US005596604A

United States Patent [19]

Cioffi et al.

[11] Patent Number: 5,596,604

[45] Date of Patent: Jan. 21, 1997

[54] MULTICARRIER MODULATION TRANSMISSION SYSTEM WITH VARIABLE DELAY

[75] Inventors: **John M. Cioffi**, Cupertino; **Po Tong**, Fremont; **James T. Aslanis**, Mountain View; **Antoinette H. Gooch**, Palo Alto, all of Calif.

[73] Assignee: **Amati Communications Corporation**, San Jose, Calif.

[21] Appl. No.: **107,200**

[22] Filed: **Aug. 17, 1993**

[51] **Int. Cl.**[6] **H04K 1/10**

[52] **U.S. Cl.** **345/260**; 371/43; 371/35

[58] **Field of Search** 375/38, 39; 371/38.1, 371/39.1, 43, 35

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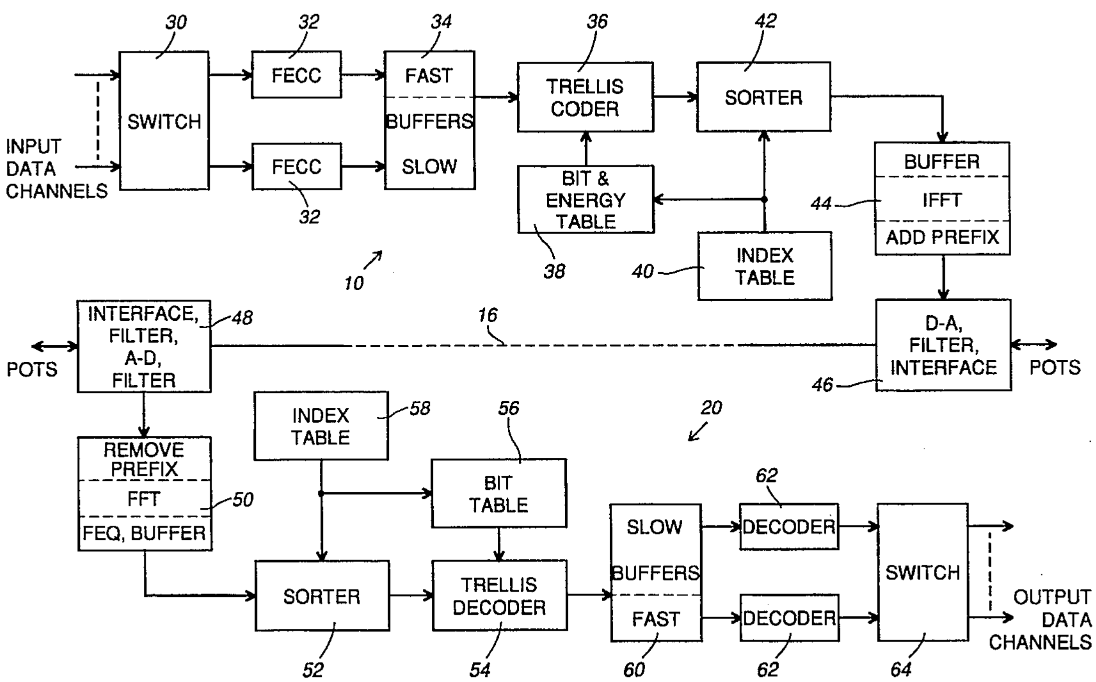
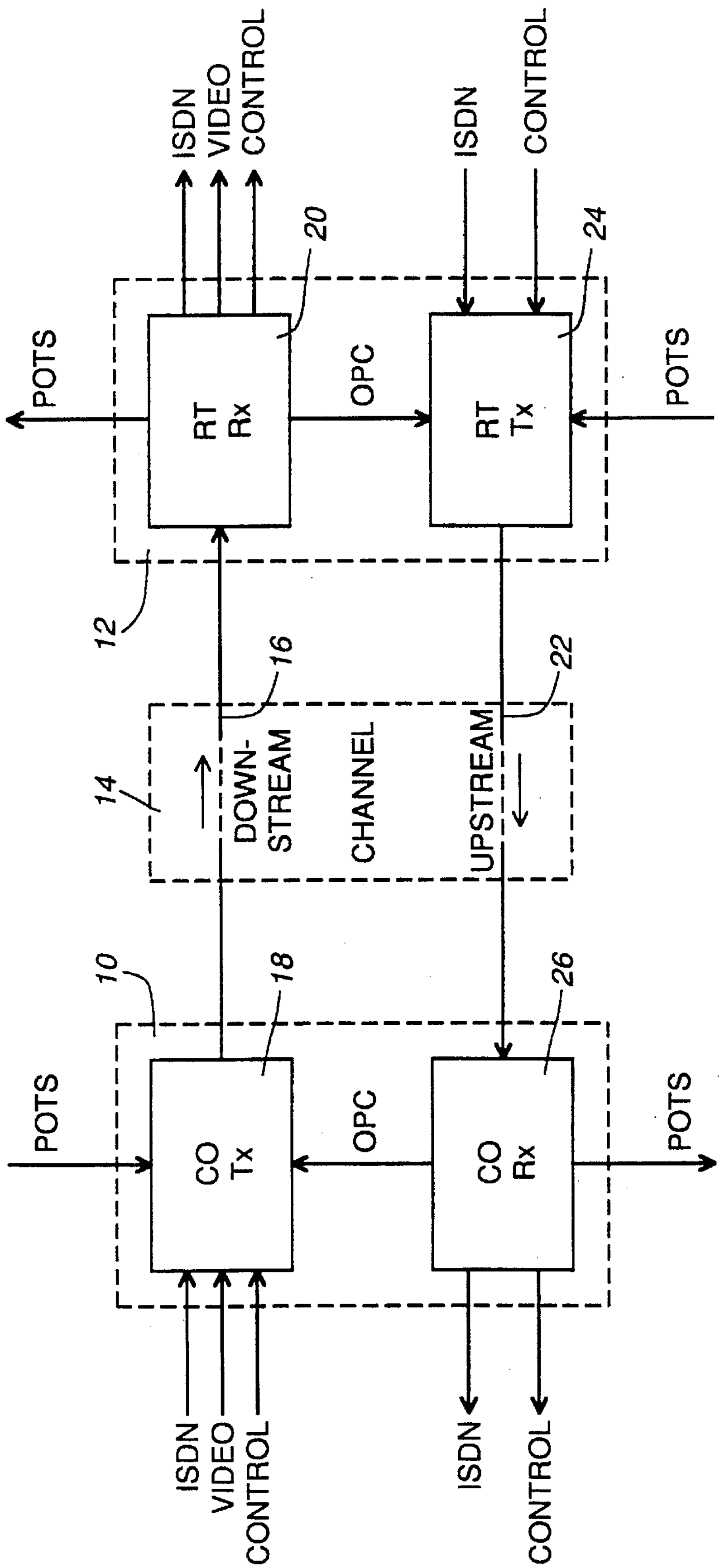
Primary Examiner—Stephen Chin
Assistant Examiner—T. Ghebretinsae
Attorney, Agent, or Firm—Hickman Beyer & Weaver, LLP

[57] **ABSTRACT**

A transmission system using multicarrier modulation applies FECC (forward error correcting code) coding and codeword interleaving differently to input signals from a plurality of different data channels to produce encoded data signals having different reliabilities and different coding delays. Bits of encoded data signals having relatively less delay are allocated to carriers that are subject to relatively more attenuation and/or channel noise, and hence that are allocated fewer bits for transmission in each symbol period, to reduce the effects of impulse noise. The data channels can comprise video, data, and control channels transmitted on an ADSL (asymmetric digital subscriber line) two-wire telephone line.

22 Claims, 3 Drawing Sheets

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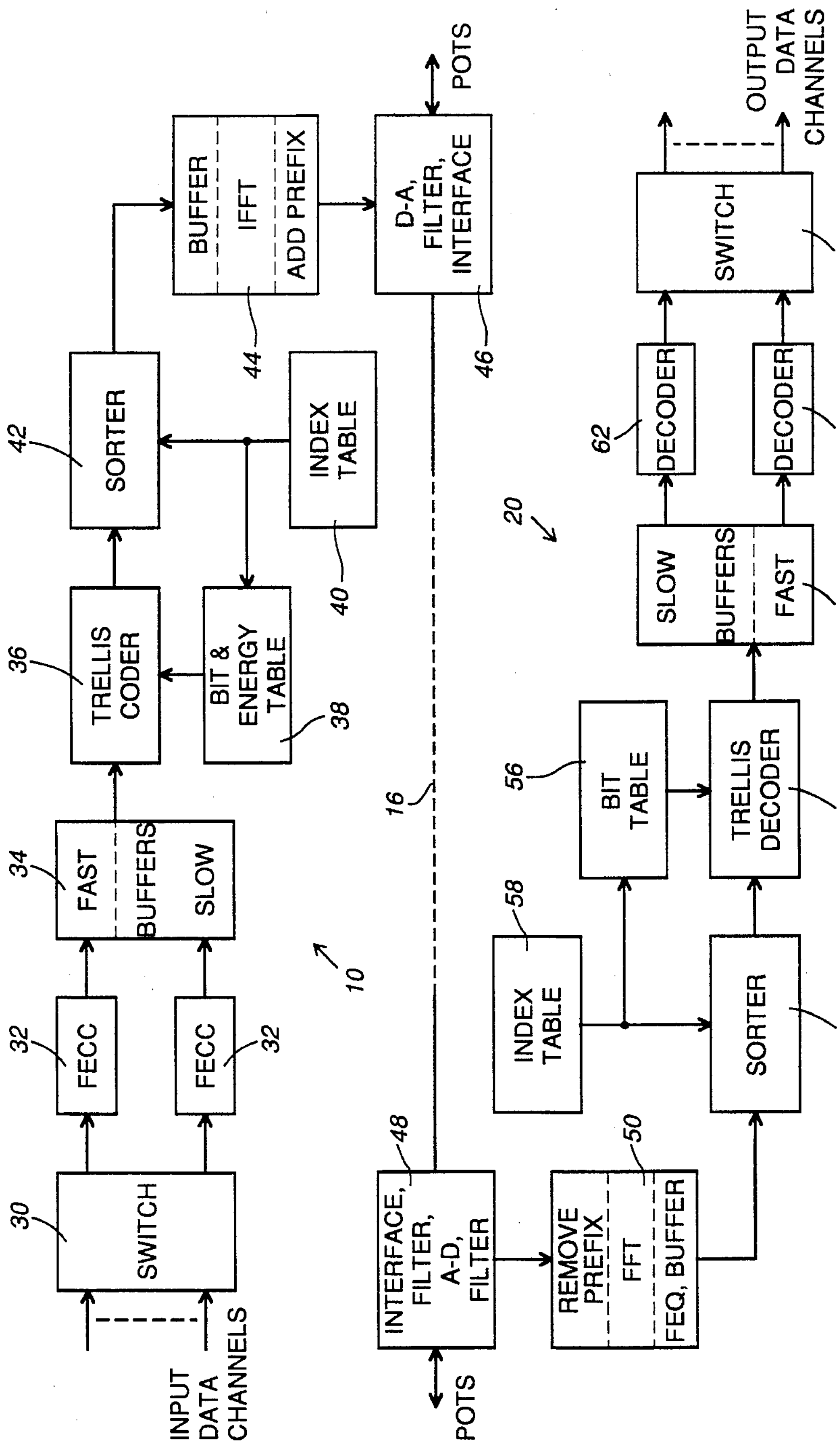
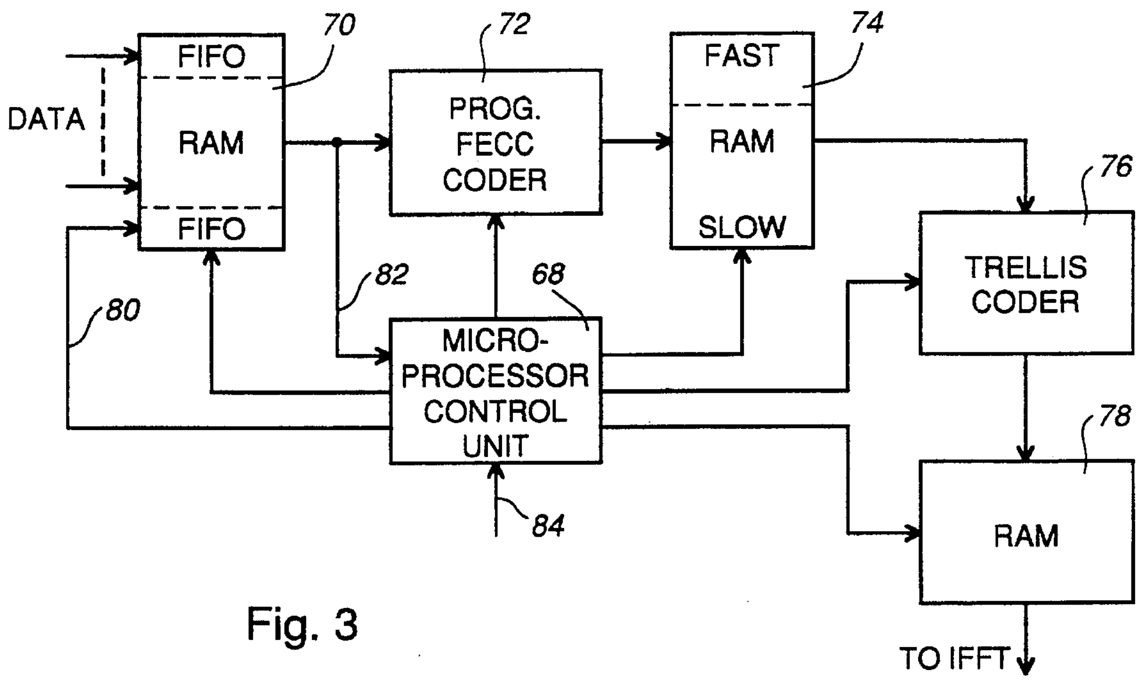
DOWN-
STREAM
CHANNEL
UPSTREAM
22
10
18
POTS
CO
Tx
ISDN
VIDEO
CONTROL
OPC
26
CO
Rx
ISDN
CONTROL
POTS

Fig. 1



INPUT DATA CHANNELS
SWITCH
30
FECC
32
FECC
32
FAST
BUFFERS
SLOW
34
TRELLIS CODER
36
BIT & ENERGY TABLE
38
SORTER
42
INDEX TABLE
40
BUFFER
IFFT
ADD PREFIX
44
D-A, FILTER, INTERFACE
46
POTS
10
16
20
INTERFACE, FILTER, A-D, FILTER
48
POTS
REMOVE PREFIX
FFT
FEQ, BUFFER
50
INDEX TABLE
58
SORTER
52
BIT TABLE
56
TRELLIS DECODER
54
SLOW
BUFFERS
FAST
60
DECODER
62
DECODER
62
SWITCH
64
OUTPUT DATA CHANNELS

Fig. 2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72
74
FIFO
RAM
FIFO
DATA
PROG.
FECC
CODER
FAST
RAM
SLOW
76
TRELLIS
CODER
82
68
80
MICRO-
PROCESSOR
CONTROL
UNIT
78
84
RAM
TO IFFT

Fig. 3

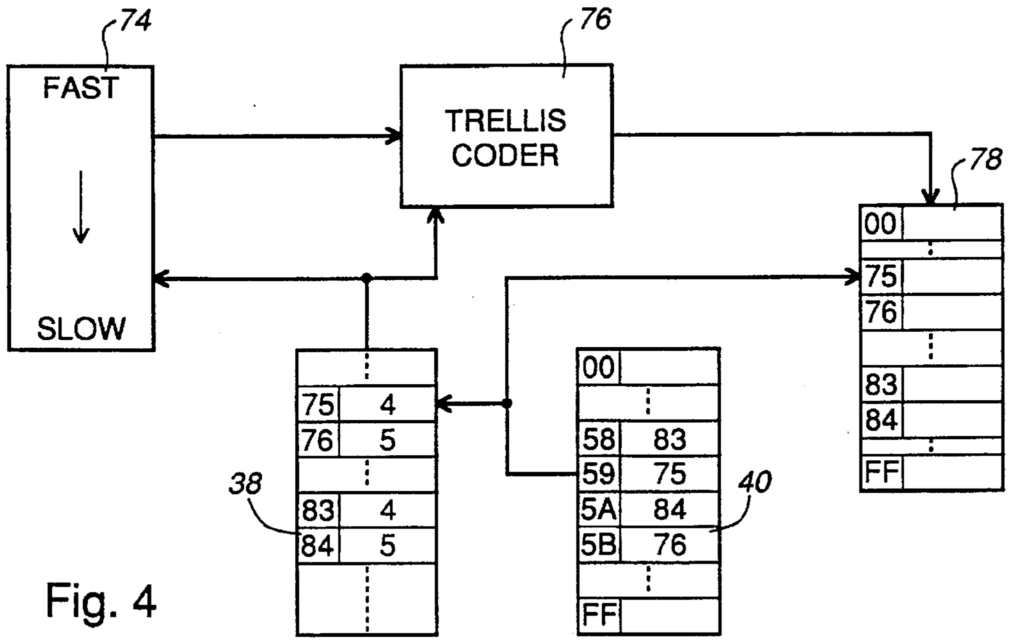
74
76
FAST
SLOW
TRELLIS
CODER
78
00
75
76
83
84
FF
00
58 83
59 75
5A 84
5B 76
FF
75 4
76 5
83 4
84 5
38
40

Fig. 4

MULTICARRIER MODULATION TRANSMISSION SYSTEM WITH VARIABLE DELAY

This invention relates to transmission systems using multicarrier modulation, also known as discrete multitone (DMT) modulation where, as is desirable, the modulation is effected using a discrete Fourier Transform.

BACKGROUND OF THE INVENTION

The principles of multicarrier modulation are described for example in "Multicarrier Modulation For Data Transmission: An Idea Whose Time Has Come" by John A. C. Bingham, IEEE Communications Magazine, Vol. 28, No. 5, pages 5–14, May 1990. As is known, in a transmission system using multicarrier modulation, FDM (frequency division multiplex) carriers spaced within a usable frequency band of a transmission channel, forming a set of subchannels, are modulated at a block or symbol transmission rate of the system. The bits of input data for transmission within each block or symbol period are allocated to the carriers or subchannels so that the bit error rates of the subchannels as monitored at the receiver, are substantially equal. As a result, the different subchannels carry different numbers of bits in each symbol period. With an appropriate allocation of bits and transmit powers to the carriers or subchannels, such a system provides a desirable performance.

The characteristics and performance of one such system, for communicating data at a rate of 1.6 Mb/s over a twisted pair channel using 256 subchannels, is described in "A Discrete Multitone Transceiver System For HDSL Applications" by J. S. Chow et al., IEEE Journal On Selected Areas In Communications, Vol. 9, No. 6, pages 895–908, August 1991. A companion paper by P. S. Chow et al. entitled "Performance Evaluation Of A Multichannel Transceiver System For ADSL and VHDSL Services", at pages 909–919 of the same publication, addresses a similar system applied to an asymmetric digital subscriber line (ADSL).

An article by S. Fleming et al. entitled "ADSL: The on-ramp to the information highway", Telephony, Jul. 12, 1993, pages 20–26 describes one example of an ADSL arrangement applied to a two-wire telephone subscriber line, in which four asymmetric 1.5 Mb/s channels are provided for transmission in a downstream direction from a telephone CO (central office) to a subscriber, in addition to various data channels and POTS (plain old telephone service) carried symmetrically (i.e. bidirectionally) on the line. The data channels for example comprise an ISDN (integrated services digital network) H0 channel at 384 kb/s or an ISDN basic access channel at 144 kb/s, and a control channel for example at a bit rate of 16 kb/s. The four asymmetric channels provide a total bandwidth of 6 Mb/s that can be used for digital video signals.

A well known problem in the art of transmission systems is that of impulse noise, which can produce bursts of errors on transmission channels. In order to address this problem, it is known to apply forward error correction coding (FECC) and interleaving techniques in which a block of input data to be transmitted is augmented with parity data that enables one or more errors in the block to be detected and corrected, the input data and parity data constituting a codeword, and over time parts of different codewords are interleaved for transmission to reduce the effect of error bursts on individual codewords. For example, Sheets U.S. Pat. No. 4,394,642 issued Jul. 19, 1983 and entitled "Apparatus For Interleaving and De-Interleaving Data" describes one such arrangement. The interleaving can instead be convolutional interleaving, for example as described in Section 8.3.1.2 of "Error-Correction Coding for Digital Communications" by George C. Clark, Jr. and J. Bibb Cain, Plenum Press, pages 347–349.

The use of FECC increases the bit rate required of the actual transmission system in dependence upon the parity overhead, i.e. the size of the parity data relative to the codeword size, and increases complexity. The interleaving process increases immunity to error bursts due to impulse noise, but adds transmission delay. Longer periods over which the interleaving is effected result in greater immunity to impulse noise, but greater transmission delays. Thus there is a trade-off between high reliability (requiring effective error correction and immunity to impulse noise) and short transmission delay.

Different types of signals, which may be required to be transmitted via a single transmission system, may have different requirements for reliability and transmission delay. For example, digital video signals that are highly compressed require a high reliability for their transmission, and ISDN voice signals must meet strict transmission delay requirements. In known transmission systems, it has been necessary to provide a compromise between high reliability and transmission delay for different types of signals.

It is also known to apply trellis code modulation (TCM) techniques to a system using multicarrier modulation in order to improve the performance of the system through the coding gain provided by the trellis coding. For example, Decker et al. U.S. Pat. No. 4,980,897 issued Dec. 25, 1990 and entitled "Multi-Channel Trellis Encoder/Decoder" discloses such a system in which the encoding and decoding processes operate on all of the subchannels sequentially in order to reduce delay. As is well known, TCM results in sequences of transmitted signal constellation points that have a greatly increased separation, hence the improved performance, and necessitates more complex decoding involving maximum likelihood sequence estimation, usually implemented using the Viterbi algorithm.

The performance improvements that are provided by TCM and by FECC as described above are largely independent of one another, so that TCM and FECC can be used together in a transmission system.

In Betts et al. U.S. Pat. No. 4,677,625 issued Jun. 30, 1987 and entitled "Distributed Trellis Encoder" there is described an FECC arrangement in which interleaving is effected by switching among a plurality of trellis coders with delay units, with corresponding switching among a plurality of trellis decoders at a receiver. The use of a plurality of encoders and decoders in such a manner undesirably adds to the costs and complexity of the arrangement. The Betts et al. patent relates to a transmission system using QAM (quadrature amplitude modulation) of a single carrier, and not to a transmission system using multicarrier modulation.

An object of this invention is to provide an improved transmission system using multicarrier modulation.

SUMMARY OF THE INVENTION

According to one aspect of this invention there is provided a data transmission system using multicarrier modulation, comprising: FECC (forward error correction code) coding and codeword interleaving apparatus arranged for

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