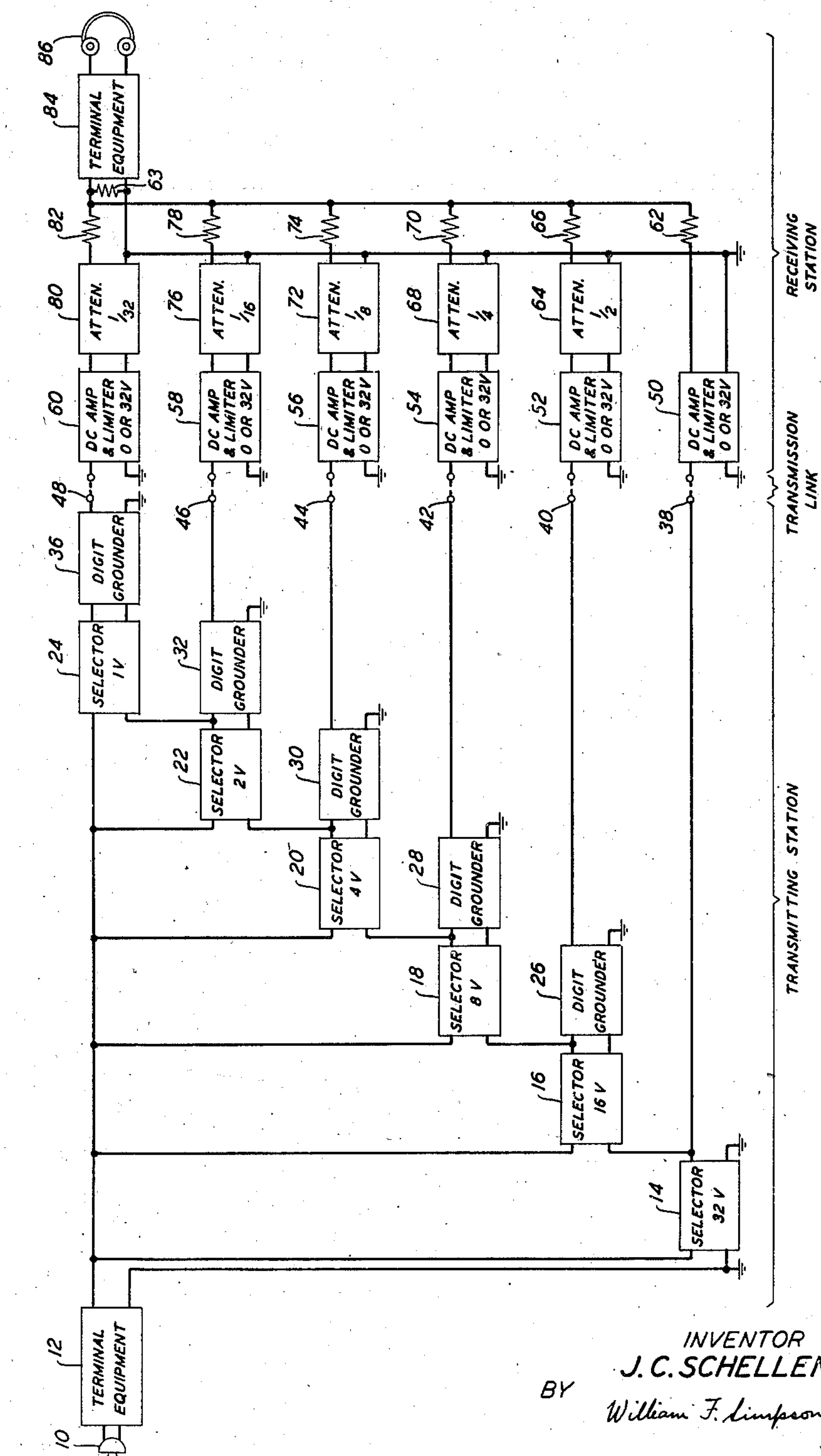
Nov. 9, 1948. J. C. SCHELLENG 2,453,461

CODE MODULATION COMMUNICATION SYSTEM

Filed June 19, 1946 2 Sheets-Sheet 1

FIG. 1



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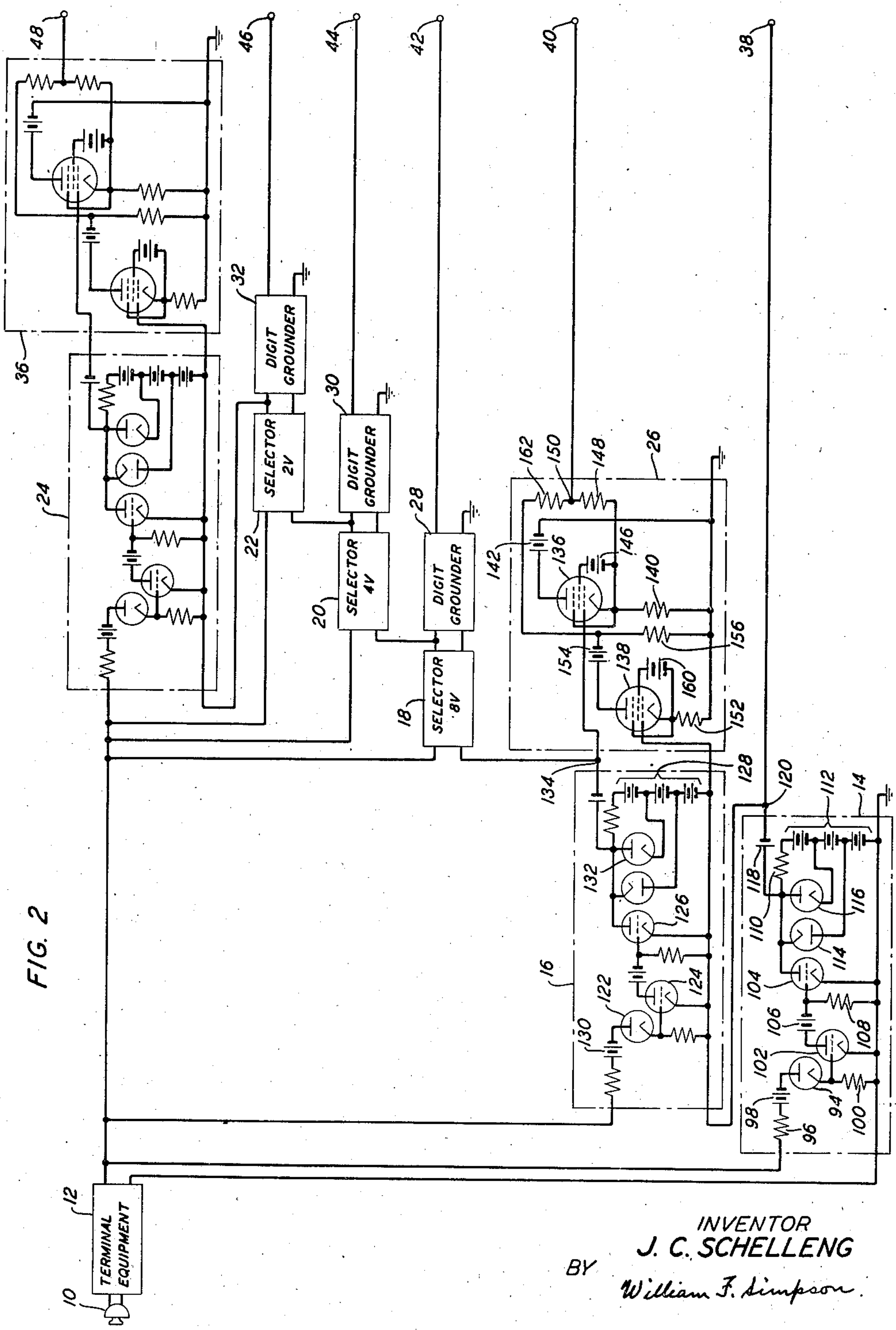

FIG. 2

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CODE MODULATION COMMUNICATION SYSTEM

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18 Claims. (Cl. 179—1.5)

1

This invention relates to communication systems for the transmission of complex wave forms of the type encountered in speech, music, telegraph, facsimile and television signals.

Communication systems have been proposed in which the instantaneous amplitude of a complex wave to be transmitted is represented in binary code form for transmission to a receiving station. In such systems, the amplitude of the complex wave in arbitrary units may be expressed as or represented by a binary number and currents or voltages which may be turned on or off in different circuits are assigned to represent each digit, i. e., denominational order, of that number. Thus each digit voltage or current may by its presence indicate a 1 and by its absence a 0 in the corresponding or representative binary numbering system. In certain prior communication systems of this type, the amplitude of the complex wave to be transmitted is sampled periodically and the sample amplitudes are converted into a binary code group of voltages. These code groups are transmitted to a receiving station at which equipment, carefully synchronized with that at the transmitter, is utilized to reconstruct the original complex wave.

This method of transmission has certain inherent advantages. Among these the most important arise from the fact that the transmitted signal comprises either a voltage or no voltage or at least one or the other of two signalling conditions for each digital position or denominational order of the code group. Consequently the receiver need only be capable of distinguishing between the two signalling conditions to permit faithful transmission of the complex wave. Nonlinearity of the transmission link and other amplitude distortion can be tolerated. In addition a low signal-to-noise ratio can be accepted in the transmission path so long as the presence of the voltage representing the 1's of the binary code can be distinguished from the noise.

Systems of the type considered above, however, involve provision of accurate means for synchronizing the operation of a number of widely separated units, the operation of which must be timed with high precision. Furthermore, they require the use of separate sampling and coding systems and relatively complex auxiliary timing devices at the transmitter to insure their successful operation.

It is an object of the present invention to provide a communication system for the code transmission of complex waves in which synchronization of the transmitting and receiving stations is not required, and in which the complexity involved in first sampling and then coding in separate circuits is eliminated.

2

It is a further object of the invention to achieve such simplification without sacrifice of the advantageous results outlined above in connection with the prior art systems.

There is provided in accordance with one aspect of the invention a communication system in which the amplitude of the complex wave to be transmitted is directly and continuously converted into a binary code group representation which is then transmitted to a receiving station at which the elements of the code group are combined to reconstruct the original complex wave.

In other aspects the invention relates to a binary coder which is operated continuously to produce a binary code group which at all times represents the instantaneous amplitude of the complex wave to be transmitted and to receiving circuits for translating a code group into the complex wave amplitude represented thereby.

The communication system of the invention is described and shown herein as arranged for the transmission of voice frequency intelligence but it is to be understood that this system may be used equally well for the transmission of telegraph, picture or television signals through modification of the terminal equipment utilized at the transmitter preceding the coding equipment and at the receiver following the decoding equipment.

The above and other features of the invention will be understood by reference to the accompanying drawings in which:

Fig. 1 is a block diagram of a communication system in accordance with the invention; and

Fig. 2 is a schematic diagram partially in block form of the binary coder utilized at the transmitting station of this communication system.

Referring to Fig. 1, the communication system of the invention is shown as comprising a transmitting station, a transmitting link and a receiving station. At the transmitting station complex wave voice-frequency currents from microphone 10 are applied to terminal equipment 12, which may comprise the necessary switching and transmitting devices including amplifiers and impedance matching devices to convey the complex wave form from source 10 to the coding and transmission system described herein. Equipment 12 is also employed to add a bias to the complex wave if necessary to prevent it from having negative values. As a result, the output signal from equipment 12 is always of positive polarity.

The signal from the terminal equipment, which will be referred to herein as the input signal is applied to a series of selectors 14 through 24 comprising over-biased and limited amplifiers or amplitude selective repeaters, each of which is responsive to a different fixed portion of the applied signal. Each of these amplitude selectors or relays 14 through 24 is biased so that it is responsive only to input voltages larger than a predetermined designated input voltage or threshold and is operative to produce zero output voltage for all input voltages less than the designated input voltage, and an output voltage equal to the designated input voltage for all inputs equal to or greater than the designated input voltage. As shown in Fig. 1, the input signal is applied directly to selector 14, while the difference between the input signal and the output of selector 14 is applied to a second selector 16. Input connections similar to those to selector 16 are made to selectors 18, 20, 22 and 24, the signal applied to each of these selective switching devices being the difference between the input signal and the output of the preceding selective switches.

In the system shown for purposes of illustration in Fig. 1, the designated input voltages of selectors 14 through 24 are related as descending powers of two, selector 14 being responsive only to input voltages greater than 32 volts (two to the fifth power). Thus, selectors 16, 18, 20, 22 and 24 have designated input voltages of 16, 8, 4, 2 and 1 volt, respectively. Recalling that the output of each selector must be either zero or its designated input voltage, it will be seen that selector 14 may have an output potential of either zero or 32 volts while selector 16 may produce a potential difference at its output of either zero or 16 volts. Similarly, selector 18 may produce a potential difference of either zero or 8 volts. Since the remaining selectors operate in the same manner, it will be seen that any input voltage from 0 to 63 volts, inclusive, may be expressed as the sum of the potential differences appearing at the outputs of these selectors. Thus there are provided six separate outputs, each of which may be either zero or some positive value, depending upon the instantaneous amplitude of the complex wave form occurring at the output of the terminal equipment 12.

It will be recognized, however, that only the output of selective repeater or selector 14 is a voltage in respect to ground, the output of the remaining selectors being merely potential differences measured in respect to the output of the preceding selector in the chain. Accordingly, selectors 16 through 24 are provided with auxiliary devices 26 through 36, respectively which will be referred to herein as digit grounders. Each of these devices is arranged to convert the potential difference existing at the output of the selector with which it is associated into a potential in respect to ground. In one embodiment of the invention the potentials in respect to ground at the outputs of the several digit grounders are positive when the associated selectors are operative and are zero at all other times. Thus there is continuously provided on output terminals 38 through 48 a binary code representation of the varying amplitude of the complex wave introduced through terminal equipment 12. It will be understood that the signal appearing at any one of these output terminals is a voltage corresponding to one of two signalling conditions, this voltage appearing and disappearing as necessary to express the instantaneous amplitude of the complex wave to be transmitted.

The six output signals are transmitted over separate paths or channels, which may be wire transmission links or radio links operating at different carrier frequencies, to a receiving station shown at the right in Fig. 1. At the receiving station, the signals from the six transmission paths or channels are applied to separate direct-current amplifiers and limiters 50 through 60. In the illustrative system, each of these identical amplifier-limiter combinations is arranged to produce an output of 32 volts for any input signal exceeding a lower limit which is made high enough to exclude extraneous transmission noise, and to produce zero output for inputs below this limit. Thus amplitude distortion or attenuation introduced by the transmission link do not affect the operation of the receiver unless the signals in one or more of the transmission paths are so reduced in amplitude that they do not exceed the noise-level threshold introduced by the limiter.

The output of amplifier-limiter 50 which is 32 volts or zero, depending upon whether or not selector 14 at the transmitter is operated, is applied through series resistor 62 to resistor 63 which has a low ohmic value in relation to that of resistor 62. The output of amplifier-limiter 52, however, which is also either 32 volts or zero, depending upon whether or not selector 16 at the transmitter is operated, is applied to an attenuator 64 arranged to provide an output equal to one-half of the voltage applied thereto or, 16 volts. This output voltage is applied through resistor 66, which has the same resistance as resistor 62, to resistor 63. In similar fashion attenuators 68, 72, 76 and 80 are associated with amplifier-limiters 54, 56, 58 and 60, respectively and provide output voltages of 8 volts, 4 volts, 2 volts or 1 volt which are respectively applied to resistor 63 through resistors 70, 74, 78 and 82 each equal in ohmic value to resistor 62, when signals are present in the corresponding transmission channels. The resistive network comprising series resistors 62, 66, 70, 74, 78 and 82 and resistor 63 is such that the outputs of the six receiving channels are effectively combined for application to receiving terminal equipment 84, which comprises the amplifiers and other audio-frequency circuits necessary to provide a suitable input for headphones 86.

In the operation of the system described above, the complex wave appearing at the output of terminal equipment 12 is translated into a 6-element binary code, the digital positions or denominational orders of which are represented by output terminals 38 through 48, voltages appearing at each of these terminals as required to produce the proper binary code representation of the instantaneous amplitude of the complex wave to be transmitted. The voltages existing at terminals 38 through 48 are transmitted to the receiver at which there is derived from each actuated channel a voltage having an amplitude equal to that to which the selector associated with the same channel is responsive. These voltages are then continuously added to reconstruct the complex wave applied to the transmitter.

Details of the selectors and digit grounders and the methods of interconnection between successive selectors in the chain are shown in Fig. 2. With the exception of operating potentials, the six selectors are similar and a detailed description of selector 14 will permit a complete understanding of all of the selectors. The output of terminal equipment 12 is applied directly to this selector which as described above has a designated input of 32 volts and is arranged to provide an output of either zero or 32 volts, depending upon whether the input voltage applied to it is less than 32 volts or is equal to or larger than 32 volts. The input voltage is applied first through a series resistor 96 to a biased diode 94, battery 98 serving to maintain a negative bias of −32 volts on the plate of diode 94. If the input voltage exceeds 32 volts, diode 94 becomes conductive and a voltage drop is developed across resistor 100 connected between the cathode of diode 94 and ground.

The voltage appearing across cathode resistor 100 is applied to a two-stage direct-current amplifier comprising triode-type vacuum tubes 102 and 104 with their associated circuit elements and sources of potential. This amplifier serves to raise the power level of the signal appearing across resistor 100. The cathode of triode 102 is connected to ground, while the plate circuit includes a battery 106 and a series load resistor 108. The potential drop occurring across load resistor 108 is applied to the grid of triode 104, the cathode of which is grounded and the plate of which is connected through load resistor 110 to a tapped battery 112, the negative terminal of which is grounded. The output of this direct-current amplifier is applied to a limiter circuit comprising diodes 114 and 116. The cathode of diode 114 is connected to the plate of triode 104, while the plate of diode 114 is connected to a tap on battery 112 such that the applied plate potential is 50 volts. The plate of diode 116 is connected to the plate of triode 104, while its cathode is connected to a tap on battery 112 such that the potential applied thereto is equal to 50+32 or 82 volts. A 50-volt bias battery 118 is connected between the plate of triode 104 and output terminal 120 and serves to oppose the potential appearing at the plate of triode 114, making the potential at terminal 120 equal to the potential at the plate of triode 104 less 50 volts.

In considering the operation of this selector, let it first be assumed that an input signal greater than 32 volts is applied through resistor 96 and bias battery 98 to the plate of diode 94. Because the negative bias on this diode is exceeded, it will become conductive and a voltage drop will be developed across resistor 100. This voltage drop raises the potential applied to the control grid of triode 102, thus increasing the plate current of that tube. Such an increase in plate current increases the voltage drop across load resistor 108 lowering plate voltage of triode 102 and decreasing the potential applied to the control grid of triode 104. The decrease of plate current through triode 104 caused by the decrease of the applied grid potential results in an increase in the voltage appearing at the plate of this tube. If, however, this voltage exceeds 82 volts, the positive bias on the cathode of limiter-diode 116 is overcome and this diode becomes conductive. In becoming conductive limiter-diode 116 causes sufficient current to flow through resistor 110 substantially to limit the voltage of the anode of tube 104 to 82 volts. After the 50 volts provided by bias battery 118 is subtracted from the voltage appearing at the plate of triode 104, the output voltage produced at terminal 120 is maintained at 32 volts so long as the input signal is equal or greater than 32 volts.

Let it now be assumed that the voltage applied to diode 94 is less than 32 volts. Under this condition the negative bias of battery 98 is not exceeded and diode 94 does not conduct. Accordingly, no potential drop occurs across cathode resistor 100 and the plate current through triode 102 assumes a value for which the voltage drop through resistor 108 is considerably less than that occurring when diode 94 is conducting. The voltage across the plate resistor 108 of triode 102 which is applied to the grid of triode 104 is thus higher, i. e., less negative and the last-mentioned tube draws a plate current which is considerably greater than that drawn when diode 94 is conducting. Under these conditions, a relatively high voltage drop occurs across load resistor 110 tending to lower the voltage at the plate of triode 104. This voltage is prevented from falling substantially below 50 volts, however, by limiter-diode 114 which has a positive plate bias of 50 volts and becomes conductive when the plate voltage of triode 104 falls below 50 volts. When this diode becomes conductive, a portion of the plate current drawn by triode 104 flows from battery 112 through diode 114 rather than through resistor 110 thus holding the plate potential of triode 104 at 50 volts. When the negative bias of 50 volts provided by battery 118 is subtracted from the plate potential of triode 104, it will be seen that under the input signal condition last assumed, the potential appearing at output terminal 120 is zero. Thus it will be understood that selector or relay 14 will provide an output voltage of substantially zero for all input voltages less than 32 volts and an output voltage of substantially 32 volts for all input voltages equal to or greater than 32 volts.

The potential appearing at output terminal 120 of selector 114 is applied to transmitter output terminal 38 and to the input of a second selector 16 to which is also applied the output of terminal equipment 12. It will be seen from Fig. 2 that selector 16 is similar to selector 14 with the exceptions that the cathode resistor of diode 122, the cathode of direct-current amplifier triodes 124 and 126, and the negative terminal of tapped battery 128 are connected to output terminal 120 of selector 14 rather than to ground. In addition, bias battery 130 provides a negative bias of 16 volts, while the tap to which the cathode of limiter-diode 132 is connected on battery 128 is chosen to provide an applied voltage of 50+16, or 66 volts.

Thus there is applied to selector 16 the output of terminal equipment 12 less the output of selector 14 whether the output of selector 14 happens to be zero or 32 volts. The operation of selector 16 is identical to that of selector 14 with the following exception produced by the changes in battery potentials and input connections described above. If the difference between the instantaneous amplitude of the complex wave appearing at the output of terminal equipment 12 and the potential appearing at the output terminal 120 of selector 14 is equal to or greater than 16 volts, a potential difference of 16 volts will be produced between output terminal 134 of selector 16 and output terminal 120 of selector 14. If, on the other hand, the difference between the output of terminal equipment 12 and that of selector 14 is less than 16 volts, zero potential difference is produced between the output terminal 134 of selector 16 and output terminal 120 of selector 14.

It will be recognized from the above, however, that the potential appearing at terminal 134 of selector 16 is either zero or 16 volts with respect to the output of selector 14 appearing at terminal 120. For purposes of transmission over the separate channels of the transmission link the outputs of the several selectors may advantageously be made separate potentials in respect to ground. Digit grounder 26 is therefore provided to convert the potential difference appearing between selector terminals 120 and 134 into a potential in respect to ground which appears at transmitter output terminal 40.

Digit grounder 26 in the exemplary embodiment described in detail herein comprises a pair of pentode-type vacuum tubes 136 and 138 which are connected for operation as cathode followers. Thus, the potential appearing at terminal 134, the output terminal of selector 16, is applied to the control grid of pentode 136, the cathode of which is connected through resistor 140 to ground. Battery 142 is connected in series between the plate of pentode 136 and ground to apply positive potential to the plate. The screen grid of pentode 136 is connected to the positive terminal of battery 146, the negative terminal of which is connected to the cathode, while the suppressor grid is connected directly to the cathode. The cathode of pentode 136 is also connected through resistor 148 to terminal 150.

The output of selector 14 appearing at output terminal 120 is applied to the control grid of pentode 138, the cathode of which is connected through resistor 152 to ground, while plate potential is provided by battery 154 the positive terminal of which is connected to the plate of pentode 138 and the negative terminal of which is connected through resistor 156 to ground. The screen grid of this tube is connected through battery 160 to the cathode, while the suppressor grid is connected directly to the cathode. The negative terminal of battery 154 is also connected through a resistor 162 to terminal 150.

Considering the operation of the digit grounder described above, it will be seen that the output voltage of selector 16 applied to the control grid of pentode 136 causes the production of a voltage drop across cathode resistor 140 substantially equal to the voltage at terminal 134, less the grid-cathode drop of pentode 136. Similarly, the output at terminal 120 of selector 14 is applied to the control grid of pentode 138 and produces a voltage drop across cathode-resistor 152 substantially equal to the potential at terminal 120 less the grid- cathode drop of pentode 138. Cathode resistor 152 of cathode-follower pentode 138 and series resistor 156 in the plate circuit thereof are so proportioned that the voltage developed across cathode resistor 152 for a given plate current is reproduced across resistor 156 with opposite polarity. Thus, a voltage proportional to that appearing at terminal 134 of selector 16 is applied through resistor 148 to point 150, while a voltage proportional to the inverse of that appearing at terminal 120 of selector 14 is applied through resistor 162 to the same point.

Resistors 148 and 162 have equal high ohmic values of the order of megohms and the voltage across cathode resistor 140 of pentode 136 and that across plate resistor 156 of pentode 138 are averaged at terminal 150. Thus it will be seen

that the voltage appearing at terminal 150 and applied to transmitter output terminal 40 is either zero or eight in respect to ground, (a voltage equal to one-half the potential difference produced by coder 16) depending upon whether or not the selector receives an input signal less than or equal to or greater than 16 volts.

The input connections to the remaining selectors 18, 20, 22 and 24 are similar to those to selector 16 and the digit grounders 28, 30, 32 and 36 are similar to digit grounder 26. In the exemplary system described in detail herein, these digit grounders provide output voltages in respect to ground of 4, 2, 1 and ½ volts, respectively, when the associated selectors are actuated and zero output at all other times.

Many of the circuits utilized at the receiving station and indicated in Fig. 1 may be of well-known types and are not described in detail herein. However, the direct-current amplifier-limiter combinations 58 through 60 may conveniently be similar to those utilized in selector 14 with the exception of changes in certain of the applied battery potentials. Thus, referring to the showing of selector 14 in Fig. 2, the potential of the selector bias battery (98 in Fig. 2) is made slightly greater than the largest noise voltage to be tolerated in the transmission link. Then, any signal voltage exceeding the noise level will cause the diode (94) to conduct, providing an increase in the voltage applied to the direct-current amplifier. This amplifier and the limiter may be identical in construction and operation to those employed in selector 14 and the unit as utilized at the receiver provides an output of 32 volts whenever the noise level is exceeded and zero output at other times. It will be understood that equivalent direct-current amplifiers and limiters may be substituted for those described above, both in the selectors and in the receiver.

Attenuators 64, 66, 72, 76 and 80 may comprise resistors connected across the outputs of the corresponding amplifier-limiters and tapped at appropriate points to produce attenuations of ½, ¼, ⅛, $\frac{1}{16}$ and $\frac{1}{32}$ corresponding to output voltages of 16, 8, 4, 2 and 1 volts, respectively. Other resistive attenuating networks of more complexity may be used if desired.

The system as described above is susceptible of modification and considerable simplification if high fidelity transmission links are available. Thus, if the six channels of the transmission link are free of amplitude distortion and introduce either zero or fixed and equal attenuations, the amplifier-limiter equipment may be eliminated from the receiver of Fig. 1. Under these conditions the signals transmitted from the digit grounders associated with the 1, 2, 4, 8 and 16-volt selectors may be applied directly to the additive network comprising resistors 62, 63, 66, 70, 74, 78 and 82 of the receiver of Fig. 1. Since the digit grounders have outputs of either zero or one-half the designated voltages, depending upon whether the associated selectors are actuated, while selector 14 has an output of either zero or the designated voltage, means must be provided for reducing by one-half the signal applied to the additive network at the receiver by selector 14 at the transmitter. This may be accomplished in several ways. For example, a potentiometer or other attenuator may be used either at the transmitter or at the receiver to halve the signal in the channel controlled by coder 14.

As will be realized, the system as described above and shown in the drawings may be subjected to wide variations to fit it for use in different types of complex wave transmission systems. For example, it may be desirable to employ additional selectors and digit grounders to extend the total range of possible amplitude which may be transmitted by the system. In the system of the illustration, six selectors were utilized to provide a total range of zero to 63 volts, inclusive, in 1-volt steps. The addition of another selector responsive to 64 volts would increase the range so that a total range extending from zero to 127 volts, inclusive, in 1-volt steps, could be accommodated. The addition of further selectors will, of course, increase the range of amplitude accommodated. The addition of selectors at the transmitting station requires the provision of an equal number of transmission channels in the transmission link and also the addition of further direct-current amplifier-limiters and attenuators of appropriate value at the receiving station.

What is claimed is:

1. In a communication system for transmitting complex waves, a plurality of selectors, each responsive to a different fixed portion of the total possible magnitude of the wave to be transmitted, each of said selectors having zero output for inputs less than the portion of the total magnitude to which it is responsive, and an output equal to that portion for all other inputs, means for applying the wave to be transmitted to the selector responsive to the largest of said portions, and means for applying to each of the other selectors the difference between the instantaneous magnitude of the wave to be transmitted, and the output of the selector responsive to the next larger portion of said magnitude.

2. In a communication system for transmitting complex waves, a plurality of selective relays, each responsive to a different fixed portion of the total possible magnitude of the complex wave, each of said relays having zero output for inputs less than the portion of the total possible magnitude to which it is responsive and being capable of producing a difference in potential equal in magnitude to that portion for all other inputs, means for applying the wave to be transmitted to the relay responsive to the largest portion of the total possible magnitude, and means for applying to each of the other relays a potential equal to the magnitude of the wave to be transmitted less the magnitude of the potential difference at the output of the relay responsive to the next larger portion of the total possible magnitude.

3. In a communication system for transmitting complex waves, a plurality of repeaters, each responsive to a different fixed portion of the total possible magnitude of the complex wave, each of said repeaters having zero output for inputs less than the portion of the total possible magnitude to which it is responsive and being capable of producing a difference in potential equal in magnitude to that portion of the total possible magnitude for all other inputs, means for applying the wave to be transmitted to the repeater responsive to the largest fraction of the total possible magnitude, means for applying to each of the other repeaters a potential difference equal to the magnitude of the wave to be transmitted less the magnitude of the potential difference at the output of the repeater responsive to the next larger portion of the total possible magnitude, and means for converting the differences in potential at the outputs of said repeaters into potentials in respect to ground.

4. In a communication system for transmitting complex waves, a plurality of selectors, each responsive to a different portion of the total possible magnitude of the complex wave, each of said selectors having zero output for input voltages less than the portion of the total possible magnitude to which it is responsive and being capable of producing a potential in respect to ground equal in magnitude to that portion of the complex wave for all other inputs, means for applying the complex wave to be transmitted to the selector responsive to the largest portion of the total possible magnitude, means for applying to each of the other selectors, the difference between the magnitude of the wave to be transmitted and the output of the selector responsive to the next larger portion of the total, and means for transmitting the output potentials of the selectors to a remote station.

5. A communication system for transmitting complex waves, comprising a plurality of selectors, each responsive to a different fixed portion of the total possible magnitude of the complex wave, each of said selectors having zero output for inputs less than the magnitude of the portion of the total possible magnitude to which it is responsive and being capable of producing an output proportional to the magnitude of that portion for all other inputs, means for applying the complex wave to be transmitted to the selector responsive to the largest portion of the total possible magnitude, means for applying to each of the other selectors the difference between the wave to be transmitted and the output of the selector responsive to the next larger portion of the total, means responsive to the outputs of the individual selectors for producing equal potentials with respect to ground, means for transmitting these potentials to a receiving station, means thereat for converting said last-mentioned potentials into potentials proportional to the output of the selectors associated with each, and means for adding the potentials so derived together.

6. In a system for expressing the magnitude of a complex wave in terms of a plurality of fixed voltages related as powers of two each of which represents a different portion of the total possible amplitude of said complex wave, a plurality of selectors each controlling one of said fixed voltages and each being responsive only to input voltages at least as great as its output voltage, means for applying a complex wave to the selector responsive to the largest input voltage, and means for applying to each of the other selectors the voltage differences between the magnitude of the complex wave and the output of all selectors responsive to larger inputs.

7. In a system for generating binary code representations of the magnitude of a message wave, a group of selectors each responsive only to an input greater than its individual operating input, the operating inputs of said selectors being related in magnitude as powers of two, means for applying the message wave to the selector having the largest operating input, and means for applying to each of the other selectors an input signal equal to the magnitude of the message wave less the operating inputs of all operated selectors having larger operating inputs.

8. In a system for generating binary code representations of the magnitude of a complex wave, a group of selectors each responsive only to an input greater than a predetermined magnitude, the predetermined magnitudes of said selectors being related in magnitude as powers of two, means for applying the complex wave to the selector

responsive to the largest predetermined magnitude, other means for applying to another one of said other selectors an input signal equal to the magnitude of the complex wave less a function of the output of a selector responsive to the largest predetermined magnitude and means for producing output signals for the selectors.

9. In a system for generating binary code representations of the magnitude of a complex wave, a group of selectors each responding only to an input greater than its individual threshold, the thresholds of said selectors being related in magnitude as powers of two, means for applying the complex wave to the selector having the largest threshold, means for applying to each of the other selectors an input signal equal to the magnitude of the complex wave less the sum of the thresholds of all responding selectors having larger thresholds and means for producing output signals for the selectors.

10. In a system for generating binary code representations of the magnitude of a complex wave, a group of selectors each responsive only to an input greater than its individual threshold, the thresholds of said selectors being related in magnitude as powers of two, means for applying the complex wave to the selector having the largest threshold, means for applying to each of the other selectors an input signal equal to the magnitude of the complex wave less the sum of the thresholds of all responding selectors having larger thresholds, means for producing output signals for the selectors, and separate channels for transmitting said signals to a receiving station.

11. In a communication system for transmitting complex waves, a coder for generating binary code representations of the instantaneous amplitude of a complex wave to be transmitted, said coder comprising a plurality of selectors each controlling an output signal representative of a different fixed portion of the total possible amplitude of said complex wave, means for applying the complex wave to all of said selectors and means for applying in opposition to said wave to each of said selectors, excepting that controlling the signal representing the largest portion of said total possible amplitude, voltages proportional to the sum of the amplitude portions represented by the outputs of all selectors corresponding to larger portions of said total possible amplitude.

12. In a system for generating binary code representations of the magnitude of a complex wave, a group of selectors each responsive only to an input greater than its individual operating input, the operating inputs of said selectors being related in magnitude as powers of two, means for applying the complex wave to the selector having the largest operating input, means for applying to each of the other selectors an input signal equal to the magnitude of the complex wave less the sum of the operating inputs of operated selectors having larger operating inputs, means for producing output signals for the selectors which are operated, separate channels for transmitting said signals to a receiving station, means at the receiving station for converting the transmitted operating voltages into voltages proportional to the operating voltages of the selectors represented thereby, and means for adding the converted voltages together.

13. In a communication system for transmission of complex waves in which a signal is generated as a difference in potential between two ungrounded points, means for converting said difference in potential into a potential with respect to ground comprising a converter for transforming the potential at one of said points into a potential with respect to ground, a second converter for transforming the potential at the other of said points into a potential with respect to ground, means for inverting the output of the second converter and means for averaging the output of the first converter and the inverted output of the second converter.

14. In a communication system for transmission of complex waves in which a signal is generated as a difference in potential between two ungrounded points, means for converting said difference in potential into a potential with respect to ground comprising a pair of cathode follower tubes each having at least a cathode, an anode and a control element, the cathodes being grounded through load resistors and the anodes being connected to sources of positive potential, means for applying said difference in potential between said control elements, means for inverting the cathode potential of one of said cathode followers and means for averaging said inverted potential with the cathode potential of the other of said cathode followers.

15. In a communication system for transmitting complex waves, a plurality of signaling means each of which may have either of two output conditions one of which in each case represents a different component of the total possible amplitude range of said complex wave, means responsive to said wave for deriving therefrom a plurality of control quantities equal in number to said amplitude components and continuously indicative of the presence or absence of the corresponding components in the wave to be transmitted, and means for applying said quantities at all times to control the output conditions of the corresponding signaling means.

16. In a communication system for transmitting complex waves, a plurality of signaling means each of which may have either of two output conditions one of which in each case represents a different component of the total possible amplitude range of said complex wave, and the combinations of which represent all amplitudes in said total possible range in integral steps determined by the smallest component represented in any case, means responsive to said wave for deriving therefrom a plurality of control quantities continuously indicative of the presence or absence of the corresponding components in the wave to be transmitted, and means for applying said quantities at all times to control the output conditions of the corresponding signaling means.

17. In a communication system for transmitting complex waves, a plurality of signaling means each of which may have either of two output conditions one of which in each case represents a different component of the total possible amplitude range of said wave and the combinations of which represent all amplitudes in said range in integral steps determined by the smallest component represented in any case, and means for applying said wave to said signaling means to continuously control the output conditions of said signaling means in accordance with the presence or absence of the corresponding amplitude components in said wave.

18. In a communication system for transmitting complex waves, a plurality of selectors each responsive to a different fixed component of the total possible amplitude of the wave to be trans-

mitted, each of said selectors having zero output for inputs less than the component of the total amplitude to which it is responsive and the same fixed output for all other inputs, means for applying the wave to be transmitted to the selector responsive to the largest of said components, and means for applying said wave to each of the other selectors effectively subtracting from said wave quantities proportional to the components represented by each other selector which has responded to a larger component of said wave.

JOHN C. SCHELLENG.

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