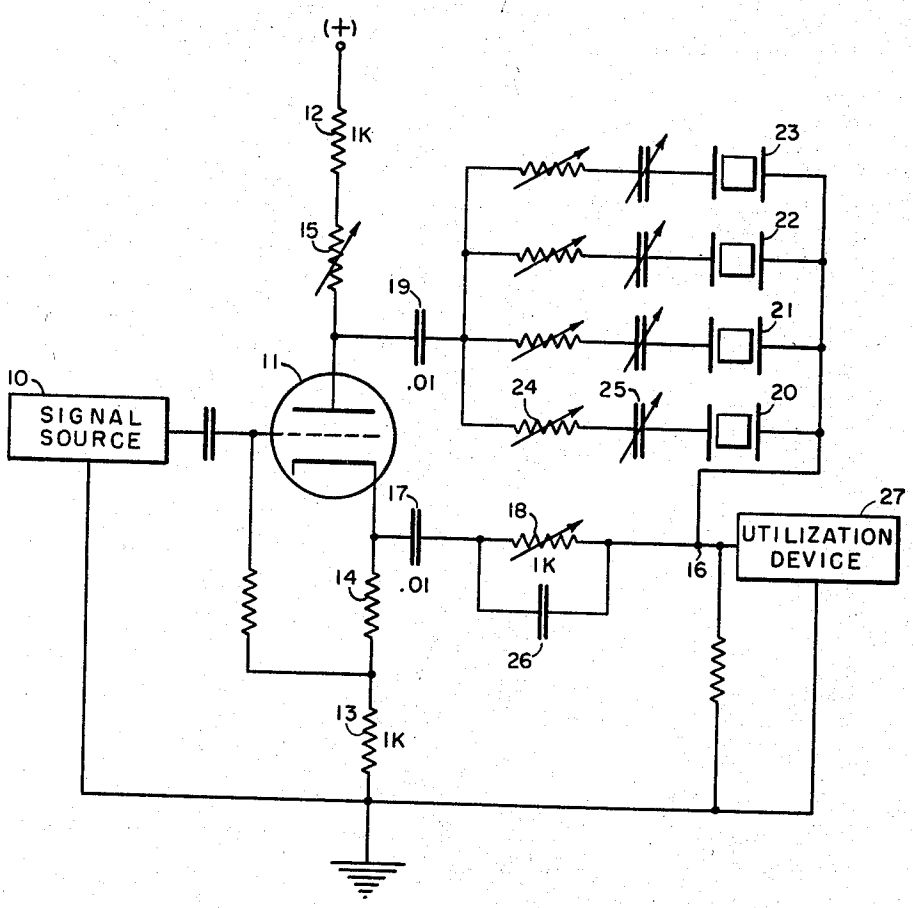
Feb. 16, 1965 G. K. JENSEN ETAL 3,170,120

ACTIVE COMB FILTER

Filed Sept. 23, 1960

2 Sheets-Sheet 1

FIG. 1



INVENTORS
GAROLD K. JENSEN
JAMES E. McGEOGH

BY Shelton McAnelly, Agt

Richard C. Reed ATTORNEY

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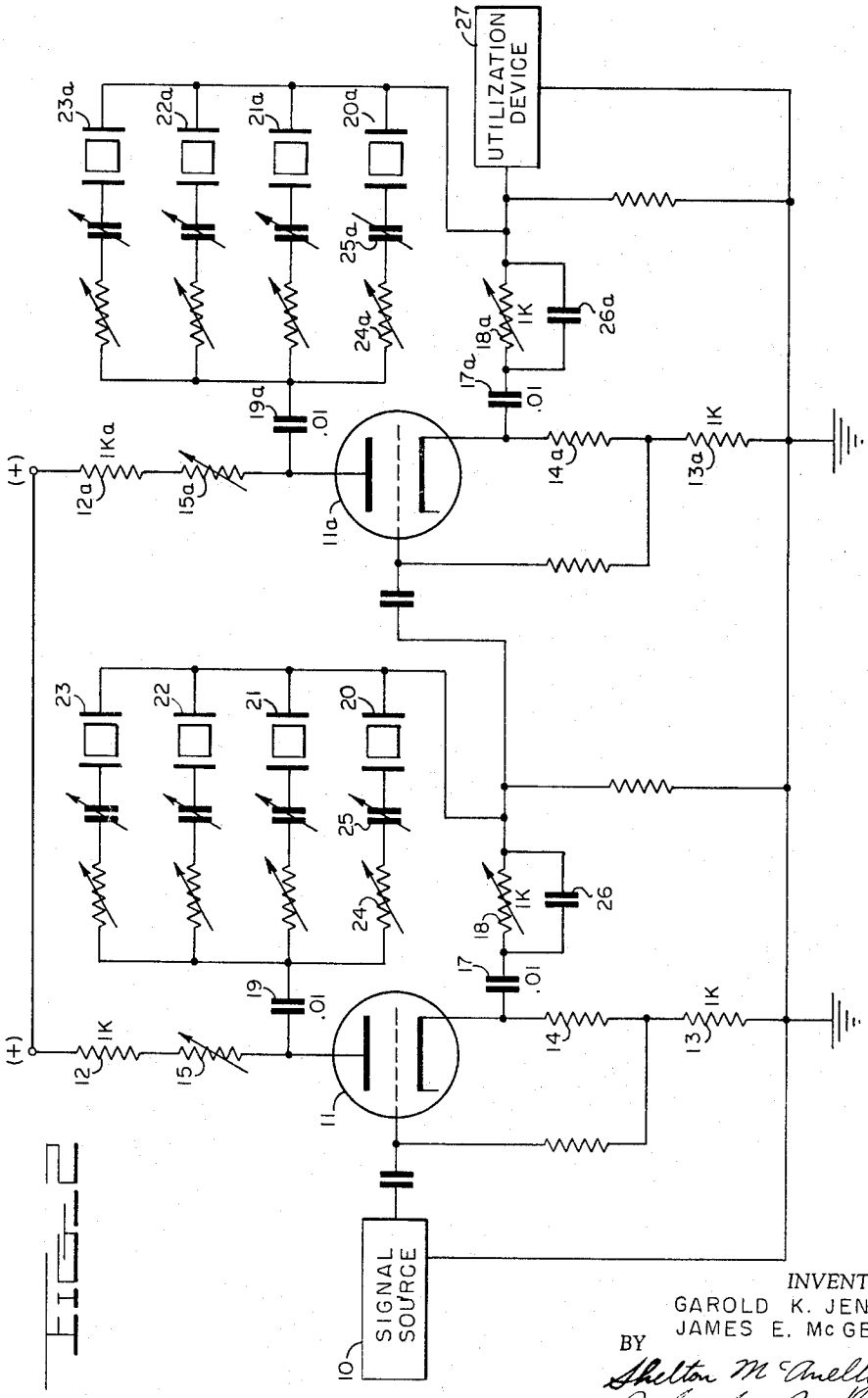


FIG. 2

INVENTORS
GAROLD K. JENSEN
JAMES E. Mc GEOGH

BY Shelton McAnelly, Agt
Richard A. Reel
ATTORNEY

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ACTIVE COMB FILTER

Garold K. Jensen, 8012 Overlook Drive, Pinecrest, Va., and James E. McGeogh, 902 Dennis Ave., Silver Spring, Md.

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The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This invention relates to electrical filters in general and in particular to filters having a plurality of selective rejection frequencies occurring over a relatively wide frequency band width.

In the electrical filter art occasionally it is necessary to provide a filter having characteristics different from the conventional high pass, low pass, or band pass or band rejection filters normally encountered. A typical instance of such an unusual filter requirement involves pulse doppler radar systems operating in the high frequency range. The transmitted pulse signal is in fact a spectrum of frequencies consisting of a carrier plus a number of sidebands on each side of the carrier separated by the pulse repetition frequency and extending as far from the carrier as necessary to define the transmitted pulse shape. In the case of a rectangular pulse a bandwidth in the order of

$$\pm\frac{1}{\text{pulse width}}$$

is usually considered adequate. In the high frequency range of operation the transmitted signal may be refracted from the ionosphere and return to the ground at some distant point where it is reflected and returns to the radar system via a similar path. The return signal is identified as "backscatter." Phenomena associated with the ionosphere cause a modulation of the backscatter at random rates generally of 5 c.p.s. or less. Each spectral component of the transmitted signal is spread over a band of ±5 c.p.s. in the backscatter return. Targets of interest generally have radial velocities which produce doppler frequencies in excess of 5 c.p.s. Then if a rejection filter of ±5 c.p.s. width is placed at each spectral component of the transmitted signal, the backscatter effects will be removed and the desired target information may be retained.

Apparatus has been available in the past for producing such "comb" filter characteristics, however all such devices known have been of limited accuracy, of a highly complex nature and not particularly suited to experimental operations wherein it might be desired to change the number of "teeth" in the "comb," or their width or spacing because of interaction of the various components necessary in prior art devices to produce the comb filter characteristics.

It is accordingly an object of the present invention to provide a comb filter of simple nature. Another object of the present invention is to provide a comb filter in which the number of teeth in the comb may be altered at will without any serious effect on the operation of the remaining components of the filter. Other and further objects and features of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein;

FIG. 1 of the drawing shows in schematic form a typical embodiment of the features of the present invention.

FIG. 2 of the drawing shows also in schematic form a

variation of the features of the present invention involving a cascaded arrangement of the basic apparatus of FIG. 1.

In accordance with the basic teachings of the present invention a comb filter is provided wherein is employed a bridge circuit consisting of parallel signal paths excited by opposite polarity signals. One path is substantially nonselective in frequency whereas the other path is sharply frequency selective, transmitting a signal thereof with extremely narrow band width at a selected frequency band. A plurality of the narrow band width filters tuned to different frequencies are employed connected in parallel in the same signal path. Thus by providing a plurality of narrow band selective transmission paths it is possible to obtain selective transmission of one of the basic signal paths at a plurality of different frequencies. With out-of-phase signals existing in the two basic signal paths, combinations of these outputs thereof will result in the cancellation of signals at the frequencies at which the selective paths are transmissive. Additional selective circuits can be provided without interaction because each selective circuit is of such nature as to be substantially complete in itself having no interaction upon associated circuits tuned to different frequencies. The foregoing basic apparatus may be duplicated with connection in cascade of a plurality of such units tuned to staggered frequencies to broaden and deepen the rejection region at each tooth. Typically three or five or more stages may be so stagger tuned.

With reference now to FIG. 1, the apparatus shown therein is a typical embodiment of the features of the present invention containing a signal source **10** which is of any suitable nature such as the aforementioned radar system, typically in this case, however being operative at a receiver intermediate frequency which may be exemplified as having a frequency of the order of 100 kilocycles per second. The principles of the invention could be applied to other signals such as audio or video frequencies. This signal has a finite band width which is typically of the order of several kilocycles and contains the portions of that band which must be rejected in the previously described "comb" manner. The signal source **10** is connected to a push-pull signal conversion device having the electron tube **11** with substantially equal anode and cathode resistive loading as identified by the reference numerals **12** and **13**. Additionally the cathode circuit has a biasing resistance **14** and the anode circuit has a balancing resistance **15** by means of which equality of signal amplitude at anode and cathode may be obtained. Alternately the resistances **14** and **15** may be made of equal size precision units and balancing effected by selection of values of the subsequent components. The similarity of the circuit of tube **11** to the conventional split load phase inverter is apparent, with the load resistors being small to prevent unnecessarily reducing the Q of the quartz crystals.

The cathode of tube **11** is connected to a junction point **16** by means of a blocking capacitance **17** and a bridge resistance **18**. The anode of tube **11** is also connected to point **16** by a blocking capacitance **19** and a typical group of quartz crystals identified by the numerals **20**, **21**, **22**, and **23**. In series with each crystal is a resistance such as **24** and a capacitance such as **25**, resistance **24** providing for controlling the Q and hence the band width of each "tooth" of the comb whereas the capacitance **25** provides a method of tuning of the crystal in that arm to obtain a particularly desired frequency. Each crystal **20** to **23** is of a high "Q" nature typically having a Q of 150,000. High "Q" crystals are desirable as that resistive heating thereof and resultant frequency shift is minimized.

Junction point **16** of the bridge is connected to a suitable

utilization device 27 which may provide further amplification or some sort of signal storage or other presentation device depending upon the particular utility of the associated circuitry.

With the circuit as described in the foregoing, substantially equal amplitude but opposite polarity signals are obtained at the anode and cathode of tube 11 responsive to the signals from signal source 10 applied to the grid of tube 11. If these signals are not equal, resistance 18 may be adjusted to compensate. The signals realized at the anode and cathode of tube 11 are applied through the parallel paths to the common junction point 16. The cathode signal path is not frequency sensitive to any substantial degree, passing all frequencies involved with substantially equal ease. The path associated with the anode of tube 11 on the other hand, is an entirely different affair. Each of the crystals 20 to 23 is very sharply resonant at a desired frequency at which point it has very low impedance so that the anode signal can reach the bridge junction point 16. When this occurs the two equal amplitude and opposite polarity signals cancel so that for all practical purposes the frequency to which a crystal is tuned is eliminated from the output. The bandwidth of each tooth is narrow compared to the space between teeth so the tuning of each crystal is susbtantially independent of all other crystals, and it is possible to add crystals to a much greater total than that indicated in FIG. 1 to provide the desired number of steps or "teeth" in the comb. For the typical pulse doppler radar previously discussed, where rejection is desired at sidebands of the carrier frequency spaced at multiples of the pulse repetition rate (PRR) the number of crystals required is the spectral bandwidth divided by the PRR, and they are operated in parallel as shown in FIG. 1.

Although the components associated with tube 11 are selected in conventional manner in consideration of the frequencies of the signals involved, resistance 18 which may have a typical value of the order of 1000 ohms is selected to be approximately equal to the ultimate effective value of the broad banding resistances 24, plus its associate crystal series resistance.

When the number of crystals is small, say 1–10, balancing of the anode and cathode paths can be accomplished to a sufficient degree by mere resistive balancing with resistance 18. Where larger quantities of crystals are required, resistive balancing alone is not adequate, but must be accompanied by reactive balancing of the capacitance of nonresonant crystals by the adjustment of a capacitance 26 placed in shunt with resistance 18, typically for a unit with 63 crystals, capacitance 26 may have a value of 600 micromicrofarads.

To complete the typification, resistance 24 may have a value of 2300 ohms and capacitance 25 a value of 100 micromicrofarads.

Operation of the apparatus can produce quite impressive results, providing a bandwidth of six cycles between 3 db points and frequency stability within 0.1 cycle per second at 100 kilocycles per second operating frequency. The signal rejection at the crystal frequencies can be of the order of 65 db.

An important characteristic of the apparatus is that with high "Q" crystals, each crystal is substantially an open circuit in relation to the non-frequency selective path except to the narrow band of frequencies which may coincide with a particular crystal. Thus crystals can be added to increase the number of "teeth" in the "comb" and be as closely spaced as required. If the requirements are such that the bands of frequencies may be so closely spaced as to prevent the avoidance of interaction it may be desired to employ a cascade of stages, each with its own means 11 for deriving a push-pull signal so that rejection frequencies so close together as to provide interaction if in a single stage are placed in different stages.

In instances where a broader and deeper rejection characteristic is desired, a plurality of basic filter stages connected in cascade as shown in FIG. 2 and tuned to different frequnencies can provide such operation. In FIG. 2, the basic apparatus of components numbered 11 through 26, is followed by a second similar stage wherein the components therein are identified by similarly numbered reference characters having the suffix *a*. The crystals 20–*a*, 21–*a*, 22–*a* and 23–*a* are tuned ½ cycle per second higher in frequency than crystals 20, 21, 22 and 23 of the first stage. If desired, the second stage can be followed by a third stage tuned ½ cycle lower in frequency than the first stage, and even additional stages to provide even further flexibility and variation.

Although FIG. 2 has been mentioned as providing certain filter characteristic possibilities, one might inquire as to why these extra filters of the second stage were not placed in a single stage of the basic apparatus of FIG. 1. Under certain circumstances it is quite possible that such an arrangement would be satisfactory, however the basic apparatus of FIG. 1 was envisioned as a device in which the crystals were so widely separated in frequency in respect to their individual bandwidths as to avoid any interaction between the crystals so that as a practical matter each crystal functioned entirely independently. When crystals are placed so close in frequency as the half cycle mentioned in connection with FIG. 2, this absence of interaction is not necessarily obtained and under certain conditions such interaction might not be desired. For this reason the separate arrangement of FIG. 2 has advantages. Another advantage of the apparatus of FIG. 2 is that even if it were not desired to vary the characteristics or shape of individual rejection "teeth" by placement of crystals a half cycle apart in different stages, but rather to provide additional teeth between those of the basic portion of FIG. 1, that again interaction between crystals can occur which might be undesirable. Thus again the apparatus of FIG. 2 would be used to provide increased number of teeth in close proximity to each other.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A filter for rejecting selected narrow bands of frequencies from an input signal comprising, means for deriving a push-pull signal in response to the input signal, a first signal path substantially non-frequency selective, a second signal path containing a plurality of crystals connected in parallel, one tuned approximately to the center of each band of frequencies, said paths having input and output connections, means for connecting the input of one path to said first named means to transmit one of the push-pull signals, means connecting the input of the other path to said first named means to transmit the other of the push-pull signals, and means for connecting the output connections of the two paths whereby equal amplitude combination at the crystal frequency occurs.

2. A filter for rejecting selected narrow bands of frequencies from an input signal comprising, means for deriving a push-pull signal in response to the input signal, a first signal path substantially non-frequency selective, a second signal path containing a plurality of crystals connected in parallel, one tuned approximately to the center of each band of frequencies, individual means in circuit with each crystal whereby crystals may be impedance balanced, said paths having input and output connections, means for connecting the input of one path to said first named means to transmit one of the push-pull signals, means connecting the input of the other path to said first named means to transmit the other of the push-pull signals, and means for combining the output of the two paths whereby equal amplitude combination at the crystal frequency occurs.

3. A filter for rejecting selected narrow bands of frequencies from an input signal comprising, means for de-

riving a push-pull signal in response to the input signal, a first signal path substantially non-frequency selective, a second signal path containing a plurality of crystals connected in parallel, one tuned approximately to the center of each band of frequencies, individual means in circuit with each crystal whereby crystals may be impedance balanced, said paths having input and output connections, means for connecting the input of one path to said first named means to transmit one of the push-pull signals, means connecting the input of the other path to said first named means to transmit the other of the push-pull signals, means for combining the output of the two paths, and means for balancing the signals delivered through the two paths whereby equal amplitude combination at the crystal frequencies occurs.

4. A filter for rejecting selected narrow bands of frequencies from an input signal comprising, means for deriving a push-pull signal in response to the input signal, a first signal path substantially non-frequency selective, a second signal path containing a plurality of crystals connected in parallel, one tuned approximately to the center of each band of frequencies, said crystals having a "Q" of sufficient magnitude that each crystal is substantially non-transmissive to frequencies outside its band, individual means in circuit with each crystal whereby crystals may be impedance balanced, said paths having input and output connections, means for connecting the input of one path to said first named means to transmit one of the push-pull signals, means connecting the input of the other path to said first named means to transmit the other of the push-pull signals, means for combining the output of the two paths, and means for balancing the signals delivered through the two paths whereby equal amplitude combination at the crystal frequencies occurs.

5. A filter for rejecting selected narrow bands of frequencies from an input signal comprising, a plurality of stages of filters each comprising; means for deriving a push-pull signal in response to the input signal, a first signal path substantially non-frequency selective, a second signal path containing a plurality of crystals connected in parallel, one tuned approximately to the center of each band of frequencies, said crystals having a "Q" of sufficient magnitude that each crystal is substantially non-transmissive to frequencies outside its band, individual means in circuit with each crystal whereby crystals may be impedance balanced, said paths having input and output connections, means for connecting the input of one path to said first named means to transmit the other of the push-pull signals, means for combining the output of the two paths, and means for balancing the signals delivered through the two paths whereby equal amplitude combination at the crystal frequencies occurs; wherein at least one of the crystals of one stage is tuned to a different frequency from the crystals of any other stage, and means connecting the stages in cascade.

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HERMAN KARL SAALBACH, *Primary Examiner.*

BENNETT G. MILLER, *Examiner.*