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Attorneys for Plaintiff VIZIO, Inc.

UNITED STATES DISTRICT COURT

CENTRAL DISTRICT OF CALIFORNIA

VIZIO, INC.,
a California corporation,

Plaintiff,

v.

COBY ELECTRONICS CORP., a New York corporation; CURTIS INTERNATIONAL, LTD., a Canadian corporation; E&S INTERNATIONAL ENTERPRISES, INC. (d/b/a Viore, Inc.), a California corporation; ON CORP US, INC., a Delaware corporation; SCEPTRE, INC., a California corporation; WESTINGHOUSE DIGITAL, LLC, a Delaware corporation,

Defendants.

CV11 04381 AHM AJWx

Case No.

Assigned for all purposes to

COMPLAINT FOR PATENT INFRINGEMENT

DEMAND FOR JURY TRIAL

IS 21 (P)

Plaintiff VIZIO, Inc., for its Complaint against Defendants Coby Electronics Corp., Curtis International, Ltd., E&S International Enterprises, Inc. (d/b/a Viore, Inc.), ON Corp US, Inc., Sceptre, Inc., and Westinghouse Digital, LLC alleges as follows:

NATURE OF THE ACTION

1. This is a civil action for infringement of United States Patent Nos. 5,511,096, 5,621,761, 5,703,887, 5,745,522, and 5,511,082. This action is based upon the patent laws of the United States, 35 U.S.C. § 1 et seq.

THE PARTIES

2. Plaintiff VIZIO, Inc. ("VIZIO") is a corporation organized and existing under the laws of the State of California with its principal place of business at 39 Tesla, Irvine, California 92618. VIZIO is a leading seller of LCD display televisions in the United States.

3. Defendant Coby Electronics Corp. ("Coby") is a corporation organized and existing under the laws of the State of New York with its principal place of business at 1991 Marcus Avenue, Suite 301, Lake Success, New York 11042. Coby and subsidiaries acting at its direction and under its control manufacture, use, offer for sale, sell, supply and/or import, *inter alia*, LCD display televisions.

4. Defendant Curtis International, Ltd. ("Curtis") is a Canadian corporation with its principal place of business at 315 Attwell Drive, Etobicoke, Ontario M9W 5C1, Canada. Curtis and subsidiaries acting at its direction and under its control manufacture, use, offer for sale, sell, supply and/or import, *inter alia*, LCD display televisions.

5. Defendant E&S International Enterprises, Inc. ("ESI") is a corporation organized and existing under the laws of the State of California with its principal place of business at 7801 Hayvenhurst Avenue, Van Nuys, California 91406. ESI, doing business as "Viore, Inc.," and subsidiaries acting at its direction and under its control manufacture, use, offer for sale, sell, supply and/or import, *inter alia*, LCD display televisions.

6. Defendant ON Corp US, Inc. ("ON Corp") is a corporation organized and existing under the laws of the State of Delaware with its principal place of business at 4370 La Jolla Village Drive, Suite 400, San Diego, California 92122.

ON Corp and subsidiaries acting at its direction and under its control manufacture, use, offer for sale, sell, supply and/or import, *inter alia*, LCD display televisions.

7. Defendant Sceptre, Inc. ("Sceptre") is a corporation organized and existing under the laws of the State of California with its principal place of business at 16800 East Gale Avenue, City of Industry, California 91745. Sceptre and subsidiaries acting at its direction and under its control manufacture, use, offer for sale, sell, supply and/or import, *inter alia*, LCD display televisions.

8. Defendant Westinghouse Digital, LLC ("Westinghouse") is a corporation organized and existing under the laws of the State of Delaware with its principal place of business at 1F Yue Thai Commercial Building, 128 Connaught Road, Central Hong Kong 19801. Upon information and belief, Westinghouse has a business office in California located at 500 North State College Boulevard, Suite 1300, Orange, California 92868. Westinghouse and subsidiaries acting at its direction and under its control manufacture, use, offer for sale, sell, supply and/or import, *inter alia*, LCD display televisions.

9. Coby, Curtis, ESI, ON Corp, Sceptre, and Westinghouse are hereafter referred to collectively as "Defendants."

10. Upon information and belief, this action arises out of the same transaction, occurrence, or series of transactions or occurrences and at least one question of law or fact is common to all Defendants in this action. In particular, upon information and belief, Defendants manufacture, use, offer for sale, sell, supply and/or import televisions incorporating common circuitry for decoding and displaying digital cable television signals encoded according to a standard protocol where such common circuitry infringes one or more claims of the patents-in-suit. Additionally, upon information and belief, ESI, ON Corp, Sceptre and Westinghouse knowingly and actively induce direct infringement by third parties of one or more claims of each of the patents-in-suit by their manufacture, use, offering for sale, sale, supplying and/or importation of televisions, and encouraging third

parties to directly infringe by reselling such televisions and/or decoding digital cable television signals encoded according to a standard protocol.

JURISDICTION AND VENUE

11. This action arises under the patent laws of the United States, Title 35, United States Code.

12. This Court has original jurisdiction over the subject matter of this patent infringement action pursuant to the provisions of 28 U.S.C. §§ 1331 and 1338(a).

13. Defendant Coby is subject to personal jurisdiction in the State of California because it transacts business in this judicial district, including: (i) regularly and systematically offering for sale and selling their products (including infringing televisions) through California retailers who in turn resell the products to California consumers and (ii) regularly soliciting business from, doing business with, and deriving revenue from goods (including infringing televisions) and services provided to, customers in this district. Coby has also committed acts of direct infringement of one or more of the claims of one or more of the patents-in-suit in this judicial district.

14. Defendant Curtis is subject to personal jurisdiction in the State of California because it transacts business in this judicial district, including: (i) regularly and systematically offering for sale and selling their products (including infringing televisions) through retailers who in turn resell the products to California consumers and (ii) regularly soliciting business from, doing business with, and deriving revenue from goods (including infringing televisions) and services provided to, customers in this district. Curtis has also committed acts of direct infringement of one or more of the claims of one or more of the patents-in-suit in this judicial district.

15. Defendant ESI is subject to personal jurisdiction in the State of California because it is a California corporation and has designated an agent for

service of process in the State of California. In addition, ESI transacts business in this judicial district, including: (i) regularly and systematically offering for sale and selling their products (including infringing televisions) through retailers who in turn resell the products to California consumers and (ii) regularly soliciting business from, doing business with, and deriving revenue from goods (including infringing televisions) and services provided to, customers in this district. ESI has also committed acts of direct infringement and inducement of infringement, of one or more of the claims of one or more of the patents-in-suit in this judicial district.

16. Defendant ON Corp is subject to personal jurisdiction in the State of California because it operates a principal place of business and has designated an agent for service of process in the State of California. In addition, ON Corp transacts business in this judicial district, including: (i) regularly and systematically offering for sale and selling their products (including infringing televisions) through California retailers who in turn resell the products to California consumers and (ii) regularly soliciting business from, doing business with, and deriving revenue from goods (including infringing televisions) and services provided to, customers in this district. ON Corp has also committed acts of direct infringement and inducement of infringement, of one or more of the claims of one or more of the patents-in-suit in this judicial district.

17. Defendant Sceptre is subject to personal jurisdiction in the State of California because it is a California corporation and has designated an agent for service of process in the State of California. In addition, Sceptre transacts business in this judicial district, including: (i) regularly and systematically offering for sale and selling their products (including infringing televisions) through retailers who in turn resell the products to California consumers and (ii) regularly soliciting business from, doing business with, and deriving revenue from goods (including infringing televisions) and services provided to, customers in this district. Sceptre has also committed acts of direct infringement and inducement of infringement, of

one or more of the claims of one or more of the patents-in-suit in this judicial district.

18. Defendant Westinghouse is subject to personal jurisdiction in the State of California because it transacts business in this judicial district, including: (i) regularly and systematically offering for sale and selling their products (including infringing televisions) through California retailers who in turn resell the products to California consumers and (ii) regularly soliciting business from, doing business with, and deriving revenue from goods (including infringing televisions) and services provided to, customers in this district. In addition, upon information and belief, Westinghouse has a business office located in California. Westinghouse has also committed acts of direct infringement and inducement of infringement, of one or more of the claims of one or more of the patents-in-suit in this judicial district.

19. Venue is proper in this judicial district pursuant to 28 U.S.C. §§ 1391(b), 1391(c), and 1391(d), as well as 28 U.S.C. § 1400(b).

THE ASSERTED PATENTS

20. On April 23, 1996, the United States Patent and Trademark Office ("USPTO") issued U.S. Patent No. 5,511,096 titled "Quadrature Amplitude Modulated Data for Standard Bandwidth Television Channel" (hereafter "the '096 Patent"). A true and correct copy of the '096 Patent is attached hereto as Exhibit A.

21. On April 15, 1997, the USPTO issued U.S. Patent No. 5,621,761 titled "Rotationally Invariant Trellis Coding Incorporating Transparent Binary Convolutional Codes" (hereafter "the '761 Patent"). A true and correct copy of the '761 Patent is attached hereto as Exhibit B.

22. On December 30, 1997, the USPTO issued U.S. Patent No. 5,703,887 titled "Synchronization and Error Detection in a Packetized Data Stream" (hereafter "the '887 Patent"). A true and correct copy of the '887 Patent is attached hereto as Exhibit C.

23. On April 28, 1998, the USPTO issued U.S. Patent No. 5,745,522 titled "Randomizer for Byte-Wise Scrambling of Data" (hereafter "the '522 Patent"). A true and correct copy of the '522 Patent is attached hereto as Exhibit D.

24. On April 23, 1996, the USPTO issued U.S. Patent No. 5,511,082 titled "Punctured Convolutional Encoder" (hereafter "the '082 Patent"). A true and correct copy of the '082 Patent is attached hereto as Exhibit E.

25. The '096 Patent, the '761 Patent, the '887 Patent, the '522 Patent, and the '082 Patent are hereafter collectively referred to as the VIZIO Patents.

COUNT I

(PATENT INFRINGEMENT OF THE '096 PATENT)

26. VIZIO repeats, realleges, and incorporates by reference, as though fully set forth herein, the preceding paragraphs.

27. VIZIO is the owner by assignment of all right, title and interest in the '096 Patent, with the full and exclusive right to bring suit to enforce the '096 Patent and recover for past infringement.

28. Upon information and belief, in violation of 35 U.S.C. § 271, Defendants have infringed, and are continuing to infringe either literally and/or under the doctrine of equivalents, the '096 Patent by their manufacture, use, offering for sale, sale, and/or importation of televisions in the United States.

29. Defendant ESI was given notice of VIZIO's rights in the '096 Patent by at least February of 2010.

30. Defendant ON Corp was given notice of VIZIO's rights in the '096 Patent by at least May of 2010.

31. Defendant Sceptre was given notice of VIZIO's rights in the '096 Patent by at least July of 2010.

32. Defendant Westinghouse was given notice of VIZIO's rights in the '096 Patent by at least February of 2010.

33. Upon information and belief, in violation of 35 U.S.C § 271, Defendants ESI, ON Corp, Sceptre, and Westinghouse have infringed, and are continuing to infringe the '096 Patent by actively inducing others to infringe one or more claims of the '096 Patent by manufacture, use, offering for sale, sale, supplying and/or importation of televisions in the United States.

34. As a result of Defendants' infringement, VIZIO has suffered, and will continue to suffer damages.

35. VIZIO is entitled to recover from Defendants the damages it has sustained as a result of Defendants' infringing acts in an amount subject to proof at trial. VIZIO is also entitled to its costs of suit and interest.

36. Upon information and belief, Defendants ESI, ON Corp, Sceptre, and Westinghouse's acts of infringement are willful and in conscious disregard of VIZIO's patent rights, and the resulting damage to VIZIO is such as to warrant the trebling of damages to provide just compensation pursuant to 35 U.S.C. § 284.

37. Unless Defendants are enjoined by this Court from continuing its infringement of the '096 Patent, VIZIO will suffer additional irreparable harm and impairment of the value of its patent rights.

COUNT II

(PATENT INFRINGEMENT OF THE '761 PATENT)

38. VIZIO repeats, realleges, and incorporates by reference, as though fully set forth herein, the preceding paragraphs.

39. VIZIO is the owner by assignment of all right, title and interest in the '761 Patent, with the full and exclusive right to bring suit to enforce the '761 Patent and recover for past infringement.

40. Upon information and belief, in violation of 35 U.S.C. § 271, Defendants have infringed, and are continuing to infringe either literally and/or under the doctrine of equivalents, the '761 Patent by their manufacture, use, offering for sale, sale, and/or importation of televisions in the United States.

41. Defendant ESI was given notice of VIZIO's rights in the '761 Patent by at least February of 2010.

42. Defendant ON Corp was given notice of VIZIO's rights in the '761 Patent by at least May of 2010.

43. Defendant Sceptre was given notice of VIZIO's rights in the '761 Patent by at least July of 2010.

44. Defendant Westinghouse was given notice of VIZIO's rights in the '761 Patent by at least February of 2010.

45. Upon information and belief, in violation of 35 U.S.C § 271, Defendants ESI, ON Corp, Sceptre, and Westinghouse have infringed, and are continuing to infringe the '761 Patent by actively inducing others to infringe one or more claims of the '761 Patent by manufacture, use, offering for sale, sale, supplying and/or importation of televisions in the United States.

46. As a result of Defendants' infringement, VIZIO has suffered, and will continue to suffer damages.

47. VIZIO is entitled to recover from Defendants the damages it has sustained as a result of Defendants' infringing acts in an amount subject to proof at trial. VIZIO is also entitled to its costs of suit and interest.

48. Upon information and belief, Defendants ESI, ON Corp, Sceptre, and Westinghouse's acts of infringement are willful and in conscious disregard of VIZIO's patent rights, and the resulting damage to VIZIO is such as to warrant the trebling of damages to provide just compensation pursuant to 35 U.S.C. § 284.

49. Unless Defendants are enjoined by this Court from continuing its infringement of the '761 Patent, VIZIO will suffer additional irreparable harm and impairment of the value of its patent rights.

COUNT III

(PATENT INFRINGEMENT OF THE '887 PATENT)

50. VIZIO repeats, realleges, and incorporates by reference, as though fully set forth herein, the preceding paragraphs.

51. VIZIO is the owner by assignment of all right, title and interest in the '887 Patent, with the full and exclusive right to bring suit to enforce the '887 Patent and recover for past infringement.

52. Upon information and belief, in violation of 35 U.S.C. § 271, Defendants have infringed, and are continuing to infringe either literally and/or under the doctrine of equivalents, the '887 Patent by their manufacture, use, offering for sale, sale, and/or importation of televisions in the United States.

53. Defendant ESI was given notice of VIZIO's rights in the '887 Patent by at least February of 2010.

54. Defendant ON Corp was given notice of VIZIO's rights in the '887 Patent by at least May of 2010.

55. Defendant Sceptre was given notice of VIZIO's rights in the '887 Patent by at least July of 2010.

56. Defendant Westinghouse was given notice of VIZIO's rights in the '887 Patent by at least February of 2010.

57. Upon information and belief, in violation of 35 U.S.C § 271, Defendants ESI, ON Corp, Sceptre, and Westinghouse have infringed, and are continuing to infringe the '887 Patent by actively inducing others to infringe one or more claims of the '887 Patent by manufacture, use, offering for sale, sale, supplying and/or importation of televisions in the United States.

58. As a result of Defendants' infringement, VIZIO has suffered, and will continue to suffer damages.

59. VIZIO is entitled to recover from Defendants the damages it has sustained as a result of Defendants' infringing acts in an amount subject to proof at trial. VIZIO is also entitled to its costs of suit and interest.

60. Upon information and belief, Defendants ESI, ON Corp, Sceptre, and Westinghouse's acts of infringement are willful and in conscious disregard of VIZIO's patent rights, and the resulting damage to VIZIO is such as to warrant the trebling of damages to provide just compensation pursuant to 35 U.S.C. § 284.

61. Unless Defendants are enjoined by this Court from continuing its infringement of the '887 Patent, VIZIO will suffer additional irreparable harm and impairment of the value of its patent rights.

COUNT IV

(PATENT INFRINGEMENT OF THE '522 PATENT)

62. VIZIO repeats, realleges, and incorporates by reference, as though fully set forth herein, the preceding paragraphs.

63. VIZIO is the owner by assignment of all right, title and interest in the '522 Patent, with the full and exclusive right to bring suit to enforce the '522 Patent and recover for past infringement.

64. Upon information and belief, in violation of 35 U.S.C. § 271, Defendants have infringed, and are continuing to infringe either literally and/or under the doctrine of equivalents, the '522 Patent by their manufacture, use, offering for sale, sale, and/or importation of televisions in the United States.

65. Defendant ESI was given notice of VIZIO's rights in the '522 Patent by at least February of 2010.

66. Defendant ON Corp was given notice of VIZIO's rights in the '522 Patent by at least May of 2010.

67. Defendant Sceptre was given notice of VIZIO's rights in the '522 Patent by at least July of 2010.

68. Defendant Westinghouse was given notice of VIZIO's rights in the '522 Patent by at least February of 2010.

69. Upon information and belief, in violation of 35 U.S.C § 271, Defendants ESI, ON Corp, Sceptre, and Westinghouse have infringed, and are continuing to infringe the '522 Patent by actively inducing others to infringe one or more claims of the '522 Patent by manufacture, use, offering for sale, sale, supplying and/or importation of televisions in the United States.

70. As a result of Defendants' infringement, VIZIO has suffered, and will continue to suffer damages.

71. VIZIO is entitled to recover from Defendants the damages it has sustained as a result of Defendants' infringing acts in an amount subject to proof at trial. VIZIO is also entitled to its costs of suit and interest.

72. Upon information and belief, Defendants ESI, ON Corp, Sceptre, and Westinghouse's acts of infringement are willful and in conscious disregard of VIZIO's patent rights, and the resulting damage to VIZIO is such as to warrant the trebling of damages to provide just compensation pursuant to 35 U.S.C. § 284.

73. Unless Defendants are enjoined by this Court from continuing its infringement of the '522 Patent, VIZIO will suffer additional irreparable harm and impairment of the value of its patent rights.

COUNT V

(PATENT INFRINGEMENT OF THE '082 PATENT)

74. VIZIO repeats, realleges, and incorporates by reference, as though fully set forth herein, the preceding paragraphs.

75. VIZIO is the owner by assignment of all right, title and interest in the '082 Patent, with the full and exclusive right to bring suit to enforce the '082 Patent and recover for past infringement.

76. Upon information and belief, in violation of 35 U.S.C. § 271, Defendants have infringed, and are continuing to infringe either literally and/or

under the doctrine of equivalents, the '082 Patent by their manufacture, use, offering for sale, sale, and/or importation of televisions in the United States.

77. Defendant ESI was given notice of VIZIO's rights in the '082 Patent by at least February of 2010.

78. Defendant ON Corp was given notice of VIZIO's rights in the '082 Patent by at least May of 2010.

79. Defendant Sceptre was given notice of VIZIO's rights in the '082 Patent by at least July of 2010.

80. Defendant Westinghouse was given notice of VIZIO's rights in the '082 Patent by at least February of 2010.

81. Upon information and belief, in violation of 35 U.S.C § 271, Defendants ESI, ON Corp, Sceptre, and Westinghouse have infringed, and are continuing to infringe the '082 Patent by actively inducing others to infringe one or more claims of the '082 Patent by manufacture, use, offering for sale, sale, supplying and/or importation of televisions in the United States.

82. As a result of Defendants' infringement, VIZIO has suffered, and will continue to suffer damages.

83. VIZIO is entitled to recover from Defendants the damages it has sustained as a result of Defendants' infringing acts in an amount subject to proof at trial. VIZIO is also entitled to its costs of suit and interest.

84. Upon information and belief, Defendants ESI, ON Corp, Sceptre, and Westinghouse's acts of infringement are willful and in conscious disregard of VIZIO's patent rights, and the resulting damage to VIZIO is such as to warrant the trebling of damages to provide just compensation pursuant to 35 U.S.C. § 284.

85. Unless Defendants are enjoined by this Court from continuing its infringement of the '082 Patent, VIZIO will suffer additional irreparable harm and impairment of the value of its patent rights.

PRAYER FOR RELIEF

WHEREFORE, VIZIO prays for relief as follows:

A. That each Defendant be found to have directly infringed, and continues to infringe, the VIZIO Patents;

B. That Defendants ESI, ON Corp, Sceptre and Westinghouse be found to have induced and continue to induce infringement the VIZIO Patents;

C. That each of the Defendants, and their officers, directors, consultants, managers, agents, servants, employees, attorneys, affiliates, subsidiaries, and all persons in active concert or participation with any of them, and their successors and assigns, be permanently enjoined from infringement of the VIZIO Patents, including, but not limited to, making, using, offering for sale, selling within the United States, or importing any products into the United States, that infringe the VIZIO Patents;

D. That Defendants ESI, ON Corp, Sceptre and Westinghouse be found to have willfully infringed the VIZIO Patents;

E. That Defendants be ordered to account for and pay over to VIZIO damages adequate to compensate VIZIO for Defendants' infringement of the VIZIO Patents, that the amount of recovery be increased as provided by law, up to three times, and that interest and costs be awarded to VIZIO pursuant to 35 U.S.C. § 284, but in no event less than a reasonable royalty for the use made of the inventions by each Defendant, together with interest and costs as fixed by the Court;

F. That the present case be found exceptional under 35 U.S.C. § 285 and that VIZIO be awarded its costs, expenses and attorneys' fees in this action;

G. That VIZIO be awarded any prejudgment interest; and

H. That VIZIO be granted such other and additional relief as the Court deems just and proper.

Dated: May 20, 2011

Respectfully submitted,

By: Kevin G. McBride
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Attorneys for Plaintiff VIZIO, Inc.

DEMAND FOR JURY TRIAL

Pursuant to Fed. R. Civ. P. 38 and Local Rule 38-1, VIZIO hereby respectfully demands a jury trial on all issues so triable.

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Attorneys for Plaintiff VIZIO, Inc.

Exhibit A

US005511096A

United States Patent [19]

Huang et al.

[11] **Patent Number: 5,511,096**

[45] **Date of Patent: Apr. 23, 1996**

[54] **QUADRATURE AMPLITUDE MODULATED DATA FOR STANDARD BANDWIDTH TELEVISION CHANNEL**

[75] Inventors: **Zheng Huang**, Willow Grove, Pa.; **Chris Heegard**, Ithaca, N.Y.

[73] Assignee: **GI Corporation**, Hatboro, Pa.

[21] Appl. No.: **184,499**

[22] Filed: **Jan. 18, 1994**

[51] **Int. Cl.**[6] **H04L 5/12**; H04L 27/36; G06F 11/10; H04N 7/12

[52] **U.S. Cl.** **375/265**; 375/264; 375/261; 375/298; 371/43; 348/384

[58] **Field of Search** 375/265, 264, 375/262, 261, 298, 341; 371/43; 348/384, 155

[56] **References Cited**

U.S. PATENT DOCUMENTS

5,023,889	6/1991	Divsalar et al.	371/43
5,233,629	8/1993	Paik et al. .	
5,321,725	6/1994	Paik et al.	348/155
5,363,408	11/1994	Paik et al.	375/261

Primary Examiner—Edward L. Coles, Sr.

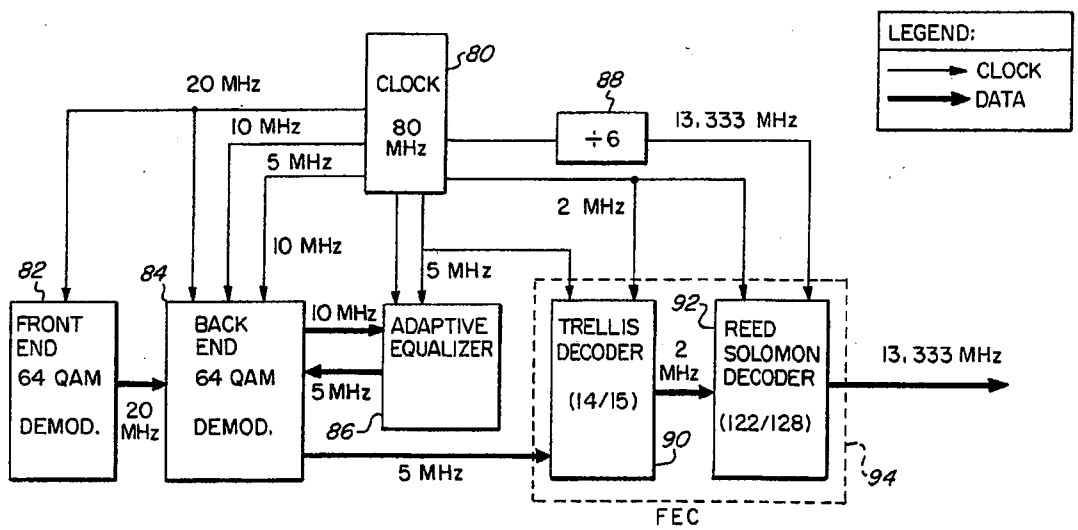
Assistant Examiner—Allan A. Esposo

Attorney, Agent, or Firm—Barry R. Lipsitz

[57] **ABSTRACT**

An outer symbol error correcting code is concatenated with a punctured multidimensional trellis code to provide an optimal scheme for communicating digital television signals in a standard (e.g., approximately six MHz) bandwidth channel via a cable television network or the like. An input signal is encoded using an outer symbol error correcting code to produce successive blocks. Each block comprises N seven-bit coded symbols of which M represent information to be communicated and the remaining N-M coded symbols comprise error correcting information. M/N is either 120/126, 121/127 or 122/128. The blocks are interleaved, and may be supplemented with control symbols that include a synchronization pattern for M/N=121/127 or M/N=122/128. The interleaved blocks are convolutionally encoded using an inner trellis code having a punctured rate 4/5 (sixty-four QAM) or 3/4 (sixteen QAM). The output symbols are multilevel modulated for transmission over a communication path using, for example, sixteen or sixty-four QAM. The transmitted symbols are decoded using a trellis decoder, deinterleaved, and further decoded in an outer symbol error decoder concatenated with the inner trellis decoder.

25 Claims, 3 Drawing Sheets



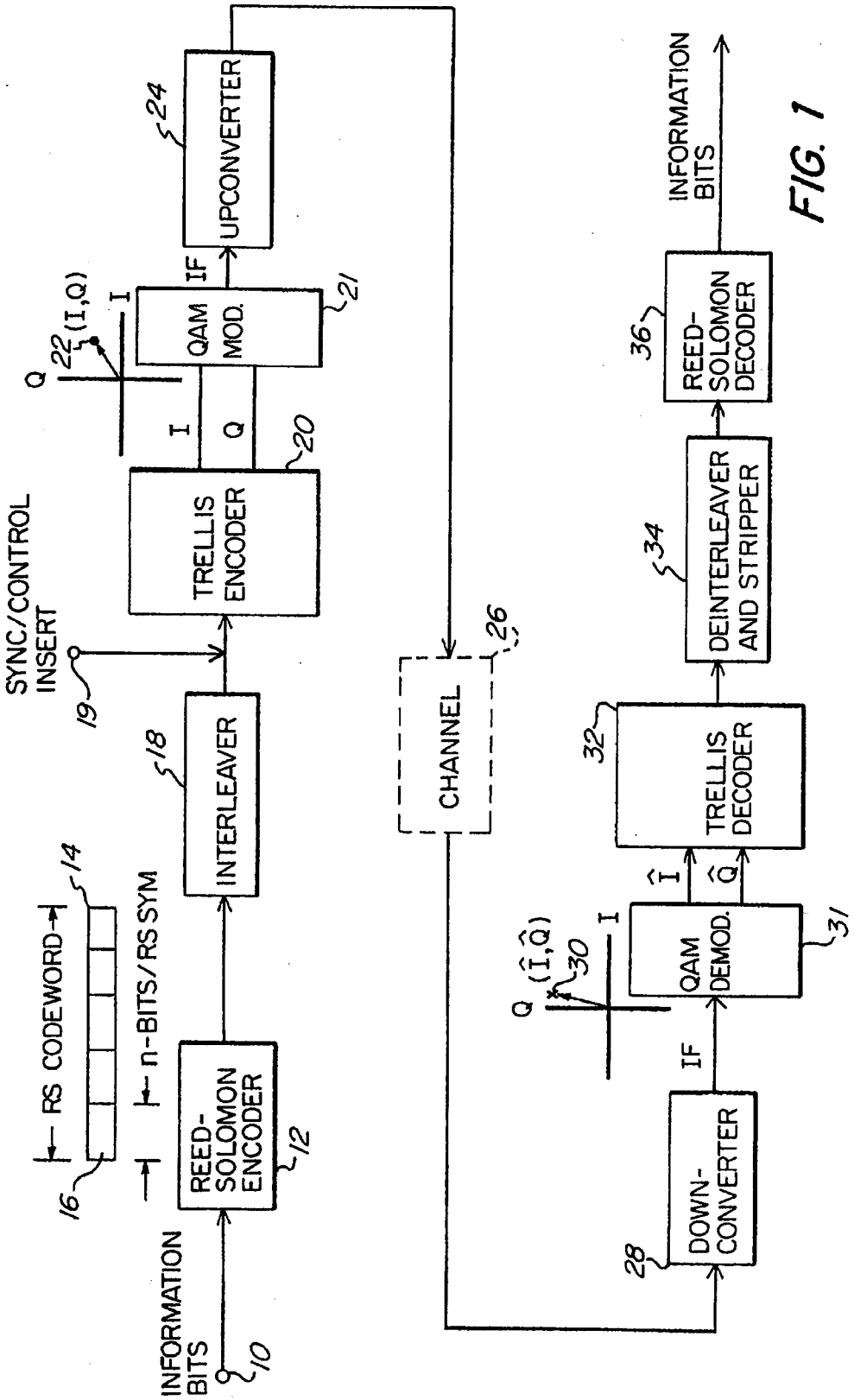

INFORMATION BITS
10
REED-SOLOMON ENCODER
12
RS CODEWORD
n-BITS/RS SYM
14
16
INTERLEAVER
18
SYNC/CONTROL INSERT
19
TRELLIS ENCODER
20
I
Q
(I,Q)
22
QAM MOD.
21
IF
UPCONVERTER
24
CHANNEL
26
DOWN-CONVERTER
28
IF
QAM DEMOD.
31
(Î,Q̂)
30
TRELLIS DECODER
32
DEINTERLEAVER AND STRIPPER
34
REED-SOLOMON DECODER
36
INFORMATION BITS

FIG. 1

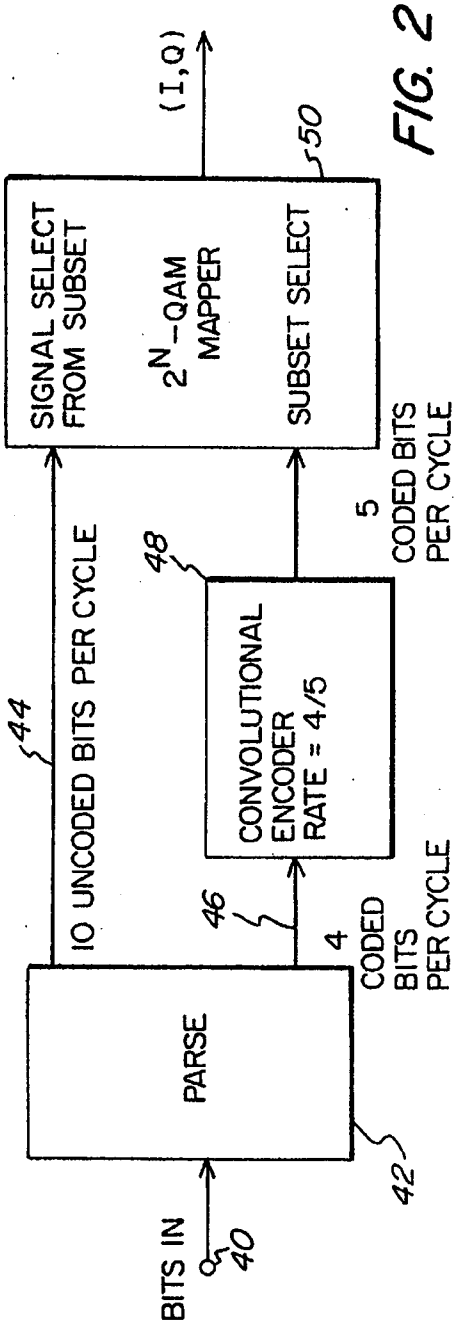

BITS IN
40
PARSE
42
4
CODED
BITS
PER CYCLE
46
CONVOLUTIONAL
ENCODER
RATE = 4/5
48
5
CODED BITS
PER CYCLE
10 UNCODED BITS PER CYCLE
44
SIGNAL SELECT
FROM SUBSET
2^N-QAM
MAPPER
SUBSET SELECT
50
(I,Q)

FIG. 2

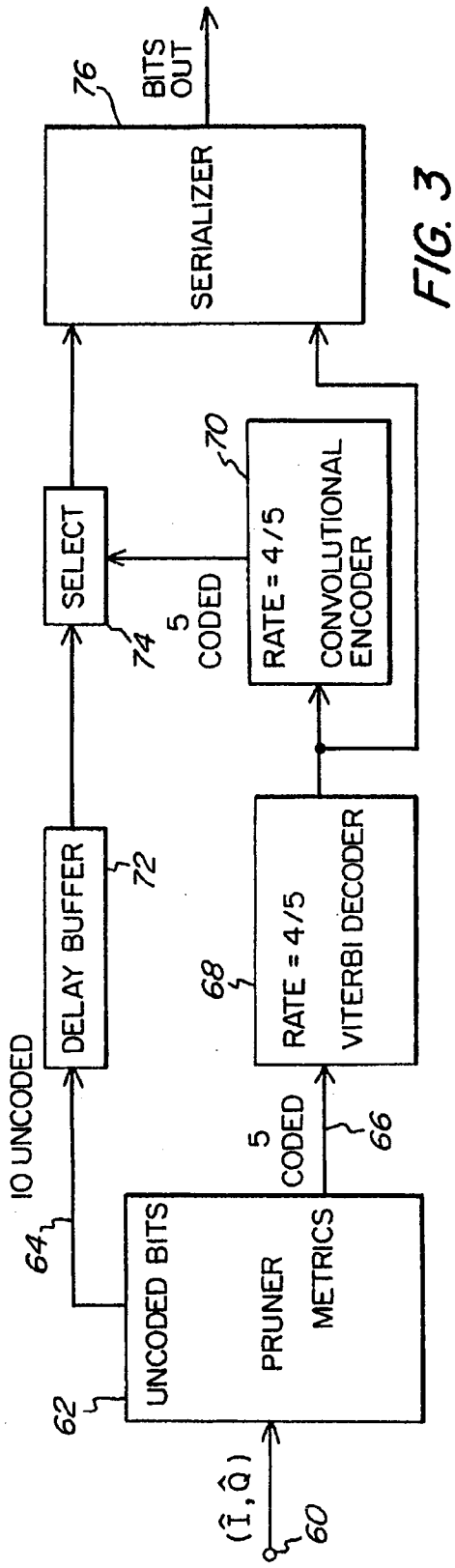

(Î,Q̂)
60
UNCODED BITS
PRUNER
METRICS
62
10 UNCODED
64
5
CODED
66
RATE = 4/5
VITERBI DECODER
68
DELAY BUFFER
72
RATE = 4/5
CONVOLUTIONAL
ENCODER
70
SELECT
74
5
CODED
SERIALIZER
76
BITS
OUT

FIG. 3

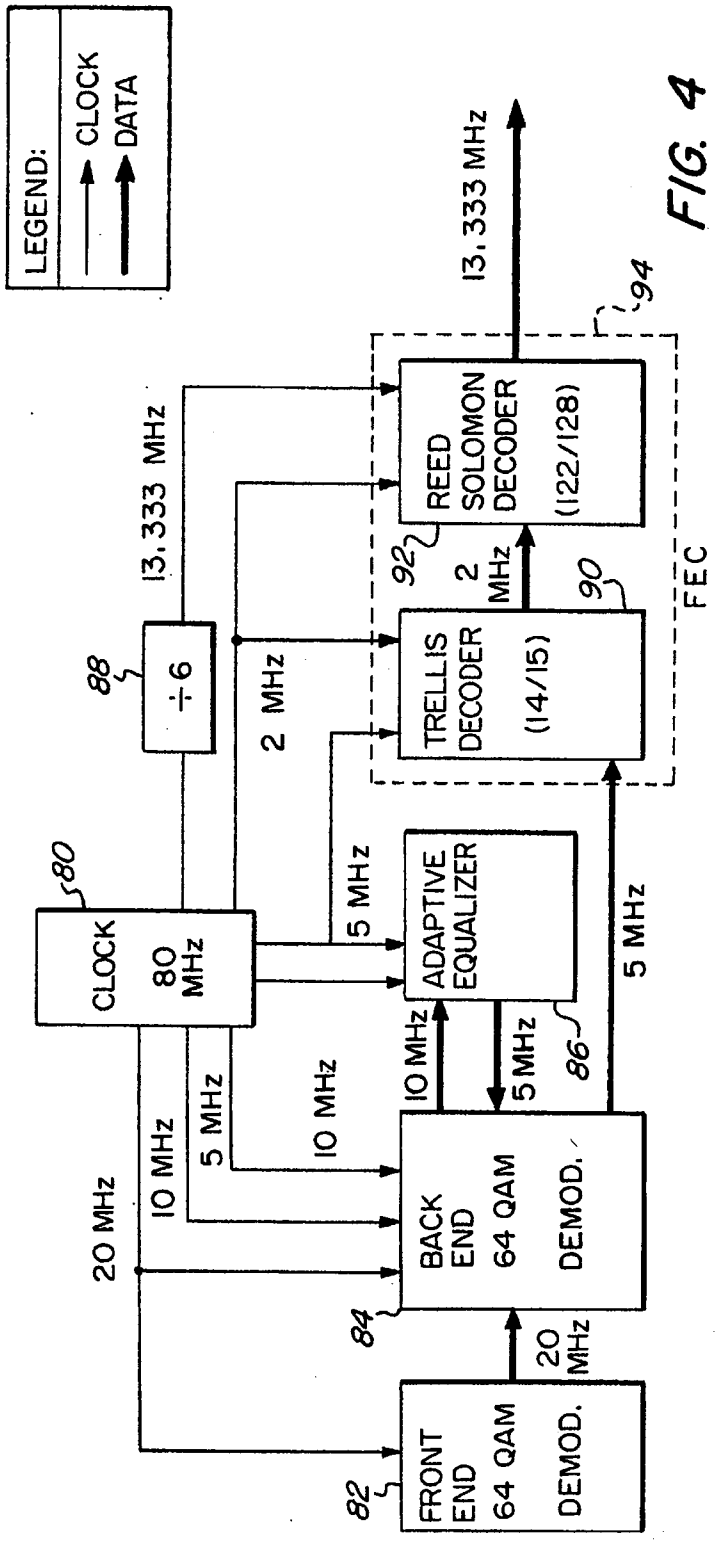

LEGEND:
CLOCK
DATA
13.333 MHz
94
REED SOLOMON DECODER (122/128)
92
2 MHz
90
TRELLIS DECODER (14/15)
FEC
13.333 MHz
88
÷6
2 MHz
80
CLOCK 80 MHz
5 MHz
ADAPTIVE EQUALIZER
86
10 MHz
5 MHz
5 MHz
10 MHz
20 MHz
10 MHz
5 MHz
BACK END 64 QAM DEMOD.
84
20 MHz
FRONT END 64 QAM DEMOD.
82

FIG. 4

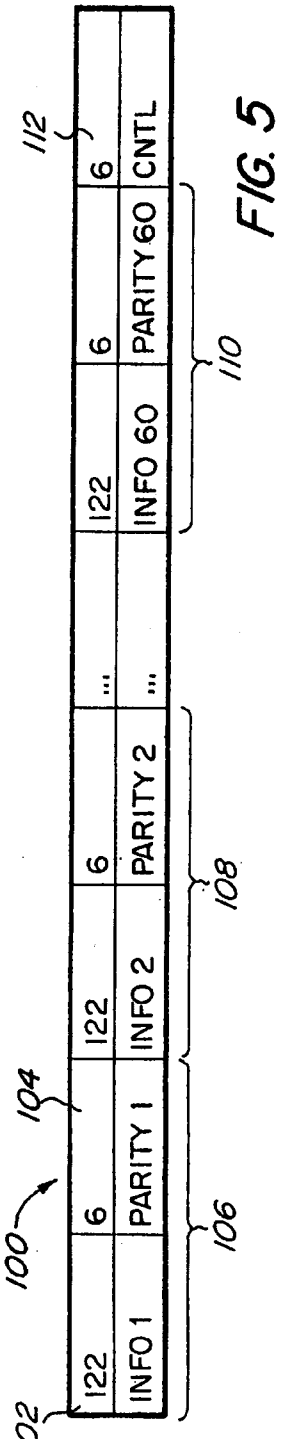

112
6
CNTL
6
PARITY 60
122
INFO 60
110
...
...
6
PARITY 2
122
INFO 2
108
6
PARITY 1
104
122
INFO 1
102
100
106

FIG. 5

QUADRATURE AMPLITUDE MODULATED DATA FOR STANDARD BANDWIDTH TELEVISION CHANNEL

BACKGROUND OF THE INVENTION

The present invention relates to trellis coded quadrature amplitude modulation (QAM) and more particularly to a practical method for coding **16** and **64** QAM transmission to enable a low-cost implementation of a digital cable television system or the like.

Digital data, for example digitized video for use in broadcasting digitized conventional or high definition television (HDTV) signals, can be transmitted over satellite, terrestrial or cable VHF or UHF analog channels for communication to end users. Analog channels deliver corrupted and transformed versions of their input waveforms. Corruption of the waveform, usually statistical, may be additive and/or multiplicative, because of possible background thermal noise, impulse noise, and fades. Transformations performed by the channel are frequency translation, nonlinear or harmonic distortion and time dispersion.

In order to communicate digital data via an analog channel, the data is modulated using, for example, a form of pulse amplitude modulation (PAM). Typically, quadrature amplitude modulation (QAM) is used to increase the amount of data that can be transmitted within an available channel bandwidth. QAM is a form of PAM in which a plurality of bits of information are transmitted together in a pattern referred to as a "constellation" that can contain, for example, sixteen, thirty-two or sixty-four points. An example of a system for communicating digital data using QAM, and specifically trellis coded QAM, is provided in U.S. Pat. No. 5,233,629 to Paik, et al., incorporated herein by reference.

In pulse amplitude modulation, each signal is a pulse whose amplitude level is determined by a transmitted symbol. In 16-bit QAM, symbol amplitudes of −3, −1, 1 and 3 in each quadrature channel (I and Q) are typically used. Bandwidth efficiency in digital communication systems is defined as the number of transmitted bits per second per unit of bandwidth, i.e., the ratio of the data rate to the bandwidth. Modulation systems with high bandwidth efficiency are employed in applications that have high data rates and small bandwidth occupancy requirements. One such application is the transmission of television signals in a standard 6 MHz or so bandwidth. QAM provides bandwidth efficient modulation that is useful for such applications.

Trellis coded modulation (TCM) has evolved as a combined coding and modulation technique for digital transmission over band limited channels. It allows the achievement of significant coding gains over conventional uncoded multilevel modulation, such as QAM, without compromising bandwidth efficiency. TCM schemes utilize redundant nonbinary modulation in combination with a finite-state encoder which governs the selection of modulation signals to generate coded signal sequences. In the receiver, the noisy signals are decoded by a soft-decision maximum likelihood sequence decoder. Such schemes can improve the robustness of digital transmission against additive noise by 3–6 dB or more, compared to conventional uncoded modulation. These gains are obtained without significant bandwidth expansion or reduction of the effective information rate as required by other known error correction schemes. The term "trellis" is used because these schemes can be described by a state-transition (trellis) diagram similar to the trellis diagrams of binary convolutional codes. The difference is that TCM extends the principles of convolutional coding to nonbinary modulation with signal sets of arbitrary size.

For applications that are band limited, and require low cost components (particularly low cost data decoders), conventional QAM systems have not been feasible due to the complexity and relatively high cost of the required encoder and decoder circuits. In fact, it is typical to implement QAM trellis encoders and decoders in expensive custom integrated circuit chips.

One band limited application in which a low cost solution is necessary for communicating digital data is the digital communication of cable television signals, which may include compressed conventional or high definition television signals. Systems for transmitting such signals have data rate requirements on the order of 15–30 megabits per second (Mbps), bandwidth occupancy requirements on the order of 6 MHz (the bandwidth of a conventional National Television System Committee (NTSC) television channel), and very high data reliability requirements (i.e., a very small bit error rate). The data rate requirement arises from the need to provide a high quality compressed television picture. The bandwidth constraint is a consequence of the U.S. Federal Communications Commission requirement that such signals occupy existing 6 MHz television channels, and must coexist with the current broadcast NTSC signals. Similar constraints are mandated by the PAL (Phase Alternating Line) and SECAM (Sequential Color and Memory) television systems used outside the U.S.

The combination of data rate and bandwidth occupancy requirements mandated by the standard television transmission systems dictates a modulation system that has high bandwidth efficiency. Indeed, the ratio of data rate to bandwidth must be on the order of 3 to 6. This means that a bandwidth efficient modulation such as QAM is required. However, as noted above, QAM systems have been too expensive to implement for high volume consumer applications.

The requirement for a very high data reliability in digitized video applications results from the fact that highly compressed source material (i.e., the compressed video) is intolerant of channel errors. The natural redundancy of the signal has been removed in order to obtain a concise description of the intrinsic value of the data. For example, for a system to transmit at 15 Mbps for a twenty-four hour period, with less than one bit error, requires the bit error rate (BER) of the system to be less than one error in 10^{12} transmitted bits.

Data reliability requirements are often met in practice via the use of concatenated coding techniques, which is a divide and concur approach to problem solving. In such a coding framework, two codes are employed. An "inner" modulation code cleans up the channel and delivers a modest symbol error rate to an "outer" decoder. The inner code is usually a coded modulation that can be effectively decoded using "soft decisions" (i.e., finely quantized channel data). A known approach is to use a convolutional or trellis code as the inner code with some form of the "Viterbi algorithm" as a trellis decoder. The outer code is most often a t-error-correcting, "Reed-Solomon" code. Such Reed-Solomon coding systems, that operate in the data rate range required for communicating digital television data, are widely available and have been implemented in the integrated circuits of several vendors. The outer decoder removes the vast majority of symbol errors that have eluded the inner decoder in such a way that the final output error rate is extremely small.

A more detailed explanation of concatenated coding schemes can be found in G. C. Clark, Jr. and J. B. Cain,

"Error-Correction Coding for Digital Communications", Plenum Press, New York, 1981; and S. Lin and D. J. Costello, Jr., "Error Control Coding: Fundamentals and Applications", Prentice-Hall, Englewood Cliffs, N.J., 1983. Trellis coding is discussed extensively in G. Ungerboeck, "Channel Coding with Multilevel/Phase Signals", *IEEE Transactions on Information Theory*, Vol. IT-28, No. 1, pp. 55–67, January 1982; G. Ungerboeck, "Trellis-Coded Modulation with Redundant Signal Sets—Part I: Introduction,—Part II: State of the Art", *IEEE Communications Magazine*, Vol. 25, No. 2, pp. 5–21, February 1987; and A. R. Caulderbank and N. J. A. Sloane, "New Trellis Codes Based on Lattices and Cosets", *IEEE Transactions on Information Theory*, Vol. IT-33, No. 2, pp. 177–195, March 1987. The Viterbi algorithm is explained in G. D. Forney, Jr., "The Viterbi Algorithm", *Proceedings of the IEEE*, Vol. 61, No. 3, March 1973. Reed-Solomon coding systems are discussed in the Clark, Jr. et al and Lin et al texts cited above.

The error rate performance at the output of the inner, modulation code in concatenated coded systems is highly dependent on signal-to-noise ratio (SNR). Some codes perform better, providing a lower error rate, at a low SNR while others perform better at a high SNR. This means that the optimization of the modulation code for concatenated coding systems can lead to different solutions, depending on the specified SNR range. To date, an optimal solution has eluded system designers.

It would be advantageous to provide an optimized data modulation system with high bandwidth efficiency and low power requirements. Such a system should provide a high data rate, with minimal bandwidth occupancy, and very high data reliability. The complexity of a receiver for use with such a system should be minimized, to provide low cost in volume production.

The present invention provides a modulation system having the aforementioned advantages. In particular, the method and apparatus of the present invention provide a concatenated coding implementation wherein the inner trellis coding rate and the outer Reed-Solomon error correction rate are optimized to provide an integer relationship between the various clocks required by the system (enabling a low cost and easily implemented clock design) while achieving excellent coding gain at a desired symbol rate and bandwidth. The invention achieves very high (e.g., 7 dB) coding gain, requires a very small transmission overhead, and provides a simple scheme for Reed-Solomon synchronization, including Reed-Solomon symbol synchronization, block synchronization, interleave block synchronization, trellis symbol synchronization and frame synchronization. These advantages all combine to provide a very robust system that is low in cost, easy to initialize, and allows synchronization to be easily regained if lost.

SUMMARY OF THE INVENTION

In accordance with the present invention, a method is provided for concatenating an outer symbol error correcting code (e.g., a Reed-Solomon algorithm) with a multidimensional trellis code for use in communicating digital data within a standard (e.g., approximately six MHz) bandwidth television channel. An input signal is encoded using the outer symbol error correcting code to produce successive blocks. Each block comprises N seven-bit coded symbols of which M coded symbols represent information to be communicated and the remaining N-M coded symbols comprise error correcting overhead. M/N is one of 121/127 and 122/128. The symbols in each block are interleaved for transmission in an interleaved order to minimize the effects of burst errors when recovering the input signal after transmission. A seven-bit control symbol is provided for each frame of F blocks, where F=10 when M/N is 122/128 and F=20 when M/N=121/127. The addition of the control symbols effectively lowers the ratio of M/N to an actual information to transmitted data ratio of 120/126=20/21.

The control symbols contain synchronization information necessary to synchronize the recovery of information at a receiver. The blocks are convolutionally encoded using an inner convolutional coding algorithm having a rate 4/5 or 3/4. In this manner, for a sixteen QAM implementation four two-bit output symbols are provided for each seven input bits for each of the I and Q QAM components, and for a sixty-four QAM implementation five three-bit output symbols are provided for each pair of seven-bit (2×7=14 bits) coded symbols. The 3/4 rate for sixteen QAM and 4/5 rate for sixty-four QAM allows for a single or double seven-bit symbol. The two-bit (sixteen QAM) or three-bit (sixty-four QAM) output symbols are multilevel modulated for transmission over a communication path.

The multilevel modulated two or three-bit output symbols are decoded after receipt from a communication path by demodulating them for decoding using a rate 3/4 or 4/5 decoding algorithm to recover the blocks of seven-bit coded symbols and said control symbols. One seven bit coded and/or control symbol is provided for each group of four of the received two-bit output symbols in the sixteen QAM embodiment. Two seven-bit coded and/or control symbols are provided for each group of five of the received three-bit output symbols in the sixty-four QAM embodiment. The recovered blocks are deinterleaved after stripping the control bits therefrom. The seven-bit coded symbols in the deinterleaved blocks are decoded using an algebraic symbol error correcting algorithm that corresponds to the outer symbol error correcting code to recover the input signal. In the illustrated embodiment, the outer symbol error correcting code comprises a Reed-Solomon algorithm and the multilevel modulating step uses either sixteen QAM or sixty-four QAM to modulate the output symbols. The rate 3/4 or 4/5 decoding algorithm is a Viterbi decoding algorithm and the algebraic symbol error correcting algorithm is a Reed-Solomon decoding algorithm.

An encoder is provided in accordance with the invention for concatenating an outer symbol error correcting code with a multidimensional trellis code to efficiently communicate digital data within a standard bandwidth television channel using multilevel modulation. An outer symbol error encoder is provided for encoding an input signal to produce successive data blocks. Each block comprises N seven-bit coded symbols of which M coded symbols represent information to be communicated. The remaining N-M coded symbols comprise error correcting overhead. M/N is one of 121/127 and 122/128. Means are provided for interleaving the symbols in each block for transmission in an interleaved order to minimize the effects of burst errors when recovering the input signal after transmission. A seven-bit control symbol is provided for each frame of F blocks, where F=10 when M/N is 122/128 and F=20 when M/N=121/127. The addition of the control symbols effectively lowers the ratio of M/N to an actual information to transmitted data ratio of 120/126=20/21. The control symbols contain synchronization information necessary to synchronize the recovery of information at a receiver. A rate 4/5 convolutional encoder is concatenated with the outer symbol error encoder for convolutionally encoding the blocks and control symbols to provide five

three-bit output symbols for two of the seven-bit coded symbols for each of I and Q in a sixty-four QAM embodiment. In a sixteen QAM embodiment, a rate 3/4 encoder provides four two-bit output symbols for each seven bits in a stream of consecutive seven-bit coded symbols. Means are also provided for multilevel modulating the two or three-bit output symbols for transmission over a communication path.

In a preferred embodiment, the outer symbol error encoder comprises a Reed-Solomon encoder. The modulating means comprise one of a sixteen QAM and sixty-four QAM modulator. The convolutional encoder is a trellis encoder.

A decoder is provided for decoding the convolutionally encoded blocks provided by the encoder. The decoder includes means for receiving and demodulating the output symbols from the communication path. An inner decoder is provided for decoding the demodulated output symbols using a rate 3/4 or 4/5 code to recover the blocks of seven-bit coded symbols and the control symbols. Two of the seven-bit coded symbols and/or control symbols are provided for each group of five three-bit output symbols received from the communication path in the sixty-four QAM embodiment. One seven-bit coded symbol or control symbol is provided for each group of four two-bit output symbols received in the sixteen QAM embodiment. Means are provided for deinterleaving the recovered blocks after the control symbols have been stripped therefrom. An outer symbol error decoder is concatenated with the inner decoder for decoding the blocks from the inner decoder to recover the input signal. In a preferred embodiment, the inner decoder is a Viterbi decoder and the outer symbol error decoder is a Reed-Solomon decoder.

A decoder is provided for multilevel modulated digital data communicated in a standard bandwidth television channel. Means are provided for receiving and demodulating convolutionally encoded output symbols from a communication path. An inner decoder is provided for decoding the demodulated output symbols using a rate 3/4 or 4/5 code to recover interleaved blocks of data. Each block comprises N seven-bit coded symbols of which M coded symbols represent information to be recovered. The remaining N-M parity symbols comprise error correcting redundancy. M/N is one of 121/127 and 122/128. The inner decoder also recovers a seven-bit control symbol for each frame F of blocks, where F=10 when M/N is 122/128 and F=20 when M/N is 121/127. The control symbols effectively lower the ratio of M/N to an actual information to transmitted data ratio of 120/126=20/21. Two of the seven-bit coded and/or synchronization symbols are provided for each group of five of the three-bit output symbols received from the communication path in a sixty-four QAM implementation. For sixteen QAM, each group of four two-bit output symbols received provides seven bits for assembly into successive seven-bit coded and/or synchronization symbols.

Means are provided for deinterleaving the recovered blocks after the control symbols have been stripped therefrom. An outer symbol error decoder is concatenated with the inner decoder for decoding the blocks from the inner decoder in response to the control symbols to recover a transmitted information signal. The inner decoder is a Viterbi decoder and the outer symbol error decoder is a Reed-Solomon decoder.

It is possible to implement the present invention in a system where separate control symbols are not necessary to obtain synchronization. For example, synchronization information can be provided as part of the transmitted information data. In order to accommodate such a scheme, a method is provided for concatenating an outer symbol error correcting code (e.g., a Reed-Solomon algorithm) with a punctured multidimensional trellis code for use in communicating digital data within an approximately six MHz bandwidth television channel. An input signal is encoded using the outer symbol error correcting code to produce successive blocks. Each block comprises N seven-bit coded symbols of which M coded symbols represent information to be communicated and the remaining N-M coded symbols comprise error correcting overhead. M/N is one of 120/126, 121/127, and 122/128. The symbols in each block are interleaved for transmission in an interleaved order to minimize the effects of burst errors when recovering the input signal after transmission. The blocks are convolutionally encoded using an inner convolutional coding algorithm having a rate 3/4 or 4/5. In this manner, five three-bit output symbols are provided for each pair of seven-bit coded symbols in a sixty-four QAM embodiment. In a sixteen QAM embodiment, four two-bit output symbols are provided for each seven successive bits of the coded input symbols. The two or three-bit output symbols are multilevel modulated for transmission over a communication path.

The multilevel modulated output symbols are decoded after receipt from a communication path using a rate 3/4 or 4/5 decoding algorithm. Two seven-bit coded symbols are provided for each group of five of the received three-bit output symbols in the sixty-four QAM mode and nine successive bits are provided for each group of five of the received two-bit output symbols in the sixteen QAM mode. The recovered blocks are deinterleaved. The coded symbols in the deinterleaved blocks are decoded using an algebraic symbol error correcting algorithm that corresponds to the outer symbol error correcting code to recover the input signal. In the illustrated embodiment, the outer symbol error correcting code comprises a Reed-Solomon algorithm. The rate 3/4 or 4/5 decoding algorithm is a Viterbi decoding algorithm and the algebraic symbol error correcting algorithm is a Reed-Solomon decoding algorithm.

An encoder is provided in accordance with the invention for concatenating an outer symbol error correcting code with a multidimensional trellis code to efficiently communicate digital data within a standard bandwidth television channel using multilevel modulation. An outer symbol error encoder is provided for encoding an input signal to produce successive data blocks. Each block comprises N seven-bit coded symbols of which M coded symbols represent information to be communicated. The remaining N-M coded symbols comprise error correcting overhead. M/N is one of 120/126, 121/127 and 122/128. Means are provided for interleaving the symbols in each block for transmission in an interleaved order to minimize the effects of burst errors when recovering the input signal after transmission. The interleaver can comprise a $2^n/N$ interleaver, where N is an integer from one to six and 2^n represents the maximum burst length to be dispersed. Such an interleaver will spread the burst error over a full block (N) of the seven-bit coded symbols. A rate 3/4 or 4/5 convolutional encoder is concatenated with the outer symbol error encoder for convolutionally encoding the blocks to provide five three-bit output symbols for two of the seven-bit coded symbols (sixty-four QAM) or four two-bit output symbols for every seven bits of the coded symbols (sixteen QAM). Means are also provided for multilevel modulating the output symbols for transmission over a communication path.

In a preferred embodiment, the outer symbol error encoder comprises a Reed-Solomon encoder. The modulat-

ing means comprise one of a sixteen QAM and sixty-four QAM modulator. The convolutional encoder is a trellis encoder.

A decoder is provided for decoding the convolutionally encoded blocks provided by the encoder. The decoder includes means for receiving and demodulating the output symbols from the communication path. An inner decoder is provided for decoding the demodulated output symbols using a rate 3/4 or 4/5 code to recover the blocks of seven-bit coded symbols. Means are provided for deinterleaving the recovered blocks. An outer symbol error decoder is concatenated with the inner decoder for decoding the blocks from the inner decoder to recover the input signal. In a preferred embodiment, the inner decoder is a Viterbi decoder and the outer symbol error decoder is a Reed-Solomon decoder.

A decoder is provided for multilevel modulated digital data communicated in a standard bandwidth television channel. Means are provided for receiving and demodulating convolutionally encoded output symbols from a communication path. An inner decoder is provided for decoding the demodulated output symbols using a rate 3/4 or 4/5 code to recover interleaved blocks of data. Each block comprises N seven-bit coded symbols of which M coded symbols represented information to be recovered. The remaining N-M coded symbols comprise error correcting overhead. M/N is one of 120/126, 121/127 and 122/128. Means are provided for deinterleaving the recovered blocks. An outer symbol error decoder is concatenated with the inner decoder for decoding the blocks from the inner decoder to recover a transmitted information signal. In a preferred embodiment, the multilevel modulated digital data is one of sixteen QAM and sixty-four QAM data. The inner decoder is a Viterbi decoder and the outer symbol error decoder is a Reed-Solomon decoder.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a QAM transmission system employing concatenated coding;

FIG. **2** is a block diagram of a trellis encoder in accordance with the present invention;

FIG. **3** is a block diagram of a trellis decoder in accordance with the present invention;

FIG. **4** is a block diagram of the receiver portion of a particular embodiment of the present invention, illustrating the integer relationships between various receiver clock signals; and

FIG. **5** is a diagrammatic illustration of a superframe of blocks provided by an outer symbol error correcting code with inserted control symbols in accordance with the present invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

FIG. **1** illustrates a concatenated coding system for communicating QAM data. Digital information to be transmitted is input to a symbol error correcting coder **12**, such as a Reed-Solomon encoder, via an input terminal **10**. Encoder **12** converts the information into a block **14** ("RS Codeword"), comprising a plurality N of successive n-bit coded symbols **16**, where n=7. Of the N coded symbols, M represent the actual information to be communicated and the remaining N-M parity symbols comprise error correcting redundancy.

While an outer convolutional code could be used for encoder **12**, the bursty nature of the errors in a transmission system, the fact that only hard quantized data is available, and the desirability of a high rate code make a Reed-Solomon code, whose symbols are formed from n-bit segments of the binary stream, a good choice for the outer code. Since the performance of a Reed-Solomon code only depends on the number of symbol errors in the block, such a code is undisturbed by burst errors within an n-bit symbol. However, the concatenated system performance is severely degraded by long bursts of symbol errors. Therefore, an interleaver **18** is provided at the output of Reed-Solomon encoder **12**, to interleave the symbols (as opposed to individual bits) between coding operations. The intent of the interleaving is to break up the bursts of symbol errors.

It may be desirable to insert synchronization information into the transmitted data stream. This may be required, for example, where the information data being communicated does not already contain synchronization information. In such a case, after the Reed-Solomon symbols are interleaved, control symbols (which include synchronization symbols) are added via terminal **19** at a rate of one seven-bit control symbol for each frame of Reed-Solomon blocks. In the illustrated embodiments, each Reed-Solomon block comprises either 126, 127 or 128 Reed-Solomon symbols, although the control symbols are only added when blocks of 127 or 128 Reed-Solomon symbols are being processed. A frame comprises F such blocks. Where the blocks contain **128** Reed-Solomon symbols, including **122** information symbols and six parity symbols, F=10. Where each block contains **127** Reed-Solomon symbols, including **121** information symbols and six parity symbols, F=20.

The interleaved Reed-Solomon symbols (with added control symbols, when required) are input to a trellis encoder **20** and QAM modulator **21**. The output of modulator **21** comprises symbols representative of coordinates in the real (I) and imaginary (Q) planes of a QAM constellation pattern. One such constellation point **22** is symbolically illustrated in FIG. 1. The symbols are transmitted by a conventional transmitter **24** via a communication channel **26**. The communication channel introduces various distortions and delays that corrupt the signal before it is received by a receiver **28**. As a result, the coordinate values embodied in the received symbols will not correlate exactly with the transmitted coordinate values, such that a received point **30** will end up on the constellation pattern in a different location than the actual transmitted point **22**. In order to determine the correct location for the received point, and thereby obtain the data as actually transmitted, the received data (I, Q) is demodulated in a QAM demodulator **31** and input to a trellis decoder **32** that uses a soft-decision convolutional decoding algorithm to recover the transmitted information. A decoder in accordance with the present invention is described in greater detail below.

The decoded output from decoder **32** is input to a deinterleaver and control symbol stripper **34** that strips out the control symbols (if provided) and reverses the effects of interleaver **18** discussed above. The deinterleaved data is input to a Reed-Solomon decoder **36** for recovery of the original information bits.

FIG. **2** illustrates an encoder in accordance with the present invention. Data bits (e.g., from interleaver **18**—FIG. **1**) are input to a conventional parsing circuit **42** via an input terminal **40**. In accordance with the specific requirements of the sixty-four QAM implementation of the invention, each group of fourteen bits of the interleaved Reed-Solomon data to be transmitted (i.e., two seven-bit Reed-Solomon symbols