

April 19, 1960

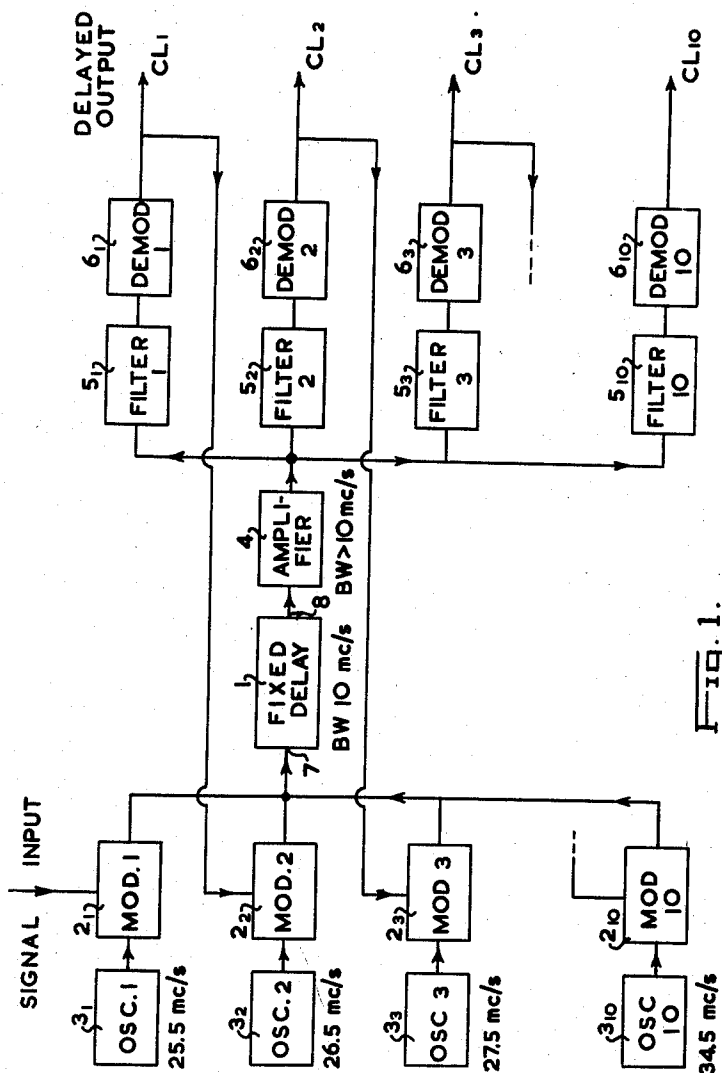
J. P. I. TYAS

2,933,717

RECIRCULATING DELAY LINE

Filed Oct. 9, 1957

5 Sheets-Sheet 1



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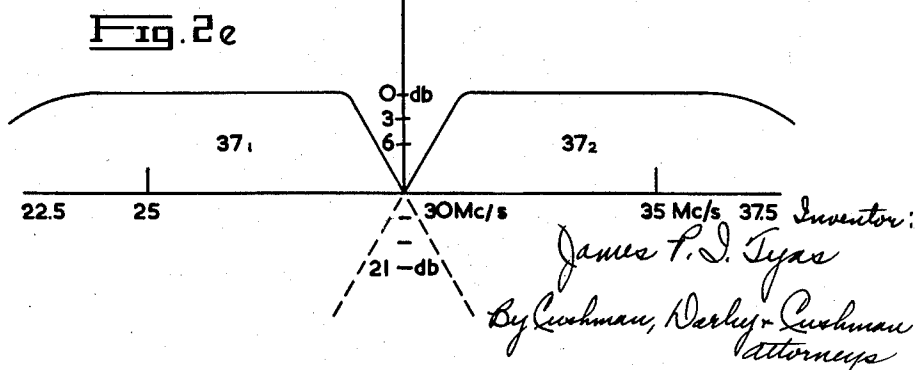
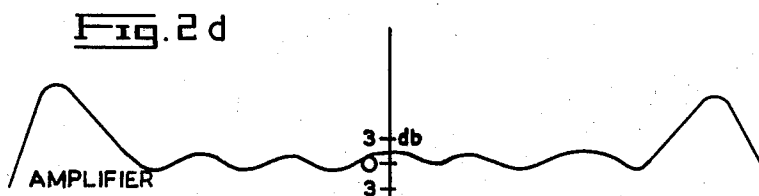
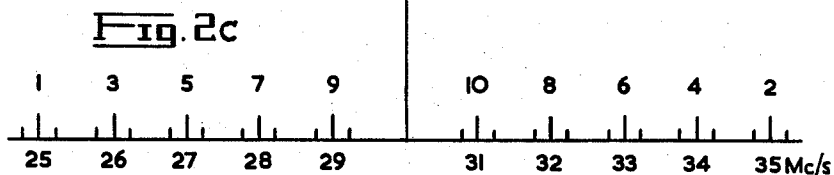
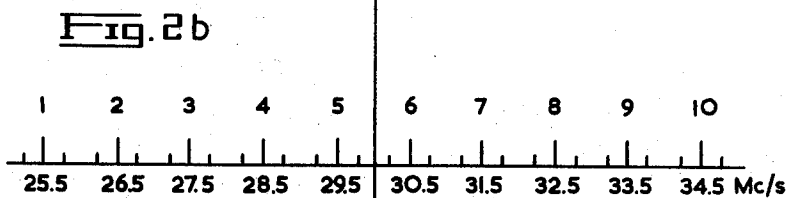
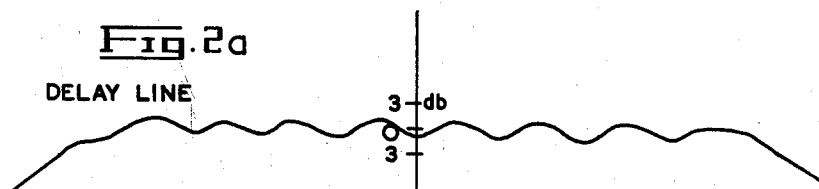
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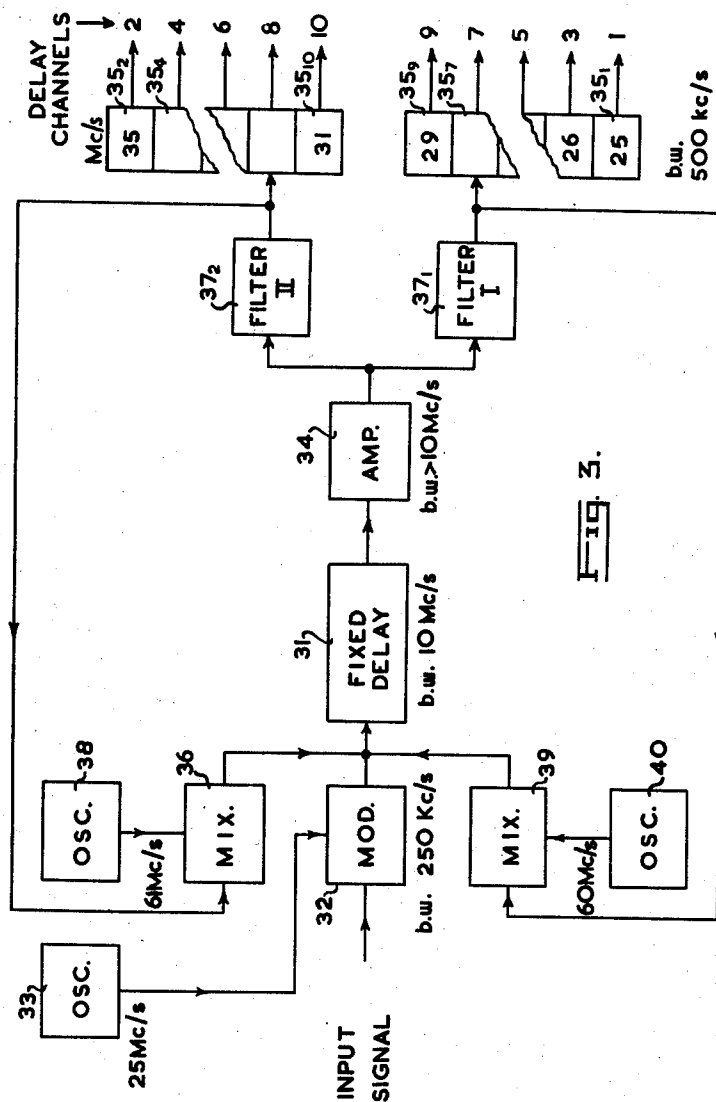
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RECIRCULATING DELAY LINE

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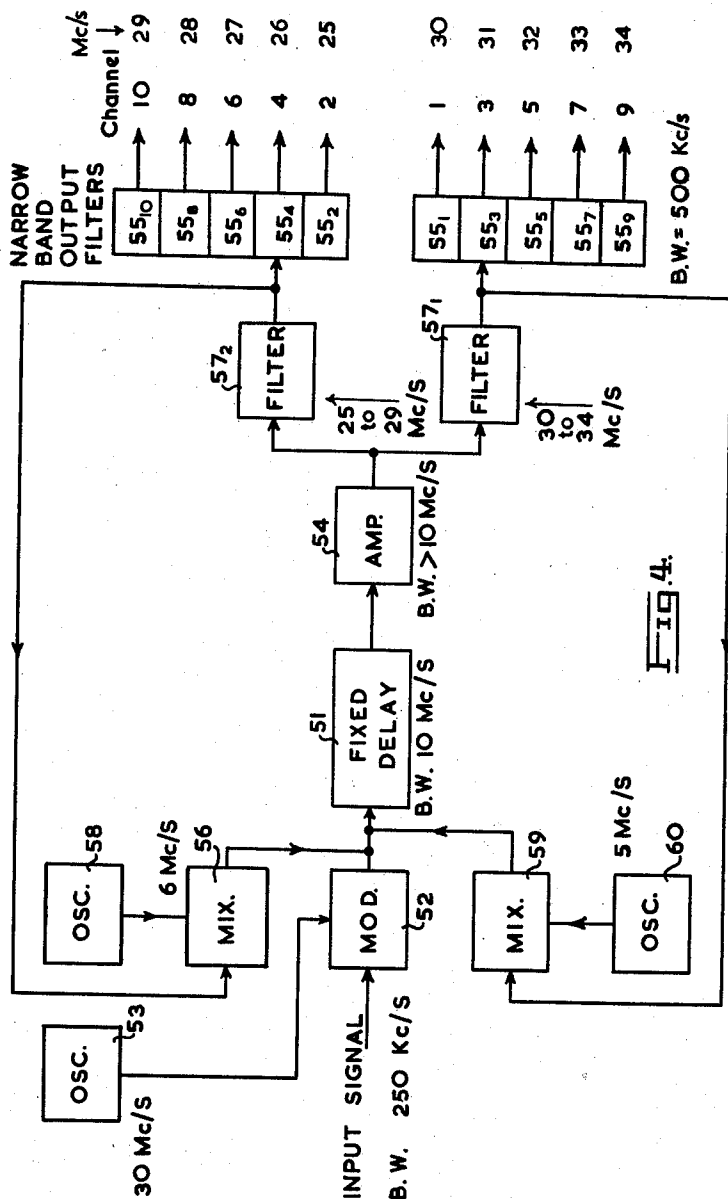
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RECIRCULATING DELAY LINE

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5 Sheets-Sheet 4



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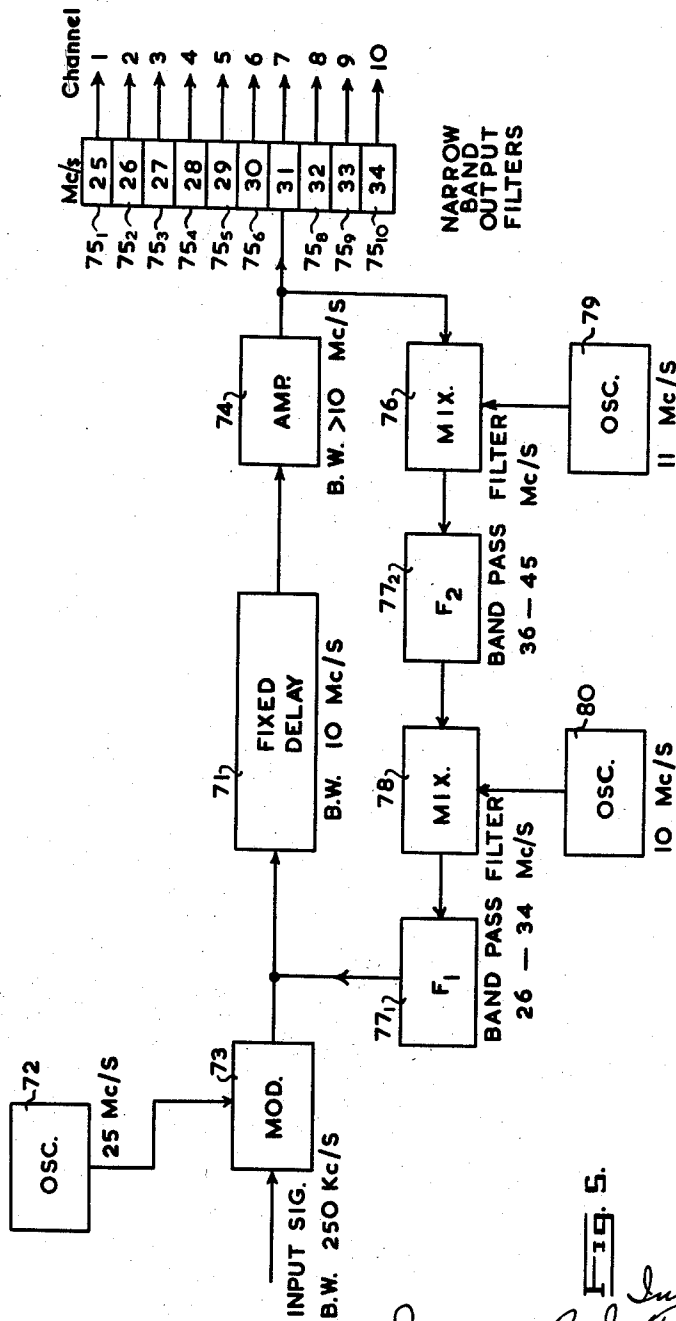
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RECIRCULATING DELAY LINE

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5 Sheets-Sheet 5



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2,933,717

RECIRCULATING DELAY LINE

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5 Claims. (Cl. 340—173)

The present invention relates to a system for storing information available as a waveform with particular reference to a system in which the information may be sampled from time to time.

There are a number of devices in use where it is necessary to store information for a definite period during which it is desired to sample the information at a series of regular intervals. Radar systems, coded communication systems, and computers provide examples of these devices.

Various methods of information preservation have been used but the one chosen in a particular case depends upon the period between generation and discard, the rate at which the information is produced, the rate at which it is required to be read back and the frequency that sampling must take place. When the periods involved are fairly long it is common to choose a magnetic storage system having a number of play back heads spaced along the path of a moving magnetic tape, such that the delay between the generation of a signal and its reproduction depends upon the separation of the recording head and the play back head chosen and the speed of travel of the tape. In cases where information need only be stored for a relatively short time and its generation is rapid, other systems are generally preferred.

Delay lines, both electro-magnetic, and sonic have been used for the temporary storing of rapidly produced information but a number of successively delayed samples of continuously produced information can only be obtained by using one line for each delayed sample that is required.

Clearly this procedure, although widely adopted, is extravagant and expensive as the cost of a delay line is a very considerable portion of that of the whole system. Any reduction in the number of delay lines to be used in a particular case represents therefore a substantial saving in cost alone, and it is an object of the invention to provide a plurality of delayed signals using a single delay medium.

According to the present invention I provide a method of storing a waveform, comprising introducing the waveform to a wave propagating medium as a wave train (in the preferred form this medium comprises a delay line), recovering the introduced waveform from the wave propagating medium after a time delay, changing the frequency of the recovered waveform, introducing the waveform of changed frequency to the propagating medium as a second wave train and recovering the introduced waveform of changed frequency from the medium after a time delay.

In the preferred form of the invention I employ a delay line in which the period of wave transmission from input to output is equal to the time interval required between one sample of the information and the next. The stored information is recirculated through the line, each time impressed upon a carrier wave train of different frequency, and thus by filtering the output from the delay

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line using filters corresponding to each of the carrier frequencies, signals may be obtained which are delayed from the input signal by multiples of the transmission time of the delay line.

In the description which follows reference will be made to the drawings in which:

Figure 1 shows a schematic block diagram of a first embodiment of my invention;

Figure 2a shows the amplitude response curve of a typical delay line employed to the same frequency base as Figures 2b and 2c;

Figure 2b is a frequency base diagram showing the arrangement of the ten information channels of the circuit of Figure 1;

Figure 2c is a frequency base diagram showing the arrangement of the ten information channels of Figure 3;

Figure 2d is an amplitude response curve for a typical amplifier employed, to the frequency base shown in Figure 2e;

Figure 2e is an amplitude response curve for the two broad band filters of Figure 3;

Figure 3 is a schematic block diagram of a second embodiment of the invention;

Figure 4 is a schematic block diagram of a third embodiment of the invention; and

Figure 5 is a schematic block diagram of a fourth embodiment of the invention.

Figure 1 shows quartz sonic delay line 1, of broad bandwidth which is equipped with conventional input and output transducers and adapted to accommodate a plurality of narrower bandwidth channels of information, chosen in this example to be ten in number. Oscillators $3_1, 3_2 \dots 3_{10}$ have their outputs impressed, with signals for recording, in modulators $2_1, 2_2 \dots 2_{10}$ respectively. The outputs from the modulators are introduced at the input 7 thus pass down the line, and after a time delay, determined by the length and wave propagation velocity of the line, appear at the output 8. The signals thence pass through amplifier 4 and are selected by filters $5_1, 5_2 \dots 5_{10}$. The outputs from the filters are taken to the respective demodulators $6_1, 6_2 \dots 6_{10}$ and from each one of these a demodulated output signal may be taken. The outputs of demodulators $6_1, 6_2 \dots 6_9$ but not 6_{10} are adapted to provide impressing signals respectively for modulators $2_2, 2_3 \dots 2_{10}$. The initial input signals which it is desired to store are introduced at modulator 2_1 .

In this example, as a typical value, we have assumed the bandwidth of the quartz delay line to be approximately 10 mc./s. and centered upon a frequency of 30 mc./s. The form of the response of such a typical quartz delay line is shown in Figure 2a, which is intended to show the type of variation encountered over the bandwidth of the line. The state of the art of manufacturing quartz delay lines is such that very considerable variations in response between specimens is found and an amplifier associated with each line must be individually adjusted to smooth out the passband. A typical amplifier response curve appears at Figure 2d, which shows particularly the rising characteristic for compensation at the extremities of the line passband. Let us further assume that the signals to be stored are of bandwidth 250 kc./s. and that double sideband modulation is introduced by the modulators $2_1 \dots 2_{10}$.

With these assumed values we may choose 10 information channels each 500 kc./s. wide, and allow a suitable channel separation or guard band of 500 kc./s. between each. The separation of carrier frequencies will thus be 1 mc./s. These may be suitably assigned the values 25.5, 26.5, 27.5, 28.5, 29.5, 30.5, 31.5, 32.5, 33.5 and 34.5 mc./s. for channels 1 to 10 respectively, and this is

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set out in Figure 2b. The filters $5_1 \dots 5_{10}$ are each designed to pass the band of frequencies occurring in its respective channel, and the frequency of each oscillator 3 is adjusted to its assigned value (i.e. oscillator 3_1 to be 25.5, oscillator 3_2 to be 26.5 mc./s. etc.). Suppose now that a signal of 250 mc./s. bandwidth is introduced to modulator 2_1 . Signals will be passed to the input 7 of the delay line 1 centered on frequency 25.5 in channel 1, these will travel through the line 1 in a time determined by the wave transmission time of the line (in a typical line this might be 500μ seconds), and will reappear at output 8 reduced in amplitude (in a typical line this reduction is of the order of 60 db.).

The amplitude of the signals is then restored by amplifier 4, whose passband is of the form of Figure 2d (relative power amplitude being shown in decibels). The effect of the amplifier-line combination is such as to produce a substantially level response over the band of 25-35 mc./s. The signals pass through filter 5_1 (being rejected by all others), and thus appear as a replica of the original signals, at the output of demodulator 6_1 . The process is then repeated by feeding these delayed signals to modulator 2_2 from which they pass on channel 2 through the delay line 1, amplifier 4, filter 5_2 and demodulator 6_2 to appear with a delay of twice the transit time of the delay line 1. It will thus be clear that this embodiment provides ten output signals delayed by multiples of 1 to 10 of the delay time of the line 1, on the input signals to modulator 2_1 .

A second embodiment of the invention having only three oscillators is shown in Figure 3. The output from an oscillator 33 is modulated by an incoming signal in modulator 32 and is passed to the input of a delay line 31. The output from the line is passed through amplifier 34, whence it is taken to two broadband filters 37_1 and 37_2 . The signal from filter 37_2 is passed to a mixer 36 where it heterodynes with the output of an oscillator 38. The signal is returned to the input of the delay line. The output from broadband filter 37_1 is taken to mixer 39 where it beats with the signal from an oscillator 40. The output of mixer 39 is taken to the input of delay line 31. The output from filter 37_1 is further taken to a number of narrow band filters $35_1, 35_3, 35_5, 35_7$ and 35_9 , and that from filter 37_2 to narrow band filters $35_2, 35_4, 35_6, 35_8$ and 35_{10} .

Let us assume that in this example we are again dealing with input signals of 250 kc./s. bandwidth and that the modulators are of the double sideband type. We shall also assume that the delay line 31 and amplifier 34 have the characteristics shown in Figures 2a and 2d respectively. Let us now choose the passbands of filters 37_1 and 37_2 to be those shown in Figure 2e where the voltage amplitude response is shown in decibels. Suppose further that we propose a series of ten channels divided up as shown in Figure 2c. Each of the filters 35 is designed to pass all the frequencies in the channel shown by its subscript and substantially to reject all others. In the operation of this circuit the oscillator 33 is adjusted to 25 mc./s. and its output is impressed in modulator 32 by the signals to be stored. The modulated signal passes through and is delayed by the line 31, has the loss of the line made good in amplifier 34, passes through broadband filter 37_1 , and thence through narrow band filter 35_1 . A signal delayed by the transit time of the line 31 is available thus at the output of filter 35_1 on a carrier wave of 25 mc./s. Demodulation is of course necessary to recover the original signal. The delayed modulated carrier is also taken to mixer 39 where it is heterodyned with the 60 mc./s. signal from oscillator 40 to produce a difference frequency of 35 mc./s. The sum frequency of 85 mc./s. is not passed by line 31. The band of frequencies on the 35 mc./s. carrier is within the passband of channel 2, and the signal therefore passes through the delay line 31 amplifier 34, filter 37_2 and is thence taken to mixer 36. The signal is also made

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available from filter 35_2 . Since the frequency of oscillator 38 is set to 61 mc./s. the difference frequency emerging from the mixer 36, is 26 mc./s. The sum frequency 87 mc./s. is blocked by the line 31 but the 26 mc./s. signal is returned to the line 31 on channel 3. Clearly this process will continue and the information will be recirculated until such time as all ten channels are occupied, the delay introduced in each successive channel will be equal to the delay lines transit time. After this, further circulation will cease as the return of frequencies centered on 31 mc./s. (from channel 10) will produce a band centered on 30 mc./s., and this will be blocked by both filter 37_1 and 37_2 upon emerging from the amplifier 34.

A development of the circuit of Figure 3 is shown as a third embodiment of the invention in Figure 4. This circuit has the same layout as Figure 3 and the reference numerals of Figure 3 have been raised by 20 to correspond with similar components in Figure 4 (i.e. the delay line of Figure 4 is designated 51 whereas that of Figure 3 is 31). In the circuit of Figure 4 the frequencies of oscillators 58 and 60 have been chosen to be 6 and 5 mc./s. respectively. The frequency of oscillator 53 is set to 30 mc./s., and the frequency response of the delay line 51 and amplifier 54 are of the form shown in Figures 2a and 2d respectively. The channels 1 to 10 are chosen such that their center frequencies are as shown opposite the corresponding channel numbers in Figure 4. The bandpass characteristics of filter 57_1 extend from 30-34 mc./s. with an extension of 250 kc./s. at the high and low frequency end, and those of filter 57_2 from 25 to 29 again with 250 kc./s. extensions. The skirts of the passbands must be fairly steep for reasons explained later.

Input signals are introduced to modulator 52 and are impressed on the output signal of 30 mc./s. from oscillator 53. This passes through the delay line 51 and amplifier 54 in the manner already described, and through filter 57_1 where it is available for separation by narrow band output filter 55_1 . The signal is also returned to mixer 59 where it beats with the 5 mc./s. signal from oscillator 60, to produce signals centered on 25 and 35 mc./s. The resultant signal centered on 25 mc./s. is taken to the delay line passed through filter 57_2 , made available to the narrow band filter 55_2 , and returned to mixer 56. The signals on 35 mc./s. pass through the line but providing filter 57_1 has a steep cutoff they will not pass beyond. Beating in mixer 56 with the 6 mc./s. output from oscillator 58 produces output signal bands centered on 31 mc./s. and 19 mc./s., the 31 mc./s. signal is passed by the delay line 51 and by filter 57_1 . The circulation continues until all channels are occupied.

This circuit has the advantage over the one of Figure 3 in that the adjustment of the mixers 56 and 59 is more easily accomplished with the low frequencies of oscillators 58 and 60.

A third embodiment of the invention which overcomes the disadvantage of the rather sharp cut-off required of broad band filter 57_1 on either side of its passband and of 57_2 above 29 mc./s. is shown in Figure 5. Here the recirculating part of the circuit consists of a closed loop having in series a delay line 71, an amplifier 74, a mixer 76 driven by an oscillator 79, a broadband filter 77_2 , a mixer 78 driven by an oscillator 80, and a broadband filter 77_1 . The output of filter 77_1 is returned to the input of the delay line 71. The line is fed initially by the output of modulator 73 driven by oscillator 72. In this embodiment ten information channels are again provided centered on the frequencies 25, 26, 27, 28, 29, 30, 31, 32, 33 and 34 mc./s. for channels 1, 2, . . . 10 respectively. If the frequency of oscillator 72 is adjusted to 25 mc./s. and the passbands of the delay line 71 and amplifier are those shown in Figures 2a and 2d respectively, then signals introduced to modulator 73 will be passed to the line as sidebands of a 25 mc./s. carrier in channel 1. The signals passing through the line 71 and

amplifier 74 may be recovered by narrow band filter 75₁ for demodulation. Recirculation also takes place and the 25 mc./s. signal beats in mixer 76 with the output of oscillator 79 on 11 mc./s. to give a sum frequency of 36 mc./s. Now, since the passband of filter 77₂ is arranged to transmit all frequencies from 36-45 mc./s. (with suitable extensions of 250 kc./s. on each side to accommodate the sideband frequencies), the 36 mc./s. signal will pass through it unhindered. Subsequently the signal is passed to mixer 78, where a difference frequency of 26 mc./s. is obtained with the output of oscillator 80 on 10 mc./s. This difference frequency is then passed by broadband filter 77₁ whose range is from 26-34 mc./s. (again with 250 kc./s. extensions) and is returned to the delay line. This signal may be recovered from amplifier 74 by filter 75₂, but is also recirculated to appear at the input of the delay line 71 in channel 3. This process continues until all ten channels are filled. The separation between the passbands of filter 77₁ and 77₂ is 1.5 mc./s. and it is somewhat easier to prevent overlap than for filters 57₁ and 57₂ of Figure 4, where the separation is only .5 mc./s.

For ease of exemplification the foregoing descriptions have described the use of double sideband modulation for continuous wave carriers, but single sideband, phase, frequency or other suitable types of modulation could be used without departing from the spirit of the invention. Suppressed carrier transmission might equally well be employed. Clearly also, the number of channels into which the passband of the delay line is divided will depend upon the bandwidth required for each channel, and the guard bandwidth between channels. The frequency spectrum passed by the delay line will be determined by its type and design, and may in certain instances be replaced by other delay media.

As an example a continuous magnetic tape passing between a recording and a pick-up head might be used in place of the quartz delay line described, in which the range of frequencies that can be recorded are divided into channels in an analogous manner to that described for ratio frequencies. In this case the carrier waves would be of audio frequency. As further examples water, mercury coaxial cable, lumped constant lines or even space transmission from point to point might be used as the delay medium, and it will not be departing from the invention to change the delay effected on some channels by introducing or removing information at points in the delay media other than the terminal points.

What I claim is:

1. An information storage system comprising a wave transmission medium, first means for introducing waveforms to said transmission medium as a wave train, second means for recovering said waveforms from said transmission medium after a time delay, waveform frequency changing means, having an input and an output, said second means being connected to the input of said frequency changing means, the output of said frequency changing means being connected to said first means, means for introducing at least one waveform to said first means, and means for withdrawing a delayed waveform corresponding to said one waveform from said system.
2. An information storage system comprising, a wave transmission medium, first means for introducing waves corresponding to electrical waveforms at a first carrier frequency into said transmission medium, second means for recovering introduced waves from the transmission medium after a time delay as electrical waveforms, wave-

form frequency changing means having an input and an output, the second means connected to the output of said frequency changing means, means for introducing a waveform to said first means, means for introducing waves corresponding to an electrical waveform at a second carrier frequency from the output of said frequency changing means to said transmission medium and means for recovering waves corresponding to said electrical waveform at the second carrier frequency from the transmission medium after a time delay.

3. An information storage system comprising, a wave transmission medium first means actuated by electrical waveforms for introducing waves corresponding to said electrical waveforms into said transmission medium at a first point at a first carrier frequency, second means for recovering said introduced waves from transmission medium as electrical waveforms at a second point remote from the first point, electrical waveform frequency changing means having an input and an output said second means being connected to the input of said frequency changing means, the output of said frequency changing means being connected to said first means, means for introducing at least one electrical waveform to said first means, and means for withdrawing a delayed electrical waveform at a first carrier frequency corresponding to said one waveform at a second carrier frequency from said system.

4. An information storage system comprising, a wave transmission medium, a carrier wave source for said wave transmission medium, means for impressing an electrical waveform upon waves from said carrier wave source, first means for introducing impressed carrier waves to the transmission medium at a first point, second means for recovering said impressed carrier waves from said transmission medium at a point remote from the first point, means for changing the frequency of the recovered impressed carrier waves, means for introducing the impressed carrier waves of changed frequency to the transmission medium, means for recovering the said impressed carrier wave of changed frequency from the transmission medium after a time delay, and means for recovering said impressing electrical waveform from said recovered impressed carrier waves.

5. An information storage system comprising, a wave transmission medium, first means for introducing continuous waveforms to said transmission medium as a wave train, second means for recovering said waveforms from said transmission medium after a time delay, waveform frequency changing means having an input and an output, said second means being connected to the input of said frequency changing means, third means which may be comprised by said first means for introducing further continuous waveforms to said transmission medium as a wave train, and fourth means which may be comprised by said second means for recovering said further waveforms from said transmission medium after a time delay, said second means being connected to the input of said frequency changing means, the output of said frequency changing means being connected to said third means, means for introducing at least one continuous waveform to said first means and means for obtaining a delayed waveform corresponding to said one waveform from said fourth means.

References Cited in the file of this patent

UNITED STATES PATENTS

2,629,820 Snyder ----- Feb. 24, 1953

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 2,933,717

April 19, 1960

James P. I. Tyas

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 6, line 12, after "medium" insert a comma; line 16, strike out "said"; same line 16, after "from" insert -- said --; line 19, after "output" insert a comma; line 25, strike out "at a first carrier frequency" and insert the same after "waveform" in line 23, same column 6.

Signed and sealed this 18th day of October 1960.

(SEAL)

Attest:

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Attesting Officer

ROBERT C. WATSON
Commissioner of Patents