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TELEPHONIC PULSE-CODE-MODULATION SYSTEM

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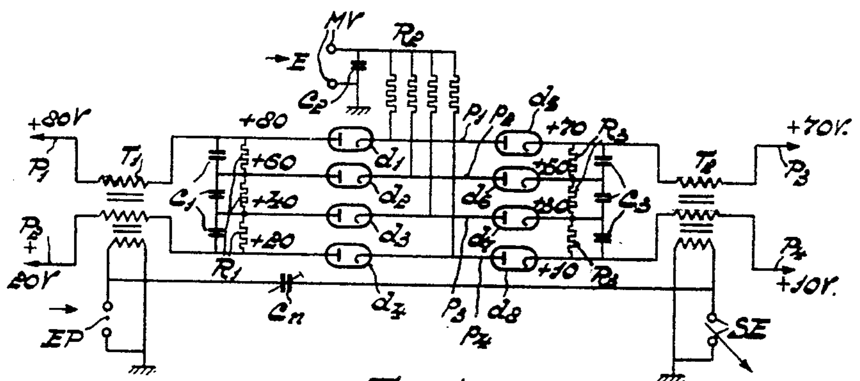

Fig. 1

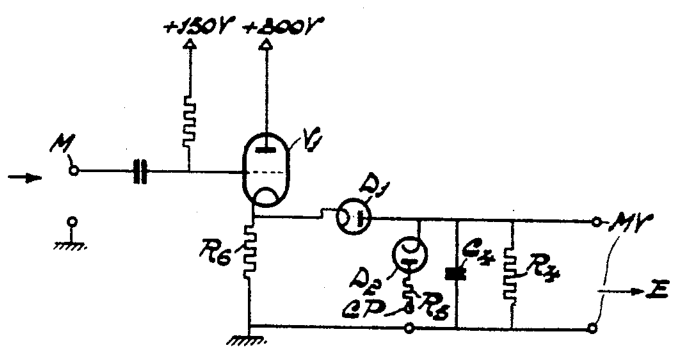

Fig. 2

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TELEPHONIC PULSE-CODE-MODULATION SYSTEM

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This invention relates to telephonic pulse-code-modulation systems and more particularly to improvements in encoding devices therefore.

In such a system the instantaneous value of an audiofrequency phenomenon (hereinafter referred to, by way of example, as the "speech voltage") at the sending station is sampled at regularly recurrent intervals and is expressed in terms of a code combination of signal elements such as marks and spaces. The combination is decoded at the receiving station and is used for reconstructing an approximate reproduction of the original speech voltage. If each code combination consists of n units the number of different combinations is 2^n. The value of the speech voltage, on the other hand, varies continuously from 0 to, say, 80 v., so that it has in theory an infinite number of possible values and can be only approximately represented by the values, finite in number, denoted by the code. Nevertheless it is found that, with quite a small number of units per combination, a sufficiently undistorted reproduction can be obtained. The system has the advantage that, since the decoder has merely to determine presence or absence of a signal, the signal to noise ratio can be made high and perfect signals can be regenerated by repeaters.

Moreover, since a very brief period (say 1.5/μs.) suffices for each signal element, a large number of speech channels can be multiplexed on a time-division or distributor basis with a single carrier frequency. An ultra-high frequency carrier is preferably employed.

The code may be simply a binary system of numeration. Thus, in what may be called the "straight code," if a mark is denoted by 1 and a space by 0, the first unit 1 or 0 in a three-element-combination stands for the value 4 or 0, as the case may be, the second for 2 or 0 and the third for 1 or 0.

With a three-element code seven different instantaneous values of the voice-voltage can be signalled, in addition to zero. By way of example the present description will be restricted to systems in which such three-element combinations are used, but it will be obvious that by increase in the number of elements per combination any desired degree of approximation to a continuous series of voice-voltage can be obtained.

In the following description and claims the expression "element period" will denote the time allocated to one element (mark or space) in a code combination, and the expression "combination period" will denote the time allocated to one complete combination of such elements. Thus in

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the systems hereinafter more particularly described, by way of example, a combination period will be three times as long as an element period.

The present invention relates more particularly to improvements in the means for encoding the signals. Suitable transmission and multiplexing equipment and other components in a pulse-code-modulation system will be known to those skilled in the art, and have been described in the Bell System Technical Journal for July 1947 (page 395) and for January 1948 (pages 1, 44) and elsewhere.

In a known encoding device for impulse-code-modulation telephony a cathode-ray tube provided with a coded stencil plate is employed. Such a device is of value when combination signals containing relatively large numbers of signal elements are used, so that the instantaneous values of the speech voltage can be finely graded into a relatively large number of steps; for instance when the combinations each comprise 7 elements so that 128 steps are provided for. For many purposes, however, such as military and police signalling, a much coarser—for instance an 8-step or 16-step—grading is adequate, and 3-element or 4-element combinations will accordingly give a sufficient degree of fidelity. In such cases an economy can be effected by discarding the cathode-ray tube and employing a circuit composed of rectifiers and other passive components, and one object of the invention is to provide an encoding device of this kind.

One feature of the invention accordingly comprises an encoding device for a pulse-code-modulation system wherein the characters of all code elements in each combination are determined by a control voltage whose initial value corresponds to the instantaneous value of the speech voltage or other audio-frequency phenomenon to be signalled, while its subsequent value decays during the combination period.

Briefly stated, a pulse-code-modulation system in accordance with a preferred embodiment of the invention is constituted by a sampling device and an encoding device.

The audio signal to be coded is fed to the sampling device which is arranged to derive therefrom periodically a control pulse whose initial value is a function of the instantaneous value of the signal, the control pulse thereafter decaying at a predetermined rate. Thus the resultant sawtooth shape of the control pulse is determined by the instantaneous value of the signal being sampled, the height of the leading edge of the pulse being a function of the instantaneous value of the signal, and the trailing edge having a fixed slope depending on said predetermined rate of decay.

The control pulse produced by the sampling device is then fed to the encoding device which contains a plurality of paralleled unidirectional paths, each of which includes two serially connected rectifiers. The paths have common input and output circuits, periodic code element pulses being supplied to the common input circuit at a rate determined by the number of elements in the code combination. Thus if three elements constitute the code combination, for each sampling control pulse, three element pulses are applied to the input circuit.

The control pulse is imposed on the parallel paths and determines whether or not any paths will be rendered conductive when an element pulse is supplied thereto, and in that sense, the control pulse preconditions said paths for conduction. The presence or absence of conductive paths determines whether a mark or a space is developed in the output circuit of the encoding device when an element pulse is fed therethrough. In this fashion, each instantaneous value of the signal is converted by the sampling device into a control pulse having a wave shape representative of said value, which control pulse, in turn, by its form determines the code combination produced by the encoding device.

In order that the nature of the invention may be better understood certain embodiments thereof will now be described with reference to the accompanying drawing, in which:

Figure 1 shows diagrammatically an encoding device in accordance with the invention.

Figure 2 shows a circuit for modifying input signals for use in the device shown in Figure 1.

The speech or modulation voltage is applied at the input terminals M, Figure 2, of a circuit, to be described later, which is controlled by synchronising or channel-timing pulses so that it samples the instantaneous value of the speech voltage once at the beginning of each combination period. Moreover, the circuit is such that its output voltage E, beginning at a level proportional to the value of the sample, falls off exponentially during the combination period. In the example here described, each combination is to comprise three code elements and the rate at which E decays is arranged to be such that the voltage E is halved during the time allocated to one element.

The output pulse voltage E yielded at the output terminals MV of the sampling circuit shown in Fig. 2 is applied as a control pulse to the similarly labelled input terminals MV of the encoding system shown in Fig. 1, which encoding system yields a code combination depending on the form of the applied control pulse.

It is assumed, for the sake of example, that the voltage E ranges from 0 to 80 volts. Then its instantaneous values at the instant of sampling can be classified in eight steps, numbered from 7 to 0 in column A in the table, the first step comprising all those values which lie between 80 and 70 volts, the second step all those between 70 and 60 volts, and so on, as shown in column B of the table. The value of E at the arrival of the first of the synchronizing pulses by which the emission of the three code elements is timed (hereinafter called "element pulses") will lie in one or other of the steps shown in column B. As a result of the exponential decay, however, the value of E will have fallen by one half by the time that the second element pulse arrives. The resulting values are shown in column C, so that any sample value which initially lay between 80 and 60, for instance, will lie between 40 and 30 at the instant when the second element is determined. At the arrival of the third element pulse, E will again have been halved and will lie between 20 and 15; it will therefore fall into the upper (20–10) of the two groups shown in column D.

TABLE

Encoding (Figure 2)

Step	Value of modulating voltage E at instant of			Code elements			Code combination
	1st element pulse	2d element pulse	3d element pulse	1st	2d	3d	
7	80–70	40–30		1	1		111
6	70–60		20–10	0		1	011
5	60–50	30–20		1	0		101
4	50–40			0			001
3	40–30	20–10		1	1		110
2	30–20		10–0	0		0	010
1	20–10	10–0		1	0		100
0	10–0			0			000
A	B	C	D	E	F	G	H

Now the circuit shown in Figure 1 is so arranged that if, at the instant when a synchronising or element pulse arrives at terminals EP, the value of E at terminals MV lies between 80 and 70, or 60 and 50, or 40 and 30, or 20 and 10, a mark (herein denoted by 1) is sent on through the signal-element terminals SE; but if the voltage E lies between 70 and 60, 50 and 40, 30 and 20, or 10 and 0, a space (denoted by 0) is sent on. As a result that first, second and third elements in the combinations representing the grades shown in column A will be those denoted by 1 for a mark and 0 for a space in columns E, F and G respectively, and the combination itself will be as shown in column H. These results are achieved as follows:

Steady D. C. voltages are applied to the terminals P_1, P_2, P_3 and P_4 so as to raise them to respective potentials of 80, 20, 70 and 10 above earth. Three equal resistors R_1, shunted by capacitors C_1, are connected between terminals P_1 and P_2 so that potentials above earth of 80, 60, 40 and 20 volts respectively are applied to the anodes of the four diodes d_1–d_4. Similarly resistors R_3, shunted by capacitors C_3, are so arranged that potentials above earth of 70, 50, 30 and 10 volts respectively are applied to the cathodes of the second set of diodes d_5 to d_8. If now the instantaneous voltage E at terminals MV lies between 80 and 70 the diodes d_1 and d_5 will both be unblocked so that a very brief impulse with a peak of one or two volts, induced in the two parallel secondary coils of transformer T_1 by a synchronising or element pulse applied at terminals EP, can travel over the path P_1 to transformer T_2, where it induces a marking impulse which goes out through terminals SE to a trigger regenerator and controls the emission of a marking signal element.

On the other hand, when the voltage E lies between 70 and 60 no effective path is available for a pulse from a transformer T_1 to transformer T_2. If, therefore, such a value of E obtains at the instant when an element pulse reaches terminals EP, no impulse passes and a space is registered at the output terminals SE. If the voltage E lies between 60 and 50 at the instant when an element pulse arrives, an effective path p_2 is open through diodes d_2 and d_6 and a mark is registered at terminals SE. Similar paths p_3, p_4 are respectively open at voltages E lying between 40 and 30, and between 20 and 10, but no effective paths are open at the remaining ranges of values.

Resistors R_2 and capacitor C_2 are provided for preventing the establishment of an effective path for impulses through pairs of diodes which are not adjacent to one another. For instance a value 65 of the voltage E opens a path through the diodes d_1 and d_6, but this path is not effectively available for the brief impulses of small amplitude by which the coding is effected, provided that appropriate values be given to the components C_2, R_2. If it is found that the capacities of the diodes provide a sufficient path to impair the functioning of the device, they can be balanced out by means of a preset capacitor C_n.

The manner in which the instantaneous speech voltage is sampled and in which the requisite decay rate is imparted to the resulting voltage E will now be described with reference to Figure 2.

The modulation or speech voltage is applied at the input terminal M of a cathode-follower valve V_1, so that a voltage proportional to the instantaneous value of the speech voltage appears across the cathode resistance R_6. Peaked positive synchronising pulses are applied to the terminal CP in such a way as to make the diodes D_1, D_2 momentarily conductive at the beginning of each combination period. A resistor R_5 is connected in series with the diode D_2 and its resistance is chosen to be much smaller than that of the time-constant resistor shown at R_4 but much larger than that of the cathode resistor R_6. Since the resistance of R_5 is large in comparison with the resistance of the remainder of the circuit D_2, D_1, R_6, most of the voltage of the controlling impulse applied at CP is taken up in the voltage drop over it, R_5, and the capacitor C_4 accordingly takes up the potential of the live end of the cathode resistor R_6.

The pulses applied to terminal CP occur once at the beginning of each combination period, that is to say once for each three of the element pulses applied at terminals EP, Figure 1. On the cessation of the impulse at terminal CP the diodes D_1, D_2 become blocked and the initial charge on the condenser C_4 has thus been determined. This is the initial value of the control voltage E applied to terminals MV, Figure 1, which are shown also in Figure 2, and it controls the character (mark or space) of the first signal element in the combination in the manner already described. The value of the voltage E across capacitor C_4 then falls off exponentially, however, owing to the discharge of the condenser through the resistance R_4, and the latter is chosen to be of such magnitude that the value of E is halved during a single element period. The second and third signal elements are thus controlled by it in the manner already described, and hence the code shown in column H is signalled.

It will be obvious that by suitable dimensioning the resistors and capacitors shown in Figure 1 the device can be adapted to effect volume-compression for use in a compander system.

What I claim is:

1. In a pulse-code-modulator system, apparatus for encoding audio frequency signals comprising a sampling system to derive periodically from said audio signals a control voltage pulse whose initial value is a function of the instantaneous value of the signals and whose value thereafter decays at a given rate, and an encoding system coupled to said sampling system and responsive to each control voltage pulse to generate a code combination having a predetermined number of code elements, the character of said elements being determined by the form of said control voltage pulse.

2. Apparatus, as set forth in claim 1, which includes compander means for regulating the magnitude of said audio signals in a predetermined fashion in order to produce audio signals with a predetermined signal-to-noise ratio.

3. Apparatus, as set forth in claim 1, wherein the control voltage pulse decays at an exponential rate.

4. Apparatus, as set forth in claim 1, wherein the control voltage pulse decays at a rate at which said voltage halves itself over the time interval in which a code element is generated.

5. Apparatus, as set forth in claim 1, wherein said sampling system includes a network for determining the rate of decay and having a capacitance and a resistance, said resistance shunting said capacitance.

6. In a pulse-code-modulator system, apparatus for encoding audio frequency signals comprising a sampling system provided with a cathode follower amplifier responsive to said audio signals and means to derive periodically from said amplifier a control voltage pulse whose initial value is a function of the instantaneous value of the signals and whose value thereafter decays at a given rate, an encoding system including a plurality of unidirectional current paths, means to supply each of said control pulses to said paths to precondition the conductivity of said paths in accordance with the control pulse values, and means to apply periodic timing pulses to said paths in the interval during which said paths are conditioned by a control pulse for rendering said paths conductive and non conductive in a sequence depending on said control pulse values thereby producing a code combination having a predetermined number of elements.

7. In a pulse-code-modulator system, apparatus for encoding audio frequency signals comprising a sampling system provided with a cathode follower amplifier responsive to said audio signals, and means to derive periodically from said amplifier a control voltage pulse whose initial value is a function of the instantaneous value of the signals and whose value thereafter decays at a given rate, an encoding system including a plurality of parallel unidirectional current paths intercoupling the common input and output circuits, each of said paths including at least two serially-connected rectifiers, means to supply each of said control pulses to said parallel paths to condition the conductivity of said paths in accordance with the control pulse values, and means to apply periodic timing pulses to said common input circuit in the interval during which said paths are preconditioned by a control pulse for rendering said paths conductive and non-conductive in a sequence depending on said control pulse values thereby yielding in the output circuit a code combination having a predetermined number of elements.

8. Apparatus, as set forth in claim 7, wherein the ends of each rectifier adjacent to the com-

mon input and output circuits of said parallel paths are coupled to points of constant potential, said points of constant potential having graded magnitudes.

9. Apparatus, as set forth in claim 8, wherein said input and output circuits are constituted by transformers, the rectifier ends being connected to said points of constant potential through a winding of a respective transformer.

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