US005732113A

United States Patent [19]

Schmidl et al.

[11] Patent Number: 5,732,113

[45] Date of Patent: Mar. 24, 1998

[54] **TIMING AND FREQUENCY SYNCHRONIZATION OF OFDM SIGNALS**

[75] Inventors: **Timothy M. Schmidl**; **Donald C. Cox**, both of Stanford, Calif.

[73] Assignee: **Stanford University**, Stanford, Calif.

[21] Appl. No.: **666,237**

[22] Filed: **Jun. 20, 1996**

[51] **Int. Cl.**[6] **H04L 7/00**

[52] **U.S. Cl.** **375/355**; 375/354

[58] **Field of Search** 375/354, 355; 370/206, 208

[56] **References Cited**

U.S. PATENT DOCUMENTS

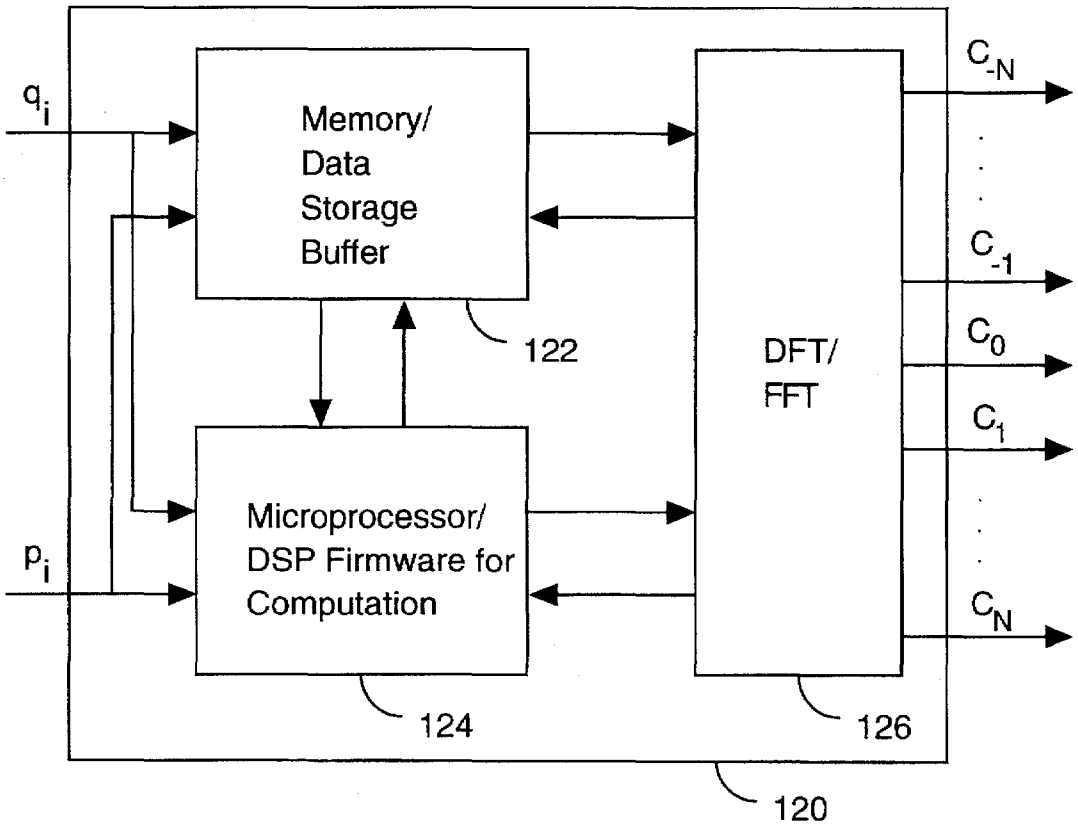
5,166,924	11/1992	Moose	370/32.1
5,228,025	7/1993	Le Floch et al	370/20
5,406,551	4/1995	Saito et al	370/19
5,444,697	8/1995	Leung et al	370/19
5,471,464	11/1995	Ikeda	370/19
5,506,836	4/1996	Ikeda et al.	370/19
5,521,943	5/1996	Dambacher	375/295
5,550,812	8/1996	Phillips	370/19
5,555,268	9/1996	Fattouche et al	375/206
5,602,835	2/1997	Seki et al	370/206

Primary Examiner—Stephen Chin
Assistant Examiner—Mohammad Ghayow
Attorney, Agent, or Firm—Lumen Intellectual Property Services

[57] **ABSTRACT**

A method and apparatus achieves rapid timing synchronization, carrier frequency synchronization, and sampling rate synchronization of a receiver to an orthogonal frequency division multiplexed (OFDM) signal. The method uses two OFDM training symbols to obtain full synchronization in less than two data frames. A first OFDM training symbol has only even-numbered sub-carriers, and substantially no odd-numbered sub-carriers, an arrangement that results in half-symbol symmetry. A second OFDM training symbol has even-numbered sub-carriers differentially modulated relative to those of the first OFDM training symbol by a predetermined sequence. Synchronization is achieved by computing metrics which utilize the unique properties of these two OFDM training symbols. Timing synchronization is determined by computing a timing metric which recognizes the half-symbol symmetry of the first OPDM training symbol. Carrier frequency offset estimation is performed in using the timing metric as well as a carrier frequency offset metric which peaks at the correct value of carrier frequency offset. Sampling rate offset estimation is performed by evaluating the slope of the locus of points of phase rotation due to sampling rate offset as a function of sub-carrier frequency number.

26 Claims, 15 Drawing Sheets



DOCKET ALARM
Find authenticated court documents without watermarks at docketalarm.com.

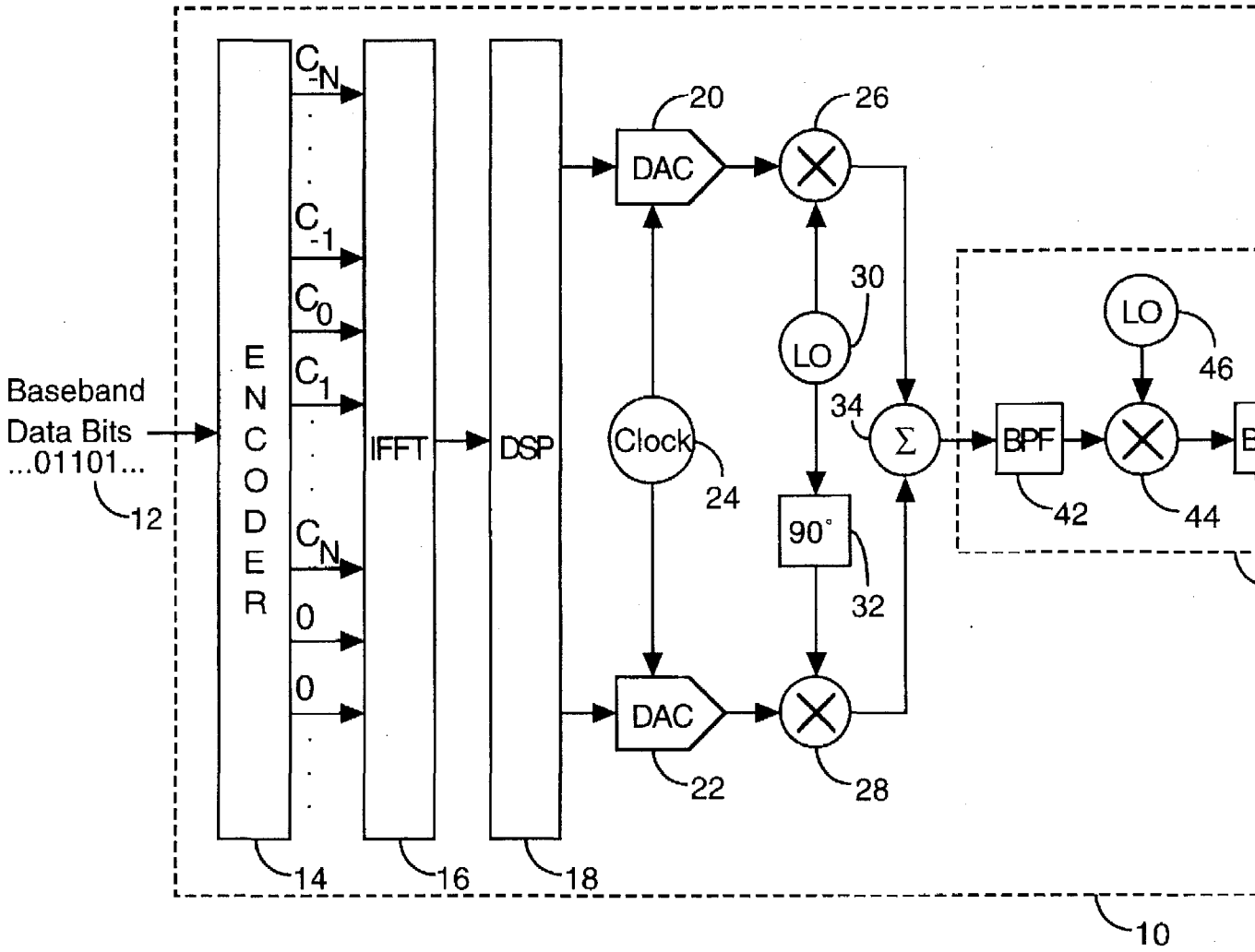


FIG. 1 (Prior Art)

DOCKET ALARM
Find authenticated court documents without watermarks at docketalarm.com.

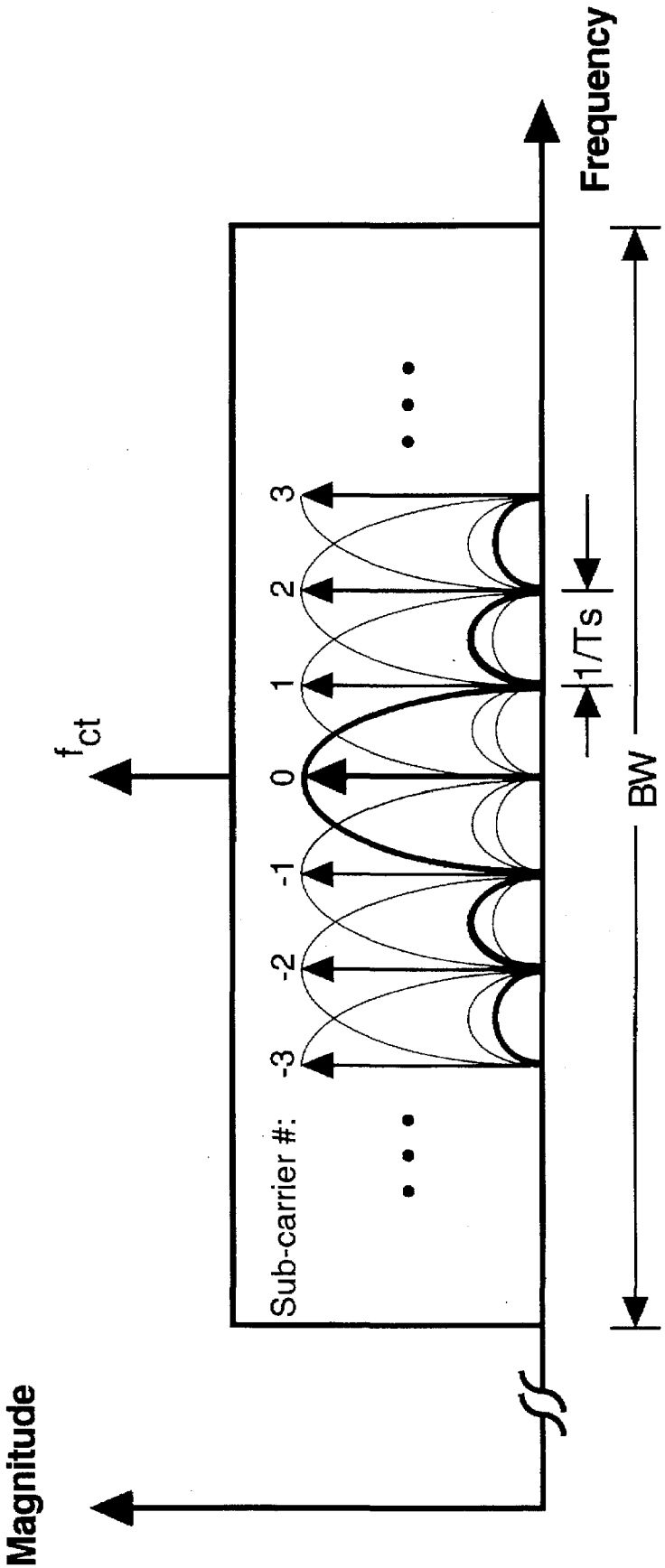


FIG. 2 (Prior Art)

DOCKET ALARM
Find authenticated court documents without watermarks at docketalarm.com.

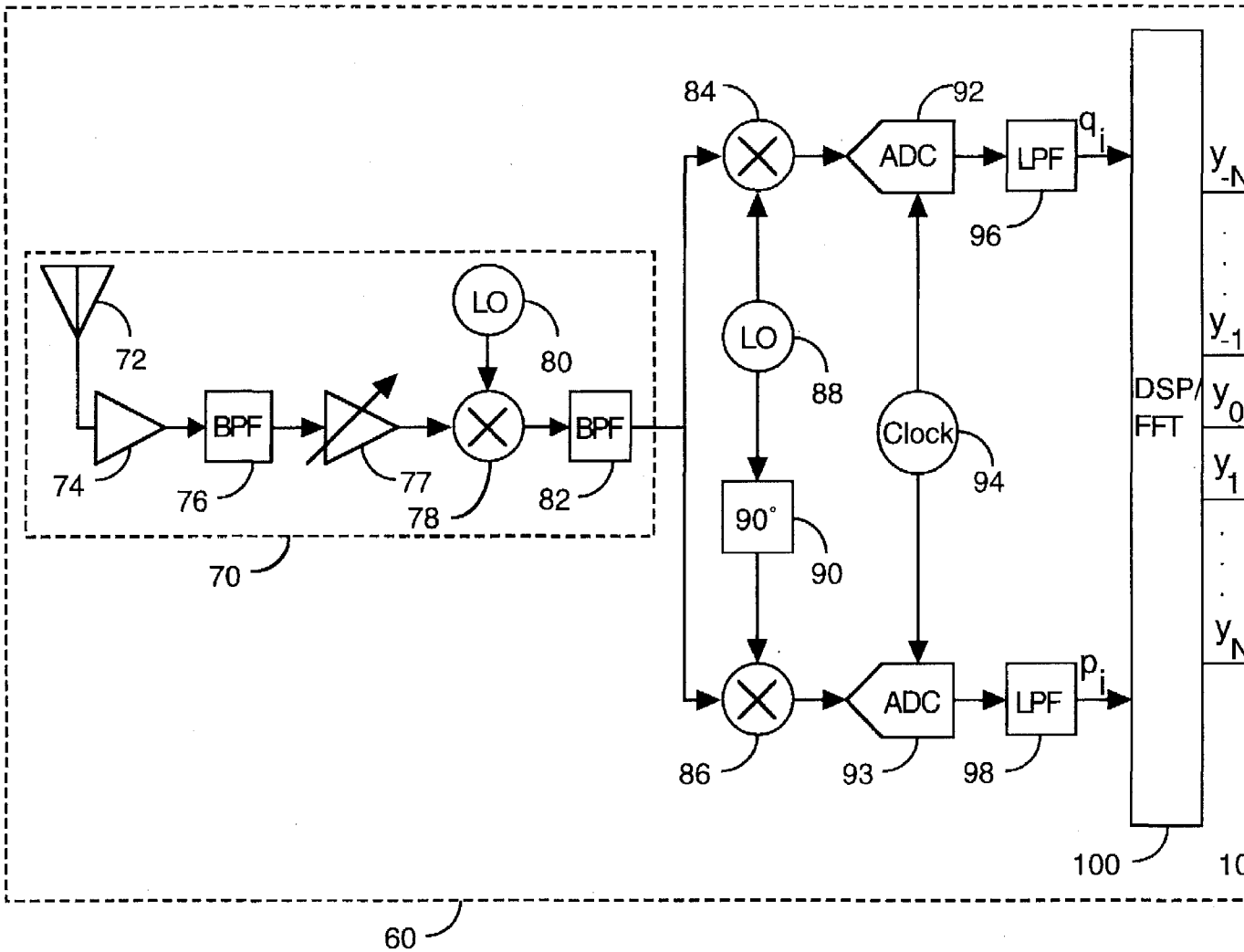


FIG. 3 (Prior Art)

DOCKET ALARM
Find authenticated court documents without watermarks at docketalarm.com.

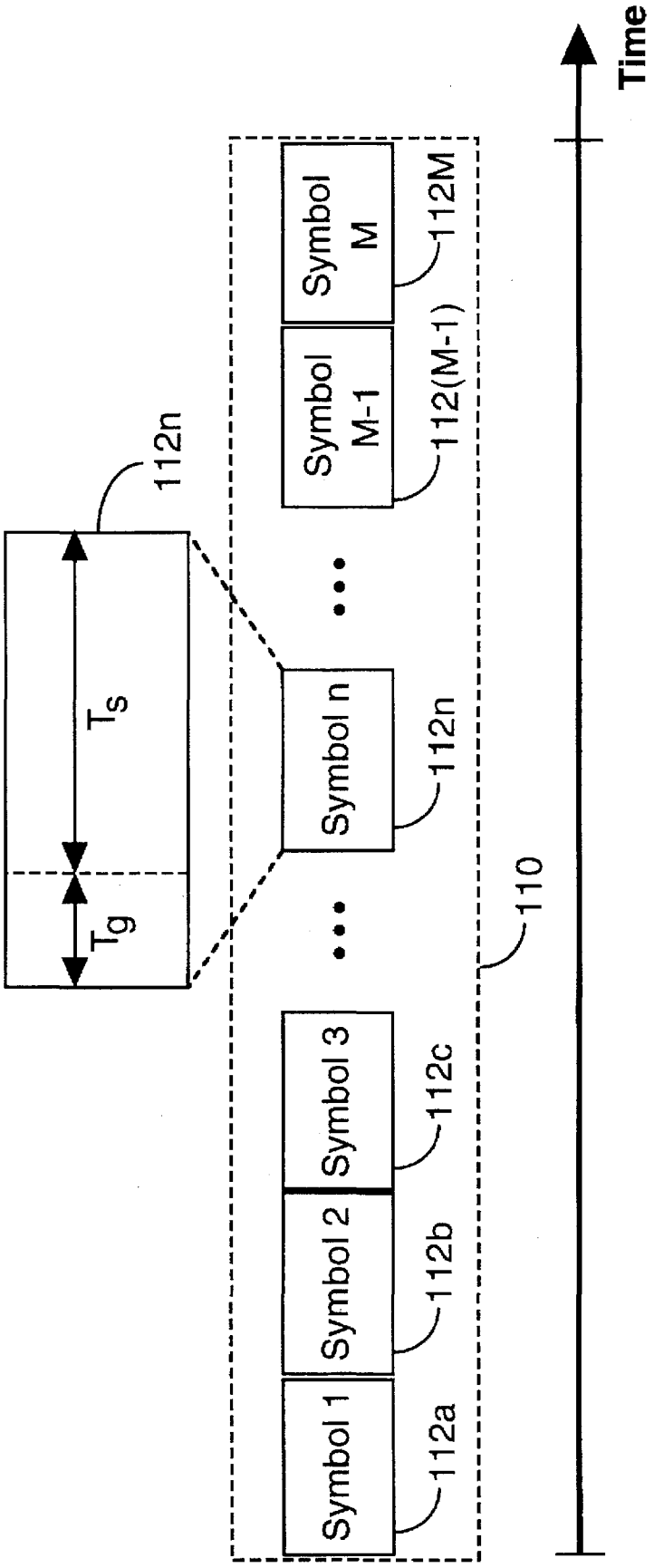


FIG. 4 (Prior Art)

DOCKET ALARM Find authenticated court documents without watermarks at docketalarm.com.

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS
Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS
Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS
Sync your system to PACER to automate legal marketing.