NASA CASE NO. FRC-11,055-1

PRINT FIG. 4

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(NASA-Case-FRC-11055-1) ACTIVE NOTCH FILTER NETWORK WITH VARIABLE NOTCH DEPTH, WIDTH AND FREQUENCY Patent Application (NASA) 13 p HC A02/MF A01

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ACTIVE NOTCH FILTER NETWORK WITH VARIABLE NOTCH DEPTH, WIDTH AND FREQUENCY

ORIGIN OF INVENTION

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

BACKGROUND OF THE INVENTION

This invention relates to active filter networks, and more particularly to notch filter networks.

In feedback control systems for mechanisms of high maneuverability, it is often necessary to attenuate structural resonances in the mechanisms that might occur. Otherwise vibrations at those resonant frequencies might be amplified with a high risk of structural failure. Such a mechanism is, for example, an aircraft designed to be highly maneuverable.

Where the resonant characteristics of the mechanism is known, a suitable notch filter may be designed to dampen oscillations. However, those characteristics are sometimes not known, so it becomes necessary to install a filter that may be adjusted in notch depth, width and notch frequency. An object of this invention is therefore to provide an adjustable notch filter, in which the notch width, depth and frequency can each be individualy adjusted.

SUMMARY OF THE INVENTION

In accordance with the present invention, an active notch filter network having an input terminal and

AWARDS ABSTRACT

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Hugh L. Dryden Flight Research Center May 30, 1980

ACTIVE NOTCH FILTER NETWORK WITH VARIABLE NOTCH DEPTH, WIDTH AND FREQUENCY

This invention relates to active filter networks, and more particularly to notch filter networks used to attenuate any structural resonances in a controlled system, such as highly maneuverable aircraft.

FIG. 1 illustrates a prior art twin-T notch filter with high Q characteristics as shown in FIG. 2. The Q (notch width) may be adjusted by adjusting the feedback voltage amplitude using a potentiometer, as shown in FIG. 3. The active filter network of this invention shown in FIG. 4 provides a similar potentiometer, P_3, to adjust notch width, but in an arrangement that permits notch depth and notch frequency to be independently adjusted through potentiometers P_1 and P_2. The filter network can be analyzed by using the principle of superposition to redraw it as shown in FIG. 5 and FIG. 6. In the configuration shown in FIG. 5, the output "A" has a phase lead, while in the configuration shown in FIG. 6, the output "B" has a phase lag. When the phase lead is 180° ahead of the phase lag, the network is at null. Only the notch frequency adjustment is sensitive. The capacitors, which are equal, are chosen to match the structural resonance of the controlled system. That sets the center frequency of the notch filter with equal resistancy R_1 and R_2 in the feedback to junctions J_1 and J_2. Adjusting the potentiometer from this centered position will vary the notch frequency up or down. In that way, notch frequency may be adjusted independently of notch width and notch depth. The notch width and notch depth may also be independently adjusted.

The novelty of the invention resides in the circuit arrangement which permits independent adjustment of notch frequency, width and depth. This facilitates filter design and fabrication for a controlled system of characteristics not known in sufficient detail to permit precision of design. The filter can be installed and easily fine tuned for the particular application.

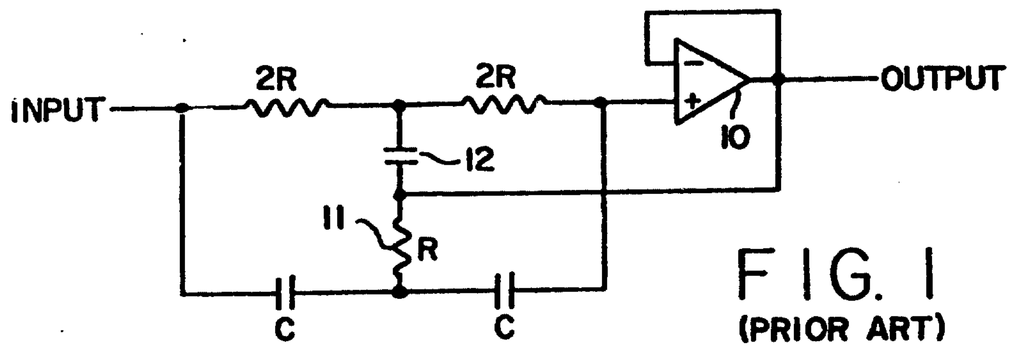


FIG. 1
(PRIOR ART)

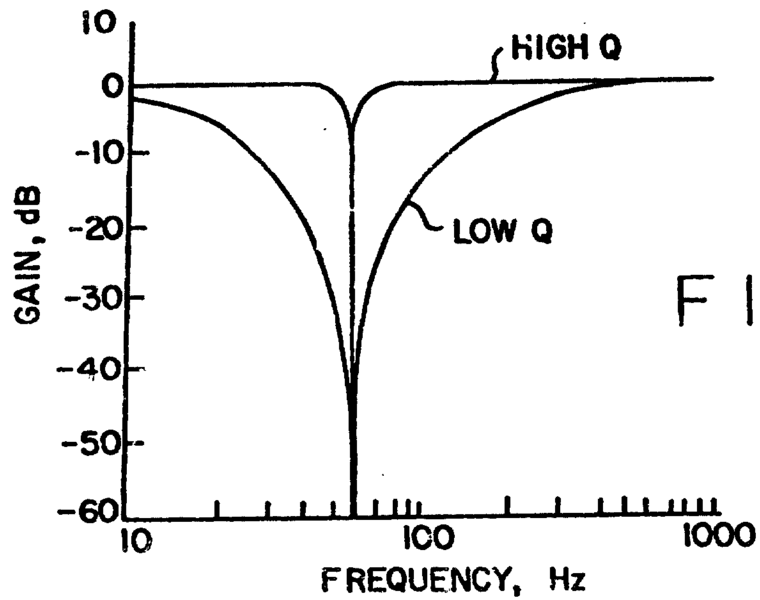
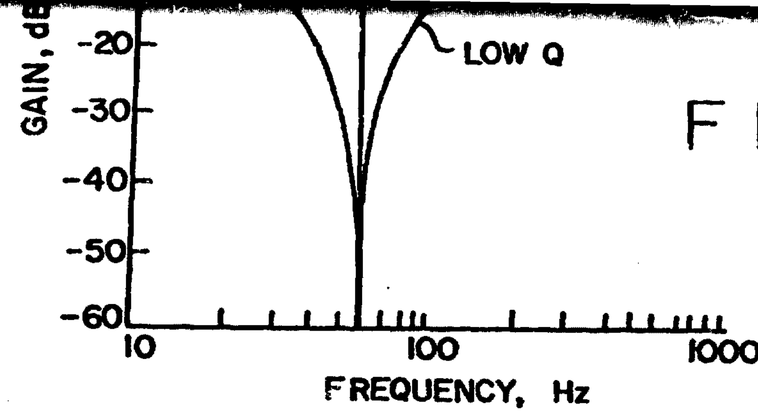


FIG. 2



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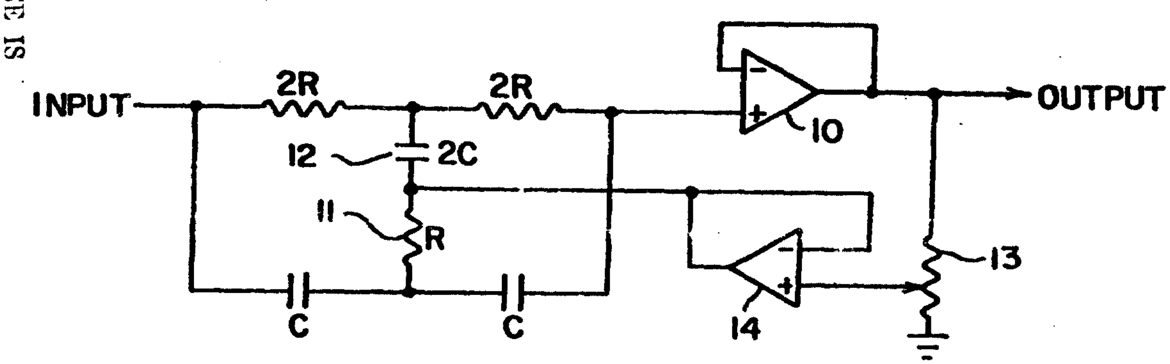

F I G. 3 (PRIOR ART)

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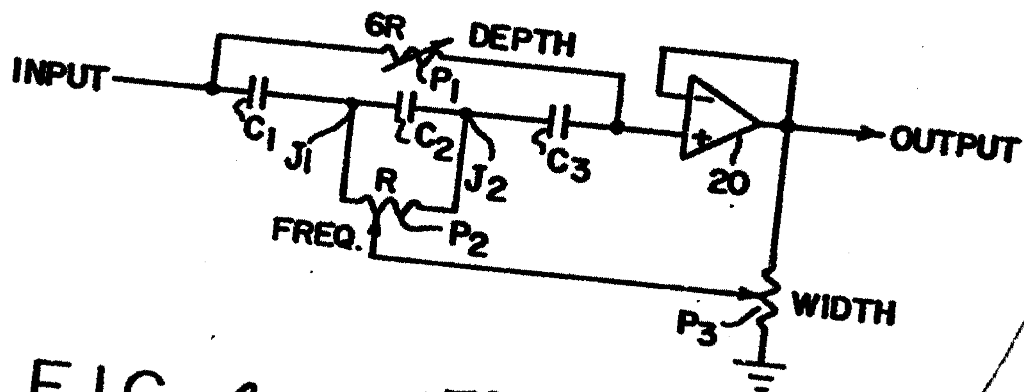
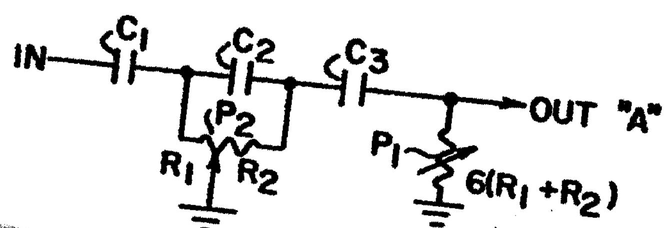


FIG. 4 173098 40%



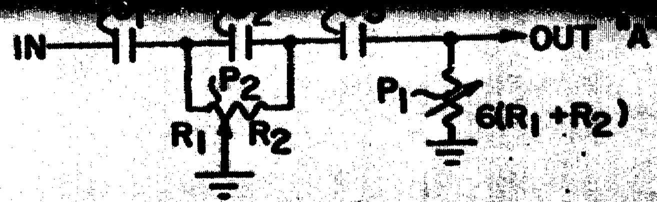


FIG. 5

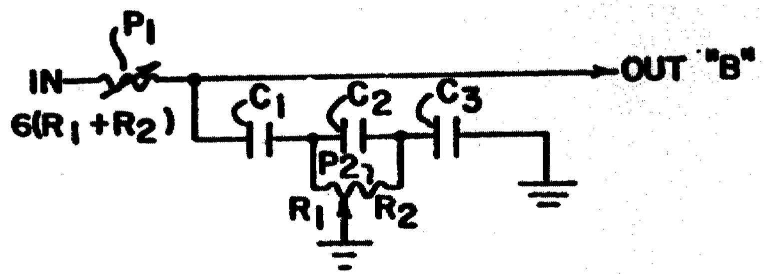


FIG. 6

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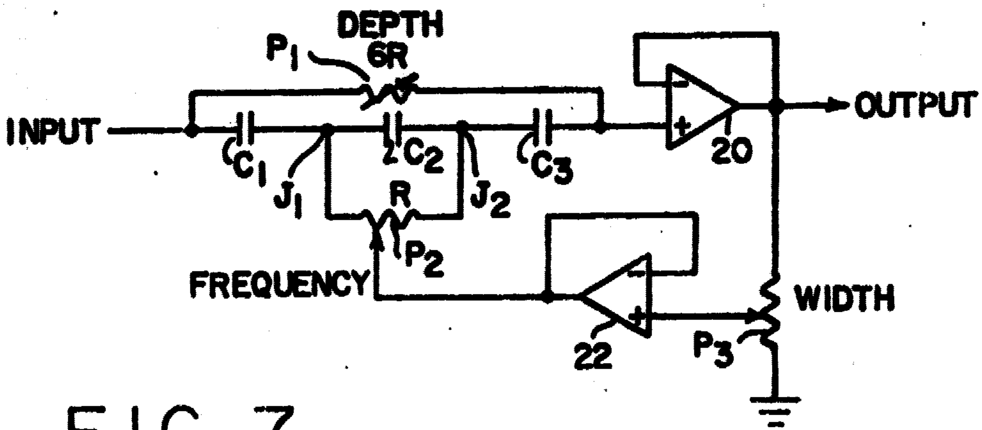
DEPTH
6R
P_1
INPUT
OUTPUT
C_1
C_2
C_3
J_1
J_2
R
20
P_2
FREQUENCY
WIDTH
22
P_3

FIG. 7

an output terminal is comprised of an operational amplifier having an inverting input terminal, a noninverting input terminal, an output terminal connected to the network output terminal, and a direct current connection from the output terminal to the inverting input terminal for operation as a voltage follower. Three equal capacitors are connected in series between the network input terminal and the noninverting input terminal of the amplifier for coupling thereto an alternating current signal from the network input terminal, and variable resistance means is connected across the series connected capacitors for notch depth adjustment. A potentiometer is provided with one end terminal connected to a junction between the first and second of the series connected capacitors, a second end terminal connected tc a junction between the second and third of the series connected capacitors. The adjustable tap of this potentiometer is connected to an adjustable voltage dividing means connected to the output terminal of said amplifier. This voltage dividing means adjusts the notch width, while the potentiometer adjusts the notch frequency.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention will best be understood from the following description when read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a circuit diagram of a prior art high Q notch filter utilizing a twin-T filter network with feedback from an operational amplifier connected in a voltage follower configuration.

FIG. 2 illustrates in a graph the characteristics of the high Q notch filter of FIG. 1.

FIG. 3 illustrates the prior art notch filter circuit of FIG. 1 with a potentiometer for adjustment of the notch width by adjusting the voltage feedback which must be through an operational amplifier for a low resistance feedback source.

FIG. 4 is a circuit diagram of the present invention which provides for independent adjustment of notch frequency and depth as well as width.

FIGs. 5 and 6 are circuit diagrams of the filter network of FIG. 4 redrawn for analysis by using the principle of super-position.

FIG. 7 is a circuit diagram of the present invention of FIG. 4 with an operational amplifier in the feedback for a low resistance feedback source, a feature which is not necessary for the proper operation of the notch filter.

Reference will now be made in detail to the drawings in order to describe preferred embodiments of the invention and its improvements over the prior art.

DESCRIPTION OF PREFERRED EMBODIMENTS

To better understand the theory and operation of the present invention, a prior art adjustable-Q notch filter described by Robert Dobkin in EEE - Magazine of Circuit Design, September, 1969, (published by Cohners Publishing Co., Inc. Denver, Colorado) will first be reviewed with reference to FIGs. 1, 2 and 3. FIG. 1 illustrates a high-Q notch filter using a twin-T network with an operational amplifier 10 connected in a voltage follower configuration. The operational amplifier 10, and all other operational amplifiers referred to hereinafter, are of the conventional type having an inverting input (-) and a noninverting input (+), such as the TI 741 amplifier. The depth and center frequency of the notch filter are a function of the filter network design; neither is changed by the voltage follower. Advantages are that the voltage follower acts as a buffer, providing a low output resistance, and the high input resistance of the operational amplifier makes possible the use of large resistance values in the filter network with small capacitors, even at low frequencies. The resistance and capacitance values are as follows:

R = 5 Megohms
2R = 10 Megohms
C = 270 pF
2C = 540 pF

In operation, the output impedance of the amplifier 10 is very low, so neither the depth nor the center frequency of the notch will change, but the Q will be proportional to the amount of output signal fed back to the junction between a resistor 11 and a capacitor 12. The low-Q response curve of FIG. 2 assumes no feedback. The high-Q response curve assumes maximum feedback in a circuit as shown in FIG. 1. An adjustable Q between those two extremes could be provided by a potentiometer 13 coupling the amplifier output to the junction in the filter network, as shown in FIG. 3, using an operational amplifier 14 connected as a voltage follower.

The problem with that prior art circuit is that if the signal to be rejected deviates from the center frequency of the high-Q filter, there will be very little filtering action. In that case, lowering the Q through the potentiometer 13 will insure some rejection over a wider range sufficient to reject the desired frequency, but without the same amount of rejection, and with rejection of some adjacent frequencies, a result sometimes not desired.

An improved filter network according to the present invention shown in FIG. 4 is comprised of three capacitors C_1, C_2 and C_3 of equal value in series, and a potentiometer P_1 having a maximum resistance of six times the resistance of a second potentiometer P_2. The potentiometer P_1 is connected as a means for varying the resistance in parallel with the capacitors in series. The output of the network is connected to an operational amplifier 20 connected as a voltage follower with its output connected to the adjustable tap of the potentiometer P_2. The potentiometer P_2 thus serves as a means for inversely adjusting the feedback resistance to a junction J_1 between the first two capacitors C_1 and C_2 in series and the feedback resistance to a junction J_2 between the second and third capacitors, C_2 and C_3. A potentiometer P_3 serves as a means for varying the feedback voltage to the adjustable tap of the potentiometer P_2, i.e., the feedback voltage to the junctions J_1 and J_2 through their respective feedback resistance paths.

The filter network can be analyzed by using the principle of superposition to redraw it as shown in FIG. 5 and FIG. 6. In the configuration shown in FIG. 5, the output "A" has a phase lead, while in the configuration shown in FIG. 6, the output "B" has a phase lag. When the phase lead is 180° ahead of the phase lag, the network is at null. From that null condition, it can then be shown that the ratio of the voltage out to the voltage in is given by

$$\frac{e_{out}}{e_{in}} = \frac{1+2jx - 3(y-y^2)x^2 - 6(y-y^2)jx^3}{1+16yx - 3(2-y^2+3y)x^2 - 6(y-y^2)jx^3}$$

where $y = \frac{R_1}{R_1+R_2}$, $\qquad x = 2\pi f(R_1+R_2)C$

Solving for the frequency, f, at null thus yields the following

$$f_{null} = \frac{1}{2\pi C\sqrt{3R_1R_2}}$$

The center frequency of the notch filter is thus shown to be a function of only the adjustment of the potentiometer P_2. The notch width is a function of the feedback amplitude, and may therefore be adjusted through potentiometer P_3, as in the prior art circuit of FIG. 3. In fact an operational amplifier corresponding to the amplifier 14 of the prior art may be used, as shown by an amplifier 22 in FIG. 7, but it is not necessary to drive the filter from a low resistance feedback source in order to avoid affecting notch frequency and depth, as was the case in the prior art circuit of FIG. 1.

As shown above, the notch frequency is a function of only the variables R_1 and R_2. The capacitance, C, remains fixed. The notch depth, set by an adjustment of the potentiometer P_1 is independent of the potentiometer P_2 and the potentiometer P_3 because it shunts the capacitors connected in series and serves only to adjust the RC time constants of the lead and lag configurations shown in FIGs. 5 and 6, thereby to set the degree of attenuation achieved at the notch (null) frequency.

The corresponding adjustment that could be made in the prior art filter of FIG. 1 might be in the resistor R. While that might adjust notch depth independent of notch width, the circuit would still not have any way of adjusting notch frequency. To vary any other element, resistor or capacitor, in an attempt to adjust frequency would result in unbalancing the symmetry of the twin-T filter, which would in turn affect the notch depth.

The filter of the present invention is not so sensitively balanced in respect to notch depth and width, but it is sensitively balanced in notch frequency. A very small adjustment of the potentiometer P_2 to the right or left from the condition $R_1 = R_2$ will shift the frequency, as may be seen from the equation for f_{null} set forth above. In practice, the capacitors are selected to approximately match the notch frequency to the structural resonance of the control system in which it is used, which is normally in the range of about 5 to 10 Hz. Once the filter is installed, it may then be tuned to the correct frequency by adjusting the imbalance of resistances R_1 and R_2 through the potentiometer P_2. That notch width and depth may also be tuned to match the characteristics of the control system.

Although particular embodiments of the invention have been described and illustrated herein, it is recognized that modifications and variations may readily occur to those skilled in the art. Consequently, it is intended that the claims be interpreted to cover such modifications and equivalents.

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ACTIVE NOTCH FILTER NETWORK WITH VARIABLE NOTCH DEPTH, WIDTH AND FREQUENCY

ABSTRACT OF THE DISCLOSURE

An active notch filter having independently adjustable notch frequency, width and depth is provided by three equal capacitors (C_1, C_2 and C_3) connected in series with an operational amplifier (20) connected in a voltage follower configuration, a potentiometer (P_1) across the series connected capacitors for notch depth adjustment, and a potentiometer (P_2) for notch frequency connected across the center capacitor with its tap connected to receive a voltage feedback signal from a variable voltage divider comprised of another potentiometer (P_3) for notch width. Adjusting the voltage dividing potentiometer (P_3) will independently set the notch width, and adjusting the tap on the potentiometer (P_2) across the center capacitor (C_2) will independently adjust the notch frequency of the filter. A second operational amplifier (22) connected in a voltage follower configuration may be used to connect the voltage divider output to the adjustable tap of the potentiometer (P_2)across the center capacitor(C_2).