March 8, 1960 J. F. McCLEAN 2,928,001

NULL CIRCUITS

Filed Dec. 15, 1955 3 Sheets-Sheet 1

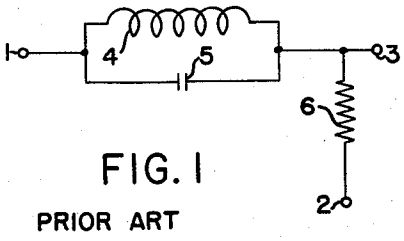


FIG. 1
PRIOR ART

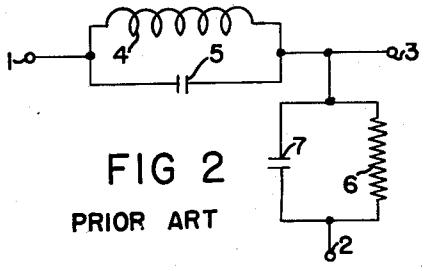


FIG 2
PRIOR ART

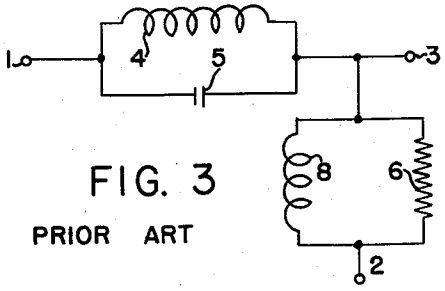


FIG. 3
PRIOR ART

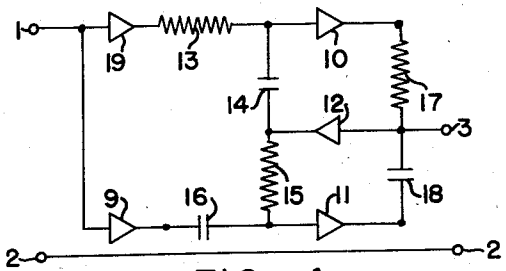


FIG. 4

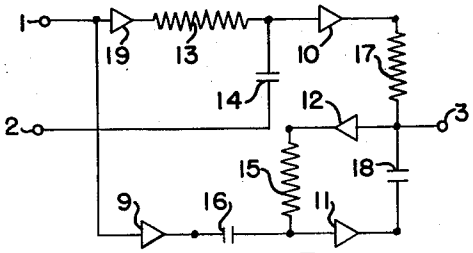


FIG. 5

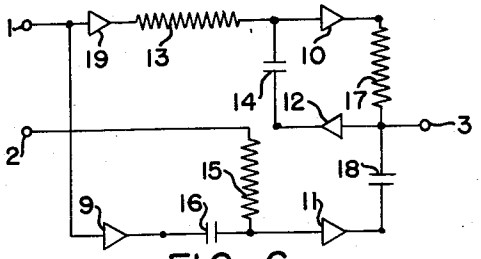


FIG. 6

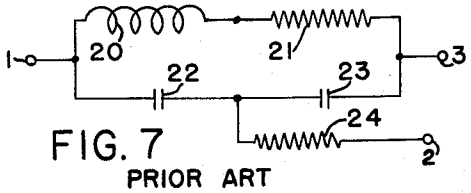


FIG. 7
PRIOR ART

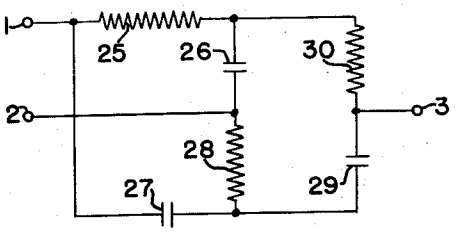


FIG. 8
PRIOR ART

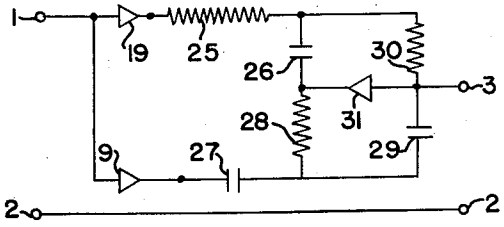


FIG. 9

INVENTOR.
JOSEPH F. McCLEAN
BY
Leonard H. King
AGENT

March 8, 1960 J. F. McCLEAN 2,928,001

NULL CIRCUITS

Filed Dec. 15, 1955 3 Sheets-Sheet 2

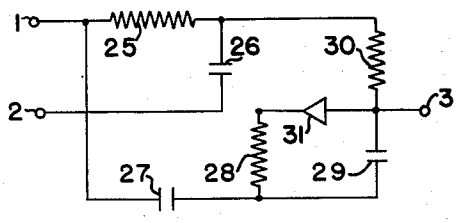


FIG. 10

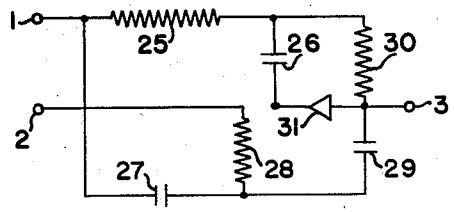


FIG. 11

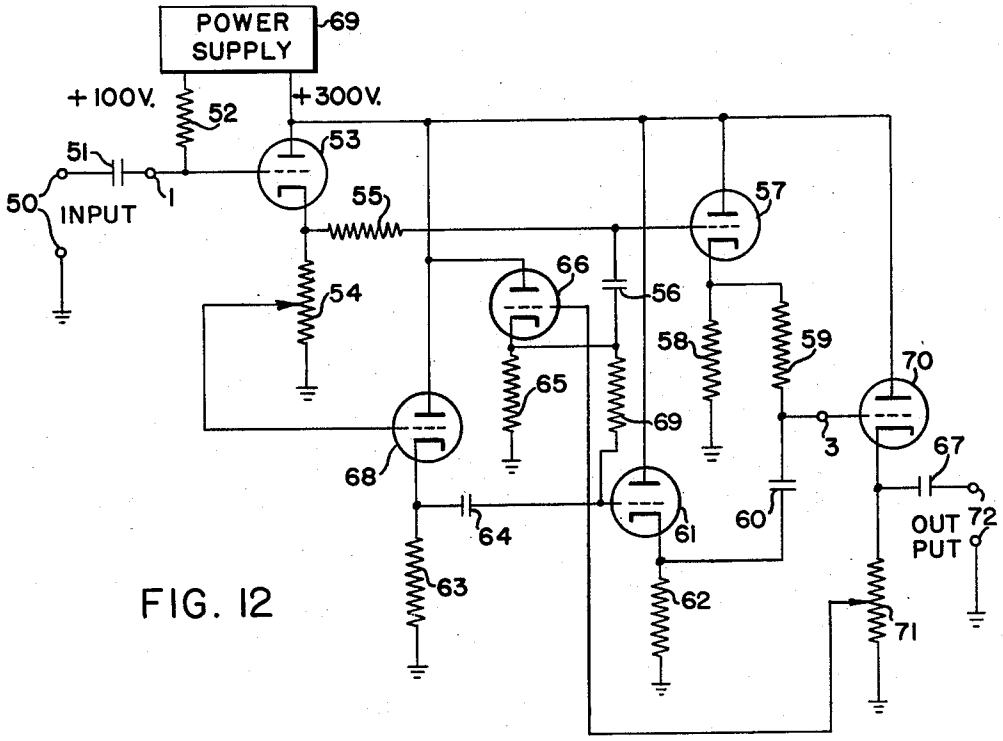


FIG. 12

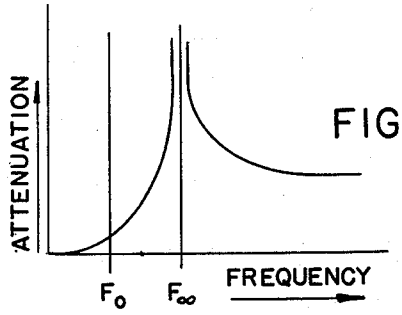


FIG. 13

INVENTOR.
JOSEPH F. McCLEAN
BY Leonard H. King
AGENT

March 8, 1960 J. F. McCLEAN 2,928,001

NULL CIRCUITS

Filed Dec. 15, 1955 3 Sheets-Sheet 3

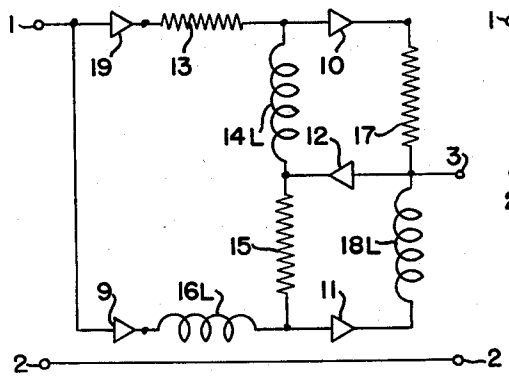


FIG. 14

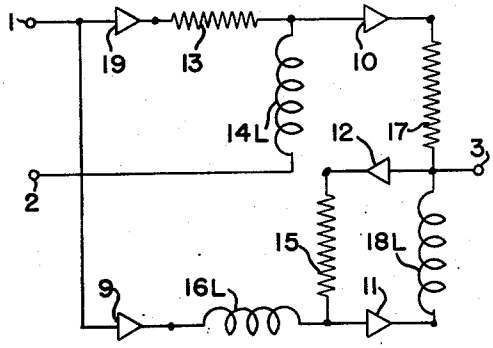


FIG. 15

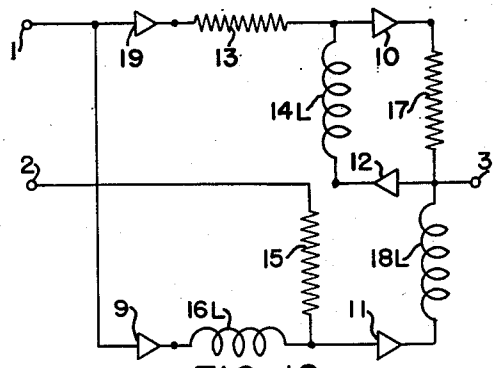


FIG. 16

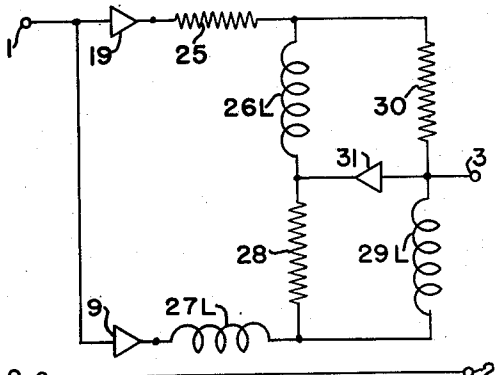


FIG. 17

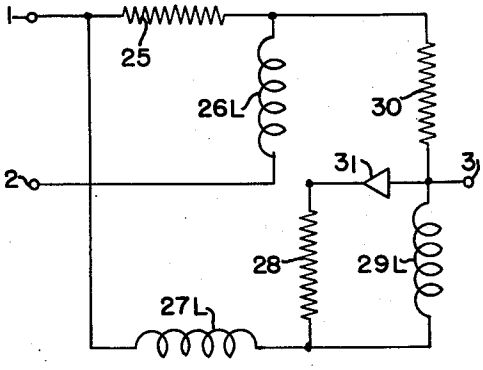


FIG. 18

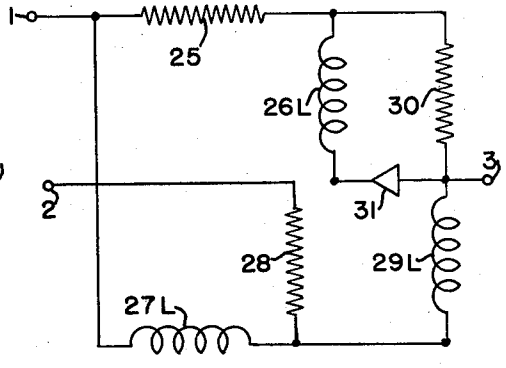


FIG. 19

INVENTOR.

JOSEPH F. McCLEAN

BY Leonard H. King

AGENT

United States Patent Office 2,928,001 Patented Mar. 8, 1960

2,928,001

NULL CIRCUITS

Joseph F. McClean, Goshen, N.Y.

Application December 15, 1955, Serial No. 553,228

13 Claims. (Cl. 250—27)

This invention relates to frequency selective networks and, in particular, to frequency selective networks employing active circuit elements. Further, this invention is primarily concerned with such active frequency selective networks as are characterized by transmission throughout an entire range of frequencies, except for a stop band of relatively small transmission, approaching zero transmission.

Such networks are useful in a manner comparable to certain passive frequency selective networks of the so-called parallel-T, bridged-T, *m*-derived and like varieties and will be shown in the description to follow to offer advantages of an electrical and physical nature over such networks in various applications.

Networks offering relatively narrow regions of small transmission are normally employed under circumstances demanding either rejection of a single undesired component frequency in a waveform, while passing others ideally unattenuated, or for producing incidental phase altering effects among the several components of a waveform. The latter use is important in so-called "correction" networks for compensating collateral time delays normally occurring in transmission systems. Depending upon the application, the transmission region, in the neighborhood of the minimum transmission, or "null," frequency may be described as exhibiting gradual slope or steep slope of the curve depicting relative transmission as a function of frequency, the former being analogous to a condition of low "Q" and the latter analogous to a condition of high "Q" in a simple tuned circuit. Similarly depending upon application, transmission may be described in frequency regions relatively removed from the stop band as (1) uniform, both for frequencies above and frequencies below the stop band, (2) uniform with given gain or attenuation, on one side of the stop band and uniform with a different gain or attenuation on the other side of the stop band, (3) non-uniform with attenuation a function of frequency on one side or on both sides of the stop band.

The networks to be described, which incorporate the principles of this invention, will be for convenience restricted to the classes (1) and (2) above. However, the principles of this invention may apply equally well to networks of class (3) or to other classes not confined to these three.

An object of this invention is to provide a filter network having means for independently controlling null frequency, cut-off frequency and the "Q" of the network.

A further object is to provide a filter network for insertion in an electronic circuit which is independent of circuit impedances at the point of insertion.

An object of this invention is to provide frequency selective networks.

Another object of this invention is to provide an improved null circuit.

A particular object of this invention is to provide a filter apparatus of the null type composed of resistance

and but one type of reactance, in combination with active circuit elements.

Another particular object is to provide a compact null circuit suitable for use at low frequencies.

Still another object is to provide a high "Q" filter circuit.

Still another object of this invention is to provide a filter circuit utilizing resistance elements and physically small inductance elements together with active elements while achieving the effects commonly attainable with but large inductances.

Still other objects and advantages will be in part apparent, and in part pointed out with particularity as the following description, taken in conjunction with the accompanying drawings, proceeds.

In the drawings:

The features of this invention will be best understood by reference to the drawings.

In the drawings.

Figure 1 is a schematic representation of a simple form of anti-resonant trap circuit.

Figure 2 is a schematic showing low-pass filter section of the so-called "*m*-derived" variety.

Figure 3 shows schematically a high-pass filter section of the *m*-derived type.

Figure 4 is a schematic showing of a form of active network embracing the principles of this invention.

Figure 5 is a schematic showing a second form of active network within the scope of this invention.

Figure 6 is a schematic showing third type of active network within the scope of this invention.

Figure 7 represents schematically one form of passive, so-called "bridged-T" filter network.

Figure 8 is a diagram of one form of resistance-capacitance passive network commonly known in the art as a "parallel-T" circuit.

Figure 9 is a diagram of still another active network based upon the principles of this invention.

Figure 10 and Figure 11 are schematic showings of alternative embodiments of active networks based upon the principles of this invention.

Figure 12 is a specific embodiment of the generalized circuit of Figure 4.

Figure 13 is a graphical representation of the filter characteristic of the filter of Figure 12 expressed as Attenuation vs. Frequency.

Figure 14 is a generalized schematic of a circuit corresponding to Figure 4 with inductances employed in place of the capacitances.

Figure 15 is a generalized schematic of a circuit corresponding to Figure 5 with inductances employed in place of the capacitances.

Figure 16 is a generalized schematic of a circuit corresponding to Figure 6 with inductances employed in place of the capacitances.

Figure 17 is a generalized schematic of a circuit corresponding to Figure 9 with inductances employed in place of the capacitances.

Figure 18 is a generalized schematic of a circuit corresponding to Figure 10 with inductances employed in place of the capacitances.

Figure 19 is a generalized schematic of a circuit corresponding to Figure 11 with inductances employed in place of the capacitances.

For the purpose of defining the electrical properties of networks here described, both within the scope of this invention and described as bases for comparison, the transmission will be described by means of the vector ratio of output to input voltages, appearing respectively at output and input terminals of the network in question. This will be referred to as "the complex voltage transfer

ratio" and will be used consistently as so defined in the discussion to follow.

Generically, the passive networks, described herein solely as exhibiting characteristics desirable in filter practice of the former art, may be classed in two categories; those employing freely the circuit elements of resistance, capacitance and inductance and those restricted in their composition to resistance and but one kind of reactance. In general, networks of the first, or unlimited, variety are distinguished in the practical sense by greater sharpness, or steepness of slope of the transfer ratio in the vicinity of the frequency of minimum transmission, while practical networks of both types offer in theory the possibility of a true zero of transmission at the null. This latter property is not strictly attainable in some unlimited networks due to the finite losses of practical inductances. For this reason, where, in the following complex voltages transfer ratios are developed for such networks, the inductive losses will be neglected and the resultant transmission will appear to permit such perfect nulls.

Referring now to Figure 1, the terminals 1 and 2 taken together comprise input terminals of a network, in which the inductance 4 and the capacitor 5 are connected in parallel, one end of the combination terminating in the terminal 1 and the second end connecting to a terminal 3 which constitutes one output terminal of the network. The other output connection to the network is made to the common terminal 2 and the network is completed by the resistor 6 connected between the terminals 2 and 3. This network will be recognized as a simple type of anti-resonant trap circuit and, if the losses inherent in the inductance 4 are neglected, can be readily shown to exhibit the complex voltage transfer ratio:

$$\frac{l_o}{l_i}=\frac{1-W^2LC}{1+jw\frac{L}{R}-W^2LC}=\frac{G+AP^2}{E+BP+DP^2}$$

Where w represents the angular frequency, j is a symbol equal to $\sqrt{-1}$, and p represents the product jw. In this case the co-efficients of the several terms are given by:

$$A=L\times C;\ B=L/R;\ G=1;\ D=L\times C \text{ and } E=1$$

In Figure 2 there is represented a form of so-called "m-derived" low-pass filter section in which 1 and 2 comprise input terminals, 3 and 2 comprise output terminals, an inductance 4, interconnects the terminals 1 and 3, a capacitor 5, likewise interconnects the terminals 1 and 3, the capacitor 7, is connected between the terminals 3 and 2 and a resistance 6 is also connected between the terminals 3 and 2, completing the network. Once again neglecting the losses inherent in the inductance 4, the complex voltage transfer ratio may be derived:

$$\frac{l_o}{l_i}=\frac{1-W^2LC_1}{1+jw\frac{L}{R}-W^2L(C_1+C_2)}=\frac{G+AP^2}{E+BP+DP^2}$$

the symbols j and w respectively being $\sqrt{-1}$ and the angular frequency of the applied wave and the symbol p again representing their product. The co-efficients, in terms of the constants of the network, being

$$A=LC_1;\ B=L/R;\ G=1;\ D=L(C_1+C_2) \text{ and } E=1$$

A similar network is set forth in Figure 3 which represents a high pass filter section of the m-derived type, and in which 1 and 3 comprise respectively input and output terminals. The terminal 2 serves as a common connection for both input and output. The inductance 4 is connected between the terminals 1 and 3. The capacitor 5 is likewise connected between the terminals 1 and 3. The inductance 8 interconnects the terminals 3 and 2 which are also interconnected by the resistance 6 which

completes the network. The complex voltage transfer ratio for the network of Figure 3 is found to be:

$$\frac{l_o}{l_i}=\frac{\frac{L_2}{L_1+L_2}W^2\left[\frac{L_1L_2}{L_1+L_2}\right]C}{1+jw\frac{1}{R}\left[\frac{L_1L_2}{L_1+L_2}\right]-W^2\left[\frac{L_1L_2}{L_1L_2}\right]C}=\frac{G+AP^2}{E+BP+DP^2}$$

With j, w and p defined as before, the several co-efficients for the circuit of Figure 3 become:

$$A=\left(\frac{L_1L_2}{L_1+L_2}\right)C;\ B=\frac{1}{R}\left(\frac{L_1L_2}{L_1+L_2}\right);$$

$$G=\frac{L_2}{L_1+L_2};\ D=\frac{L_1L_2}{L_1+L_2};\ E=1$$

The networks of Figure 1, Figure 2 and Figure 3 represent common passive combinations of the three circuit parameters of resistance, inductance and capacitance which have in their practical embodiments useful electrical properties. Although the ideal performance permitted by their respective complex voltage transfer ratios is not possible with physically realizable inductances, in many applications losses of the reactive elements can be curtailed to a degree permitting a close approximation of the ideal. In other applications, however, it is not possible to achieve sufficiently good components to produce the performance desired. For example, when, in the course of designing such passive networks for operation at lower and lower frequencies, a point is reached where inductors of reasonable size, Q and cost become difficult to produce, the passive networks discussed, as well as those offering similar transfer ratios, do not provide a solution. It is thus an object of this invention to provide alternative networks, composed of resistance and but one type of reactance, in conjunction with active circuit elements, which not only overcome the practical shortcomings of passive networks, containing resistance and both types of reactance, but also to provide such active networks capable of the theoretical "infinite-Q" performance of non-realizable passive networks.

Figure 4 is one form of active network embodying the principles of this invention, in which: the terminal 1 provides a means for connecting a source of input voltage, in association with the common terminal 2; the terminal 3 in association with the common terminal 2 forms a means for observing the output voltage. The elements 9, 10, 11, 12 and 19 having the respective gain constants k_1, k_2, k_3, k_4, k_5 are active unilateral translating devices whose common characteristic is their ability to repeat at their output terminals voltages applied to their respective input terminals such voltages modified only by the said dimensionless proportionality constants k_1, k_2, k_3, k_4, k_5 and exhibiting the dual properties of relatively high input impedance and relatively low output impedance with respect to the impedances coupled to their terminals, as observed in the vicinity of the so-called "cut-off" frequency of the entire network. The active devices 9 and 19 are mutually fed from the input terminal 1. The resistance 13 is connected between the output of the device 19 and the input of the device 10. The capacitor 16 is similarly connected from the output of the device 9 to the input of the device 11. A capacitor 14 is connected to the input of the device 10 and the remaining terminal of the capacitor 14 is joined to the resistance 15, the remaining terminal of the latter being connected to the input side of the device 11. A resistance 17 connects from the output side of the device 10 to the input side of the device 12 which is also connected to one end of the capacitor 18. The opposite terminal of the capacitor 18 connects to the output side of the device 11. The output terminal of the network 3 is connected to the junction of 17, 18 and 12, completing the circuit.

Analysis of the circuit of Figure 4 for the complex voltage transfer ratio reveals the expression:

$$\frac{l_o}{l_i}=\frac{JP^3+LP^2+MP+N}{RP^3+SP^2+VP+W}$$

and upon the fulfillment of the condition:

$$R_1C_1=R_2C_2=RC$$

the above reduces to the form:

$$\frac{l_o}{l_i}=\frac{G+AP^2}{E+BP+DP^2}$$

the symbols j and w defined as before, the several co-efficients become:

$$A=K_1K_3R^2C^2;\ B=(2-K_3K_4-K_2K_4)RC;\ D=R^2C^2;\ G=K_2K_5;\text{ and } E=1$$

Thus, by proper selection of the circuit parameters R and C and the gain constants of the several active devices, namely k_1, k_2, k_3 and k_4, co-efficients A, B, D, G and E of the voltage transfer equation may be made identical to their equivalents in the same general equation as found for the anti-resonant trap circuit of Figure 1, the m-derived low-pass section of Figure 2 and the m-derived high-pass section of Figure 3, with the exception that, whereas in the said passive networks composed of resistance, inductance and capacitance, the assumption of lossless reactances was required to produce a perfect null in the examples given, no such restriction exists for the embodiment of this invention in Figure 4, provided only that the condition $R_1C_1R_2C_2$ stated above is fulfilled.

Figure 5 is another embodiment of the principles of this invention whose circuit is in all respects save one identical to that of the circuit of Figure 4 and whose component parts bear identical numbers. Whereas in the circuit of Figure 4 the capacitor **14** is terminated at the output connection of the active device **12** in the circuit of Figure 5 the capacitor **14** is terminated instead at the common circuit terminal **2**. The form of the transfer equation is unchanged and the co-efficients of the several terms are unchanged, with the exception of the second denominator term co-efficient, which becomes:

$$B=(2-K_3K_4)RC$$

Figure 6 is a representation of still another circuit employing the principles of this invention, identical in all respects save one to the circuit of Figure 4 and whose component parts are identical and bear identical numbers in the drawing as those comprising the circuit of Figure 4. Whereas in the circuit of Figure 4 the resistance **15** is terminated at one end at the output connection of the device **12** in the circuit of Figure 6 the resistance **15** is connected instead to the common circuit terminal **2**. The form of the transfer equation given for the circuit of Figure 4 applies equally to the equation for the complex voltage transfer ratio of the circuit of Figure 6 and the co-efficients of the terms, except for the co-efficient of the second denominator terms are identical. The second denominator terms co-efficient is found to be:

$$B=(2-K_2K_4)RC$$

In practice the circuits of the several drawings, Figure 4, Figure 5 and Figure 6 differ in performance only in the conceivable minimum value of the co-efficient B. An examination of the mathematical effects of control over the magnitude of the said co-efficient B reveals that this co-efficient controls the steepness of the plotted voltage transfer ratio curve in the vicinity of the null, i.e., the "sharpness" of the null, such effect appearing in inverse variation, or increasing steepness with decreasing value of the co-efficient, B.

The usefulness of the described circuits of Figure 4, Figure 5 and Figure 6 is not limited to the stimulation of or replacement of circuits of the type shown in the drawings of Figure 1, Figure 2 and Figure 3 which, it has been noted, are capable of true nulls only when theoretically composed of lossless reactances in whole or in part. Such circuits embracing the principles of this invention may also be employed in lieu of those types of passive circuits which, though constituted of realizable reactances and their accompanying losses or resistive components, are, by virtue of special design characteristics capable of producing true nulls. An example of a class of networks capable of true nulls is the so-called "bridged-T" network of Figure 7.

Referring to Figure 7, the terminals **1** and **2** constitute input terminals to a network, the terminal **2** being common to both input and output. The output terminals **3** and **2** provide access to the output voltage, e_0, which appears when the driving, or input, voltage is applied to the input terminals. The inductance **20** is connected between the terminals **1** and **3** together with its loss resistance **21** here represented as a physical resistance in series with the said inductance **20**. The capacitor **22** is connected at its one end to the terminal **1** and at its second terminus to the capacitor **23** and to the resistance **24**. The remaining terminal of the capacitor **23** is connected to the circuit output terminal **3** and the circuit is completed by the connection of the resistance **24** to the common terminal **2**.

The solution for the complex voltage transfer ratio of the circuit of Figure 7 is of the form:

$$\frac{l_o}{l_i}=\frac{JP^3+LP^2+MP+N}{RP^3+SP^2+VP+W}$$

which, for the condition; $2RR^1=L/C$ reduces to the form:

$$\frac{l_o}{l_i}=\frac{1-W^2RR^1C^2}{1+jwR^1C-W^2RR^1C^2}=\frac{G+AP^2}{E+BP+DP^2}$$

where the symbols j and w represent $\sqrt{-1}$ and the angular frequency respectively, and the several co-efficients are as follows:

$$A=RRC^2;\ B=LC+RRC^2;\ D=RLC^2;\ G=1 \text{ and } E=1$$

Thus it is seen that the circuits of Figure 4, Figure 5 and Figure 6 comprised of active circuit elements, resistance and but one type of reactance, may also be given performance characteristics similar to passive circuits, employing resistance and both types of reactance known to the art as bridged-T circuits, with the additional property, as respects the active network, of simple control of circuit "Q" and the possibility of realizing circuit "Q's" in excess of the capabilities of the passive networks.

Referring now to Figure 8, the drawing illustrates a common type of null circuit of the prior art, known as a "parallel-T." Again the network is provided in the drawing with input terminals **1** and **2** of which **2** is a terminal common to both input and output and with output terminals **3** and **2**. The resistance **25** is connected to the input terminal **1** at its one juncture and to the capacitor **26** and the resistance **30** at its other, the free end of the capacitor **26** being connected to the common circuit terminal **2**. Similarly, the capacitor **27** is connected at its one end to the terminal **1** and at its other end to the resistance **28** and the capacitor **29**. The resistance **28** is connected at its far end to the common circuit **2**. The circuit is completed by the junction of the remaining ends of the resistance **30** and the capacitor **29** to each other and to the output terminal **3**. It is found upon

analysis that the complex voltage transfer ratio for this circuit is given by the equation:

$$\frac{l_o}{l_i}=\frac{1+jw(2C_2R_2)-2w^2(C_2^2R_1R_2)-jw^3(C_1R_1^2C_2^2R_2)}{[1+jw(2C_2R_2+2C_2R_1+C_1R_1)-W^2(C_2R_1R_2+2C_1R_1C_2R_2+C_1C_2R_1^2)-jw^3(C_1C_2^2R_1^2R^2)]}=\frac{JP^3+LP^2+MP+N}{RP^3+SP^2+VP+W}$$

which equation reveals that the parallel-T network exhibits a real null when the real and imaginary parts of the numerator respectively are zero, a condition requiring that $R_1C_1=R_2C_2$.

In Figure 9 is shown a network within the scope of this invention, which, while resembling the parallel-T in many respects, possesses characteristics which render it markedly different and superior in performance and utility to that of the said parallel-T circuit. Circuit elements in the Figure 9 bear like numbers as those in the Figure 8 and are connected in like manner with the following exceptions: the addition of an active unilateral translating device **31**, which has the attributes of such devices as previously described herein, so that its input is connected to the circuit output terminal **3** and its output terminal forms a common junction with the capacitor **26** and the resistance **28** said terminals of the said capacitor **26** and resistance **28** being those terminals connected in the circuit of Figure 8 to the common terminal **2**.

Analysis of the circuit of Figure 9 reveals a complex voltage transfer ratio:

$$\frac{l_o}{l_i}=\frac{1+2jwC_2R_2-2W^2C_2^2R_1R_2-jw^3C_1C_2^2}{1+jw[2C_2R_2+2C_2R_1(1-K)+C_1R_1(1-K)]-W^2[2C_1C_2R_1R_2(1-K)+C_1C_2R_1^2(1-K)+2C_2^2R_1R_2]-jw^3C_1C_2^2R_1^2R_2}$$

where the symbol *"k"* is a constant representing the gain of the active device **31** and the symbols *j*, *w* and *p* are as previously defined. The numerator of the latter expression is identical in all manner with that of the transfer equation of the parallel-T circuit of Figure 8 thus the conditions necessary for a transmission null are also identical. It will be noted that the interposition of the active device **31** serves to modify the co-efficient of the first and second order denominator terms in *w* and *p*, such that increasing *k* serves to reduce the magnitude of these co-efficients, having the physical significance of increasing the sharpness or rapidity of change of transmission in the vicinity of the null.

Figure 10 and Figure 11 are modifications of the circuit of Figure 9 in a manner analogous to the relationship of the circuits of Figure 6 and Figure 5 to the circuit of Figure 4. Analysis of the circuits of Figure 10 and Figure 11 reveal transfer equations identical in form to the transfer equation applying to the circuit of Figure 9 and differing from it only as respects the interrelation between the active gain factor *k* and the co-efficients of the first and second order denominator terms.

While I have elected to show generalized schematic circuits so as to make the basic concepts of this invention readily understood, I wish it to be appreciated that the practical embodiments corresponding thereto may be built in accordance with standard engineering practice. By way of example, the circuit of Figure 4 has been implemented in Figure 12. The other generalized circuits may be translated in a like manner. It should be noted that while I have chosen to show triode vacuum tubes as the translating device, I regard the use of other translation devices within the scope of this invention.

Referring now to Figure 12, a pair of input terminals **50** have connected thereto a D.-C. blocking capacitor **51**, which is in turn connected to the grid of cathode follower tube **53**; this corresponds to terminal **1** of Figure 4. Resistor **52** serves as a grid resistor and potentiometer resistor **54** the cathode resistor. This cathode follower stage serves as a matching and isolating stage and repeats across low impedance resistor **54**, the A.-C. signal, applied to high impedance input terminals **50**.

A second cathode follower stage utilizes tube **68** driven from a variable tap of potentiometer **54**. The resistor **13** and capacitor **14** of Figure 4 are shown as resistor **55** and capacitor **56**. The voltage appearing at the common junction of the two components **55** and **56** is in turn applied to the grid of cathode follower tube **57**. The capacitor **64**—resistor **69** arm of the network corresponding to resistor **15** and capacitor **16** is driven in like fashion with the voltage across resistor **63**. The junction of capacitor **64** and resistor **69** is connected to the grid of cathode follower tube **61**.

A resistance **59**—capacitance **60** branch is connected between the respective cathodes of cathode follower tubes **57** and **61**, the junction of resistor **59** and capacitor **60** being connected to the grid of cathode follower tube **70**, whose cathode provides output voltage through the D.C. blocking capacitor **67**. The output voltage may be derived from output terminals **72**. The grid of cathode follower tube **66** is connected to the variable tap of resistor **71** permitting a selected portion of the output voltage to be applied between the junction of capacitor **56** and resistor **59**. The generalized circuit of Figure 4 terminates at terminal **3** which point is also shown in Figure 12.

In operation the three R–C time constants are made equal ($R_{55}C_{56}=R_{19}C_{14}=R_9C_{10}$), where R is the resistance in ohms and C is the capacitance in farads. The value of M is controlled by the tap setting of potentiometer **54** and the Q is adjusted by means of the tap setting of potentiometer **71**.

In practice particular filter characteristics are realized by the cascading of so-called filter "sections," each of which contributes important properties to the aggregate performance. Thus, by way of example, it is common to compose a filter of one or more sections of the so-called "constant-*k*" or similar type—such sections contributing continuingly greater attenuation with frequency removal from the passband—combined with one or more sections of "*m*-derived" or related types. The said *m*-derived sections contribute the desired property of rapid attenuation beyond cut-off in the region of frequencies immediately adjacent to the passband. Corollary to their desired properties, each of the types of section mentioned complements the other, the constant-*k* type being relatively weak in attenuation performance immediately beyond the cut-off frequency and the *m*-derived type being relatively poor in attenuating frequencies well beyond cut-off in the stop band. In the design of component filter sections for use in multi-section filters, particular voltage transfer functions are desired. In preparing sections of the constant-*k* or like type, control is ordinarily exercised over the cut-off frequency, the rate of attenution per octave of frequency departure in the stop band and the peaking, or "Q" factor, in the immediate vicinity of cut-off. In *m*-derived or like sections control is available to the designer over the above properties and, in addition, over the null, or maximum attenuation, frequency.

Referring in particular to the network of Figure 4 and the corresponding general expression for the complex voltage transfer ratio thereof and also to the passive networks of Figure 2 and Figure 3 and the respective expressions for their complex voltage transfer ratios, it is apparent that said expressions are all identical as respects the frequency-containing terms and differ only as respects the several dimensionless co-efficients. Thus, specifically, to simulate entirely the voltage transfer ratio of the low-pass network of Figure 2 by means of the network of the present invention shown in Figure 4, one need adjust the resistances, capacitances and gain constants of the latter to produce co-efficients A, B, D, E and G identical to those of the network of Figure 2.

In this regard it will be noted that the null frequency, or frequency of zero transmission, will be controlled by the simple magnitudes of the co-efficients G and A, which may be conveniently adjusted, for example, by manipulation of the respective gain constants k_5 and k_1, for simulation of circuit *m*. Further inspection will reveal that the conventionally defined "cut-off frequency" of the simulating circuit is controlled entirely by the co-efficients D and E, which in turn are conveniently adjustable by manipulation of respective resistances and capacitances of the network. Lastly, the peaking or "Q" factor of the simulation is tied to duplication of the co-efficient B, which may be adjusted, without affecting prior adjusted cut-off and null, by manipulation of the gain constant k_4. In an exactly parallel procedure it may be shown that complete simulation of the passive high-pass network of Figure 3 may be had also by proper control of the design constants of the network of Figure 4 of this invention.

By exactly similar procedures it may be shown that the networks of this invention, Figure 5 and Figure 6, may be employed to exactly simulate in respect to complex voltage transfer ratio the passive networks described by Figure 2 and Figure 3 as well as those of Figure 1, Figure 7, Figure 8 and other networks.

When employed in lieu of the cited conventional passive networks and others generically similar, certain advantages accrue which make such substitution particularly advantageous: (1) The restriction of circuit elements to resistance-capacitance (or resistance-inductance) combinations and the corollary elimination of one form of reactance make possible physical realization of properties not possible with conventional networks. Example: complete realization of low-frequency filter designs normally prohibitive or impossible to achieve using inductances; (2) independent control over the separate properties of null frequency, cut-off frequency and peaking ("Q") not possible because of the physical interdependence of critical network properties in the latter. Example: the peaking of conventional passive filters is inextricable tied, in some cases, to the physical limitations of Q in inductors, limiting the possibility of modifying this important property in the finished filter; (3) separation of the problem of achieving a suitable overall voltage transfer ratio in a section or in an entire filter from impedance conditions, either at input or output, or at intermediate points among said sections. Design of passive resistance-inductance-capacitance filters is not possible without close simultaneous attention to impedances as well as to voltage transfer. Impedance considerations frequently impose severe limitations upon the attainable voltage transfer properties.

A typical attenuation curve with reference to frequency is shown in Figure 13.

In Figures 14 to 19 I have shown inductances substituted for the capacitances of the equivalent filters of Figures 4, 5, 6, 8, 9, 10 and 11.

In order to make readily apparent the substituted components, they have been identified as inductance 26L in place of capacitor 26 and inductance 27L in place of capacitor 27, etc.

While I have disclosed what is at present considered the best mode for carrying out the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

I claim:

1. A frequency sensitive apparatus, including means for introducing an input signal and means for deriving an output signal from said apparatus, comprising in combination: a first translation device having a high impedance input circuit and a low impedance output circuit; a first two terminal-resistor having one of said terminals connected in series with said first translation device output circuit; a second translation device having a high impedance input circuit and a low impedance output circuit, said input circuit being connected to the other of said terminals of said first resistor; a second two-terminal resistor having one of said terminals connected to said second translating device output circuit; a first two-terminal reactance; a third translation device having a high impedance input circuit and a low impedance output circuit, said output circuit being connected to one terminal of said first reactance and said input circuit being connected in parallel with said first translation device input circuit; a fourth translation device having a high impedance input circuit and a low impedance output circuit, said input circuit being connected to the other terminal of said first reactance; a second two-terminal reactance having one of said terminals connected to said fourth translation device output circuit and the other of said terminals connected to the other of said terminals of said second resistor; a third two-terminal reactance having one terminal connected to said other terminal of said first resistor; a third two-terminal resistor having one terminal connected to the said other terminal of said first reactance and the other terminal connected to the other said terminal of said third reactance; and means for feeding back a portion of the output signal to a portion of said apparatus isolated from said input signal introducing means by one of said translation devices.

2. The apparatus of claim 7 wherein said reactances are capacitors.

3. A frequency sensitive apparatus comprising in combination: a first translation device having a high impedance input circuit and a low impedance output circuit; a first two-terminal resistor having one of said terminals connected in series with said first translation device output circuit; a second translation device having a high impedance input circuit and a low impedance output circuit, said input being connected to the other of said terminals of said first resistor; a second two-terminal resistor having one of said terminals connected to said second translating device output circuit; a first two-terminal reactance; a third translation device having a high impedance input circuit and a low impedance output circuit, said output circuit being connected to one terminal of said first reactance and said input circuit being connected in parallel with said first translation device input circuit; a fourth translation device having a high impedance input circuit and a low impedance output circuit, said input circuit being connected to the other terminal of said first reactance; a second two-terminal reactance having one of said terminals connected to said fourth translation device output circuit and the other of said terminals connected to the other of said terminals of said second resistor; a third two-terminal reactance having one terminal connected to the common junction of said first resistor and said second translation device input circuit; a third two-terminal resistance having one terminal connected to the common junction of said first reactance and said fourth translating device input circuit; a fifth translation device having a high impedance input circuit and a low impedance output circuit, said input circuit being connected to the common junction of said second resistor and said second reactance, said output circuit being connected so as to provide a signal to at least one of said other terminals of said third reactance and said third resistor associated respectively with said second and fourth translation device input circuits; means for introducing a signal to said first and third translation device input circuits and means for deriving a signal from said apparatus.

4. A frequency sensitive apparatus comprising in combination: a first translation device having a high impedance input circuit and a low impedance output cir-

cuit; a first two-terminal resistor having one of said terminals connected in series with said first translation device output circuit; a second translation device having a high impedance input circuit and a low impedance output circuit, said input being connected to the other of said terminals of said first resistor; a second two-terminal resistor having one of said terminals connected to said second translating device output circuit; a first two-terminal reactance; a third translation device having a high impedance input circuit and a low impedance output circuit, said output circuit being connected to one terminal of said first reactance and said input circuit being connected in parallel with said first translation device input circuit; a fourth translation device having a high impedance input circuit and a low impedance output circuit, said input circuit being connected to the other terminal of said first reactance; a second two-terminal reactance having one of said terminals connected to said fourth translation device output circuit and the other of said terminals connected to the other of said terminals of said second resistor; a third two-terminal reactance having one of said terminals conected to the common junction of said first resistor and said second translation device input circuit and the other of said terminals comprising a common input-output terminal for said apparatus; a third two-terminal resistor having one terminal connected to said fourth translation device input circuit; a fifth translation device having a high impedance input circuit and a low impedance output circuit, said input circuit being connected to the common junction of said second resistor and said second reactance and said output circuit connected to the other said terminal of said third resistor; means for introducing a signal to said first and third translation device input circuits and means for deriving an electrical signal from said apparatus.

5. A frequency sensitive apparatus comprising in combination: a first translation device having a high impedance input circuit and a low impedance output circuit; a first two-terminal resistor having one of said terminals connected in series with said first translation device output circuit; a second translation device having a high impedance input circuit and a low impedance output circuit, said input circuit being connected to the other of said terminals of said first resistor; a second two-terminal resistor having one of said terminals connected to said second translating device output circuit; a first two-terminal reactance; a third translation device having a high impedance input circuit and a low impedance output circuit, said output circuit being connected to one terminal of said first reactance and said input circuit being connected in parallel with said first translation device input circuit; a fourth translation device having a high impedance input circuit and a low impedance output circuit, said input circuit being connected to the other terminal of said first reactance; a second two-terminal reactance having one of said terminals connected to said fourth translation device output circuit, and the other of said terminals connected to the other of said terminals of said second resistor; a third two-terminal reactance having one terminal connected to the common junction of said first resistor and said second translation device input circuit; a third two terminal resistance having one terminal connected to said fourth translation device input circuit and said other of said terminals comprising a common input-output terminal of said apparatus; a fifth translation device having a high impedance input circuit and a low impedance output circuit, said input circuit being connected to the common junction of said second resistor and said second reactance, said output circuit being connected to the other of said terminals of said third reactance; means for introducing an electrical signal to said first and third translation device input circuits and means for deriving an electrical signal from said apparatus.

6. A frequency sensitive apparatus for producing an output signal differing from an input signal including signal input means and means for deriving an output signal comprising: a first branch circuit, interconnecting said signal input means and said signal output means, including at least one translation device having a high input circuit impedance and a low output circuit impedance and a plurality of resistors in cascade; a second branch circuit in parallel with said first branch circuit comprising at least one translation device having a high impedance input and low impedance output circuit and a plurality of reactances in cascade; and a feedback circuit including a translation device, having a high input circuit impedance and a low output circuit impedance in cascade with an impedance element, said feedback circuit being interposed between said means for deriving an output signal and an intermediate portion of one of said branch circuits.

7. A frequency sensitive apparatus for producing an output signal differing from an input signal, including a two terminal signal input circuit means, including a first terminal and a second terminal, and a two terminal signal output circuit means, including a third terminal and said second terminal, comprising: two branch circuits, one of said branch circuits including a plurality of resistor elements connected in cascade between said first and third terminals and the other of said branch circuits including a plurality of reactance elements connected in cascade between said first and third terminals so that said branch circuits are in parallel; a signal feedback circuit connected between said third terminal and a point on one of said branch circuits between a pair of said cascaded elements of said branch circuit, said signal feedback circuit including an element of the type included in the other of said branch circuits and a translation device having a high impedance input circuit and a low impedance output circuit, said last named element being connected in cascade between said one branch circuit and said translation device output circuit; a signal coupling circuit including said translation device connected between said signal output means, and a point on said other branch circuit between a pair of said cascaded elements of said other branch circuit; and an element of the type included in the said one branch circuit connected in series with said signal coupling circuit.

8. The apparatus of claim 7 wherein translating devices are interposed between each of said branches, and said signal input means, said translating devices being characterized by a high impedance input circuit and a low impedance output circuit.

9. The apparatus of claim 7 wherein translating devices having high input impedance circuits and low impedance output circuits are interposed between said branch circuits and said signal input means and between succeeding cascaded elements in each of said branch circuits.

10. A frequency sensitive apparatus for producing an output signal differing from an input signal including signal input means and means for deriving an output signal comprising: a first branch circuit, interconnecting said signal input means and said signal output means, including at least one translation device, having a high input circuit impedance and a low output circuit impedance, and a plurality of resistors in cascade; a second branch circuit in parallel with said first branch circuit comprising at least one translation device, having a high impedance input and a low impedance output circuit, and a plurality of reactances in cascade; and a feedback circuit comprising a translation device having a high impedance input circuit and a low impedance output circuit in cascade with an impedance element, said feedback circuit being interposed between said means for deriving an output signal and a point common to a plurality of said reactances in said second branch circuit so as to feed back a portion of said output signal to an intermediate portion of one of said branch circuits.

11. A frequency sensitive apparatus for producing an output signal differing from an input signal including signal input means and means for deriving an output signal comprising: a first branch circuit interconnecting said signal input means and said signal output means including at least one translation device having a high input circuit impedance and a low output circuit impedance and a plurality of resistors in cascade; a second branch circuit in parallel with said first branch circuit comprising at least one translation device having a high impedance input and low impedance output circuit and a plurality of reactances in cascade; and a feedback circuit comprising a translation device having a high impedance input circuit and a low impedance output circuit in cascade with an impedance element, said feedback circuit being interposed between said means for deriving an output signal and a point common to a plurality of said resistors in said first branch circuit so as to feed back a portion of said output signal to an intermediate portion of one of said branch circuits.

12. A frequency sensitive apparatus for producing an output signal differing from an input signal including signal input means and means for deriving an output signal comprising: a first branch circuit, interconnecting said signal input means and said signal output means, comprising a plurality of resistances in cascade and a translating device, having a high impedance input circuit and a low impedance output circuit, interposed between a pair of said resistances; a second branch circuit in parallel with said first branch circuit comprising a plurality of reactances in cascade and a translating device, having a high impedance input circuit and a low impedance output circuit interposed between a pair of said reactances; and a feedback circuit including a translation device having a high impedance input circuit and a low impedance output circuit in cascade with an impedance element, said feedback circuit being interposed between

said means for deriving an output signal and an intermediate portion of one of said branch circuits.

13. A frequency sensitive apparatus for producing an output signal differing from an input signal including signal input means and means for deriving an output signal comprising: a first branch circuit interconnecting said signal input means and said signal output means including at least one translation device, having a high input circuit impedance and a low output circuit impedance, and a plurality of resistors in cascade; a second branch circuit in parallel with said first branch circuit comprising at least one translation device, having a high impedance input and low impedance output circuit, and a plurality of reactances in cascade; and a feedback circuit comprising a two-terminal reactance, a two-terminal resistance and a translation device having a high impedance input circuit and a low impedance output circuit, said input circuit being connected to said means for deriving an output signal and said output circuit connected to one terminal of each of said two-terminal resistance and said two-terminal reactance, the other said terminal of said resistance being connected to a point common to a plurality of said reactances and the other said terminal of said reactance being connected to a point common to a plurality of said resistances for feeding back a portion of said output signal to intermediate portions of said branch circuits.

References Cited in the file of this patent

UNITED STATES PATENTS

2,341,067	Wise	Feb. 8, 1944
2,565,497	Harling	Aug. 28, 1951
2,581,456	Swift	Jan. 8, 1952
2,658,993	Seeley	Nov. 10, 1953
2,672,529	Villard	Mar. 16, 1954
2,692,343	Spiro	Oct. 19, 1954
2,756,283	Bach	July 24, 1956
2,771,518	Sziklai	Nov. 20, 1956