-violating lookahead paths must be prevented from being chosen as the most-likely path, a technique similar to the one used in the (1,7) coded FDTS/DF channel [9]. To illustrate the idea, consider Fig. 3 that shows a τ=2 lookahead tree utilized in FDTS/DF detection. By utilizing the past decision, an illegal path, which contains three consecutive transitions, can be identified as indicated by either the solid (when the past decision is -1) path or the shaded (when the past decision is 1) path. The complexity of the FDTS/DF detector can also be reduced considerably with the MTR code, as elaborated in a companion paper [10].

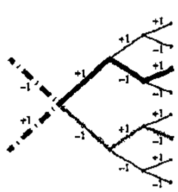

Fig. 3: Modified FDTS detection with MTR coding

With this modification in FDTS/DF detection, the squared minimum Euclidean distance between any two diverging paths, denoted by β^2_{min}, is given by $4\cdot(1+f_1^{\,2}+f_2^{\,2}+\cdots+f_\tau^{\,2})$ for τ greater than or equal to 2, where f_k represents the equalized dibit response (at the output of the forward equalizer). For example, the effective SNR gain of the τ=2 FDTS/DF over the decision feedback equalization (DFE) channel, assuming the same MTR code, is given by $10\cdot\log_{10}(1+f_1^{\,2}+f_2^{\,2})$ dB.

The distance gain with MTR coding is also significant for high order PRML systems such as E^2PR4. When the critical NRZ error pattern is $\pm\{2\ -2\ 2\}$, the minimum distance for the E^2PR4 response {1 2 0 -2 -1} is $6\sqrt{2}$. With MTR coding, the worst case error pattern becomes a single bit error pattern of $\pm\{2\}$, and the corresponding channel output distance is simply the square root of the energy in the equalized dibit response, or $10\sqrt{2}$. This increase in the minimum distance is equivalent to an SNR gain of 2.218 dB. When the code rate penalty is small, the overall coding gain is significant.

IV. BER SIMULATION RESULTS

To verify the coding gain, FDTS/DF detection was simulated with the rate 4/5 and rate 16/19 MTR codes as well as with a rate 8/9 (0,k) code. The BERs were first obtained as a function of readback SNR for different tree depths. The BER of the PR4ML detector was also simulated for comparison. The Lorentzian transition response was assumed, and the user density, defined as PW50 over the user bit interval, is fixed at 2.5 for all codes. The SNR value required to achieve an error rate of 10^{-5} was then recorded for each depth/code combination.

The results are summarized in Fig. 4, where the effective SNR improvement of each system over PR4ML is shown. The performance advantage of MTR codes is clear. With the rate 16/19 MTR code, for example, the depth 1 FDTS/DF performs as well as the depth 5 FDTS/DF used with the conventional (0,k) code, yielding a 2.5 dB gain over the PR4ML. When the 4/5 MTR code is used, FDTS/DF with a tree depth of 2 outperforms the depth 5 FDTS/DF with the 8/9 (0,k) code. For a given tree depth, the rate 16/19 MTR code yields a 1.5 - 2 dB coding gain over the conventional 8/9 (0,k) code.

Also shown are the SNR performances of PRML systems with and without MTR coding. The coding gain is obvious with E^2PRML and E^3PRML, in which the minimum distance is improved with the MTR code. However, with EPR4ML the performance advantage of the MTR code is small since the MTR code does not improve the minimum distance in the EPR4 system. This is because the minimum distance error pattern in an EPR4 system is of the form $\pm\{2\}$, which is not affected by the MTR constraint. The MTR code does, however, eliminate non-minimum distance error patterns of the form $\pm\{...2\ -2\ 2...\}$, resulting in a small performance improvement over the (0,k) coded EPR4 system when the code rate is sufficiently high as with the 16/19 code.

Comparisons also can be made between the PRML systems and FDTS/DF systems. For example, the depth 2 FDTS/DF with the rate 4/5 MTR code improves more than 1 dB over EPR4ML with the rate 8/9 (0,k) code. At this density and with a Lorentzian transition response, EPR4ML has a 1.5 dB advantage over PR4ML. Of the PR targets, the EPR4 appears to provide a best fit to the natural channel as indicated by the superior performance of EPR4ML over even higher order PRML systems. Large enough FIR filters are used for equalization for both PRML and FDTS/DF systems so that the performances are not degraded by imperfect equalization.

In Fig. 5, similar plots are presented for a modeled MR head response. The trends are similar to the Lorentzian case, except that within the PRML family the performance improves as the order of the PR polynomial increases. Also, the MTR coding gain is larger than in the case of the Lorentzian response for all detectors. The depth 2 FDTS/DF channel with the rate 4/5 MTR code provides a 2.5 dB SNR gain over the EPR4ML channel with the rate 8/9 $(0,k)$ code. With the particular MR head response used here, EPR4ML already has a 4 dB advantage over PR4ML at this linear density.

Since the MTR code eliminates data patterns with crowded transitions, the overall transition noise, as measured per unit length of track, is expected to be reduced. Fig. 6 shows the simulation results similar to those presented in Fig. 5, except random transition position jitter and transition width variations are included in the read waveform construction process [11]. The rms values of both transition noise parameters are set at 4.4 % of the user bit interval. The SNR reflects only the additive noise component. As is evident from the figure, the coding gain of the MTR code over the $(0,k)$ code is much larger in the presence of transition noise. For example, with τ=2 FDTS/DF detection, the SNR difference is 6 dB between the rate 4/5 MTR code and the rate 8/9 $(0,k)$ code which allows long runs of consecutive transitions.

Although the results are not shown here, we have also observed that the MTR code tends to reduce the relative frequencies of long error events in DFE and FDTS/DF systems.

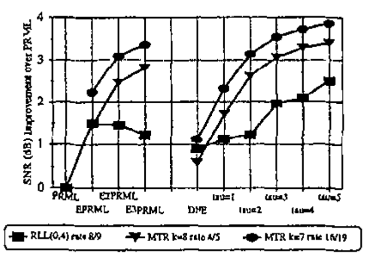

Fig. 4: Summary of PRML and FDTS/DF performances with and without MTR codes (Lorentzian response and additive noise).

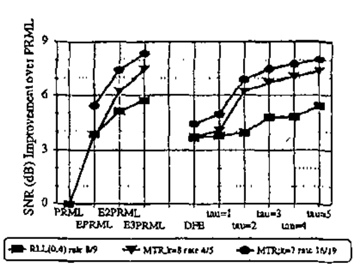

Fig. 5: Summary of PRML and FDTS/DF performances with and without MTR codes (MR head response and additive noise).

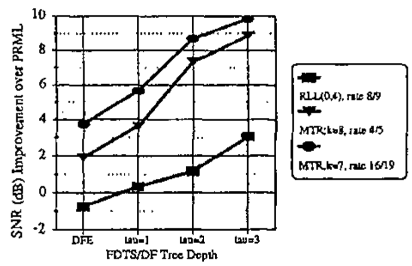

Fig. 6: Summary of FDTS/DF performances with and without MTR codes (MR head response and mixed noise).

V. CONCLUSION

A simple coding scheme is presented which improves the performance of FDTS/DF and high order PRML systems operating at relatively high linear densities. The code eliminates three or more consecutive transitions while allowing the k-constraint for timing purposes. The code can be implemented as simple block codes with reasonable rates such as 4/5, 8/10 and 16/19. BER simulations on FDTS/DF and PRML systems confirm large coding gains over the conventional $(0,k)$ code.

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APPENDIX B

On–track and off–track distance properties of Class 4 partial response channels

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ABSTRACT

We consider Class 4 partial response (PR) channels, and examine off-track performance of maximum likelihood sequence estimators for these channels that ignore inter-track interference (ITI). We assume that the pulse response to the head from an adjacent track is the same Class 4 channel, and only its amplitude varies with the track-to-head distance, in a way not known to the receiver. For each of these channels, we find analytical expressions for off-track performance, as well as sets of sequences most susceptible to errors in the ITI environment. We also discuss how the problem of off-track error rate can be alleviated through coding.

Keywords: magnetic recording, class 4, partial response, off–track performance, coding.

1 INTRODUCTION

The transfer function of a digital magnetic recording channel for a given linear density can be closely approximated by a partial response (PR) polynomial of the form $(1-D)(1+D)^N$, for some integer $N \geq 1$. In general, higher linear densities require higher order polynomials. Equalization of a recording channel to the PR channel with the transfer function that best approximates the channel transfer function at a given density will incur the least equalization loss.

A significant noise source in magnetic recording channels is inter-track interference (ITI). When the read head is not centered over the data track, it is partially positioned over an adjacent track and picks up the magnetization from it. When tracks become narrow, the side *fringing* causes the head to pick up signals from an adjacent track, even if it is not physically over that track. An important issue that should affect the choice of N is, therefore, the performance of the corresponding channel in the presence of ITI, often referred to as off-track performance.

0-8194-1969-9/95/$6.00

Magnetic recording channels at current linear densities resemble channels with transfer functions of the above form for $N = 1, 2, 3$, referred to as *Class 4* partial response. These channels are also known as $1 - D^2$ or PR4, $(1 - D)(1 + D)^2$ or EPR4, and $(1 - D)(1 + D)^3$ or EEPR4. Most of the commercially available detectors employ PR equalization to the PR4 channel. Using the same detection system at higher linear densities would result in a performance loss. Thus the system should be either augmented by a coding scheme, which would recover the loss through the coding gain, or replaced by a detection system employing PR equalization to the EPR4 or EEPR4 channel. In any case the new system should have good off-track properties.

Several studies analyzed off-track performance of Class 4 channels by simulation (see for example Sayiner[9] and references therein). We find analytical expressions for off-track performance of these channels, as well as sets of sequences most susceptible to errors in the ITI environment. We discuss how the problem of off-track error rate can be alleviated through coding.

In Section II we derive a bound on the error-probability performance for a general discrete-time recording channel with additive white Gaussian noise and a general model of ITI. In Section III we consider Class 4 channels under the assumption that the pulse response to the head from an adjacent track is the same Class 4 channel and only its amplitude varies with the track to head distance. In Section IV we discuss possibilities of coding for these systems. In Section V we provide an extensive summary of the obtained results, for the benefit of a reader not very interested in mathematical details.

2 DISCRETE TIME MAGNETIC RECORDING CHANNEL

2.1 Channel model

We consider a discrete-time model for the magnetic recording channel with input $\boldsymbol{a} = \{a_n\} \in \mathcal{C} \subseteq \{-1, 1\}^\infty$, impulse response $\{h_n\}$, and output $\boldsymbol{y} = \{y_n\}$ given by

$$y_n = \sqrt{E} \sum_m a_m h_{n-m} + \eta_n, \tag{1}$$

where h_n are integer, η_n are independent Gaussian random variables with zero mean and variance σ^2, and E is a constant related to the output voltage amplitude. We refer to E/σ^2 as the signal-to-noise ratio (SNR) per track. In the case of ITI, when the read head picks up magnetization from an adjacent track, the channel model becomes

$$y_n = \sqrt{E} \sum_m a_m h_{n-m} + \sqrt{E} \sum_m x_m g_{n-m} + \eta_n, \tag{2}$$

where $\{g_n\}$ is the discrete-time impulse response of the head to the adjacent track and $\boldsymbol{x} = \{x_n\} \in \mathcal{C}$ is the sequence recorded on that track.

We analyze the performance of the receiver that ignores the ITI assuming the received signal to be as given by (1). It performs maximum likelihood sequence estimation (MLSE) for that model, *i.e.*, it determines an $\hat{a}$ satisfying

$$\min_{a \in C} \Omega(a) = \Omega(\hat{a}),$$

where $\Omega(a)$ is the well known log-likelihood function for channels with inter-symbol interference,[4]

$$\Omega(a) = \sum_n \left(y_n - \sqrt{E} \sum_m a_m h_{n-m}\right)^2. \quad (3)$$

2.2 Error–probability performance

Let $a = \{a_n\}$ and $b = \{b_n\}$ be two allowable recorded sequences which differ in a finite number of places, and $\epsilon = \{\epsilon_n = (a_n - b_n)/2\}$ be the normalized error sequence corresponding to a and b. In the case of no ITI, probability of detecting b given that a was recorded equals to $Q(d(\epsilon)\sqrt{\text{SNR}})$, where $d(\epsilon)$ is the distance between a and b given by

$$d^2(\epsilon) = \sum_n \left(\sum_m \epsilon_m h_{n-m}\right)^2. \quad (4)$$

Thus a lower bound to the minimum probability of an error event in the system is proportional to $Q(d_{\min}\sqrt{\text{SNR}})$, where $d_{\min} = \min_{\epsilon \neq 0} d(\epsilon)$.

In the case of ITI we examine the probability of detecting sequence b given that sequence a was recorded on the track being read and sequence x was recorded on an adjacent track. This probability is given by

$$P[\Omega(b) < \Omega(a) | a, x] = P[\Omega(b) - \Omega(a) < 0 | a, x].$$

Expressing $\Omega(a)$ and $\Omega(b)$ as in (3), we obtain

$$P[\Omega(b) - \Omega(a) < 0 | a, x] = P\left[\sum_n \left(y_n - \sqrt{E}\sum_m a_m h_{n-m}\right)^2 - \sum_n \left(y_n - \sqrt{E}\sum_m b_m h_{n-m}\right)^2 < 0 | a, x\right]$$

Substituting (2) for y_n in the above equation gives

$$P[\Omega(b) - \Omega(a) < 0 | a, x] = P\Big[\sum_n \eta_n \sum_m \epsilon_m h_{n-m} + \sqrt{E}\sum_n \left(\sum_m \epsilon_m h_{n-m}\right)^2 + \sqrt{E}\sum_n \left(\sum_m x_m g_{n-m}\right)\left(\sum_m \epsilon_m h_{n-m}\right) < 0\Big],$$

where and $\epsilon_n = (a_n - b_n)/2$. Since

$$\frac{1}{\sigma\left[\sum_n \left(\sum_m \epsilon_m h_{n-m}\right)^2\right]^{1/2}} \sum_n \eta_n \sum_m \epsilon_m h_{n-m}$$

is a zero-mean, unit-variance Gaussian random variable, we have

$$P[\Omega(b) - \Omega(a) < 0 | a, x] = Q\left(\delta(\epsilon, x)\sqrt{\text{SNR}}\right),$$

where $\delta(\epsilon, x)$ is the distance between a and b in the *presence* of x given by

$$\delta(\epsilon, x) = \frac{\sum_n \left(\sum_m \epsilon_m h_{n-m}\right)^2 + \sum_n \left(\sum_m x_m g_{n-m}\right)\left(\sum_m \epsilon_m h_{n-m}\right)}{\left[\sum_n \left(\sum_m \epsilon_m h_{n-m}\right)^2\right]^{1/2}}.$$

Thus a lower bound to the minimum probability of an error event in the system is proportional to $Q(\delta_{\min}\sqrt{\mathrm{SNR}})$, where $\delta_{\min} = \min_{\epsilon \neq 0, x \in C} \delta(\epsilon, x)$.

We derive a simple lower bound on $\delta(\epsilon, x)$ as follows:

$$\begin{aligned} \delta(\epsilon, x) &\geq \frac{\sum_n \left(\sum_m \epsilon_m h_{n-m}\right)^2 - \left|\sum_n \left(\sum_m x_m g_{n-m}\right)\left(\sum_m \epsilon_m h_{n-m}\right)\right|}{\left[\sum_n \left(\sum_m \epsilon_m h_{n-m}\right)^2\right]^{1/2}} \\ &\geq \frac{\sum_n \left(\sum_m \epsilon_m h_{n-m}\right)^2 - \sum_n M \left|\sum_m \epsilon_m h_{n-m}\right|}{\left[\sum_n \left(\sum_m \epsilon_m h_{n-m}\right)^2\right]^{1/2}}, \end{aligned}$$

where $M = \max_{n, x \in C} \sum_m x_m g_{n-m}$, *i.e.*, M is the maximum absolute value of the interference. Note that $M = \sum_n |g_n|$. We'll assume that $M < 1$. Since the h_n are integers and $\epsilon_n \in \{-1, 0, 1\}$, we can further bound $\delta(\epsilon, x)$ as follows:

$$\begin{aligned} \delta(\epsilon, x) &\geq \frac{\sum_n \left(\sum_m \epsilon_m h_{n-m}\right)^2 - M \sum_n \left(\sum_m \epsilon_m h_{n-m}\right)^2}{\left[\sum_n \left(\sum_m \epsilon_m h_{n-m}\right)^2\right]^{1/2}} \\ &= (1 - M)\left[\sum_n \left(\sum_m \epsilon_m h_{n-m}\right)^2\right]^{1/2}, \end{aligned}$$

and thus

$$\delta_{\min} = \min_{\epsilon, x} \delta(\epsilon, x) \geq (1 - M) d_{\min}.$$

The bound is achieved if and only if there exists an $\epsilon \in \arg\min_{\epsilon \neq 0} d(\epsilon)$ for which $\sum_m \epsilon_m h_{n-m} \in \{-1, 0, 1\}$ for all n, and there exists an $x \in C$ such that $\sum_m x_m g_{n-m} = \mp M$ whenever $\sum_m \epsilon_m h_{n-m} = \pm 1$. We show below that this bound can be achieved for the PR4 and the EPR4 channels but not for the EEPR4 channel.

3 DISTANCE PROPERTIES OF BINARY CLASS 4 CHANNELS

We now consider Class 4 channels, *i.e.*, channels with transfer functions given by $H(D) = \sum_n h_n D^n = (1 - D)(1 + D)^N$ for $N = 1, 2, 3$. We assume that the pulse response to the head from an adjacent track is the same Class 4 channel, and only its amplitude varies with the track to head distance with a parameter α, *i.e.* $g_n = \alpha h_n$. This assumption is only approximate since the transition response from a track to a head gets wider as the distance between them increases, as discussed by Vea and Moura[2] and Lindholm.[3] With $g_n = \alpha h_n$, the above lower bound becomes

$$\delta_{\min} = \min_{\epsilon, x} \delta(\epsilon, x) \geq (1 - \alpha A) d_{\min}, \tag{5}$$

where A is the maximum value of the noiseless Class 4 channel output; $A = 2, 4, 6$ and $d_{\min}^2 = 2, 4, 6$ for $N = 1, 2, 3$, respectively.

For the three Class 4 channels, we examine if the bound can be achieved by working in the transform domain where each sequence $\{s_n\}$ has a corresponding function $S(D) = \sum_n s_n D^n$. For that purpose, we note that the minimum distance of the uncoded channel with transfer function $H(D)$ with no ITI, defined by (4), can be expressed as

$$d^2_{\min} = \min_{\epsilon(D)\neq 0} \|H(D)\epsilon(D)\|^2,$$

where $\epsilon(D) = \sum_{i=0}^{l-1} \epsilon_i D^i$, $\epsilon_i \in \{-1, 0, 1\}$, $\epsilon_0 \neq 0$, $\epsilon_{l-1} \neq 0$, is the polynomial corresponding to a normalized error sequence $\epsilon = \{\epsilon_i\}_{i=1}^{l-1}$ of length l, and the squared norm of a polynomial refers to the sum of its squared coefficients. The bound (5) is achieved if and only if there exists an $\epsilon(D)$ for which $\|H(D)\epsilon(D)\|^2 = d^2_{\min}$ and all coefficients y_n of $y(D) = H(D)\epsilon(D)$ are in the set $\{-1, 0, 1\}$, and there exists an $x \in \mathcal{C}$ such that in $H(D) \cdot \sum_n x_n D^n = \sum_n z_n D^n$, $z_n = \mp A$ whenever $y_n = \pm 1$.

3.1 The PR4 channel

For $N = 1$ the channel transfer function is equal to $1 - D^2$. This channel is usually treated as two interleaved $1 - D$ channels. For the $1 - D$ channel $d^2_{\min} = 2$ is attained for $\epsilon(D) = \sum_{k=0}^{l-1} D^k$. In this case $\delta(\epsilon, x)$ achieves lower bound (5) for $x = \{\cdots, x_{-2}, 1, -1, x_1, \cdots, x_{l-2}, -1, 1, x_{l+1}, \cdots\}$, since the only non-zero coefficients of $y(D) = 1 - D^l$ are $y_0 = 1$, $y_l = -1$, and in $(1 - D) \cdot \sum_n x_n D^n = \sum_k z_k D^k$, we have $z_0 = -2$ and $z_l = 2$. Therefore, for the PR4 channel, $\delta_{\min} = \sqrt{2}(1 - 2\alpha)$.

EXAMPLE 1. Consider a noiseless $1 - D$ channel. Let sequences a, b, $\epsilon = (a - b)/2$, and x be as follows:

$$\begin{aligned} a &= \cdots, a_{-1}, -1, +1, +1, +1, a_4, \cdots \\ b &= \cdots, a_{-1}, -1, -1, -1, +1, a_4, \cdots \\ \epsilon &= \cdots,\ 0,\ 0, +1, +1,\ 0,\ 0, \cdots \\ x &= \cdots, x_{-1}, +1, -1, -1, +1, x_4, \cdots \end{aligned}$$

Let a be recorded on the track being read and x recorded on an adjacent track. Then $\delta(\epsilon, x) = \sqrt{2}$ for $\alpha = 0$, $\delta(\epsilon, x) = 1/\sqrt{2}$ for $\alpha = 0.25$, and $\delta(\epsilon, x) = 0$ for $\alpha = 0.5$.

3.2 The EPR4 channel

For $N = 2$ the channel transfer function is equal to $(1 - D)(1 + D)^2$. It is well known that $d^2_{\min} = 4$ is attained for $\epsilon(D) = 1$, which gives $y(D) = 1 + D - D^2 - D^3$. However, for the corresponding error sequence, $\delta(\epsilon, x)$ cannot achieve lower bound (5) because that would require a sequence x for which two successive outputs of the EPR4 channel equal to 4. In order to see if the lower bound can be achieved, we find all error polynomials $\epsilon(D)$ for which $\|(1 - D)(1 + D)^2\epsilon(D)\|^2 = 4$.

Polynomial $y(D) = (1 - D)(1 + D)^2\epsilon(D)$ with $\|y(D)\|^2 = 4$ is of the form $1 + c_1 D^{p_1} + c_2 D^{p_2} + c_3 D^{p_3}$ where, for $i \in \{1, 2, 3\}$, $c_i \in \{-1, 1\}$ and p_i are three different positive integers. From the definition of $y(D)$, we know that $y(1) = 0$, $y(-1) = 0$, $y'\epsilon(1) = 0$ must be satisfied. It can be shown that these conditions require that $y(D)$ be either of the form $(1 - D^{2k} + D^{2n+1} - D^{2(k+n)+1})$, $k \geq 1$, $n \geq 0$, or of the form $(1 - D^{2k} - D^{2n} + D^{2(k+n)})$, $k, n \geq 1$, $k \neq n$. To further specify $y(D)$ and find the corresponding $\epsilon(D)$, we consider these two cases separately.

1. Polynomial $(1-D)(1+D)^2\epsilon(D) = 1 - D^{2k} + D^{2n+1} - D^{2(k+n)+1}$ factors as
$$(1-D)(1+D)^2 \cdot \Big(\sum_{j=0}^{k-1} D^{2j}\Big)\Big(\sum_{i=0}^{2n}(-1)^i D^i\Big).$$
Therefore $\epsilon(D) = \left(\sum_{i=0}^{2n}(-1)^i D^i\right)\left(\sum_{j=0}^{k-1} D^{2j}\right)$. Since the coefficient of $\epsilon(D)$ are in $\{-1, 0, 1\}$, we conclude that an arbitrary $k > 1$ requires $n = 0$ and an arbitrary $n > 0$ requires $k = 1$. In the first case $\epsilon(D) = \sum_{j=0}^{k-1} D^{2j}$ and $y(D) = 1 + D - D^{2k} - D^{2k+1}$. In the second case $\epsilon(D) = \sum_{i=0}^{2n}(-1)^i D^i$ and $y(D) = (1 - D^2 + D^{2n+1} - D^{2n+3})$.

2. Polynomial $(1-D)(1+D)^2\epsilon(D) = 1 - D^{2n} - D^{2k} - D^{2(k+n)}$ factors as
$$(1-D)(1+D)^2 \cdot \Big(\sum_{j=0}^{k-1} D^{2j}\Big)\Big(\sum_{i=0}^{2n-1}(-1)^i D^i\Big).$$
Therefore $\epsilon(D) = \left(\sum_{i=0}^{2n-1}(-1)^i D^i\right)\left(\sum_{j=0}^{k-1} D^{2j}\right)$. Since the coefficient of $\epsilon(D)$ are in $\{-1, 0, 1\}$, we conclude that an arbitrary $k > 1$ requires $n = 1$ and an arbitrary $n > 1$ requires $k = 1$. In the first case $\epsilon(D) = \sum_{j=0}^{2k-1}(-1)^j D^j$ and $y(D) = 1 - D^2 - D^{2k} + D^{2k+2}$. In the second case $\epsilon(D) = \sum_{i=0}^{2n-1}(-1)^i D^i$ and $y(D) = 1 - D^2 - D^{2n} + D^{2n+2}$. These two cases are equivalent as was expected from the symmetry of the original $y(D)$ with respect to n and k.

From 1. and 2. we conclude that the error polynomials $\epsilon(D)$ for which $\|(1-D)(1+D)^2\epsilon(D)\|^2 = 4$ are either of the form $\epsilon(D) = \sum_{j=0}^{k-1} D^{2j}$, $k \geq 1$, in which case $y(D) = (1 + D - D^{2k} - D^{2k+1})$, or of the form $\epsilon(D) = \sum_{i=0}^{l-1}(-1)^i D^i$, $l \geq 3$, in which case $y(D) = (1 - D^2 - (-1)^l D^l + (-1)^l D^{l+2})$. In the former case $\delta(\epsilon, x)$ cannot achieve lower bound (5) because, as above, it would require a sequence x for which two successive outputs of the EPR4 channel equal to 4. It can be shown that in this case $\min_{x \in C} \delta(\epsilon, x) = \sqrt{4}(1 - 3\alpha)$. In the latter case $\delta(\epsilon, x)$ achieves the lower bound for
$$x = \{\cdots, x_{-4}, -1, -1, 1, 1, -1, -1, x_3, \cdots, x_{l-4}, -1, -1, 1, 1, -1, -1, x_{l+3}, \cdots\}$$
for odd $l \geq 5$, or
$$x = \{\cdots, x_4, -1, -1, 1, 1, -1, -1, x_3, \cdots, x_{l-4}, 1, 1, -1, -1, 1, 1, x_{l+3}, \cdots\}$$
for even $l \geq 6$. It can be shown that $\min_{x \in C} \delta(\epsilon, x) = \sqrt{4}(1 - 3\alpha)$ for $l = 3, 4$. Therefore, for the EPR4 channel, $\delta_{\min} = \sqrt{4}(1 - 4\alpha)$.

EXAMPLE 2. Consider a noiseless EPR4 channel. Let sequences a, b, $\epsilon = (a - b)/2$, and x be as follows:
$$\begin{aligned}
a &= \cdots, a_{-3}, a_{-2}, a_{-1}, -1, +1, -1, +1, -1, +1, a_6, a_7, a_8, \cdots \\
b &= \cdots, a_{-3}, a_{-2}, a_{-1}, +1, -1, +1, -1, +1, -1, a_6, a_7, a_8, \cdots \\
\epsilon &= \cdots, 0, 0, 0, -1, +1, -1, +1, -1, +1, 0, 0, 0, \cdots \\
x &= \cdots, -1, -1, +1, +1, -1, -1, +1, +1, -1, -1, +1, +1, \cdots
\end{aligned}$$

Let $\boldsymbol{a}$ be recorded on the track being read and $\boldsymbol{x}$ recorded on an adjacent track. Then $\delta(\epsilon, \boldsymbol{x}) = \sqrt{4}$ for $\alpha = 0$, and $\delta(\epsilon, \boldsymbol{x}) = 0$ for $\alpha = 0.25$.

3.3 The EEPR4 channel

For $N = 3$ the channel transfer function is equal to $(1 - D)(1 + D)^3$. Again, it is well known that $d^2_{\min} = 6$ is attained for $\epsilon(D) = 1 - D + D^2$, which gives $y(D) = 1 + D - D^2 + D^4 - D^5 - D^6$. However, similarly as above, for the corresponding error sequence, $\delta(\epsilon, \boldsymbol{x})$ cannot achieve lower bound (5) because that would require a sequence $\boldsymbol{x}$ for which a string of three successive outputs of the EEPR4 channel equals to $6, 6, -6$. In order to see if the bound can be achieved, we find all error polynomials $\epsilon(D)$ for which $\|(1-D)(1+D)^3\epsilon(D)\|^2 = 6$. We consider polynomial $y(D) = (1-D)(1+D)^3\epsilon(D) = (1+2D-2D^3-D^4)\cdot(1+\epsilon_1 D+\epsilon_2 D^2+\cdots+\epsilon_{l-3}D^{l-3}+\epsilon_{l-2}D^{l-2}+\epsilon_{l-1}D^{l-1})$. It is easy to check that for all error sequences of length $l \leq 2$, $\|y(D)\|^2 \geq 10$. For error sequences of length $l \geq 3$, polynomial $y(D)$ is of the form $1+(\epsilon_1+2)D+(\epsilon_2+2\epsilon_1)D^2+D^3z(D)+(-2\epsilon_{l-2}-\epsilon_{l-3})D^{l+1}+(-2\epsilon_{l-1}-\epsilon_{l-2})D^{l+2}+(-\epsilon_{l-1})D^{l+3}$, where $z(D)$ is a polynomial with degree of at most $l - 3$. Since $\epsilon_{l-1} \neq 0$, we have $\|y(D)\|^2 \geq 3 + \|z(D)\|^2 + 3$, and therefore $\|y(D)\|^2 = 6$ only if $z(D) = 0$. Therefore $y(D) = 1 + D - D^2 + (-2\epsilon_{l-2} - \epsilon_{l-3})D^{l+1} + (-2\epsilon_{l-1} - \epsilon_{l-2})D^{l+2} + (-\epsilon_{l-1})D^{l+3})$. For $y(1) = 0$, we need $y(D) = 1 + D - D^2 + D^{l+1} - D^{l+2} - D^{l+3}$. For $y(-1) = 0$, we need $y(D) = 1 + D - D^2 + D^{2k} - D^{2k+1} - D^{2k+2}$. For $y'(-1) = 0$, we need $y(D) = 1 + D - D^2 + D^4 - D^5 - D^6$. Note that $y(D) = 1 + D - D^2 + D^4 - D^5 - D^6 = (1 - D)(1 + D)^3 \cdot (1 - D + D^2)$, and therefore $\epsilon(D) = 1 - D + D^2$ is the only error polynomial for which $\|(1 - D)(1 + D)^3\epsilon(D)\|^2 = 6$. It can be shown that for the corresponding error sequence ϵ, $\min_{\boldsymbol{x}\in\mathcal{C}} \delta(\epsilon, \boldsymbol{x}) = \sqrt{6}(1 - 4\alpha)$. Note that this does not determine $\delta_{\min}$ for the EEPR4 channel.

4 CODING FOR IMPROVING OFF–TRACK PERFORMANCE

It was shown above that a lower bound to the minimum probability of an error-event in the system with ITI is proportional to $Q(\delta_{\min}\sqrt{\mathrm{SNR}})$, where

$$\delta_{\min} = \min_{\epsilon,\boldsymbol{x}} \delta(\epsilon, \boldsymbol{x}) \geq (1 - M)d_{\min}.$$

This bound was derived for an arbitrary set of recorded sequences, $\mathcal{C} \subseteq \{-1, 1\}^\infty$, and therefore holds in coded as well as uncoded systems. Whether it can be achieved depends on the code. The value of $d^2_{\min}$ is also determined by the code. To improve the error-probability performance of the system, we need codes that increase $d^2_{\min}$ or ensure that the above bound is never achieved or, preferably, perform both tasks.

Codes that increase $d^2_{\min}$ are existing codes designed to improve the on-track performance, *i.e.*, performance of channels with no ITI, as for example matched spectral null codes.[7] In general, these codes may improve the off-track performance as well, since they are likely to reduce the fraction of sequences $\boldsymbol{x}$ for which the bound on $\delta(\epsilon, \boldsymbol{x})$ can be achieved for a given ϵ. To argue that, we recall that the bound is achieved if and only if there exists an $\epsilon \in \arg\min_{\epsilon\neq 0} d(\epsilon)$ for which $\sum_m \epsilon_m h_{n-m} \in \{-1, 0, 1\}$ for all n and there exists an $\boldsymbol{x} \in \mathcal{C}$ such that $\sum_m x_m g_{n-m} = \mp M$ whenever $\sum_m \epsilon_m h_{n-m} = \pm 1$. Codes for improving noise immunity reduce the set of sequences $\epsilon \in \arg\min_{\epsilon\neq 0} d(\epsilon)$ for which $\sum_m \epsilon_m h_{n-m} \in \{-1, 0, 1\}$ for all n. For the sequences that remain, the number of n such that $\sum_m \epsilon_m h_{n-m} = \pm 1$ is higher, and therefore sequence x has to satisfy more conditions. A good example of this case is a dc-free coded PR4 channel.

Design of high rate codes which improve both on- and off-track error probability performance of Class 4 channels may be a complex problem, and we do not attempt to solve it at this point. Instead, we discuss off-track performance of a dc-free coded PR4 channel and present some coding ideas for the EPR4 and EEPR4 channels which transpired from the above distance properties analysis.

4.1 The PR4 channel

It has been observed in laboratory experiments that a dc-free coded PR4 channel has better off-track performance than its uncoded counterpart.[5] For a dc-free coded $1-D$ channel $d^2_{min} = 4$ is obtained for $e(D) = 1 - D^{l-1}$, and the corresponding $y(D)$ is equal to $1 - D - D^{l-1} + D^l$. It is easy to see that in this case $\delta(\epsilon, x)$ achieves lower bound (5) for $x = \{\cdots, x_2, 1, -1, 1, x_2, \cdots, x_{l-3}, -1, 1, -1, x_{l+1}, \cdots\}$ where $l \geq 4$. Therefore, for the dc-free coded PR4 channel, $\delta_{\min} = \sqrt{4}(1 - 2\alpha)$ degrades with α at the same rate as it does for the uncoded system. However, the sequence x for which the bound is achieved has 6 symbols specified as opposed to at most 4 in the uncoded case. In addition, the bound cannot be achieved for all error sequences for which $||e(D)H(D)||^2 = d^2_{\min}$, as in uncoded case, but only for those of length $l \geq 4$.

4.2 The EPR4 channel

Based on the distance properties described above, we know that $\min_{x \in C} \delta(\epsilon, x) = \sqrt{4}(1 - 4\alpha)$ if and only if $\epsilon(D) = \sum_{i=0}^{l-1} (-1)^i D^i$, $l \geq 5$. It can be shown that for all other error sequences for which $||H(D)\epsilon(D)||^2 = 4$, we have $\min_{x \in C} \delta(\epsilon, x) = \sqrt{4}(1 - 3\alpha)$. Therefore, an improvement in the off-track performance of this channel can be accomplished by limiting the length of subsequences of alternating symbols to four. For the NRZI type of recording, this can be achieved by a code that limits the runs of successive ones to three, as the binary complement of the industry standard $8/9\,(0,3)$ block code, introduced for IBM 3480 tape drive. This code has a simple and inexpensive implementation proposed by A. M. Patel.[6] In general, using a code that removes long sequences of alternating symbols at the input of the EPR4 channel is advantageous since these sequences result in long sequences of zeros at the channel output, which is undesirable for timing and gain control.

4.3 The EEPR4 channel

It was shown above that the only error polynomial for which $||(1-D)(1+D)^3\epsilon(D)||^2 = 6$ is $\epsilon(D) = 1 - D + D^2$. This error event can be removed by a code that does not allow successive transitions. For the NRZI type of recording, this can be achieved by a code that does not allow successive ones, as $2/3\,(1,7)$ code. Using this code for high linear density recording systems has already been proposed as a means of reducing the problems associated with closely recorded neighboring transitions. It can be shown that the code also removes all error sequences for which this polynomial has all its coefficients in the set $\{-1,0,1\}$. Therefore $2/3\,(1,7)$ code gives a performance improvement of for EEPR4 channel with no ITI, and ensures that the lower bound on the performance of the channel with ITI is never achieved. An additional benefit of the code is that it reduces the number of states in the EEPR4 Viterbi detector from 16 to 10 since successive transitions are illegal. The main drawback of the code is its low rate.

5 SUMMARY AND CONCLUSIONS

Magnetic storage detectors employing PR4 equalization exhibit loss in performance at high recording densities and need to be replaced. Two systems are being considered for next generation products: the dc-free coded PR4 channel and the EPR4 channel. Various error probability performance and implementation issues of these two systems should be examined in order to decide which one is a better choice. The analytical results of this paper together with the simulation results obtained by Sayiner[8,9] allow as to compare the systems on the basis of their off-track performance. In addition, the analytical results give an understanding of the systems necessary if coding is to be used for performance improvement.

We analyzed on- and off-track distance properties of PR4, EPR4, and EEPR4 channels, known as Class 4. We also looked at off-track performance of the dc-free coded PR4 channel, and showed some possibilities of improving performance of the EPR4 and EEPR4 channels through coding. Design of high rate codes which improve both on- and off-track error probability performance of Class 4 channels is, however, an interesting open problem. Most of the obtained results are summarized below.

Magnetic recording channels operate at high SNR where the probability of an error event in the system with no ITI is well approximated by $Q(d_{\min}\sqrt{\mathrm{SNR}})$. We found that under the same conditions probability of an error event in the system with ITI is well approximated by $Q(\delta_{\min}\sqrt{\mathrm{SNR}})$, where $\delta_{\min} \geq d_{\min}(1-M)$ and M is the maximum value that the output of the noiseless channel between the reading head and an adjacent track can take. With the assumption that the pulse response to the reading head from an adjacent track is the same Class 4 channel, and only its amplitude varies with the track to head distance with a parameter α, we have $\delta_{\min} \geq d_{\min}(1-\alpha A)$ where A is the maximum value the noiseless Class 4 channel output can take ($A = 2, 4$, and 6 for PR4, EPR4, and EPR4 respectively).

We found that the uncoded as well as coded PR4 channel have much better off-track performance than the EPR4 channel, *i.e.*, $\delta_{\min}/d_{\min} = 1-2\alpha$ for the PR4 channel and $\delta_{\min}/d_{\min} = 1-4\alpha$ for the EPR4 channel, as shown in Fig. 1. The results are in agreement with the ones reported earlier by Sayiner.[8,9] It was found[8] that at a given user density of 2.2, the EPR4 is about 1.2 dB better than the PR4 at 0 % off-track, but only about 0.2 dB at 5 % off-track. In Fig. 1 we see that at 5 % off-track the loss in performance of the PR4 is about 1 dB smaller than the loss of the EPR4.

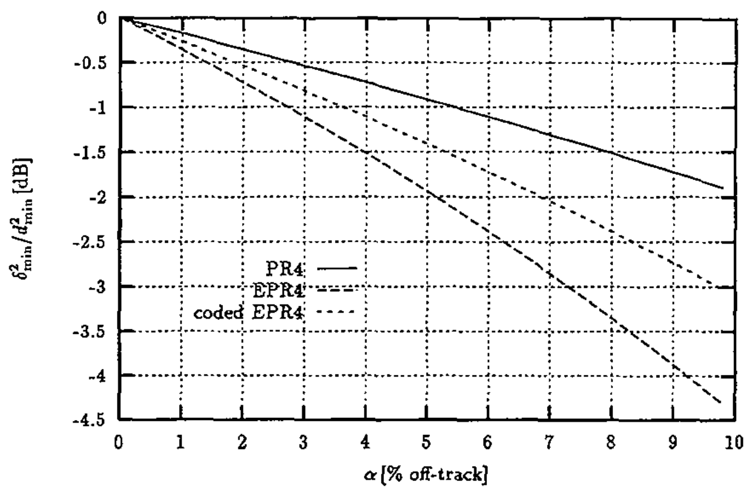

Figure 1: Off-track performance of PR4 and EPR4 channels.

From the EPR4 channel distance properties analysis, we concluded that the channel off-track performance can be improved by a code that limits the runs of successive ones to three. For this purpose we can use the binary complement of the industry standard 8/9 (0, 3) block code.

As mentioned above, we also analyzed the distance properties of the EEPR4 channel and showed that its off-track performance for small α is the same as the off-track performance of the EPR4 channel. We also found that the 2/3 (1, 7) code gives a performance improvement for the EEPR4 channel with no ITI, and ensures that the lower bound on the performance of the channel with ITI is not achieved.

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APPENDIX C

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Theoretical understanding and practical solutions that enable efficient, reliable, and secure operation of communications networks. Power systems. Quantum computation.

EDUCATION

Ph.D. Electrical Engineering, Texas A&M University, *1994*.

Dissertation: *Coding for Improving Noise Immunity in Multi-Track, Multi-Head Recording Systems*

Research areas: constrained coding, symbolic dynamics, multi-input, multi-output communications, and data storage.

M.S. Electrical Engineering, Texas A&M University, *1989*.

Thesis: *New Approach to the Design of Digital Algorithms for Electric Power Measurements*

Research areas: power systems and digital signal processing.

B.S. European Diploma Degree (M.S. equivalent), Electrical Engineering, University of Sarajevo, Bosnia and Herzegovina (former Yugoslavia), *1986*.

Thesis: *Long-Term Hydro-Plants Scheduling for Electric Power Networks*

Research areas: power systems, stochastic and combinatorial optimization, and graph theory.

EMPLOYMENT HISTORY

Professor, Rutgers University, *Jan. 2016 –*

Member of Technical Staff, Mathematics of Networks and Systems Research Department, Bell Labs, **Postdoctoral** *Sept. 1994 – Dec. 2015 Jan. 1996*, **Regular** *Feb. 1996 – Mar. 2004*, **Distinguished** *Apr. 2004 –*.
Working on a wide range of mathematical problems arising in communications and storage networks; in particular coding, information theoretic, and (more recently) queueing problems concerning efficient, reliable, and secure networking for big data.

Research Engineer, Energoinvest, IRIS Institute, Department for Mathematical Modelling, Sarajevo, Bosnia, *June 1986 – May 1988*.
Developing optimization algorithms and software for power system planning and operation.

TEACHING, MENTORING, AND UNIVERSITY RESEARCH VISITS

Visiting Scientist The Simons Institute for the Theory of Computing, UC Berkeley, *Spring 2015.*

Lecturer for the *2011 Information Theory Summer School.*

Guest Professor at ENSEA/Univ. Cergy-Pontoise/CNRS, ETIS group, France, *Sept. 2010.*

Guest Lecturer at the University College Dublin, Claude Shannon Institute, *Jan. 2009,* teaching an intensive course on *Network Coding.*

Visiting Professor at Ecole Polytechnique Fédérale de Lausanne (EPFL), *Jan.-Dec. 2008*

Adjunct Professor at Columbia University, *Spring 2004-Fall 2005,* teaching *Communication Theory I & II.*

Adjunct Professor at Brooklyn Polytechnic University, *Fall 2004,* teaching *Inform. Theory*

Lecturer at Texas A&M University, *academic year 1993/1994,* teaching *Elec. Circuit Theory.*

Lecturer at University of Sarajevo, Bosnia, *academic years 1986/1987 and 1987/1988,* teaching *Signal Processing I & II.*

Mentor for an NSF postdoctoral researcher at Bell Labs, *July 2010 - July 2012*

Mentor for two Bell Labs postdoctoral researchers, *May 1998 - May 2000* and *Jan. 2000 - Jan. 2001,* organizing and supervising their research projects.

Mentor for summer interns at Bell Labs and DIMACS, organizing and supervising research projects for up to three interns almost every summer since 1997.

Ph.D Thesis Committee Member, students at Rutgers (4), Columbia (1), EPFL (3), Aalborg (1), MIT (2), Toronto (1). – *various degrees of supervision/involvement*

Host Scientist for Bell Labs Global Science Scholars program for final-year high-school (2003–2005). Project design, lecturing, and a week-long supervision for visiting students.

PROFESSIONAL ACTIVITIES AND SERVICE

IEEE Information Theory Society Fellows Committee Member, 2016 – .

IEEE Koji Kobayashi Award Committee Member, 2014 –

IEEE Richard W. Hamming Medal Committee Member, 2013 –2016.

External Advisory Committee and **Industrial Board Member** for the NSF Science & Technology Center for Science of Information (NSF-STC-CSoI), 2013 –.

Best Paper Award Committee Member (3 times) for *IEEE Inform. Theory Society*

Board of Governors Member for the *IEEE Inform. Theory Soc.*, 2009 – 2011 and 2013 –.

DIMACS Council Member, 2003 –.

DIMACS Postdoctoral Committee Member, 2001 – 2011.

Co-Chair for DIMACS Special Focus on Cybersecurity, 2011 – 2015.

Co-Chair for DIMACS Special Focus on Comput. Inform. Th. and Coding, 2000 – 2005.

Guest Editor for the *Elsevier-PhyCom, Special Issue on Network Coding and its Applications to Wireless Communications,* March 2013.

Editorial Board Member *Springer Journal on Applicable Algebra in Engineering, Communication and Computing,* 2008 –.

Associate Editor for Coding Techniques, *IEEE Trans. on Inform. Theory,* 1997 – 2000.

Technical Program Co-Chair for the *2008 IEEE Inform. Theory Workshop* and *2012 International Symposium on Network Coding*

Workshop Co-Organizer
(upcoming, organization and funding granted based on a proposal):
Codes for Data Storage with Queues for Data Access, July, 2017 within the ICERM Women in Data Science and Mathematics Research Collaboration Workshop.
(past selected, organization and funding granted based on a proposal):
Dagstuhl Seminar on *Coding Theory in the Time of Big Data,* Schloss Dagstuhl, Aug. 2016, DIMACS Workshop on *Network Coding: the Next 15 Years,* Dec. 2015, BIRS Workshop on *Mathematical Coding Theory in Multimedia Streaming,* Banff, Oct. 2015. DIMACS Workshop on *Coding Theoretic Methods for Network Security,* April 2015, INFOCOM Workshop on *Communications and Networking Techniques for Contemporary Video,* April 2014, DIMACS Workshop and Working Group on Algorithms for Green Data Strage, Dec. 2013, Dagstuhl Seminar on Coding Theory, Schloss Dagstuhl, Aug. 2013, BIRS Workshop on *Applications of Matroid Theory and Combinatorial Optimization to Information and Coding Theory,* Banff, Aug. 2009, DIMACS Working Group and Workshop on *Coding, Streaming and Compressive Sensing* (March 2009), DIMACS Working Group on *Network Coding* Jan. 2005 and DIMACS Working Group and Workshop on *Theoretical Advances In Information Recording* (March 2004).

Special-Session Organizer *(selected, invited to organize):* Tutorials at *2015 IEEE Internat. Symp. on Inform. Theory (ISIT'15),* "Information Theory & Coding for Contemporary Video," *2013 IEEE Inform. Theory Workshop (ITW'13)* in Seville, "Network Coding" at *2006 IEEE Comm. Theory Workshop* (CTW'06) in Puerto Rico, "Network Coding" at *2006 IEEE Inform. Theory Workshop (ITW'06)* in Chengdu, "Emerging Applications of Information Theory" at *2004 IEEE Inform. Theory Workshop (ITW'04)* in San Antonio.

Technical Program Committee Member for *(selected) IEEE Internat. Symp. on Inform. Theory (ISIT),* 2000 – 2002, 2004, and 2008 – , *IEEE Inform. Theory Workshop (ITW),* 2004 – 2009, *IEEE 2005 Int. Conf. Wireless Networks, Commun., and Mobile Comput., Int. Workshop on Wireless Networks: Communication, Cooperation and Competition,* 2007, *Commun. Theory Symp. at IEEE Global Telecommun. Conf. (GLOBECOM) 2007–2008, Internat. Conf. on Comm. (ICC)* 2009.

Technical proof-reader for the *IEEE Transac. Inform. Theory,* 1990 – 1992.

Research Proposal Reviewer for NSF, BSF (United States-Israel Binational Science Foundation), Danish Research Council for Technology and Production Sciences, Research Grants Council of Hong Kong, SFI (Science Foundation of Ireland), UC MICRO Program (University of California Microelectronics Innovation and Computer Research Opportunities).

Affiliations with IEEE Inform. Theory Society, American Mathematical Society (AMS), NSF Center for Discrete Mathematics and Computer Science (DIMACS).

SELECTED BELL LABS SERVICE

Graduate Research Program for Women (GRPW) and **Cooperative Research Fellowship Program (CRFP) for Minorities and Women** committee member, 2002 – 2009.

Global Science Scholars committee member and host to student visitors, 2003–2005.

Afirmative Action Committee Member, 1996 – 1999.

Library Liaison, provided periodic recommendations for book ordering, collected and provided feedback on journal usage, 1996 – .

Seminars Sponsor, recruited and hosted speakers for several internal seminars and reading groups, 1996 – .

Committee Service, served on numerous hiring and various ad-hoc committees, 1995 – .

RECOGNITIONS

- *Distinguished Lecturer* for IEEE Information Theory Society, 2015 – 2016.
- *IEEE Fellow*, for contributions to coding theory and coding schemes for transmission and storage systems, *class of 2014*.
- *IEEE IT Society 2013 Padovani Lecturer,* a person whose research is considered to be of particular interest to students and postdocs is selected to give a special lecture at the yearly North American School of Information Theory. Lecture Ttile: "Secret Lives of Codes: From Theory to Practice and Back"
- *Best Paper Award* for the paper "Trade-off between cost and goodput in wireless: replacing transmitters with coding," (with M. Kim, M. Medard, MIT, J. Barros, Univ. of Porto, and T. Klien, Bell Labs) at *MONAMI'13.*
- *Honorable mention of the paper* "Asymptotic spectra of trapping sets in irregular LDPC code ensembles," (with O. Milenkovic, and P. Whiting, Bell Labs) at the *ICC 2006;* citation: "It provided an important contribution towards the statistical characterization and understanding of trapping sets, which are crucial to the assessment of error-floor effects in LDPC codes."
- *Distinguished Member of Technical Staff*, Bell Labs, March 2004.
- *IEEE Senior Member*, July 2003.
- Recognized as an *exceptional Bell Labs intern mentor* for the Summer 2003.
- IEEE *Referee Recognition* Award, 1998.
- Recognized in the 25th anniversary issue of *EE Times* as one of the 20 young engineers who are likely to make "significant contributions in the new millennium", Oct. 1997.
- Recognized for *teamwork at Bell Labs*, Dec. 1994.
- *Fouraker Fellowship* by EE Department, Texas A&M University, Sep. 1992 – Aug. 1993.
- *Electrical Powe Institute Fellowship* for the masters at EE Department, Texas A&M University, Jun. 1988 – Dec. 1989.

FUNDING

DIMACS Funds – awarded by the NSF and other funding agencies for *DIMACS Special Focus on Cybersecurity,* for workshops, seminar series, visitors, and postdocs from 2011 through 2015. *(Focus Co-Chair)*

NSF NeTS Medium Grant for *Collaborative Research: Secure Networking Using Network Coding* at the level of $882,357 (with Caltech, Purdue, and UT Austin), Sept. 2009 – Aug. 2013. *(Co-PI)*

DARPA IAMANET Contract for *PIANO: Principles for Intrinsically Assurable Network Operation,* with a multidisciplinary team from several universities (Caltech, MIT, Stanford, UMass, UT Austin), led by BAE, 2008. *(personal share $241,000 over 18 months)*

NSF NeTS-NBD Small Grant for *Coding and Transmission Schemes for Content Download* at the level of $569,000 (with UIUC and Rutgers), Sept. 2007 – Aug. 2010. *(Co-PI)*

NSF ITR Medium Grant for *Network Coding From Theory to Practice* at the level of $1.85 million (with Caltech, MIT, and UIUC), Sept. 2003 – Aug. 2008. *(Co-PI)*

DIMACS Funds – $205,000 budget awarded by the NSF and other funding agencies for *DIMACS Special Focus on Computational Information Theory and Coding* for workshops, seminar series, visitors, and postdocs from 2001 through 2004. *(Focus Co-Chair)*

NAE Research Grant – American recipient of the 1999 $10,000 Research Grant by the German-American Networking Program of the *National Academy of Engineering* and its German counterpart. (Elke Offer, TU Munich, was the German recipient.)

JOURNAL PUBLICATIONS

1. L. Tan, Y. Li, A. Khisti, E. Soljanin, "Successive segmentation-based coding for broadcasting over erasure channels," *IEEE Trans. Inform. Theory,* pp. 3026–3038, Jun. 2016.

2. C. Fragouli and E. Soljanin, "(Secure) Linear network coding multicast - A theoretical minimum and some open problems," *Journal on Des. Codes and Cryptography, The 25th Anniversary Issue,* pp. 269–310, Jan. 2016.

3. G. Joshi, E. Soljanin, and G. Wornell, "On the delay-storage trade-off in content download from coded distributed storage systems," *ACM Transactions on Modeling and Performance Evaluation of Computing Systems,* submitted Oct. 2015, revised Nov. 2016.

4. K. Guan, A. Tulino, P. Winzer, and E. Soljanin, "Secrecy capacities in space-division multiplexed fiber-optic communication systems," *IEEE Trans. Inform. Forensics & Security,* pp. 1325–1335, July 2015.

5. M. Kim, T. Klein, E. Soljanin, J. Barros, M. Médard, "Modeling network coded TCP: analysis of throughput and energy cost," *ACM Springer Mobile Networks and Applications (MONET) Journal,* pp. 790–803, Dec. 2014.

6. G. Joshi, Y. Liu, and E. Soljanin, "On the delay-storage trade-off in content download from coded distributed storage systems," *IEEE J-SAC Special Issue on Communication Methodologies for the Next-Generation Storage Systems,* pp. 989–997, May 2014.

7. E. Song, E. Soljanin, P. Cuff, and V. H. Poor, "Rate-distortion-based physical layer secrecy with applications to multimode fiber," *IEEE Trans. Commun.,* pp. 1080–1090, March 2014.

8. S. Kokalj, E. Soljanin, and P. Spasojevic, "Low complexity differentiating adaptive erasure codes in multimedia wireless broadcast," *IEEE Trans. Commun.*, pp. 3462-3471, Aug. 2013.

9. Y. Li, E. Soljanin, and P. Spasojević, "Three schemes for wireless coded broadcast to heterogeneous users," *Elsevier-PhyCom, Special Issue on Network Coding and its Applications to Wireless Communications*, pp. 114–123, March 2013.

10. Z. Kong, E. Yeh, and E. Soljanin, "Coding improves the throughput-delay trade-off in mobile wireless networks," *IEEE Trans. Inform. Theory*, pp. 6894–6906, Nov. 2012.

11. I. Andriyanova and E. Soljanin, "Optimized IR-HARQ schemes based on punctured LDPC codes over the BEC," *IEEE Trans. Inform. Theory*, pp. 6433-6445, Oct. 2012.

12. S. Kokalj and E. Soljanin, "Suppressing the cliff effect in video reproduction quality," *Bell Labs Technical Journal, Video Issue,* March 2012.

13. S. El Rouayheb, E. Soljanin, and A. Sprintson, "Secure network coding for wiretap networks of type II," *IEEE Trans. Inform. Theory*, pp. 1361–1371, March 2012.

14. Y. Li, E. Soljanin, and P. Spasojević, "Effects of generation size and overlap on throughput and complexity in randomized linear network coding," *IEEE Trans. Inform. Theory*, pp. 1111–1123, Feb. 2011.

15. Z. Kong, S. Aly, and E. Soljanin, "Decentralized coding algorithms for distributed storage in wireless sensor networks," invited for *IEEE J-SAC Special Issue on Data Communication Techniques for Storage Channels and Networks*, pp. 261–267, Feb. 2010.

16. S. Kokalj, P. Spasojevic, and E. Soljanin, "Doped Fountain coding for minimum delay data collection in circular networks," *IEEE J-SAC Special Issue on Network Coding for Wireless Communication Networks*, pp. 673–684, June 2009.

17. E. Soljanin, P. Gupta, G. Kramer, "Network coding for efficient network multicast," *Bell Labs Technical Journal, Enabling Science and Technology Issue*, pp. 157-166, March 2009.

18. Z. Kong, S. Aly, E. Soljanin, E. Yeh, and A. Klappenecker, "Network coding capacity of random wireless networks under a signal-to-noise-and-interference ratio model," *IEEE Trans. Inform. Theory*, submitted 2008.

19. E. Soljanin, "Network Multicast with Network Coding," *IEEE Signal Processing Magazine*, pp. 109–112, Sept. 2008.

20. R. Liu, P. Spasojevic, and E. Soljanin, "Incremental redundancy cooperative coding for wireless networks: cooperative diversity, coding, and transmission energy gain," *IEEE Trans. Inform. Theory*, pp. 1207–1224, March 2008.

21. O. Milenkovic, E. Soljanin, and P. Whiting, "Asymptotic spectra of trapping sets in regular and irregular LDPC code ensembles," *IEEE Trans. Inform. Theory*, pp. 39–55, Jan. 2007.

22. C. Chekuri, C. Fragouli, and E. Soljanin, "On average throughput benefits and alphabet size in network coding," *IEEE Trans. Inform. Theory*, pp. 2410–2424, June 2006.

23. R. Liu, P. Spasojevic, and E. Soljanin, "Reliable channel regions for good binary codes transmitted over parallel channels," *IEEE Trans. Inform. Theory*, pp. 1405–1424, April 2006.

24. C. Fragouli and E. Soljanin, "Information flow decomposition for network coding," *IEEE Trans. Inform. Theory*, pp. 829–848, March 2006.

25. R. Liu, P. Spasojevic, and E. Soljanin, "On the weight spectrum of good linear binary codes," *IEEE Trans. Inform. Theory*, pp. 4369–4373, Dec. 2005.

26. E. Soljanin, N. Varnica, and P. Whiting, "Incremental redundancy hybrid ARQ with LDPC and Raptor codes," submitted to *IEEE Trans. Inform. Theory,* Sept. 2005.

27. E. Soljanin and E. Offer, "Bit-optimal decoding of codes whose Tanner graphs are trees," J. Discrete Applied Mathematics, Elsevier Science, vol. 128/1, pp. 293–303, 2003.

28. E. Soljanin, "Compressing quantum mixed-state sources by sending classical information," *IEEE Trans. Inform. Theory,* pp. 2263–2275, Aug. 2002.

29. E. Soljanin, "Writing sequences on the plane," *IEEE Trans. Inform. Theory,* pp. 2263–2275, June 2002.

30. A. Mojsilović, J. Hu, and E. Soljanin, "Extraction of perceptually important colors and similarity measurement for image matching, Retrieval, and Analysis," *IEEE Trans. Image. Proc.*, pp. 1238–1248, Nov. 2002.

31. A. Mojsilovic and E. Soljanin, "Color quantization and processing by Fibonacci lattices," *IEEE Trans. Image Proc.*, pp. 1712–1725, Nov. 2001.

32. E. Soljanin and A. J. Van Wijngaarden, "Application of distance enhancing codes," *IEEE Trans. Magn.,* pp. 762–767, Mar. 2001.

33. R. Karabed, P. H. Siegel and E. Soljanin, "Constrained coding for binary channels with high intersymbol interference," *IEEE Trans. Inform. Theory,* pp. 1777–1797, Sept. 1999.

34. B. E. Moision, P. H. Siegel, and E. Soljanin, "Distance-enhancing codes for digital recording," *IEEE Trans. Magn.,* pp. 69-74, Jan. 1998.

35. E. Soljanin and C. N. Georghiades, "Multihead detection for multitrack recording channels," *IEEE Trans. Inform. Theory,* pp. 2988–2997, Nov 1998.

36. E. Soljanin "A coding scheme for generating bipolar dc-free sequences," *IEEE Trans. Magn.*, pp. 2755–2757, Sept. 1997.

37. E. Soljanin and C. N. Georghiades, "Coding for two-head recording systems," *IEEE Trans. Inform. Theory,* pp. 747–755, May 1995.

38. M. Kezunovic, E. Soljanin, B. Perunicic, and S. Levi, "New approach to the design of digital algorithms for electric power measurements," *IEEE Trans. Power Delivery,* Vol. 6, pp. 516–523, Apr. 1991.

39. B. Perunicic, M. Kezunovic, and E. Soljanin, and S. Levi, "Digital signal processing algorithms for power and line parameter measurements with low sensitivity to frequency change," *IEEE Trans. Power Delivery,* Vol. 5, pp. 1209–1215, Apr. 1990.

REFEREED CONFERENCE PUBLICATIONS

1. M. Noori, E. Soljanin, M. Ardakani, "On storage allocation for maximum service rate in distributed storage systems," *2016 IEEE Int. Symp. Inform. Theory (ISIT'16),* Barcelona, July 2016.

2. K. Guan, P. Winzer, A. Tulino, and E. Soljanin, "Physical layer security of space-division multiplexed fiber-optic communication system in the presence of multiple eavesdroppers," *2015 IEEE Global Telecommunications Conf. (GLOBECOM'15),* San Diego, Dec. 2015.

3. G. Joshi, E. Soljanin, and G. Wornell, "Using efficient redundancy to reduce latency in cloud systems," *52nd Annual Allerton Conference,* Monticello, IL, Oct. 2015.

4. S. Kadhe, E. Soljanin, and A. Sprintson, "When do the availability codes make the stored data more available?" invited for *53nd Annual Allerton Conference,* Monticello, IL, Oct. 2015.

5. Y. Li, K. Guo, X. Wang, E. Soljanin, and T. Woo, "SEARS: Space efficient and reliable storage system in the cloud," *40th IEEE Conference on Local Computer Networks (LCN)*, Clearwater Beach, FL, USA, Oct. 2015.
6. U. J. Ferner, M. Médard, E. Soljanin, "Why reading patterns matter in storage coding and scheduling design," *8'th IEEE International Conference on Cloud Computing (IEEE CLOUD 2015)*, New York, July, 2015.
7. G. Joshi, E. Soljanin, and G. Wornell, "Queues with Redundancy: Latency-Cost Analysis," *Mathematical Performance Modeling and Analysis (MAMA) Workshop in conjunction with ACM SIGMETRICS,* Prtland, OR, June 2015.
8. S. Kadhe, E. Soljanin, and A. Sprintson, "Analyzing the download time of availability codes," *2015 IEEE Int. Symp. Inform. Theory (ISIT'15),* Hong Kong, June 2015.
9. L. Tan, M. Kaveh, A. Khisti, and E. Soljanin, "Coding for source-broadcasting over erasure channels with feedback," *2015 IEEE Int. Symp. Inform. Theory (ISIT'15),* Hong Kong, June 2015.
10. M. Heindelmaier and E. Soljanin, "Isn't hybrid ARQ enough?" invited for *52nd Annual Allerton Conference,* Monticello, IL, Oct. 2014.
11. A. Singh Rawat and E. Soljanin, "Dynamic control of video quality for AVS," *2014 IEEE Int. Symp. Inform. Theory (ISIT'14),* Honolulu, July 2014.
12. Y. Li, L. Tan, A. Khisti, and E. Soljanin, "Successive segmentation-based coding for broadcasting over erasure channels," *2014 IEEE Int. Symp. Inform. Theory (ISIT'14),* Honolulu, July 2014.
13. I. Andriyanova, A. Julé, and E. Soljanin, "The code rebalancing problem for a storage-flexible data center network," *2013 IEEE International Conference on Big Data (IEEE BigData 2013)*, Santa Clara, CA, Oct. 2013.
14. K. Guan, P. Winzer, E. Soljanin, and A. Tulino, "On the secrecy capacity of the space-division multiplexed fiber optical communication systems," *2013 First IEEE Conference on Communications and Network Security (CNS'13),* Washington, DC, Oct. 2013.
15. M. Kim, T. Klien, E. Soljann, M. Médard, and J. Barros,"Trade-off between cost and goodput in wireless: replacing transmitters with coding," *5th Int. Conf. on Mobile Networks and Management (MONAMI'13)*, Cork, Ireland, Sept. 2013. *(best paper award)*
16. E. Soljanin, "Some coding and information theoretic problems in contemporary (video) content delivery," *2013 IEEE Inform. Theory Workshop (ITW'13),* Seville, Spain, Sept. 2013. *(invited)*
17. L. Tan, Y. Li, A. Khisti, and E. Soljanin, "Source broadcasting over erasure channels: distortion bounds and code design," *2013 IEEE Inform. Theory Workshop (ITW'13),* Seville, Spain, Sept. 2013.
18. G. Joshi and E. Soljanin, "Round-robin overlapping generations coding for fast content download," *2013 IEEE Int. Symp. Inform. Theory (ISIT'13),* Istanbul, Turkey, July 2013.
19. L. Tan, A. Khisti, E. Soljanin, "Distortion bounds for broadcasting a binary source over binary erasure channels," *13'th Canadian Workshop on Information Theory (CWIT'13),* Toronto, Canada, June 2013.
20. K. Guan, E. Song, E. Soljanin, and P. Winzer, "Physical layer security in space-division multiplexed fiber optic communications," *46th Asilomar Conference on Signals, Systems, and Computers,* Monterey, California, Amsterdam, The Netherlands Nov. 2012.
21. K. Guan, P. Winzer, and E. Soljanin, "Information-Theoretic Security in Space-Division Multiplexed Fiber Optic Networks," *2012 European Conference and Exhibition on Optical Communication (ECEOC'2012),* Amsterdam, The Netherlands, June 2012.

22. G. Joshi, Y. Liu, and E. Soljanin, "Coding for fast content download," invited for *50th Annual Allerton Conference,* Monticello, IL, Oct. 2012.

23. U. J. Ferner, M. Médard, E. Soljanin, "Toward sustainable networking: storage area networks with network coding," *50th Annual Allerton Conference,* Monticello, IL, Oct. 2012.

24. L. Tan, A. Khisti, E. Soljanin, "Quadratic gaussian source broadcast with individual bandwidth mismatches," *2012 IEEE Int. Symp. Inform. Theory (ISIT'12),* Cambridge, MA, June 2012.

25. Y. Li, P. Vingelmann, M. V. Pedersen, and Emina Soljanin, "Round robin streaming with generations," *2012 Int. Symp. on Network Coding, (NetCod'12),* Cambridge, MA, June 2012.

26. S. Kokalj, E. Soljanin, and P. Spasojevic,"Is rateless paradigm fitted for lossless compression of erasure–impaired sources?" invited for *49th Annual Allerton Conference,* Monticello, IL, Sept. 2011.

27. A. Bhowmick, A. Rawat, E. Soljanin, and S. Vishwanath, "Update efficient codes for distributed storage," *2011 IEEE Int. Symp. Inform. Theory (ISIT'11),* St. Petersburg, July 2011.

28. S. Kokalj-Filipovic, E. Soljanin, and Y. Gao, "Cliff effect suppression through multiple-descriptions with split personality," *2011 IEEE Int. Symp. Inform. Theory (ISIT'11),* St. Petersburg, July 2011.

29. N. P. Anthapadmanabhan, E. Soljanin, and S. Vishwanath, "Update-Efficient Codes for Erasure Correction," invited for *48th Annual Allerton Conference,* Monticello, IL, Sept. 2010.

30. E. Soljanin, "Reducing Delay in Mobile Muti-Agent Information Relaying," invited for *48th Annual Allerton Conference,* Monticello, IL, Sept. 2010.

31. Y. Li, E. Soljanin, and P. Spasojević, "Collecting coded coupons over generations," *2010 IEEE Int. Symp. Inform. Theory (ISIT'10),* Austin, USA, June 2010.

32. M. Sardari, R. Restrepo, F. Fekri, and E. Soljanin, "Memory allocation in distributed storage networks," *2010 IEEE Int. Symp. Inform. Theory(ISIT'10),* Austin, USA, June 2010.

33. Y. Li, E. Soljanin, and P. Spasojević, "Collecting coded coupons over overlapping generations," *2010 Int. Symp. on Network Coding, (NetCod'10),* Toronto, Canada, June 2010.

34. I. Andriyanova and E. Soljanin, "IR-HARQ schemes with finite-length punctured LDPC codes over the BEC," *Proc. 2009 IEEE Int. Inform. Theory Workshop (ITW'09),* Taormina, Italy, Oct. 2009.

35. Y. Li and E. Soljanin, "Rateless codes for single-server streaming to diverse users," in *Proc. 48th Annual Allerton Conference,* Monticello, IL, Sept. 2009.

36. Z. Kong, E. Yeh, and E. Soljanin, "Coding improves the throughput-delay trade-off in mobile wireless networks," *2009 IEEE Int. Symp. Inform. Theory (ISIT'09)*, Seul, Korea, July 2009.

37. S. Kokalj, P. Spasojevic, E. Soljanin, and R. Yates, "ARQ with doped Fountain decoding," *Proc. 2008 IEEE Int. Symp. on Spread Spectrum Techniques and Applications (ISSSTA'08),* Bologna, Italy, Aug. 2008.

38. S. Aly, Z. Kong, and E. Soljanin, "Raptor codes based distributed storage algorithms for large-scale wireless sensor networks," *2008 IEEE Int. Symp. Inform. Theory (ISIT'08)*, Toronto, Canada, July 2008.

39. A. Mills, B. Smith, T. C. Clancy, E. Soljanin, and S. Vishwanath "On secure communications over wireless erasure networks," *2008 IEEE Int. Symp. Inform. Theory (ISIT'08)*, Toronto, Canada, July 2008.

40. S. Aly, Z. Kong, and E. Soljanin, "Fountain codes based distributed storage algorithms for large-scale wireless sensor networks," in *Proc. Int. Conf. Inform. Processing in Sensor Networks (IPSN'08),* St. Louis, MO, USA, April 2008.

41. S. Kokalj, P. Spasojevic, R. Yates, and E. Soljanin, "Decentralized Fountain codes for minimum-delay data collection," *Proc. 42nd Annual Conference on Information Sciences and Systems (CISS'08)*, Princeton, NJ, March 2008.

42. Z. Kong, S. Aly, E. Soljanin, A. Klappenecker, and E. Yeh, "Network coding capacity of random wireless networks under a signal-to-interference-and-noise model," in *Proc. 45th Annual Allerton Conference,* Monticello, IL, Sept. 2007.

43. C Lott, O Milenkovic, and E. Soljanin, "Hybrid ARQ: theory, state of the art and future directions," in *Proc. 2007 IEEE Int. Workshop Inform. Theory (ITW'07),* Bergen, Norway, July 2007 (*Invited*)

44. S. El Rouayheb and E. Soljanin, "On wiretap networks II," *2007 IEEE Int. Symp. Inform. Theory (ISIT'07)*, Nice, France, June 2007.

45. S. El Rouayheb, C. N. Georghiades, E. Soljanin, A. Sprintson, "Bounds on codes based on graph theory," *2007 IEEE Int. Symp. Inform. Theory (ISIT'07)*, Nice, France, June 2007.

46. E. Soljanin, N. Varnica, and P. Whiting, "Raptor codes for hybrid ARQ," in *Proc. 44th Annual Allerton Conference,* Monticello, IL, Oct. 2006.

47. O. Milenkovic and E. Soljanin, "Enumeration of RNA secondary structures: a constrained coding approach," *40th Asilomar Conference on Signals, Systems, and Computers,* Monterey, California, Oct. 2006.

48. C. Chekuri, C. Fragouli, and E. Soljanin, "Achievable information rates in single-source non-uniform demand networks," in *Proc. 2006 IEEE Int. Symp. Inform. Theory (ISIT'06)*, Seattle, WA, USA., July 2006.

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SELECTED INVITED TUTORIAL/EXPOSITORY TALKS

1. "Network coding: a combinatorial framework and an open problem," *BIRS Workshop on Mathematics of Communications: Sequences, Codes and Designs*, Banff, January 2015.

2. "Basics of Network Coding," *BIRS Workshop on Applications of Matroid Theory and Combinatorial Optimization to Information and Coding Theory,* Banff, August 2009.

3. "Network Coding: Theory and Practice," *2007 IEEE Int. Symp. Inform. Theory (ISIT'07)*, Nice, France, June 2007.

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SELECTED PLENARY AND INVITED RESEARCH TALKS

1. *Queues for Data Access from Coded Distributed Storage,* 18th INFORMS Applied Probability Society Conference, Istanbul, July. 2015.

2. *Cloud Storage Space vs. Download Time for Large Files,* NYIT REU Program, New York, June 2015.

3. *Storage Codes and Data Retrieval,* Workshop on Coding: From Practice to Theory, The Simons Institute for the Theory of Computing, UC Berkeley, Feb. 2015.

4. *Codes for Storage with Queues for Access,* Workshop on Inform. Theory and Applic. (ITA), UCSD, Feb. 2015.
5. *Codes For All Seasons,* plenary talk at 2014 IEEE Workshop on Inform. Theory, Nov. 2014.
6. *Urns & Balls and Communications,* Dept. of Statistics, Univ. of Auckland, Nov. 2014.
7. *How Does Applied Math Become Applicable?* MIT Graduate Women (GW6) student group coffee hour seminar, May 2014.
8. *A coding Tale of a Tail at Scale,* Stanford, Apr. 2014.
9. *How Should We Code in Multicast to Diverse Users and What For?* Stanford, Apr. 2014, and University of Hawaii, Nov. 2014.
10. *Secret Lives of Codes: From Theory to Practice and Back* 2013 Padovani Lecture at the 2013 North American School of Information Theory, Purdue University, June 2013.
11. *Is Coding Beyond the Physical Layer Helpful in Content Centric Networking?,* Workshop on Inform. Theory and Applic. (ITA), UCSD Feb. 2013.
12. *Rateless Codes for Efficient Content Download in Highly Heterogeneous Scenarios,* Aalborg University, Sept. 2012.
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14. *Urns & Balls and Communications,* MIT Math Seminar, Apr. 2012.
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16. *How Does Applied Math Become Applicable?* plenary talk at Workshop on Inform. Theory and Applic. (ITA), UCSD Jan. 2012.
17. *Three Types of Redundancy Against Three Sources of Delay,* UIUC CSL Seminar, Apr. 2011.
18. *Double Dixie Cup Unicast,* UIUC CS Theory Seminar, Apr. 2011, Dagstuhl Seminar on Coding Theory, Nov. 2011.
19. *Content Preparation, Delivery, and Storage for Highly Heterogenous Networks,* EPFL, Oct. 2011, MIT EECS, Sept. 2011.
20. *Urns & Balls and Communications,* 2013 North American School of Information Theory, UT Austin, May 2011.
21. *On Storing and Retrieving (Coded) Data in Mobile P2P Networks,* Isaac Newton Institute for Mathematical Sciences, special programme on *Stochastic Processes in Communication Sciences,* Cambridge, UK, April 2010.
22. *Coded Streaming in Heterogenous Networks,* BL/HHI Joint Workshop, June 2011, ENST Sept. 2011.
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24. *Quantum Network Multicast and Coding,* International Seminar on Quantum Networking (Towards Quantum Internet, Madrid, June 2009.
25. *Two (Non)standardized Applications of Fountain Codes,* ETH Zürich, December 2008.
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31. *Hybrid ARQ: Theory, State of the Art, and Future Directions,* EPFL, April 2008, ENST June 2008, and University of Arizona, EE, Nov. 2007.

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UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

LSI CORPORATION and AVAGO TECHNOLOGIES U.S., INC.
Petitioner,

v.

REGENTS OF THE UNIVERSITY OF MINNESOTA
Patent Owner.

Case No. IPR2017-01068
Patent No. 5,859,601

DECLARATION OF PROFESSOR EMINA SOLJANIN, PH.D.
REGARDING U.S. PATENT NO. 5,859,601

I, Emina Soljanin, Ph.D., do hereby declare and state, that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true. I am over the age of 21 and am competent to make this declaration. These statements were made with the knowledge that willful false statements are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Dated: 3/9, 2017

Emina Soljanin, Ph.D.

TABLE OF CONTENTS

I. INTRODUCTION AND QUALIFICATIONS

A. Introduction

1. I, Dr. Emina Soljanin, submit this declaration in support of LSI Corporation and Avago Technologies U.S. Inc.'s ("Petitioners"), Petition for *Inter Partes Review* ("IPR") of claims 1, 2, 8-10, 12-17, and 21 ("the Challenged Claims") of U.S. Patent 5,859,601 ("the '601 patent"). I understand that the '601 patent is currently owned by the Regents of the University of Minnesota ("Patent Owner").

2. I have been asked to provide my opinion about the state of the art of the technology described in the '601 patent and on the patentability of certain claims of this patent.

3. The statements herein include my opinions and the bases for those opinions, which relate to the following documents:

1001	U.S. Patent No. 5,859,601 ("the '601 patent")
1002	Patent Owner's Complaint (without exhibits)
1003	First Amended Complaint (without exhibits)
1004	Affidavit of Service on LSI Corporation
1005	Affidavit of Service on Avago Tech. U.S.

1006	File History of U.S. Patent No. 5,859,601
1007	U.S. Patent No. 5,392,270 ("Okada")
1008	U.S. Patent No. 5,341,386 ("Shimoda")
1009	U.S. Patent No. 5,731,768 ("Tsang")
1011	Okada Tables showing data in NRZI format
1012	Maximum Transition Run Codes for Data Storage Systems, Moon and Brickner, Sept. 5, 1996

4. Although I am being compensated for my time at a rate of $420 per hour in preparing this declaration, the opinions herein are my own. I have no stake in the outcome of this IPR proceeding. My compensation does not depend in any way on the outcome of the Petitioner's petition or this IPR proceeding.

B. Qualifications

5. I am currently a professor of electrical and computer engineering at Rutgers University. My research interests are broad, but mainly concern theoretical understanding and practical solutions that enable efficient, reliable, and secure operation of communications networks. I also have expertise and interest in power systems and quantum computation.

6. My research has been funded by the National Science Foundation, the Center for Discrete Mathematics and Theoretical Computer Science (DIMACS), DARPA, and other funding agencies.

7. All of my degrees are in electrical engineering. I earned a European Diploma degree from the University of Sarajevo, Bosnia, in 1986, and PhD and MS degrees from Texas A & M University in 1989 and 1994, respectively.

8. Between my studies at the University of Sarajevo and my graduate studies, from 1986 to 1989, I worked in industry developing optimization algorithms and software for power system control.

9. Upon earning my PhD, I joined Bell Laboratories in Murray Hill, NJ, where I was a Member of the Technical Staff in the Mathematics of Networks and Communications research department. Over a dozen alumni of Bell Labs have won the Nobel prize in physics, with several more having been awarded the Turing Award, the highest distinction in computer science. In 2004 I was elevated to Distinguished Member of the Technical Staff.

10. During my time at Bell Labs I was also an adjunct professor, guest lecturer, or visiting professor at various academic institutions around the world including, Columbia University, ENSE in Cergy-Pontoise, France, the University College Dublin, and others. I also mentored many students, interns, and postdoctoral researchers during that time.

11. In the course of my twenty year employment with Bell Labs, I participated in a very wide range of research and business projects. These projects include designing the first distance enhancing codes to be implemented in commercial magnetic storage devices.

12. Other projects that I worked on at Bell Labs included the first forward error correction for Lucent's optical transmission devices, color space quantization and color image processing, quantum computation, link error prediction methods for the third generation wireless network standards, and anomaly and intrusion detection. Some of my most recent activities are in the area of network and application layer coding.

13. According to the Patent Owner, the alleged invention of '601 patent is a "maximum transition run" ("MTR") code featuring a "j constraint" which "imposes a limit on the maximum number of consecutive transitions that are written to the disk" of a hard drive disk. (Ex. 1003, at ¶¶ 65-72.) I was conducting research in this area before the '601 patent was filed.

14. The inventors of the '601 patent authored a paper published in 1996 entitled "Maximum Transition Run Codes for Data Storage Systems," which is attached as Appendix A (and is also Exhibit 1012). The Patent Owner asserts that this so-called "Moon 1996 IEEE Paper" is "substantially similar to the '601 Patent." (Ex. 1003, at ¶¶ 51-52.) This is noteworthy because the inventors

confirmed in their paper that I, in my "independent study," had found that "removing long runs of consecutive transitions" can improve the performance of data storage systems. (Appendix A, first page, right column (citing reference [6].) My work was presented at a public conference in October 1995. (Appendix A, Reference [6].) It also resulted in a paper published in 1995 entitled "On-track and off-track distance properties of class 4 partial response channels," which is attached as Appendix B.

15. I also note that the face of the '601 patent cites as prior art one of my own patents, U.S. Patent No. 5,608,397, which is entitled "Method and apparatus for generating DC-free sequences." Besides that patent, I am the inventor of ten other issued U.S. patents. I am also the named inventor on a variety of additional patent applications that are pending at this time.

16. I have authored numerous peer-reviewed journal and conference publications, as well as books and book chapters. Among other professional recognitions, I was elected an IEEE Fellow for my "contributions to coding theory and coding schemes for transmission and storage systems."

17. My curriculum vitae includes additional details about my experience and professional background. It is attached as Appendix C.

II. MATERIALS REVIEWED

18. My opinions are based on years of education, research and experience, as well as investigation and study of relevant materials. In forming my opinions, I have considered the materials identified in this report, including the Exhibits mentioned above.

19. I may rely upon these materials and/or additional materials to respond to arguments raised by the Patent Owner. I may also consider additional documents and information in forming any necessary opinions—including documents that may not yet have been provided to me.

20. My analysis of the materials produced in this investigation is ongoing and I will continue to review any new material as it is provided. This report represents only those opinions I have formed to date. I reserve the right to revise, supplement, and/or amend my opinions stated herein based on new information and on my continuing analysis of the materials already provided.

III. PERSON OF ORDINARY SKILL IN THE ART OF THE '601 PATENT

21. I have been informed that the '601 patent and its claims, as well as the prior art, are interpreted the way a hypothetical person having ordinary skill in the relevant art would have interpreted these materials at the time of the invention. I understand that the "time of the invention" in this IPR proceeding is the earliest "priority date" that the applicant for the '601 patent claimed in the United States

Patent & Trademark Office ("USPTO"). Here, the face of the patent indicates that the application claims priority to a provisional patent application filed April 5, 1996. As mentioned above, I was conducting research in the relevant technological field at that time.

22. In determining the characteristics of a person of ordinary skill in the art at the time of the claimed invention, I considered several things, including the factors discussed below, as well as (1) the levels of education and experience of the inventor and other persons actively working in the relevant field; (2) the types of problems encountered in the field; (3) prior art solutions to these problems; (4) the rapidity in which innovations are made; and (5) the sophistication of the relevant technology. I also placed myself back in the relevant time period and considered the individuals that I had worked with in the field.

23. It is my opinion that a person having ordinary skill in the relevant art at the time of the invention would have been someone with at least an undergraduate degree in electrical engineering or similar field, and three years of industry experience in the field of read channel technology.

24. I understand that a person of ordinary skill in the relevant art is a hypothetical person who is assumed to be aware of all the pertinent information that qualifies as prior art. He or she is a person of ordinary creativity, not an automaton. He or she makes inferences and takes creative steps. In addition, a

person of ordinary skill recognizes that prior art items may have obvious uses beyond their primary purposes, and in many cases he or she will be able to fit the teachings of multiple pieces of prior art together like pieces of a puzzle.

25. I am prepared to testify as an expert in this field and also as someone who had at least the knowledge of a person having ordinary skill in the art at the time of the claimed invention, and someone who worked with others that had at least the knowledge of a person having ordinary skill in the art at the time of the alleged invention.

26. Unless otherwise stated, my statements below refer to the knowledge, beliefs and abilities of a person having ordinary skill with respect to the arts relevant to the '601 patent at the time of the claimed invention.

IV. STANDARDS OF ANTICIPATION AND OBVIOUSNESS

27. I offer no opinions on the law. However, I have developed an understanding of several legal principles regarding invalidity of patent claims, and other relevant legal issues. I have applied this understanding in arriving at my stated opinions and conclusions in this declaration.

28. I understand that the '601 patent contains independent and dependent claims. An independent claim is one that does not refer to other claims in the patent, and it must be read separately from the other claims to determine the scope of such a claim. On the other hand, a dependent claim refers to at least one other

claim in the patent. Such a claim incorporates all of the elements of any claim to which the dependent claim refers, as well as the additional elements recited in the dependent claim itself.

29. I understand that, for example in federal district court infringement actions, a claim in an issued patent is presumed to be valid. In such federal court actions, a patent claim can be "invalidated" upon a showing of clear and convincing evidence. This is not such an action.

30. I understand that in an IPR proceeding, the Petitioner has the burden of proving a proposition of "unpatentability" by a "preponderance of the evidence." I understand that preponderance of the evidence means the greater weight of evidence. In an IPR proceeding, the USPTO may cancel "as unpatentable" one or more claims of a patent on a ground that could be raised under section 102 or 103 of the Patent Act, and only on the basis of prior art consisting of patents or printed publications.

31. I understand that section 102 deals with the "novelty" of patent claims. I understand that under section 102(a), a person is not entitled to a patent if, among other things, the invention was patented or described in a printed publication in this or a foreign country, before the invention thereof by the applicant for patent. Under section 102(b), a person is not entitled to a patent if, among other things, the invention was patented or described in a printed

publication in this or a foreign country, more than one year prior to the date of the application for patent in the United States. Under section 102(e), a person is not entitled to a patent if the invention was described in a published or issued patent application that was filed by another in the United States before the invention by the applicant for patent. Under section 102(g), a person is not entitled to a patent if, before the applicant's invention, the invention was made in the United States by another inventor who had not abandoned, suppressed, or concealed it.

32. I understand that prior art under one or more of these provisions can include, for example but not limited to, one or more of printed publications, patent applications, published patent applications, and domestic, foreign patents, or international patents. These are sometimes referred to as prior art "references."

33. I understand that in order for a claim to be unpatentable for lack of novelty, *i.e.*, anticipated, a single prior art reference must disclose each and every claim limitation of that patent claim. It is not considered in a void, rather, one must take into account what a person having ordinary skill in the art would have understood from the reference. I also understand that one should consider not only what is expressly disclosed in the prior art reference, but also what would naturally, inherently have been understood from what is disclosed in the prior art reference. I understand that to prove inherency, the matter that is not expressly

described must be necessarily present in the reference, and it would be so recognized by an ordinarily skilled artisan.

34. I understand that in order to cancel as unpatentable a dependent claim, all elements of that dependent claim and the claim (or claims) from which it depends must be disclosed or suggested in the prior art.

35. I understand that determining anticipation of a patent claim requires a comparison of the properly construed claim language to the prior art on an element-by-element basis. As it pertains to an IPR proceeding, a claim is "anticipated" if each and every element of the claim, as properly construed, has been disclosed in a single prior art reference, either expressly or inherently, and the claimed arrangement or combination of those elements must also be disclosed, either expressly or inherently, in that same prior art reference.

36. I also understand that while anticipation cannot be established by combining references, additional references may be used to interpret the anticipating reference by, for example, indicating what the anticipating reference would have meant to one having ordinary skill in the art. Additionally, the description provided in the prior art must be such that a person of ordinary skill could, based on the reference, practice the invention without undue experimentation.

37. I understand that section 103 of the Patent Act deals with "obviousness" of patent claims. In particular I understand that a patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains.

38. My understanding is that a patent claim is obvious—and therefore can be cancelled as unpatentable in an IPR—if the claimed subject matter as a whole would have been obvious to a person of ordinary skill as of the date of the invention. I understand that this determination is made after weighing the following factors: (1) the level of ordinary skill in the relevant art; (2) the scope and content of the prior art; (3) the differences between the prior art as a whole and the claim at issue; and (4) when such evidence is made of record, secondary considerations of non-obviousness.

39. I understand that the knowledge and understanding of a person having ordinary skill in the art provides a reference point from which the prior art and claimed invention should be viewed. This reference point prevents one from using his or her own hindsight in deciding whether a claim is obvious, but I understand that if a person of ordinary skill can implement the claimed invention as a

predictable variation of a prior art device or method, then the claim may be rendered obvious.

40. As stated earlier, a person having ordinary skill in the art is presumed to have knowledge of the relevant prior art at the time of the claimed invention. I understand that in order for references to be used in an obviousness analysis, the prior art references should be "analogous" to the claimed invention. I understand that a reference is analogous art to the claimed invention if: (1) the reference is from the same field of endeavor as the claimed invention (even if it addresses a different problem); or (2) the reference is reasonably pertinent to the problem faced by the inventor (even if it is not in the same field of endeavor as the claimed invention). A reference is "reasonably pertinent" to the problem if it would have logically commended itself to an inventor's attention in considering his or her problem.

41. I understand that an obviousness evaluation can be made using a single prior art reference or a combination of multiple references. I understand that a proper analysis as to the combination of two or more references generally requires a reason that would have motivated a skilled artisan to combine the elements of multiple references in the way the claimed invention does. I understand that the prior art references themselves may provide a suggestion, motivation, or reason to combine. This suggestion may be found in the art

explicitly or implicitly. I further understand that market demand, rather than scientific literature, often drives innovation, and that a motivation to combine references may be supplied by the direction of the marketplace or other external factors. I understand that advances that would occur in the ordinary course without real innovation are unpatentable.

42. I understand further that "common sense" may, in some circumstances properly be used in an obviousness analysis. First, common sense can be invoked to provide a known motivation to combine references. Second, common sense can be invoked to supply a limitation that is missing from the prior art if the limitation in question is unusually simple and the technology particularly straightforward. In either case, a reference to common sense cannot be used as a wholesale substitute for reasoned analysis and evidentiary support, especially when dealing with a limitation missing from the prior art references specified.

43. I understand that a particular combination may be proven obvious merely by showing that it was "obvious to try" that combination. For example, when there is a design need or market pressure to solve a problem and there are a finite number of identified, predictable solutions, a person of ordinary skill has good reason to pursue the known options within his or her technical grasp because the result is likely the product not of innovation but of ordinary skill and common sense.

44. I further understand that a proper obviousness analysis focuses on what was known or obvious to a person having ordinary skill, not just the patentee. Accordingly, I understand that any need or problem known in the field of endeavor at the time of the alleged invention and addressed by the patent can provide a reason for combining the elements in the manner claimed.

45. In summary, my understanding is that prior art references or teachings are properly combined where a person having ordinary skill, having the understanding and knowledge reflected in the prior art and motivated by the general problem facing the inventor, would have been led to make the combination of elements recited in the claim. Under this analysis, the prior art references themselves, or any need or problem known in the field of endeavor at the time of the claimed invention, can provide a reason for combining the elements of multiple prior art references in the claimed manner.

46. Further, I understand that at least the following rationales may support a finding of obviousness:

a. Combining prior art elements according to known methods to yield predictable results;

b. Simple substitution of one known element for another to obtain predictable results;

c. Use of a known technique to improve similar devices (methods, products) in the same way;

d. Applying a known technique to a known device (method or product) ready for improvement to yield predictable results;

e. "Obvious to try"—choosing from a finite number of identified, predictable solutions, with a reasonable expectation of success;

f. A predictable variation of work in the same or different field of endeavor if a person having ordinary skill would be able to implement the variation;

g. If, at the time of the alleged invention, there existed a known problem for which there was an obvious solution encompassed by the patent's claims;

h. Known work in one field of endeavor may prompt variations of it for use in either the same or a different field based on design incentives or other market forces if the variations would have been predictable to a person having ordinary skill; and

i. Some teaching, suggestion, or motivation in the prior art that would have led a person having ordinary skill in the art to modify the prior art reference or to combine prior art reference teachings to arrive at the claimed invention.

47. I earlier referred to secondary considerations of non-obviousness. I understand that these may include: (1) whether the invention proceeded in a direction contrary to accepted wisdom in the field; (2) whether there was a long felt but unresolved need in the art that was satisfied by the invention; (3) whether others had tried but failed to make the invention; (4) whether others copied the invention; (5) whether the invention achieved unexpected results; (6) whether the invention was praised by others; (7) whether others have taken licenses to the invention; (8) whether experts or those skilled in the art expressed surprise or disbelief regarding the invention; (9) whether products incorporating the invention have achieved commercial success that is attributable to the invention; and (10) whether or not others having ordinary skill in the field independently made the claimed invention at about the same time the inventor made the invention.

48. I understand that alleged secondary considerations evidence is not relevant unless the patentee can establish a connection or nexus between the secondary consideration and the claimed invention. For example, evidence that allegedly shows commercial success is not relevant unless there is a showing that the success of the product is related to a feature recited in the patent claims. If, however, the commercial success is due to things like advertising, promotion, or salesmanship, or if it is due to features of the product other than the claimed

invention, then any commercial success should not be considered an indication of non-obviousness.

49. Okada is a U.S. patent that issued on February 21, 1995, and thus, as informed by counsel, is prior art under 35 U.S.C. §102(b). (Ex. 1007.) Okada was not cited by the applicant or the USPTO during the prosecution of the application leading to the '601 patent.

50. Shimoda is a U.S. patent that issued on August 23, 1994. It is thus, as informed by counsel, prior art under 35 U.S.C. §102(b). (Ex. 1008.) Shimoda was not cited during the prosecution of the application leading to the '601 patent.

51. Tsang is a U.S. patent that was filed on January 31, 1996, and thus, as informed by counsel, is prior art under 35 U.S.C. §§ 102(e) and/or 102(g). (Ex. 1009.) Tsang was not cited during the prosecution of the application leading to the '601 patent.

V. THE '601 PATENT

52. I have reviewed the '601 patent and its prosecution file history. (Ex. 1001, 1006.) The Challenged Claims of the '601 patent are reproduced below:

Claim 1
[A] Apparatus for encoding m-bit binary datawords into n-bit binary codewords, in a recorded waveform, where m and n are preselected positive integers such that n is greater than m, comprising:
[B] receiver means for receiving the dataword;

[C] encoder means coupled to the receiver means, for producing sequences of fixed length codewords;
[D] means for imposing a pair of constraints (j;k) on the encoded waveform wherein the j constraint is defined as the maximum number of consecutive transitions allowed on consecutive clock periods in the encoded waveform to facilitate the reduction of a probability of a detection error in said receiver means;
[E] said sequences generating no more than j consecutive transitions in the recorded waveform such that j is an integer equal to or greater than 2; and
[F] said sequences generating no more than k consecutive sample periods without a transition in the recorded waveform.
Claim 2
Apparatus as in claim 1 wherein the j consecutive transition limit is defined by the relationship $2 \leq j < 10$.
Claim 8
Apparatus as in claim 2 wherein the consecutive transition limit is defined by the relationship j=2.
Claim 9
Apparatus as in claim 2 wherein the binary sequences produced by combining codewords have no more than j consecutive 1's and no more than k consecutive 0's when used with a NRZI recording format.
Claim 10
Apparatus as in claim 2 wherein binary sequences produced by combining codewords have no more than one of j consecutive transitions from 0 to 1 and from 1 to 0 and no more than k+1 consecutive 0's and k+1 consecutive 1's when used in conjunction with a NRZ recording format.
Claim 12
Apparatus as in claim 2 wherein the receiver means incorporates means for removing certain code-violating patterns from the detection process wherein the

detection process comprises ***at least one of*** the steps of: removing states and state transitions corresponding to more than j consecutive transitions from a Viterbi trellis … [Emphasis added.]
Claim 13
[A] A method for encoding m-bit binary datawords into n-bit binary codewords in a recorded waveform, where m and n are preselected positive integers such that n is greater than m, comprising the steps of:
[B] receiving binary datawords; and
[C] producing sequences of n-bit codewords;
[D] imposing a pair of constraints (j;k) on the encoded waveform;
[E] generating no more than j consecutive transitions of said sequence in the recorded waveform such that $j \geq 2$; and
[F] generating no more than k consecutive sample periods of said sequences without a transition in the recorded waveform.
Claim 14
The method as in claim 13 wherein the consecutive transition limit is defined by the relationship $2 \leq j < 10$.
Claim 15
The method as in claim 14 wherein the consecutive transition limit is j=2.
Claim 16
The method as in claim 14 wherein the binary sequences produced by combining codewords have no more than j consecutive 1's and no more than k consecutive 0's when used with the NRZI recording format.
Claim 17
The method as in claim 14 wherein the binary sequences produced by combining codewords have no more than one of j consecutive transitions from 0 to 1 and from 1 to 0 and no more than one of k+1 consecutive 0's and k+1

consecutive 1's when used in conjunction with the NRZ recording format.
Claim 21
The method as in claim 13 wherein the method of receiving data incorporates the removal of certain code-violating patterns from the detection process wherein the detection process comprises ***at least one*** of the steps of: removing states and state transitions corresponding to more than j consecutive transitions from a Viterbi trellis … [Emphasis added.]

53. The references [A], [B], etc., in the chart above with respect to claims 1 and 13 do not appear in the '601 patent, but have been added for reference.

54. The '601 patent generally relates to digital storage systems. More specifically, the patent pertains "to an improved coding technique involving data recovery channels utilizing sequence detection methods." (Ex. 1001, at 1:9-12.)

55. According to the "Background of the Invention" section of the '601 patent, certain "channel codes," also known as "modulation codes," were known in the prior art. These codes "are mappings of data bits into the symbols that are either transmitted in a communication system or recorded onto a medium in a storage device." (Ex. 1001, at, 1:15-21.) "The purpose of these codes is to prevent certain characteristics in the stream of symbols that make their recovery difficult." (*Id.*)

56. The '601 patent confirms that before the time of the purported invention, "[r]unlength limited (RLL) codes" were "commonly used in magnetic

recording." (Ex. 1001, at 1:21-41.) It was known that RLL codes "impose a (d,k) constraint on the recorded data sequence." (*Id.*) In the NRZ recording format, where "1" represents a positive level in the magnetization waveform and "0" represents a negative level, "d+1 is the minimum number of consecutive like signals and k+1 is the maximum number of consecutive like symbols in the binary sequence." (*Id.*) In the NRZI recording format, where a "1" represents a magnetic transition and a "0" represents no transition, "d and k are the minimum and maximum number of consecutive 0's between any two 1's, respectively …." (Id. (citing prior art)) "The k constraint guarantees that a change in readback waveform will occur at regular intervals for the purpose of synchronizing a phase locked loop to the data." (*Id.*)

57. The alleged invention of the '601 patent is a "coding scheme" referred to as "the maximum transition-run (MTR) coding …" (Ex. 1001, at 2:40-3:17). More specifically, the "MTR code imposes a limit on the maximum number of consecutive transitions that can occur in the written magnetization pattern in magnetic recording." (*Id.*) The benefit of the alleged invention "is most significant … when the maximum number of consecutive transitions is limited to two." (*Id.*) The '601 patent refers to this as an "MTR code with a constraint length of j = 2 …" (*Id*) "With the NRZI format, the MTR code constraint is equivalent to limiting the maximum number of 1's." (*Id.*)

58. Independent claims 1 and 13 of the '601 patent respectively claim a generic "apparatus" and a generic "method" for converting "m-bit binary datawords" of unspecified length into "n-bit binary codewords" of unspecified length. These claims require that a pair of constraints "j;k" are imposed. But the "k" constraint is entirely unspecified while "j" can be any integer "greater than 2." (Ex. 1001, claims 1 and 13.) As such, these claims effectively attempt to cover the concept of MTR coding, *per se*. I understand that the Patent Owner alleged in the corresponding litigation that "[a]ny commercially-viable implementation of MTR coding requires performance of the methods of claim 13 of the '601 Patent." (Ex. 1003, at ¶ 131.)

59. MTR coding, however, was already known before the '601 patent. For example, Okada (assigned to Pioneer) discloses apparatuses for converting 8-bit data to 13-bit data such that, after NRZI modulation, "1" does not appear "three or more times in a row" in the recorded waveform. (Ex. 1007 at 3:34-60; *id.* at 10:8-22). Thus, Okada disclosed MTR coding—including an MTR code with a constraint length of $j = 2$—more than one year before the filing date of the '601 patent.

60. The named inventors of the '601 patent, Drs. Moon and Brickner, were, respectively, a professor and a graduate student at the University of Minnesota. (Ex. 1003, at ¶ 2.) Their MTR-related work was admittedly

"supported" by Seagate Technology ("Seagate"). (Ex. 1012, bottom left corner of first page.) On January 31, 1996, a Seagate scientist from Minnesota, Dr. Kinhing P. Tsang, (*see* face of Tsang patent, Ex. 1009), filed a patent application entitled "Method and Apparatus for Implementing Codes with Maximum Transition Run Length." Dr. Tsang's application disclosed and claimed "MTR" codes with a constraint length of j = 2. (Ex. 1009 at *e.g.*, 2:25-44; 19:33-64.) In particular, Dr. Tsang set forth a key finding from Seagate's research—a finding previously presented in the Seagate Annual Report:

> symbol length is known as the code rate, "r". **The upper bound of the MTR=2 code rate in which k=∞ has been found to be 0.8791 as indicated in the Seagate Annual Report.** This

(Ex. 1009 at 2:36-38)

61. Months later, the named inventors of the '601 patent filed their application, bearing the strikingly similar title "Method and Apparatus for Implementing Maximum Transition Run Codes." The inventors also set forth as part of the "description of the preferred embodiment" of their supposed invention certain disclosures for the scenario where MTR=2 and k=∞:

Fig. 4

RLL k Constraint	Capacity with MTR $j = 2$
∞	0.8791

(Ex. 1001 at Fig. 4:51-53.)

62. I understand that none of these prior art references were considered by the patent examiner during the prosecution of the '601 patent. In my opinion, the alleged inventions claimed in the '601 patent are not patentable.

VI. CLAIM CONSTRUCTION

63. I understand that in this IPR proceeding, the claim terms are construed as understood by persons of skill in the art.

64. Counsel informs me that sometimes such a meaning is readily apparent even to lay judges and claim construction involves little more than the application of widely accepted meaning of commonly understood words. Otherwise, courts look to the words of the claims themselves, the remainder of the specification, the prosecution history, and extrinsic evidence concerning relevant scientific principles, the meaning of technical terms, and the state of the art. I have considered the claim terms at issue here, the specification, and the prosecution history of the '601 patent. I am familiar with the relevant scientific principles and

the state of the art at the time the patent was filed. As mentioned above, I was conducting research in the relevant art at the time of the purported invention.

CLAIM 1: "*encoder means ... for producing sequences of fixed length codewords*":

65. I am informed by counsel that there is rebuttable presumption that a limitation containing the word "means" and reciting a function was drafted in the so-called means-plus-function format. When that presumption is not rebutted, the limitation "shall be construed to cover the corresponding structure, material, or acts described in the specification and equivalents thereof," under 35 U.S.C. § 112(f).

66. I understand that this presumption is rebutted when the claim conveys sufficient structure to perform the recited function.

67. Here, the structure of "*encoder* means … for producing sequences of fixed length codewords" is an "encoder," which is recited in the claim. Encoders for read channels were known at the time of the invention, and represent sufficient structure to perform the claimed "producing sequences of fixed length codewords" function. Indeed, during prosecution, the examiner treated this limitation as not invoking § 112(f) in rejecting claims over Iketani (U.S. Patent No. 4,760,378), stating "refer to either Figure 19 or 23 of Iketani, which shows *encoders* including receiver means for receiving datawords, and encoder means for producing … sequences of fixed length codewords for generating no more than 1 consecutive

transition in the recorded waveform ..." (Ex. 1006 at 54.) Thus, this limitation does not invoke § 112(f), and no construction is necessary.

68. Alternatively, given that the recited function is "producing sequences of fixed length codewords," the specification discloses corresponding structures, namely, "[while] **state-dependent encoders** and sliding block decoders can be designed for the MTR constraint, **simple fixed length block codes can be realized with good rates and reasonable k values**." (Ex. 1001 at 4:61-64.) Thus, if § 112(f) applies, the corresponding structures are state-dependent encoders or block encoders, or their equivalents.

CLAIM 1: "*receiver means for receiving the dataword*":

69. The structure that performs the function of "receiving the dataword" is a "receiver," which is expressly recited in claim 1. Receivers were known in the art at the time of the invention. As discussed above, the examiner also treated "receiver" as having sufficient structure not to invoke § 112(f), stating "Figure 19 or 23 of Iketani, which shows encoders including receiver means for receiving datawords, and encoder means for producing … sequences of fixed length codewords." (Ex. 1006 at 54.) Thus, this term does not invoke § 112(f) and needs no construction.

70. Alternatively, in light of the recited function "receiving the dataword," the specification discloses the corresponding structure in that it teaches

types of read channel encoders, as discussed previously. A person of ordinary skill in the art would understand that read channel encoders are necessarily coupled to an input receiver, otherwise there would be no datawords for the encoder to encode.

71. Further, the '601 patent teaches that "good rates" can be realized by state-dependent and block encoders, (Ex. 1001 at 4:61-64), where "rate" is "the ratio of the number of input bits to output bits" (*id.* at 4:19-20). *See also id.* at 2:43-47, 4:18-21, 4:34-35 ("input"). Thus, if § 112(f) applies, the structure corresponding to the function "receiving the dataword" is an **input receiver associated with a read channel encoder**.

CLAIM 1: "***means for imposing a pair of constraints (j;k) ...***"

72. The recited function is "imposing a pair of constraints (j;k)." This limitation was added during prosecution after the examiner rejected the claims over the Iketani patent "to better define the invention." (Ex. 1006 at at 61; *see id.* at 62-71.) As the prosecution shows, the "means for imposing a pair of constraints" does not recite a structure that is different than the "encoder means"—the limitation was added merely to make clear that the recited encoder "*imposes*" MTR constraints (*i.e.*, j greater than or equal to 2; k), in order to distinguish the claimed encoder from the RLL (d>0; k) encoder in the prior art Iketani patent. (*Id.*) Thus, this

limitation needs no construction because the "encoder" represents sufficient structure and is recited in the claim.

73. Alternatively, as discussed above, the corresponding structures described in the specification are **state-dependent encoders** or **block encoders**, or their equivalents.

CLAIM 12: "*means for removing certain code-violating patterns from the detection process*"

74. The claimed function is "removing certain code-violating patterns from the detection process," and the specification discloses a corresponding structure: **a "Viterbi trellis" corresponding to a detection system**, or its equivalents. (Ex. 1006 at 6:56-7:3, 2:10-37, 3:1-14, Fig. 7.)

75. Unless otherwise addressed herein, no express construction of any additional term is believed to be needed to resolve the challenges herein.

VII. CLAIMS 1, 2, 8-10, AND 13-17 ARE ANTICIPATED BY OKADA

76. As mentioned above, Okada was not cited by the applicant or the patent examiner during prosecution of the application that led to the '601 patent. As discussed in detail below, it is my opinion that claims 1, 2, 8-10, and 13-17 of the '601 patent are anticipated by Okada.

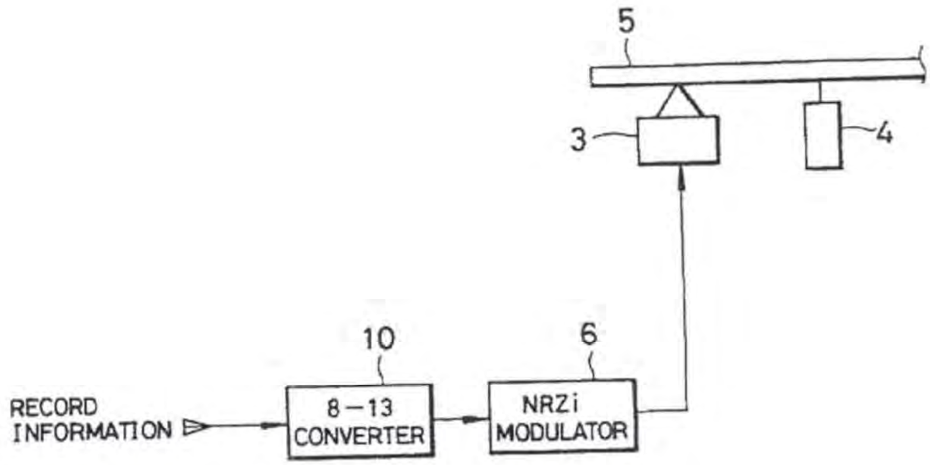
A. Claim 1 is anticipated by Okada

1. Claim 1[A]: "Apparatus for encoding m-bit binary datawords into n-bit binary codewords, in a recorded waveform, where m and n are preselected positive integers such that n is greater than m, comprising:"

77. I am informed that the preamble of independent claim 1 may not be limiting because, for instance, it merely provides a description for the limitations recited in the body of the claim. In any event, Okada discloses claim 1 [A].

78. In particular, Okada discloses methods and apparatuses for reproducing "information from a recording medium designed to have a high linear recording density ..." (Ex. 1007, at 2:48-56). Okada discloses "a data converting means for performing data conversion on record information consisting of a digital signal in accordance with a predetermined data conversion table …" (*Id.*, at 2:57-3:3). In a preferred embodiment, Okada discloses apparatuses and methods where 8-bit binary datawords are encoded into 13-bit binary codewords (*i.e.*, m = 8 and n = 13):

FIG. 6



(*Id.* at Fig. 6). Okada discloses that "in recording information data on an optical disk **5**, the information recording apparatus in FIG. 6 embodying the present invention causes an 8-to-13 converter 10 to perform data conversion before NRZi modulation in such a way that '1' will not appear three or more times in a row in a train of information data after the NRZi modulation." (Ex. 1007 at 3:54-60; *see also id.* at Fig. 7; 3:35-4:16; Tables 1-9 at 4:17-8:64 (8-to-13 bit data conversion tables); 9:24-10:22.). The "NRZi data is … supplied to an optical head **3** to be recorded on an optical disk **5**." (*Id.* at 4:13-16.)

79. Okada discloses "data conversion" Tables 1-9, which contain rows corresponding to all 8-bit binary datawords, each of which is converted to a corresponding 13-bit binary codeword, and a sequence of which form a waveform

of 13-bit codewords "recorded on an optical disk 5" following NRZI modulation. (Ex. 1007 at 4:13-16; 9:33-38.)

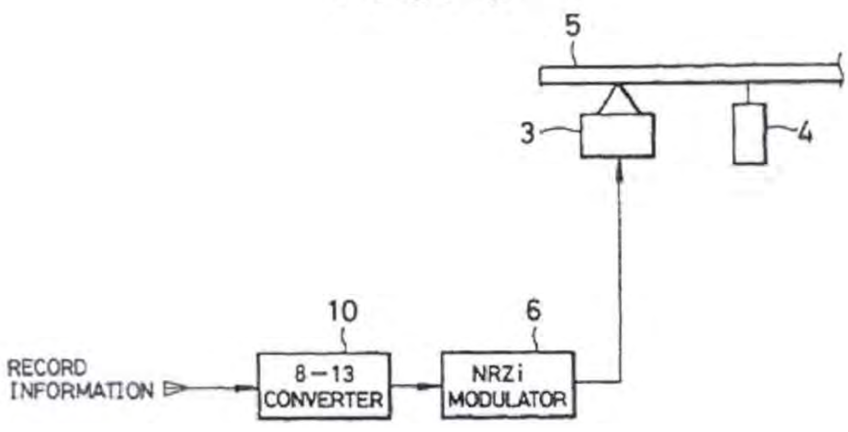
80. Thus, to the extent it is a limitation, Okada discloses claim limitation 1 [A].

2. Claim 1[B]: "receiver means for receiving the dataword;"

81. As discussed in the "Claim Construction" section above, this limitation does not invoke § 112(f) and thus needs no construction. Alternatively, the limitation reads on an input receiver associated with a read channel encoder, or its equivalent.

82. Okada discloses receiver means for receiving the dataword in that "record information" is received and inputted into a "8-13 converter":

FIG. 6



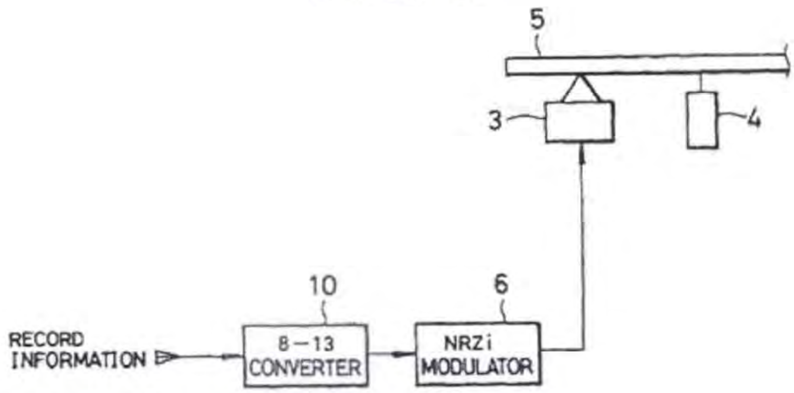
(Ex. 1007, Fig. 6 (annotated)). In particular, Figures 6 and 7 depict an "information recording/reproducing apparatus" that receives record information associated with a read channel encoder. Okada discloses that the received "record information" consists of "a digital signal." (*Id.* at 2:57:61). In the exemplary recording embodiment shown in Figure 6, the record information consists of "8-bit input record information," which is an example of a "dataword." (*Id.* at 3:61-63). Okada therefore discloses claim limitation 1 [B].

3. Claim 1[C]: "encoder means coupled to the receiver means, for producing sequences of fixed length codewords;"

83. As discussed in the "Claim Construction" section above, this limitation does not invoke § 112(f) and thus needs no construction. Alternatively, the limitation reads on state-dependent encoders or block encoders, or their equivalents.

84. Okada discloses an 8-to-13 bit converter (10) coupled to the receiver means, for producing sequences of 13-bit codewords:

FIG. 6



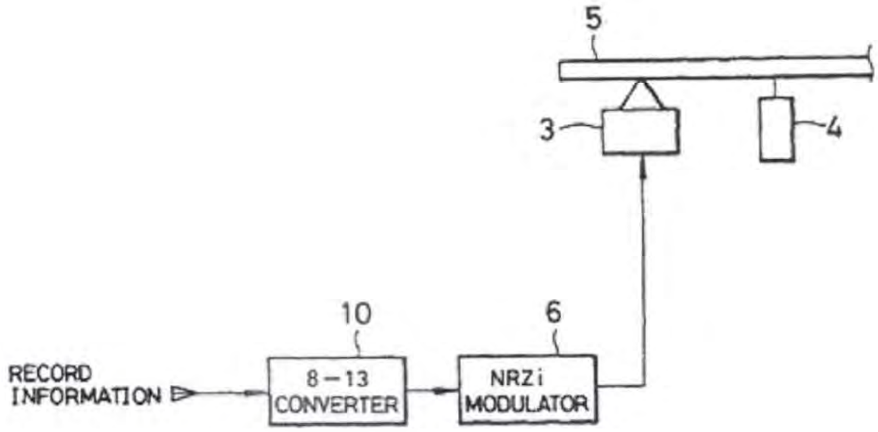
(Ex. 1007, Fig. 6 (annotated)). As discussed above with respect to claim 1 [A], the 8-to-13 converter (10) is a block encoder that converts 8-bit datawords into corresponding fixed-length, 13-bit codewords, as shown in "data conversion" Tables 1-9. Okada therefore discloses claim limitation 1 [C].

4. **Claim 1[D]: "means for imposing a pair of constraints (j;k) on the encoded waveform wherein the j constraint is defined as the maximum number of consecutive transitions allowed on consecutive clock periods in the encoded waveform to facilitate the reduction of a probability of a detection error in said receiver means;"**

85. As discussed in the "Claim Construction" section above, this limitation does not invoke § 112(f) and thus needs no construction. Alternatively, the limitation reads on state-dependent or block encoders, or their equivalents.

86. As discussed above with respect to claims 1 [A], 1 [B], and 1 [C], Okada discloses an 8-to-13 bit converter (10) coupled to the receiver means, for producing sequences of 13-bit codewords:

FIG. 6



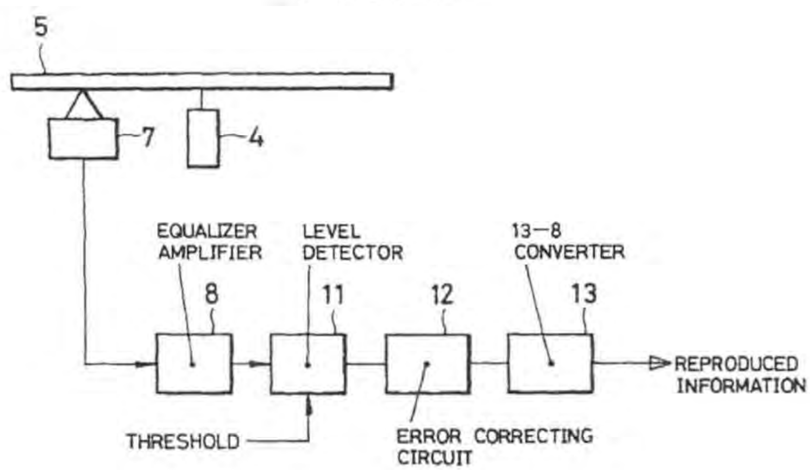
(Ex. 1007, Fig. 6 (annotated)). The 8-to-13 bit converter (10) "expands" 8-bit input record information to 13-bit data according to either one of two "rules." (*Id.*, a 3:61-68). In particular, "Rule (1)" is that each 13-bit dataword "consists of at least one '0' and an even number of consecutive '1'." (*Id.*). The entries in Tables 1-7 were constructed with Rule (1). (*Id.* at 4:1-12.) "Rule (2)" includes a pattern "consisting of '01010'" and a section consisting of 0's or an even number of consecutive 1's. (*Id.* at 3:61-68). Tables 8 and 9 were constructed using Rule (2). (*Id.* at 4:1-12.)

87. "Rule (1)" and "Rule (2)" of Okada each imposes a "maximum number of consecutive transitions allowed on consecutive clock periods in the encoded waveform," as recited in claim limitation 1 [D]. As can be seen by inspection, each of the 13-bit data sequences shown in Tables 1-7 (corresponding to Rule (1)) has a finite number of *consecutive* transitions (*e.g.*, sequences where the data switches consecutively between "1" and "0"). (*See* Ex. 1007 at Tables 1-7.) More specifically, none of the encoded datawords from Tables 1-7 that form the claimed "encoded waveform" have more than two (2)—a "finite number"—such consecutive transitions. Further, any concatenation of such 13-bit codewords likewise would result in no more than two consecutive transitions. (*See id.*) Similarly, as can be seen by inspection, each of the 13-bit data sequences shown in Tables 8-9 (corresponding to Rule (2)) has a finite number of *consecutive* transitions. In particular, these sequences each include a section consisting of "01010"— encoded waveforms in Tables 8 and 9 thus each have exactly two consecutive transitions from 0 to 1 or from 1 to 0. Thus, after NRZI modulation, these waveforms contain exactly two consecutive 1's.

88. The consecutive transition restraint imposed by Rule (1) and Rule (2) of Okada facilitates the reduction of the probability of a detection error in said

receiver means. For example, such constraint causes the "8-to-13 converter 10 to perform data conversion before NRZI modulation in such a way that ***'1' will not appear three or more times in a row*** in a train of information data after the NRZi modulation" when the data is recorded to the optical disk. (Ex. 1007 at 3:54-60 (emphasis added); *see also* Ex. 1011). When the process is then reversed in the "reproducing apparatus" of Figure 7 of Okada, an "optical pickup" (7) which picks up information from the optical disk (5) and supplies the acquired reproduced signal to an "equalizer amplifier" (8):

FIG. 7



(Ex. 1007, Fig. 7; *see also id.* at 8:65-9:24.) The reproduced signal amplified by the equalizer amplifier (8) is sent to a "level detector" (11). (Ex. 1007 at 8:65-9:24.) The level detector (11) "compares the level of the signal" from the equalizer amplifier (8) "with a threshold level as a reference for level discrimination to acquire digital data from the reproduced signal." (*Id.*) The level detector (11) sends digital data of "0" to an "error correcting circuit" (12) "when the level of the signal form the equalizer amplifier" (8) is "lower than the threshold level," otherwise, it sends digital data of "1" to the error correcting circuit (12) (*i.e.*, it sends a "1" when the signal level is equal to or higher than the threshold level). (*Id.*).

89. Okada discloses that "[w]hen a sequence of '01110' [three consecutive "1's"] is present in the received 13-bit data, the error correcting circuit (12) corrects it to '01010' and sends the corrected data to a 13-to-8 converter (13)." (Ex. 1007 at 9:10-15). Again, the embodiment depicted in Figure 6 causes the 8-to-13 converter to perform data conversion before NRZI modulation "in such a way that ***'1' will not appear three or more times in a row***" after NRZI modulation. (Ex. 1007 at 3:54-60) (emphasis added). This feature thus allows the error correcting circuit (12) to detect and correct errors, as discussed above. Similarly, "when the received 13-bit data does not contain a sequence of '01110,' the error correcting circuit" (12) "performs no error correction and sends the received data directly to the 13-to-8 converter" (13). (Ex. 1007 at 9:15-24.) By doing so, the transition restraints imposed by Rule (1) and Rule (2) facilitate the reduction of a probability of a detection error in the receiver means of the "information recording/reproducing apparatus" of Figures 6 and 7. Finally, the 13-to-8

converter (13) "refers to the data conversion table in the reverse manner to the one done by the 8-to-13 converter" (10 in Figure 6) to "convert 13-bit data to 8-bit data" and "the resultant data" is outputted "as reproduced information." (*Id.*)

90. Okada discloses an example wherein 8-bit data record information is recorded and reproduced according to the preferred embodiment disclosed in Figures 6 and 7 and Tables 1-9. (Ex. 1007 at 9:25-68.) This example involves the 8-bit dataword "01111010," ("7A" in hexadecimal notation) which converts to a 13-bit encoded codeword given in Table 4 (*i.e.*, "0011011000000" after encoding but before NRZI modulation). In the example, the correct record information was recovered in the presence of "code interference." (Ex. 1007 at 9:25-68.) Earlier in the specification, Okada explains that if "information is recorded with a high linear recording density increased to near the upper limit of the frequency response of the recording and reproducing systems, a read error occurs due to a so-called code interference by which reproduced waveforms are likely to interfere with each other at the time adjacent marks are read." (Ex. 1007 at 1:21-27; *see also id.* at 1:28-43 and Fig. 1).

91. A second example involving Rule 2 shows that the 8-bit dataword "11101000" ("E8" in hexadecimal notation) is converted to the 13-bit codeword "0010100110000," as shown in Table 8. After NRZI modulation, this becomes "0011000100000." (Ex. 1007 at 9:50-68; *see also* Ex. 1011 at Table 4.) In this

second example, the correct record information was again recovered despite the presence of "code interference." (Ex. 1007 at 9:50-68.)

92. Okada thus discloses the imposition of a constraint on the encoded waveform data—through either Rule (1) or Rule (2)—"to facilitate the reduction of a probability of a detection error in said receiver means," which limitation is recited in claim limitation 1 [D].

93. Thus, Okada discloses claim limitation 1 [D].

5. Claim 1[E]: "said sequences generating no more than j consecutive transitions in the recorded waveform such that j is an integer equal to or greater than 2; and"

94. As discussed above, Okada teaches that the 8-to-13 bit converter (10) "expands" 8-bit input record information to 13-bit data according to either one of two "Rules." Imposition of the first rule, Rule (1), results in a maximum of one consecutive transition allowed on consecutive clock periods, not just in the *encoded* waveform output from the block converter, but also later in the *recorded* waveform that is "recorded to an optical disk" following NRZI modulation. This is seen in Exhibit 1011, which shows each of the values from Tables 1-7 following NRZI modulation (*i.e.*, as they would exist in the recorded waveform recorded to the optical disk). An example from the specification—showing how the value 7a becomes 0011011000000 in Table 4 following 8-13 encoding and 001001000000 after NRZI modulation—corroborates the post-NRZI codewords in Exhibit 1011,

and illustrates that there are no more than two (2) consecutive transitions in the recorded waveform following NRZI modulation.

95. Similarly, imposition of Rule (2) results in a maximum of two consecutive transitions allowed on consecutive clock periods, both in the encoded waveform before NRZI modulation (as seen in Tables 8 and 9), and in the recorded waveform after NRZI modulation (as shown in Exhibit 1011). As discussed above, a second example in the specification—showing how the hexidecimal value "e8" becomes 0010100110000 in Table 8 following 8-13 encoding and 0011000100000 after NRZI modulation—corroborates the post-NRZI codewords in Exhibit 1011, and illustrates that there are no more than exactly two (2) consecutive transitions in the recorded waveform following NRZI modulation

96. Therefore, Okada discloses claim limitation 1 [E].

6. Claim 1[F]: "said sequences generating no more than k consecutive sample periods without a transition in the recorded waveform."

97. The 8-to-13 data conversion tables, Tables 1-7, were constructed using the first of two "Rules." (*See* the discussion of claim 1 [D], *supra*.) Rule (1) also ensures that a 13-bit codeword cannot be comprised of all 1s or all 0s following NRZI modulation. (Ex. 1011.) Indeed, even in the scenario where any two 13-bit codewords are evaluated in succession, there would be no more than 22 consecutive samples periods without a transition with respect to the 13-bit

codewords disclosed in Okada, since Rule (1) requires there to be "at least one '0' and an even number of consecutive '1['s]'," (Ex. 1007 at 3:64-68), which hypothetically allows for a run of 22 consecutive 1's when two codewords having eleven (11) consecutive 1's are concatenated. There can be even fewer consecutive sample periods without a transition when Okada's Rule (2) is used, because a string of "01010" must be included in each of the 13-bit codewords. (*See* Tables 8 and 9 (codewords before NRZI modulation); Ex. 1011 at Tables 8 and 9 (after NRZI modulation).) The sequences generated thus have "no more than k consecutive sample periods without a transition in the recorded waveform," as recited in claim 1 [F]. In any case, there can never be a codeword consisting of *all* 0's or *all* 1's—thus, k is a finite number.

98. Thus, Okada discloses claim limitation 1 [F], and claim 1 in its entirety is anticipated by Okada.

B. Claim 2 is anticipated by Okada

99. Claim 2 recites "Apparatus as in claim 1 wherein the j consecutive transition limit is defined by the relationship $2 \leq j < 10$." As shown above, Okada anticipates claim 1 from which claim 2 depends. As to the additional limitation of claim 2, Okada discloses apparatuses and methods wherein the consecutive transition limit is defined as $j = 2$. (*See* the discussion of claims 1 [D] and 1 [E], *supra*.) Okada thus anticipates claim 2.

C. Claim 8 is anticipated by Okada

100. Claim 8 recites "Apparatus as in claim 2 wherein the consecutive transition limit is defined by the relationship j=2." As shown above, Okada discloses all the elements of claims 1 and 2 from which claim 8 depends. As to the additional limitation of claim 8, Okada discloses apparatuses and methods wherein j = 2. (*See* the discussion of claims 1 [D] and 1 [E], *supra.*) Okada thus anticipates claim 8.

D. Claim 9 is anticipated by Okada

101. Claim 9 recites "Apparatus as in claim 2 wherein the binary sequences produced by combining codewords have no more than j consecutive 1's and no more than k consecutive 0's when used with a NRZI recording format." As to the additional limitation of claim 9, Okada discloses that the binary sequences produced by combining the disclosed 13-bit codewords, after NRZI modulation, have no more than 2 consecutive 1's and no more than k consecutive 0's. (*See* the discussion of claims 1 [D], 1 [E], and 1 [F], *supra.*; Ex. 1011) Okada thus anticipates claim 9.

E. Claim 10 is anticipated by Okada

102. Claim 10 recites "Apparatus as in claim 2 wherein binary sequences produced by combining codewords have no more than one of j consecutive transitions from 0 to 1 and from 1 to 0 and no more than k+1 consecutive 0's and k+1 consecutive 1's when used in conjunction with a NRZ recording format." As

shown above, Okada anticipates claims 1 and 2 from which claim 10 depends. Okada discloses an MTR constraint of j = 2 (*i.e.* at most two consecutive "1s" following NRZI modulation) and k=22 (*i.e.*, at most k consecutive "0's" in NRZI format). (*See* the discussion of claims 1 [D], 1 [E], and 1 [F], *supra*.; Ex. 1011.)

103. As to the additional limitations of claim 10, Okada discloses no more than one of 2 consecutive transitions from 0 to 1 and from 1 to 0 in NRZ format. In particular, Tables 1-7 show at most 1 such consecutive transition, because each codeword consists of an even number of 1's surrounded by strings of 0's. (Ex. 1007.) Tables 8 and 9 show at most 2 such consecutive transitions (*i.e.*, j = 2), as the interior of each codeword includes the string "0010100." (*See* Ex. 1007 at Tables 8 and 9.) Sequences such as "010" and "101" do not occur at the beginning or end of codewords, thus ensuring that the j = 2 constraint is met when codewords are combined. (*Id.*) Further, as confirmed in the '601 Patent, k consecutive 0's in *NRZI* format is equivalent to no more than k + 1 consecutive 0's and k + 1 consecutive 1's, in *NRZ* format. (Ex. 1001 at 1:15-36;; *see* Ex. 1007, Tables 1-9 (NRZ format); Ex. 1011 (NRZI format)).

104. Okada thus anticipates claim 10.

F. Claim 13 is anticipated by Okada

1. Claim 13[A]: "A method for encoding m-bit binary datawords into n-bit binary codewords in a recorded waveform, where m and n are preselected positive integers such that n is greater than m, comprising the steps of:"

105. Claim 13 is highly similar to claim 1, but claim 13 recites a "method" while claim 1 recites an "apparatus."

106. As informed by counsel, the preamble of the claim may not be limiting. Alternatively, if the preamble is found to be limiting, as shown above with respect to claim 1 [A], Okada discloses apparatuses and methods for encoding 8-bit binary datawords into 13-bit binary codewords, in a recorded waveform. Okada thus discloses claim 13 [A].

2. Claim 13[B]: "receiving binary datawords; and"

107. As shown above with respect to claim element 1 [B], Okada discloses "receiving binary datawords" in that "record information" consisting of 8-bit binary datawords is received and inputted into a "8-13 converter." (*See* Ex. 1007, Fig. 6). The "record information" consists of "a digital signal," *i.e.*, a binary signal. (*Id.* at 2:57:61). In the embodiment of Figure 6, the binary signal information consists of "8-bit input record information." (*Id.* at 3:61-63). Okada therefore discloses claim element 13 [B].

3. Claim 13[C]: "producing sequences of n-bit codewords;"

108. As shown above with respect to claim 1 [C], Okada discloses producing sequences of 13-bit codewords from 8-bit input datawords. Okada therefore discloses claim element 13 [C].

4. Claim 13[D]: "imposing a pair of constraints (j;k) on the encoded waveform;"

109. As explained above with respect to claim element 1 [D], Okada discloses an 8-to-13 bit converter (10) that imposes a pair of constraints (j;k) on the encoded waveform output from the converter. Thus, Okada discloses claim element 13 [D].

5. Claim 13[E]: "generating no more than j consecutive transitions of said sequence in the recorded waveform such that $j \geq 2$; and"

110. As explained above with respect to claim element 1 [E], Okada discloses the generation of no more than two (2) consecutive transitions in the recorded waveform. Therefore, Okada discloses $j = 2$, and thus discloses claim 13 [E].

6. Claim 13[F]: "generating no more than k consecutive sample periods of said sequences without a transition in the recorded waveform."

111. For the reasons discussed above with respect to claim element 1 [F], Okada discloses generation of no more than k consecutive sample periods of said

sequences without a transition in the recorded waveform. Okada thus discloses claim element 13 [F].

G. Claim 14 is anticipated by Okada

112. Claim 14 recites "The method as in claim 13 wherein the consecutive transition limit is defined by the relationship $2 \leq j < 10$." As discussed previously, Okada anticipates claim 13 from which claim 14 depends. As to the additional limitation of claim 14, as shown above with respect to apparatus claims 2 and 8, Okada discloses $j = 2$, and thus anticipates claim 14.

H. Claim 15 is anticipated by Okada

113. Claim 15 recites "The method as in claim 14 wherein the consecutive transition limit is $j=2$." As discussed previously, Okada anticipates claims 13 and 14 from which claim 15 depends. As to the additional limitation of claim 15, as shown above with respect to apparatus claims 2, 8, and 14, Okada discloses $j = 2$, and thus anticipates claim 15.

I. Claim 16 is anticipated by Okada

114. Claim 16 recites "The method as in claim 14 wherein the binary sequences produced by combining codewords have no more than j consecutive 1's and no more than k consecutive 0's when used with the NRZI recording format."

115. As discussed previously, Okada anticipates claim 14 from which claim 16 depends. As to the additional limitation of claim 16, Okada discloses that

the binary sequences produced by combining the disclosed 13-bit codewords, after NRZI modulation, have no more than 2 consecutive 1's (*i.e.*, j = 2) and no more than a finite number of k consecutive 0's, as explained previously with respect to claim 9. Okada thus anticipates claim 16.

J. Claim 17 is anticipated by Okada

116. Claim 17 recites "The method as in claim 14 wherein the binary sequences produced by combining codewords have no more than one of j consecutive transitions from 0 to 1 and from 1 to 0 and no more than one of k+1 consecutive 0's and k+1 consecutive 1's when used in conjunction with the NRZ recording format."

117. As discussed previously, Okada anticipates claim 14 from which claim 17 depends. In addition, for the reasons discussed previously with respect to claim 10, Okada discloses that the binary sequences produced by combining codewords have no more than one of j consecutive transitions from 0 to 1 and from 1 to 0 and no more than one of k+1 consecutive 0's and k+1 consecutive 1's when used in conjunction with the NRZ recording format.

118. Okada thus anticipates claim 17.

VIII. CLAIMS 1, 2, 8-10, AND 13-17 ARE ANTICIPATED BY TSANG

119. As mentioned above, Tsang was not cited by the applicant or the patent examiner during prosecution of the application that led to the '601 patent.

As discussed in detail below, it is my opinion that claims 1, 2, 8-10, and 13-17 of the '601 patent are anticipated by Tsang.

A. Claim 1 is anticipated by Tsang

1. Claim 1[A]: "Apparatus for encoding m-bit binary datawords into n-bit binary codewords, in a recorded waveform, where m and n are preselected positive integers such that n is greater than m, comprising:"

120. I am informed that the preamble of independent claim 1 may not be limiting because, for instance, it merely provides a description for the limitations recited in the body of the claim. In any event, Tsang discloses and claims the limitation recited in claim 1 [A].

121. Tsang discloses apparatuses and methods for encoding "data words … having 'm' successive bits" into "code words … having 'n' bits where 'n' is greater than 'm.'" (Ex. 1009 at 2:28-44.) In a first embodiment, Tsang discloses m = 5 and n = 6. (Ex. 1009 at 4:1-6 ("To achieve a m/n rate equal to 5/6 in an MTR code with MTR=2 using code words of 6 bits in length (n=6)…").) In a second embodiment, Tsang discloses m = 6 and n = 7. (*Id.* at 10:17-19 ("A further maximum transition run code example is provided by such a code having a 6/7 rate.").)

122. Indeed, Tsang itself claims "[a]n apparatus for encoding selected data blocks having a selected data number [m] of ordered symbols therein into corresponding code blocks having a selected code number [n] of ordered symbols

therein, with said code number [n] being greater than said data number [m]." (Ex. 1009 at 19:34-38) (claim 1). Claim 5 recites the apparatus of claim 1 wherein "said selected data number [m] equals five, and wherein said selected code number [n] equals six." (*Id.* at 19:65-68.) Claim 6 recites the apparatus of claim 1 wherein "said selected data number [m] equals six, and wherein said selected code number [n] equals seven." (*Id.* at 20:1-3.)

123. Thus, Tsang discloses claim element 1 [A].

2. Claim 1[B]: "receiver means for receiving the dataword;"

124. As discussed in the "Claim Construction" Section above, this limitation does not invoke § 112(f) and thus needs no construction. Alternatively, if § 112(f) applies, then the limitation reads on input receivers associated with read channel encoders, or their equivalents.

125. In a first embodiment, depicted in Figure 4A, Tsang discloses datawords (11) being supplied to a receiver means, *i.e.*, a "five bit input register, 10" that serves "as the data word receiver at a system input":

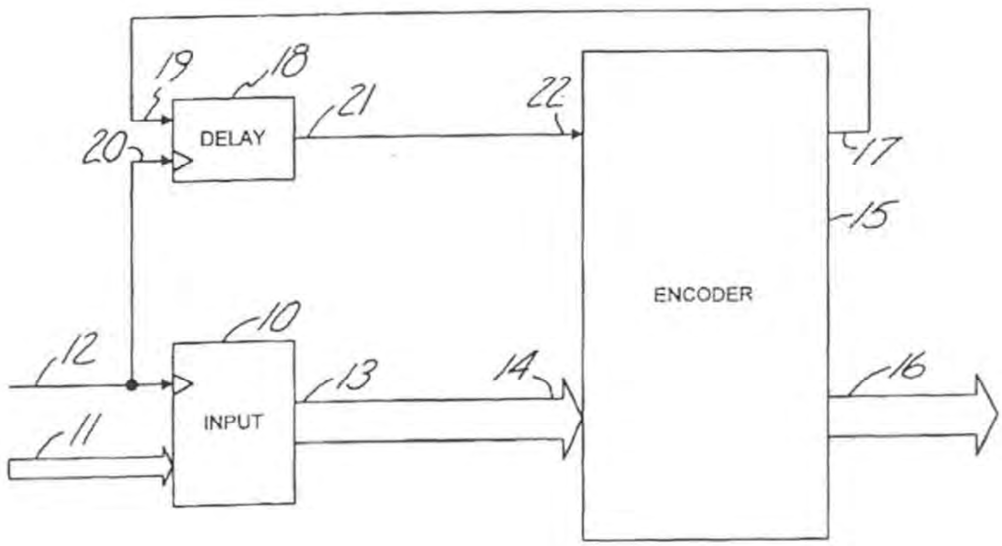


Fig. 4A

(Ex. 1009 at Fig. 4A; *see id.* at 6:5-10.) The receiver means (10) is coupled to a read channel encoder (15).

126. In a second embodiment, depicted in Figure 9A, Tsang discloses datawords (61) being supplied to a receiver means, *i.e.*, a "six bit input register, 60":

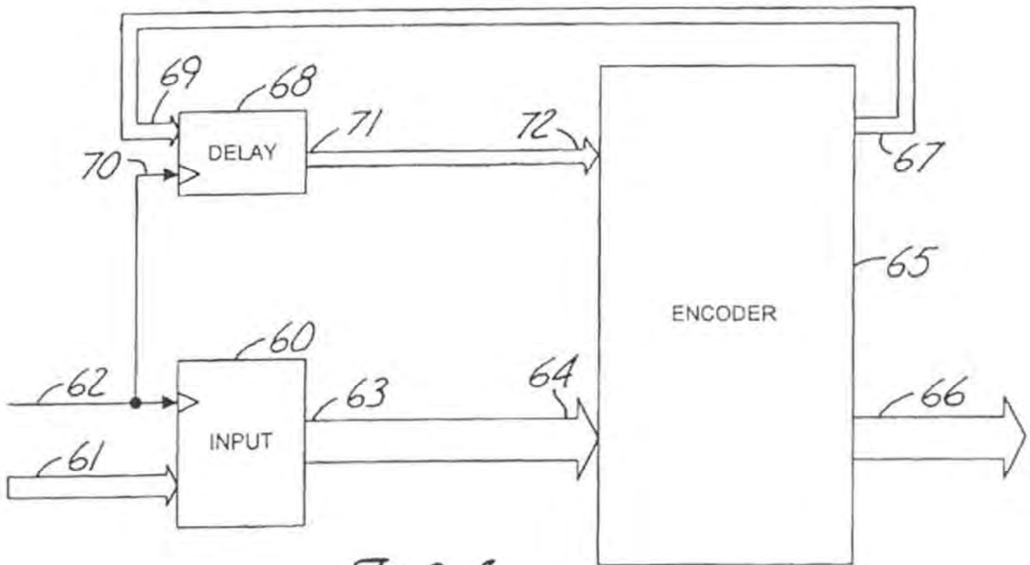


Fig. 9A

(Ex. 1009 at Fig. 9A; *see id*. at 11:43-49.) The receiver means is coupled to a read channel encoder (65).

127. Tsang further claims an "encoding receiver for receiving said data blocks." (Ex. 1009 at 19:39-40) (claim 1).

128. Thus, Tsang discloses claim element 1 [B]

3. Claim 1[C]: "encoder means coupled to the receiver means, for producing sequences of fixed length codewords;"

129. As discussed in the "Claim Construction" Section above, this limitation does not invoke § 112(f) and thus needs no construction. Alternatively, then the limitation reads on state-dependent encoders or block encoders, or their equivalents.

130. In a first embodiment, Tsang discloses an encoder (15) coupled to a receiver means (10, a 5-bit register) for producing sequences of 6-bit codewords:

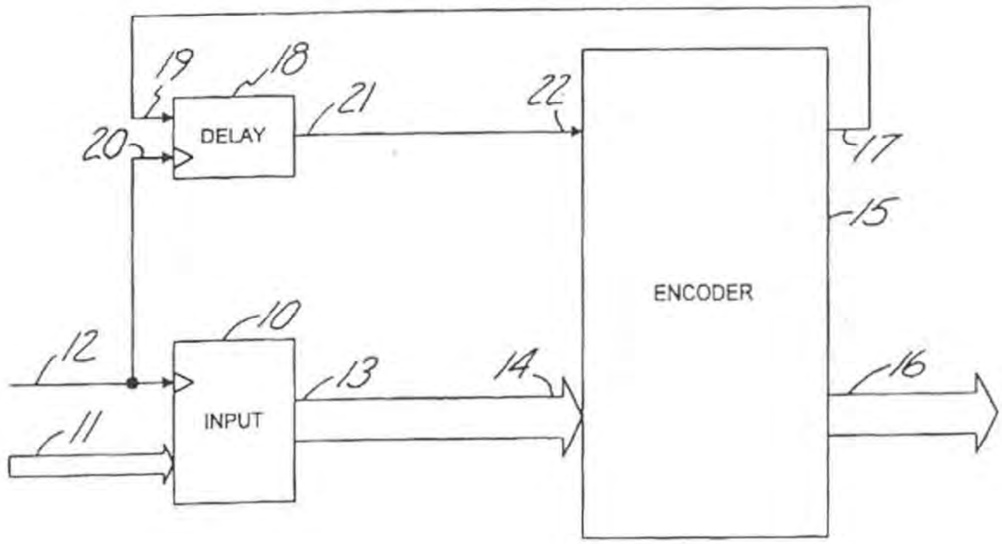


Fig. 4A

(Ex. 1009 at Fig. 4A; 6:5-28.) Thus Tsang discloses "encoder means coupled to the receiver means, for producing sequences of fixed length codewords " from claim element 1 [C].

131. To the extent § 112(f) applies, with regards to encoder (15) in Figure 4A, in order to limit the resulting code to having at most two (2) consecutive transitions, *i.e.*, j = 2, after concatenation of codewords, "constraints are imposed on the transition branches in the trellis diagram so that the branches may only be associated with certain code words having suitable bit patterns to avoid the

occurrence of three or more successive '1's'." (*Id.* at 4:33-39.) Thus Tsang discloses a state-dependent encoder.

132. In a second embodiment, Tsang discloses an encoder (65) coupled to a receiver means (60, a 6-bit register) for producing sequences of 7-bit codewords:

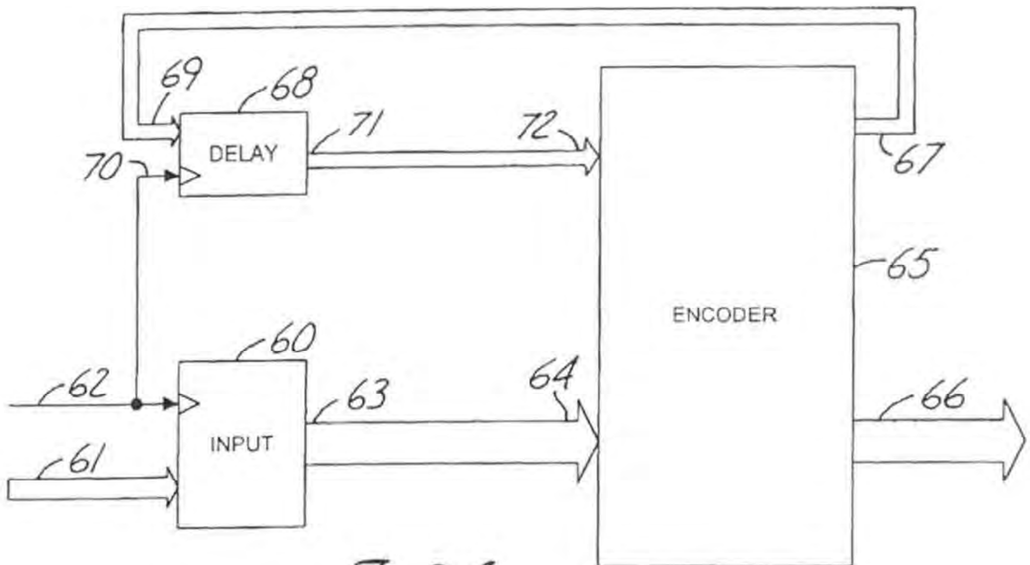


Fig. 9A

(Ex. 1009 at Fig. 9A; *see id.* at 11:43-56.) Thus the second embodiment of Tsang also discloses "encoder means coupled to the receiver means, for producing sequences of fixed length codewords " from claim element 1 [C].

133. Encoder (65) converts 6-bit input data to 7-bit codewords, and is a state-dependent encoder. (Ex. 1009 at 10:17-11:57.)

134. Further, Tsang claims "an encoder coupled to said encoding receiver for providing a corresponding said code block for each said data block." (Ex. 1009 at 19:41-43) (claim 1).

135. Thus, Tsang discloses claim element 1 [C]

4. Claim 1[D]: "means for imposing a pair of constraints (j;k) on the encoded waveform wherein the j constraint is defined as the maximum number of consecutive transitions allowed on consecutive clock periods in the encoded waveform to facilitate the reduction of a probability of a detection error in said receiver means;"

136. As discussed in the "Claim Construction" section above, this limitation does not invoke § 112(f) and thus needs no construction.

137. Alternatively, the limitation reads on state-dependent or block encoders, or their equivalents. As discussed above with respect to claim 1 [C], Tsang discloses state-dependent encoders (15 in Figure 4A; 65 in Figure 4B).

138. The "MTR value" disclosed in Tsang is the same as the constraint "j" in claim element 1 [D]. "A class of block codes **that limits the number of consecutive symbol transitions** . . . are known as maximum transition run (MTR) codes." (Ex. 1009 at 2:22-28 (emphasis added).) For example, Tsang describes "[t]he upper bound of the MTR=2 code rate in which k=∞ has been found to be 0.8791 as indicated in the Seagate Annual Report." (Ex. 1009 at 2:36-38.) This precisely matches the scenario described in the later-filed '601 patent:

Fig. 4

RLL k Constraint	Capacity with MTR $j = 2$
∞	0.8791

(Ex. 1001 at Fig. 4.)

139. In a first embodiment, depicted in Figure 4A, Tsang discloses an encoder (15) "comprising a finite state machine based on the table in FIG. 3" (Ex. 1009 at 6:5-28.) A finite state machine based on the table in Figure 3 provides a "maximum transition run code having a 5/6 rate" (*i.e.*, m = 5, n = 6), "with MTR=2 [*i.e.*, j=2] and k=9." (*Id.* at 5:25-6:4; Fig. 3.) In a second embodiment, depicted in Figure 9A, Tsang discloses an encoder (65) "comprising a finite state machine based on the table in FIG. 8." (Ex. 1009 at 11:43-56.) A finite state machine based on the table in Figure 8 provides a "maximum transition run code having a 6/7 rate" (*i.e.*, m = 6, n = 7), " with MTR=2 [*i.e.*, j = 2] and k=9." (*Id.* at 11:27-42; Fig. 8.)

140. Further, Tsang discloses:

> As the recording densities become greater, the result is that transitions representing binary "1's" become recorded very close to each other in the magnetic media such that severe intersymbol-interference results. At densities considerably greater than those in currently commercially available products, the most likely error sequence has been