PULSE POSITION MODULATION KEY SIGNALING SYSTEM

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Filed: May 19, 1945

Appl. No.: 592,966

FOREIGN PATENTS OR APPLICATIONS

551,282 2/1943 United Kingdom 179/15

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EXEMPLARY CLAIM

1. In a signaling system, a source of signal waves, a source of key waves, a transmission line or channel, means to allot periodic time intervals on said line to the transmission of signal indications thereover derived from said signals, means to produce signal indications for transmission and to encipher them comprising means to produce a pair of pulses of energy separated in time, and means to vary the absolute time positions of said pulses together under the conjoint control of said signal and key waves, one or the other of said two pulses always occurring within said time interval and the other always occurring outside said time interval, and means to transmit the former pulse over said line.

6 Claims, 6 Drawing Figures
PULSE POSITION MODULATION KEY SIGNALING SYSTEM

The present invention relates to electrical wave transmission for signaling purposes and more particularly to communication with privacy. A known form of telephone privacy first analyzes the speech message waves into low frequency component currents in a plurality of separate paths or channels and then enciphers each of these component currents by means of a secret key. At the receiver, duplicate keys are used to decipher the received currents in the various channels to recover the low frequency component currents and these currents are used to control the reconstitution of the speech message waves. The method of analysis and reconstruction is in accordance with the disclosure in U.S. Pat. to H. W. Dudley No. 2,151,091, granted Mar. 21, 1939. This type of transmission system as disclosed by Dudley has come to be known as the Vocoder.

In the known secrecy system referred to, each of the component low frequency currents, having a frequency range extending from zero to about 25 cycles per second, is translated into a current of stepped form and is enciphered by adding to it a key current also of stepped form, and the summation current is subjected to a reentry process, by which it is meant that whenever the summation current exceeds the maximum signal current, a fixed number of steps is subtracted such as always to bring the resultant current within the range of variation of the message current. To illustrate, if the total range of the message by itself is zero to five steps and the key also varies from zero to five steps, then whenever the summation message plus key current is six steps or greater, a reduction of six steps is made. Since the maximum value of the summation current is ten steps, the maximum value of the resultant current after reentry is four steps. The summation n currents, after reentry if such occurs, are transmitted. It has been demonstrated in connection with such prior known systems that if a key is used which has a fortuitous or random type of variation, the summation current of message plus key including the reentered resultant where it occurs, also varies in fortuitous or random manner so that it is impossible to recover the message from the line currents without knowledge of thay key. One instance of such prior or known system is to be found in patent application of R. C. Mathes Ser. No. 412,054, filed Sept. 24, 1941 and another instance is to be found in patent application of Lundstrom and Schimpf Ser. No. 456,322, filed Aug. 27, 1942, by way of example.

In accordance with a general feature of the present invention, the component low frequency currents in the several vocoder channels are combined with key currents as heretofore but are transmitted on a time division basis as displacements in time or phase of a channel pulse from its zero or normal position in time with respect to the limits of the time interval allotted to the particular channel. Applicant has devised a novel manner of modulating the time position of the channel pulse which accomplishes the reentry step as an incidental accompaniment to the modulation, with the consequent elimination of reentry circuits and with the addition of but a small amount of equipment in the modulating circuits.

The general object of the invention is to accomplish pulse position modulation in accordance with modulating signals in a novel and expeditious manner. A further object is to accomplish pulse position modulation in accordance with a modulating current representing the summation of a signal plus a key and effecting an accompanying reentry operation.

Further objects and features of the invention will appear more fully from the following detailed description of the illustrative embodiment shown in the accompanying drawings in which:

FIG. 1 is a schematic circuit diagram of a transmitting system according to the invention;
FIG. 2 is a diagram illustrating the principle made use of in effecting reentry operation;
FIG. 3 is a schematic circuit diagram of one form of receiving system according to the invention;
FIG. 4 is a similar diagram of an alternative form of receiving system according to the invention;
FIG. 5 is an explanatory diagram showing time relations involved in the operation of the system of FIG. 4; and
FIG. 6 is a timing chart showing the time relations of different voltages or currents used in the system.

The principle of operation made use of in effecting reentry is illustrated by the simple diagram of FIG. 2, to which reference is made. Two pulses are shown at P1 and P2 displaced from each other in time by the time interval allotted to one channel. Assuming that we are concerned with channel 1, when the signal is zero the pulse P1 is transmitted at the beginning of the channel time as indicated in the figure by the position of the pulse P1 at the left edge of the portion measured off by the dotted lines marking the boundary time for channel 1. If the signal had a value of step 1, both pulses would occupy positions one step to the right of the zero positions but since only pulse P1 occurs in the channel time allotted to channel 1, this is the only one of the two pulses to be transmitted due to the action of the channel gate. As signals of successively higher step value are applied, this has the effect of moving both pulses successively to the right in the figure. At step 5 pulse P1 occupies a time position just inside the right-hand margin of channel 1 time, while pulse P2 occupies position 5' just outside the left margin. On step 6 pulse P2 falls outside the channel time of channel 1 and is not transmitted but pulse P1 occupies position 6 within channel 1 and is transmitted. Thus the same pulse position is transmitted for impressed steps of 6, 7, 8, 9 and 10 as for impressed steps of 0, 1, 2, 3 and 4, respectively. This gives the same effect as subtracting six steps from the impressed modulating current for all step values in excess of five steps.

Referring to FIG. 1, speech currents from the transmitter 10 or other input line are applied to the speech analyzer 11 which may be of the type shown in the Dudley patent referred to and is provided with subdividing filters, rectifiers and the like for obtaining in this case eight low frequency speech-defining currents in the eight channels indicated. One of these channels is a fundamental pitch channel as in the Dudley disclosure for deriving a pitch-defining current, while the other seven channels are spectrum channels in which the low frequency waves are derived as respective indices of the energy content in a different respective frequency band of the total speech range. It will be understood that the number of vocoder channels used may differ in
practice, the number eight being chosen for illustration in this case. The maximum frequency component present in the low frequency speech-defining currents is about 25 cycles per second as already noted. In the present system these speech-defining currents are sampled fifty times per second by means of the steppers 12 of which one stepper is provided per channel. These steppers may be constructed in accordance with the disclosure of the Lundstrom and Schnipf application referred to, each comprising five gas-filled tubes with interrupted supply voltages for the grid and plate circuits such as to cause the five tubes to be excited simultaneously to the speech-defining current or signal once every 20 milliseconds. The grids of the five tubes in any one stepper are coupled to the common input circuit by means of potential dividing resistors or transformers so that the input signal voltage applied to each tube is made to vary in definite steps. This results in different numbers of tubes firing during an exposure period depending upon the strength of the input signal. For the weakest signal none of the tubes fire, while for the strongest signal all five tubes are excited. The output currents from the tubes are combined in additive manner to produce an output voltage in leads 13 varying in definite steps in dependence upon the strength of the input signal.

The timing of the steppers 12 is determined from a prime source of 50-cycle waves shown at 15. This may comprise, for example, a vacuum tube oscillator designed to have a highly constant frequency in a manner known in the art. An exciter 16 is driven from this 50-cycle source and in turn controls a cathode impulser 17 and a grid impulser 18. The cathode impulser supplies interrupted negative voltage between ground and the cathodes of the stepper tubes, the plates of these tubes being connected to ground through a common load coupling resistor in the case of each stepper. The exciter, cathode impulser and grid impulser are not disclosed in detail since these may be constructed in accordance with the detailed disclosure of the Lundstrom and Schimpf application referred to. In brief, the exciter 16 includes a pair of pentode tubes with different amounts of grid bias so that on the positive swing of the 50-cycle wave the first tube of the pair begins to transmit current before the second tube. The difference between the times when the two tubes begin to transmit current may be readily controlled by proportioning the grid biases. When the second tube begins to transmit current its plate current flows through a resistor in the grid circuit of the first tube cutting off the current flow in the first tube. In this way a pulse is transmitted through the first tube and the length of the pulse can be accurately determined. The pulse transmitted through the first tube is used to determine the length of voltage pulses produced by the cathode impulser 17 and the grid impulser 18 each of which may contain a regulated voltage supply including a voltage controlled interrupter such as a grid controlled tube. The circuits can be arranged so that the utilization voltage has a duration proportional to the exciter pulse or that the utilization voltage flows for all of the 20-millisecond period except for a time equal to the length of the exciter pulse. The polarity of the supply pulses may be either positive or negative. The exciter may contain more than one pair of tubes operating in the manner described with a phase shifter in the 50-cycle supply so that the second pair of tubes is brought into operation at a later time than the first pair. In short, by use of the devices broadly outlined, a great flexibility of control is provided such that pulses of any duration from a small fraction of a millisecond to approximately 20 milliseconds duration of either polarity and of any convenient amplitude may be generated by means of the elements 16, 17 and 18. The character of the pulses used can be readily seen by reference to FIG. 6. The plate voltage for the steppers 12 is shown at E, while the grid voltage is shown at e. From inspection of these two voltage curves, it is seen that the steppers 12 transmit pulses of approximately 20 milliseconds duration with interruption times of a fraction of a millisecond between pulses. The grids are held negative beyond the cut-off except that the voltage pulses e, are applied and during small times the grids are thrown in the positive direction a sufficient amount to permit the tubes of the steppers to fire provided a signal voltage equal to step 1 or greater value is present in the circuit. The grid pulses e, are applied immediately after the plate voltage of the steppers has been interrupted to allow the tubes to restore and has been reapplied.

Stepped key pulses are added to the stepped signal pulses in the output conductors 13 on the output side of the steppers 12. These key pulses are obtained from a second set of eight steppers shown at 19 which receive their grid and plate supplies from the same sources that supply the steppers 12. The key waves are obtained from a phonograph record 20 on which the eight key waves are recorded as modulations of different frequency carrier waves. The manner of generating the key waves themselves in order to secure random distribution of the amplitude values of the keys may be in accordance with the disclosure in the Newby-Vaughan application Ser. No. 456,556, filed Aug. 27, 1942. The different key channels are selected by means of the eight band filters 21 and are individually detected at 22 to obtain varying direct current signals which are applied to the steppers 19.

The combined message plus key pulses appearing in the leads 13 are each applied to a modulator circuit of the pulse position modulation type, one of these being indicated in detail at 25 and the others being similar. The modulator for channel 8 is shown by the box 26. Referring to the modulator 25, this consists of a pair of modulator elements in the form of inductance coils 29 and 31 which may each be of the type shown in L. R. Wrathall U.S. Pat. No. 2,117,752, May 17, 1938. Each coil includes a saturable core and the applied waves are of such amplitude as to sweep through and well beyond the unsaturated region of the coil into the saturation region on each reversal of the applied waves. In this way short, sharp pulses of output current are obtained as described more fully in the Wrathall application. The exciting current for producing the pulses in the two coils 29 and 31 is obtained from respective phases of a multiphase supply generally indicated by the rectangle 29. The phase of the exciting wave for coil 29 will for convenience be referred to as phase O, while that exciting the coil 31 will be referred to as phase 1. These differ in phase by 36°, there being ten phases in the multiphase supply circuit 30. A pair of pulses is, therefore, produced by the coils 29 and 31 every 20 milliseconds. When the 50-cycle exciting voltage swings upwardly across the zero voltage axis and these pulses are separated in time by 1/10 cycle or 2 milliseconds. (A second pair of pulses of opposite polarity are also produced a half cycle later but these are not used, being suppressed by an output gate circuit to be described.
If there is no applied signal voltage in the channels 13, the pair of pulses produced by the coils 29 and 31 appear as indicated in FIG. 2 immediately after the 50-cycle exciting wave crosses the zero axis in a positive direction. Signal voltages in the leads 13, however, which are all of the same polarity, supply bias currents to the windings of the coils 29 and 31 and result in different amounts of time delay in the occurrence of the pair of pulses, the amount of delay being directly proportional to the amplitude of the input current. As the input representing the signal plus the key varies in steps from zero to a total of ten steps, the pair of pulses is displaced in time also in ten steps, as indicated in the diagram in FIG. 2. The line CC of FIG. 6 shows the times at which the different phases in the output of the supply 30 cross the zero axis. The dotted line between phases 4 and 5 shows the point at which the zero phase wave crosses the axis in the negative direction and there would, of course, be a corresponding wave for each of the other phases. The ten-phase source 30 comprises a circuit resembling the Scott transformer circuit consisting of a first transformer 32 having a multiwinding secondary and a second transformer 33 also having a multiwinding secondary. A two-phase 50-cycle current is supplied to the primaries of these transformers with the aid of a 90° shifter 34. The secondaries of the two transformers are connected in pairs to output transformers one of which is shown at 35 comprising a primary winding and a pair of secondary windings. By properly connecting the secondaries of the transformers 32 and 33 are proportioning the number of turns, five different phases equally rotated with respect to the prime source are obtained in the five transformers of which one is shown at 35. Each of the transformers 35 has one of its secondary windings connected with respect to the other so that in this way ten phases are derived and connected, respectively, to ten output terminals. The reason for providing ten phases instead of only eight is to provide two extra channel times corresponding to phases 9 and 0 which are not used for the transmission signals but are used to handle auxiliary switching problems.

In order to allow only that one of the two pulses $P_1$ or $P_2$ of FIG. 2 to be used that falls within the channel interval of channel 1, the gating tube 40 is provided in the uppermost channel following the modulator 25 and a similar gate is provided in each of the other channels for a similar purpose. The gate 40 is shown as comprising a pentode tube having its space grid 41 connected to the point 42 at the plate circuit of a single trip multivibrator output tube 43, the normal voltage of point 42 being too low to permit the tube 41 to transmit current except during the time interval corresponding to channel 1. The cathode of gate tube 40 receives a more or less steady positive bias from condenser-resistance combination 14, sufficient to block transmission when the grid 41 has its minimum voltage from point 42. Phase 1 of multiplex source 30 is connected to an amplitude limiter tube 45 and thence through a differentiating circuit 46 to the control grid of the input stage 47 of the single trip multivibrator. This multivibrator operates in the usual manner to maintain maximum current flow through tube 43 while tube 47 is cut off except when the high amplitude short input pulse is received from the differentiating circuit 46. This pulse is produced by the leading edge of the phase 1 current. This throws the control grid potential of tube 47 so far positive as to overcome the negative bias obtained from the cathode resistor 48 and to allow tube 47 to transmit maximum current. The voltage transferred from the screen grid 49 through coupling condenser 50 to the control grid 51 of output stage 43 cuts off space current flow through tube 43, sending the potential of point 42 highly positive. This conditions the gating tube 40 for transmission so that this tube will pass on to the output circuit whatever pulse voltage is applied to the input circuit of the tube. The duration of the positive pulse on the screen grid 41 is determined by the time constant of the multivibrator circuit including capacitor 50 and associated resistors. This adjustment is to be just slightly less than 2 milliseconds to insure that the gate 40 is closed just slightly before the end of the full 2-millisecond period corresponding to phase 1. The other gates 40 are controlled in similar manner from phases 2 to 8, inclusive, to permit passage into the common output line 53 of one only of the two pulses produced in each respective channel by its modulator. A bias battery can be inserted in the lead from point 42 to grid 41 to aid in properly controlling gate 40 if found desirable in any case. The operate times of the various gates are indicated in FIG. 6 by the graphs $T_{G1}$, $T_{G2}$ and $T_{G3}$ for channels 1, 2 and 8, respectively.

In this way, as more fully described above in connection with FIG. 6, the reentry operation is automatically accomplished since no pulse in any channel is allowed to be transmitted to the common lines 53 which has any step value greater than five steps, step values in excess of five steps being automatically translated to step values from zero to four. The pulses transmitted through the gates 40 are spread out in time over the channel times 1 to 8, inclusive, and they may be transmitted directly over the line or channel 53 to the distant receiving station or they may be used to modulate a radio or carrier wave as desired. The total frequency band required to transmit these pulses in practice be greater than the order of 2,500 to 3,000 cycles wide.

Referring to FIG. 3, the incoming line or channel from station 1 leads first to eight amplifiers 60 each of which has its output connected to a circuit 61 for converting from pulse position modulation to pulse length modulation. Each of these circuits 61 also operates as a gate and each has applied to it a gating pulse corresponding to a different one of the eight channel times. The time of the currents and duration of these pulses are indicated by RG and channel subscript in FIG. 6, all receiver times in FIG. 6 being referred to the phases at the top of the figure as generated at the receiver.

Referring to the converter circuit 61 for channel 1, this is similar to a multivibrator circuit in that it comprises initial stage 62 and output stage 63 of which stage 63 normally transmits saturation current and due to the drop in potential across common cathode resistor 64 holds the tube 62 cut off. The negative voltage on the control grid of tube 62 obtained from the drop of potential across resistor 64 is sufficiently great to prevent recovery of signal pulses from the line from causing tube 62 to transmit current. This negative grid voltage may be supplemented where necessary by battery 59 in lead 65. In order to permit tube 62 to transmit current it is necessary to apply to it a gating pulse over conductor 65 and, in addition, a received line pulse, the gating pulse 65 merely reducing the negative grid bias sufficiently to permit the received line pulse to render the tube conducting. The gating pulses are derived from a prime source 15' which is a duplicate of the 50-cycle generator 15 and generates standard frequency
50-current in close synchronism therewith. This leads to a ten-phase source 30' which is a duplicate of source 30. Each of phases 1 to 8 leads to an amplitude limiter 45' and single trip multivibrator similar to those shown in FIG. 1 for producing a gating pulse which exactly coincides in time with the channel times of the various received channels. These gating pulses, therefore, "open" the gates of the various channels in succession to admit the channel pulses to the converters 61.

When a pulse is received on the control grid of initial stage 62, the converter current flows in the plate circuit of tube 62 immediately cutting off the normal current flow through tube 63 and applying a positive voltage to the integrating circuit comprising series resistor 66 and shunt condenser 67. This condition of the two tubes 62 and 63 is maintained until the end of the channel or gating pulse at which time the current in the tube 62 is cut off by the cessation of the gating pulse. The effect of this is to produce output pulses of varying length, the length depending upon the time of occurrence of the input pulse. The charging of the condenser 67 continues during the time of the current flow through tube 62, that is, during the time when the plate voltage of tube 63 is maximum, and the condenser has its highest charge at the end of the gating time. The voltage across the condenser 67 at the end of the gating period gives, therefore, a measure of the signal amplitude in the respective channel. Although an inverse relation exists between this voltage and the displacement which the pulse received in time from its zero position at the transmitter, this still permits the signal to be properly received. The charge on condenser 67 is impressed on the grid of coupling tube 69 which is a cathode follower tube for coupling the condenser 67 to the input of the stepper 70, there being one of these steppers per channel. Negative battery 68 is connected through a suitably high resistance to the plate of tube 63 to annul the initial voltage that might otherwise place a charge on condenser 67 before the channel pulse in tube 62 begins.

In order that the stepper 70 shall respond only to the maximum value of the voltage across condenser 67 the exposure times of these steppers are controlled by a series of grid waves $e'_1$ to $e'_9$ derived from exciter and grid impulse circuits 71 which are, in turn, driven from respective phases of the ten-phase source 30'. The time relation between the voltages $e'_1$ to $e'_9$ and the gating pulses may be seen from FIG. 6 where three of these exposure voltages are indicated for channels 1, 2 and 8 and where the gating pulses for channels 1 and 8 are indicated at RG1 and RG8. The plate voltage pulses for the steppers 70 are of about 20 milliseconds duration and come on as indicated at El of FIG. 6 just before phase O. These steppers 70 are, therefore, prepared so far as their plate supply is concerned for operation just prior to the opening of channel 1 gate and are kept in this condition until after all eight gates have been opened. The steppers, however, operate in succession as determined by the timing of the $e'_n$ pulses as already indicated. This results in the flow of different lengths of pulses in the output conductors C1 to C8, the longest of these pulses being about 16 milliseconds as shown at C1 of FIG. 6, the shortest duration being about 2 milliseconds as shown at C8 of FIG. 6. These pulses are negative in sign since they are derived from the plates of the stepper tubes, which are connected to ground through a load coupling resistor, as disclosed in the Lundstrom-Schimpf application.

The plate voltage $E_l$ is obtained from the cathode impulse 72 which is controlled, in turn, from exciter 73 fed from 50-cycle voltage from source 15'. These elements and the exciters and grid impulses 71 for the respective channels may be constructed similarly to the corresponding elements 16, 17 and 18 of FIG. 1 as above described. A triode 75, normally biased beyond cut-off, has its plate circuit shunted across condenser 67 and has its grid connected to a pulse producing circuit comprising elements 76 and 77 connected to phase 2 of the source 30' in such a way as to drive the grid positive during all or part of channel time 2. The effect of this is to place a low impedance discharge circuit across condenser 67 to discharge this condenser in readiness for use when the next pulse is received in channel 1. Similarly, the condenser 67 of each of the other channels is discharged in a triode in the next or some subsequent channel time, tube 78 being indicated for channel 8 and being rendered conductive during channel time 9.

As a result of the application of pulses of different amplitude to the grid circuits of the steppers 70 plate or output currents of stepped amplitude representing the received enciphered signals (inverted) appear in the output branches C1 to C8. (In FIG. 6 these pulses are for convenience indicated as having the same amplitude but they would, of course, vary in amplitude in steps over the total range zero to five steps.) Since the low frequency speech-defining currents or vocoder channel currents were sampled in FIG. 1 by the steppers 12 simultaneously in all eight channels, it is desirable to avoid phase distortion to reproduce all of these currents at the receiver at the same time. By comparison of the graphs C1 and C8 of FIG. 6 it will be noted that all eight channels have signals stored in them and that these signals exist simultaneously throughout the major portion of phase 9 so that sampling the currents existing in the circuits C1 to C8 during phase 9 the simultaneous reproduction of all of the signals can be effected. This is done by use of the gating tubes 80. The control grid of each gating tube 80 is connected to the corresponding output conductor C1 and is also connected to the output of corresponding stepper 81 in the key producing circuit since that is the point of the circuit at which the receiving key currents are introduced. These gating tubes are held beyond cutoff, however, by a large negative voltage supplied to their screen grids obtained over conductor 82 from a suitable bias voltage, such as the battery 83. This voltage is, however, arranged to be overcome in phase 9 by the application to the common lead 82 of positive voltage from the single trip multivibrator circuit 85 energized from phase 9 of the source 30'. All gating tubes 80 are, therefore, rendered conductive during phase 9. The steppers 81 are applying key currents during phase 9 to the gating tubes 80 because of the fact their plate voltage $E_l$ is on at (and prior to) the beginning of phase 9 and remains on until near the end of phase 9, while their grids receive an exposure pulse $e'_n$ prior to phase 0 over conductor 87 from the grid impulse 88. The key steppers 81, therefore, send pulses of about 2 milliseconds duration to the control grids of gating tubes 80 and these pulses occur simultaneously with the pulse existing in channel 8 (C8). It will be understood that the key pulses are obtained in the same manner as in FIG. 1 from a record 20' which is an exact duplicate of the record 20 for enabling duplicate key currents to be supplied at the receiver. The key impulses are put into the system.
at the receiver in the same sign as those of the transmitter but the message plus key pulses are reversed in sign at the outputs of the steppers 70 as already noted. This is the effect, therefore, of subtracting the key from the message plus key and yielding the message currents without the key. The message currents are, therefore, recovered at the outputs of the gating tubes 80 except as reentry may be necessary to reverse the process of reentry which took place at the transmitter.

The reentry circuits are shown at 90. Each reentry circuit comprises two parallel paths from its input to its output, one of these paths leading through merely the resistor 91 to junction point 96 while the other path leads through a phase reversing amplifier 92 and a pair of vacuum tubes in tandem shown at 93 which operate as a multivibrator circuit in that the second stage tube is normally transmitting current while the first stage tube is not. When reentry is to occur the situation is reversed in the two tubes causing a positive voltage of always the same increment over value to be applied to the plate circuit of the second stage tube through the resistance network 95 to the point 96 to augment the voltage directly transmitted to the same point through the path containing resistance 91. The battery 97 may be used to balance out in the resistance network 95 residual voltage which is applied to point 96 in the non-reentry case.

The cathode voltage of tube 69 is always positive toward ground and varies in steps, step 0 corresponding to the greatest value and step 5 to the smallest. The output voltage from steppers 70 is negative, as already noted, and is also at its greatest numerical value for step 0 and at its smallest numerical value for step 5. The key output from steppers 81 is also negative and adds to the negative output from steppers 70. The combined received pulses and key pulses put on to the control grids of gates tubes 80 have a total range of variation of ten steps and can be represented by a negative constant, \(-Q\), plus the received step value minus the key value, or denoting these latter by S and K, respectively, the voltage at this point is

\[-Q + S + K\]

when there is no reentry (M being the true message value) and \(S = M + K - R\) where reentry has occurred (R being the reentry value). For these two cases, we have

\[-Q + M + K - K\]

and

\[-Q + M + K - R - K,\]

respectively. In the first or no-reentry case the message M is recovered as \(-Q + M\) from which the constant, \(-Q\), can be eliminated as presently indicated. For the reentry case, however, it is necessary to add steps equal to R in order to recover the signal.

Since R is equal to size steps and the maximum number of steps which either M or S can have is five steps, \(M - R\) considered by itself can be negative in value only when reentry has occurred at the transmitter, for the minimum value which M alone can have is zero. When this is translated into the inverted polarity steps that are applied to the control grid of gate 80, it means that reentry is to occur only when the step value existing at this point (all steps negative at this point) is in the range, step 6 to step 10. These latter are the steps which produce least voltage on the cathode of gate tube 80.

The voltage applied from the cathode of gate 80 to the reentry circuit is always positive and can be represented as \(Q' + M\) or as \(Q' + M - R\), depending upon whether reentry has not occurred or has occurred. These voltages are directly transmitted to point 96 in the reentry output as already noted. When these positive voltages are applied to the grid of phase reversing tube 92 they cause opposite polarity voltage variations in the plate circuit which are impressed on the grid 94 of the initial stage of the multivibrator 93. For received voltage values in the higher range (\(Q' + M\)) the voltages on the grid 94 are insufficiently positive to allow tube 93 to become conducting but lower values of voltage (corresponding to \(Q' + M - R\)) drive the grid 94 sufficiently positive to operate circuit 93 to its normal state in which the output tube is cut off and a voltage +R is applied to the output circuit at point 96, giving at this point a voltage \(Q' + M\) in place of the value \(Q' + M - R\). There is, therefore, a critical voltage range between the minimum value of \(Q + M\) and the maximum value of \(Q' + M - R\), amounting to at least one full step value, within which the bias existing on grid 94 must be set so that applied voltage corresponding to one of these two voltages fails to cause tube 93 to conduct while that corresponding to the other value causes full conduction. The constant value \(Q'\) can be eliminated by use of an opposing voltage source of suitable size shown as battery 97. At the inputs of the steppers 99, therefore, the message values have been fully recovered and are of proper sign to operate the steppers.

The output steppers 99 receive short pulses from the output side of the reentry circuits 90 of slightly less than 2 milliseconds duration occurring in channel time 9. It is desirable in the interest of receiving strong signals to lengthen these pulses out to substantially the full 2 milliseconds time duration corresponding to the time elapsing between sampling periods at the transmitter. These steppers are, therefore, provided, although they could, of course, be omitted, if desired. They are supplied with plate voltage \(E_p\) from the exciter and plate impulse 100, this voltage lasting for 20 milliseconds and coming on just before the beginning of channel time 9. The grid exposures for these steppers are governed by application to the grids of the voltage \(e_p\). The 20-millisecond pulses occurring in the output sides of the steppers 99 are applied through low-pass filters 101 to the respective input channels of the speech synthesizer 102 which may be constructed in accordance with the disclosure of the Dudley patent referred to. As fully explained in that patent, local sources of waves simulating voiced and unvoiced speech sounds are provided and are controlled in accordance with the restored low frequency speech-defining waves transmitted through the low-pass filters 101 in such a way as to reconstruct the original speech message for transmission over the receiving telephone line or into the receiver instrument 103.

Referring to the alternative type of receiver circuit shown in FIG. 4, this differs from the FIG. 3 type of receiver principally in the way in which the receiving key is applied and in which reentry is performed. As the signals come in from the line or channel they are allowed to pass through the appropriate gates 110 of which there are eight, one gate per channel. These gates may be similar to the gates 80 of FIG. 3 but in this case they are individually controlled from the output terminals of eight single trip multivibrators 111 connected to phases I to 8 of the supply 30'. Each gate is opened, therefore, for the duration of one channel time.
When the channel pulse is received through gate 110 it encounters two paths, one being the conductor 112 and series resistor 113 leading to junction point 114 and the other including the delay multivibrator 115, differentiating circuit 116 and series resistor 117 leading to junction point 114. The delay multivibrator 115 may be similar to the single trip multivibrators previously described and it produces a rectangular current pulse of exactly one channel duration. The leading edge of this current pulse generates in the differentiating circuit 116 a negative current which is shunted off through the diode 120 and is prevented from appearing at point 114. The trailing edge of the rectangular pulse generates a positive pulse similar to the received channel pulse but delayed by precisely one channel time. Referring to the diagram, FIG. 5, the received channel pulse is indicated at b assumed to be in channel 1, and this pulse as it appears at point 114 is shown at c and again as the first of the two pulses in line d, the second of these two pulses being the delayed pulse produced in the output of the delay multivibrator 115. Both of these pulses are applied to the input of the pulse-position-to-pulse-length converter 112. The receiving key is also introduced into these converters 122 after the key has been translated into a variable delayed pulse, in a manner now to be described.

The key is derived from record 20' and is translated into direct current pulses of varying amplitude in the output of steppers 81 in the same manner as in FIG. 3. These pulses are then applied to delay multivibrator circuits 126 along with pulses derived from the multivibrators 111 of the multiphase source. Considering the key channel 1 apparatus, the leading edge of the rectangular pulse of current from element 111 of phase 1 is differentiated in the circuit 124 so that a sharp positive pulse is applied to the grid of the initial stage 125 of the two-stage circuit 126. This tube is normally without current since the second stage 127 is normally passing maximum current through the common cathode resistor 128. If it were not for the voltage impressed over lead 130 from the stepper 81, this circuit 126 would immediately interrupt current through tube 127 and send a current pulse into the single trip multivibrator 135 through phase reversing tube 132. Lead 130, however, applies varying amounts of negative bias voltage to the grid of tube 127 depending upon the key value at the moment and it requires a proportionately longer time for enough negative voltage to be transferred through the condenser 131 to cut off current flow in tube 127. This has the effect of delaying the output pulse for a definite number of steps after the start of the channel time, corresponding to the step value of the key. This delayed pulse is sent into the multivibrator 135 which produces an output current of rectangular wave form and of precisely one channel time duration. The delayed key pulse (arbitrarily chosen for illustration) is shown in line f of FIG. 4. The pulse from circuit 111 marking the beginning of the channel time is shown in line e and the long pulse of channel width produced by circuit 135 is shown in line g. These long pulses are used to gate the pulse-position to pulse-length converter 122 in the same way that the similar converters 61 of FIG. 3 are gated. That is, zero or nearly zero output current is normally present in the output leading through resistor 66 to condenser 67 since the second stage tube is normally passing maximum steady current. The first stage tube is biased so far negative by flow of this current through the common cathode resis-
amplitude in steps and representing the signal component currents into which the original speech message was analyzed. The phase reversing tubes 145 are inserted between the output sideof steppe 136 and the input side of steppe 144 since the stepper outputs are assumed to consist of negative pulses whereas positive pulses must be applied to their grids.

From the output sides of the steppe 144 the remainder of the system is the same as in FIG. 3, the construction and operation except for the step of reversing the signals. As previously noted, the signals appear at the input of steppe 136 as the inverse of the original signal since the condenser 67 receives a larger voltage for a step O signal than for a step S signal. The message M is, therefore, recovered at this point as a voltage equal to \( C' - M \) where \( C' \) is some constant. The pulses in the output of steppe 144 are negative in form and equal to \(-C' + M\) so that the desired message \( M \) is recovered, by putting in a fixed positive voltage at 146 to annul \(-C'\). On account of the interruption time of the space current in steppe 144 short spikes of current flow for the order of a fraction of a millisecond between message pulses. When these pass through the low-pass filters 101 they are integrated into a small average direct current which can be annulled by use of a suitably chosen counter-voltage. This can comprise a separate source or can be effectively introduced by changing by a small amount the voltage of source 146 from the value that is required to annul the constant voltage \(-C'\). For example, source 146 is given a slightly smaller value as can be determined by trial in any case.

It will be noted from the description that FIG. 4 dispenses with reentry circuits, the reentry being accomplished by developing two signal pulses spaced apart in time by one channel width and variably gating these pulses under control of the key in such a way as to subtract (numerically) the key from the enciphered signal directly when reentry does not occur but to subtract the key from a quantity six steps larger than the received enciphered and reentered signal.

The invention is not to be construed as limited to the specific details disclosed nor to numerical or other quantities given, which are to be regarded as by way of example, rather than as limiting. The scope of the invention is defined in the claims, which follow.

What is claimed is:

1. In a signaling system, a source of signal waves, a source of key waves, a transmission line or channel, means to allot periodic time intervals on said line to the transmission of signal indications thereover derived from said signals, means to produce signal indications for transmission and to encipher them comprising means to produce a pair of pulses of energy separated in time, and means to vary the absolute time positions of said pulses together under the conjoint control of said signal and key waves, one or the other of said two pulses always occurring within said time interval and the other always occurring outside said time interval, and means to transmit the former pulse over said line.

2. In secret signaling, the method of effecting reentry in a pulse position modulating system comprising producing a plurality of pulses to be modulated, simultaneously modulating the time position of each of said pulses relative to a channel time in accordance with both a message component and a key component in additive sense, the maximum value of the summation of said message and key components being sufficient to shift a plurality of said pulses completely across the time allotted to one channel, and utilizing for transmission only that one of said pulses which when so modulated falls within said allotted time.

3. In a secret signaling system, a combination pulse position modulator and reentry circuit comprising means to produce simultaneously a plurality of pulses differing from one another in time of occurrence by the time interval corresponding to one channel, means to simultaneously modulate in the same sense the pulse position of each of said pulses relative to a channel time in accordance with both a message component and a key component in additive sense, the maximum value of the summation of said message and key components being sufficient to shift a plurality of said pulses completely across said channel time, a line, a gate located between said modulating means and said line for allowing pulses to pass from said modulating means to said line, and means to time the operation of said gate to permit only pulses occurring within said channel time to pass into said line.

4. In combination in a pulse position modulation system, a pair of pulse position modulator units, means to supply a current variation to each unit at periodic times to cause the production of a series of output pulses from each unit, means causing the current variations supplied to one unit to lag behind those supplied to the other unit by a time equal to one channel period, means to supply to both units simultaneously a signal current and a key current in additive sense for varying the time of occurrence of said pulses relative to a channel time, said signal and key currents together when at their maxima simultaneously, shifting the time of occurrence of said pulses by an amount greater than, and approaching twice, the period of said channel, a transmission line, and means inserted between said modulator units and line for allowing only pulses occurring within said channel period to pass into said line.

5. In a multiple pulse position modulation system, a plurality of input signal circuits, a plurality of pulse position modulators for supplying modulated pulses in respective time division channels, a line for transmitting the time position modulated pulses from said modulators, each pulse position modulator comprising a saturable core inductance, means to supply alternating current waves of the same frequency but differing phase to said inductances, of sufficient amplitude to drive said inductances entirely through their unsaturated range while said waves are passing through only a small fraction of their total oscillation and are in the vicinity of zero amplitude whereby very short sharp pulses are generated in said inductances twice per cycle of said waves, said waves differing from one another in phase by an amount corresponding to the time period of one channel, means to apply signal currents to the respective modulator inductances to vary, in the case of each modulator, the time of occurrence of said generated pulses as a function of a signal amplitude, a gate inserted between each modulator, and said line and timing means for varying the transmission characteristics of each gate to permit a pulse to pass into said line from a respective modulator only within the channel time allotted to the respective modulator.

6. In secret signaling by pulse position modulated waves in which the pulse position is modulated in accordance with summation signal and key currents and reentered, the method of receiving, deciphering and reentering to recover the signal comprising receiving...
the modulated pulse, producing therefrom a second pulse occurring exactly one channel period later than the received pulse, deriving a duplicate key current at the receiver, producing a pulse, position-modulating said last pulse in accordance with said duplicate key, and deriving as the recovered signal a measure of the difference in time of occurrence between said last pulse and said second pulse.

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