Nov. 29, 1949 G. HECHT **2,489,883**

PULSE CODE MODULATION RECEIVER EMPLOYING CATHODE-RAY TUBE DEMODULATORS

Filed Dec. 28, 1946 2 Sheets-Sheet 1

FIG. 1

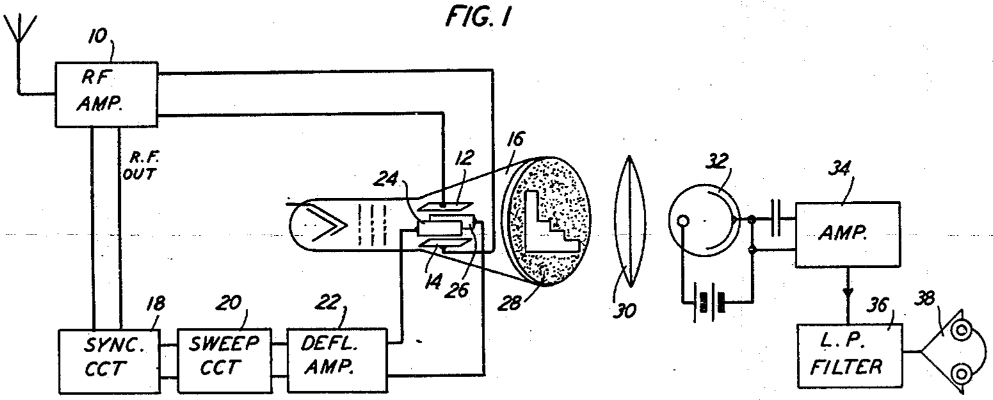


FIG. 2

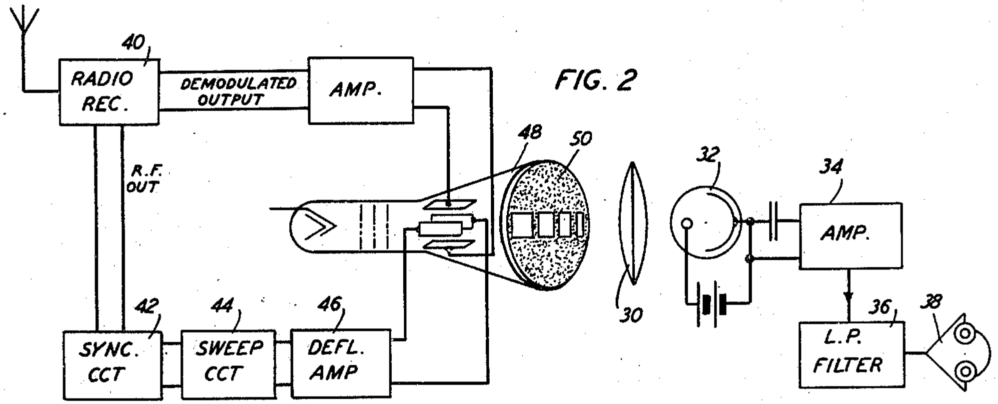
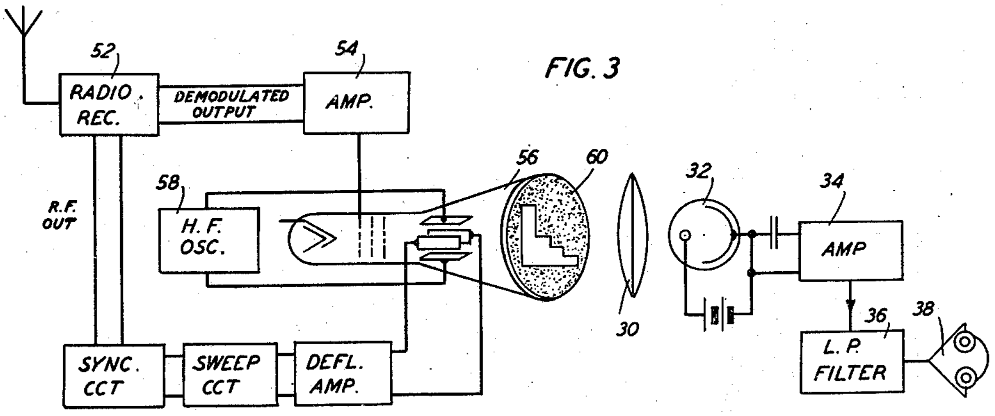


FIG. 3



INVENTOR
G. HECHT
BY George C. Ford
ATTORNEY

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G. HECHT

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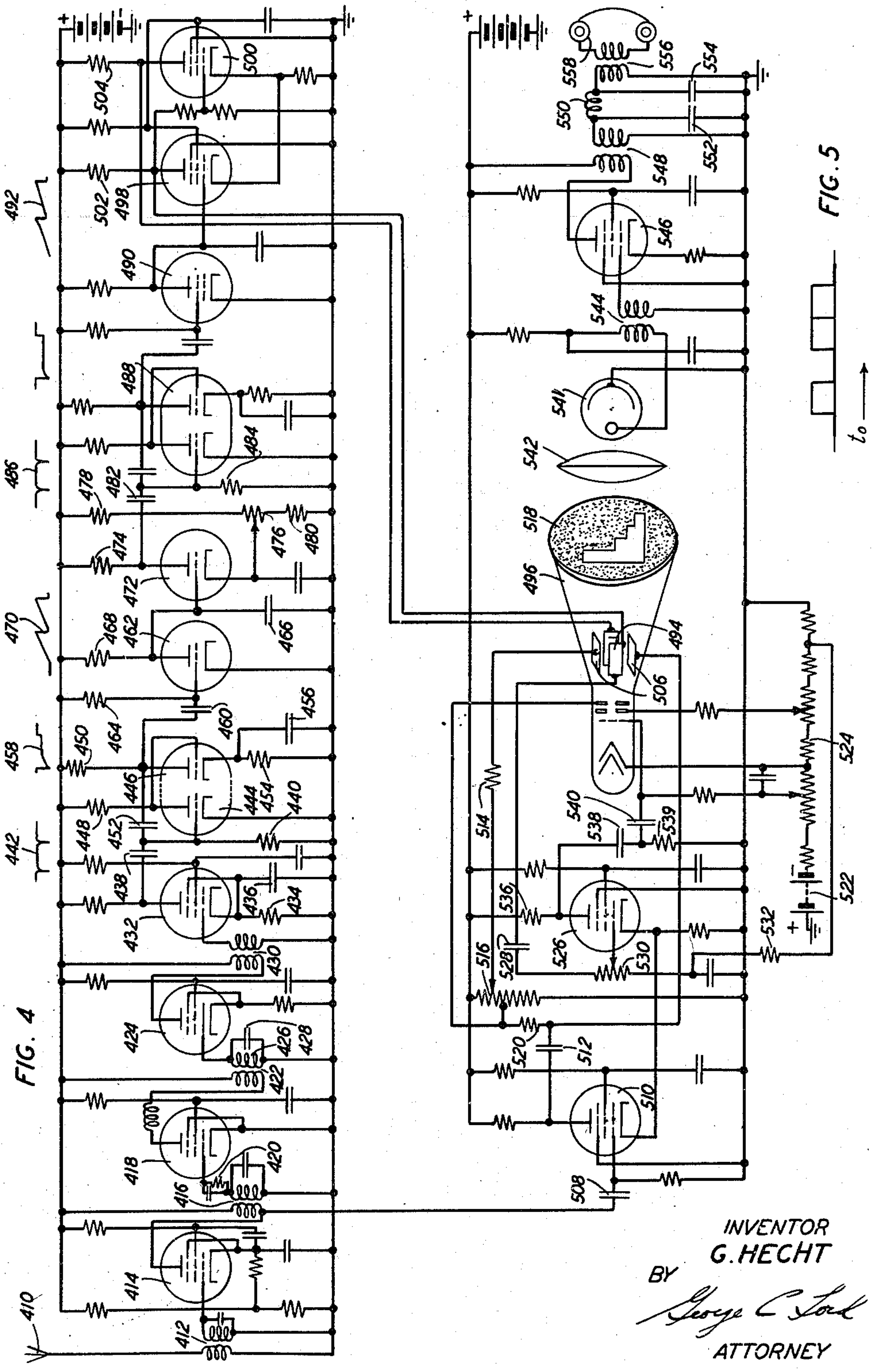

FIG. 4

FIG. 5

INVENTOR
G. HECHT
BY George C Ford
ATTORNEY

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PULSE CODE MODULATION RECEIVER EMPLOYING CATHODE-RAY TUBE DEMODULATORS

George Hecht, Astoria, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application December 28, 1946, Serial No. 718,968

9 Claims. (Cl. 179—1.5)

This invention relates to receivers for communication systems and more particularly to decoders for use in the receiving equipment of communication systems employing pulse code modulation.

In communication systems utilizing what is known as pulse code modulation, a speech wave or other signal to be transmitted is sampled periodically to ascertain its instantaneous amplitude. The measured instantaneous amplitude is expressed by pulse codes analogous to telegraph codes.

One code which conveniently may be employed in pulse code transmission involves permutations of a fixed number of code elements each of which may have any one of several conditions or values. An advantageous code of this type is the so-called binary code in which each of the fixed number of code elements may have either of two values. One advantageous way of representing these values is to represent one by a pulse sometimes referred to as an "on pulse" and the other by the absence of a pulse sometimes referred to as an "off pulse." Alternatively, one value may be represented by a positive pulse and the other by a negative pulse. The total number of permutations obtainable with the binary code is proportional to 2^n where n is the number of code elements employed.

Because the total number of different amplitudes which may be represented by such a code of a fixed number of elements is limited, it is found desirable to divide the continuous range of amplitude values of which the transmitted signal is capable into a fixed number of constituent ranges which together encompass the total range. Each of these smaller or constituent amplitude ranges may then be treated as if it were a single amplitude instead of a range and is represented by an individual one of the permutations of the code. In the use of this method of code transmission the instantaneous amplitude ascertained by a sampling operation is represented by the respective permutation indicative of the amplitude range, or step, which most nearly approximates the amplitude of the measured sample. If, for example, the sample amplitude is nearest to that amplitude represented by the ninth step of the signal amplitude range the permutation code corresponding to range 9 is transmitted. A typical system for communication by pulse code modulation is disclosed in an article entitled "An experimental multichannel pulse code modulation system of toll quality," by L. A. Meacham and E. Peterson in The Bell System

Technical Journal for January 1948, beginning at page 1.

It will be observed that each code element in one of its values represents the presence in the sampled amplitude of a particular fixed portion of the total amplitude range, while in the other value it represents the absence of that same portion.

The groups of code pulses representing by their permutations the successive sampled amplitudes of the signal wave may be transmitted to a remote station and employed thereat to reproduce or to control the regeneration of the complex signal wave to which they correspond. In general, the receiving and decoding apparatus for this purpose must be synchronized with the transmitting equipment. It is a customary practice to transmit a synchronizing pulse at the beginning or at the end of each of the groups of code pulses. At the receiver various gating, switching and other auxiliary circuits may be employed to separate the synchronizing pulse from the permutation code pulses representing the transmitted signal and to insure that the mechanisms at the receiving station and at the transmitting station are properly synchronized.

It is an object of the present invention to simplify the decoding and receiving apparatus employed in pulse code modulation systems and to reduce the complexity of the circuits required for synchronizing and timing the operation of the decoder.

It is another object of the invention to provide a decoder which may be arranged to receive pulse code modulation code groups in which the code elements are sent in any arbitrary order, that is, transmissions in which the order or arrangement of the code element signals of each code group is not necessarily determined by the magnitudes of the amplitude increments of the complex wave amplitude which they represent.

In accordance with one aspect of the invention, there is provided decoding apparatus which comprises a cathode ray tube over the face of which is positioned a mask. A plurality of openings are formed in this mask and are disposed across the screen of the cathode ray tube. These openings are equal in number to the code elements employed in the code groups constituting the pulse code modulation to be received, one opening being provided for each of the code elements. The openings are of different areas and more particularly are of areas proportional respectively to the portions of the total possible complex wave amplitude represented by the code elements to which they correspond. A sweep circuit deflects the electron beam of the cathode ray tube across the screen thereof during receipt of each code group, and the individual code element signals of the code group are applied effectively to permit the electron beam to strike the screen of the cathode ray tube behind only those mask openings for which, in the code group received, the code element signals are of the value representing the presence of increments of the total possible amplitude in the complex wave. Means are provided also for generating an output signal proportional in amplitude to the total amount of light passing through the mask.

In accordance with another aspect of the invention, the received code element signals when of the value representing the presence of portions of the total possible amplitude are employed to permit the normally cut-off electron beam to flow thus unblanking the cathode ray tube, and means are provided to oscillate the beam of the cathode ray tube in a direction normal to the direction of sweep across the tube behind the perforated mask.

In accordance with still another aspect of the invention means are provided whereby the transmitted carrier signals are demodulated and emplode to deflect the electron beam of the cathode ray tube so that the sweep path thereof across the screen is in alignment with the mask openings only when signals of the value representing the presence of a portion of the total complex wave amplitude are received and the mask openings are made respectively proportional in width to the amplitudes of the portions of the total possible amplitude of the complex wave represented by the code element signals to which they correspond.

In another aspect, the invention relates to means for timing and controlling the sweep of the electron beam across the screen of the cathode ray tube during the receipt of a code group and to means for adjusting the sweep so that the sweep deflection begins at the initiation of a code group and is of the same duration as the code group.

The above and other features of the invention will be described in detail in the following specification taken in connection with the accompanying drawings in which:

Fig. 1 is a block diagram showing a decoder which constitutes one embodiment of the invention;

Fig. 2 is a block diagram of an alternative decoder in accordance with the invention;

Fig. 3 is a block diagram showing a modification of the decoder of Fig. 1;

Fig. 4 is a circuit schematic of the decoder shown in block form in Fig. 1; and

Fig. 5 is a graph representing a received code group which will be referred to in explaining the operation of the decoder of Fig. 4.

In the decoders shown in the drawings and described herein provision is made, for purposes of illustration, for the reception of code groups having a synchronizing signal and four code element signals, these signals being of equal durations and being transmitted successively. These code groups are transmitted at a suitable fixed group or frame repetition rate which for the transmission of speech may, for example, be 8,000 frames per second. The code groups may include greater numbers of code element signals as required to obtain the desired amplitude range while the frame frequency may be increased if desired to increase the fidelity of the transmission system.

In the decoding system of Fig. 1, the pulse code modulated radio frequency signals received from the transmitter are applied to a radio frequency amplifier **10** having two output connections. One of the two output signals from amplifier **10** is applied to synchronizing and sweep deflection circuits while the other is applied to the vertical deflection plates **12** and **14** of a cathode ray tube **16**. It will be recognized that if desired radio frequency amplifier **10** may comprise a conventional superheterodyne receiver in which case the output applied to the cathode ray tube will be taken from the intermediate frequency amplifier. The output signal applied to the synchronizing and deflection equipment is applied first to a synchronizing circuit **18** in which there is produced a series of synchronizing pulses occurring at the code group repetition rate or frame frequency of the transmitted pulse code modulation signal and accurately phased so that each pulse occurs at the initiation of a code group. These synchronizing pulses are applied to a sweep circuit **20** in which there is generated a saw tooth wave. This wave is applied through a deflection amplifier **22** to the horizontal plates **24** and **26** of cathode ray tube **16**, one saw tooth occurring for each code group. A mask **28** is mounted over the screen of the cathode ray tube and has openings therein the areas of which are respectively proportional to the different fixed portions of the total possible amplitude of the complex wave represented by the several code element signals comprising the transmitted code groups.

In the embodiment shown in Fig. 1, it is assumed for convenience in description that the separate code element signals of the code groups are transmitted in accordance with the decreasing order of amplitude of the portions of the total possible complex wave amplitude which they represent, that is, the individual code element signal representing the largest portion of the total possible amplitude is transmitted first, that representing the next largest portion second, etc., and the openings in mask **28** are arranged in the same order. Thus it will be understood that if the electron beam of the cathode ray tube is swept horizontally (in Fig. 1) from left to right, it will, if suitably deflected in the vertical direction, first strike the screen behind the opening in mask **28** corresponding to the largest portion of the total possible complex wave amplitude and progress across the screen behind those openings corresponding to successively smaller portions of the total possible amplitude. As will appear hereinafter, the code element signals may be transmitted in any other fixed order and may be satisfactorily decoded in accordance with the invention.

It will be recalled that the output of radio frequency amplifier **10** is applied to the vertical deflection plates **12** and **14** of cathode ray tube **16**. Let it be assumed for purposes of illustration that the code element signaling condition corresponding to the presence of a fixed portion of the total complex wave amplitude is an "on" or current pulse while the signaling condition corresponding to the absence of that portion is an "off" or no-current pulse and that the "on" and "off" pulses are employed to gate or switch the radio frequency carrier. Then, each time a code element signal corresponding to the presence of a portion of the total amplitude is received, the beam of the cathode ray tube will be oscillated vertically at radio frequency and the envelope of the trace as the beam is swept horizontally will be essentially a rectangular pulse. Thus during the receipt of a signal representing the presence of an increment of the total amplitude, the portion of the cathode ray tube screen behind the corresponding mask opening will be traversed by the electron beam which is oscillated vertically at a relatively high frequency and a rectangular area of the screen will be illuminated. On the other hand, in the absence of such a signal, that is, when the code element signal represents the absence of a given portion of the total possible amplitude, the electron beam will not be oscillated in the vertical direction, and the area behind the corresponding mask opening will not be illuminated.

The light produced by the screen of the cathode ray tube and transmitted through mask **28** is focussed through a lens system indicated at **30** upon the cathode of a photoelectric tube **32**. For each code group this tube produces an output signal proportional to the total amount of light passing through the mask and thus proportional to the amplitude represented by the code group received at that time. This signal is applied to an amplifier **34** and thence to a low-pass filter **36** which removes the pulse and frame frequency components from the signal which is then applied to headphones **38** or other suitable terminal equipment.

The embodiment of the invention shown in the block diagram of Fig. 2 employs the same synchronizing and sweep circuits as that of Fig. 1 but includes a different signal channel and a different type of decoding mask. In this embodiment, the transmitted signals are applied to a radio receiver **40**. The output of the intermediate frequency amplifier thereof is applied to synchronizing and sweep deflection circuits **42**, **44** and **46**, which correspond to circuits **18**, **20** and **22** of Fig. 1.

Here, however, the demodulated output of the radio receiver, comprising the "on" and "off" pulses referred to above is amplified and applied to the vertical deflection plates of cathode ray tube **48**. Thus as the electron beam is swept across the screen of the tube, it is deflected vertically whenever a positive pulse or signaling condition corresponding to the presence in the complex wave of a given increment of the total possible amplitude is received, and is not deflected in the vertical direction upon receipt of signals of the second type corresponding to the absence of the same increment of the complex wave. Mask **50** mounted over the screen of the cathode ray tube has formed therein a series of openings, the widths of which are proportional respectively to the portions of the total possible amplitude of the complex wave represented by the individual code element signals. The openings are arranged in the order of transmission of these signals and spaced uniformly on centers. The vertical deflection circuit is so arranged that in the absence of code element signals of the first type, that is, signals representing the presence of a portion of the total possible amplitude, the electron beam is swept across the screen below the line of mask openings and no light is transmitted through the mask. Upon receipt of such signals, however, the beam is deflected vertically during the portions of the sweep in which such signals are received. Consequently, the electron beam strikes the screen behind those mask openings which correspond to code element signals of the first type and for each of these signals a strip of light of essentially the width of the beam and of a length proportional in that portion of the total possible amplitude represented by the signal causing the vertical deflection is transmitted through the mask. As in the case of the embodiment of Fig. 1, the light transmitted through the mask is applied to a photoelectric tube, thence through an amplifier and low-pass filter to headphones or other terminal equipment.

The decoder shown in Fig. 3 represents a modification of that of Fig. 1 which is useful when the carrier frequency of the transmitted signals is too high for convenient use in deflecting the electron beam of a cathode ray tube. In this arrangement the transmitted signals are applied to a radio receiver **52** and the output of the radio frequency amplifier thereof is applied to a synchronizing and sweep deflection circuit identical to that employed in the systems of Figs. 1 and 2. The demodulated output of radio receiver **52**, however, is applied through an amplifier **54** to the control grid of cathode ray tube **56**, means being provided in the amplifier normally to produce an output signal suitable for blanking the electron beam in the cathode ray tube. The output of the sweep deflection circuit is applied to the horizontal deflection plates of cathode ray tube **56**, while the output of high frequency oscillator **58** is applied to the vertical deflection plates of the cathode ray tube. The frequency of oscillator **58** is high compared to the code element frequency but low as compared to the carrier frequency. Mask **60**, mounted over the screen of cathode ray tube **56** is identical to mask **28** described in connection with the system of Fig. 1.

In the operation of the embodiment of Fig. 3, the electron beam is swept across the screen of the cathode ray tube during the receipt of each code group and is continually oscillated in the vertical direction. However, the beam is cut off at all times except during reception of a code element signal of the type corresponding to the presence in the complex wave to be transmitted of a finite portion of the total possible amplitude thereof. At such times, the electron beam is deblanked and the screen is illuminated by the rapidly oscillating electron beam as it is swept across the screen behind the mask opening corresponding to the same portion of the total possible amplitude. The remainder of the equipment comprising the lens system, photoelectric tube, amplifier and filter, together with headphones or other terminal equipment is identical with that provided in the embodiment of Fig. 1.

The detailed circuit arrangements of the decoder shown in the block diagram of Fig. 1 will now be considered with reference to the schematic diagram of Fig. 4. In this system input signals from antenna **410** are applied through transformer **412** to the control grid of radio frequency amplifier **414** which may conveniently comprise a single pentode-type tube, although multistage amplifiers employing other types of tubes may also be employed. The amplified radio frequency signal is then applied to the deflection amplifier of the cathode ray tube **496** and through transformer **416** to synchronization and sweep deflection circuits.

In the synchronization and sweep deflection channel, the signal is applied through transformer **416** to a conventional grid leak detector

418 which may conveniently comprise a second pentode-type vacuum tube.

The output from grid leak detector 418 is transformer-coupled through transformer 422 to signal amplifier 424, the grid circuit of which, including inductor 426 and capacitor 428, comprises a resonant circuit. In the embodiment described herein by way of illustration the transmitted code groups are sent successively and that each includes a synchronizing signal or pulse and four code element signals or pulses, each of which may be present or absent. Accordingly, if the code groups are sent at a repetition rate of 8,000 frames per second as suggested above and the amplitude of the complex wave to be transmitted is such that all code element pulses are present, the pulse repetition rate is 40,000 cycles per second. Accordingly, the resonant circuit including inductor 426 and capacitor 428 is tuned to 40,000 cycles per second. For other amplitudes of the complex wave the code groups will contain fewer code pulses or even in relatively rare instances, no code pulses. The synchronizing signal pulse will, however, be transmitted in each code group and under these conditions, the energy storage of the tuned circuit including inductor 426, capacitor 428 is sufficient to maintain the 40,000-cycle output of amplifier 424. Thus at the receiver there is derived a signal the frequency of which is an exact multiple of the code group or frame frequency.

This signal is coupled through transformer 430 to a clipper stage 432 which may conveniently comprise a pentode-type vacuum tube. The cathode resistor 434 of this tube is by-passed by capacitor 436 so that a self-biasing voltage is developed tending to cut off the flow of current through the tube. During the positive peaks of the 40,000-cycle sine wave input signal, the control grid is driven positive and plate current flows. As a result of the current flow through cathode resistor 434, the cathode becomes more positive relative to the control grid tending to cut off the tube. After the positive peak has passed, there is sufficient energy storage in the circuit including cathode resistor 434 and capacitor 436 to maintain the cut-off bias until the next positive peak occurs.

The output signal 442 from clipper 432 comprises a series of negative pulses which occur at a rate of 40,000 cycles per second in the illustrative system described herein. These pulses are shaped by the differentiating circuit comprising capacitor 438 and resistor 440.

The output signal of clipper stage 432 is employed to trigger a single trip on "one shot" multivibrator comprising two vacuum tubes 444 and 446 which are shown in this embodiment as comprising the two halves of a twin-triode type tube, although it will be understood that separate triode-type tubes or other types of tubes may be employed in this circuit. This single trip multivibrator, which is of the type sometimes referred to as a single square pulse generator is adjusted to produce a single square pulse in response to each triggering impulse, this square pulse having a duration of 125 microseconds ($^1/_{8,000}$ cycles per second). In this "one-shot" multivibrator circuit the plate of vacuum tube 444 which will be referred to hereinafter as the "on" tube is connected through anode resistor 448 to a source of positive potential and is also connected directly to the control grid of vacuum tube 446 which will be referred to hereinafter as the "off" tube. The cathode of "on" tube 444 is connected directly to ground. The plate of "off" tube 446 is connected through anode resistor 450 to the source of positive potential and through capacitor 452 to the control grid of "on" tube 444. The cathode of "off" tube 446 is connected through resistor 454 to ground and this resistor is by-passed by capacitor 456.

Let it be assumed that "on" tube 444 normally operates at or near zero bias with plate current flowing therethrough. This flow of plate current causes a voltage drop across anode resistor 448 which because of the connection of the plate of "on" tube 444 to the control grid of "off" tube 446 tends to prevent the flow of current through the latter tube.

Upon receipt of each of the negative pulses from the differentiating circuit comprising capacitor 438 and resistor 440 the control grid of "on" tube 444 is suddenly driven negative cutting off the flow of plate current through this tube. Accordingly, the plate potential of this tube rises sharply and because of the connection to the control grid of "off" tube 446 this control grid is driven positive to initiate flow of current through the "off" tube. Capacitor 452, which has been charged to the full plate potential during the period in which tube 446 was cut off, begins to discharge through the plate-cathode circuit of tube 446. After a period determined by the time constant of capacitor 452 and resistor 440, the voltage on the control grid of "on" tube 444 rises sufficiently to permit current again to flow through this tube. Such current flow lowers the plate voltage of tube 444 and this voltage applied to the grid of tube 446 tends to return it to its normal "off" condition. This action is facilitated by the self-biasing operation of "off" tube 446, the cathode of this tube tending to become more positive during periods of current flow. In addition, there is sufficient energy storage in the circuit comprising resistor 454 and capacitor 456 to maintain tube 446 cut off during the periods in which no negative triggering pulse is applied to the "on" tube.

The time constant of the R. C. circuit comprising resistor 440 and capacitor 452 is so adjusted in this embodiment that the single trip multivibrator completes its cycle of operation in exactly 125 microseconds. The output of this stage is taken from the plate of "off" tube 446 and comprises a single negative pulse of the form shown at 458. Thus there is derived at the output of the single trip multivibrator a single negative square pulse of duration just equal to that of the code group. However, due to time delays and phase shifts through those portions of the circuit thus far described, this square pulse may not necessarily coincide in time with the receipt of a code group. Means for adjusting the phase of the synchronizing system will now be described.

The output from the plate of "off" tube 446 of the single trip multivibrator is applied through coupling capacitor 460 to the control grid of vacuum tube 462 which is arranged as a saw tooth wave generator of conventional type. The control grid of the triode-type tube employed in this saw tooth wave generator is connected through resistor 464 to a source of positive potential such that plate current normally flows through tube 462. Capacitor 466 which is connected between the plate of tube 462 and ground is thus normally discharged. Upon receipt of the negative square pulse from the single trip multivibrator, tube 462 is cut off and capacitor 466 begins to charge through plate resistor 468. At the termination of the negative square pulse input signal, tube **462** again becomes conducting and capacitor **466** discharges through the tube which at this time comprises essentially a short circuit across the capacitor. Accordingly, a saw tooth wave of the form shown at **470** is developed across plate resistor **468**.

This saw tooth wave is applied to a phase adjuster and pulse sharpening circuit including vacuum tube **472** which may conveniently be a triode-type tube. The plate of tube **472** is connected through an anode resistor **474** to a source of anode voltage, while the cathode is connected to the movable contact of a potentiometer **476** which is connected in series with resistors **478** and **480** between the source of anode potential and ground. Depending upon the setting of potentiometer **476**, vacuum tube **472** may be caused to conduct during all or a portion of each of the individual saw teeth of the input saw tooth wave. The output of this tube is differentiated in the circuit comprising capacitor **482** and resistor **484** to obtain a series of negative pulses or pips occurring at the code group or frame repetition frequency of 8,000 cycles per second and having a wave form as shown at **486**. Depending upon the point at which vacuum tube **472** begins to conduct the negative pips generated by the differentiating circuit will be of a particular phase in relation to the input saw tooth wave. Thus the phase of these pips may be adjusted so that one pip occurs at the onset of each code group of the input signal merely by adjusting the setting of potentiometer **476**.

These negative pips are applied to a second single trip multivibrator **488** which is identical in all respects to the single trip multivibrator comprising vacuum tubes **444** and **446** and previously described. As in the case of the first single trip multivibrator, single trip multivibrator **488** is adjusted to produce negative square pulses of 125-microsecond duration in response to each negative pip of the applied signal. These negative square pulses are applied to a saw tooth wave generator **490**, which is identical to and operates in the same manner as saw tooth wave generator **462**, to produce an output wave of the form shown in **492**. This saw tooth wave which is accurately phased with respect to the input code groups is applied to the horizontal deflection plates **494** of cathode ray tube **496** through an amplifier comprising vacuum tubes **498** and **500** which are connected in a phase inverting circuit variously called a cathode phase inverter or a cathode-coupled paraphase amplifier. This circuit arrangement is described by O. H. Schmitt in the Journal of Scientific Instruments, volume 15, pages 136 and 234, for 1938 and in Review of Scientific Instruments, volume 12, page 548, for 1941 and is referred to on page 137 of Theory and Applications of Electron Tubes by H. J. Reich, second edition. In this circuit as described in the above references, a signal applied to the control grid of tube **498** appears with substantially equal amplitudes and in opposite phase across load resistors **502** and **504** of tubes **498** and **500**, respectively. The push-pull output appearing between the plates of these two tubes is applied to the horizontal deflection plates of cathode ray tube **496** to sweep the electron beam thereof across the screen during the time occupied by a single code group of the pulse code modulated signal. In view of the assumption made above that the code element pulse or signaling condition representing the largest portion of the total possible amplitude of the complex wave is transmitted first and followed by those signals representing successively smaller portions, the electron beam is caused to sweep across the screen of cathode ray tube **486** from left to right in Fig. 4.

In addition to being applied to the synchronizing circuit described above, the amplified pulse code modulated radio frequency signal from radio frequency amplifier **414** is also applied through coupling capacitor **508** to vertical deflection amplifier **510** which conveniently comprises a single pentode-type vacuum tube. The output signal from this amplifier is applied through coupling capacitor **512** to the lower of vertical deflection plates **506** of cathode ray tube **496**. The other vertical deflection plate of the cathode ray tube is connected through series resistor **514** to the movable contact of a potentiometer **516** connected between the source of anode potential and ground. Potentiometer **516** serves as a vertical centering or position control and is normally adjusted so that, in the absence of code pulses in the input signal, the electron beam of the cathode ray tube will strike the screen behind the lower opaque portion of mask **518** mounted over the face of the tube and no light will be transmitted therethrough. Vertical deflection plates **506** are held at substantially the potential of the second anode of cathode ray tube **496** by virtue of the connection through resistor **520** for the lower deflection plate and through a portion of the winding of potentiometer **516** for the upper vertical deflection plate to the second anode.

Appropriate potentials for the operation of cathode ray tube **496** are obtained from a power supply comprising battery **522**, the positive terminal of which is connected to ground, in series with a voltage divider **524** to ground.

The electron beam of cathode ray tube **496** is brightened or intensified during the forward sweep across the screen from left to right (in Fig. 4) and blanked or turned off during the retrace by a blanking circuit responsive to the sweep signal and including vacuum tube **526**. This circuit is similar to those employed in commercial cathode ray oscillographs as, for example, the oscillograph identified as model 208 and manufactured by the A. B. Dumont Company of Clifton, New Jersey. In this circuit, a connection is made through capacitor **528** from one of the horizontal deflection plates and through potentiometer **530** to the control grid of blanking tube **526**. A suitable biasing potential is also applied to this control grid from divider **524** through series resistor **532**. The sweep signal as applied to the control grid of blanking tube **526** comprises a series of negative saw teeth which become gradually more negative during the forward sweep and return sharply to the original value during the reverse or retrace sweep. This signal appears in the opposite phase across anode resistor **536** of blanking tube **526** and is applied to a differentiating circuit comprising capacitor **538**, and resistor **539** which sharpens the pulse corresponding to the retrace portion of the sweep. The output of the differentiating circuit is coupled through capacitor **540** to the control grid of cathode ray tube **496**. Thus during the forward sweep capacitor **538** charges at a constant rate and a substantially constant positive voltage is applied to the control grid of the cathode ray tube serving to intensify the electron beam. During the retrace interval capacitor **538** discharges rapidly and a negative pulse is applied to the control grid of cathode ray tube 496. This negative pulse is sufficient to cut off or blank the electron beam.

Returning now to a consideration of mask 518 it will be evident from Fig. 4 that this mask is identical to that shown in the block diagram of Fig. 1. Accordingly, it has formed therein a series of contiguous openings of decreasing area arranged in the direction of sweep (from left to right in Fig. 4). The area of each of the openings is one-half the area of the preceding opening and these openings taken together have a stepped profile. It will be recalled that the sweep deflection circuits are so adjusted that during each code element interval of the received code group, the electron beam may be caused to sweep across the screen of the cathode ray tube behind the opening in mask 518 corresponding to the same portion of the total possible amplitude of the transmitted wave as the code element signal being received at the particular time in question. If a code element signal of the type representing the presence of a portion of the total possible amplitude of the complex wave is present in any code element interval, it results in the application of a pulse of carrier frequency energy to vertical deflection plates 506. This overcomes the bias from potentiometer 516 and the electron beam is oscillated at carrier frequency and in a vertical direction for the duration of the time in which that code element signal is received. Since the horizontal sweep of the electron beam is synchronized with the received code group, the vertically oscillating electron beam of the cathode ray tube strikes the screen thereof immediately behind the appropriate part of the opening in mask 518.

By way of example, let it be assumed that the instantaneous amplitude of the complex wave a particular moment is such that a code group as shown in Fig. 5 of the drawing is transmitted following the synchronizing signal, the first code element interval at the left of Fig. 5 representing the largest portion of the total possible amplitude of the complex wave and succeeding code element intervals representing successively smaller portions thereof. During receipt of this code group the electron beam of cathode ray tube 496 will begin its horizontal travel as receipt of the first code element signal is initiated. Since, as shown in Fig. 5, the first code element interval is occupied by an "on" pulse, the bias which normally prevents the electron beam of the cathode ray tube from striking the screen thereof behind the largest opening in mask 518 is overcome and the electron beam, which is oscillated vertically by the carrier frequency, strikes the screen behind the largest opening of the mask as it traverses the corresponding portion of the horizontal sweep. Since that portion of the total possible amplitude of the wave represented by the second code element is not present in the wave represented by the code group of Fig. 5, an "off" pulse or signal is transmitted. Accordingly the electron beam will again be deflected by the bias voltage on the vertical deflection plates to prevent its striking the screen behind the second largest opening in the mask and no light will be transmitted through the mask during the sweep of the beam across that area. As in the case of the first "on" pulse, the electron beam is permitted to strike the screen behind the third and fourth openings in mask 518. Thus the total amount of light passing through mask 518 from the screen of the cathode ray tube will be proportional to the sum of the areas of the first, third and fourth openings in the mask. It will be recalled that these openings correspond respectively to fixed portions of the total possible amplitude of a complex wave to which also correspond the first, third and fourth code element intervals of the transmitted code group. Thus the total amount of light passing through mask 518 in response to a code group signal as shown in Fig. 5 is proportional to the instantaneous amplitude of the complex wave which resulted in the generation of that code group.

It will be noted that in the above consideration of the operation of the decoder of Fig. 4, in response to the code group shown in Fig. 5, no mention has been made of the synchronizing pulse or signal. As has been pointed out above, this signal is conveniently transmitted either at the beginning or the end of each code group. Thus mask 518 may be so shaped that the synchronizing pulse occurs either before or after the electron beam of cathode ray tube 496 traverses the portion of the screen behind the perforations of the mask during its sweep across the screen.

In the preceding description it has been assumed for convenience of illustration that the code element signals are transmitted in the order of decreasing amplitude of the portions of the complex wave amplitude which they represent. These code elements may be transmitted in the reverse order or in any arbitrary order if desired. In such cases it is necessary only to replace mask 518 with a mask in which the several perforations or openings of different areas are arranged in the direction of sweep in the same way as the code element signals are arranged in the transmitted code groups. Then the decoder will operate in the manner described above and the total amount of light passing through the new mask will again be proportional to the instantaneous amplitude of the complex wave represented by the code group received.

The light passing through mask 518 is focussed upon the anode of a photoelectric tube 541 by a lens system shown diagrammatically at 542 which may comprise any suitable arrangement of lenses effective to form an image of the mask on the cathode thereof. The output signal from photoelectric tube 541 varies in amplitude with the amount of light falling on its cathode and thus the total output for a code group is proportional to the instantaneous value of the transmitted complex wave. This output signal is coupled through transformer 544 to an amplifier shown herein as a single stage pentode amplifier 546 with constant screen voltage, although, other types of amplifiers acting as constant current sources may be employed for this purpose. The output of amplifier 546 is coupled through transformer 548 to a low-pass filter comprising inductor 550 and capacitors 552 and 554 connected in a shunt-terminated arrangement. This filter effectively removes from the output signal of amplifier 546 components of code group and code element frequencies, so that its output which is coupled through transformer 556 to headphones 558 is of audio frequency, all other components having been eliminated. It will be understood that other forms of terminal equipment such as repeaters, amplifiers, loudspeakers, or other transducers may be substituted for headphones 558.

What is claimed is:

1. In a communication system which includes means at the transmitter for producing pulse code modulation signals representative of instantaneous amplitudes of a message wave and com-

prising code groups of individual elements each having any of a plurality of values, and in one of said values representing a fixed portion of the total possible amplitude of said message wave, a receiver for said signals which includes a decoder comprising a cathode ray tube, means controlled by said individual signals permitting the electron beam of said cathode ray tube to reach a chosen area on the screen of said tube only when a signal of value representing the respective portion of the amplitude of said message wave is received, means for sweeping the electron beam across the chosen area of said screen during the time occupied by a code group, a mask mounted over said chosen area and shaped to permit passage of an amount of light from said screen which is for each signal time during the sweep of the electron beam across the screen proportional to the portion of the message wave amplitude represented by the signal being received at that time, and means for generating an output varying in amplitude as the total amount of light transmitted through said mask.

2. In a communication system which includes means at the transmitter for producing pulse code modulation signals representative of the instantaneous amplitude of a message wave and comprising successively transmitted code element signals each of which may have either of two values, one value denoting the presence of a different fixed portion of the amplitude of said message wave and the other value denoting the absence of said portion, a decoder which comprises a cathode ray tube, a mask over the screen thereof shaped to define light transmitting areas proportional respectively to said portions of the message wave amplitude and disposed in line across the mask, means for sweeping the electron beam of the cathode ray tube across the screen to complete a single sweep during the time occupied by a code group, means permitting the beam to strike the screen behind a light transmitting area of said mask only if the signal corresponding to the same portion of a message wave amplitude is of said one value, and means for generating an output which varies with the total amount of light transmitted through said mask.

3. In a communication system including means at the transmitter for producing pulse code modulation signals representative of the instantaneous amplitude of a message wave and comprising a fixed number of code element signals transmitted in a predetermined order, each of said signals being of one of two types, one type denoting the presence of a different fixed portion of amplitude of said message wave and the other type denoting the absence of that portion, a receiver for said pulse code modulation signal comprising a cathode ray tube, a mask mounted over the screen thereof and shaped to define light transmitting areas proportional respectively to said portions of message wave amplitude and arranged across the mask in the same order as the order of transmission of said signals, beam deflection means effective during the receipt of each code element signal of said one value to direct the electron beam to that part of the screen behind the light transmitting area corresponding to the same portion of amplitude as the signal and effective during receipt of code element signals of said other value to direct the beam away from parts of the screen behind light transmitting areas of said mask, and means for generating an output proportional to the total amount of light transmitted through said mask.

4. In a communication system having a transmitter and means thereat for producing pulse code modulation signals representative of the instantaneous amplitude of a message wave and comprising a fixed number of two-valued code element signals, each of which in one value represents the presence of a different fixed component of the amplitude of said message wave and in the other value represents the absence of that component, a receiver for said pulse code modulation signals comprising a cathode ray tube, a mask mounted over the screen thereof and shaped to define transmitting areas proportional respectively to said components of message wave amplitude, means for sweeping the electron beam of the cathode ray tube across the mask to strike the screen behind the transmitting area corresponding at any time to the code element signal being received, means effective normally to blank the electron beam of said cathode ray tube, means responsive only to signals of said one value to deblank the electron beam, and means for generating an output signal which varies as the total amount of transmission through said mask.

5. In a communication system having a transmitter for generating pulse code modulation signals representative of the instantaneous amplitude of a message wave and comprising a plurality of two-valued signals each of which in one value represents a fixed component of the total possible amplitude of said message wave and in the other value represents the absence of such component, a receiver for said pulse code modulation signals including, a decoder which comprises a cathode ray tube, a mask mounted over the screen thereof and shaped to define light transmitting openings of constant width and varying areas proportional respectively to said components of message wave amplitude, means for oscillating the electron beam of said cathode ray tube in a direction normal to the width of said mask openings, means for sweeping the electron beam in a direction parallel to the width of said mask openings to strike the screen of the cathode ray tube behind the light transmitting area corresponding to the same component of the message wave amplitude as the signal being received at any time, means for turning on the electron beam during receipt of signals of said one value, means for cutting off the electron beam during the receipt of signals of said other value, and means for generating an output proportional to the total amount of light transmitted through said mask.

6. In a communication system including a transmitter, a receiver, means at the transmitter for generating pulse code modulation signals comprising code groups of bi-valued code element pulses, and means for modulating a carrier wave by said signals, the pulses of one value representing different fixed portions of the amplitude of a message wave to be transmitted and pulses of the other value representing the absence of these portions, means at the receiver for decoding said pulse code modulation signals comprising a cathode ray tube, a mask mounted over the screen thereof and having openings therein respectively proportional in area to said portions of message wave amplitude, means for sweeping the electron beam of the cathode ray tube so that it falls for each code element pulse upon the screen behind the opening mask corresponding to the same portion of message wave amplitude, means for normally cutting off the

electron beam of the cathode ray tube, means for demodulating the transmitted signal, means for applying the demodulated pulses of said one value to the control grid of the cathode ray tube to turn on said electron beam, and means for generating an output signal proportional in amplitude to the total amount of light passing through said mask.

7. In a communication system including a transmitter and a receiver, means at the transmitter for generating pulse code modulation signals representing the instantaneous amplitude of a message wave and comprising a fixed number of successively transmitted two-valued signals, each of which in one value denotes the presence of a different fixed portion of the amplitude of said message wave and in the other value represents the absence of that portion, a decoder for said pulse code modulation signals at the receiver comprising a cathode ray tube, a mask over the screen thereof having openings therein of widths proportional to the portions of the message wave amplitude and arranged across said mask in the order of transmission of the corresponding signals, means normally deflecting the electron beam of the cathode ray tube to sweep across the screen to strike areas other than those behind the openings in said mask, means effective only upon the receipt of signals of said one value to deflect the beam for sweeping across the screen behind the mask openings corresponding respectively to said signals of said one value, and means for producing an output signal which varies with the total amount of light transmitted through said mask.

8. In a communication system including means at the transmitter for producing pulse code modulation signals representing the instantaneous amplitude of a message wave and comprising a fixed number of bi-valued signals representing components of the message wave amplitude which are related as decreasing powers of two, said signals in one value indicating the presence of said components in the message wave and in the other value representing the absence of said components, means at the receiver for decoding said pulse code modulation signals comprising a cathode ray tube, means for sweeping the electron beam of the cathode ray tube across the screen thereof, a mask mounted over the face of the cathode ray tube having therein light transmitting openings arranged in the direction of sweep and each having an area one-half that of the preceding opening, and means for deflecting the electron beam of the cathode ray tube to strike the screen thereof behind only those openings in the mask corresponding to components of message wave amplitude for which signals of said one value are received, and means for generating an output signal corresponding in amplitude to the total amount of light transmitted through said mask.

9. In a communication system having transmitting and receiving stations and means at the transmitting station for generating pulse code modulation signals representative of the instantaneous amplitude of a message wave and comprising a fixed number of code element signals transmitted in arbitrary order, said signals having either of two values, one value denoting the presence of a fixed portion of the total possible amplitude of the message wave and the other value denoting the absence of said portion, a decoder for said pulse code modulation signals at said receiving station comprising a cathode ray tube, means for sweeping the electron beam across the screen thereof during the receipt of a code group, a mask mounted over said screen having therein light transmitting openings of areas proportional respectively to said amplitude portions, said openings being arranged in the direction of sweep in the same order as that in which the corresponding code element signals are transmitted, means deflecting the electron beam of said cathode ray tube to strike the screen thereof only behind mask openings for which corresponding signals of said one value are received, and means for generating an output signal proportional to the total amount of light passing through said mask.

GEORGE HECHT.

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