March 16, 1948. J. R. PIERCE 2,437,707

COMMUNICATION SYSTEM EMPLOYING PULSE CODE MODULATION

Filed Dec. 27, 1945 3 Sheets-Sheet 1

FIG. 1

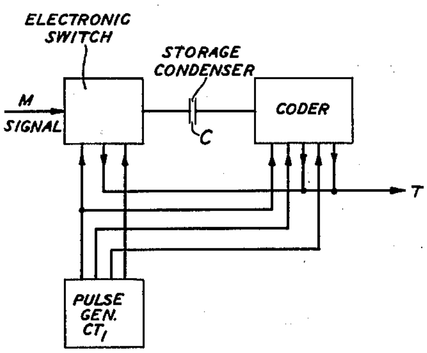


FIG. 2

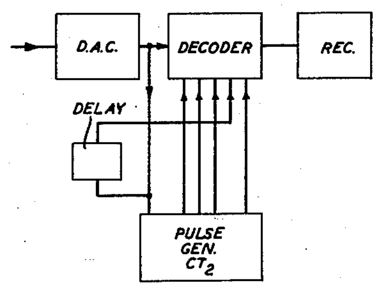


FIG. 3

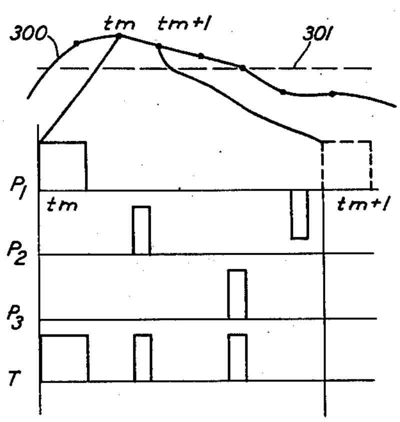


FIG. 4A

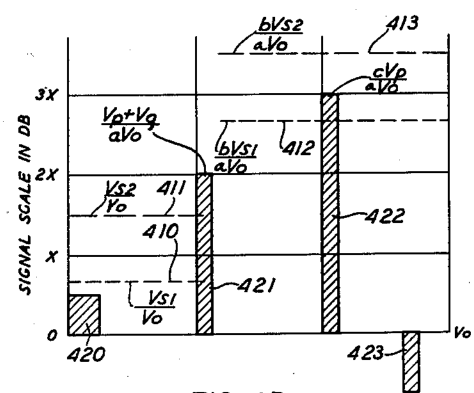
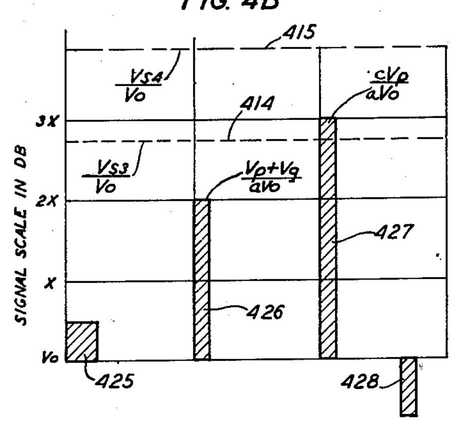


FIG. 4B



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COMMUNICATION SYSTEM EMPLOYING PULSE CODE MODULATION

Filed Dec. 27, 1945 3 Sheets-Sheet 2

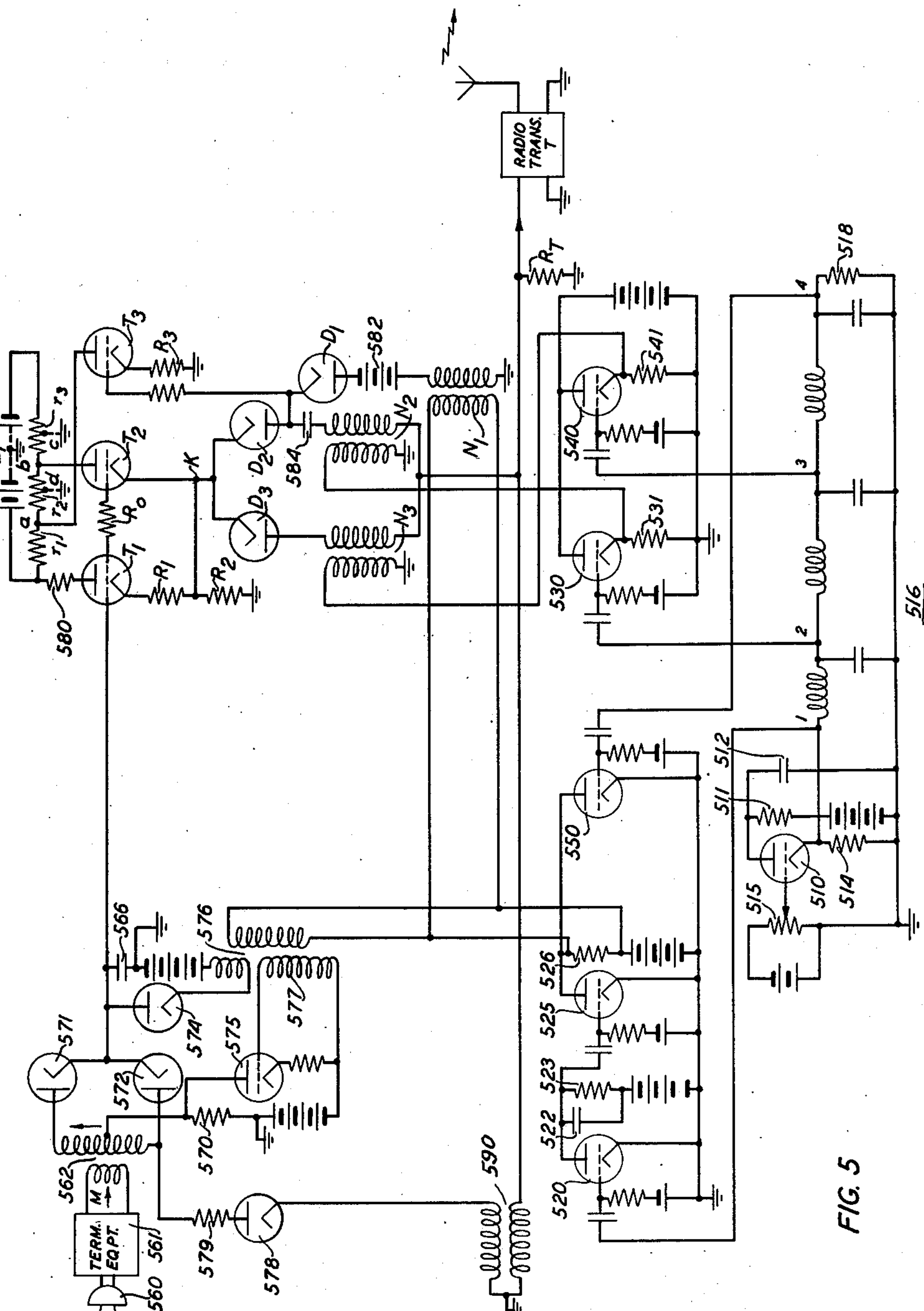

FIG. 5

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COMMUNICATION SYSTEM EMPLOYING PULSE CODE MODULATION

Filed Dec. 27, 1945 3 Sheets-Sheet 3

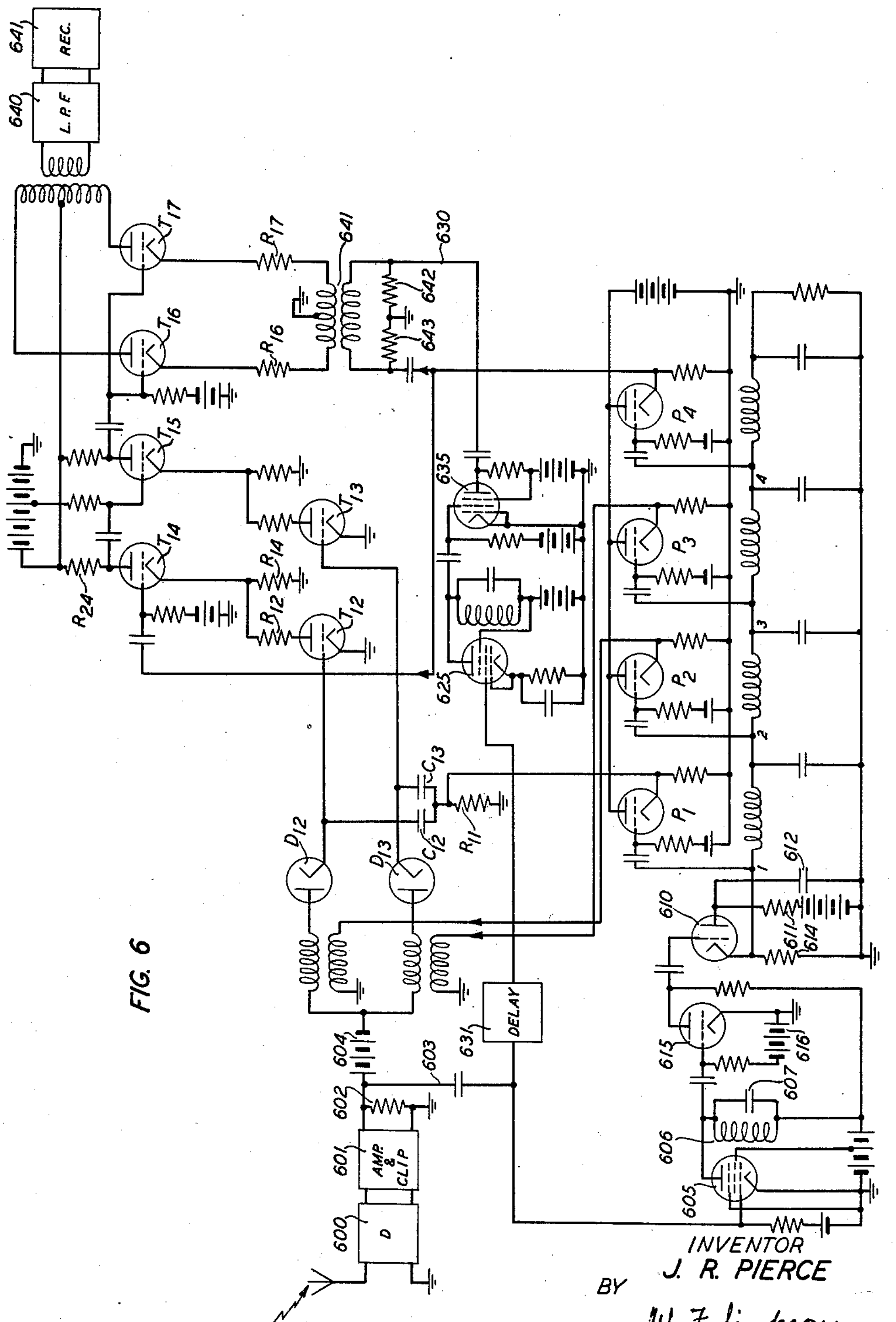

FIG. 6

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COMMUNICATION SYSTEM EMPLOYING PULSE CODE MODULATION

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Application December 27, 1945, Serial No. 637,386

13 Claims. (Cl. 179—1.5)

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This invention relates to a communication system for the transmission of complex wave forms of the type encountered in speech, music, sound, mechanical vibrations and picture transmission by means of code groups of a uniform number of signal pulses of a plurality of different types of signaling conditions transmitted at high speed. Systems of this type have sometimes been identified as "PCM" or "pulse code modulation" systems.

The object of the present invention is to provide a communication system capable of transmitting and reproducing a complex wave form over an electrical transmission path such as a microwave radio path, a wave guide, cable circuit, etc., in such manner that the signal-to-noise ratio of the received signal is materially improved over the signal-to-noise ratio of the transmission path.

Another object of this invention is to provide improved and simplified apparatus capable of transmitting and receiving signal pulses over a path having a low signal-to-noise ratio.

More specifically, it is the object of the present invention to provide circuits and apparatus for transmitting a group of pulses in sequence over a given channel representative of the amplitude of a complex wave at successive instants of time.

Still another object of the present invention is to transform a series of pulses representing the amplitude of a complex wave at a given instant of time into a single pulse having an amplitude which is a function of the amplitude of the original complex wave at the given instant and to recombine a succession of such single pulses of varying amplitude in a manner to reconstruct a wave form of substantially the same shape as the wave form to be transmitted.

A feature of the invention is that of accomplishing the above objects with a small number of pulses requiring a minimum of apparatus and equipment, taking advantage of the considerable distortion permissible in speech without loss of intelligibility. The invention is similar in some respects to my copending application, Serial No. 592,961, filed May 10, 1945, and Serial No. 603,934, filed July 9, 1945, as will be pointed out hereinafter.

Other features of the invention relate to synchronizing and coordinating the various circuits and equipment at the transmitting terminal with each other and with the circuits and equipment of the receiving end so as to secure proper operation of the system as a whole.

Briefly, in accordance with the present invention, equipment is provided for generating a group of control pulses of predetermined time relation one with another. Apparatus is also provided for rapidly sampling a wave function, the sampling means being under control of the control pulse generator. Furthermore, for each of the control pulses, a code element timing circuit generates a series or cycle of code element timing pulses and these in combination with the sample amplitude first test the polarity of the sample and then compare its amplitude under different conditions with known voltages.

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In the meantime there is set up and transmitted a code of pulses corresponding to the polarity information and to the amplitude information, which code thus characterizes the polarity and the amplitude of the complex wave sample. At the receiving station a control pulse generator, code element timing generator and associated apparatus are provided whereby each cycle or group of received pulses is employed to produce a pulse having a magnitude proportional to the magnitude of the complex wave sample at the transmission end of the system. The complex wave is then reconstructed from a succession of such reproduced pulses of varying magnitude.

A special feature of the system consists in measuring the sample amplitude on a decibel basis and in this respect the system is similar to that described in my application Ser. No. 592,961 as contrasted with the system described in my application Ser. No. 603,934 which operates on a linear or proportional basis.

The invention both as to its organization and method of operation, together with other features thereof, will be better understood from the following description when read with reference to the accompanying drawings in which:

Figs. 1 and 2 show in functional block form the various elements of the transmitter and of the receiver and the manner in which they cooperate to form an exemplary communicating system embodying the present invention;

Fig. 3 illustrates the timing and nature of the pulses charcteristic of the system at the transmitting end;

Figs. 4A and 4B are explanatory of the operation of the system; and

Figs. 5 and 6 show in detail the various circuits and operations of the transmitting and the receiving equipment, respectively, of an exemplary system embodying the present invention.

Referring more specifically to Fig. 1 let M be a signal function representative of any complex wave such as a speech wave, a small portion of which is indicated by curve 300 of Fig. 3. The signal function may be obtained from any suitable source either directly or over any suitable transmission path. The signal source and transmission path may include the usual types of transmission, switching, and repeating equipment and operate in their usual and well understood manner.

A pulse generator CT_1 sets up a plurality of cycles of pulses, the cycles coming in rapid succession, perhaps about 8,000 per second. The first pulse of each cycle, which is a relatively broad positive pulse, activates an electronic switch which causes the signalling wave or function to be sampled, whereby a storage condenser C is charged to a potential equal to the amplitude of the wave function at the instance of the pulse. From the electronic switch there is then sent to the transmitter information as to the polarity of the sample signal. This first pulse of each group or series is also applied to a coding circuit to initiate action therein or operation thereof. The next two pulses, which are narrow positive pulses, from the generator are applied to the coder and give rise to information, to be transmitted, bearing on the amplitude of the sample. Finally a negative fourth pulse from the generator resets the circuit in preparation for the next cycle of operation. As a result of these operations there is passed on to the transmitter a binary representation of the polarity and amplitude of the sample digit by digit, the first digit defining the polarity and the next two the amplitude on a non-linear or decibel basis.

At the receiver these pulses are received and trigger off a pulse generator to generate a series of pulses similar to and in synchronism with those at the transmitter. These pulses, cooperating with the corresponding received signal pulses, adjust the gain in decibels of a train of amplifiers to a total gain corresponding to the decibel amplitude of the original sample with respect to its reference voltage. Following this a pulse from the generator is impressed on the input of the train for amplification and at the same time the polarity pulse, appropriately delayed, operates to control the direction of the output. A suitable resetting pulse is also provided. The output resulting from the successive cycles are then passed through a low pass filter to substantially reproduce the original wave.

In speaking of transmitted or received pulses it is understood that reference is had to two signaling conditions, such as +1 and −1 or 1 and 0, but even in the latter case an "off" or 0 signal is a signal pulse.

A more detailed understanding of the transmitter end of my system will be had by reference to Fig. 5. This circuit shows the sampling apparatus and the coding unit along with the pulse generator, but since the operation of the first two are dependent on the pulse generator and since the generator operation is independent of these two, it will be described first.

Pulse generator

The controlling element in the pulse generator is a relaxation oscillator comprising a gas tube 510. This oscillator is of a form well known in the art and includes a resistance 511 for charging a condenser 512. Assuming that the condenser 512 is discharged, then on closure of the circuit it is charged at a rate determined in part by the resistance 511. When the potential of the condenser and the plate of tube 510 rises to a "firing

value" the condenser suddenly discharges through the tube and resistor 514. The duration of the discharge is short and gives rise to a sharp positive pulse across resistor 514. The duration of this pulse and the rate at which it is followed by identical pulses can be completely controlled by the parameters of the circuit; in particular by the values of the elements 511 to 514 taken with the potential of the grid of the tube 510 as determined by the potentiometer 515. Any of several forms of relaxation oscillators will function equally well for the controlling oscillator or element and may be so used, the one shown being simple and satisfactory.

The positive pulse formed across impedance element 514 is now used to control the emission of pulses to various parts of the circuit. This is accomplished by connecting across the element 514 a delay line, network, circuit or "time stick" 516. A suitable form of delay device or network is shown in the drawing and is made up of sections of inductance and capacitance connected seriatum. The positive pulse travels down this delay network and upon the arrival at each section gives rise to corresponding positive pulses at points 1 to 4 of the network spaced in time one after another by an interval determined by the number and contents of the elements in the preceding sections of the time stick. These pulses will control the operation of additional pulse circuits and, through them, the sampling circuit and the coder, as will be pointed out hereinafter. The delay network is terminated by a load 518 of proper value to suppress any reflected wave.

The parameters of the relaxation oscillator may be adjusted so that pulses are delivered across resistor 514 at any frequency desired. For the purpose of my invention it is preferred to have a sampling frequency higher than that of the highest frequency component in the complex wave to be transmitted. If, for example, this wave is to be a speech wave and it is desired to transmit all components up to 3,000 cycles then there should be at least two samples per cycle for this highest frequency component. A suitable value, therefore, for the relaxation oscillator frequency which becomes the sampling frequency, would be 6,000 cycles although a higher value may be used if desired.

At the time t_m when the pulse is formed across 514 it is transmitted immediately to triode 520 and appears at the plate thereof as a reversed or a negative pulse. Furthermore, by virtue of the condenser 522 in parallel to the load resistor 523 the length of the pulse is increased to correspond to the initial wide pulse P_1 shown in Fig. 3 for purposes to be hereinafter described. This pulse is now applied to the grid of triode 525 and appears as a positive pulse, amplified if desired, across the load resistor 526.

When the pulse reaches the point 2 on the time stick, it is transferred to the grid of triode 530 and appears as a positive pulse across the cathode resistor 531, which pulse is then available for use. Also, when it reaches the point 3 on the time stick it is applied to grid of tube 540 and appears as a positive pulse across cathode resistor 541. Finally when it reaches the point 4 on the time stick it is applied to the grid of tube 550 and appears as a negative pulse across the plate resistor 526.

Sampling circuit

Associated with the sampling circuit of Fig. 5

now to be described there is shown a source of complex wave to be transmitted, such as a speech wave. This source may comprise a microphone or other suitable source 560 and suitable terminal equipment 561 including a transmission line to transfer the signal function M to the transformer 562. In sampling the signaling wave the sampling circuit is arranged to respond to the polarity and magnitude of this wave at the sampling instant.

Diode 578 is employed to distinguish between the two polarities.

Associated with the secondary of the transformer is a storage condenser 566 which tends to take on a potential difference related to that developed in the transformer 562 by the magnitude of the signal wave. It is desired to charge this condenser in the same direction whether the function M is positive or negative, since the upper plate is always to be positive. To this end the mid-point of the secondary of transformer 562 is connected to ground through resistor 570 and the condenser is supplied from both ends of the secondary through the pair of diodes 571 and 572 so poled that charge flows to the condenser 566 in the same direction without regard to the polarity of the M function. Furthermore, the circuit is provided with diode 574 to discharge condenser 566 at the end of a cycle and triode 575 which controls the charging of the condenser.

The operation of the sampling circuit will now be described. When, at the beginning of a cycle, a positive pulse appears across resistor 526 current flows through the primary of transformer 576. One secondary 577 of that transformer is connected to the grid of tube 575 being so poled as to render the grid negative, whereupon the plate of that tube rises in potential by such an amount that current flows through diodes 571 and 572 to charge condenser 566 to a potential substantially equal to the instantaneous potential of the M function. The condenser 566 is so connected that it retains its charge with no appreciable loss during one cycle.

One end of the secondary of transformer 562 is connected through diode 578 in series with a protecting resistor 579 and a transformer to the transmitter. Accordingly, if the polarity of the M function relative to a zero or reference potential such as illustrated by line 301 of Fig. 3 is such as to give current in the secondary in the direction indicated by the arrow then a negative pulse will be sent to the transmitter indicating what may be designated as a positive polarity. If the polarity of the M function is negative relative to the reference potential, then no pulse, i. e., a "zero" pulse, will be transmitted. Thus, information is provided to indicate the polarity of the signal, a condition which is necessary if measurement of sample amplitude is to be on a decibel rather than a linear or proportional basis. This "off" or "on" pulse is the first pulse in the train of a cycle to be transmitted to the remote receiving point. The duration of this pulse, as already mentioned and as indicated in Fig. 3, is longer than that of the other pulses in the cycle.

Coder

The coder comprises three tubes, T_1, T_2 and T_3, shown as triodes. Battery B_1 supplies voltage to the plates of these tubes through a bleeder circuit shown as comprising the resistors r_1, r_2 and r_3 in sequence. An intermediate point such as the midpoint of battery B_1 is connected to

ground. The two triodes T_1 and T_2 link the storage condenser 566 to a pair of diodes D_2 and D_3. The plate of T_1 is connected through protecting resistor 580 to the positive end of battery B_1 and its cathode is connected through cathode resistors R_1 and R_2 in series to ground. The plate of T_2 is connected to the point b of the bleeder and its cathode includes as its cathode resistor the portion R_2 of the cathode resistor of T_1. The cathode of T_3 is connected to ground through its cathode resistor R_3. The grids of tubes T_1 and T_2 are connected to the upper side of storage condenser 566, which is at a positive potential when a sample is stored on it. Current is therefore normally flowing through T_1. Current will or will not flow through T_2 depending on whether the point b is at a positive or a negative potential with respect to its cathode. Current will or will not flow through T_3 depending on the potential of its grid.

It will be evident that there will be some point along the bleeder circuit which will be at the same potential as the grounded point of battery B_1. The resistors r_1, r_2 and r_3 are so proportioned that when tube T_3 is turned off that point is at some place along r_3 such as c. Consequently the plate of T_2 is positive and current tends to flow through tube T_2 under control of its grid potential. When T_3 is turned on the increased current through r_1 is such that the ground point is moved to some such place as d and consequently the plate of T_2 is negative with respect to its cathode and no current flows to the plate substantially independently of the potential difference between its grid and cathode. A small current may flow to the grid but the resistance R_0 is made large enough so that the reduction of the charge of the storage condenser is not appreciable during the length of one cycle.

These triodes can now function in two ways. If the grid of T_3 is somewhat positive current flows therethrough, the plate of T_2 is negative and the voltage across R_2 is

$$V_2=aV_s$$

where V_s is the voltage on the storage condenser and a is a constant having a value which a function of the circuit and tube parameters. If, however, the grid of T_3 is quite negative the plate of T_2 is positive and

$$V_2=bV_s$$

where b is a different constant which is greater than a. It may be shown that if the tubes are similar, if the cathode resistors are large compared to the tube resistance, and if the gain of the tubes is substantially the same and large compared to unity; that

$$\frac{b}{a} \text{ approaches } \frac{R_1+R_2}{R_2}$$

and thus the ratio of b to a can be changed by altering the ratio R_1/R_2. The ratio of b/a may also be changed by changing other circuit and tube parameters as is well understood by persons skilled in the art.

The operation of the triodes in the coder is controlled by the diodes D_1, D_2, and D_3, which may be rendered conducting by positive pulses initiated at the time stick or delay line and operating through transformers N_1, N_2 and N_3 all in a manner to be now described.

Tube 575 is biased so that, except when a negative potential or pulse is applied to its grid, appreciable current flows between its anode and cathode and thus through resistor 570. The potential drop across resistance 570 makes the plate of tube 575 negative with respect to ground but still positive with respect to its cathode. The plate of tube 575 is connected to the center of the secondary winding of transformer 562. Consequently, the negative potential of the anode of tube 575 with respect to ground maintains the diodes 571 and 572 non-conducting.

At the beginning of a cycle of operation a positive pulse initiated at the point 1 on the time stick and acting through transformer 576 to give a negative potential to the grid of tube 575 removes the drop across resistance 570 so the potential of the mid-point of the secondary or transformer 562 returns to substantially ground potential and allows the complex signaling wave operating through the diodes 571, 572 to charge the storage condenser 566 to a plus value proportional of the wave amplitude.

At the same time if the plate of diode 572 is positive with respect to ground a positive pulse is transmitted through diode 578 to the transmitter; if not, no pulse is sent out. Obviously, this positive pulse may be changed to a negative pulse by means of a transformer 590 or vacuum tube if desired.

At the same time a positive pulse acting through transformer N_1 on the diode D_1 overcomes the bias battery 582 and causes current to flow through diode D_1 and charge condenser 584 which in turn renders the grid of T_3 positive by an amount V_g. Current thereupon flows through T_3 and lowers the potential of point b so that the potential of the plate T_2 is negative and the voltage across R_2 is aV_s. Shortly thereafter, a positive pulse initiated from the point 2 of the time stick and operating through transformer N_2 is applied to the diode D_2 through condenser 584. Let the pulse voltage from transformer N_2 be V_p. If $V_p+V_g>aV_s$ current will flow through diode D_2 and on the recession of the pulse the grid of T_3 will go strongly negative, T_3 will be turned off, T_2 will be turned on and aV_s will change to bV_s. If the current flows it will flow through resistor R_t and send a negative pulse to the transmitter, meaning that the sample on the condenser is less than a certain level, that is

$$V_s<\frac{V_p+V_g}{a}$$

Using V_0 as a reference level, let

$$20 \log \frac{V_p+V_g}{aV_0}=2X$$

where X is given any desired value. Then a pulse transmitted at this time means that the sample is less than 2X decibels above the level V_0, while no pulse transmitted means that the sample is more than 2X decibels above the level V_0.

Following this, a pulse cV_p initiated by the pulse from the point 3 on the time stick is applied to the plate of diode D_3. Current will flow through this diode and a pulse will be transmitted if $cV_p>(a, b)\ V_s$. Here the factor multiplying V_s may be either a or b depending on the result of the first operation, as will be pointed out later.

The ratio of b/a is so adjusted by adjustment of the various circuit and tube parameters that

$$20 \log (b/a)=2X$$

and the ratio of transformer and other circuit parameters is chosen that c is given such a value that

$$20 \log \frac{cV_p}{aV_0}=3X$$

where X is as defined above and may be given any desired value, then it will be apparent that if 0 represents no pulse and 1 represents a pulse to the transmitter the following combinations represent the following numbers of decibels above V_1:

1	1	0 decibels
1	0	X decibels
0	1	2X decibels
0	0	3X decibels

This will be better understood by reference to Figs. 4A and 4B. In these figures a number of signal voltages are plotted on a decibel scale against time; in particular one sample V_{s1} is taken as of an amplitude between 0 and X decibels, with respect to the reference level V_0. Examples are also taken of an amplitude sample V_{s2} lying between X and 2X decibels, V_{s3} between 2X and 3X decibels and V_{s4} above 3X decibels.

Case 1, Fig. 4A (V_s between 0 and X decibels above reference level V_0). When V_{s1} as shown by line 410 of Fig. 4A is between 0 and X decibels above the reference level V_0, V_{s1} will be less than

$$\frac{V_p+V_g}{a}$$

Consequently when pulse V_p, which is illustrated by the shaded area 420 of Fig. 4A, from point 2 of the delay line is applied to the circuit of the diode D_2 the voltage drop aV_{s1} over R_2 is small so that current flows through D_2 and a pulse of short duration is transmitted by the radio transmitter. During the pulse, condenser 584 will be discharged to a voltage difference equal to the difference between V_p and aV_{s1}. On the termination of this pulse the upper plate of condenser 584 and therefore the grid of T_3, falls to a more negative value so tube T_3 is turned off for the remainder of the cycle. Current immediately flows through T_2 increasing the drop across R_2 from aV_{s1} to bV_{s1} and consequently raising the potential of the cathodes of tubes T_1 and T_2 at point K by 2X decibels. In other words the potential of point K changes from the value aV_{s1} to a value bV_{s1}. The amplitudes are plotted in Figs. 4A and 4B on a logarithmic or *db* scale above a reference voltage V_0. Hence as shown in the drawings the lines represent the ratio of the various quantities to V_0. Shortly thereafter the pulse cV_p, illustrated by the shaded area 422 of Fig. 4A, arriving at diode D_3 finds that enlarged voltage bV_{s1} is still so low that current flows through D_3 transmitting a pulse. The code for this amplitude then, is made up of the digits 1 1 and transmits the information that the sample voltage is to be taken as 0 decibels.

Case 2, Fig. 4A (V_s between X and 2X decibels above reference level V_0). Here aV_{s2} as illustrated by line 411 of Fig. 4A is less than V_p+V_g, consequently, current will flow through D_2, yielding a digit 1, rendering the grid of T_3 negative, turning T_3 off and T_2 on, whereupon the potential at point K is raised 2X decibels to bV_{s2}. It will be observed that this potential is higher than cV_p and consequently the pulse cV_p arriving at D_3 transmits no pulse. The code thus transmitted is 1 0 meaning that the signal voltage is less than 2X but more than 1X decibels above reference voltage V_a.

Case 3, Fig. 4B (V_s between 2X and 3X decibels above reference level V_0). In this case aV_{s3} is greater than V_p+V_g, consequently no pulse flows through D_2 and no pulse is transmitted. The tube T_3 is not turned off and T_2 is not turned on; therefore, the potential of point K remains aV_{s2}, where V_{s3} is a fairly large value. However, aV_{s3} is less than cV_p and consequently on the arrival of that pulse current flows through D_3 and a pulse is transmitted. Thus, the code transmitted is 0 1 meaning that the signal is more than 2X but less than 3X decibels above reference level.

Case 4, Fig. 4B (V_s above 3X decibels above reference level V_0). The potential drop aV_{s4} is now quite large and no pulse is passed through D_2, consequently tube T_2 remains off and the potential of the point K does not alter. Also, since aV_{s4} is in excess of cV_p, no pulse is transmitted during the application of cV_p to the circuit of diode D_3 and the code message is 00, indicating that V_{s4} is in excess of 3X decibels. From the above it is seen that the following combinations represent the following number of decibels above V_0:

1	1	0 decibels
1	0	X decibels
0	1	2X decibels
0	0	3X decibels

and this is the result desired.

The combination of two amplitude pulses indicated above is accompanied, of course, by the polarity pulse; thus, if the code transmitted is 100 the left-hand one would be the pulse first transmitted and indicates positive polarity. The next zero would indicate that the amplitude is 2X decibels or more above reference level and in combination with the last zero at the right indicates that the amplitude is more than 3X above reference level.

After the transmission of this code of three pulses, the pulse from the point 4 on the time stick and operating through triode **550** is applied as a negative pulse to transformer **576**. This renders tube **574** conducting and the condenser **566** is then discharged or reset for the next cycle of operations. The timing of the various pulses is indicated in Fig. 3 on the lines P_1, P_2 and P_3 as they come from the pulse generator and on line T there is shown the timing of the transmitted pulses. The polarity pulse and the reset or restoring pulse are also represented in Figs. 4A and 4B; **420** and **425** representing the polarity pulse and **423** and **428** representing the restoring pulse.

Receiver

A receiver circuit appropriate for the system is shown in Fig. 6, in which **600** represents one or more detector and amplifier units for receiving and reducing the received radio signal to a video signal. Further amplification may be obtained, if desired, in the unit **601** in which at the same time all signaling pulses are clipped to the same amplitude and applied to the load resistor **602**. The signaling pulses are all positive as applied to resistor **602** and the output circuits connected thereto.

The receiver circuit includes a pulse generator, indicated by CT_2 in Fig. 2; this pulse generator being similar to the one at the transmitter end and comprising a relaxation circuit with a gas tube **610** and a timestick or delay line. More specifically the relaxation circuit should have a high degree of frequency stability and includes resistor **611** capacitance **612** and cathode resistor **614**. It possesses the same control elements as at the transmitter end and the timestick similarly gives rise to pulses P_1, P_2, P_3, and P_4.

Signal pulses from amplifier and pulse shaping equipment **601** are transmitted over conductor **603** to the grid of tube **610** but the relaxation circuit is so adjusted that it will be triggered off by the broad or longer pulses representing the polarity signal only. To accomplish this there is included in the path to the grid of **610** a pentode **605**, the control grid of which receives the signal pulses and a limiting tube **615**. The output circuit of tube **605** includes inductance **606** and condenser **607**. The pentode, serving essentially as a constant current source, will build up a voltage over the condenser **607** approximately proportional to the duration of the pulse on the control grid. Consequently, the long polarity pulses will cause a greater voltage change across condenser **607** than the short pulses. These pulses are applied to tube **615** which is biased by battery **616** so that it will not repeat the short pulses but will repeat the longer pulses and apply a voltage to the grid of tube **610** sufficient to trigger it. In this way definite synchronization is maintained between receiver and transmitter.

Incoming polarity signal pulses will also be conducted over lead **603** through the delay circuit **631** of any suitable type to operate on amplifier tube T_{18} in a manner and for a purpose hereinafter described.

Briefly, the operation of the receiver circuit consists in adjusting the gain of two amplifiers T_{14} and T_{15} by a cooperative operation of incoming signal pulses with locally generated pulses. The gain of these two tubes having been adjusted in correspondence with the received code, a pulse from the generator is applied to them resulting in an output pulse of amplitude determined in accordance with the received code pulses. This output pulse is applied to a gating device controlled by the received polarity pulse and the final output is accordingly a pulse of amplitude and polarity corresponding to the original sample at the transmitter.

This will be made more clear by the following description, in which reference is first made to the output portion. The output is derived from the triodes T_{16} and T_{17} an essential function of which is to determine the polarity. These are high μ triodes with a slight negative bias so that no anode current flows through them except when the grids are driven positive by the output from tube T_{15}. If tube T_{15} alone drives the grids of tubes T_{16} and T_{17} positive, there still will be no output to the low pass filter **640** because the plates of T_{16} and T_{17} are connected in push-pull and the grids are connected in parallel. In addition to the pulse applied to the grids of tubes T_{16} and T_{17}, one or two other pulses are substantially simultaneously applied to the cathodes of tubes T_{16} and T_{17}.

For each code group or cycle of pulses a pulse P_4 from the delay line through tube P_4 is applied to the cathodes of tubes T_{16} and T_{17} through transformer **641** in such a direction and of such magnitude that the cathode of tube T_{16} is made sufficiently positive to prevent the flow of anode current through this tube even when the most positive pulse from the tube T_{15} is applied to its grid. This pulse is applied to the cathode of tube T_{17} in the opposite direction, and its cathode is made sufficiently negative to provide a proper bias or operative condition for tube T_{17} so that an output pulse flows in its anode circuit having a magnitude which is proportional to or a function of the magnitude of the pulse or potential applied to its grid at that time.

The received pulses appearing across resistor **602** are passed through the delay line **631** and selection tubes **625** and **635**. Tubes **625** and **635** function to repeat the long polarity pulses but suppress and do not repeat the shorter pulses. The operation of tubes **625** and **635** in suppressing the shorter pulses and repeating the longer pulses is similar to the operation of tubes **605** and **615** respectively as described above. The circuits may also include pulse shaping networks and apparatus.

The delayed polarity pulse is applied to the cathodes of tubes T_{16} and T_{17} over lead **630**. This delayed polarity pulse as applied to the cathodes of tubes T_{16} and T_{17} is of opposite polarity to pulse P_4 and the delay apparatus **631** and selecting circuits and tubes **625** and **635** are adjusted so that the magnitude of the polarity pulse is substantially twice the magnitude of pulse P_4. Thus when both P_4 and a delayed polarity pulse are applied to the cathodes of tubes T_{16} and T_{17}, tube T_{17} is cut off while tube T_{16} functions to apply a pulse to the low pass filter **640** the magnitude of which is controlled by the potential applied to the grid of tube T_{16}.

Inasmuch as the anodes or output circuits of tubes T_{16} and T_{17} are connected to supply pulses of opposite polarity to the low pass filter, the polarity of the impulse which the low pass filter receives depends on the presence or absence of a polarity pulse in the signal. The amplitude of the pulse that the low pass filter receives depends on how positive the triode T_{15} drives the grids of the triodes T_{16} and T_{17}.

It should be noted that there are resistances R_{16} and R_{17} in series with the cathode leads of T_{16} and T_{17}. Thus when the grids are driven positive the cathodes rise in potential and the grids do not become positive with respect to the cathodes and therefore do not draw current. They merely become positive with respect to ground.

The positive pulse supplied by T_{15} is controlled on a decibel basis by the received signal pulses. For this purpose the gain of both tubes T_{14} and T_{15} is controlled by received pulses acting through tubes T_{12} and T_{13}. Let us consider that the grids of triodes T_{12} and T_{13} have been rendered negative by application of a positive reset pulse which causes electrons to flow to the grids leaving them with a negative charge when the reset pulse has subsided. This is accomplished by a pulse P_1 from the timestick applied across the resistor R_{11} and through condensers C_{12} and C_{13}. This reset pulse occurs immediately with the triggering of the relaxation oscillator **610** and therefore is substantially coincident with the arrival of the polarity pulse across **602**. Initially the gain of triode T_{14} will be A decibels where A may have any desired arbitrary value and is determined largely by tube constants, the cathode resistor R_{14} and load resistor R_{24}. Connected in parallel with the resistor R_{14} is a circuit comprising the plate of tube T_{12} and resistor R_{12}. Normally when the grid of T_{12} is negative the tube will be substantially open-circuited and the gain produced by tube T_{14} will be the normal A decibels. If however, triode T_{12} is rendered conducting by bringing its grid to substantially zero potential, then the gain of T_{14} is modified by the circuit connected in shunt to resistor R_{14} and becomes A+2X decibels. This may be achieved by adjusting the relative magnitudes of resistors R_{14} and R_{12} and selecting suitable tubes and equipment.

Following the polarity pulse a positive signal pulse may be received from amplifier and pulse shaping apparatus **601** and together with pulse P_2 is applied to diode D_{12}. Because of a bias battery **604** neither the signal pulse nor the pulse P_2 alone is sufficient to render diode D_{12} conducting and to bring the grid of T_{12} to zero potential. Hence operation by spurious pulses or static or by the polarity pulse alone is prevented. However, when the signal pulse representing a change of 2X decibels occurs in combination with the pulse P_2, the bias of battery **604** is overcome, current flows in diode D_{12} bringing the grid of T_{12} to zero potential and the gain of T_{14} is increased by 2X decibels. Similarly triode T_{13} which was rendered non-conducting by the reset pulse can be rendered conducting only by a combination of the signal pulse representing X decibels and the pulse P_3 to change of triode T_{13} from the non-conducting to the conducting condition. Tubes T_{13} and T_{15} and their associated circuits are so designed that when tube T_{13} is rendered conductive the gain of tube T_{15} increases by X decibels from its gain when tube T_{13} is non-conducting.

It is now evident that the gain of triodes T_{14} and T_{15} will have been adjusted so that the increase in their gain is in accordance with the two amplitude pulses arriving from the transmitter. Shortly thereafter, the pulse from P_4 on the timestick arrives on the grid of T_{14} and appears as a positive pulse at the plate of T_{15} with a gain corresponding to the received signaling pulses. This positive pulse operating on the grids of T_{16} and T_{17} in parallel will give rise to a flow of current corresponding thereto in one of those tubes. Simultaneously with this pulse from T_{15} the pulse P_4 will have been transmitted to resistor **643** and the polarity pulse, if present, will have been transmitted to resistor **642**. If both these pulses are present the resulting effect is to cause tube T_{16} to repeat the pulse from T_{15} in the manner described above and to apply an output pulse of one polarity to the low pass filter **640**, whereas if no polarity signal arrives and pulse P_4 alone is present tube T_{17} repeats the pulse from tube T_{15} and applies a pulse of the opposite polarity to the output circuit.

From the above it is seen that there is finally delivered to the low pass filter **640** and the receiver **641**, a current pulse the polarity and amplitude of which are in accordance with the original sample. A series of such pulses following each other will yield a reproduction of the original complex wave within the limits of granularity contemplated in the system.

It will be observed also that the action in the tubes T_{16} and T_{17} calls for the application of the polarity pulse thereto simultaneously with the application of the pulse P_4 thereto and to the grid of T_{14}. Accordingly, the delay circuit **631** should be adjusted to this end. The pulse P_4 from the timestick would ordinarily be adjusted to come very shortly after the termination of the pulse P_3 which gives the gain setting for triode T_{15}. Shortly after this last action the next code cycle will start coming in and its first pulse being a polarity pulse will trigger the relaxation oscillation **610** and the resulting pulse P_1 will reset the system in preparation for the next train of pulses.

In order to avoid the production of a positive pulse on the plate of T_{15} when the grid of tube

T_{12} is changed from negative to zero potential in response to a signaling pulse, the grid of T_{14} must be biased beyond cut-off and the tube must be made conducting only when pulse P_4 is applied to its grid. Changing the grid of T_{13} from negative to zero potential will cause a negative pulse on the plate of T_{15} and hence will cause no output. The reset pulse will cause a positive pulse at the plate of T_{15} but since no pulse is applied to transformer 641 at the time of the reset pulse the tubes T_{16} and T_{17} are balanced and hence the reset pulse causes no output.

It is apparent that many variations may be made in the circuits of my system without departing from the spirit of the invention. For example, instead of introducing the delay for the polarity pulse in the receiver, it could have been introduced at the transmitter end in the lead from the diode 578 so that for a cycle of operations the polarity pulse would have come at the end instead of at the beginning. In any case, the delay line would have a delay slightly less than or equal to the reciprocal of the sampling rate thus delaying the polarity pulse just one cycle of operations.

Also the delay device may be of any suitable type such as any delay network of one or more sections, a transmission line, an artificial transmission line, a transmission path through any suitable medium, etc.

What is claimed is:

1. In a communication system, means for measuring the voltage on a condenser comprising a first amplifier tube and a second amplifier tube with grids connected in parallel with each other and to said condenser, the two tubes having a common cathode resistor, a source of pulses of predetermined value and time spacing, means by which a first pulse will turn off the second tube, a second pulse which will turn on the second tube if the drop over the common cathode resistor is less than a given amount and will leave it off if more than the given amount, a third pulse of larger amplitude than the second which will determine whether the drop over the cathode resistor is in excess of or below the voltage of said third pulse.

2. In a signaling system for transmitting information relating to a complex wave, a transmitting station comprising a circuit for periodically sampling the wave to charge a storage condenser to the instantaneous voltage V_s, which is a function of the instantaneous amplitude of said wave, an amplifier tube subject to said condenser, said tube including a cathode resistor giving a sample voltage drop aV_s over one portion of the cathode resistor, a gain means for changing the sample drop over the said cathode resistor to bV_s, where b is in excess of a, a source of pulses of predetermined value, a first pulse rendering the said means inactive, a second pulse testing whether aV_s is greater or less than the said second pulse amplitude plus a constant and if larger then leaving the said means inactive but if smaller then rendering the said means active to raise the sample voltage over the cathode resistor to bV_s, a third pulse to test whether the aV_s or the bV_s, whichever is present, is greater or less than the amplitude of the third pulse.

3. In a signaling system for transmitting information relating to a complex wave, a transmitting station comprising a circuit for periodically sampling the wave to charge a storage condenser to the instantaneous wave voltage V_s, an amplifier tube subject to said condenser, said tube circuit including a cathode resistor giving a sample voltage drop aV_s over a portion of the cathode resistor where a is less than unity, a gain device for changing the sample drop over the said cathode resistor to bV_s where b/a is a gain of 2X decibels, a pulse generator giving rise to cycles of pulses, a first pulse cooperating to charge the condenser and to render the said gain device inactive, a second pulse testing whether aV_s is greater or less than the second pulse amplitude plus a constant and if larger then leaving the said device inactive but if smaller then rendering said device active to raise the sample voltage over the cathode resistor to bV_s, a third larger pulse to test whether the aV_s or the bV_s, whichever is present, is greater or less than the amplitude of a third pulse.

4. A combination of claim 3 with the added feature of means whereby a signal pulse is transmitted by the second pulse if the gain device is not rendered active and by the third pulse if it is in excess of the voltage drop over the cathode resistor, the two pulses thus characterizing the amplitude of the condenser voltage.

5. A combination of claim 3 characterized by the fact that the gain device is a second amplifier tube with a cathode resistor which is the portion of the cathode resistor referred to in connection with the first named amplifier tube, the grid of this second tube being also subject to the condenser.

6. A combination of claim 3 characterized by the fact that the gain device is a second amplifier tube with a cathode resistor which is the portion of the cathode resistor referred to in connection with the first named amplifier tube, the grid of this second tube being also subject to the condenser, and characterized further by a third amplifier tube on which the first pulse operates such that when the third tube is on the second tube is rendered non-conducting and when the third tube is turned off, the second tube is rendered conducting to raise the sample drop across the common cathode resistor.

7. In a signaling system for transmitting information as to the shape of a complex wave, a receiver station adapted to receive cycles of three pulse codes of two different signaling conditions, one pulse designating the polarity of the voltage and the other two pulses characterizing the amplitude on a decibel basis, a train of amplifiers in tandem, the two amplitude pulses cooperating to adjust the gain of the train of amplifiers to conform with the amplitude which the said two pulses characterize, the polarity pulse cooperating to control the direction of the amplifier output in conformity with the polarity designated.

8. A combination according to claim 7 including a pulse generator for producing control pulses synchronous with the received said two pulses characterizing the amplitude, and means for preventing said adjustment of the gain of the train of amplifiers except upon the coincidence of a received amplitude pulse and a corresponding pulse from said pulse generator.

9. A combination according to claim 8 including means responsive to the first amplitude pulse for adjusting the gain of said train of amplifiers by 2X decibels, and means responsive to the second amplitude pulse for adjusting the gain of said train of amplifiers by X decibels, thus providing four amplitude steps of X decibels each from zero to 3X decibels with respect to a reference voltage.

10. In a signaling system for transmitting information on the shape of a complex wave, means at the transmitter for sampling the wave amplitude at frequent intervals and for transmitting cycles of three pulse codes of two different signaling conditions timed in accordance with a pulse generator, one of the three pulses designating the polarity of the sample and two characterizing the amplitude on a decibel basis, a receiver station adapted to receive said three pulse codes and comprising a pulse generator, a train of three stages of amplifiers the last being a normally balanced push-pull pair with no output, the polarity pulse serving to synchronize the pulse generator and operating over a delay circuit to the push-pull circuit, the received first amplitude pulse cooperating to adjust the gain of the first stage of the amplifier depending on whether the said received pulse is an on or an off pulse, the received second amplitude pulse similarly operating on the second stage whereupon the delayed polarity pulse operates to unbalance the push-pull circuit in one direction or the other depending on whether the polarity pulse is an on or off signal.

11. A combination according to claim 10 in which said pulse generator produces pulses coincident respectively with the received first amplitude pulse, the received second amplitude pulse and the delayed polarity pulse, and including means for adjusting the gain of said first stage of the amplifier only in response to the combination of said first amplitude pulse and the corresponding pulse from said pulse generator, means for adjusting the gain of said second stage only in response to the combination of said second amplitude pulse and the corresponding pulse from said pulse generator, means to unbalance said push-pull circuit in response to said delayed polarity pulse and the corresponding pulse from said pulse generator, and means for transmitting through said train of three stages of amplifiers the last-mentioned pulse from said pulse generator.

12. A combination according to claim 11 including means responsive to the first amplitude pulse for adjusting the gain of said first stage of the amplifier by 2X decibels, and means responsive to the second amplitude pulse for adjusting said second stage by X decibels, thus providing four amplitude steps of X decibels each from zero to 3X decibels with respect to a reference voltage.

13. A combination of claim 10 characterized by the fact that the first stage in the train of amplifiers is normally below cut-off and is activated by a pulse from the generator after the gain adjustments have been made, the said last pulse cooperating with the delay polarity pulse to at the same time unbalance the push-pull stage.

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REFERENCES CITED

The following references are of record in the file of this patent:

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