

March 11, 1952

E. S. PURINGTON
ELECTRICAL FILTER

2,589,133

Filed Jan. 13, 1948

2 SHEETS—SHEET 1

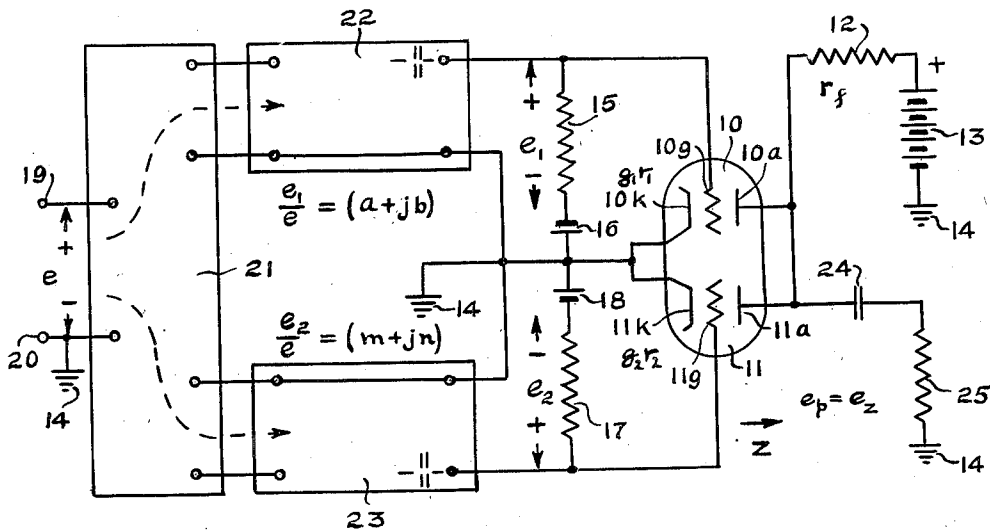


Fig. 1.

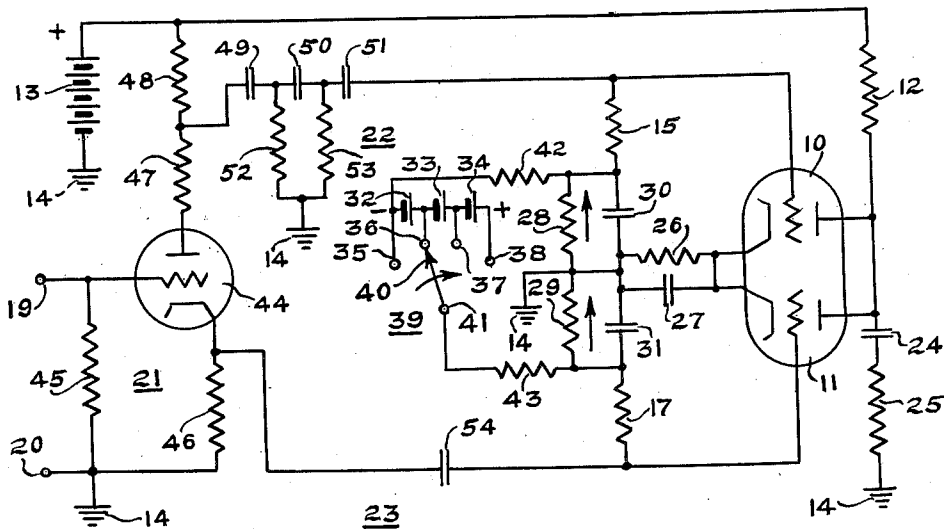


Fig. 2.

INVENTOR
ELLISON S. PURINGTON.
BY

W. Leek

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2 SHEETS—SHEET 2

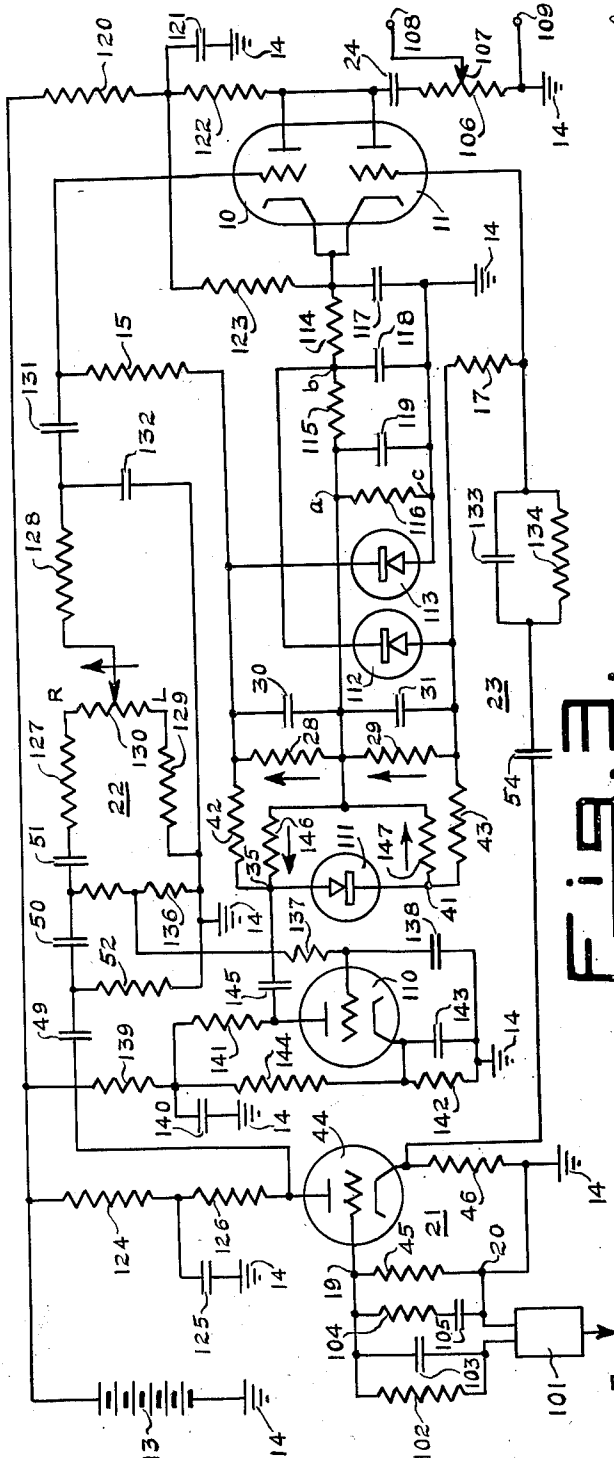


Fig. 3.

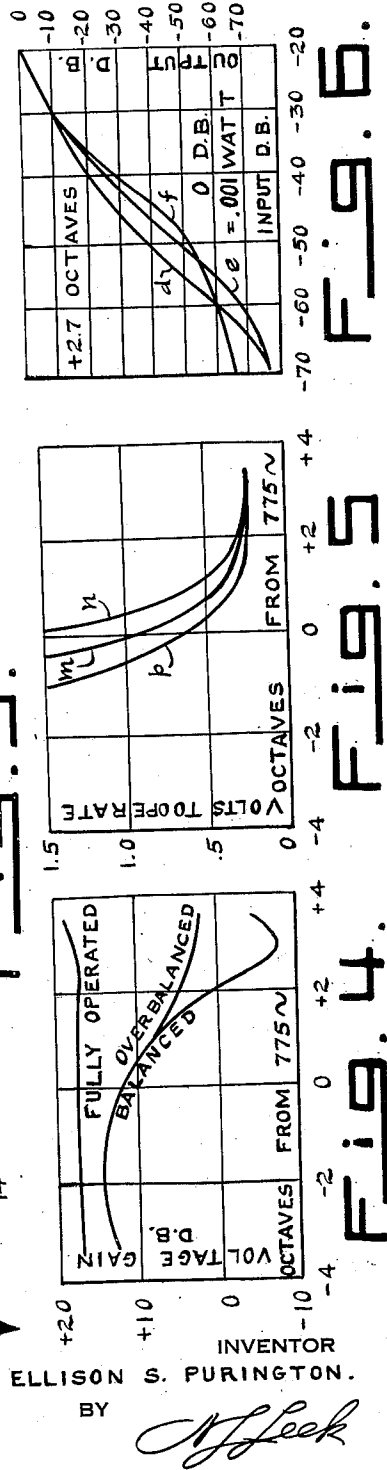


Fig. 6.

Fig. 5.

Fig. 4.

INVENTOR
ELLISON S. PURINGTON.
BY *W. Leek*

UNITED STATES PATENT OFFICE

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ELECTRICAL FILTER

Ellison S. Purington, Gloucester, Mass., assignor
to John Hays Hammond, Jr., Gloucester, Mass.

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3 Claims. (Cl. 178-44)

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This invention relates to a method of producing an electrical transmission system through which the transfer of energy is a frequency function of the input signal, and to a method of modifying the transmission in accordance with the strength and frequency distribution of the input signal.

In Patent No. 1,979,035 to John Hays Hammond, Jr., has been shown a sound reproducing system including a sound record, a pickup device therefor, a variable filter fed by said pickup device, a sound propagating device fed by said filter, and means controlled by the amount of energy from said pickup device for varying the frequency characteristics of said filter.

Various types of filters and various methods of control of the transmission through such filters have been disclosed in Patents 2,008,825 and 2,009,229 to John Hays Hammond, Jr., in my Pat. No. 2,096,760, and in my copending application Serial No. 778,684, filed October 8, 1947, entitled "Selective Amplifier System."

The present invention relates to a further method of filter construction and control. One of the especial advantages of my present system is that suitable results for many purposes may be obtained with circuits employing standard resistors, capacitors and electronic tubes, without requiring the use of special inductors or transformers as in previous arrangements.

Fig. 1 is a schematic diagram showing a general method of construction of a filter in accordance with my invention.

Fig. 2 is a schematic diagram showing a more specific case of a low pass filter, with means for changing the transmission characteristics by application of a direct current.

Fig. 3 is a schematic diagram showing an arrangement suitable for use in automatic scratch filters for phonograph circuits; and

Figs. 4, 5, and 6, are curves illustrating the performance of a circuit constructed in accordance with Fig. 3.

In Fig. 1 is shown a pair of triode tubes 10, 11, with plates or anodes 10a and 11a connected together, and with cathodes 10k and 11k connected together. The anodes are connected through feed resistor 12 of resistance value r_1 to the positive end of battery 13, the negative end of which is connected to ground at 14. The cathodes are also connected to ground. The grid 10g is connected to ground through grid resistor 15 and bias battery 16, and the grid 11g is connected to ground through grid resistor 17 and

bias battery 18. The input filter terminals are 19 and 20, the latter of which is connected to ground 14. These input terminals are connected into distributor 21 which diverts some of the signal input through network 22 to the grid-ground circuit of triode 10, and which diverts other of the signal input through network 23 to the grid-ground circuit of triode 11. Blocking capacitors may be included in the networks 22 and 23 in the leads to the grids of the triodes 10 and 11. The plates of triodes 10 and 11 are connected to ground through blocking capacitor 24 and the load impedance 25. The blocking capacitor 24 may be chosen of negligible impedance, so that the external output impedance indicated as Z may be the load impedance 25. In this manner the output voltage of the system across 25 is identical with the A. C. component of the plate to ground voltage for triodes 10 and 11.

Suppose the ratios of the voltages e_1 and e_2 on the grids of triodes 10 and 11 to the voltage e across the input terminals 19 and 20 are given by—

$$e_1/e = (a + jb) \quad (1)$$

$$e_2/e = (m + jn) \quad (2)$$

where a, b, m, n are functions of frequency, and j is the vector operator of well known significance. Let g_1 and g_2 be the conductances and r_1 and r_2 the internal resistances of triodes 10 and 11. Let $e_p = e_z$ be the output voltage for the system.

If the triodes are of identical construction with like grid bias, it is evident that there will be no transmission from e to e_z for any frequency for which $m = -a$ and $n = -b$ in Equations 1 and 2. That is, although both grids of the triodes may be energized, nevertheless the system may be balanced for some frequency, and partly balanced for a range of frequencies, such that the transmission from input to output is greatly reduced for some frequency regions over that for other frequency regions. Thus by choice of networks 21, 22, 23, the overall transmission from input to output may have any desired characteristic, such as low pass, high pass, band pass or band elimination. The transconductance of the filter system from input to load, neglecting stray impedances such as inter-electrode capacitances not shown is given by—

$$\frac{e_p}{e} = \frac{e_z}{e} = - \left[\frac{g_1(a + jb) + g_2(m + jn)}{Y} \right] \quad (3)$$

where Y is the admittance for an A. C. signal

impressed across the external load circuit Z when there is no input signal, and is given by—

$$Y = \left[\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_f} + \frac{1}{Z} \right] \quad (4)$$

This equation will suffice to enable those skilled in the art to design amplifying circuits with gain bands with loss bands.

Fig. 2 shows for example how a low pass filter with variable characteristics may be constructed to give a treble control system for phonograph and radio receiver circuits and the like, with fairly uniform transmission in the low audio frequency range, and with variable loss in the high audio frequency range. Elements of Fig. 2 corresponding to those of Fig. 1 have been given the same reference numerals and will not be redescribed. The cathodes of triodes 10 and 11 are not directly connected to ground, however, but are connected to ground 14 through bias resistor 26 and bypass capacitor 27, which establishes the cathode at more positive potential than the grids under all conditions of operation. In place of fixed bias batteries 16 and 18 of Fig. 1, the grid returns of triodes 10 and 11 are connected to ground through resistors 28 and 29, bypassed by capacitors 30 and 31, through which resistors D. C. currents may be caused to flow in the direction shown to provide for variation of the operating characteristics of the triodes 10 and 11. In the present instance, this D. C. current is provided by a series of batteries 32, 33, 34 connected across the fixed contacts 35, 36, 37, 38 of a single section four position non-shorting switch 39 with movable contact 40 shown to be on fixed contact 36. Fixed contact 35 to which the negative end of battery 32 is connected, is connected through resistor 42 to the junction of resistors 15 and 28; and switch terminal 41, which is connected to variable contact 40 which touches fixed contact 36 to which the positive end of battery 32 is connected, is connected through resistor 43 to the junction of resistors 17 and 29. Thus with suitable construction the grid of triode 10 may be biased negative to ground, and the grid of triode 11 may be biased positive to ground but not so positive as the cathodes of the triodes 10 and 11, by suitable D. C. currents derived from the batteries 32 to 34 in accordance with the switch setting. For a switch position with movable contact 40 on fixed contact 35 so that no D. C. current flows in the biasing resistors 28 and 29, the construction may be such that the triodes operate with somewhat more bias than Class A. As the switch arm is moved, the construction may be such that in final position with contact 40 on 38, the triode 11 operates as Class A, and the triode 10 is cutoff, so that transmission from input terminals 19—20 to the filter output is through the use of triode 11 only.

Constants may be so chosen that the sum of the D. C. space currents through the triodes 10 and 11 is substantially independent of the setting of the switch 39, so that no abrupt transient changes occur in the voltage to 25 as the switch is moved.

The distributor 21 of Fig. 1 has its representation in Fig. 2 in the form of a triode 44; with the grid connected to input terminal 19, and connected to ground through resistor 45, with the cathode connected to ground through resistor 46, and with the plate connected to the positive end of battery 13 through resistors 47 and 48 in series. This in effect is an electronic phase

inverter system which supplies substantially oppositely phased voltages for actuating triodes 10 and 11 in a balanced sense for the frequency bands which it is desired for the filter to suppress. The network 22 of Fig. 1 is represented in Fig. 2 by a high-pass RC filter here shown with two full sections, comprising series capacitor elements 49, 50, 51, and shunt resistor elements 52 and 53 connected from the junctions of capacitors 49 and 50 and of capacitors 50 and 51 to ground 14. And finally, network 23 of Fig. 1 has its counterpart in Fig. 2 in a single blocking capacitor 54, which provides efficient coupling from the cathode of triode 44 to the grid of triode 11 for all frequencies.

In the operation of Fig. 2, the values of resistors 47 and 48 may be so chosen that for the switch 39 full left, the system is nearly in balance for very high frequencies which networks 22 and 23 both transmit well with little phase shift. Low frequencies as well as high frequencies will be transmitted by network 23. As the switch 39 is moved to the right, there is a reduction of the effect of network 22 upon the final output and a somewhat increased effect of the network 23, due to the opposite changes of bias. As a result, the system as a whole ceases to have frequency discriminating properties, and transmits well on all frequencies by way of network 23.

While in Fig. 2 a performance results similar to that of "constant-K" type low pass filter, it is also possible to make simple changes and produce a result similar to a "variable-k" trap circuit low pass filter, commonly termed "m-derived." Thus in Fig. 2, balance cannot exist except for infinite frequency, since there is even at highest audio frequencies a slight phase advance in network 22. However, balance can be made at a finite high frequency by use of a phase retarding device associated with network 22, such as a shunt capacitor across resistor 53, or by a phase advancing device associated with network 23, such as a resistor paralleled by a capacitor, both in series with blocking capacitor 54. In this manner the system may be brought into quite complete balance for one frequency in the high frequency loss range, with incomplete balance for both higher and for lower frequencies.

Other characteristics may be given by using different construction, such as a variable high pass filter using a low pass RC network for 22, suitable for bass tone control. Or by making network 22 a high pass filter paralleled by a low pass filter so that balance is approached both for very high and for very low frequencies, a band pass filtering arrangement is provided, which can be modified by electrical methods.

The circuit of Fig. 3 is that of a system whereby the transmission characteristics of the arrangements of Figs. 1 and 2 may be made to change automatically in accordance with the nature of the input signal. Here parts corresponding to Fig. 2 have corresponding reference numbers the same, and all parts with numbers in excess of 100 are additional or modified devices.

In Fig. 3, the input to the phase inverter tube 44 is from a phonograph input pickup 101 with a suitable compensating network including elements 102 to 105. The output of triodes 10 and 11 is to a potentiometer 106 with the variable tap 107 connected to output terminal 108, with the grounded end of the potentiometer connected to output terminal 109. This potentiometer may be a volume control, and the output terminals may

be connected through a manual tone control system to a power amplifier stage before driving a loudspeaker.

In place of manually operated switch 39, provisions are made to vary the filtering characteristics by use of a rectifier driver tube 110 with input signal from a point on the network 22, operating into a rectifier 111 which may be a diode electronic tube or an oxide or crystal detector rectifier. Also unidirectional conductors 112, 113 are used to limit the changes of bias produced by rectifier 111.

To accommodate the functioning of devices 112, 113, the cathode circuit for triodes 10 and 11 includes resistors 114, 115 and 116 in series from cathode to ground, with bypass capacitors 117, 118 and 119. The plate circuit of triodes 10 and 11 is also modified by use of decoupling resistor 120 and capacitor 121, with plate feed resistor 122 and a bleeder resistor 123 connected from the junction of resistor 120 and capacitor 121 to the plates and cathodes of triodes 10 and 11. The junctions of automatic bias resistors 28 and 29 are not connected to ground, but to the junctions of resistors 115 and 116, so that the grid returns for triodes 10 and 11 are at a positive point designated *a*. The point *b* at the junction of resistors 114 and 115 corresponds to proper bias for triode 11 for Class A operation, with peak signals, and ground point *c* corresponds to cutoff for triode 10 with peak signals. Unidirectional conductor 112 has its anode connected to the junction of resistors 17 and 29, and its cathode connected to junction *b*. Similarly unidirectional conductor 113 has its anode connected to the ground junction point *c* and its cathode connected to the junction of resistors 15 and 28, whereby the triode 11 will not operate with cathode to grid bias less than that corresponding to Class A operation, and the triode 10 will not have its grid driven beyond cutoff.

The inverter tube 44 uses a decoupling plate resistor 124 and capacitor 125, with a feed resistor 126 across which the output A. C. voltage develops. The plate of triode 44 is direct connected to the first capacitor 49 of the network 22, which network also includes the T pad including resistors 127, 128, 129 and balancing potentiometer 130, as well as an added series capacitor 131 and a shut capacitor 132. The network 23 includes the main capacitor 54, and also capacitor 133 paralleled by resistor 134. These networks and the inverter tube circuits are properly correlated to give good balance both as to amplitude and as to phase for a high frequency slightly below the cutoff of pickup 101 and of the succeeding amplifier and loudspeaker beyond the output volume control 106. They are also arranged to provide suitable transmission mainly in the lower audio frequency range where the frequency contributions to the scratch noise are small.

In place of shunt resistor 53 of Fig. 2, a pair of resistors 135 and 136 in series is used, with their junction connected through resistor 137 to the grid of driver tube 110. A capacitor 138 may be connected from grid to ground to minimize excitation of the driver by very highest frequencies. Thus the driver tube 110 is suitably excited from signal which arises on the network 22 which carries frequencies in the high frequency range.

The plate circuit of the driver tube 110 includes decoupling resistor 139 and capacitor 140, and feed resistor 141. The cathode circuit in-

cludes cathode resistor 142 and capacitor 143, and also a bleeder 144 may be used to bias the driver below cutoff so that it does not amplify until the input signal is greater than a threshold amount.

In place of switch 39, the rectifier 111 is connected between terminals 35 and 41 to serve as a source of D. C. for automatic bias. The plate of the driver 110 is connected through blocking capacitor 145 to the anode of 111, and resistors 146 and 147 may be connected from the anode and from the cathode of 111 to the junctions of resistors 28 and 29. These should not be bypassed, since A. C. voltage across the rectifier is necessary for proper action. The capacitors 30 and 31 serve as filter capacitors to keep the A. C. components across 146 and 147 from getting into the output of the triodes 10 and 11. These capacitors are chosen for providing quick dynamic action without the delays that are usually required in expander amplifiers. It will be understood the resistors associated with the grid of 10 may be of higher resistance values than corresponding resistors for the grid of 11 so that no modulation of importance will develop across resistor 122. Correspondingly, however, the capacitors 30 and 31 should be differently chosen to keep the time constants of both systems approximately the same.

In the operation of Fig. 3, the system is balanced by potentiometer 130 using the entrance or exit grooves of a record, or so that noises in the scratch range are minimized in the absence of signals. When high frequency signals are absent, so that tube 110 is not energized, low frequency signals such as those representing kettle drums will come through without high frequency scratch noises present. When, however, there are high frequency signals present to actuate the driver tube 110, the rectifier 112 will be actuated and upset the balance by driving the grid of triode 10 negative and driving the grid of triode 11 positive, in proportion to the intensity of the high frequency signals, until limited by the action of devices 112, 113. When the high frequency signals cease, the biases change back quickly to normal. This provides for elimination of scratch noises when there are no signals in the scratch range suitable to mask the noises.

Illustrative examples of the performance obtainable with an automatic scratch filter constructed in accordance with Fig. 3 are shown in Figs. 4, 5 and 6.

Fig. 4 shows the overall gain characteristics of a filtering amplifier in decibels, as a function of signal frequency. The curve "Balanced" refers to the gain for very weak signals when the potentiometer 130 is set to give maximum rejection of 5000 c. p. s., while curve "Overbalanced" gives the gain for weak signal when the potentiometer is moved to increase the amount of signal through the high frequency channel to the grid of tube 10. The curve "Fully Operated" refers to the gain when there is a signal combination which causes the rectifier 111 to operate the limiters 112 and 113. A dynamic expansion range in excess of 15 db for all frequencies above 3000 is provided. This range is adjusted by the setting of the potentiometer 130.

Fig. 5 shows the control characteristics, namely the amount of input signal on any frequency to cause the limiters 112 and 113 to operate. Three different curves are shown, for different designs, with curve *m* that which cooperates with the characteristics of Fig. 4 in a most suitable manner.

Fig. 6 shows the expansion characteristics for a fixed frequency input of 2.7 octaves above 775 cycles, with different control settings. Curves *d* and *e* refer to the relation of output to input db with the control set at "Balanced" position, with strong and with weak feed to the driver tube 110. Curve *f* shows the expansion when the "Over-balanced" curve of Fig. 4 is used with weak feed to rectifier driver 110. This arrangement especially prevents the gain of the system from rising until the signals which control the dynamic characteristics as in Fig. 4 are quite strong. While it is within the scope of this invention to provide various controls over the dynamic operation, or to control both the balance and the feed to the tube 110 by a single knob, it also works out well to set these controls for a best average condition, with slight overbalance and neither too great nor too weak feed to the rectifier driver 110.

The circuit arrangements may be simplified in many ways by those skilled in the art. Thus limiters 112 and 113 may be eliminated and corresponding simplifications made in the cathode to ground circuit for triodes 10 and 11. In place of these limiters, the resistor 139 for driver tube 110 may be so chosen that excessive output will not be produced by the rectifier 111. Various other modifications may be made to adapt the principle to other types of performance curves than shown. It is within the broad scope of this invention to arrange for greatest expansion on low frequencies by using a low pass RC filter for 22 instead of a high pass filter. Such a system could be driven by the output of the variable high pass filter of Fig. 3. It is also within the scope of this invention to make the transmission characteristics of networks 22 and 23 approximately the same, to provide for expansion characteristics that are substantially aperiodic. It is also within the scope of this invention to rearrange the initial conditions and to operate the system dynamically so that the amplifier gain in general is a decreasing function of the signal input, whereby the device operates as a compressor for use in recording. In short, the invention is deemed to be expressed by any circuit operable in accordance with the principles pointed out in Eqs. 1 to 4. The system specifically shown in Fig. 3 and explained with reference to Figs. 4 to 6 is not to be construed as expressing the entire invention, but to serve as one example of construction only.

What is claimed is:

1. An electrical filter circuit comprising a pair of parallel channels each including an electron

tube, said electron tubes having grid control circuits and output circuits; said grid circuits including means connected to apply a substantially equal bias voltage to each grid circuit and said output circuits being connected in opposed relationship to be balanced out when both channels transmit equal signals, said channels having means transmitting equally signals in a first frequency range, means transmitting unequally signals of a second frequency range, whereby the former signals only are suppressed in said output, and biasing means including a source of variable unidirectional voltage and connected between said grid circuits to alter said bias in opposite source for unbalancing the transmission characteristic of said channels.

2. An electrical filter circuit comprising a pair of parallel channels, having outputs connected in opposed relationship to be balanced out when both channels transmit equal signals, said channels having means transmitting equally signals in a first frequency range, each of said channels including an electron tube grid control circuit, biasing means coupled with said circuits to normally bias each of said grid circuits equally for signals in said first range, means transmitting unequally signals of a second frequency range, whereby the former signals only are suppressed in said output, and further means coupled to said grid circuits to alter said bias in opposite sense to unbalance the transmission characteristics of said channels for said first range for controlling the transmission of said signals to said output.

3. A filter as set forth in claim 2 in which said further means includes unidirectional voltage developing means coupled to one of said channels for response to said first signals and connected to said grid control circuits to alter said bias in opposite sense for unbalancing the transmission of said channels so as to pass said first signals only when present in a predetermined volume.

ELLISON S. PURINGTON.

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