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(54) **SYSTEM FOR, AND METHOD OF, PROCESSING QUADRATURE AMPLITUDE MODULATED SIGNALS**

(75) Inventors: **Henry Samueli**, Corona Del Mar, CA (US); **Charles P. Reames**, Laguna Hills, CA (US)

(73) Assignee: **Broadcom Corporation**, Irvine, CA (US)

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Filed: **Aug. 3, 1994**

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(52) **U.S. Cl.** **375/235**; 375/261; 375/326; 375/344; 375/345; 375/373; 375/350; 329/307
(58) **Field of Search** 375/229, 232, 375/233, 235, 261, 266, 326, 344, 345, 346, 349, 350, 371, 373; 329/304, 307

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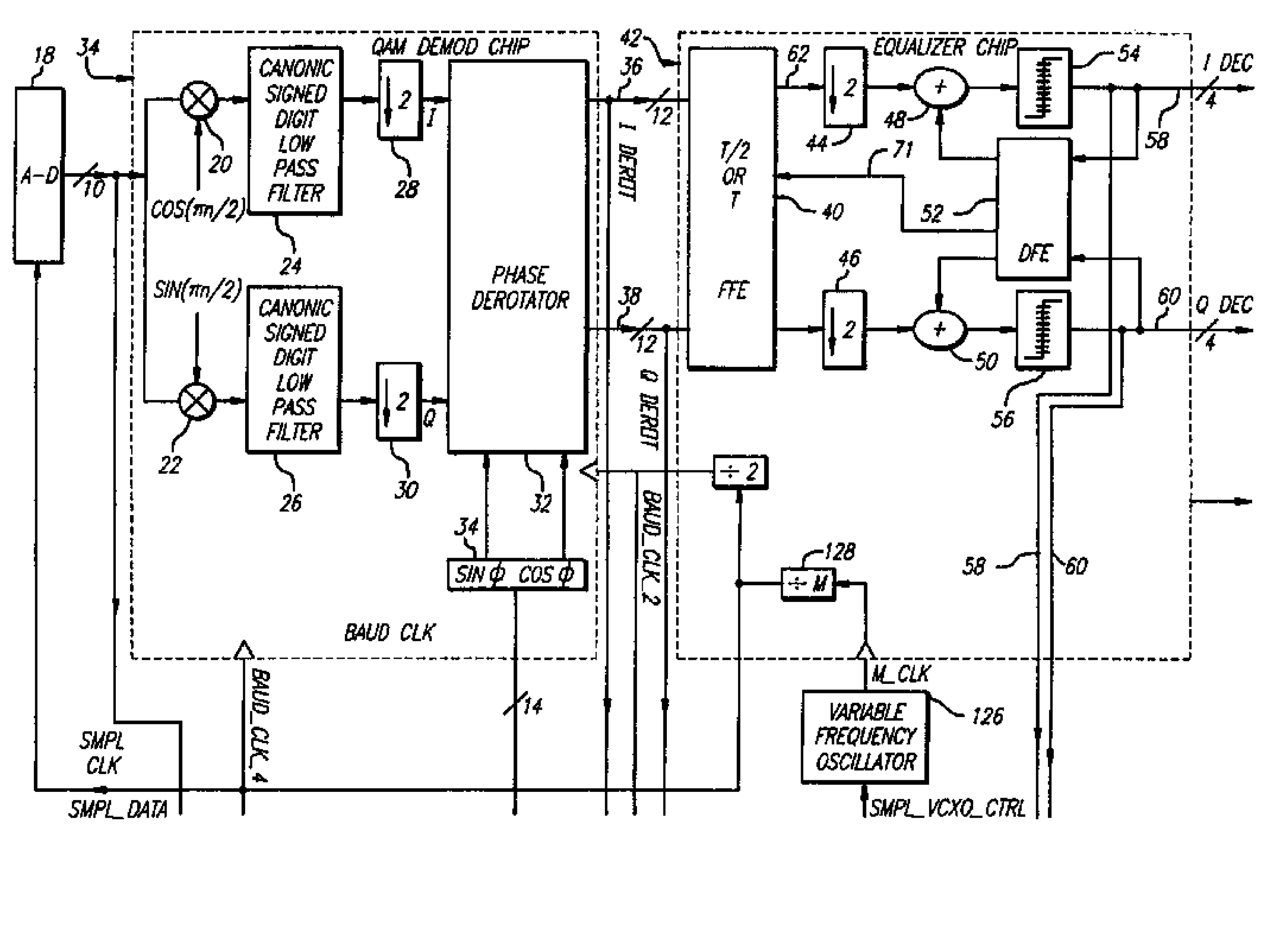
Primary Examiner—Don N. Vo
(74) *Attorney, Agent, or Firm*—Christie, Parker & Hale, LLP

(57) **ABSTRACT**

Analog signals encoded with quadrature amplitude modulation (QAM) pass through a coaxial cable at a particular baud rate. These signals have a carrier frequency individual to the TV station being received. They are mixed with signals from a variable frequency oscillator to produce signals at a particular intermediate frequency (IF). An analog-digital converter (ADC) converts the IF signals to corresponding digital signals which are demodulated to produce two digital signals having a quadrature phase relationship. After being filtered and derotated, the digital signals pass to a symmetrical equalizer including a feed forward equalizer (FFE) and a decision feedback equalizer (DFE) connected to the FFE in a feedback relationship. The DFE may include a slicer providing amplitude approximations of increasing sensitivity at progressive times. Additional slicers in the equalizer combine the FFE and DFE outputs to provide the output data without any of the coaxial cable noise or distortions. The equalizer outputs and initially the derotation outputs, and the slicer outputs, servo (1) the oscillator frequency to obtain the IF frequency, (2) the ADC sampling clock to obtain the digital conversion at a rate related to the particular baud rate and (3) the derotator. The servos may have (1) first constants initially after a change in the station selection and (2) second time constants thereafter. The ADC gain is also servoed (1) initially in every ADC conversion and (2) subsequently in every nth ADC conversion where n=integer>1. The above recover the QAM data without any of the coaxial cable noise or distortions.

156 Claims, 5 Drawing Sheets



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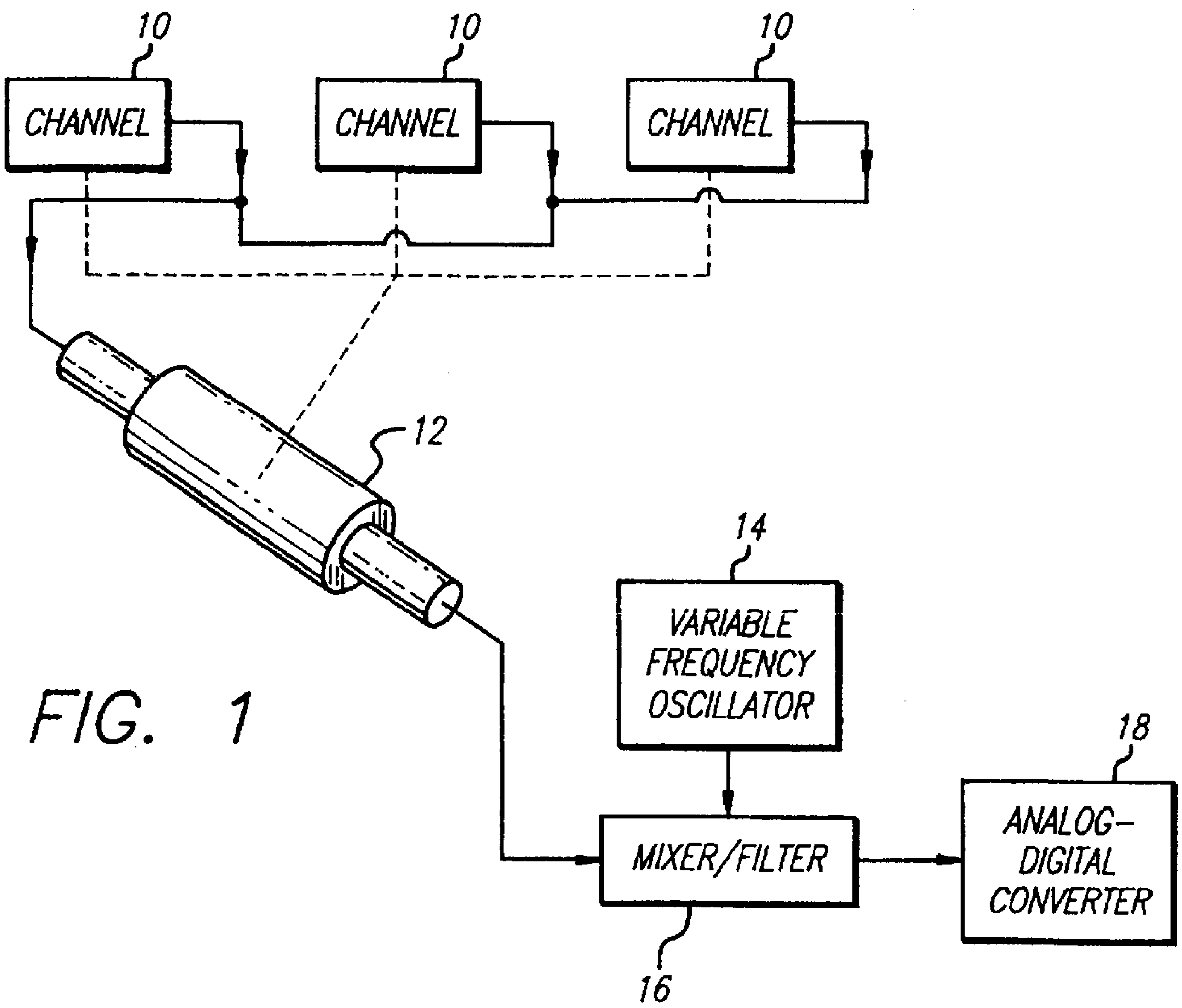


FIG. 1

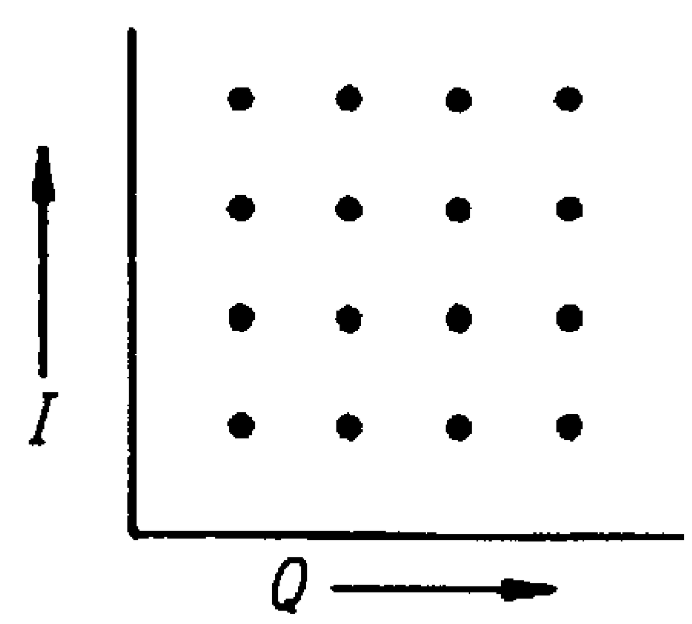


FIG. 4

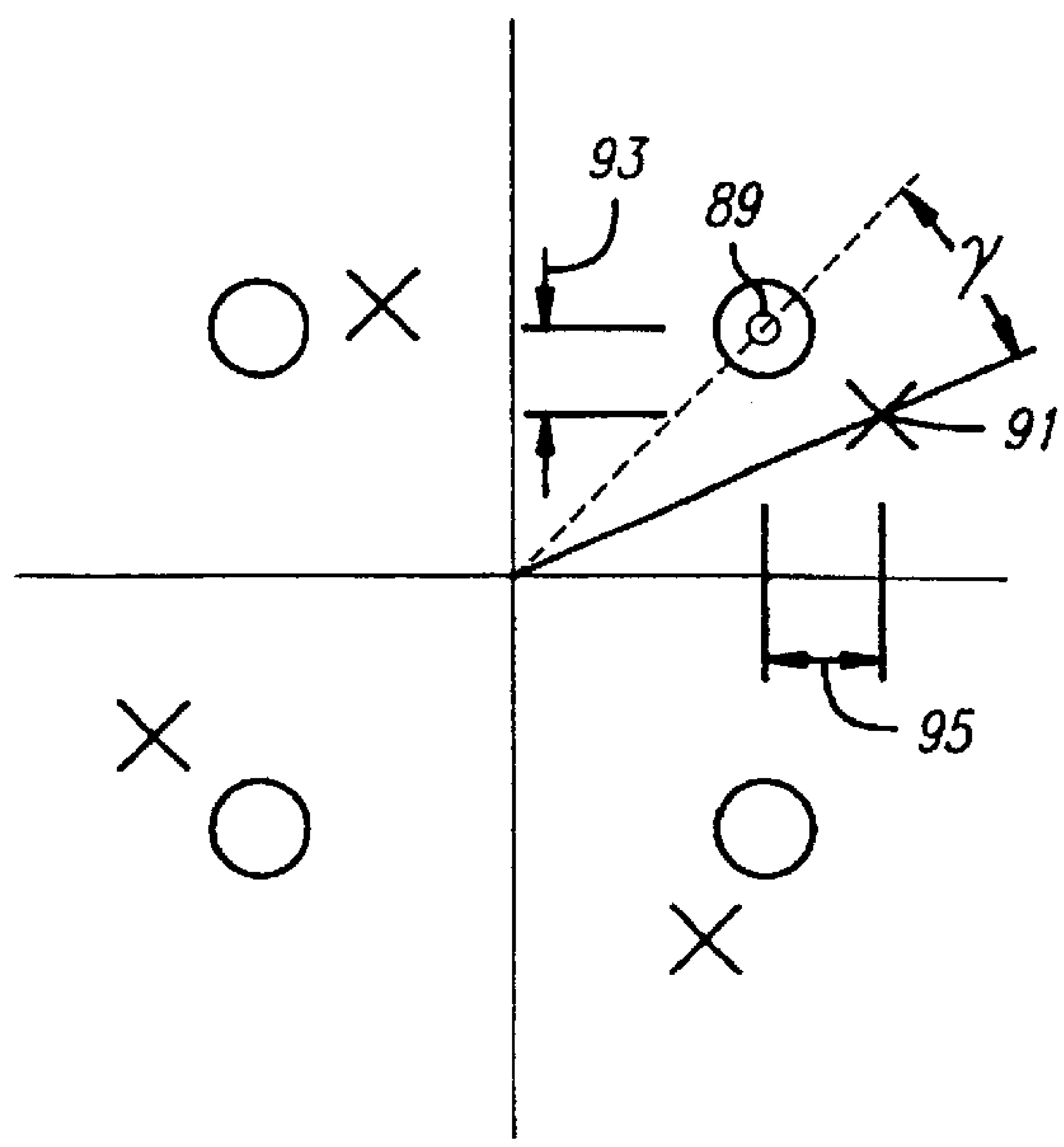


FIG. 7

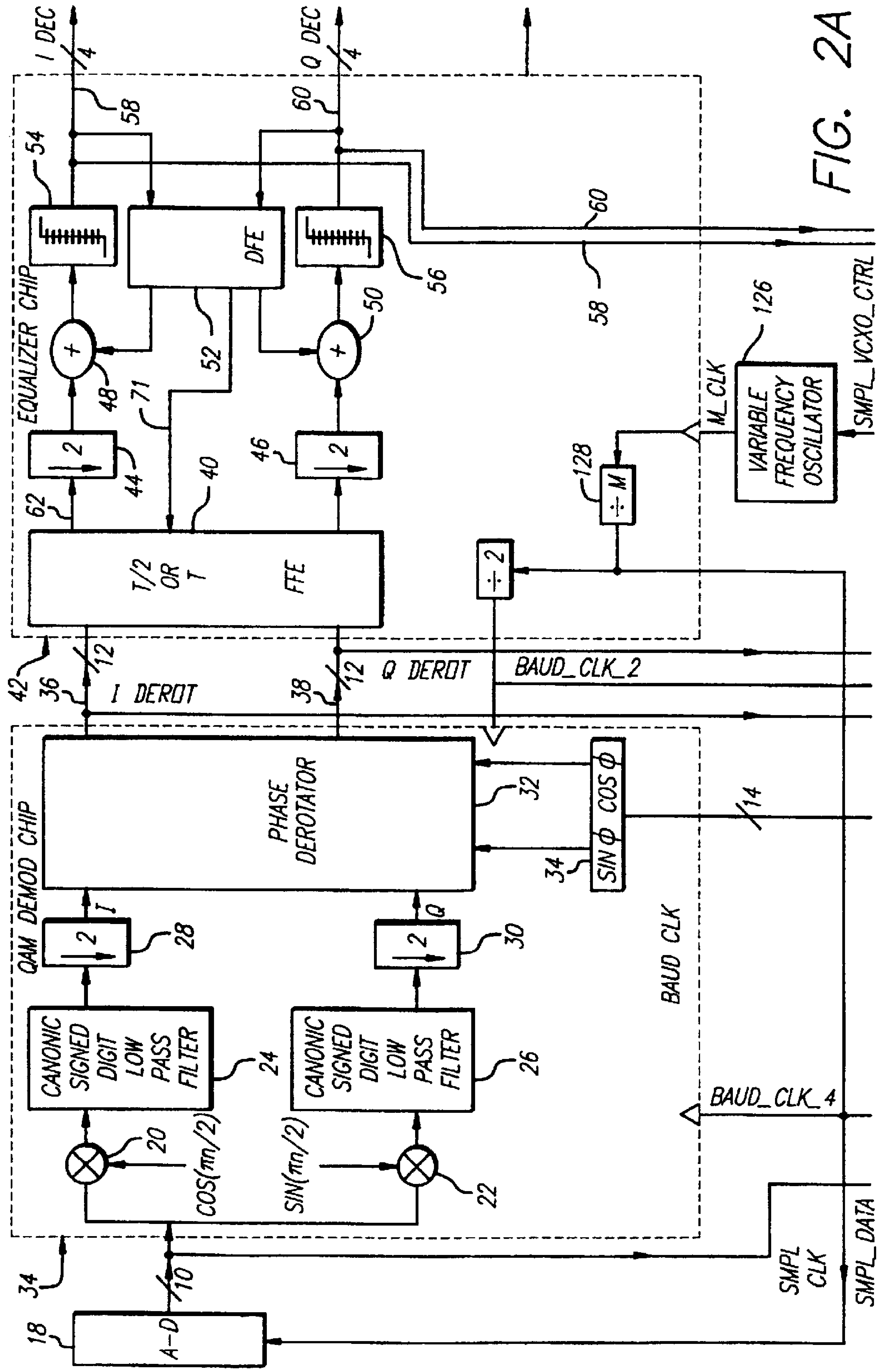
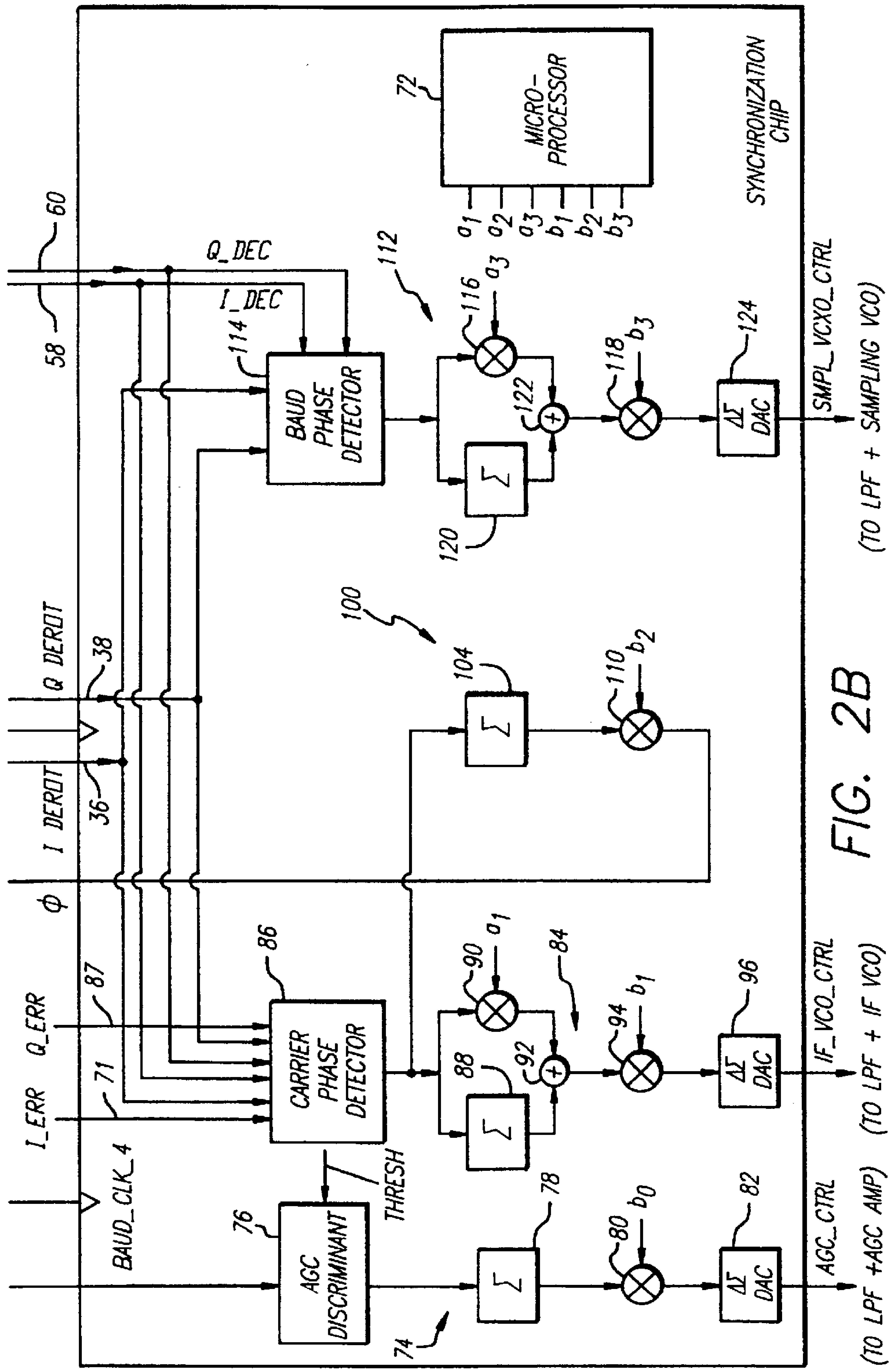

I DEC
Q DEC
EQUALIZER CHIP
DFE
T/2 OR T
FFE
Q DEROT
I DEROT
BAUD_CLK_2
M_CLK
VARIABLE FREQUENCY OSCILLATOR
SMPL_VCXO_CTRL
÷ M
÷ 2
PHASE DEROTATOR
SIN Φ COS Φ
QAM DEMOD CHIP
BAUD CLK
CANONIC SIGNED DIGIT LOW PASS FILTER
CANONIC SIGNED DIGIT LOW PASS FILTER
COS(πn/2)
SIN(πn/2)
BAUD_CLK_4
A-D
SMPL CLK
SMPL_DATA

FIG. 2A



MICRO-PROCESSOR
72
SYNCHRONIZATION CHIP
a1
a2
a3
b1
b2
b3
60
58
Q_DEC
I_DEC
112
114
BAUD PHASE DETECTOR
116
118
122
120
124
ΔΣ DAC
SMPL_VCXO_CTRL
(TO LPF + SAMPLING VCO)
Q DEROT
I DEROT
38
36
φ
100
104
110
86
CARRIER PHASE DETECTOR
87
71
Q_ERR
I_ERR
84
88
90
92
94
96
IF_VCO_CTRL
(TO LPF + IF VCO)
BAUD_CLK_4
THRESH
76
AGC DISCRIMINANT
74
78
80
82
AGC_CTRL
(TO LPF +AGC AMP)

FIG. 2B

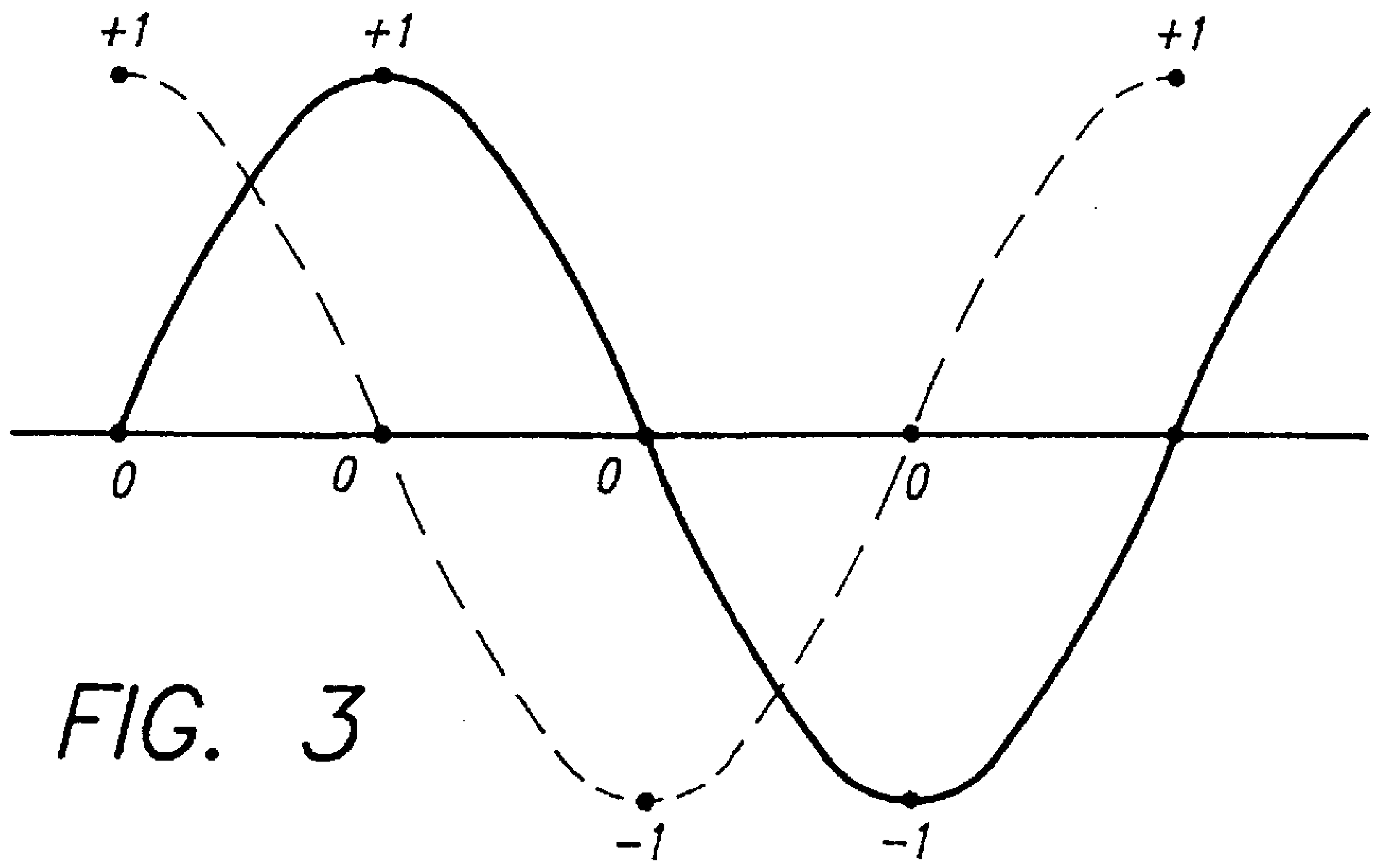


FIG. 3

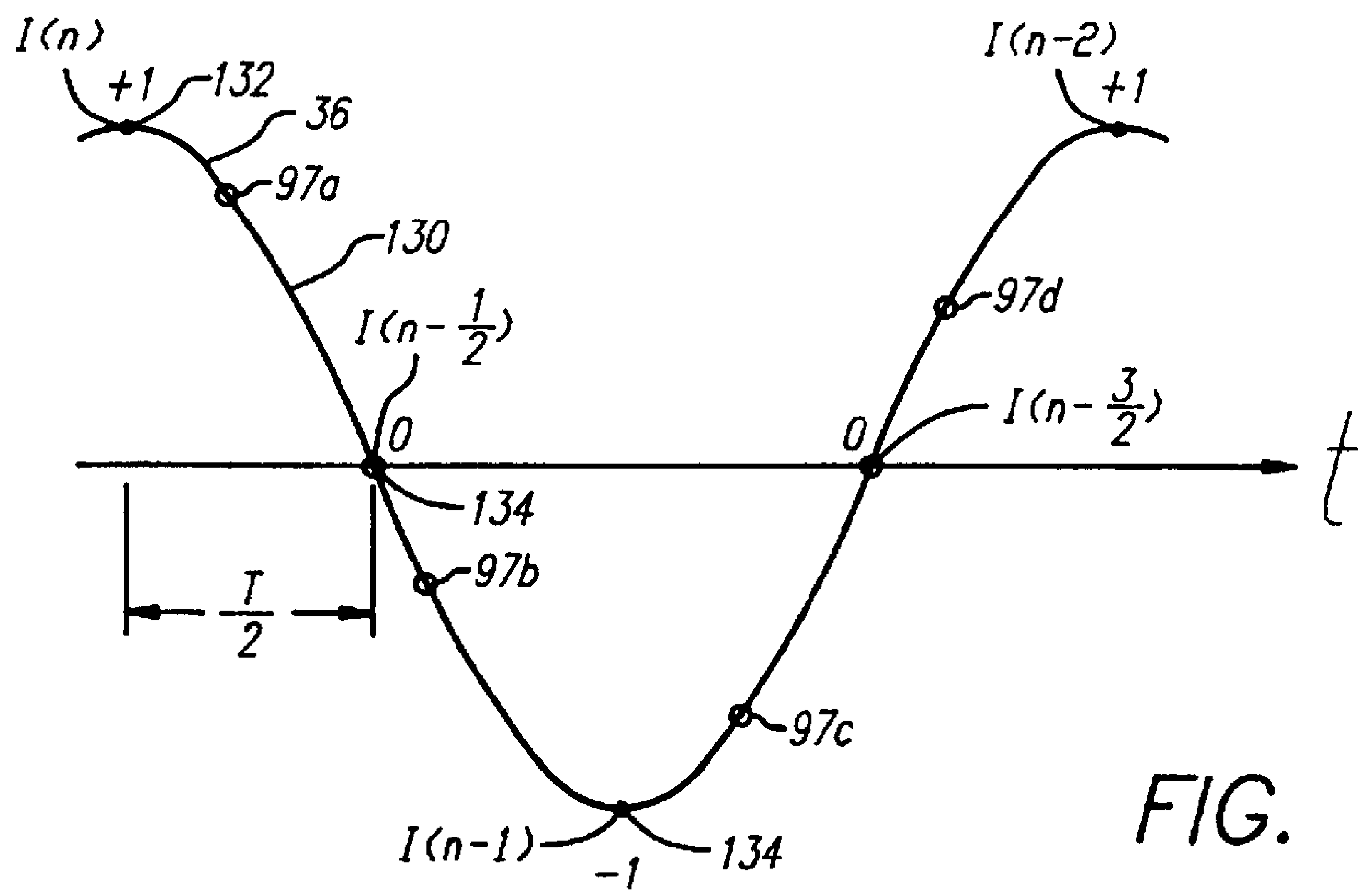


FIG. 8

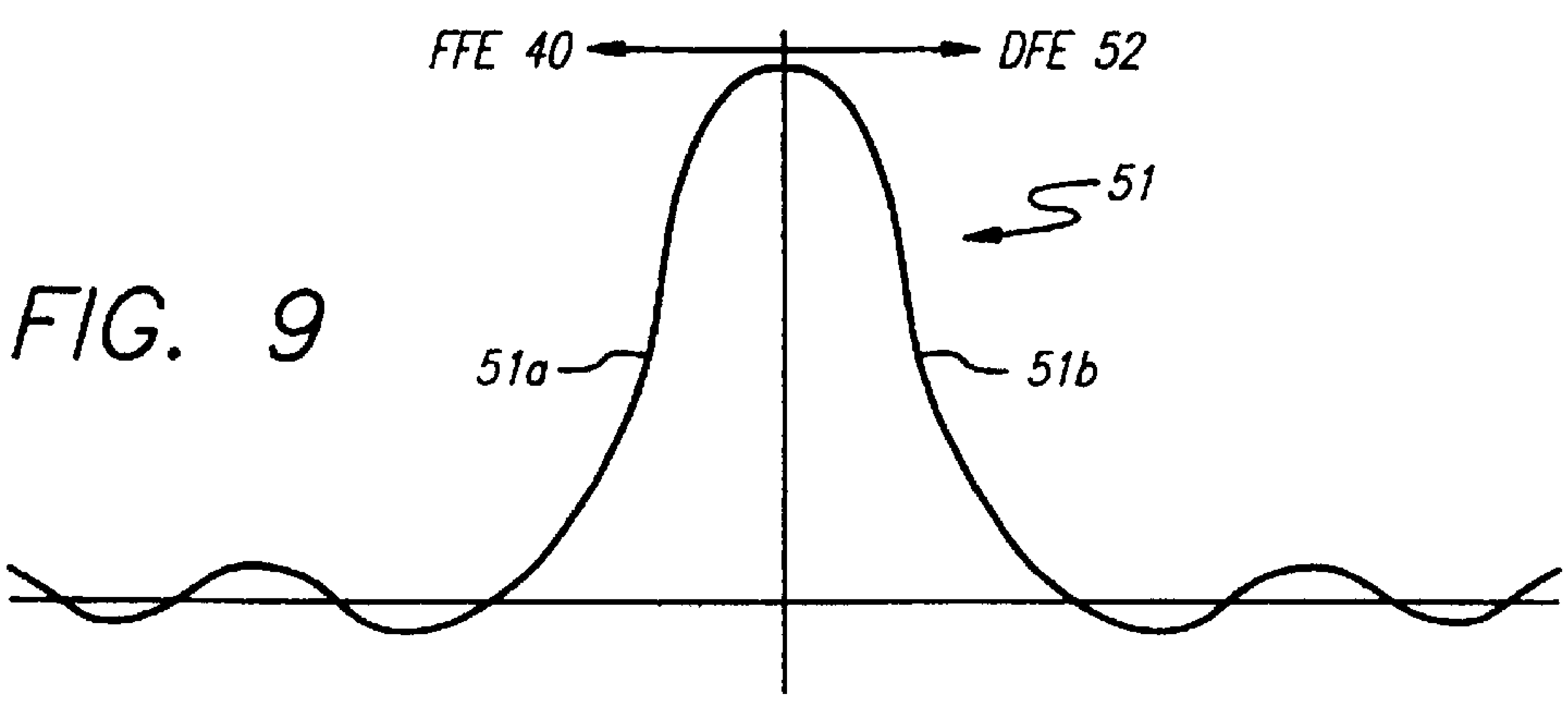
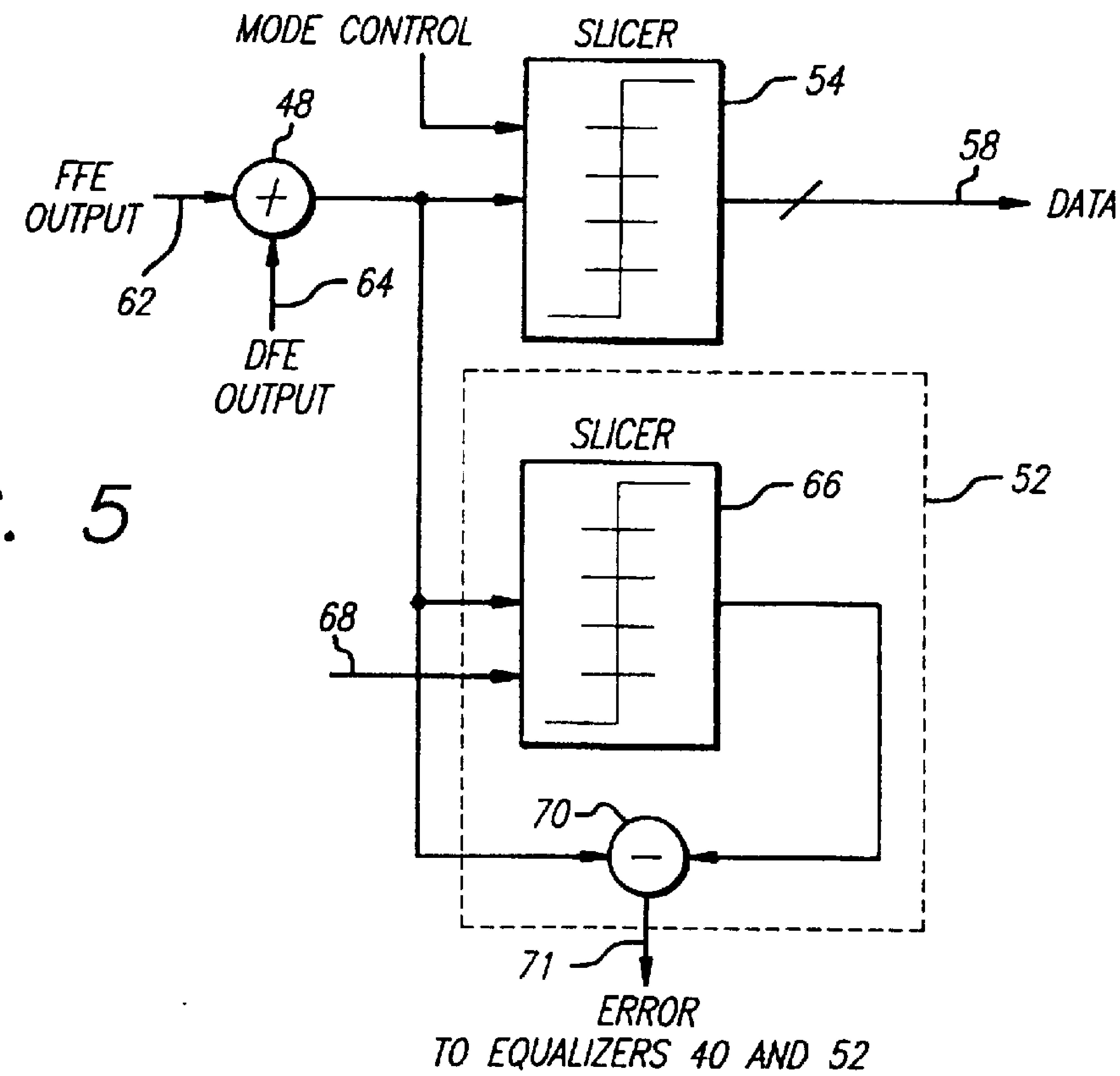
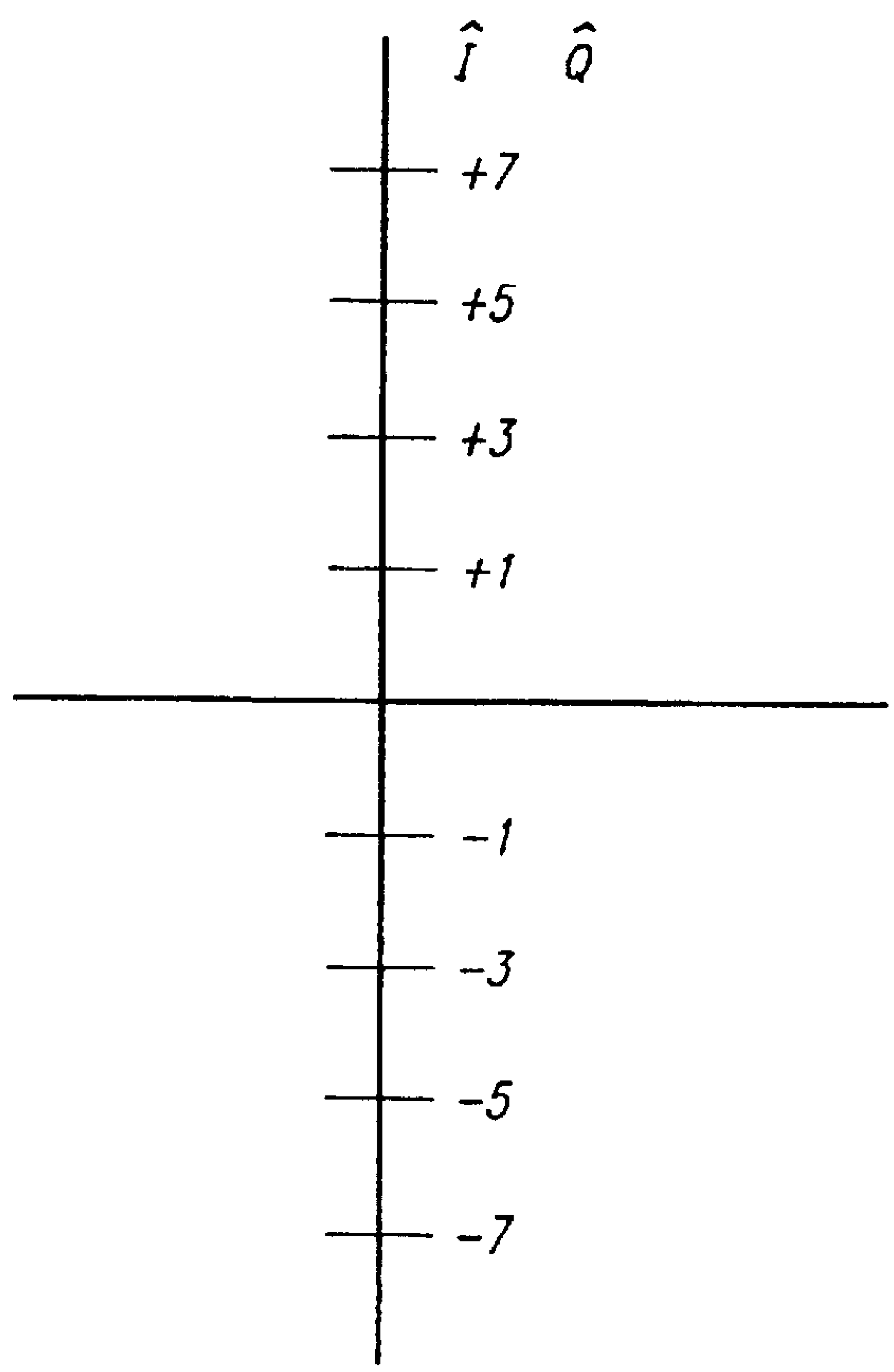


FIG. 9



MODE CONTROL
SLICER
54
48
58
FFE OUTPUT
DATA
62
64
DFE OUTPUT
SLICER
66
52
68
70
71
ERROR
TO EQUALIZERS 40 AND 52

FIG. 5



$\hat{I}$ $\hat{Q}$
+7
+5
+3
+1
-1
-3
-5
-7

FIG. 6

SYSTEM FOR, AND METHOD OF, PROCESSING QUADRATURE AMPLITUDE MODULATED SIGNALS

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

This invention relates to systems for, and methods of recovering digitally modulated television signals from the noise and distortion in coaxial cables. More particularly, this invention relates to systems for, and methods of, recovering quadrature amplitude modulated signals from the noise and distortion in coaxial cables. In these systems and methods, quadrature amplitude modulation is used to transmit the television information. The systems and methods of this invention use digital techniques to recover the quadrature amplitude modulated signals from the noise and distortion in the coaxial cables.

BACKGROUND OF THE INVENTION

Modern digital telecommunication systems are operating at ever-increasing data rates to accommodate society's growing demands for information exchange. However, increasing the data rates, while at the same time accommodating the fixed bandwidths allocated by the Federal Communications Commission (FCC), requires increasingly sophisticated signal processing techniques. Since low cost, small size and low power consumption are important in the hardware implementations of such communications systems, custom integrated-circuit solutions are important in achieving these goals.

Next-generation digital television systems such as proposed cable television (CATV) and high-definition television (HDTV) will rely on transceivers to deliver data at rates in excess of thirty megabits per second (30 Mb/s). Quadrature amplitude modulation (QAM) techniques, used in high-speed modems and digital ratio systems, represent a promising transmission format for CATV and HDTV systems. In quadrature amplitude modulation (QAM) systems, a pair of amplitude modulated signals having a quadrature (90°) phase relationship to each other are summed to transmit the television signals through the coaxial cable.

There are problems in the use of quadrature amplitude modulation for CATV and HDTV systems. One significant problem is that a considerable amount of noise and distortion is generated in the coaxial cables. Such distortion may result in CATV systems in part from impedance mismatches and reflections from unterminated stubs. In HDTV systems, the distortion may result in part from multi-path reflections. Such distortion is so significant that it impairs a good reception of the television signals.

Until now, analog systems have been proposed to recover the quadrature amplitude modulated data from the analog CATV and HDTV signals in the coaxial cables. Such systems have been disadvantageous because they have not been able to eliminate a significant amount of the noise and distortion in the coaxial cables. Even with their inefficiencies, they have required large amounts of power and considerable space.

BRIEF DESCRIPTION OF THE INVENTION

This invention recovers the quadrature amplitude modulated data by using digital techniques. The current embodiment of the invention uses only three (3) integrated circuit chips to provide such recovery. The invention recovers the quadrature amplitude modulated data while eliminating substantially all of the noise and distortion in the coaxial cables. The invention also provides for an increased speed of operation, thereby being capable of handling television signals transmitted at increased baud rates. The three (3) integrated circuit chips consume a relatively low amount of power and occupy a relatively small space. Steps are now being taken to provide in a single chip the system now provided in three (3) chips. This chip will occupy even less space and consume less power than the three (3) chip system.

In one embodiment of the invention, analog signals encoded with quadrature amplitude modulations (QAM) on a carrier frequency individual to a selected TV station pass through a coaxial cable at a particular baud rate. The analog signals from a variable frequency oscillator to produce signals at a particular intermediate frequency (IF). An analog-digital converter (ADC) converts the intermediate frequency (IF) signals to corresponding digital signals which are demodulated to produce two quadrature phrase digital signals.

After being filtered and derotated, the two digital signals pass to a symmetrical equalizer including a feed forward equalizer (FFE) and a decision feedback equalizer (DFE) connected to the FFE in a feedback relationship. The DFE may include a slicer providing amplitude approximations of increasing sensitivity at progressive times. Additional slicers in the equalizer combine the FFE and DFE outputs to provide the output data without any of the coaxial cable noise or distortions.

The equalizer outputs, and initially the derotation outputs and subsequently the slicer outputs, servo (1) the oscillator to obtain the IF frequency, (2) the ADC sampling clock to obtain the digital conversion at a rate having a particular relationship to the particular baud rate and (3) the derotator. The servos may have (1) first constants initially after the selected TV channel is changed and (2) second time constants thereafter. The ADC gain is also sevoed (1) initially in every ADC conversion and (2) subsequently in every nth ADC conversion where n=integer>1. The above recover the QAM data without any of the noise or distortion in the coaxial cable.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. **1** is a diagram schematically illustrating a system for transmitting analog television signals (video and audio) from a selected one of a number of channels or stations through a coaxial cable for reception by a subscriber, the analog signals having been encoded using quadrature amplitude modulation;

FIGS. **2**A and **2**B collectively constitute a circuit diagram, primarily in block form, of a system constituting one embodiment of the invention for recovering the quadrature amplitude modulated signals from the noise and distortion in the coaxial cable;

FIG. **3** is a schematic diagram illustrating how a cosine signal is generated in one of the stages of FIG. **2** on a digital basis;

FIG. **4** is a simplified schematic diagram illustrating how the derotator and equalizer included in the embodiment of FIGS. **2**A and **2**B produce an undistorted quadrature amplitude modulation constellation corresponding to the quadrature amplitude modulation signal generated by the transmitting station;

FIG. **5** is a circuit diagram, primarily in block form, illustrating in additional detail data and error slicer stages in an equalizer chip shown in FIG. **2**A;

FIG. **6** is a chart further illustrating the possible output values of the slicer when operating in a 64-QAM mode;

FIG. **7** is a schematic diagram illustrating how certain closed loop servos included in the embodiment of FIGS. **2**A and **2**B operate when the equalizer chip shown in FIG. **2** provides a QAM constellation with a phase rotation displaced from the QAM constellation transmitted through the coaxial cable by the selected station;

FIG. **8** is a curve further illustrating how the closed loop servos included in the embodiment of FIGS. **2**A and **2**B operate when the equalizer chip shown in FIG. **2**A provides a QAM waveform with a sampling phase displaced from the ideal sampling phase generated by the transmitting station; and

FIG. **9** illustrates how filters included in the equalizer chip shown in FIG. **2** produce different parts of the composite QAM signal which is free of the distortion in the coaxial cable.

DETAILED DESCRIPTION OF THE INVENTION

In one embodiment of the invention, a plurality of television stations or channels **10** (FIG. **1**) are provided to transmit television signals (video and audio) through a coaxial cable **12** to a receiver (not shown). Each of the television channels **10** provides a carrier signal at a frequency individual to such channel. The carrier frequency for the lowest one of the stations or channels **10** may be approximately thirty (30) megahertz (30 MHz) and the carrier frequency for the highest one of the stations or channels may have a value of approximately seven hundred and fifty megahertz (750 MHz). The separation in frequency between adjacent pairs of channels may be approximately six megahertz (6 MHz).

The television signals (video and audio) are digitally compressed and encoded and transmitted through the coaxial cable **12** using quadrature amplitude modulation. The television signals modulated as described above are transmitted through the coaxial cable **12** at a particular baud rate. The signals may be compressed by an amount depending upon the baud rate.

A system as described above is well known in the art. Such a system is being proposed to transmit cable television (CATV) signals and is proposed for use to transmit high definition television signals (HDTV) through a coaxial cable such as the cable **12**.

As the modulated television signals are transmitted through the coaxial cable **12**, noise and distortion develop in the coaxial cable. The distortion may develop from a number of factors. For example, the distortion may develop in cable television systems from impedance mismatches and reflections from unterminated stubs. In high definition broadcast television signals, the distortion may result from multi-path reflections. The distortion in the coaxial cable **12** is so significant that it may prevent the QAM signal from being recovered. The QAM signal has to be recovered in order for the television signals (audio and video) to be processed in the set-top box.

The invention provides a system for, and method of, processing the analog signals in the coaxial cable **12** for any selected one of the individual channels **10** to recover the quadrature amplitude modulated data for such channel from the noise and distortion in the coaxial cable. When the quadrature amplitude modulated data has been recovered by the system of this invention, the television signals (video and audio) for the selected channel **10** can be processed by known techniques to obtain the image and the sound being transmitted in that channel.

The analog signals in the coaxial cable **12** are introduced to a mixer/filter **16** and an oscillator **14** having a variable frequency. The oscillator **14** may preferably be a voltage controlled oscillator whose frequency is varied in accordance with variations in the voltage introduced to the oscillator. As will be described subsequently, the voltage introduced to the oscillator **14** is varied to have the frequency of the oscillator be separated by an intermediate frequency (IF) such as five megahertz (5 MHz) from the individual one of the channels or stations **12** selected at any instant. These signals are mixed in a mixer/filter **16** with the carrier signals in the coaxial cable **12** to produce the intermediate frequency (IF) signal of five megahertz (5 MHz).

The IF analog signals are then introduced to an analog-to-digital converter **18** (FIGS. **1** and **2**A). As will be seen subsequently, the converter **18** operates on the analog signals at four (4) times the baud rate of the selected one of the channels **10** and converts the analog signals to digital signals at this baud rate. The digital signals are then introduced to a pair of multipliers **20** and **22** in FIG. **2**A. The multiplier **20** multiplies the digital signals by a cosine function and the multiplier **22** multiplies the digital signals by a sine function. The multiplication by the cosine function occurs from a phase standpoint at progressive 90° intervals. Thus the multiplication occurs with successive digital values of +1,0,−1,0,+1,0,−1,0, etc. In like manner, the multiplication of the digital signals by the sine function occurs at 90° intervals as by successive digital values of 0,+1,0,−1,0,+1,0,−1, etc. The sine and cosine functions formulated as specified above are shown in FIG. **3**. The sine function is shown in a solid line and the cosine function is shown in broken lines.

Since the multiplication by each of the sine and cosine functions occurs at four times the baud rate, each of the multipliers **20** and **22** produces signals at a frequency four (4) times the baud rate. The signals from the multipliers **20** and **22** are respectively introduced to canonic signed digit low pass filters **24** and **26**. Such low pass filters are well known in the art. For example, they are disclosed in an article entitled "A 200 MHz, All-Digital QAM Modulator and Demodulator in 1.2-um CMOS for Digital Radio Applications" written by Bennett C. Wong and Henry Samueli and published in the IEEE Journal of Solid-State Circuits in December 1991. One advantage of such a low pass filter is that is employs a series of adders rather than multipliers as in other filters. Adders are distinctly advantageous over multipliers because they are considerably less complicated in construction and operation than multipliers. This provides for simplicity in the construction and operation of the low pass filters and for a minimal dissipation of power in the filters.

The frequency of the signals from the low pass filters **24** and **26** is divided by two (2) in a pair of stages **28** and **30**. The dividers **28** and **30** are disclosed in the article specified in the previous paragraph. After such division, the frequency of the digital signals is still two (2) times the baud rate of the quadrature amplitude modulated data in the coaxial cable **12**. The signals from the dividers **28** and **30** are then introduced to a phase derotator **32**. The phase derotator **32** is considered to be one (1) of the novel features of this invention. The phase derotator **32** multiplies the baseband digital signals from the dividers **28** and **30** by the trigonometric functions sin Ø and cos Ø. These trigonometric functions have a sampling frequency corresponding to that of the digital signals from the dividers **28** and **30**. The functions cosine Ø and sine Ø are supplied by a stage **34**.

If the output from the divider **28** is considered as I and the output from the divider **30** is considered as Q, the multiplications provided in the derotator **32** may be indicated as

I cos Ø

Q sin Ø

I sin Ø

Q cos Ø

The multiplicands listed above may be combined in pairs as

I cos Ø–Q sin Ø and

I sin Ø–Q cos Ø

to produce outputs on lines **36** and **38** of the phase derotator.

If the phases of the pairs of the signals I cos Ø–Q sin Ø and I sin Ø–Q cos Ø do not match the phases of the transmitted QAM constellation, there will be a rotation of the signals. This may be seen from FIG. **4** where four (4) columns and four (4) rows are shown and where Q is shown on the horizontal axis and I is shown on the vertical axis. When the phases of I and Q are properly aligned, the QAM constellation will have the relationship shown in FIG. **4**. In this relationship, the I values have a perpendicular relationship and are stationary and the Q values have a horizontal relationship and are stationary. If the phases of I and Q are not properly aligned with the transmitted QAM constellation, the I and Q constellation will spin at a rate dependent upon the differences in phase between the I and Q constellation on the one hand and the transmitted QAM constellation in the coaxial cable **12** on the other hand.

The stages **20**, **22**, **24**, **26**, **28**, **30** and **32** have been included in an integrated circuit chip generally indicated at **34** in FIG. **2**A. This chip is designated in FIG. **2**A as QAM DEMOD CHIP and is shown in broken lines. The signals from the phase derotator **32** in the integrated circuit chip **34** pass through the lines **36** and **38** to a feed forward equalizer (FFE) **40** in an integrated circuit chip generally indicated at **42**. The chip **42** is designated in FIG. **2** as an "EQUALIZER CHIP" and is shown in broken lines. A suitable feed forward equalizer **40** is disclosed in an article entitled "A 100 MHz, 5 MBaud Decision Feedback Equalizer for Digital Television Applications" written by Robindra B. Joshi and Henry Samueli and published in the IEEE International Solid-States Circuits Conference on Feb. 16, 1994. The feed forward equalizer **40** may perform either a T-spaced function or a T/2-spaced function.

The rate of occurrence of the outputs from the feed forward equalizer **40** is divided in the chip **42** by a pair of stages **44** and **46**. Each of these divisions is by a factor of two (2). This causes the digital signals from the dividers **44** and **46** to have the baud rate of the analog signals introduced to the converter **18**. The signals from the dividers **44** and **46** are respectively introduced to adders **48** and **50** as are outputs from a decision feedback equalizer **52**. The adders **48** and **50** and the decision feedback equalizer **52** are included in the equalizer chip **42**. The decision feedback equalizer **52** and the combination of the stages in the equalizer chip **42** are considered to be new to this invention.

The adder **48** adds the outputs of the feed forward equalizer **40** and the decision feedback equalizer **52** to provide an output which is introduced to a slicer **54**. This addition may be seen from FIG. **9**. As will be seen, a composite signal generally indicated at **51** is shown as being comprised respectively of left and right halves **51**a and **51**b. The feed forward equalizer **40** may be considered to correct for distortions in the left half **51**a of the composite signal **51** and the decision feedback equalizer **52** may be considered to correct for distortions in the right half **51**b of the composite signal **51**. The adder **48** accordingly provides the binary value of the composite signal **51**.

The outputs from the adders **48** and **50** are shown in FIG. **2**A as being respectively introduced to a pair of slicers **54** and **56**. Slicers such as the slicers **54** and **56** are considered to be known in the art. Each of the slicers **54** and **56** operates to provide a plurality (such as eight (8)) of progressive values and to determine the particular one of the eight (8) values closest to the output of the associated adder. For example, the slicer **54** selects a particular one of the eight (8) values closest to the output of the adder **48** and then provides this output on a line **58**. Similarly, the slicer **56** selects a particular one of the eight (8) values closest to the output of the adder **50** and then provides this output on a line **60**. The slicers **54** and **56** are included in the integrated circuit chip **42**.

As will be seen in FIG. **2**A, the stages on the integrated circuit chip **42** are symmetrical with respect to the I and Q channels. The symmetry is provided because of the symmetrical relationship of the stages **44**, **48** and **54** between the equalizers **40** and **52** and the stages **46**, **50** and **56** between the equalizers. The symmetrical relationship of the stages in the integrated circuit chip **42** facilitates an optimal detection of the quadrature amplitude modulated signals on the lines **58** and **60** with much less complexity than an asymmetrical structure. The symmetrical structure is practical when the analog-digital converter **18** operates on the IF signal. When the analog-digital converter operates on the baseband I and Q signals, an asymmetrical structure is required. This increases the complexity of the hardware.

FIG. **5** illustrates certain of the stages in FIG. **2**A in additional detail. FIG. **5** shows the adder **48** and the slicer **54** also shown in FIG. **2**A. FIG. **5** also shows the output from the feed forward equalizer **40** on a line **62** and the output from the decision feedback equalizer **52** on a line **64**, both of these outputs being introduced to the adder **48**. As in FIG. **2**A, the output of the adder **48** is shown as being introduced to the slicer **54**. The output of the adder **48** is also shown in FIG. **5** as being introduced to the input of a slicer **66** which is included in the decision feedback equalizer **52** shown in broken lines in FIG. **5**. The slicer **66** also receives a control input on a line **68**. The output of the slicer **66** is introduced to a stage **70** which determines the difference between the output of the slicer **66** and the output of the adder **48**. The output of the stage **70** is introduced on a line **71** to both the feed forward equalizer **40** and the decision feedback equalizer **52** also shown in FIG. **2**A. This output may be considered to constitute the error feedback from the slicer **66** to the feed forward equalizer **40** and the decision feedback equalizer **52** in FIG. **2**A.

The control line **68** receives successive binary indications from a microprocessor **72** (FIG. **2**B) of two (2), four (4), eight (8) and sixteen (16) binary values. These respectively represent the square roots of four (4), sixteen (16), sixty four (64) and two hundred and fifty six (256). When the control line **68** in FIG. **5** receives a binary indication of two (2), the slicer **66** selects the binary value from the adder **48** closest to the two (2) progressive binary values in the slicer **66** and substitutes the closest of these two (2) values in the slicer **66** as the output from the slicer **66**.

After a fixed period of time preset into the microprocessor **72**, the slicer **66** provides four (4) progressive binary values and determines which one of these four (4) progressive binary values is closest to the binary value now provided as the output from the slicer. After an additional fixed period of time preset by the microprocessor **72**, the slicer **66** again increases the number of progressive binary values, this time to eight (8). The slicer **66** then determines the individual one of the eight (8) progressive binary values closest to the adjusted input to the slicer **66** and selects this individual one of the progressive binary values as the new adjusted output from the slicer **66**. If the receiver is operating in the 256-QAM mode, then, after another fixed period of time preset by the microprocessor **72**, the slicer **66** again repeats this procedure, but this time with sixteen (16) progressive values in the slicer **66**.

In this way, the slicer **66** initially provides a coarse control and, in subsequent time periods preset by the microprocessor **72**, provides controls of progressively increasing sensitivity. These controls of progressively increasing sensitivity are fed by the slicer **66** to the stage **70**, which produces the error signal that is fed back to the feed forward equalizer **40** and the decision feedback equalizer **52** to control the operation of coefficient updating loops in the equalizers. Upon each such feedback, the feed forward equalizer **40** and the decision feedback equalizer **52** adjust the values of the binary filter coefficients in the equalizers to provide an output of progressively increasing accuracy from the slicer **54**.

Although the discussion above has centered specifically on the adder **48**, the slicer **66** and the slicer **54**, it will be appreciated that similar operations may be provided for a slicer (corresponding to the slicer **66**) associated with the adder **50** and the slicer **56** to provide an output of progressively increasing accuracy from the slicer **56**. As a result, the slicers **54** and **56** progressively provide, at successive instants of time, in-phase (I) and quadrature (Q) data estimates which progressively approach the values of the quadrature amplitude modulated data in the coaxial line **12**.

In providing at progressive instants of time the outputs discussed in the previous paragraph, the slicer **66** in FIG. **5** provides at progressive instants of time two (2), four (4), eight (8) and sixteen (16) binary levels. The corresponding slicer associated with the adder **50** provides similar numbers of binary levels at progressive instants of time. Since the two (2) slicers respectively represent I and Q, they provide at successive instants of time four (4), sixteen (16), sixty four (64) and two hundred and fifty six (256) possible output pairs. This may be seen from the representation shown in FIG. **4** for the case of sixteen (16) outputs.

There are a number of closed loop servos which enhance the response of the system constituting this invention. One of these is indicated generally at **74** in FIG. **2**B. It provides an automatic gain control for the analog signals introduced to the analog-digital converter **18**. As will be appreciated, it is desirable to regulate the gain of the analog signals before they are converted to digital signals by the converter **18**. One reason is that the amplitude of the analog signals at each instant affects the characteristics of the television information. The automatic gain control (AGC) servo **74** includes an AGC discriminant stage **76**, an accumulator stage **78**, a multiplier **80** and a digital-to-analog converter **82**. The converter **82** may be a delta-sigma converter well known in the art. Although the stages **74**, **76**, **78**, **80** and **82** may be considered to be individually known in the art, they are not known in the environment included in this invention for regulating the gain of the input to the analog-digital converter **18** in this invention.

The AGC discriminant stage **76** initially provides a determination of the digital value (after conversion from analog) at a rate four (4) times the rate of the baud samples. This stage provides a close regulation of the gain in the analog signals. After a fixed time preset by the microprocessor **72**, the AGC discriminant stage **76** provides a determination of the digital value (after conversion from analog) in every nth baud sample where n is an integer greater than one (1) and is preset by the microprocessor **72** (FIG. **2**B).

The AGC discriminant stage **76** is able to operate in every nth sample because the stage has previously provided a strong (or coarse) regulation by determining and regulating the digital value at a rate four (4) times the rate of the baud samplings. Providing the determination in every nth baud sample after this initial strong (or coarse) regulation is desirable because it minimizes the consumption of power and because the circuitry for providing the determination in every nth baud sample is simpler than the circuitry for providing the determination at a rate four (4) times the rate of the baud samples.

The output from the AGC discriminant stage **76** is introduced to the accumulator **78** which operates to sum and average this output with the previous outputs from the stage **76**. The multiplier **80** then multiplies the output from the accumulator **78** by a constant value b_0 preset by the microprocessor **72**. The constant b_0 is initially set by the microprocessor **72** at a first fixed value. This first value for the constant b_0 is set so that the servo **74** can provide strong (or coarse) adjustments after the television station or channel **10** desired to be viewed has been changed.

After a fixed period of time preset by the microprocessor **72**, the constant b_0 is changed by the microprocessor **72** to a second value. This second value of the constant b_0 provides for a weaker regulation than the first value of the constant b_0. This weaker regulation is quite satisfactory because of the previously strong (or coarse) regulation during the period of the first value of the constant. The output of the multiplier **80** is converted to an analog value by the converter **82**. This analog value is used to regulate the gain of the analog signals introduced to the input to the analog-digital converter **18**.

Another closed loop servo, generally indicated at **84** in FIG. **2**B, corrects for the frequency of the variable frequency oscillator **14** (e.g. voltage controlled oscillator) to provide the oscillator with a frequency which differs from the carrier frequency for the selected station **10** by the intermediate frequency of five megahertz (5 MHz). In this way, a constant intermediate frequency can be provided regardless of which one of the stations **10** in the plurality is selected. The servo **84** includes an intermediate frequency (IF) carrier phase detector **86** having inputs respectively connected initially to the two (2) output lines **36** and **38** from the derotator **32** in FIG. **2**A. The output lines **36** and **38** are respectively designated as IDEROT and QDEROT in FIG. **2**A. Inputs to the intermediate carrier phase detector **86** are also respectively connected to the output lines **58** and **60** from the slicers **54** and **56**.

As will be seen, the phase detector **86** has four (4) inputs. Two of these inputs may be considered as decision values and are obtained from the output lines **58** and **60**. These decision values may be respectively designated as $\hat{I}$ and $\hat{Q}$. The outputs from the lines **36** and **38** may be respectively designated as I and Q. The four (4) inputs may be combined to obtain the following outputs:

$I\hat{Q}$

$Q\hat{I}$

These two (2) values are subtracted from each other as follows:

$I\hat{Q}-Q\hat{I}$

When there is no phase error in the output signals on the lines **58** and **60** relative to the ideal QAM constellation as shown in FIG. **4**, $I\hat{Q}-Q\hat{I}=0$. When $I\hat{Q}-Q\hat{I}$ is different from zero (0), the magnitude of this difference represents the amount of the phase error in the output signals on the lines **58** and **60** relative to the ideal QAM constellation.

The phase error signal $I\hat{Q}-Q\hat{I}$ may be simplified in hardware by instead computing the following phase error from

$$\mathrm{sgn}\,[I\,\mathrm{sgn}\,(\hat{Q})-Q\,\mathrm{sgn}\,(\hat{I})]$$

where the designation "sgn" in front of a term indicates whether the term is positive or negative. This simplified phase error term can be computed without the need for multiplications. This greatly simplifies the hardware implementation.

As previously described, the decision values $\hat{Q}$ and $\hat{I}$ correspond to an individual one of a number of binary values. For example, FIG. **6** indicates four (4) binary values between zero (0) and plus seven (+7) and four (4) binary values between zero and minus seven (−7). One of these binary values is indicated at **89** in FIG. **7** for the case of 4–QAM. If there is a phase error between the outputs on the lines **58** and **60** and the ideal QAM constellation represented by the circles in FIG. **7**, the I and Q outputs of the phase derotator **32** may be shifted to a position **91** in FIG. **7**. As will be seen, this shift to the position **91** causes I to have an error indicated at **93** in FIG. **7** and Q to have an error indicated at **95** in FIG. **7**. The phase detector **86** detects the difference **93** in the position between I and $\hat{I}$ along the vertical axis and the difference **95** in the position Q and $\hat{Q}$ along the horizontal axis and, on the basis of these differences, computes the phase error denoted by γ in FIG. **7**.

The above phase detector technique is used in conjunction with a sweep circuit to obtain an initial coarse acquisition of the QAM signal. The sweep circuit is implemented under the control of the microprocessor **72** which provides a small positive or negative offset value at the input of an accumulator **88** in FIG. **2**B. This offset causes the accumulator output to either ramp up or down depending on whether the offset was positive or negative. A digital-analog converter **96** converts these binary numbers to a ramping voltage which controls the variable frequency oscillator **14**. This enables the oscillator **14** to sweep through a range of frequencies and thus match up exactly with the carrier frequency of the incoming QAM signal.

After a fixed period of time preset by the microprocessor **72**, the phase detector technique is changed to provide a more precise, fine resolution, phase tracking capability. The fine resolution phase tracking algorithm is computed as

$$e_I\hat{Q}-e_Q\hat{I}$$

where e_I is the I channel slicer error on the line **71**, and e_Q is the channel slicer error **56** on a line **87** corresponding to the line **71**. The phase error computation specified in the equation immediately above is similar to the coarse acquisition technique except that I and Q have been respectively replaced by e_I and e_Q. The fine resolution phase error signal $e_I\hat{Q}-e_Q\hat{I}$ may be simplified in hardware by instead computing the following phase error term

$$e_I\mathrm{sgn}\,(\hat{Q})-e_Q\,\mathrm{sgn}\,(\hat{I})$$

This simplified phase error term can be computed without the need for multiplications. This greatly simplifies the hardware implementation. In these equations, the designation "Sgn" in front of a term indicates whether the term is positive or negative.

The output from the detector **86** is introduced to a pair of stages connected in parallel in FIG. **2**B. One of these stages constitutes the accumulator **88** and the other stage constitutes a multiplier **90**. The multiplier **90** is multiplied by a constant a_1 which is preset by the microprocessor **72**. The multiplier **90** in effect damps the output of the accumulator **88** by a factor dependent upon the value of the constant a_1. The accumulator **88** and the multiplier **90** provide outputs which are combined in an adder **92**. The output from the adder **92** is introduced to a multiplier **94** which multiplies this output by a constant b_1 preset by the microprocessor **72**. The output of the multiplier **94** is introduced to a digital-analog converter **96** which is well known in the art. For example, the converter **96** may be a delta-sigma type of converter. Stages such as the stages **88**, **90**, **92**, **94** and **96** may be individually well known in the art but not in the environment shown in FIGS. **2**A and **2**B.

The servo **84** is shown as having two constants a_1 and b_1. Actually, each of these constants may have two (2) values. One of these values for each of the constants a_1 and b_1 may be provided by the microprocessor **72** for a fixed period of time after a change in the selection of the station or channel **10** to be viewed. In effect, these first values provide a coarse control over the frequency of the oscillator **14**. After a fixed period of time preset by the microprocessor **72**, each of the constants a_1 and b_1 is changed to a second value. In effect, this provides a fine control over the selection of the frequency in the oscillator **14**. It will be appreciated that each of the first and second values of the constant a_1 may be different from each other and from the first and second values of the constants b_0 and b_1. This is also true of the other constants which will be discussed subsequently.

The digital signals on the output lines **36** and **38** and on the output lines **58** and **60** are initially introduced to the phase detector **86** to provide a strong, but coarse, control over the phases of the signals cos Ø and sin Ø. This control is particularly strong (or coarse) since the output of the derotator **32** is used to regulate the input to the derotator. After a fixed period of time preset by the microprocessor **72**, the phase detector **86** receives the error output **71**, and the slicer error output on the line **87** associated with the slicer **56** and corresponding to the line **71** and also receives the outputs on the lines **58** and **60**. This provides a fine resolution phase control because, after equalizer convergence, the slicer error on the line **71** and the slicer error on the line corresponding to the slicer **71** are very precise.

The output of the detector **86** is also introduced to a filter stage, generally indicated at **100** consisting of an accumulator **104** and a multiplier **110**. The output of the multiplier **110** is a filtered phase error term Ø which is applied to the phase derotator blocks **32** and **34** to decrease the difference in phase between the signals from the derotator **32** and the QAM constellation. The filter stage **100** may also be considered as a servo.

The stage **110** multiplies the output from the accumulator **104** by a constant b_2. The constant b_2 has a first value preset by the microprocessor **72**. After a fixed period of time preset by the microprocessor **72**, the constant b_2 has another value. These different values are provided so that the servo **86** will be initially able to adapt on a coarse basis to a change in the station or channel **10** selected and the servo **100** will subsequently be able to operate on a fine basis to regulate the phases of the signals cos Ø and sin Ø.

Furthermore, the I Derot and Q Derot signals respectively on the lines **36** and **38** initially provide a coarse control in the operation of the servo **84** and the filter stage **100** when combined with the signals on the lines **58** and **60**. Subsequently, the I error signals on the line **71** from the slicer **66** and the corresponding error signals on the line **97** from the slicer corresponding to the slicer **66** provide a fine control in the operation of the servos **84** and the filter stage **100** when combined with the signals on the lines **58** and **60**.

The overall carrier tracking servo loop thus consists of two servos operating in parallel. The first servo **84** is a relatively slow reacting loop since it feeds all the way back to the variable frequency oscillator **14**. The second servo **100** is a fast reacting loop which can track very rapid fluctuations in the phase of the incoming QAM signal. Each of these servos is considered to be an important feature of the invention. The combination of these servos in the manner described above is also considered to be an important feature of this invention.

Another closed loop servo generally indicated at **112** in FIG. **2**B regulates the rate at which the analog-digital converter **18** converts the analog signals in the coaxial cable **12** to digital signals. This rate is regulated so that the digital conversion will occur at four (4) times the baud rate of the analog signals in the coaxial cable **12**. The servo **112** includes the same stages as the servo **84**. For example, a baud phase detector **114** receives the digital signals on the lines **36** and **38** and the lines **58** and **60** and computes a sampling phase error which is filtered as at **116**, **118**, **120** and **122**, is converted from digital to analog as at **124** and is applied to a variable frequency oscillator **126** (FIG. **2**A) which generates a master clock M-CLK as at **128** for the system. The two multipliers **116** and **118** in the servo **112** respectively receive constants a_3 and b_3 from the microprocessor **72**. Each of these constants a_3 and b_3 initially has a first value and subsequently has a second value as described previously for other constants.

The operation of the baud phase detector **114** can be described by referencing FIG. **8**. FIG. **8** illustrates an example of an I channel waveform **130** with a trajectory that traverses from +1 to −1 and back to +1, thereby crossing zero twice. The Q channel waveform (not shown in FIG. **8**) has a trajectory similar to that of the I channel waveform **130** shown in FIG. **8**. The frequency of occurrence of the derotator output samples on the lines **36** and **38** is twice the baud rate. Thus, the time interval between samples is T/2 as shown in FIG. **8** where T is the reciprocal of the baud rate.

If the analog-digital converter **18** is sampling the received QAM signal perfectly, then the derotator output samples will be +1, 0,−1,0,+1 as shown in FIG. **8**. On the other hand, if, for example, the analog-digital converter **18** is sampling too late, then the derotator output samples will be **97**a, **97**b, **97**c, and **97**d. The baud phase detector **114** initially determines if a zero crossing has occurred, i.e., it checks to determine if $\text{sgn}[\hat{I}(n)] \neq \text{sgn}\,[\hat{I}(n-1)]$ where $\hat{I}(n)$ and $\hat{I}(n-1)$ are two consecutive slicer data decisions **132** and **134** in FIG. **8**. If a zero crossing has occurred, then the baud phase error is $\text{sgn}\,[\hat{I}(n)]\ \text{sgn}\,[I(n-\frac{1}{2})]$ where $I(n-\frac{1}{2})$ is indicated at **136** in FIG. **8**.

A similar computation is performed on the Q channel derotator output, i.e., if a Q channel zero crossing has occurred, then the Q channel baud phase error is

$$\text{sgn}\,[\hat{Q}(n)]\ \text{sgn}\,[Q(n-\tfrac{1}{2})]$$

The baud phase detector output can either be the I channel baud phase error, the Q channel baud phase error or the sum of the two:

$$\text{sgn}[\hat{I}(n)]\ \text{sgn}\,[I(n-\tfrac{1}{2})]+\text{sgn}\,[\hat{Q}(n)]\ \text{sgn}\,[Q(n-\tfrac{1}{2})]$$

In the preferred embodiment, the baud phase detector output is chosen as the sum of the I channel and Q channel phase errors.

In FIG. **2**A, the variable frequency oscillator **126** provides a master clock signal. This signal has a suitable frequency such as approximately eighty (80) megahertz. This is higher than the baud rate. From this master clock, frequencies constituting (a) four (4) times the baud rate, (b) two (2) times the baud rate and (c) the baud rate are generated. These are designated in FIGS. **2**A and **2**B as "BAUD CLK **4**", "BAUD CLK **2**" and "BAUD CLK".

The system and method described above have certain important advantages. They can optimally detect the quadrature amplitude modulated data transmitted over the coaxial cable **12** with very low complexity. The system and method of this invention detect such quadrature amplitude modulated data in the lines **58** and **60** in FIG. **2**A without being affected by any of the distortions in the coaxial cable **12**. The detected data in the lines **58** and **60** can then be processed in a manner well known in the art to recover the television signals (video and audio). The recovered television signals are then processed to provide a television image and the accompanying sound.

The system and method of this invention employ techniques which have not previously been employed in systems and methods involving quadrature amplitude modulation and which provide for results significantly advanced in relation to the prior art. For example, the system and method of this invention employ digital signal processing techniques to provide on the lines **58** and **60** optimally detected QAM data which eliminate substantially all of the distortions in the coaxial cable. The system and method of this invention include the derotator **32** to improve the phase tracking capabilities in spite of the noise and distortion and include the symmetrical relationship of the stages in the equalizer chip **42** to significantly reduce hardware complexity. The system and method of this invention are also advantageous in employing the slicers **54** and **66** in FIG. **5** and in employing the slicer **56** and a slicer corresponding to the slicer **66** in providing this robust symmetric equalization. The system and method of this invention are further advantageous in providing the decision feedback equalizer **52** and the feed forward equalizer **40** in FIG. **2**A to optimally correct for the distortion in the coaxial cable **12**.

Servos are included in the system and method of this invention. These servos are believed to be broadly new and patentable in providing on the lines **58** and **60** QAM data which are substantially free of noise and distortion and which are provided with very accurate baud and carrier phases corresponding to the phases of the transmitted QAM signals in the coaxial cable **12**. An individual one of the servos regulates the frequency of the signals from the oscillator **14** to obtain the intermediate frequency of five megahertz (5 MHz). Another one of the servos regulates the gain of the analog signals introduced in the coaxial cable **12** to the converter **18**. A third one of the servos regulates the conversion of these analog signals to digital signals at four (4) times the baud rate. A fourth one of the servos regulates the phase and frequency of the cosine ∅ and sine ∅ signals introduced to the stage **34** so that the phase of the digital signals from the derotator **32** will correspond to the phase of the QAM signals in the coaxial cable **12**.

The servos described in the previous paragraph have sophistications which further enhance their operation in providing on the output lines **58** and **60** quadrature amplitude demodulated signals free of the noise and distortions in the coaxial cable **12** and corresponding in baud and carrier phase to the phases of the quadrature amplitude modulated signals in the coaxial cable. One of these sophistications for three (3) of the four (4) servos is initially to use the signals on the lines **36** and **38** for regulation and subsequently to use the signals representing the slicer errors on the line **71** and the slicer error on the line corresponding to the line **71** for such regulation.

Another sophistication is the use of two parallel servos for carrier acquisition and tracking. One slow reacting servo controls the IF variable frequency oscillator to track the incoming frequency. The second fast reacting servo controls the phase derotator to track any phase variations on the incoming signal. Both effectively provide controls of frequency, one providing a coarse control and the other providing a fine control.

Another sophistication is to provide individual time constants in the different servos and to provide each of these time constants with a first value for a first period of time after a change in the individual one of the channels **10** selected and then with a second value after the first period of time. All of the sophistications specified in this paragraph and in the previous paragraphs cause each of the servos initially to provide a coarse control and subsequently to provide a fine control.

Although this invention has been disclosed and illustrated with reference to particular embodiments, the principles involved are susceptible for use in numerous other embodiments which will be apparent to persons skilled in the art. The invention is, therefore, to be limited only as indicated by the scope of the appended claims.

We claim:

1. In combination for operating upon analog signals transmitted through a coaxial cable providing quadrature amplitude modulated data to recover the quadrature amplitude modulated data from noise and distortions in the coaxial cable,

first means for converting the analog signals to analog signals having a particular intermediate frequency,

second means for converting the analog signals at the particular intermediate frequency to corresponding digital signals,

third means for operating upon the digital signals to provide the digital signals with a quadrature phase relationship,

fourth means for passing the low frequency components in the digital signals with the quadrature phase relationship,

fifth means for derotating the digital signals passed by the fourth means,

sixth means responsive to the derotated digital signals for recovering, in digital form, the quadrature amplitude modulated data,

the fifth means including seventh means for multiplying the output from the fourth means by trigonometric signals in a quadrature phase relationship to provide for a recovery in digital form of the quadrature amplitude modulated data from the noise and distortions in the coaxial cable,

eighth means responsive to the derotated digital signals for producing error signals, and

ninth means responsive to the error signals from the eighth means for regulating the analog signals from the first means at the particular intermediate frequency.

2. In a combination as set forth in claim **1**,

tenth means for equalizing the derotated signals from the fifth means, and

eleventh means responsive to the outputs from the fifth means and the tenth means for providing a servo feedback to the fifth means to adjust the phases of the trigonometric signals form the seventh means for facilitating the recovery of the quadrature amplitude modulated data by the sixth means from the noise and distortions in the coaxial cable.

3. In a combination as set forth in claim **2**,

twelfth means for obtaining the recovery of the phase and amplitude modulations in the coaxial cable at the output of the tenth means.

4. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from noise in the coaxial cable,

first means for converting the analog signals to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship to the other of the digital signals in the pair,

third means for derotating the digital signals in the pair, and

fourth means for equalizing the derotated signals from the third means,

fifth means for providing progressive pluralities of values, each progressive plurality having a greater number of values than the numbers of values in the previous ones of the progressive pluralities,

sixth means for determining the individual one of the values in each of the progressive pluralities closest to the derotated equalized signals.

5. In a combination as set forth in claim **4**,

fifth means responsive to the signals from the third means and the fourth means for servoing the operation of the third means to facilitate the derotation of the digital signals in the pair.

6. In a combination as set forth in claim **4**,

the signals in the coaxial cable including carrier signals having a carrier frequency,

seventh means for producing signals having a variable frequency, and

eighth means responsive to the signals from the second means and the signals from the fourth means for varying the frequency of the signals from the seventh means to provide a difference of a particular intermediate frequency between the frequency of the carrier signals and the frequency of the signals from the oscillator, and

the first means being operative to convert the signals at the particular intermediate frequency to the corresponding digital signals.

7. In a combination as set forth in claim **6**,

ninth means responsive to the signals from the first means for regulating the gain of the analog signals converted at the particular intermediate frequency by the first means to the corresponding digital signals.

8. In a combination as set forth in claim **6**,

tenth means responsive to the derotated signals from the third means and the derotated equalized signals from the fourth means for regulating the frequency of the intermediate frequency signals at the particular value.

9. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from noise and distortions in the coaxial cable, first means for converting the analog signals to digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable, and

fourth means responsive to the signals from the third means for providing a closed loop servo with the third means for locking the phases of the digital signals from the third means to the phases of the quadrature amplitude modulated signals in the coaxial cable, and

fifth means for providing progressively refined approximations in the amplitudes of the digital signals in the pair to obtain a selection of an individual one of a plurality of binary values closest to the progressively refined approximations in the amplitudes of the digital signals in the pair.

10. In a combination as set forth in claim **9**,

the third means including sixth means for derotating the digital signals in the pair, and

seventh means for recovering the quadrature amplitude modulated data from the individual one of the binary values in the plurality.

11. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from noise an distortions in the coaxial cable,

first means for converting the analog signals to digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable, and

fourth means responsive to the signals from the third means for providing a closed loop servo with the third means for locking the phases of the digital signals from the third means to the phases of the quadrature amplitude modulated signals in the coaxial cable,

the third means including a feed forward equalizer and a decision feedback equalizer and a pair of slicers each operable on an individual one of the digital signals in the pair to slice the digital signals into the closest of a number of binary values.

12. In a combination as set forth in claim **11**,

the third means including fifth means for derotating the digital signals in the pair,

the fourth means being responsive to the derotated signals from the third means and to the digital signals from the slicers in the pair to lock the phases of the digital signals from the third means to the phases of the quadrature amplitude modulated signals in the coaxial cable.

13. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data at a particular baud rate to recover the quadrature amplitude modulated data from noise and distortions in the coaxial cable,

first means for converting the analog signals to digital signals at a variable rate,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable, and

fourth means responsive to the signals from the third means for varying the rate of converting the analog signals to the digital signals to provide the digital signals at a rate having a particular relationship to the particular baud rate, and

fifth means for equalizing the digital signals in the pair from the second means, the fifth means being constructed to be symmetrical with respect to the second means to provide the same equalizations for the digital signals in the pair.

14. In a combination as set forth in claim **13**,

the third means including means for derotating the digital signals in the pair.

15. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data at a particular baud rate to recover the quadrature amplitude modulated data from noise and distortions in the coaxial cable,

first means for converting the analog signals to digital signals at a variable rate,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable, and

fourth means responsive to the signals from the third means for varying the rate of converting the analog signals to the digital signals to provide the digital signals at a rate having a particular relationship to the particular baud rate,

the third means including a feed forward equalizer and a decision feedback equalizer and a pair of slicers each operable on an individual one of the digital signals in the pair to slice the digital signals into the closest of a number of binary values.

16. In a combination as set forth in claim **15**,

the third means including fifth means for derotating the digital signals in the pair,

the fourth means being responsive to the derotated signals from the third means and to the digital signals from the slicers in the pair to lock the phases of the digital signals from the third means to the phases of the quadrature amplitude modulated signals in the coaxial cable.

17. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data on a carrier signal of a particular frequency to recover the quadrature amplitude modulated data from noise and distortions in the coaxial cable,

first means for converting the analog signals to digital signals at a variable rate,

second means for operating upon the digital signals to provide a pair of digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals from the second means to conform to the phases of the analog signals in the coaxial cable, fourth means for providing an oscillator having a variable frequency, the fourth means being disposed before the first means in the combination, and

fifth means responsive to the digital signals from the third means for varying the frequency of the oscillator to obtain the production, from the mixing of the analog signals and the oscillator signals, of intermediate frequency signals having a particular frequency, and

sixth means responsive to the digital signals from the second means for servoing the operation of the fifth means to maintain the production of the intermediate frequency signals at the particular frequency.

18. In a combination as set forth in claim **17**,

the third means including means for derotating the digital signals in the pair.

19. In a combination as set forth in claim **17**,

the sixth means including seventh means for servoing the operation of the fifth means at a first rate to maintain the production of the intermediate frequency signals at the particular frequency,

the sixth means also including eighth means for servoing the operation of the fifth means at a second rate greater than the first rate to maintain the production of the intermediate frequency signals at the particular frequency.

20. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data on a carrier signal of a particular frequency to recover the quadrature amplitude modulated data from noise and distortions in the coaxial cable,

first means for converting the analog signals to digital signals at a variable rate,

second means for operating upon the digital signals to provide a pair of digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals from the second means to conform to the phases of the analog signals in the coaxial cable,

fourth means for providing an oscillator having a variable frequency, the fourth means being disposed before the first means in the combination, and

fifth means responsive to the digital signals from the third means for varying the frequency of the oscillator to obtain the production, from the mixing of the analog signals and the oscillator signals, of intermediate frequency signals having a particular frequency,

the third means including a feed forward equalizer and a decision feedback equalizer and a pair of slicers each operable on an individual one of the digital signals in the pair to slice the digital signals into the closest of a number of binary values.

21. In a combination as set forth in claim **20**,

the third means including fifth means for derotating the digital signals in the pair,

the fourth means being responsive to the derotated signals from the third means and to the digital signals from the slicers in the pair to lock the variable frequency of the oscillator to obtain the production, from the mixing of the analog signals and the oscillator signals, of intermediate frequency signals having a particular frequency.

22. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data at a particular baud rate to recover the quadrature amplitude modulated data from noise and distortions in the coaxial cable,

first means for converting the analog signals to digital signals at a variable rate,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable,

fourth means responsive to the signals from the third means for providing a first closed loop servo with the third means for adjusting the operation of the first means to a rate having a particular relationship to the particular baud rate,

fifth means responsive to the signals from the third means for providing a second closed loop servo with the third means for locking the phases of the pair of the digital signals from the third means to the phases of the quadrature amplitude modulated signals in the transmitter, and

sixth means having inputs and outputs and operative in a closed loop between the inputs and the outputs for providing an equalization in the digital signals in the pair from the second means.

23. In a combination as set forth in claim **22**,

means responsive to the digital signals from the first means for regulating the amplitude of the digital signals.

24. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data at a particular baud rate to recover the quadrature amplitude modulated data from noise and distortions in the coaxial cable,

first means for converting the analog signals to digital signals at a variable rate,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable,

fourth means responsive to the signals from the third means for providing a first closed loop servo with the third means for adjusting the operation of the first means to a rate having a particular relationship to the particular baud rate, and

fifth means responsive to the signals from the third means for providing a second closed loop servo with the third means for locking the phases of the pair of the digital signals from the third means to the phases of the quadrature amplitude modulated signals in the transmitter,

the fourth means including a first digital-to-analog converter for converting the digital signals from the third means to corresponding analog signals for adjusting the operation of the first means to a rate having the particular relationship to the particular baud rate, and

the fifth means including a second digital-to-analog converter for converting the digital signals from the third means to corresponding analog signals for locking the phases of the pair of the digital signals from the third means to the phases of the quadrature amplitude modulated signals in the coaxial cable.

25. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data at a particular baud rate to recover the quadrature amplitude modulated data from noise and distortions in the coaxial cable,

first means for converting the analog signals to digital signals at a variable rate,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable,

fourth means responsive to the signals from the third means for providing a first closed loop servo with the third means for adjusting the operation of the first means to a rate having a particular relationship to the particular baud rate, and

fifth means responsive to the signals from the third means for providing a second closed loop servo with the third means for locking the phases of the pair of the digital signals from the third means to the phases of the quadrature amplitude modulated signals in the transmitter,

the quadrature amplitude modulated analog signals in the coaxial cable including carrier signals at a particular frequency, and

sixth means for providing signals having a variable frequency, and

seventh means responsive to the pair of the digital signals from the third means and to the carrier signals at the first particular frequency for varying the frequency of the signals from the sixth means to obtain, upon a mixture of the signals from the sixth means and the carrier signals, intermediate frequency signals having a second particular frequency.

26. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data at a particular carrier frequency to recover the quadrature amplitude modulated data from noise and distortions in the coaxial cable,

first means for converting the analog signals to digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable,

fourth means responsive to the signals from the third means for providing a first closed loop with the third means for locking the phases of the pair of the digital signals from the third means to the phases of the quadrature amplitude modulated signals in the coaxial cable,

fifth means for providing signals having a variable frequency, and

sixth means responsive to the signals from the third means for providing a second closed loop with the third means for varying the frequency of the signals from the fifth means to obtain, upon a mixture of the signals at the carrier frequency and the signals having the variable frequency, intermediate frequency signals having a particular frequency.

27. In a combination as set forth in claim 26,

means responsive to the analog signals from the first means for regulating the amplitude of the analog signals.

28. In a combination as set forth in claim 26,

the third means including seventh means for derotating the digital signals in the pair and further including eighth means for equalizing the derotated digital signals in the pair from the seventh means.

29. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data at a particular carrier frequency to recover the quadrature amplitude modulated data from noise and distortions in the coaxial cable,

first means for converting the analog signals to digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable,

fourth means responsive to the signals from the third means for providing a first closed loop with the third means for locking the phases of the pair of the digital signals from the third means to the phases of the quadrature amplitude modulated signals in the coaxial cable,

fifth means for providing signals having a variable frequency, and

sixth means responsive to the signals from the third means for providing a second closed loop with the third means for varying the frequency of the signals from the fifth means to obtain, upon a mixture of the signals at the carrier frequency and the signals having the variable frequency, intermediate frequency signals having a particular frequency,

the fourth means including a first digital-to-analog converter for converting the pair of the digital signals from the third means to corresponding analog signals for adjusting the operation of the third means to lock the phases of the pair of the digital signals from the third means to the phases of the quadrature amplitude modulated signals in the coaxial cable,

the sixth means including a second digital-to-analog converter for converting the digital signals from the third means to corresponding analog signals for locking the frequency of the signals from the fifth means relative to the carrier frequency for obtaining the intermediate frequency signals with a particular frequency.

30. In a combination as set forth in claim 29,

seventh means responsive to the analog signals from the first means for regulating the amplitude of the analog signals, and

the third means including eighth means for derotating the digital signals in the pair and further including ninth means for equalizing the derotated digital signals in the pair from the eighth means.

31. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from noise and distortions in the coaxial cable,

first means for converting the analog signals to digital signals, second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair, and

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable, the third means including a feed forward equalizer and a decision feedback equalizer, the decision feedback equalizer including a pair of slicers each operable on an individual one of the digital signals in the pair to slice the digital signals into the closest of a number of binary values, the number being progressively increased with time.

32. In a combination as set forth in claim **31**,

the decision feedback equalizer having an output connected to the feed forward equalizer to control the operation of the feed forward equalizer in accordance with the operation of the decision feedback equalizer.

33. In a combination as set forth in claim **31**,

the pair of the slicers constituting a first pair, each of the slicers in the first pair being operable on an individual one of the digital signals in the pair to slice the digital signals into the closest of a number of binary values and the third means including a second pair of slicers each operative to progressively increase the number of the binary values with time.

34. In a combination as set forth in claim **31**,

the feed forward equalizer being operative to correct for distortions in a leading portion of the digital signals in the pair and the decision feedback analyzer being operative to correct for distortions in a trailing portion of the digital signals in the pair.

35. In a combination as set forth in claim **34**,

the output of the decision feedback equalizer being introduced to the feed forward equalizer to enhance the operation of the feed forward equalizer,

the feed forward equalizer being operative to correct for distortions in a leading portion of the digital signals in the pair and the decision feedback analyzer being operative to correct for distortions in a trailing portion of the digital signals in the pair.

36. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from noise and distortions in the coaxial cable,

first means for converting the analog signals to digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair, and

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable, the third means including a feed forward equalizer and a decision feedback equalizer, the decision feedback equalizer including a first pair of slicers each operable on an individual one of the digital signals in the pair to slice the digital signals into the closest of a number of binary values, the number being progressively increased with time,

the decision feedback equalizer having an output connected to the feed forward equalizer to control the operation of the feed forward equalizer in accordance with the operation of the decision feedback equalizer,

a second pair of slicers,

the third means including a pair of adders each operative to receive the output of the decision feedback equalizer and the output of the feed forward equalizer and each operative to introduce its output to an individual one of the slicers in the second pair.

37. In a combination as set forth in claim **36**,

means responsive to the output from the third means for feeding the output back to the third means to facilitate the adjustment of the amplitudes and phases of the digital signals in the pair to conform to the amplitudes and phases of the quadrature amplitude modulated signals in the transmitter.

38. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from noise and distortion in the coaxial cable,

first means for converting the analog signals to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable,

the third means including fourth means for derotating the phases of the digital signals in the pair and including fifth means for providing a feed forward equalization of the derotated digital signals in the pair and including sixth means for providing a decision feedback equalization of the signals from the fifth means,

the fifth means and the sixth means being connected in an asymmetrical relationship.

39. In a combination as set forth in claim **38**,

means for feeding the signals from the sixth means back to the fifth means to enhance the feed forward equalization provided by the fifth means.

40. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from noise and distortion in the coaxial cable,

first means for converting the analog signals to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable,

the third means including fourth means for derotating the phases of the digital signals in the pair and including fifth means for providing a feed forward equalization of the derotated digital signals in the pair and including sixth means for providing a decision feedback equalization of the signals from the fifth means,

the decision feedback equalizer including a pair of slicers each operable on an individual one of the digital signals in the pair to slice the digital signals into the closest of a number of binary values, the number being progressively increased with time.

41. In a combination as set forth in claim **40**,

a pair of adders each operatively coupled to the feed forward equalizer and the decision feedback equalizer to operate upon one of the digital signals in the pair, and

a pair of additional slicers each operatively coupled to an individual one of the adders in the pair to provide an output of one of the digital signals in the pair without the noise and distortion in the coaxial cable.

42. In a combination as set forth in claim **41**,

the feed forward equalizer and the decision feedback equalizer being connected in a symmetrical relationship with each individual one of the adders, the slicers and the additional slicers relative to the connection of the feed forward equalizer and the decision feedback analyzer with the other one of the adders, the slicers and the additional slicers, and

means for feeding the signals from the fifth means back to the fifth means to enhance the feed forward equalization provided by the fifth means.

43. In a combination as set forth in claim **40**,

seventh means for feeding the signals from the sixth means back to the fifth means to enhance the feed forward equalization provided by the fifth means.

44. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from noise and distortion in the coaxial cable,

first means for converting the analog signals to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable,

the third means including fourth means for derotating the phases of the digital signals in the pair and including fifth means for equalizing the derotated digital signals in the pair, and

fifth means responsive to the derotated digital signals in the pair and to the equalized digital signals in the pair for operating upon the fourth means to facilitate the derotation of the digital signals in the pair by the fourth means.

45. In a combination as set forth in claim **44**,

means for providing an automatic gain control of the digital signals from the second means.

46. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from noise and distortion in the coaxial cable,

first means for converting the analog signals to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable,

the third means including fourth means for derotating the phases of the digital signals in the pair and including fifth means for equalizing the derotated digital signals in the pair,

the quadrature amplitude modulated signals in the coaxial cable having a particular baud rate, and

means responsive to the derotated digital signals and to the equalized digital signals for operating upon the first means to obtain the conversion of the analog signals to the digital signals at a rate having a particular relationship to the particular baud rate.

47. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from noise and distortion in the coaxial cable,

first means for converting the analog signals to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable,

the third means including fourth means for derotating the phases of the digital signals in the pair and including fifth means for equalizing the derotated digital signals in the pair,

the signals in the coaxial cable including carrier signals with a particular carrier frequency, and

an oscillator having a variable frequency, and

means responsive to the derotated digital signals and the equalized digital signals for varying the frequency of the oscillator to provide, upon a mixing of the analog signals and the signals from the oscillator, intermediate frequency signals having a particular frequency.

48. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from noise and distortions in the coaxial cable,

first means for converting the analog signals to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable,

the third means including a derotator and an equalizer, the equalizer including a feed forward equalizer and a decision feedback equalizer, and

servo means responsive to the outputs of the derotator and the equalizer for adjusting the operation of the derotator and the equalizer to adjust the phases of the digital signals in the pair from the third means to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable.

49. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from noise and distortions in the coaxial cable,

first means for converting the analog signals to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable,

the third means including a derotator, a feed forward equalizer and a decision feedback equalizer,

means responsive initially to the outputs of the derotator and the decision feedback equalizer, and subsequently to signals from the feed forward equalizer and the decision feedback analyzer, for operating upon the derotator to facilitate the derotation of the phases of the digital signals in the pair in phase with the quadrature amplitude modulated signals in the coaxial cable.

50. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from noise and distortions in the coaxial cable,

first means for converting the analog signals to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable,

the third means including a derotator, a feed forward equalizer and a decision feedback equalizer,

the quadrature amplitude modulated signals in the coaxial cable having a particular baud rate, and

servo means responsive to the outputs of the derotator and the decision feedback equalizer for operating upon the first means to obtain the conversion of the analog signals to the digital signals at a rate having a particular relationship to the particular baud rate.

51. In a combination as set forth in claim **50**,

the servo means being initially responsive to the outputs of the derotator and the decision feedback equalizer, and being subsequently responsive to the outputs of the feed forward equalizer and the decision feedback equalizer, for operating upon the first means to obtain the conversion of the analog signals to the digital signals at a rate having a particular relationship to the particular baud rate.

52. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from noise and distortions in the coaxial cable,

first means for converting the analog signals to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the coaxial cable,

the third means including a derotator, a feed forward equalizer and a decision feedback equalizer,

the signals in the coaxial cable including carrier signals with a particular carrier frequency,

an oscillator having a variable frequency, and

means responsive initially to the outputs of the derotator and the decision feedback equalizer, and subsequently to the outputs of the feed forward equalizer and the decision feedback equalizer, for varying the frequency of the oscillator to obtain, upon a mixing of the carrier signals and the signals from the oscillator, intermediate frequency signals having a particular frequency.

53. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulation data to recover the quadrature amplitude modulated data from noise and distortion in the coaxial cable,

first means for converting the analog signals in the coaxial cable to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated data to the coaxial cable,

the third means including a feed forward equalizer and a decision feedback equalizer and means for combining the outputs of the feed forward equalizer and the decision feedback equalizer to obtain resultant decisions and including means for providing progressive slicings of the resultant decisions to obtain the quadrature amplitude modulated data free from noise and distortions,

the number of the levels in each progressive slicing being greater than the number of the levels in the preceding slicings and the successive levels in each progressive slicing being closer together than the successive levels in the preceding slicings.

54. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulation data to recover the quadrature amplitude modulated data from noise and distortion in the coaxial cable,

first means for converting the analog signals in the coaxial cable to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated data in the coaxial cable,

the third means including a feed forward equalizer and a decision feedback equalizer and means for combining the outputs of the feed forward equalizer and the decision feedback equalizer to obtain resultant decisions and including means for slicing the resultant decisions to obtain the quadrature amplitude modulated data free from noise and distortions,

the decision feedback equalizer including an additional slicer connected to receive the output of the combining means and to provide, at progressive instants of time, binary outputs of progressive sensitivity and including means for determining any difference between the output of the combining means and the binary outputs of progressive sensitivity and including means for introducing the difference determinations to the feed forward equalizer and decision feedback equalizer to enhance the equalizing operation of the feed forward equalizer and the decision feedback equalizer.

55. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulation data to recover the quadrature amplitude modulated data from noise and distortion in the coaxial cable,

first means for converting the analog signals in the coaxial cable to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated data in the coaxial cable,

the third means including a feed forward equalizer and a decision feedback equalizer and means for combining the outputs of the feed forward equalizer and the decision feedback equalizer to obtain resultant decisions and including means for slicing the resultant decisions to obtain the quadrature amplitude modulated data free from noise and distortions,

control means responsive to the outputs of the feed forward equalizer and the decision feedback equalizer for providing a closed loop servo in the third means to enhance the operation of the third means in producing the quadrature amplitude modulated data without noise and distortions.

56. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulation data to recover the quadrature amplitude modulated data from noise and distortion in the coaxial cable,

first means for converting the analog signals in the coaxial cable to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated data in the coaxial line,

the third means including a feed forward equalizer and a decision feedback equalizer and means for combining the outputs of the feed forward equalizer and the decision feedback equalizer to obtain resultant decisions and including means for slicing the resultant decisions to obtain the quadrature amplitude modulated data free from noise and distortions,

the quadrature amplitude modulated signals in the coaxial cable occurring at a particular baud rate, and

means responsive to the outputs of the third means and the slicing means for providing a closed loop servo to provide for the operation of the first means in converting the analog signals to the digital signals at a rate having a particular relationship to the particular baud rate.

57. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulation data to recover the quadrature amplitude modulated data from noise and distortion in the coaxial cable,

first means for converting analog signals to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated data in the coaxial line,

the third means including a feed forward equalizer and a decision feedback equalizer and means for combining the outputs of the feed forward equalizer and the decision feedback equalizer to obtain resultant decisions and including means for slicing the resultant decisions to obtain the quadrature amplitude modulated data free from noise and distortions,

the quadrature amplitude modulated signals in the coaxial cable having a particular carrier frequency, and

an oscillator having a variable frequency, and

means responsive to the outputs of the feed forward equalizer and the decision feedback equalizer for varying the frequency of the oscillator to provide, upon a mixing of the signals at the particular carrier frequency and the oscillator signals, intermediate frequency signals having a particular frequency,

the first means being operative to convert to the digital signals the intermediate frequency signals having the particular frequency.

58. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from noise and distortions in the coaxial cable,

first means for converting the analog signals to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for derotating the phases of the digital signals in the pair, and

fourth means including first and second paths each responsive to an individual one of the derotated digital signals in the pair from the third means in a symmetrical relationship with the other one of the derotated signals in the pair for equalizing the derotated digital signals in the pair.

59. In a combination as set forth in claim **58**,

means responsive to the signals from the third means and the equalized signals from the fourth means for providing a closed loop servo for facilitating the derotation by the third means of the digital signals in the pair.

60. In a combination as set forth in claim **58**,

the quadrature amplitude modulated signals in the coaxial cable having a particular baud rate, and

means responsive to the signals from the third means and the equalized signals from the fourth means for providing a closed loop servo for providing for the operation of the first means at a rate having a particular relationship to the particular baud rate in converting the analog signals in the coaxial cable to the corresponding digital signals.

61. In a combination as set forth in claim **58**,

the quadrature amplitude modulated signals in the coaxial cable having a particular carrier frequency,

an oscillator having a variable carrier frequency, and means responsive to the signals from the third means and the equalized signals from the fourth means for providing a closed loop servo for maintaining the operation of the oscillator in producing analog signals at a frequency related to the particular carrier frequency,

the oscillator being responsive to the analog signals in the coaxial cable before the operation of the first means in converting the analog signals in the receiver to the corresponding digital signals and the first means being operative to convert, to the corresponding digital signals, the analog signals at the frequency related to the particular carrier frequency.

62. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from noise and distortions in the coaxial cable,

there being a plurality of stations each providing an individual carrier frequency for the analog signals from such station and each providing quadrature amplitude modulated signals in the coaxial cable,

first means for converting the analog signals at the individual carrier frequency for each of the stations to analog signals at a particular intermediate frequency,

second means for converting the analog signals at the particular intermediate frequency to corresponding digital signals,

third means for operating upon the digital signals from the second means to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

fourth means for adjusting the phases of the digital signals in the pair to recover the quadrature amplitude modulated data from the noise and distortions in the coaxial cable, and

fifth means responsive to the output from the third means for providing a closed loop servo with the fourth means for facilitating the recovery of the quadrature amplitude modulated data from the noise and distortions in the coaxial cable,

the fifth means initially having a first response for a first period of time after switching from a first one of the stations in the plurality to a second one of the stations in the plurality to facilitate the recovery of the analog signals at the particular intermediate frequency from the carrier frequency of the second one of the stations in the plurality and subsequently having a second response after the first period of time to facilitate the recovery of the quadrature amplitude modulated data for the second one of the stations in the plurality from the noise and distortions in the coaxial cable.

63. In a combination as set forth in claim **62**,

the fifth means including means for converting the digital indications from the fourth means to analog signals for facilitating the recovery of the quadrature amplitude modulated data for the second one of the stations in the plurality from the noise and distortions in the coaxial cable.

64. In a combination as set forth in claim **62**,

the fifth means including sixth means responsive to the digital signals from the fourth means for adjusting the phases of the digital signals in the pair to facilitate the recovery of the quadrature amplitude modulated data for the second one of the stations in the plurality from the noise and distortions in the coaxial cable.

65. In a combination as set forth in claim **62**,

sixth means operatively coupled to the fourth means and the fifth means and operative in a closed loop servo for maintaining at the particular intermediate frequency the analog signals from the first means.

66. In a combination as set forth in claim **65**,

the analog signals at the particular intermediate frequency being sampled at a rate having a particular relationship to the particular baud rate,

the fifth means being responsive to the digital signals from the third means for adjusting, to a particular rate, the operation of the first means in converting the analog signals to the digital signals.

67. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from the noise and distortions in the coaxial cable,

first means for converting the analog signals in the coaxial cable to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to recover the quadrature amplitude modulated data from the noise and distortions in the coaxial cable,

the third means including a feed forward equalizer and a decision feedback analyzer,

the third means including slicer means operative upon the digital signals in individual ones of the pairs to conform such digital signals to the closest of the individual ones of a plurality of different levels, the slicer means being operative at successive periods of time to provide progressive numbers of levels in the plurality for conforming such digital signals,

fourth means responsive to the outputs of the feed forward equalizer and the decision feedback equalizer and the slicer means for producing an error signal, and

fifth means for feeding the error signal back to the feed forward equalizer and the decision feedback equalizer for adjusting the operation of the feed forward equalizer and decision feedback equalizer in accordance with such error signal.

68. In a combination as set forth in claim **67**,

the analog signals occurring at a particular baud rate, and

means responsive to the quadrature amplitude modulated data in the third means and the quadrature amplitude modulated data from the additional slicer means for controlling the operation of the first means to provide for the conversion of the analog signals to the digital signals at a rate having a particular relationship to the particular baud rate.

69. In combination for operating upon analog signals transmitted through a coaxial cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from the noise and distortions in the coaxial cable,

first means for converting the analog signals in the coaxial cable to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair, third means for adjusting the phases of the digital signals in the pair to recover the quadrature amplitude modulated data from the noise and distortions in the coaxial cable,

the third means including a feed forward equalizer and a decision feedback equalizer,

the third means including slicer means operative upon the digital signals in individual ones of the pairs to conform the amplitudes of such digital signals to the closest of individual ones of a plurality of different levels, the slicer means being operative at successive periods of time to provide progressive numbers of levels in the plurality for conforming the amplitudes of such digital signals,

means responsive to the outputs of the feed forward equalizer and the decision feedback equalizer and the slicer means for producing an error signal, and

means for feeding the error signal back to the feed forward equalizer and the decision feedback equalizer for adjusting the operation of the feed forward equalizer and the decision feedback equalizer to minimize such error signal.

70. In a combination as set forth in claim **69**,

means responsive to the outputs of the decision feedback equalizer and the slicer means for combining such outputs, and

a pair of additional slicer means each responsive to the combined outputs of the decision feedback equalizer and the slicer means for providing the quadrature amplitude modulated data without the noise and distortions in the coaxial cable.

71. In a combination as set forth in claim **70**,

means responsive to the quadrature amplitude modulated data in the third means and the quadrature amplitude modulated data from the additional slicer means for feeding signals back to the third means to facilitate the recovery of the quadrature amplitude modulated data by the third means.

72. In a combination as set forth in claim **70**,

there being a carrier signal at a particular frequency for the quadrature amplitude modulated signals in the coaxial cable,

an oscillator having a variable frequency, and

means responsive to the quadrature amplitude modulated data in the third means and the quadrature amplitude modulated data from the additional slicer means for varying the frequency of the oscillator to obtain, from a mixing of the carrier signal and the signal from the local oscillator, an intermediate frequency signal having a particular frequency.

73. In combination for operating upon analog signals transmitted through a cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from the noise and distortions in the coaxial cable,

there being a plurality of stations each having an individual carrier frequency and each providing quadrature amplitude modulated signals in the coaxial cable,

first means for converting the analog signals in the coaxial cable to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to recover the quadrature amplitude modulated data from the noise and distortions in the coaxial cable, and

fourth means responsive to the indications from the first means for regulating the gain of the analog signals before the conversion of the analog signals to the digital signals by the first means, the fourth means having a first response for a first period of time after switching from a first one of the stations in the plurality to a second one of the stations in the plurality and subsequently having a second response after the first period of time to facilitate the recovery of the quadrature amplitude modulated data for the second one of the stations in the plurality from the noise and distortions in the coaxial cable.

74. In a combination as set forth in claim **73**,

the fourth means including means for converting the digital indications from the first means to analog indications for regulating the gain of the analog signals in the coaxial cable.

75. In a combination as set forth in claim **73**,

the analog signals having a particular baud rate, and

means for regulating the rate of conversion by the first means of the analog signals to the digital signals to correspond to a rate having a particular relationship to the baud rate of the analog signals.

76. In a combination as set forth in claim **73**,

the analog signals having a particular carrier frequency,

the oscillator having a variable frequency,

fifth means for mixing the signals from the oscillator with the analog signals in the coaxial cable before the conversion of the analog signals to the digital signals by the first means to obtain analog signals at an intermediate frequency, and

sixth means for regulating the variable frequency of the oscillator to maintain the analog signals from the fifth means at the particular intermediate frequency,

the first means being operative to convert the analog signals at the particular intermediate frequency to the corresponding digital signals.

77. In combination for operating upon analog signals transmitted through a cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from the noise and distortions in the coaxial cable,

there being a plurality of stations each having an individual carrier frequency and each providing quadrature amplitude modulated signals in the coaxial cable,

first means for converting the analog signals in the coaxial cable to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to recover the quadrature amplitude modulated data from the noise and distortions in the coaxial cable, and

fourth means responsive to the indications from the first means for regulating the gain of the analog signals before the conversion of the analog signals to the digital signals by the first means, the fourth means having a first response for a first period of time after switching from a first one of the stations in the plurality to a second one of the stations in the plurality and subsequently having a second response after the first period of time to facilitate the recovery of the quadrature amplitude modulated data for the second one of the stations in the plurality from the noise and distortions in the coaxial cable, the fourth means being responsive to every digital conversion by the first means for the first period of time and being responsive to every nth conversion by the first means after the first period of time where n is an integer greater than 1.

78. In combination for acting upon analog signals transmitted through a cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from the noise and distortions in the coaxial cable,

first means for converting the analog signals in the coaxial cable to corresponding digital signals,

second means for operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship with the other of the digital signals in the pair,

third means for adjusting the phases of the digital signals in the pair to recover the quadrature amplitude modulated data from the noise and distortions in the coaxial cable,

the third means including a feed forward equalizer and a decision feedback equalizer connected to receive the output of the feed forward equalizer and including means for feeding the output of the decision feedback equalizer to the feed forward equalizer to regulate the operation of the feed forward equalizer in adjusting the amplitudes and phases of the digital signals in the pair to recover the quadrature amplitude modulated data from the noise and distortions in the coaxial cable.

79. In a combination as set forth in claim **78**,

means for adding the outputs of the feed forward equalizer and the decision feedback equalizer, and

means responsive to the outputs of the adding means for providing the quadrature amplitude modulated data without the noise and distortions in the coaxial cable.

80. In a combination as set forth in claim **78**,

the decision feedback equalizer having a pair of slicers each operative to provide outputs of increased sensitivity at progressive instants of time and including means responsive to the outputs of the slicers and the outputs of the decision feedback equalizers for producing error signals for regulating the operation of the feed forward equalizer and decision feedback equalizer.

81. In a combination as set forth in claim **80**,

a second pair of slicers responsive to the outputs of the feed forward equalizer and the decision feedback equalizer for combining these outputs to obtain the quadrature amplitude modulated data without the noise and distortions in the coaxial cable.

82. An apparatus for operating upon quadrature amplitude modulated data transmitted through a co-axial cable to recover the quadrature amplitude modulated data from noise and distortions in the co-axial cable, the apparatus comprising:

an analog to digital converter that is operative to convert an incoming analog signal to a corresponding digital signal;

a pair of multipliers that operate upon the digital signal to provide a pair of digital signals, one of the digital signals in the pair having a quadrature phase relationship relative to the other digital signal;

a phase derotator that operates upon the respective digital signals by multiplying said signals by trigonometric functions; and

an equalizer that performs equalization upon the derotated digital signals from the phase derotator, wherein the equalizer comprises a feed forward equalizer, a decision feedback equalizer, and a pair of slicers operative to provide approximations of the respective incoming signals.

83. The apparatus of claim 82, and further including:

a feedback control loop that is responsive to at least one of the derotated digital signals from the phase derotator and the equalized signals from the equalizer to control the phase derotator to adjust the phases of the digital signals output by the phase derotator.

84. The apparatus of claim 83, wherein the feedback control loop includes a phase detector that receives the outputs from at least one of the phase derotator and the slicers to detect the phase errors in the signals relative to an ideal QAM constellation.

85. The apparatus of claim 84, wherein the phase detector receives the outputs from both the phase derotator and the slicers.

86. The apparatus of claim 82, wherein the quadrature amplitude modulated signals in the cable have a particular baud rate and the analog to digital converter is operative to produce the digital signals at a selected rate related to the particular baud rate, and further including a feedback control loop that is responsive to at least one of the derotated digital signals from the phase derotator and the equalized digital signals from the equalizer for maintaining the production of the digital signals at the selected baud rate.

87. The apparatus of claim 82, further including a feedback control loop that is responsive to the digital signals from the analog to digital converter for regulating the gain of the analog to digital converter.

88. The apparatus of claim 82, wherein the slicers are each operable on an individual one of the digital signals in the equalizer to convert the digital signals into the closest of a number of generated binary values.

89. The apparatus of claim 88, wherein the slicers are operative to convert the digital signals into the closest of a progressively increasing number of generated binary values.

90. The apparatus of claim 82, wherein the analog signals in the co-axial cable are provided at a variable carrier frequency, and further including an oscillator and a mixer that are operative to convert the analog signals into signals at an intermediate frequency, and wherein the analog to digital converter is operative on the intermediate frequency analog signals to convert said intermediate frequency analog signals to the digital signals.

91. The apparatus of claim 90, further including a feedback control loop that is responsive to the derotated digital signals from the phase derotator and the digital signals from the slicers for maintaining the intermediate frequency signals at a particular frequency.

92. The apparatus of claim 82, where the feed forward equalizer is operative to receive the derotated digital signals from the phase derotator and to output a pair of filtered signals.

93. The apparatus of claim 82, wherein the decision feedback equalizer is connected to the respective slicers and to the feed forward equalizer, and wherein the decision feedback equalizer provides feedback to the feed forward equalizer in response to the signals from the respective slicers.

94. The apparatus of claim 82, further including a pair of adders that are operative to add the outputs of the feed forward equalizer and decision feedback equalizer, and to provide the combined signals to the respective slicers.

95. The apparatus of claim 82, wherein the equalizer defines a pair of symmetrical stages between the feed forward equalizer and the decision feedback equalizer.

96. The apparatus of claim 95, further including a pair of dividers to divide the baud rates of the respective signals from the feed forward equalizer by a predetermined factor.

97. The apparatus of claim 82, wherein the decision feedback equalizer includes a slicer to provide amplitude approximations based on the incoming signal.

98. The apparatus of claim 97, wherein the slicer of the decision feedback equalizer is operative to slice the digital signal into the closest of a progressively increasing number of generated binary values.

99. The apparatus of claim 82, wherein the feed forward equalizer corrects for distortions in the left half of a composite signal, and the decision feedback equalizer corrects for distortions in the right half of the composite signal.

100. The apparatus of claim 82, wherein the feed forward equalizer is operative in one of a T-spaced function and a T/2-spaced function.

101. The apparatus of claim 94, further including a stage that computes the difference between a slicer in the decision feedback equalizer and one of the adders, and that provides such difference to the feed forward equalizer and to the decision feedback equalizer in the form of an error signal.

102. The apparatus of claim 82, wherein the trigonometric functions have a sampling frequency corresponding to the frequency of the digital signals introduced to the phase derotator.

103. A method of operating upon analog signals transmitted through a co-axial cable using quadrature amplitude modulated data to recover the quadrature amplitude modulated data from noise and distortions in the co-axial cable, comprising:

converting the analog signals to digital signals,

operating upon the digital signals to provide a pair of digital signals, such that one of the digital signals in the pair has a quadrature phase relationship with respect to the other digital signal in the pair,

adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the cable,

equalizing symmetrically each of the phase-adjusted digital signals, and

performing a slicing function to convert the respective phase-adjusted digital signals into approximated values.

104. A method as set forth in claim 103, further including:

converting the analog signals to analog signals at an intermediate frequency before the conversion of the analog signals to the digital signals, and

using the digital signals with the adjusted phases to regulate the intermediate frequency of the analog signals.

105. The method of claim 103, wherein the quadrature amplitude modulated signals in the cable have a particular baud rate, and further including using the digital signals with the adjusted phases to adjust the baud rate of the digital signals so that the baud rate of the digital signals is at the particular rate.

106. The method of claim 103, wherein performing the slicing function including converting the digital signals to progressively more accurate approximations based on a number of generated binary values.

107. A method of operating upon quadrature amplitude modulated data, transmitted through a co-axial cable as an analog signal, to recover the quadrature amplitude modulated data from noise and distortions in the co-axial cable, comprising:

converting the analog signals to analog signals at a particular intermediate frequency,

converting the analog signals at the particular intermediate frequency to digital signals,

operating upon the digital signals to provide a pair of the digital signals, one of the digital signals in the pair having a quadrature phase relationship to the other digital signal in the pair,

adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the cable, and

using the digital signals with the adjusted phases to maintain the intermediate frequency at the selected frequency.

108. A method as set forth in claim 107, including the steps of:

providing a feed forward equalizer and a decision feedback equalizer,

introducing the digital signals to the feed forward equalizer and the decision feedback equalizer and combining the outputs of the feed forward equalizer and the decision feedback equalizer to produce resultant signals,

slicing the resultant signals to obtain an approximation of the quadrature amplitude modulated data.

109. A method of operating upon quadrature amplitude modulated data, transmitted through a co-axial cable as an analog signal, to recover the quadrature amplitude modulated data from noise and distortions in the co-axial cable, comprising:

converting the analog signal to a digital signal,

operating upon the digital signal to provide a pair of digital signals, wherein one of the digital signals in the pair has a quadrature phase relationship relative to the other digital signal in the pair,

adjusting the phases of the digital signals in the pair to conform to the phases of the quadrature amplitude modulated signals in the cable, and

introducing the phase-adjusted digital signals to feed forward and decision feedback equalizers and to a pair of slicers to obtain an approximation of the digital signals based on the closest of a number of binary values provided by the slicers.

110. A method of operating upon quadrature amplitude modulated data, transmitted through a co-axial cable as an analog signal, to recover the quadrature amplitude modulated data from noise and distortions in the co-axial cable, comprising:

converting the analog signals to digital signals at a particular baud rate,

multiplying the digital signals with trigonometric signals to provide the digital signals with a quadrature phase relationship,

derotating the digital signals with the quadrature phase relationship,

operating upon the derotated digital signals to recover the amplitude modulated data from noise and distortions in the co-axial cable,

operating upon the derotated digital signals and the recovered amplitude modulated data to produce error signals, and

adjusting the rate of the conversion of the analog signals to the digital signals in response to the error signals to regulate the conversion of the analog signals to the digital signals at the particular rate.

111. A method as set forth in claim 110, further including:

adjusting the gain of the analog signals, before the conversion of the analog signals to the digital signals, in response to an error signal to regulate the gain of the analog signals at a particular value.

112. A method as set forth in claim 110, further including:

converting the frequency of the analog signals to an intermediate frequency using an oscillator-generated signal before the conversion of the analog signals to digital signals, and

adjusting the frequency of the oscillator-generated signal in response to an error signal to regulate the intermediate frequency at a particular frequency.

113. An apparatus for operating upon quadrature amplitude modulated data transmitted through a co-axial cable to recover the quadrature amplitude modulated data from noise and distortions in the co-axial cable, the apparatus comprising:

an analog to digital converter that is operative to convert an incoming analog signal to a corresponding digital signal;

a pair of multipliers that operate upon the digital signal to provide a pair of digital signals, one of the digital signals in the pair having a quadrature phase relationship relative to the other digital signal;

a phase derotator that operates upon the respective digital signals to adjust the phases of said signals;

an equalizer that receives the phase-adjusted digital signals from the phase derotator and provides equalization of the digital signals; and

a feedback control loop that is operative to receive signals from the equalizer and phase derotator and to dynamically control at least one of the analog to digital converter and the derotator.

114. The apparatus of claim 113, wherein the feedback control loop is responsive to at least one of the signals from the phase derotator and the equalized signals from the equalizer to dynamically control the phase derotator.

115. The apparatus of claim 113, wherein the quadrature amplitude modulated signals in the cable have a particular baud rate and the analog to digital converter is operative to produce the digital signals at a rate related to the particular baud rate, and further including a feedback control loop that is responsive to at least one of the derotated digital signals from the phase derotator and the equalized digital signals from the equalizer for maintaining the production of the digital signals at the baud rate related to the particular baud rate.

116. The apparatus of claim 113, further including a feedback control loop that is responsive to the digital signals from the analog to digital converter to regulate the gain of the analog to digital converter.

117. The apparatus of claim 113, further including a pair of slicers that are each operable on an individual one of the digital signals in the equalizer to convert the digital signals into the closest of a number of generated binary values.

118. The apparatus of claim 117, wherein the slicers are operative to convert the digital signals into the closest of a progressively increasing number of generated binary values.

119. The apparatus of claim 113, wherein the analog signals in the co-axial cable are provided at a variable carrier frequency, and further including an oscillator and a mixer that are operative to convert the analog signals into signals at an intermediate frequency, and wherein the analog to digital converter is operative on the intermediate frequency analog signals to convert said intermediate frequency analog signals to the digital signals.

120. The apparatus of claim 119, further including a feedback control loop that is responsive to at least one of the derotated digital signals from the phase derotator and the digital signals from the slicers to maintain the intermediate frequency signals at a particular frequency.

121. The apparatus of claim 113, wherein the feedback control loop is operative to control the sampling rate of the analog to digital converter.

122. The apparatus of claim 113, wherein the equalizer includes a decision feedback equalizer that provides feedback within the equalizer.

123. The apparatus of claim 113, further including a pair of multipliers that operate upon the digital signal to provide a pair of digital signals, with one of the digital signals in the pair having a quadrature phase relationship relative to the other digital signal.

124. The apparatus of claim 123, further including a pair of low pass filters to filter the respective digital signals from the multipliers.

125. The apparatus of claim 113, wherein the phase derotator operates upon the respective digital signals by multiplying said signals by a trigonometric function.

126. The apparatus of claim 117, wherein the feedback control loop includes a phase detector that receives the outputs from at least one of the phase derotator and the slicers to detect the phase errors in the signals relative to an ideal QAM constellation.

127. The apparatus of claim 126, wherein the phase detector receives the outputs from both the phase derotator and the slicers.

128. An equalizer for operating upon in-phase and quadrature signals, the equalizer comprising:

a feed forward equalizer that is operative to receive the signals and to output a pair of filtered signals;

a pair of slicers that are operative on the respective filtered signals to provide approximations of the respective incoming signals on respective output lines; and

a decision feedback equalizer connected to the respective output lines and to the feed forward equalizer, wherein the decision feedback equalizer provides feedback to the feed forward equalizer in response to the signals on the output lines.

129. The equalizer of claim 128, further including a pair of adders that are operative to add the outputs of the feed forward equalizer and decision feedback equalizer, and to provide the combined signals to the respective slicers.

130. The equalizer of claim 129, wherein the equalizer defines a pair of symmetrical stages between the feed forward equalizer and the decision feedback equalizer.

131. The equalizer of claim 129, further including a pair of dividers to divide the baud rates of the respective signals and to introduce the divided signals to the respective adders.

132. The equalizer of claim 128, wherein the decision feedback equalizer includes a slicer to provide amplitude approximations based on the incoming signal.

133. The equalizer of claim 132, wherein the slicer is operative to convert the digital signal into the closest of a progressively increasing number of generated binary values.

134. The equalizer of claim 128, wherein the slicers are each operable on an individual one of the digital signals in the equalizer to convert the digital signals into the closest of a number of generated binary values.

135. The equalizer of claim 134, wherein the slicers are operative to convert the digital signals into the closest of a progressively increasing number of generated binary values.

136. The equalizer of claim 128, wherein the feed forward equalizer corrects for distortions in the left half of a com-

posite signal, and the decision feedback equalizer corrects for distortion in the right half of the composite signal.

137. The equalizer of claim 128, wherein the feed forward equalizer is operative in one of a T-spaced function and a T/2-spaced function.

138. The equalizer of claim 129, further including a stage that computes the difference between a slicer in the decision feedback equalizer and one of the adders, and that provides such difference to the feed forward equalizer and to the decision feedback equalizer in the form of an error signal.

139. A method of processing in-phase and quadrature signals, comprising:

passing the in-phase and quadrature signals through a first filtering system to generate a pair of filtered signals;

introducing the filtered in-phase and quadrature signals to respective adders;

introducing the outputs from the adders to respective slicers;

passing the signals output from the respective slicers through a feedback filtering system;

introducing a control signal from the feedback filtering system to the first filtering system; and

introducing the output signals from the feedback filtering system to the respective adders.

140. The method of claim 139, wherein the in-phase and quadrature signals are processed by a pair of symmetrical stages between the respective filtering systems.

141. The method of claim 139, further including dividing the baud rates of the respective filtered signals by a predetermined factor and introducing the divided signals to the respective adders.

142. The method of claim 139, wherein passing the signals through the feedback filtering system comprises passing the signals through a decision feedback equalizer.

143. The method of claim 142, wherein passing the signals through the decision feedback equalizer includes introducing the signals to a slicer in the equalizer to provide amplitude approximations based on the incoming signals.

144. The method of claim 139, wherein passing the signals through the first filtering system comprises passing the signals through a feed forward equalizer.

145. The method of claim 139, wherein the first filtering system corrects for distortions in the left half of a composite signal, and the feedback filtering system corrects for distortions in the right half of the composite signal.

146. The method of claim 139, wherein passing the signals through the first filtering system comprises passing the signals through a filtering system that is operative in one of a T-spaced function and a T/2-spaced function.

147. The method of claim 139, further including introducing an output from the feedback filtering system and one of the adders to a stage that computes the difference between the signals and provides said difference to the respective filtering systems in the form of an error signal.

148. A method of processing in-phase and quadrature signals, comprising:

filtering the respective signals in a first filtering system;

adding the respective signals in a pair of adders to respective feedback signals;

slicing the combined signals to generate approximations of the signals;

filtering the sliced signals in a feedback filtering system to define the feedback signals introduced to the respective adders; and

controlling the first filtering system with a feedback signal from the feedback filtering system.

149. The method of claim 148, wherein the in-phase and quadrature signals are processed by a pair of symmetrical stages between the respective filtering systems.

150. The method of claim 148, further including dividing the baud rates of the respective filtered signals by a predetermined factor and introducing the divided signals to the respective adders.

151. The method of claim 148, filtering the sliced signals in the feedback filtering system comprises passing the signals through a decision feedback equalizer.

152. The method of claim 151, wherein passing the signals through the decision feedback equalizer includes introducing the signals to a slicer in the equalizer to provide amplitude approximations based on the incoming signals.

153. The method of claim 148, wherein filtering the signals in the first filtering system comprises passing the signals through a feed forward equalizer.

154. The method of claim 148, wherein filtering the signals in the first filtering system corrects for distortions in the left half of a composite signal, and filtering the signals in the feedback filtering system corrects for distortions in the right half of the composite signal.

155. The method of claim 148, wherein filtering the signals in the first filtering system comprises passing the signals through a filtering system that is operative in one of a T-spaced function and a T/2-spaced function.

156. The method of claim 148, further including introducing an output from the feedback filtering system and one of the adders to a stage that computes the difference between the signals and provides said difference to the respective filtering systems in the form of an error signal.

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