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CONTROLLED DECAY FEEDBACK TYPE COMB FILTERS

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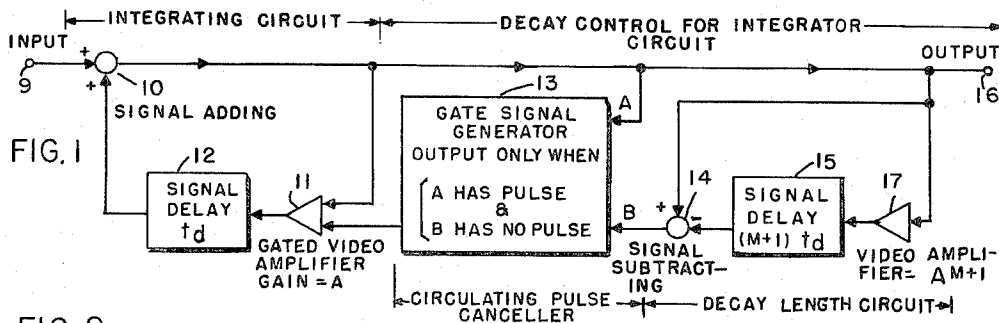


FIG. 2

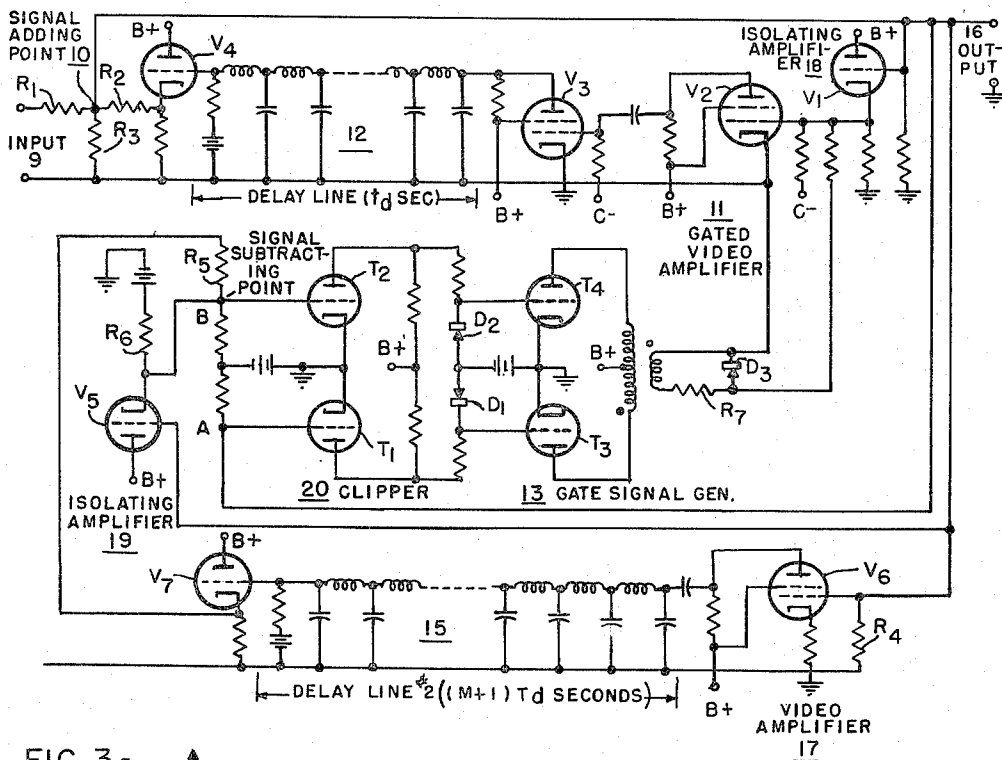


FIG. 3a

INPUT

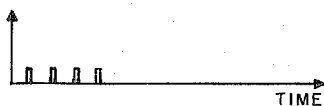


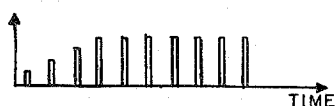
FIG. 3b

OUTPUT WITH
DECAY CONTROL
CONNECTED



FIG. 3c

OUTPUT
WITHOUT DECAY
CONTROL



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3,175,158 CONTROLLED DECAY FEEDBACK TYPE COMB FILTERS

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This invention relates to a feedback comb filter, and more particularly, to a feedback comb filter having an infinite build-up time and a finite decay time.

A comb filter is generally defined as a filter whose frequency response characteristic has periodically spaced pass bands or stop bands over an infinite frequency range. The stop band or pass band regions of the filter, because of their repetitive nature, appear as the teeth of a comb. The term comb filter is generally applied in the practical approximation of these characteristics, even though the periodic pass bands do not cover an infinite frequency range in the physical device.

Comb filters are useful wherever it is desirable to separate a signal consisting of a pulse train or periodic signals from other signals of different repetitive frequency, or non-repetitive signals or noise. The dominant application of comb filters is in pulse radar systems, where signals are weak and must be separated from the noise, or to separate moving targets from stationary ones in a moving target indicator radar. Comb filters have a decay time that is essentially infinite. Due to this infinite decay time prior art comb filters have not been satisfactory for some applications because the pulses occurring during the decay period interfere with succeeding input pulses. The comb filter of the present invention has a finite decay time; thereby, eliminating the decay problem of the prior art.

It is, therefore, an object of the present invention to provide a feedback type comb filter having a finite decay time.

It is a further object of this invention to provide a means to increase the signal-to-noise ratio of a given signal.

It is still a further object of this invention to provide means to detect and separate a signal having a given repetition frequency from non-repetitive signals or from signals having a different repetition frequency.

These and other objects of the invention will be more clearly understood from the following description and accompanying drawings in which:

FIG. 1 is a block diagram of a comb filter in accordance with this invention.

FIG. 2 is a schematic diagram of a preferred embodiment of the invention.

FIGS. 3a-3c show certain time-amplitude relationships of interest in this invention.

The general mode of operation of the present invention will now be explained with reference to FIGS. 1 and 3. The elements, adder 10, amplifier 11 and delay line 12 are connected together to form a simple feedback-type comb filter. The operation of the comb filter can be more clearly understood if we assume that gate generator 13 is turned off so that it has no effect on amplifier 11. When this is true a single input pulse applied to input terminal 9 will appear at output terminal 16 with an essentially undiminished amplitude. In addition, this input pulse is amplified by amplifier 11 and is fed to delay 12. After a given period of time determined by the time delay introduced by delay line 12, the pulse is again available at output terminal 16. If we assume that the delay time of delay line 12 is T_d seconds, then every T_d seconds a pulse appears at output terminal 16. It is generally desirable to keep the gain in the feedback loop close to unity so that the pulse will not decay too rapidly; how-

ever, the feedback loop gain must be kept smaller than unity for stability.

The operation will now be considered where, instead of a single pulse, a pulse group consisting of four equal amplitude pulses, as shown in FIG. 3a, is applied to input terminal 9. The first pulse of the group will, of course, appear at terminal 16 with an essentially undiminished amplitude. As stated before, this pulse will also be applied to delay line 11. If the time delay introduced by delay line 12 is equal to the time between pulses, the pulse emerging from line 12 will appear at adder 10 at the same time the second input pulse is applied to the adder. If no losses were introduced in the feedback loop, the output from adder 10 would now be a single pulse having twice the amplitude of the input pulse. It is apparent that when the fourth and last pulse is applied to adder 10, the output from the adder will be a single pulse having an amplitude that is essentially four times greater than the amplitude of the original input pulses. Since the gain of the feedback loop is very close to unity there will be a pulse circulating through the comb filter for an extremely long period of time after the last pulse has been applied to adder 10. In other words, for practical purposes the decay time of the filter is essentially infinite. This infinite decay feature is shown in FIG. 3c.

The fact that the input signal is enhanced in amplitude by the comb filter makes this circuit desirable when a weak signal is masked by a random signal such as noise, because the input signal increases in amplitude more rapidly than the increase in the noise signal. The noise increases at a slower rate because a noise signal emerging from delay line 12 will not always be incident with like noise, and thus additive thereto, at input terminal 10. As was pointed out above, a comb filter as thus far described has one major disadvantage. This disadvantage is the extremely long decay time. In a filter of the type described not only will the decaying pulses mask any succeeding pulse group but any noise present, in the absence of an input signal, may continue to add to the noise already present, so the noise will eventually increase to the point where signal detection is impossible. The remainder of the circuits shown in FIG. 1 overcome the disadvantages just described by controlling the decay time of the filter. Any input signal applied to input terminal 9 is also applied to delay line 15 through amplifier 17. Delay line 15 is designed to have a delay of $(M+1) T_d$ seconds when the delay time of delay line 12 is T_d seconds. A decay time of MT_d seconds means that MT_d seconds after the last input pulse, the pulse circulating in the comb filter will be blanked or removed. In order to obtain this decay time the time delay of delay line 15 must be $(M+1) T_d$. The pulse appearing at the input of amplifier 17 is also applied to signal subtracting circuit 14. The output of delay line 15 is also applied to subtract circuit 14. The signal emerging from delay line 14 $(M+1) T_d$ seconds after it was applied to the line will have the same size and shape as the signal circulating in the comb filter. Since the two signals applied to subtract circuit 14 are the same, they will cancel each other. Stated in another way, MT_d seconds after the last input pulse has been applied to input terminal 9 the signal circulating in the filter will have completed $(M+1)$ trips and the amplitude (A) of the signal will be reduced to $A^{(M+1)}$. At this time the signal emerging from line 15 will also have an amplitude reduced to $A^{(M+1)}$; therefore, the two signals applied to subtract circuit 14 will cancel each other. Gate signal generator 13 has two inputs A and B. Input A is connected to the output of adder 10 and input B is connected to the output of subtract circuit 14. When no signal is present at B but a signal is present at A, generator 13 will develop a gating pulse. At all times other than

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MT_d seconds after the last pulse has been applied to terminal 9, there will be a signal present at input terminal B. As long as a signal is present at input B, generator 13 will not develop a gating signal. The gating signal generated by generator 13 turns off amplifier 11 so that the circulating pulse can not again enter delay line 12 and hence the signal recirculating pulses and extraneous recirculating pulses are blanked. FIG. 3b shows the output pulses appearing at terminal 16. FIG. 3b shows that the recirculating pulses in the filter of FIG. 1 abruptly decay to zero after a given interval of time.

FIG. 2 is a schematic diagram of a preferred embodiment of the invention. Input signals are applied to isolating amplifier 13. Amplifier 13 comprises a triode V₁ connected in a cathode-follower configuration and is used to isolate output 16 from the feedback loop. The output of amplifier 13 is fed to delay line 12 by means of amplifier 11 consisting of tetrode V₂ and by means of coupling tetrode V₃. The output of delay line 12 is coupled to adder 10 by means of cathode-follower triode V₄.

The output pulses from the delay line are added to the succeeding input pulses across resistors R₁, R₂ and R₃ and, as was pointed out above, the output of adder 10 will continue to grow in amplitude as long as pulses having an interspace time equal to the delay time of line 12 are applied to input 9.

Tetrode V₃ and triode V₄ are used to couple the input signals in and out of delay line 12, and to control the gain in the feedback loop. The operation of amplifier 11 will be discussed later. The input pulses are also applied to point A, to isolating amplifier 19 (V₅), and to video amplifier 17 (V₆). The output of amplifier 17 is connected to the input of delay line 15. The output from delay line 15 is coupled to point B by means of cathode-follower triode V₇. The output of cathode-follower V₅ is also coupled to point B. The output of delay line 15 and the output of triode V₅ are subtracted at point B. As was previously pointed out, at MT_d seconds after the last input pulse has been received the two pulses at point B will cancel each other, provided delay line 12 has a delay of T_d seconds and delay line 15 has a delay of (M+1) T_d seconds. Triodes T₁ and T₂ and diodes D₁ and D₂ are connected in clipper and limiter fashion so that any positive pulse present at points A and B will result in a fixed amplitude pulse at the grids of triodes T₃ and T₄, respectively. Triodes T₃ and T₄ are connected to operate as a balanced-gate signal generator. When signals appear at points A and B simultaneously, the grids of triodes T₃ and T₄, due to the action of clipper 20, will receive the same size signals so that the generator will not develop any output. When a positive signal appears at B and nothing at A, generator 13 develops an output which causes diode D₃ to conduct heavily. Heavy conduction of diode D₃ shorts out resistor R₇; thus, the output of generator 13 does not appear at the control grid of tetrode V₂. With no signal at point B and a positive signal at point A, the output of generator 13 back-biases diode D₃ and the diode looks like a large resistance. Under these conditions the negative pulse from generator 13 passes on to the grid of tetrode V₂ of amplifier 11, and amplifier 11 is cut-off. Cutting-off amplifier 11 blocks the input pulses from the feedback loop and the recirculating pulses drop abruptly to zero.

From the foregoing remarks it is apparent that the present invention retains the desirable features of the comb filter and eliminates the undesirable pulse decay time of a conventional comb filter.

It is to be understood that the scope of this invention is to be determined by the following claims and not by the specific embodiment described herein, which has been given by way of example only.

What is claimed is:

1. A comb filter comprising: signal input means; signal output means; adder means coupled between said input and output means; first signal delay means coupled

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between said output means and said adder means; a second signal delay means coupled to said output means; a subtract circuit coupled to said output means and to said second delay means; a pulse canceller coupled to said subtract circuit and to said first delay means.

2. A comb filter comprising: a signal adder comprising first, second and third resistors connected to a common junction point; signal input means connected to said first and second resistors; signal output means connected to said common junction point; a gated amplifier comprising a vacuum tube having an anode, a cathode, and a control grid; a cathode-follower amplifier having a grid connected to said output means and a cathode connected to the grid of said gated amplifier; a delay line having an input coupled to the anode of said gated amplifier and an output coupled to said second and third resistors; and means coupled to said means output and to the grid of said gated amplifier to cut-off said gated amplifier.

3. A finite decay time comb filter comprising: input signal means; output signal means; signal adder means connecting said input means to said output means; a gated amplifier comprising an anode, a cathode and a control grid; a first cathode-follower having a grid connected to said output means and a cathode connected to the control grid of said gated amplifier; a coupling amplifier comprising an electron tube having a cathode, a control grid and an anode; means coupling the anode of said gated amplifier to the grid of said coupling amplifier; a delay-line having an input and an output; means to couple said delay line input to the anode of said coupling amplifier; a second cathode-follower amplifier having a cathode, a grid, and an anode; means coupling the grid of said second cathode-follower to said delay-line output; means coupling the cathode of said second cathode-follower to said adder; and means including a second delay-line coupled between said output means and said gated amplifier to cut-off of said gated amplifier after a predetermined time.

4. A finite decay time comb filter comprising: input terminals for applying a pulse train of equally spaced pulses to said filter; output terminals; a signal adder connected between said input and output terminals; a gated amplifier having an input coupled to said output terminals and an output; a first signal delay means coupled between the output of said gated amplifier and said adder, said delay means having a delay time equal to the interspace time of said input pulses so that an output pulse from said delay means will be added to an input pulse by said adder; a video amplifier having an input coupled to said output terminals and an output; a second delay means having an input coupled to the output of said video amplifier and an output; a signal subtract circuit having one input coupled to the output of said second delay means, a second input coupled to said output terminals, and an output; a clipper circuit having a first input coupled to the output of said subtract circuit, a second input coupled to said output terminals, and a pair of outputs; a balanced signal generator having a first input coupled to one of the pair of outputs from said clipper circuit, a second input connected to the other of said clipper outputs, and an output; and means coupled between the output of said generator and the input of said gated amplifier for applying an output pulse from said generator only when no signal is present at the output of said subtract circuit and a signal is present at said output terminals.

5. A comb filter comprising: input terminals for applying equally spaced pulses to said comb filter; signal output terminals; an adder circuit coupled between said input terminals and said output terminals; a first electron tube having an anode, a cathode and a grid, means to couple the grid of said first electron tube to said output terminals; a second electron tube having a cathode, a first grid, a second grid, and an anode; means to connect the cathode of said first electron tube to the first

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grid of said second electron tube; a delay-line having a pulse delay time equal to the interpulse time of said input pulses; means including a third electron tube having a cathode, a first grid, a second grid, and an anode for coupling the anode of said second electron tube to said delay line; a fourth electron tube having a cathode, a grid, and an anode; means to couple output signals from said delay line to the grid of said fourth electron tube; means to couple the cathode of said fourth electron tube to said adder; and means coupled between said output terminals and said first grid of said second electron tube for electrically disconnecting said cathode of said first electron tube from said first grid of said second electron tube.

6. A comb filter as described in claim 5, said disconnecting means comprising: a fifth electron tube having a cathode, a grid, and an anode; means to couple the grid of said fifth electron tube to said output terminals; sixth and seventh electron tubes each having a cathode, a grid, and an anode arranged to operate as a clipper circuit; a signal subtract circuit coupled to the cathode of said fifth electron tube and to the grids of said sixth and seventh electron tubes; eighth and ninth electron tubes each having a cathode, a grid, and an anode; means to couple the grid of said eighth electron tube to the anode of said sixth electron tube; means to couple the grid of said ninth electron tube to the anode of said seventh electron tube; first and second diodes each having an anode connected to a common point and a cathode; means to connect the

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cathode of said first diode to the grid of said eighth electron tube; means to connect the cathode of said second diode to the grid of said ninth electron tube; a transformer having a primary connected to the anodes of said eighth and ninth electron tubes; and a secondary; a third diode connected across said secondary; means to couple said third diode to the first grid of said second electron tube; a tenth electron tube having a cathode, a first grid, a second grid and an anode; means to connect the first grid of said tenth electron tube to said output terminals; a second delay line having an input coupled to the anode of said tenth electron tube and an output; an eleventh electron tube having a cathode, a grid, and an anode; means to couple the output of said second delay line to the grid of said eleventh electron tube; and means to couple the cathode of said eleventh electron tube to said subtract circuit.

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