[54] **METHOD AND APPARATUS FOR FRAME SYNCHRONIZATION IN MOBILE OFDM DATA COMMUNICATION**

[75] Inventors: **Cybil S. Leung**, Richmond; **William D. Warner**, Maple Ridge, both of Canada

[73] Assignee: **The University of British Columbia**, Vancouver, Canada

[21] Appl. No.: **104,563**

[22] Filed: **Aug. 11, 1993**

[51] Int. Cl.^{6} **H04J 11/00**

[52] U.S. Cl. **370/19**; 370/69.1; 370/100.1; 375/362

[58] **Field of Search** 370/69.1, 20, 21, 23, 370/70, 74, 50, 121, 19, 100.1, 74; 375/98, 111, 97, 38; 455/59, 71, 54.1

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,101,738	7/1978	Bellanger et al.	370/74
4,438,511	3/1984	Baran	370/19
4,847,880	7/1989	Karmerman et al.	375/111
4,881,241	11/1989	Pommier et al.	375/38
5,012,491	4/1991	Iwasaki	375/97
5,063,574	11/1991	Moose	375/27
5,170,413	12/1992	Hess et al.	375/38
5,191,576	3/1993	Prommier et al.	370/18
5,228,025	7/1993	Le Floch et al.	370/20
5,274,629	12/1993	Helard et al.	375/38

FOREIGN PATENT DOCUMENTS

0008521	3/1980	European Pat. Off. .
0529421A2	3/1993	European Pat. Off. .

OTHER PUBLICATIONS

B. Hirosaki, A 19.2 kbps voiceband data modem based on orthogonally multiplexed QAM techniques, 1985, pp. 21.1.1–21.1.5.

W. E. Keasler, Reliable Data Communication Over the Voice Bandwidth Telephone Channel Using Orthagonal Frequency Division Multiplexing, University of Illinois, 1982.

P. H. Moose, Differential modulation and demodulation of multi–frequency digital communications signals, in Milcom 90, pp. 273–277 or 12.4.1–12.4.5, Oct., 1990.

E. F. Casas and C. Leung, A simple digital fading simulator for mobile radio, IEEE Transactions on Vehicular Technology, vol. 39, pp.205–212, Aug., 1990.

P. G. Moore and E. A. C. Shirley, Standard Statistical Calculations. New York: John Wiley & Sons, 1972.

(List continued on next page.)

Primary Examiner—Melvin Marcelo
Assistant Examiner—Chau T. Nguyen
Attorney, Agent, or Firm—Oyen Wiggs Green & Mutala

[57] **ABSTRACT**

A method and apparatus are disclosed for achieving symbol (frame) synchronization of digital data in an OFDM channel such as an OFDM/FM radio link. The method and apparatus are suitable for use in a pure ALOHA environment because synchronization is achieved on a frame-by-frame basis. The required bandwidth overhead is less than 10%. The bit-error-rate performance achievable with this technique is within 1.5 dB of the performance assuming ideal synchronization. The method and apparatus provide a three-stage synchronization process. First the onset of an ODFM frame is detected. Second, coarse synchronization is achieved by sampling the received signal, and measuring the correlation between the received signal and a reference signal. Coarse synchronization provides synchronization to within $\pm\frac{1}{2}$ sample period. The correlation is preferably carried out in the frequency domain after carrying out a Fast Fourier Transform on the sampled signal data. Third, synchronization is achieved by calculating the time-shift between the coarse synchronization point and the actual synchronization point and using the calculated time shift to determine the phase correction to apply to each data carrying sub-carrier. Finally the transmitted data is recovered by decoding the information obtained about the phase and amplitude of the data-carrying sub-carriers.

16 Claims, 19 Drawing Sheets
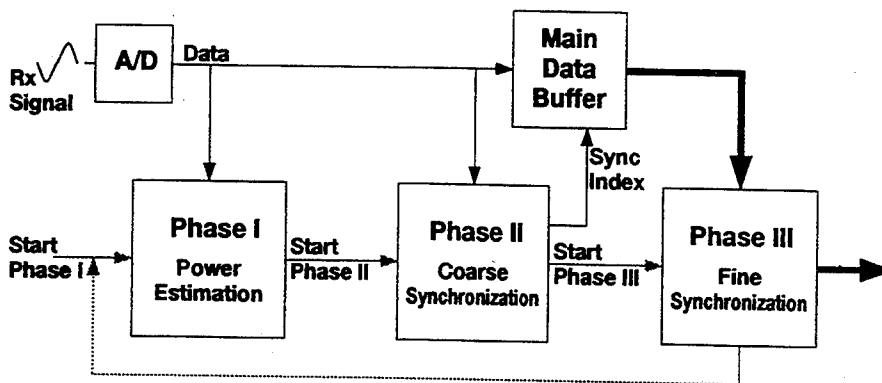
OTHER PUBLICATIONS

D. C. Cox, A Radio System proposal for Widespread Low–Power Tetherless Communications, IEEE Transactions on Communication, vol. 39, pp.324–335, Feb., 1991.

L. J. Cimini, Analysis and simulation of a digital mobile channel using orthogonal frequency division multiplexing, IEEE Transactions on Communications, vol. COM–33, pp. 665–675, Jul. 1985.

E. Casas and C. Leung, OFDM for Data Communication over Mobile Radio FMChannels, Part I: Analysis and Experimental Results, IEEE Transactions on Communications, vol. 39, pp. 783–793, May 1991.

B. R. Salzberg, Performance of an efficient parallel data transmission system, IEEE Transactions on Communications Technology, vol. COM–15, pp. 805–811, Dec. 1967.

S. B. Weinstein and P. M. Egert, Data Transmission by frequency–division multiplexing using the discrete Fourier transform, IEEE Transactions on Communications Technology, vol. COM–19, pp. 628–634, Oct., 1971.

J. A. C. Bingham, Multicarrier modulation for data transmission: An idea whose time has come, IEEE Communications Magazine, pp. 5–14, May, 1990.

Electronic Industries Association, Minimum standards for land mobile communiction FM or PM receivers, 25–947 MHz, Feb. 1970. EIA Standard RS–152–B.

Electronic Industries Association, Minimum standards for land mobile communication FM or PM receivers, 25–947 MHz, Jan. 1982. EIA Standard RS–204–C.

Electronic Industries Association, Minimum standards for portable/personal radio transmitters, receivers, and transmitter/receiver combination land mobile communications FM or PM equipment, 25–1000 MHz, May 1979. EIA Standard RS–316–B.

Abraham Peled and Antonio Ruiz, *Frequency Domain Data Transmission using Reduced Computational Complexity Algorithms,* ICASSP 80 Proceedings, vol. 3 of 3, 2 May, 1980 964–967.
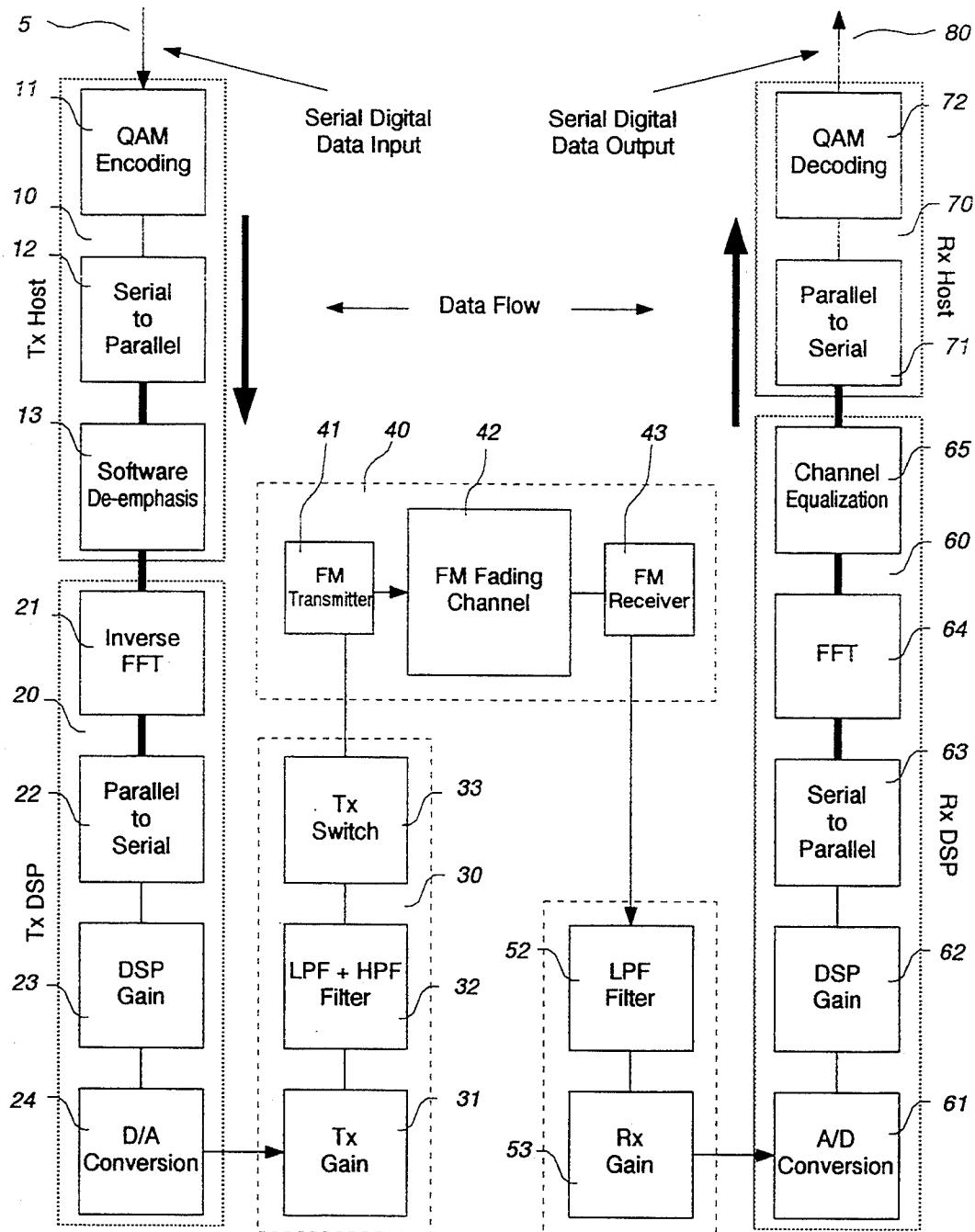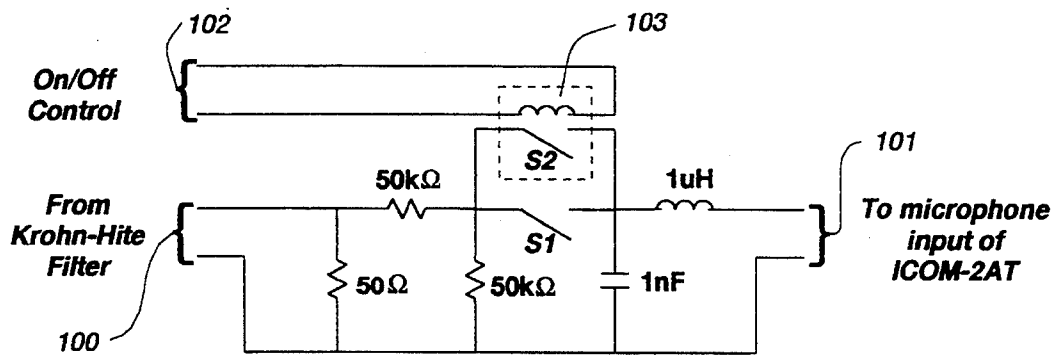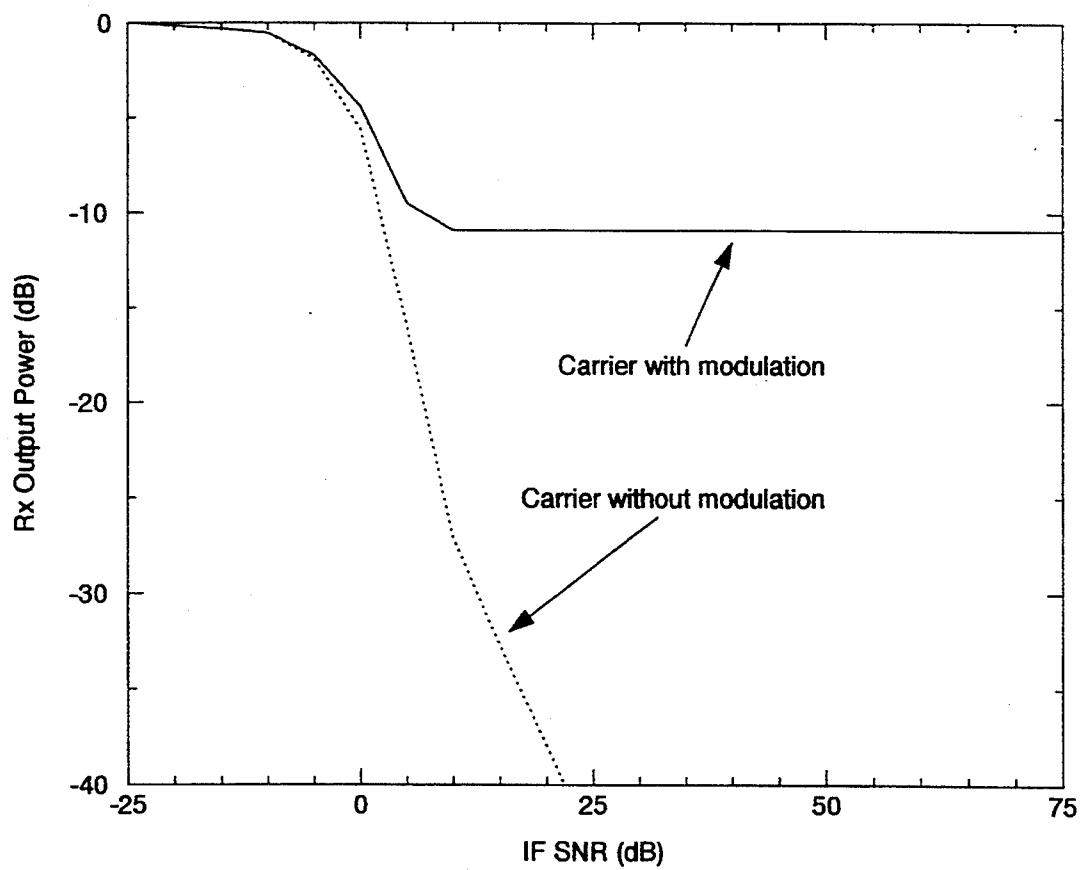
FIGURE 1

S1 - Manual Switch   S2 - Voltage Controlled Switch

FIGURE 2

FIGURE 3

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.