

July 16, 1963

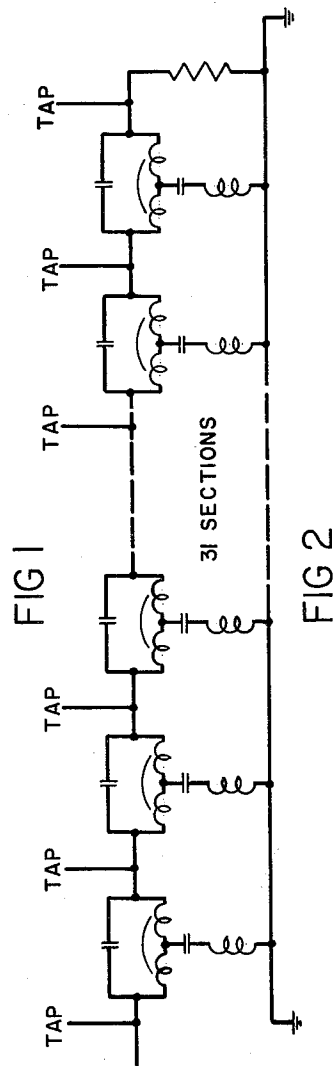
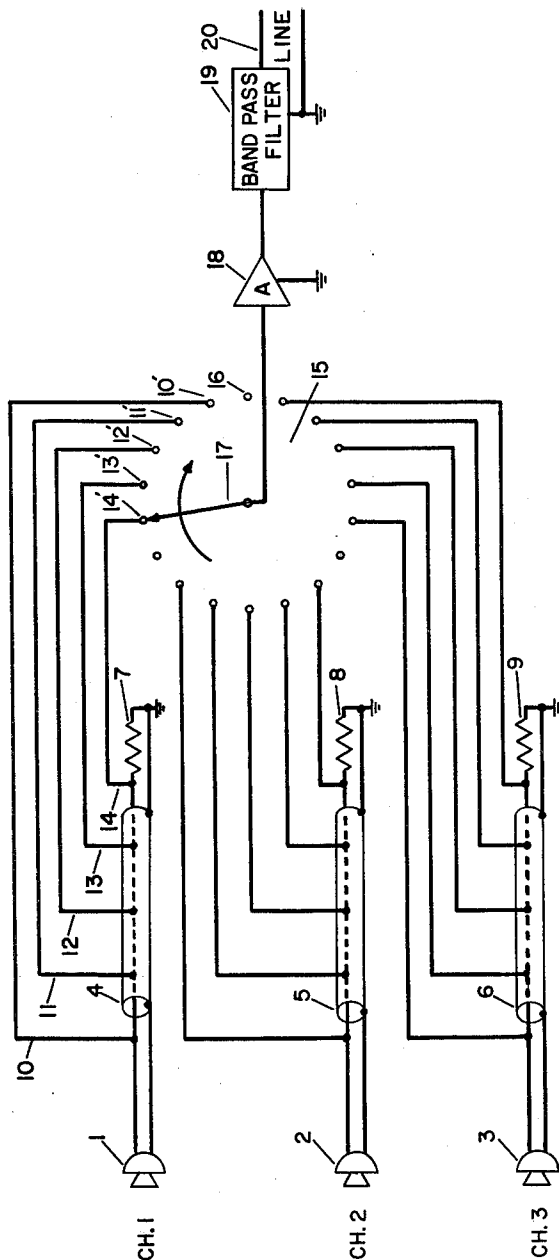
C. B. FISHER

3,098,124

MULTIPLEX TELEPHONY

Filed Oct. 13, 1958

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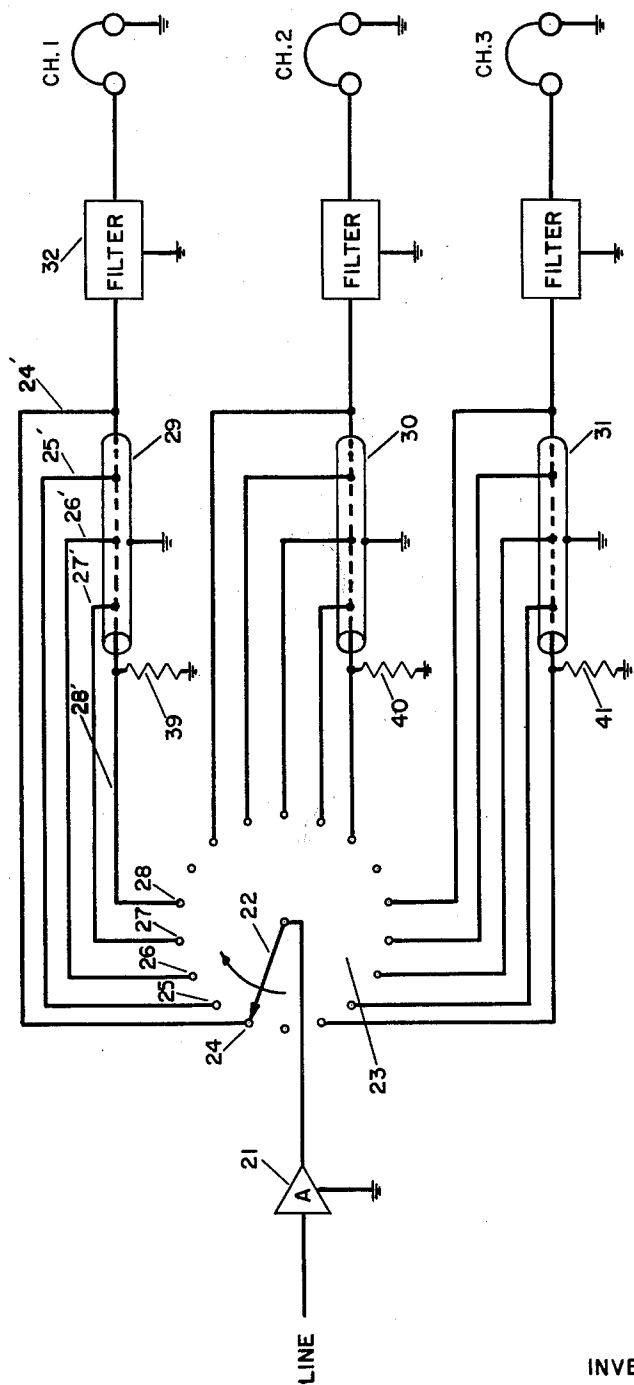
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INVENTOR

Charles B Fisher

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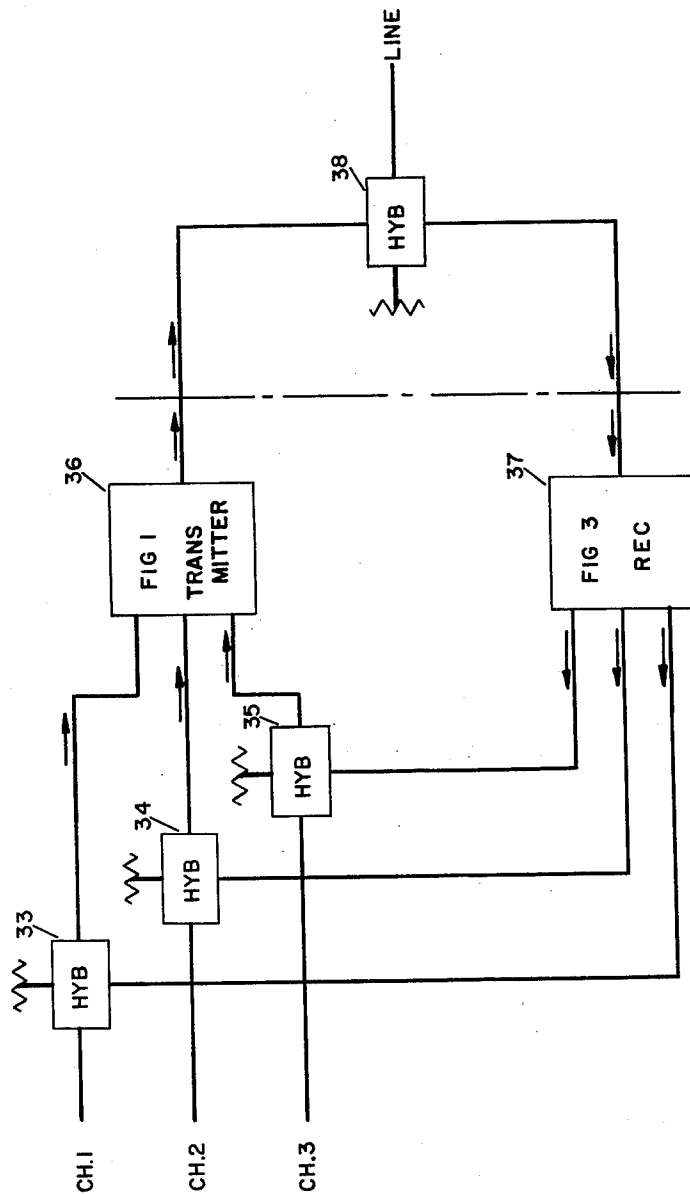


FIG 4

INVENTOR

Charles B Fisher

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3,098,124

MULTIPLEX TELEPHONY

Charles B. Fisher, 2850 Hill Park Road, Montreal 25,
Quebec, Canada

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This invention relates to multiplex telephony and more particularly to time-division multiplex systems employing compression and subsequent expansion of the voice signals.

The general method of multiplexing employed in systems constructed in accordance with the invention is one that has been known for some time, but which has not been practiced because of the complicated character of the devices heretofore proposed for carrying it out. In accordance with the present invention it comprises essentially, the steps of storing the voice signals, compressing the time duration of equal successive portions of the signal in each channel, interleaving the compressed portions of the several channel signals for transmission, and at the receiving end of the system, separating the interleaved portions of the multiple signal and expanding them to reproduce the original signal. A characteristic feature of the method is that the portions of the signal subjected to time compression are longer than the period of any voice frequency it is desired to transmit.

The advantages of this system in relation to other types of multiplex systems are pointed out in an article by V.D. Landon, entitled, "Theoretical Analysis of Various Systems of Multiplex Transmission," R.C.A. Review, vol. IX, No. 2, June 1948 and No. 3, September 1948. It is shown there, that under comparable conditions, the system should exhibit superior characteristics with respect to noise reduction and to economy of frequency space when the compressed multiple signal is transmitted as a frequency modulation of a carrier wave. The general method of multiplexing, including the step of frequency modulation, is designated as PAM-FM (slow) in the Landon article and is described in pages 339 to 441 in the June 1948 issue of the R.C.A. Review referred to above.

The general object of the present invention is to improve the signal to noise characteristics of multiplex systems.

Other objects include the simplification of the apparatus for effecting compression and expansion of voice signals and the reduction of band width required for multiplex transmission.

A feature of the invention is the method employed for compressing the voice signals according to which short sample pulses, representing the instantaneous values of the signal voltage, are taken from equal successive portions of the voice signal, at a rate greater than twice the highest voice frequency to be transmitted, and in time intervals that are short in comparison with the length of the sampled portions.

Another feature of the invention is the use of a converse method, also employing pulses sampling, for expanding the compressed signal portions to restore the original signals at the receiving end of the system.

These and other features of the invention will be more fully understood from the detailed description which follows and by reference to the accompanying drawings of which:

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FIG. 1 is a simplified schematic of a multiplex transmitter in accordance with the invention;

FIG. 2 shows a preferred form of electrical storage line for use in the circuit shown in FIG. 1 and in the receiving circuit of the receiver shown in FIG. 3;

FIG. 3 is a simplified schematic of a multiplex receiver arranged to cooperate with the transmitter shown in FIG. 1; and

FIG. 4 is a block diagram of a two-way system in accordance with the invention.

The circuit shown in FIG. 1 is that of a three channel multiplex transmitter. It contains principally the circuit elements that take part in the storage of the voice signals, the compression of the signals and the interleaving of the channel signals for transmission. For the sake of clarity in the drawing, certain of the elements are shown in simplified form and in a practical circuit would be modified as explained later.

Telephone transmitters 1, 2 and 3 represent the sources of signals in the respective channels. These supply voice currents to storage lines 4, 5 and 6 which are shown as coaxial cables terminated in matching resistances 7, 8 and 9. Line 4 is tapped at a plurality of equally spaced points, and leads 10, 11, 12, 13 and 14 connect the taps respectively to contacts 10', 11', 13' and 14', equally spaced in a segment of the periphery of a distributor 15.

Lines 5 and 6 are tapped in the same manner as line 4 and the taps are connected to contacts in additional groups in distributor 15. The three groups of channel contacts are separated by three blank contacts, one of which is indicated at 16. Contact arm 17, of distributor 15, rotates at a constant speed when the system is in operation and as it passes over the contacts it establishes momentary connections between the taps on the storage lines and an output amplifier 18, which is connected to a transmission line 20 through band-pass filter 19.

As stated above, certain of the elements of the circuit have been shown in simplified form for the sake of clarity. In practice, storage lines 4, 5 and 6 would preferably be constructed as artificial lines comprising large numbers of all-pass networks connected in tandem and distributor 15 would be provided with a correspondingly large number of contact points. In a typical example of a three-channel multiplex system, the storage lines would consist of thirty-one network sections with thirty-two tap connections, and distributor 15 would have a total of ninety-nine contacts including the three blank contacts separating the channel groups. Typical rotation speeds of contact arm 15 would be 250 revolutions per second or less, depending upon the lower limit of the desired voice frequency range.

A suitable form of storage line is shown in FIG. 2. This line comprises thirty-one similar bridged-T all-pass networks with tap connections at each end, and at each junction. The networks are characterized by the connection of the shunt branches to the junction of two coupled inductances in the series branches of the T's. This configuration, with the added element of mutual inductance, facilitates the design of the network to provide substantially uniform delay throughout the voice-frequency range.

In describing the operation of the transmitter it will be assumed that the circuit is modified by substituting 31-section storage lines of the type shown in FIG. 2 for the

coaxial lines, and that the distributor has 32 contacts in each channel group. It will be assumed also that the distributor contact arm makes one complete revolution in 4 milliseconds, or 250 revolutions per second, so that the time required for it to traverse the contacts in each channel group is 4/3 milliseconds. The delay time of the line will be taken as 8/3 milliseconds for reasons that will appear later.

At any given instant when the system is operating, the storage line in channel 1, for example, will contain a portion of the voice signal of length equal to the delay time of the line, and the voltages at the tap connections will correspond to the signal voltage at equal successive time intervals. These voltages are sampled in their proper time sequence as contact arm 15 swings in a clockwise direction over the contacts in the group assigned to the channel. The voltage samples are in the form of very short pulses, representing substantially instantaneous values of the signal voltage, and are separated by intervals corresponding to the separation of the contacts. Since the contact arm takes a definite time to traverse the contacts, and since the voice signal is travelling along the storage line during this time, the length of the portion of the signal sampled will be equal to the delay time of the line plus the time required for sampling.

For the example chosen, the sampling time was assumed to be 4/3 milliseconds and the delay time to be 8/3 milliseconds, consequently the length of the signal portion sampled is 4 milliseconds. By the process of sampling, the pulses representing the signal portion are compressed into an interval of 4/3 milliseconds, that is, by a factor of three.

The interval between successive samplings of a channel is 8/3 milliseconds for the example chosen. The delay time of the storage line was chosen to be equal to this interval so that the next contiguous portion of the signal would have entered and occupied the line at the start of the next sampling period, thus ensuring continuous sampling of the signal without gaps or overlaps.

The number of pulses taken from the line during a sampling period is 32 and these are taken from a signal portion of 4 milliseconds length. The signal sampling rate is therefore 8000 pulses per second which is sufficient for the reproduction of voice frequencies as high as 3500 c.p.s. Since the 32 samples are taken in a time interval of 4/3 milliseconds, the pulses are delivered to amplifier 18 and filter 19 at a rate of 24,000 per second.

The purpose of amplifier 18 is to prevent any disturbance of the storage line characteristics during sampling. These lines exhibit their constant resistance and their appropriate delay characteristics only when properly terminated. The intermittent bridging of the delay lines, by the common output circuit during the sampling periods, could disturb these characteristics unless the impedance of the output circuit is very large compared with that of the line. The introduction of an amplifier 18 having a very high input impedance avoids such disturbances. The amplifier should be capable of handling the high speed pulses, 24,000 per second, without introducing any distortion.

The process of time compression by a factor of 3 results in an increase in the frequencies of the voice currents by the same factor. A voice signal, originally occupying a band from 300 c.p.s. to 3500 c.p.s. will, after compression in time, occupy a band from 900 to 10,500 c.p.s. The compressed signals in each channel will all occupy this band. At the input of filter 19 the signals are in the form of short pulses, of varying amplitude, and recurring at a rate of 24,000 per second. By limiting the filter pass band to the range from 900 to 10,500 c.p.s. the signals are restored to continuously varying currents corresponding to the original signals, but having the component frequencies multiplied.

The relationships among the time intervals exemplified above may be expressed in more general terms as fol-

lows: Let the number of channels be denoted by N , the delay time of the storage lines by T_1 , the time for one complete rotation of the distributor contact arm by T_2 , and the number of taps in each line by n . The time T_2 is divided equally among the channels consequently the time devoted to the sampling of one channel is T_2/N , and the time interval between successive samplings is $(T_2 - T_2/N)$. This latter interval is the time available for a new portion of the signal to enter and occupy the storage line, and since this takes a time equal to T_1 , the requirement that the signal be sampled continuously without gaps or overlaps leads to the relationship

$$T_1 = T_2 - T_2/N \quad (1)$$

The length of the sampled portion of the signal, denoted by T_s , was shown to be equal to the delay time plus the sampling time or

$$T_s = T_1 + T_2/N = T_2 \quad (2)$$

The number of pulses derived from each signal portion of length T_2 is n , consequently the pulse rate, referred to the original signal, is n/T_2 , and is independent of the number of channels. The pulse rate at the output of the transmitter is Nn/T_2 since each group is compressed into the sampling period T_2/N .

The time compression factor is, therefore, equal to the number of channels and this also is the frequency expansion factor.

The receiving circuit shown in FIG. 3 comprises a distributor 23, similar to distributor 15 in the transmitter, and three storage lines 29, 30 and 31 of the same character as the storage lines 4, 5 and 6 in the transmitter. While these elements are shown in simplified forms in the figure, it will be understood that the storage lines would in practice be of the type shown in FIG. 2 and have the same number of sections and also that the distributor would have the corresponding number of contacts.

The contacts for the several channels are disposed in groups, one group for each channel, occupying separate segments of the distributor and are connected as shown to taps in the respective storage lines. At their output ends the storage lines are connected through filters, such as 32, to telephone receivers. Contact arm 22, of the distributor, is connected to the line through an amplifier 21, having an output impedance large compared with that of the storage lines, so that the intermittent connection of the amplifier to the line taps will not disturb the delay characteristic.

When the system is operating, contact arm 22 will be controlled by appropriate synchronising means, not shown, to rotate in synchronism with contact arm 17 of the transmitting distributor, and in phase therewith, so that the same channel groups of contacts are scanned simultaneously at both ends. In the figure, contacts 24 to 28 are those for channel 1 and are connected respectively to taps 24' to 28' in line 29. Contact arm 22 is shown in its position at the start of the scanning period for channel 1 at which time a compressed portion of the channel 1 signal has just arrived at the receiver. During the scanning period the voltage at the contact arm follows the voltage variations of the received signal portion, and as the arm traverses contacts 24 to 28, in that order, it impresses on these contacts and on the corresponding storage line taps, short pulses representing the received voltage at successive instants.

Expansion of the compressed signal portion takes place in the storage line by virtue of the order of the connections between the distributor contacts and the line taps. The first pulse passes to tap 24' and is subject to zero delay as it passes to filter 32. The later pulses are subjected to progressively increasing amounts of delay. The last pulse being delayed by the full delay time of the line. The time interval between the arrivals of the first and the last pulses, at the output and of the storage line, is evidently the sum of the scanning time and the delay time

of the network. This represents the degree of expansion obtained.

In the practical example discussed in connection with the transmitter, the delay lines were assumed to be of the type shown in FIG. 2, having 31 sections and 32 taps, the total delay time being $8/3$ milliseconds. The distributor had 32 contacts in each channel group and the distributor arm made a complete revolution in 4 milliseconds. The scanning time for each channel was $4/3$ milliseconds which also the length of the compressed signal portions.

Assuming the same values to apply to the receiver elements, it will be seen that as the contact arm scans a channel group of contacts thirty-two pulses will be produced and delivered to the taps of the storage line in an interval of $4/3$ milliseconds. The time interval between the first and the last pulses at the line output will be 4 milliseconds, and the pulse rate at that point will be 8000 a second.

Because the same values apply to both transmitter and receiver the successive signal portions in each channel will be contiguous and will have no noticeable gaps or overlaps. At the output of the channels the signals are expanded to their original length, but are in the form of short pulses recurring at a rate of 8000 a second. Filter 32, having a pass band of 300 to about 4000 c.p.s., serves to restore the signal to its continuous wave form.

A unique advantage of the system of the invention will appear from a comparison of FIGS. 1 and 3. It is well known that transmission lines and networks cannot be made to be free from energy dissipation and that consequently, waves transmitted along them must necessarily suffer attenuation. In FIG. 1, therefore, the pulses derived from the later taps are subject to greater attenuations than those derived from taps closer to the input ends of the lines. However, the correspondence between the distributor contacts and the contacts of the transmitting distributor is such that all pulses traverse the same total length of delay line and are, therefore, subject to the same degree of attenuation. For example, contact 25 in the receiver corresponds to contact 13' in the transmitter, the pulse derived from contact 13' at the transmitter has traversed three portions of the delay line 4, and the corresponding pulse produced at contact 25 in the receiver, representing the same element of the signal, traverses only one section of line 29. Each element of the signal traverses the same total number of line sections, and to that degree, the attenuations of the pulses are automatically compensated.

Duplexing a multiplex system of the invention to permit two way operation of each channel can be effected by arranging the apparatus at a terminal in the manner shown in block diagram FIG. 4. In this figure, 36 represents a transmitter comprising the storage lines, the distributor and the output amplifier and filter shown in FIG. 1. Circuit block 37 represents the receiver shown in FIG. 3. The lines representing the three channels may be subscribers' lines. They are connected respectively to hybrid coils 33, 34 and 35 by means of which directional separation, of outgoing and incoming signals, is effected. The outgoing signals are passed to transmitter 36 in which they are compressed and interleaved and from which the compressed signals pass to another hybrid coil 38. This coil separates the transmitted and received signals in the line, the received signals going to receiver 37 in which the signals are expanded and separated into their respective channels. The several outputs of the receiver pass to hybrid coils 33, 34 and 35 where they are directed into the subscribers' lines.

It will be seen that the production of the short sampling pulses is confined to apparatus units and that the pulses are transmitted only over short lengths of conductor. Accordingly, no special arrangements need be made for preserving the shape of these pulses, which, in fact, exist only for very brief periods.

It will be clear that features of the multiplex system described in the foregoing may be modified in various manners without departing from the spirit of the invention. For example the distributor contacts may be replaced by electronic gates which are opened in sequence by suitable controls and which transmit the pulses to the common line, at the transmitter, or to the individual storage lines, at the receiver. Electronic switching arrangements suitable for the purpose are within the scope of present day practice and are capable of operating at very high speeds thus permitting a large number of channels to be multiplexed.

I claim:

1. A receiver for multiplex telephone signals transmitted as interleaved portions of the signals in a plurality of channels compressed in time in proportion to the number of channels, comprising distributor means for sampling the received signal portions at successive instants to produce sequences of pulses representing the signal voltages, signal storage lines for each channel having delay times substantially independent of frequency, an output circuit for each line, a plurality of equally spaced taps on each of said lines corresponding to the number of pulses in said pulse sequences, connections between said distributor and the tap points in said lines so disposed that the first pulse of a sequence passes directly to the respective output circuit and the succeeding pulses are delayed by progressively greater amounts thereby expanding the signal portion to its original length, and a filter in each output circuit for reproducing the signal.

2. A multiplex receiver in accordance with claim 1 in which the said distributor means comprises a circular array of equally spaced contacts and a concentrically mounted contact arm connected to receive the incoming signal currents, the contacts corresponding to the individual channels being equal in number to the taps on the respective storage lines, and being disposed in separate segments of the circular array, connections from the contacts in each group to the taps on the respective storage lines arranged in such order that, as the contact arm rotates, it makes connection with the line taps consecutively starting at the output end of the line.

3. A receiver for multiplex telephone signals transmitted as interleaved portions of the signals in a plurality of channels compressed in time in proportion to the number of channels, comprising means for separating the received signal portions corresponding to the different channels and producing therefrom sequences of pulses representing consecutive instantaneous voltages of the separated signal portions, means individual to each channel for delaying consecutive pulses of each sequence by progressively increasing amounts to expand the signal portions to their original lengths.

4. A receiver for multiplex telephone signals transmitted as interleaved portions of the signals in a plurality of channels compressed in time in proportion to the number of channels, comprising means for separating the received signal portions corresponding to the several channels and producing therefrom sequences of pulses representing consecutive instantaneous voltages of the separated signal portions, tapped delay lines individual to each channel, output circuits for said lines, and circuits for impressing consecutive pulses of each sequence on progressively increasing lengths of the corresponding tapped delay line, whereby the consecutive pulses are delayed by progressively increasing amounts in reaching said output circuits.

5. A receiver for multiplex telephone signals transmitted as interleaved portions of the signals in a plurality of channels compressed in time in proportion to the number of channels, comprising distributor means for sampling the received signal portions at successive instants to produce sequences of pulses representing signal voltages, delay lines individual to each channel, output circuits for said lines, a plurality of spaced taps on each of said lines corresponding to the number of pulses in said sequences, and

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circuit connections between said distributor and said lines so disposed that the successive pulses of a sequence are caused to traverse progressively increasing lengths of the corresponding delay line towards its output circuits.

6. A telephone receiver for signals transmitted as equal contiguous portions of a speech signal compressed in time to an integral fraction of the length of said portions and recurring at intervals equal to the duration of said portions, comprising means for producing from the compressed signals sequences of pulses representing successive instantaneous signal voltages, a delay line and an output circuit therefor, a plurality of spaced taps on said line equal in

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number to the number of pulses in said sequences, and circuits connecting said pulse producing means with said taps so disposed that the successive pulses of a sequence are caused to traverse progressively increasing lengths of said line towards said output circuit.

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