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V. D. LANDON

2,187,805

HIGH IMPEDANCE BAND PASS FILTER

Filed Nov. 30, 1936

Fig. 1.

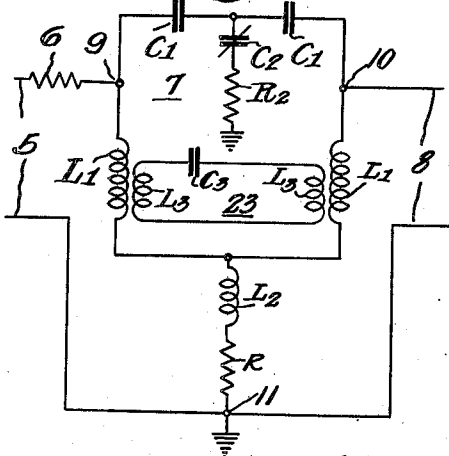


Fig. 2.

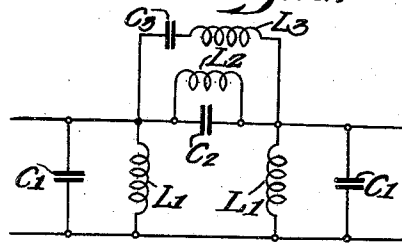


Fig. 3.

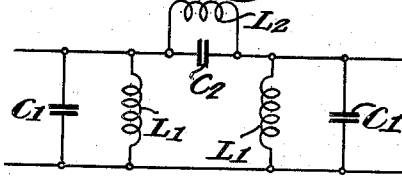


Fig. 5.

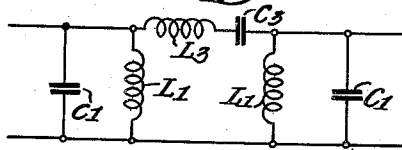


Fig. 6.

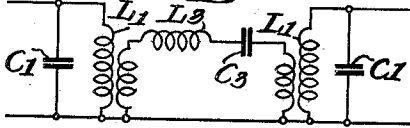


Fig. 7.

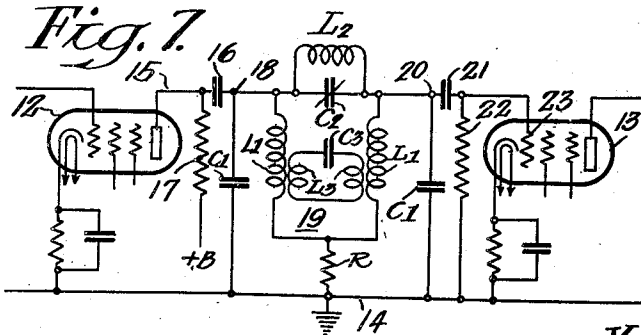
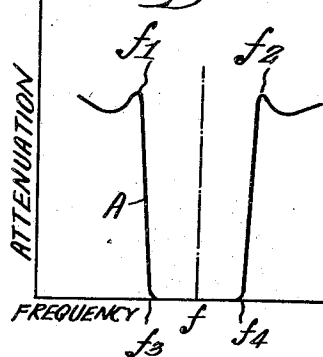


Fig. 8.



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2,187,805

HIGH IMPEDANCE BAND PASS FILTER

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5 Claims. (Cl. 178-44)

The present invention relates to band pass filters of the high frequency type, and has for its object to provide a band pass filter of the so-called M-derived shunt type which may have high input and output impedance whereby it is adapted to provide coupling means between high impedance amplifier tubes in a high frequency amplifier.

A high gain amplifier utilizing a crystal filter is shown in the patent to Mason 1,967,249 of July 24, 1934. It is a further object of the present invention to provide a high frequency amplifier of the type shown in Mason wherein the crystal may be eliminated without sacrificing desirable operation characteristics.

The cost of providing a satisfactory crystal filter is relatively high in comparison to the cost of providing tuned circuits and it is, therefore, a still further object of the present invention to provide as a substitute for a crystal in a high frequency filter, a tuned circuit which may operate to provide substantially the same sharp cut-off characteristic on either side of the pass band and at a much lower cost.

A further object of the invention is to provide the theoretical performance of an M-derived band pass filter without requiring inductances of impractically low resistance and capacity.

The invention will, however, be better understood from the following description when considered in connection with the accompanying drawing, and its scope will be pointed out in the appended claims.

In the drawing,

Fig. 1 is a schematic diagram of a filter network embodying the invention,

Fig. 2 is a schematic diagram of an equivalent filter network used in analyzing the performance of the circuit of Fig. 1,

Figs. 3, 4, 5 and 6 are schematic circuit diagrams illustrating the relation between the circuits of Figs. 1 and 2,

Fig. 7 is a schematic circuit diagram showing a further modification of the invention and the application of a filter embodying the invention or coupling means between high impedance circuits, and

Fig. 8 is a curve showing the frequency response of the filter circuits of Figs. 1, 2 and 7.

Referring to Fig. 1, a signal transmission circuit represented by input leads 5 are connected through an input circuit impedance 6 which may be the plate impedance of a preceding tube, to a filter network 7 having output leads 8. The filter 7 is of the band pass type adapted to provide

sharp attenuation on each side of the pass band and may be of the M-derived type with mid-shunt termination, as shown in Fig. 2 to which attention is now directed along with Fig. 1.

Broadly considered, the circuit of Fig. 1 comprises a high impedance input terminal 9, a high impedance output terminal 10 and a common ground terminal 11 with a T structure of capacitors C_1 , C_1 and C_2 connected between the three terminals, the latter connection including a resistor R_2 , hereinafter referred to.

The inductance elements of the filter network comprising inductances L_1 , L_1 and L_2 likewise provide a T structure connected to the same three terminals and a resonant circuit 23 coupled to the two inductors forming the arms of the T of inductors and a resistance R connected in the stem of the T of the inductors.

The filter of Fig. 1 embodies a circuit which is the equivalent in performance to that shown in Fig. 2. The same reference numerals and reference characters are used in both figures to designate like parts, and the circuit of Fig. 2 will be recognized as a band pass filter in which the circuits comprising L_2C_2 , L_3C_3 form the rejector elements of the filter. The circuit of Fig. 2 would be ideal if reactors having the proper constants could be designed. However, this can not practically be done, particularly in connection with the inductance L_3 , as design formulas call for the inductance L_3 to be very large to be resonated by capacity C_3 which should be relatively low.

When an inductance of the proper value is constructed for use at L_3 , it is found to have a distributed capacity larger than the capacity called for at C_3 . Hence, it can not be resonated by C_3 . Also, the losses in L_3C_3 and L_2C_2 should be extremely small for best operation.

These disadvantages in a circuit in accordance with Fig. 2 have heretofore been overcome by utilizing a crystal in place of the circuit C_3L_3 to provide sharp attenuation at each side of the pass band. However, in the circuit shown in Fig. 1, the difficulties have also been overcome in that the requirement for a large inductance of unduly low capacity is eliminated by replacing L_3C_3 of Fig. 2 by a tuned circuit $L_3C_3L_3$ coupled to the input and output circuit of the filter. In this case the tuned circuit is coupled to the input and output inductances L_1 and L_1 of the filter as shown.

Referring now to Figs. 3 to 6 inclusive, in addition to Figs. 1 and 2, and in which the same reference characters are used throughout, the

circuit of Fig. 2 can best be resolved into the circuit of Fig. 1 by progressive steps illustrated by the figures referred to. For example, it will be seen that the circuit C_3L_3 of Fig. 2 may be provided as shown in the circuit of Fig. 6, since the circuit of Fig. 6 may be shown to be equivalent to the circuit shown in Fig. 5, in which the series resonant circuit C_3L_3 of Fig. 2 or of Fig. 5 is replaced by a circuit inductively coupled to the input and output inductances L_1 and L_1 of Fig. 6.

Similarly, L_2C_2 can be replaced by inductive and capacitive couplings as in Fig. 2. This is illustrated in Fig. 4 which can be shown to be equivalent to Fig. 3 by performing a T to π transformation in accordance with the conversion formulas, examples of which are found in "Transmission Circuits for Telephone Communications" by K. S. Johnson, page 282, Fig. 27. The transformation is taken first on the T of the inductances and secondly on the T of the capacity.

If, as shown, Fig. 4 is equivalent to Fig. 3, and Fig. 5 is equivalent to Fig. 6, it follows that Fig. 1 is equivalent to Fig. 2. However, Fig. 1 has the advantage that L_3 and L_2 may have more reasonable constants.

In Fig. 2 the reactances L_2-C_2 , L_3-C_3 are assumed to be dissipationless. If losses are present, the effect is chiefly to reduce the attenuation at the two frequencies adjacent to the pass band where the attenuation is desired to be infinite.

In the circuit of Fig. 1 the presence of losses in the circuit L_3C_3 has an effect analogous to losses in L_3C_3 in Fig. 2. However, resistance in series with L_2 appears mathematically as a negative resistance in series with the series arm of the filter when a T to π transformation is applied to the T of inductances. Thus, while dissipation in L_3C_3 decreases the peak attenuation, dissipation in L_2 or C_2 increases the attenuation. A resistor may be inserted in series with L_2 and adjusted to give infinite attenuation at the two attenuation peaks f_1 and f_2 . This resistance may be inserted wholly in series with L_2 in Fig. 1 as shown at R or may be included also in circuit with C_2 as shown at R_2 .

The attenuation characteristic takes the form of the curve A of Fig. 8. The double attenuation peaks at frequencies f_1 and f_2 are provided by the combination of series resonant and parallel resonant circuits, L_2C_2 , L_3C_3 of Fig. 2, which are tuned to the same frequency f . The pass band of the filter is effective between the frequencies f_3 and f_4 .

It has been shown in the foregoing description that the circuit of Fig. 1 is equivalent to the circuit of Fig. 2. The latter is a well known M-derived filter, as may be seen with reference to page 255, Fig. 141, of "Transmission Networks and Wave Filters", by T. E. Shea, published by D. Van Nostrand Company in 1929.

The circuit parameters of Fig. 1 are obtained by the method used in showing the equivalence, for example, of C_1 , C_1 , C_2 of Fig. 1, which are obtained from the values of the same elements of Fig. 2 by well known formulas relating to T and π circuits given in the work by Johnson, hereinbefore referred to.

The value of R in Fig. 1 to use for peak attenuation is, in general, found by experiment. However, the value is adjusted for peak attenuation at f_1 , f_2 . This value may be solved for by the following:

$$R_2 + R = R_3 \frac{L_2}{2L_3}$$

where R_3 is the total resistance of the link circuit.

From the above reference in Johnson, the series arm of the π network is, in Johnson's terminology:

$$Z = \frac{Z_A Z_B + Z_A Z_C + Z_B Z_C}{Z_C} \quad 10$$

in our terminology $Z_A = Z_B = j\omega L_1$; for Fig. 2, $Z_C = j\omega L_2 + R$

$$Z = \frac{j^2 \omega^2 L_1^2 + 2j\omega L_1(j\omega L_2 + R)}{j\omega L_2 + R} \quad 15$$

$$= \frac{\omega^2 L_1^2}{\omega^2 L_2^2 + R^2} (j\omega L_2 - R) + 2j\omega L_1$$

The non-reactive term is seen to be negative.

If the band is narrow so that (in Fig. 1) L_1 is much greater than L_2 , then the last term of the above may be neglected for a first approximation. Then (except for the negative sign) the power factor of the series arm of the π (L_2 of Fig. 2) is the same as that of the stem of the T (L_2 of Fig. 1). If this power factor is the same as that of $L_3 C_3$ then the branch comprising $L_3 C_3$, $L_2 C_2$ (of Fig. 2) presents infinite impedance at frequencies f_1 and f_2 .

Then

$$R = R_3 \frac{L_2}{L_3} \quad 30$$

In regard to the relation of the L_1C_1 , L_2C_2 , L_3C_3 , Fig. 2, combinations to the pass band and attenuation peaks, these may have various values, as discussed in Shea above referred to, where the circuit parameters are evaluated on Fig. 141 in terms of the equivalent constant K filter.

Referring to the circuit of Fig. 7, the use of the filter network as a coupling impedance between a high impedance high gain amplifier tube 12 and a second amplifier tube 13 is shown. The ground lead 14 forms the common ground lead for the amplifiers, and the output circuit 15 of the amplifier 12 is coupled to the impedance coupling means 16, 17 with the high impedance input terminal 18 of the filter network 19. The high potential output terminal of the filter network indicated at 20 is connected through a similar impedance coupling means 21, 22 with the input electrode 23 of the amplifier 13. The signals amplified by the device 12 are applied to the amplifier device 13 subject to the band pass characteristic of the filter and to the attenuation characteristic thereof. This filter network corresponds in form to that shown in Fig. 2 but indicates a practical coupling network for two amplifier tubes providing high impedance output and input circuits which are to be coupled.

In form, the filter network shown is a π network of resonant elements, each element being a parallel resonant circuit tuned to the mean pass band with a fourth circuit comprising the elements L_3 , C_3 , L_3 , also resonant to the mean pass band frequency and inductively coupled to the two shunt elements L_1 and L_1 of the π structure. The resistor R is common to the inductive branches L_1 and L_1 of the input and output circuits. Thus, as in Fig. 1, means are provided in the filter network for effecting the theoretical performance of a dissipationless M-derived filter.

In this circuit the π form of filter network is retained for the reactances $L_1L_2L_1$ and the ca-

capacity $C_1C_2C_1$, to show an operable variation of equivalent performance to that of Fig. 1. As in Fig. 1 the resistance R in series with L_2C_2 is given such a value that infinite attenuation is obtained at the rejection frequencies.

In the circuit of Fig. 2, if $L_3C_3=L_2C_2=L_1C_1$, each pair of elements being resonant at a mid-band frequency, at some lower frequency L_3C_3 being a series circuit has a capacitive reactance while L_2C_2 , being a parallel circuit, has an inductive reactance. Thus, at a certain frequency below the pass band of the filter network the combination acts as a parallel resonant circuit. A similar action takes place above the transmission band and the impedance developed by the combination of these two frequencies is inversely proportional to the resistance of the elements. This is likewise true of the circuits of Figs. 1 and 7. The attenuation peaks f_1 and f_2 , one on each side of the desired transmission band, are provided by the combination L_3-C_3 and L_2-C_2 , acting like a parallel resonant circuit at each of the attenuation frequencies.

It will be seen that the difficulty in the way of duplicating the performance of an ideal filter because of the presence of resistance in each element of the circuit may be overcome by the corresponding filter networks, as shown in Figs. 1 and 7, and may be rendered substantially as effective by introducing negative resistance in opposition to the positive resistance of the series circuit elements.

By providing means, as shown in Figs. 1 and 7 at R and R_2 , to reflect in a phantom negative resistance in series with the rejector inductance L_2 of the equivalent network in Fig. 2, the parallel resonant impedance in the series arm of Fig. 2 is raised to an infinitely high value, giving high attenuation at the proper points when the negative resistance is adjusted to balance out the other resistance of the combination.

The circuit of Fig. 1 has been tested and found to give results which are highly satisfactory as a substitute for a crystal filter. The advantages over the crystal filter are found in the low cost of the elements of the filter and flexibility in the design thereof.

An embodiment of the invention, as shown in Fig. 1, may have the following constants:

$f = 175$ kc.	$R = 51$ ohms
$f_1 = 165$ kc.	$L_1 = 4300$ microhenries
$f_2 = 185$ kc.	$L_3 = 4300$ microhenries
$f_3 = 170$ kc.	$L_2 = 940$ microhenries
$f_4 = 180$ kc.	

The capacitors are adjusted for resonance at 175 kc.

The terminal resonance for the above constants may be considered to be 120,000 ohms. At f_2 the best value of R was 62 ohms, and at f_1 40 ohms. Therefore, a compromise value of 51 ohms was considered best to use. The gain of the circuit when used between high impedance circuits, as in Fig. 7, was approximately 50.

The resulting response curve was flat from 171 to 179 kc. and the attenuation on f_2 and f_1 was more than 100 to 1, as indicated by the curve in Fig. 8.

The use of a tertiary circuit as in Fig. 1 has the advantage that the cost of the filter circuit may be reduced materially and permits more nearly the ideal circuit of Fig. 2 to be provided by reactance elements having practical physical and electrical characteristics.

I claim as my invention:

1. A band pass filter comprising, in combination, means providing input and output circuits therefor each resonant to a mean pass band frequency and including an inductance element, means including additional inductance elements providing inductive coupling between said circuits, means providing capacity coupling between said circuits for balancing out the inductive coupling at the mean pass band frequency, additional coupling means between said input and output circuits comprising a tunable tertiary circuit resonant to the mean pass band frequency and inductively coupled to both the input and the output circuits of said filter, and a common resistor in circuit with the inductance elements of the input and output circuits, the resistance of the resistor being so proportioned with respect to the impedance of said circuits that substantially infinite impedance is effected at two frequencies adjacent to and on opposite sides of resonance.

2. In a band pass filter, the combination of a high signal potential input terminal, a high signal potential output terminal, a common ground terminal, a T structure of capacitors connected between said terminals, a T structure of inductances connected between said terminals, the electrical values of the elements of the two T-structures being such that an arm and the stem of the inductive T is resonant with an arm and the stem of the capacitive T at the mean pass band frequency, means providing a resonant circuit inductively coupled to the arms of the inductance T-structure, and a resistance connected in the stem of said last named T structure having a value to provide substantially infinite impedance at rejection frequencies adjacent to and above and below the mean pass band frequency.

3. A band pass filter comprising, in combination a π structure of resonant elements, each element comprising a parallel resonant circuit having inductive and capacitive branches and being tuned to a mean pass band frequency, means providing a fourth circuit resonant to the mean pass band frequency and inductively coupled to the two shunt arms of the π structure, and a resistor common to the inductive branches of said shunt elements of the π structure, the resistance of the resistor being so proportioned with respect to the impedance of said circuits that substantially infinite impedance is effected at two frequencies adjacent to and on opposite sides of resonance.

4. In an electric discharge amplifier, the combination of means providing a high impedance output circuit and means providing a high impedance input circuit, and a band pass filter comprising parallel resonant circuits connected in parallel relation to said output and input circuits, said parallel resonant circuits forming the arms of a π structure and having inductive branches, a resistor common to the inductive branches of said parallel resonant circuits, a third parallel resonant circuit forming the series arm of said π structure, and a fourth circuit inductively coupled to the inductive branches of said first named parallel resonant circuits, all of said circuits being tuned to a mean pass band frequency within which the amplifier operates.

5. A band pass filter providing substantially the performance of a dissipationless M-derived filter comprising, in combination, a T network of inductance elements and a T network of capacity elements providing two parallel T struc-

tures between high potential input and output terminals for said filter and a common ground terminal, the electrical values of the elements of the two T networks being such that an arm and the stem of the inductive T is resonant with an arm and the stem of the capacitive T at the mean pass band frequency, means for increasing the resistance in the stem of at least one of said T structures to a value to provide substan-

tially infinite impedance at rejection frequencies adjacent to and above and below the mean pass band frequency, and a series tuned circuit resonant to the mean pass band frequency inductively coupled to the series arms of said inductance T structure, said last named circuit being tuned to the mean pass band frequency of said filter.

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