Dec. 24, 1935. N. M. RUST 2,025,128

BAND PASS NETWORK

Filed Sept. 26, 1933 4 Sheets-Sheet 1

Fig. 1

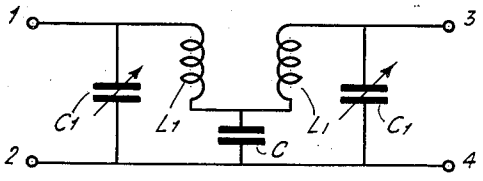


Fig. 2

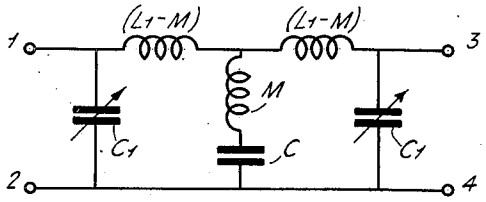


Fig. 3

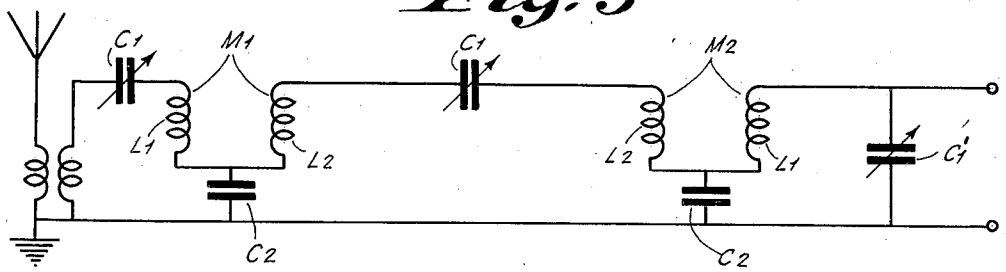


Fig. 4

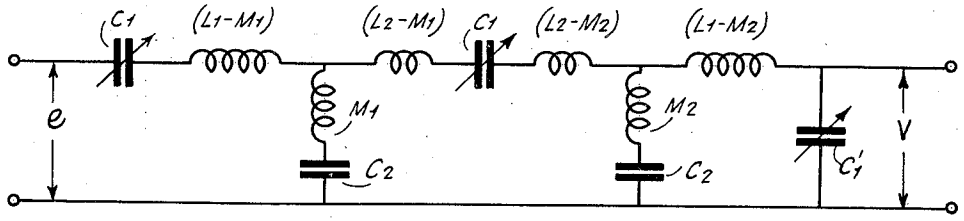
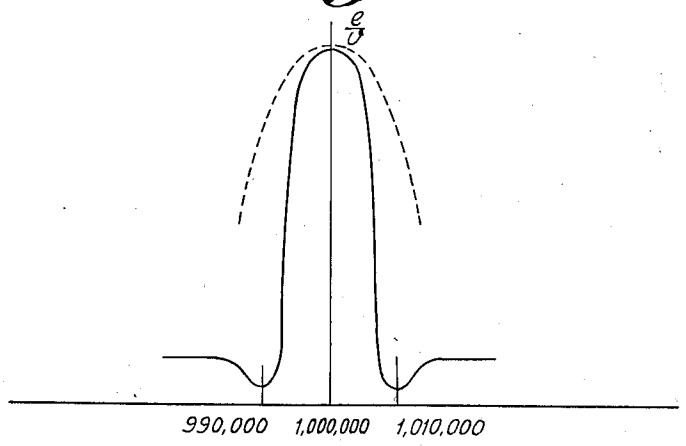


Fig. 5



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Fig. 6

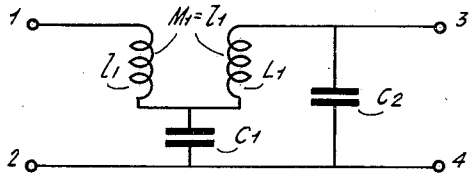


Fig. 7

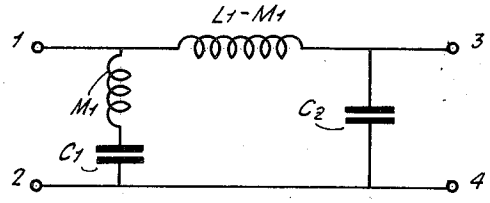


Fig. 8

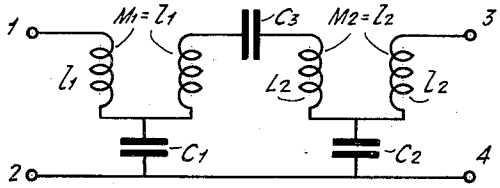


Fig. 9

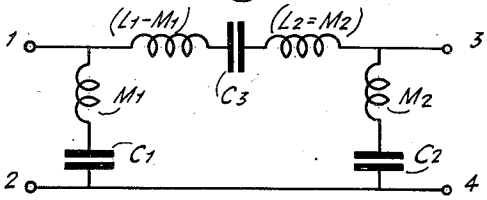


Fig. 10

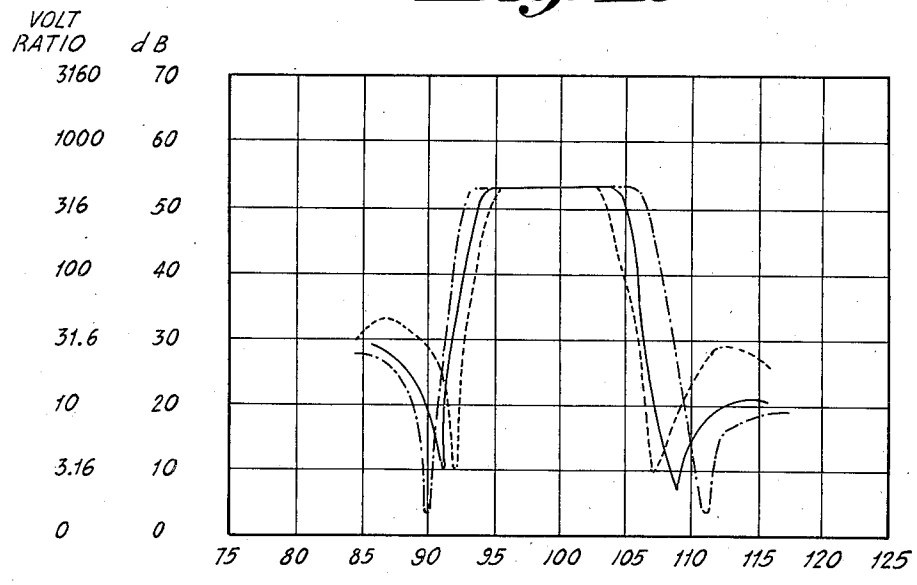
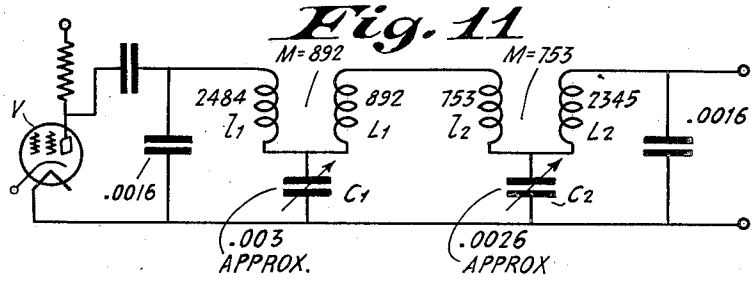


Fig. 11



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Fig. 12

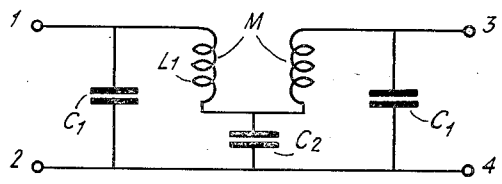


Fig. 13

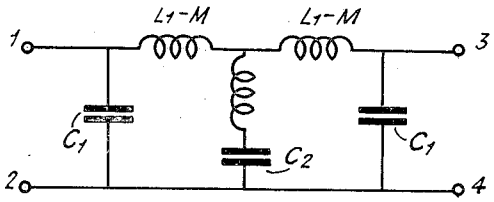


Fig. 14

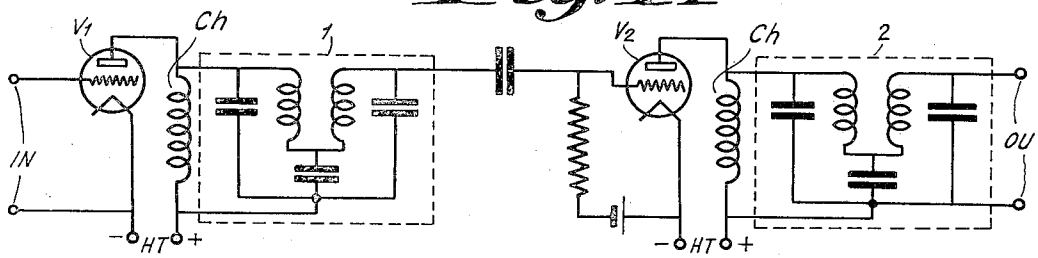


Fig. 15

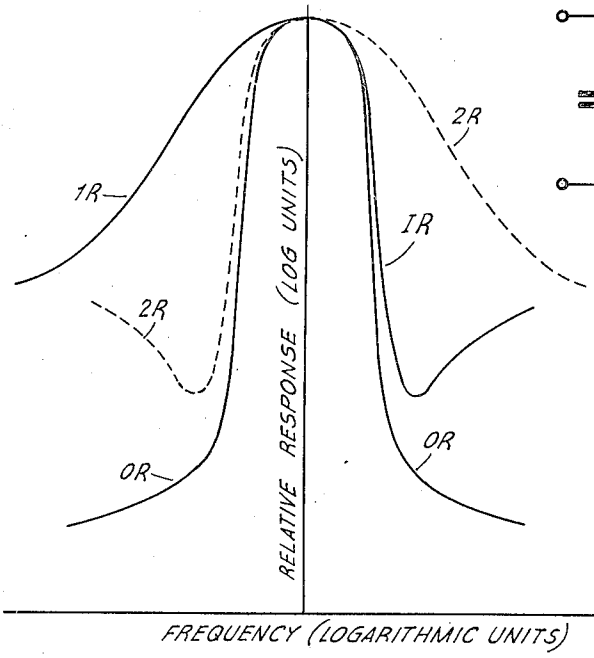


Fig. 16

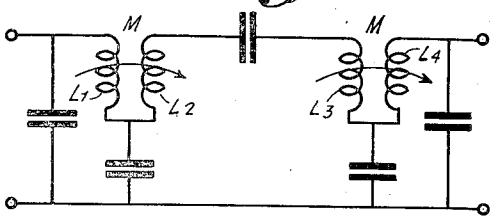
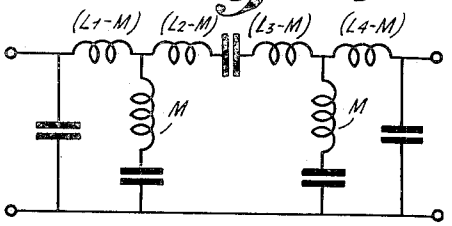


Fig. 17



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Fig. 18

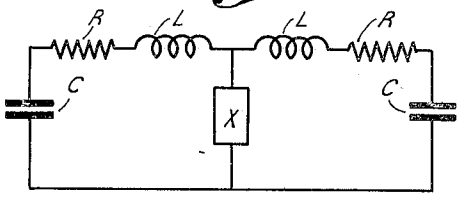


Fig. 19

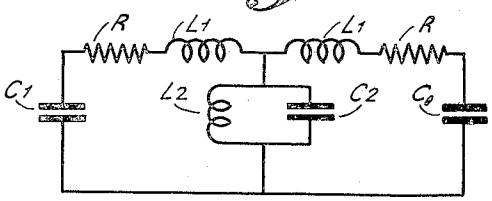


Fig. 20

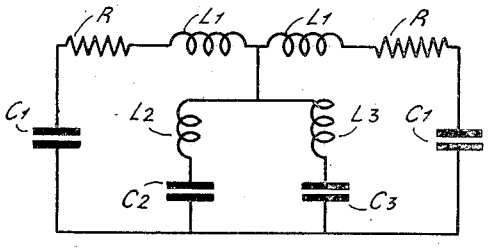


Fig. 21

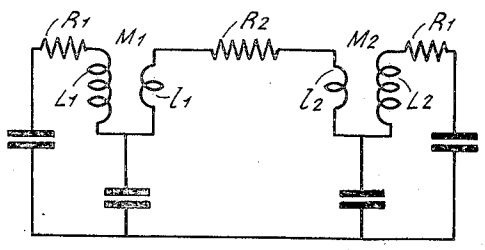


Fig. 22

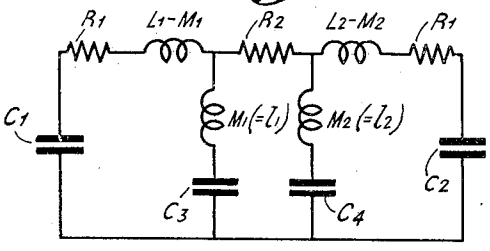


Fig. 23

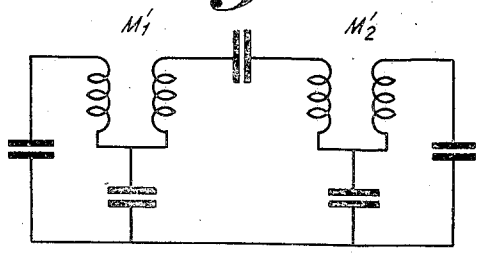
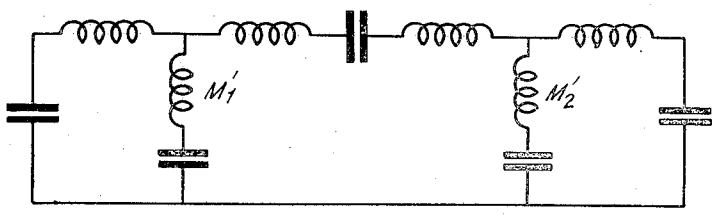


Fig. 24



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Patented Dec. 24, 1935 2,025,128

UNITED STATES PATENT OFFICE

2,025,128

BAND PASS NETWORK

Noël Meyer Rust, Chelmsford, England, assignor to Radio Corporation of America, a corporation of Delaware

Application September 26, 1933, Serial No. 690,989
In Great Britain October 8, 1932

2 Claims. (Cl. 178—44)

This invention relates to frequency selective electrical circuit arrangements and filters. Though not exclusively confined thereto the invention is particularly advantageous when applied to provide improved circuit arrangements of the band pass filter type i. e. adapted to give a response which is approximately constant over a predetermined band of frequencies and which falls away rapidly on either side of the limits of that band of frequencies.

Such band pass filters are frequently required for a variety of different purposes; for example, in radio receivers it is commonly required to provide a turnable band pass filter adapted to give approximately constant response over a band of frequencies of width approximately equal to that required for speech or music modulation, the response falling away rapidly on either side of the limits of this band. Common requirements at the present time are that the width of the band passed shall be about 10,000 cycles, and that the position of the band in the frequency spectrum shall be movable by tuning over the relatively wide range of frequencies occupied by the so-called lower or higher broadcast range. These requirements are difficult to satisfy with relatively cheap and simple apparatus it being more particularly difficult to secure sharp cut-off effects on either side of the accepted band, and, as will be readily appreciated such sharp cut-off effects are highly desirable for the purpose of minimizing interference due to the reception of more than one transmission station at a time.

The present invention though applicable to so-called radio frequency circuits i. e. to circuits performing selective functions at received radio frequencies is most advantageously applicable to so-called intermediate frequency circuits in superheterodyne receivers i. e. to circuits performing selective functions at the (fixed) intermediate frequency of a superheterodyne receiver.

The primary object of the invention is to provide frequency selective electrical circuit arrangements giving sharp tuning and rejector effects or sharp band-pass tuning effects i. e., band pass tuning effects with sharp "cut-offs" at the ends of the band to be passed.

The invention, though not limited to its application thereto, is particularly adapted to the provision of a complex resonant circuit arrangement in the intermediate frequency amplifier of a superheterodyne receiver giving a so-called band pass filter effect whereby a desired band of frequencies will be passed by said amplifier with clearly defined cut-off effects on either side of the central frequency of that band.

The invention is illustrated in and further explained in connection with the drawings accompanying the present application.

As is well known if there be provided in association in a network, two tuned circuits and a third acceptor circuit of suitable value a so-called band-pass filter effect can be obtained. For example, referring to Figure 2 if a network consisting of two tuned circuits each comprising an inductance (L_1—M) and a condenser C_1 associated therewith, and with an acceptor circuit consisting of an inductance M and a condenser C, then if the two tuned circuits (L_1—M)C_1 be similar and the acceptor circuit MC suitably proportioned a comparatively sharp cut-off effect may be obtained by reason of the said circuit MC, the remaining circuits giving a resonant peak effect at a predetermined distance in the frequency scale from the frequency at which the cut-off effect occurs. The terminals 1, 2, represent the input terminals of the network shown in Figure 2, and the terminals 3, 4, the output terminals.

By an important feature of the present invention there is provided an improvement in the fundamental type of circuit exemplified by Figure 2, the improvement resulting in the obtaining of sharper cut-off effects and better resonant voltage response. In the known fundamental circuit shown in the said Figure 2 an actual inductance M is utilized to provide rejector effects, and in essence the present feature of the invention consists in so modifying the fundamental circuit shown in the said Figure 2 that the inductance utilized to provide the rejector effects is a mutual inductance instead of an actual physical inductance. Thus the inductance M of the circuit MC of the said Figure 2 is constituted in accordance with this feature of the invention not by a separate coil, but by the mutual inductance between two coils each of which is in one of the two remaining tuned circuits. The use of mutual inductance in this way produces sharper selectivity characteristics than obtainable in the ordinary way by reason of the fact that, where mutual inductance is so employed, coil losses (energy losses) present in ordinary known arrangements are reduced.

Figure 1 shows the circuit of Figure 2, modified in accordance with the present invention, and as will be seen the modified circuit consists of coils L_1 and condensers C_1 the coils being similar and

the condensers being similar, each pair L_1C_1 forming a tuned circuit. The junction of the two coils L_1 and the junction of the two condensers C_1 are connected together through the fixed condenser C. The two coils L_1 are mutually coupled, the mutual inductance not being represented in Figure 1, and this mutual inductance M replaces, in accordance with the present invention, the actual coil M of Figure 2.

Figure 3 shows in conventional circuit diagram form, and Figure 4 in what may be regarded as an electrically equivalent diagram form, an actual practical arrangement in accordance with the present invention and suitable for use, for example, in connection with radio reception. Referring to the said Figure 3, it will be seen that there is an aerial circuit which is coupled to a complex resonant network comprising two inductance coils designated L_1; two inductance coils designated L_2; two variable condensers designated C_1; a third variable condenser designated C_1', and two fixed condensers designated C_2.

The arrangement of the said Figure 3 may be regarded as an extension of the arrangement of Figure 1 to two stages. As will be seen, the arrangement of the said Figure 3 includes three series connected tuned circuits $C_1(L_1-M_1)$; $C_1(L_2-M_1)+(L_2-M_2)$; and $C_1'(L_1-M_2)$. These three circuits are tuned to the fundamental frequency e. g. to 1,000,000 cycles per second in the case of a radio receiver; in other words these three circuits are tuned to the middle frequency of the band desired to be passed. M_1 represents the mutual inductance between the coils L_1 and L_2 as represented to the left of Figure 3, and M_2 represents the mutual inductance between the coils L_2 and L_1, as represented to the right of the said Figure 3. The acceptor circuits constituted by the mutual inductance M_1 with the condenser C_2, and the mutual inductance M_2 with the condenser C_2 are tuned to frequencies on either side of the fundamental or central frequency e. g. to take the numerical example above given M_1C_2 may be tuned to 990,000 cycles per second, and M_2C_2 may be tuned to 1,010,000 cycles per second.

It is thought that from the description already given, the relation of the said Figure 3 to Figure 4 will be evident from the drawings. Figure 5 shows graphically the relation between the ratio

$$\frac{e}{V}$$

(ordinates—see the said Figure 4) and the frequency (abscissæ). The symbol *e* represents the input voltage impressed at the input terminals of the filter network shown in Fig. 3, while the symbol V designates the output voltage across the output terminals of the same network; this is shown in Fig. 4. The broken line curve shown in the said Figure 5 is inserted for purposes of comparison and shows the nature of the improvement obtained by a circuit as shown in Figure 3, as compared to an ordinary tuned circuit.

It will be noted that in the arrangement shown in the said Figure 3 there is employed what may be termed a "mutual inductance acceptor circuit" i. e. an acceptor circuit in which the inductance is a mutual inductance as distinct from a self-inductance, this acceptor circuit being utilized in conjunction with other resonant circuits to produce (in the case of the said Figure 3) a band pass effect. As above stated, the use of a mutual inductance instead of (as hitherto) a self inductance to produce rejector effects constitutes an important feature of this invention, and in the embodiments so far described the mutual inductance acts as an auxiliary between two coupled circuits, the arrangements so far described being of the band pass type. Figure 6 of the accompanying drawings shows diagrammatically an arrangement involving the same fundamental principles but wherein the mutual inductance is not employed as a coupling link.

Referring to Figure 6, the network therein shown consists of two inductance coils l_1 and L_1 in series with one another between terminals **1** and **3**, and two condensers C_1 and C_2, the former being connected between a conductor joining terminals **2** and **4** and the junction points of coils l_1 and L_1, and the latter being connected between the terminals **3** and **4**. The coils l_1 and L_1 are coupled together to have a mutual inductance M_1 equal to the inductance of the coil l_1. The combination M_1C_1 is resonant to a frequency to be rejected, and the condenser C_2 resonates with L_1-M at a frequency to be accepted. Figure 7 is the theoretically equivalent diagram corresponding to Figure 6.

As will be apparent to those skilled in the art, a circuit as shown in the accompanying Figure 6 will have the property of "cutting" out an undesired frequency, namely, that at which the combination M_1C_1 is resonant. The said circuit is, therefore, well adapted for use in the radio frequency selecting stage or stages of a superheterodyne receiver. As is well known, a difficulty frequently met with in superheterodyne receivers is that known as "second channel interference"—namely that form of interference which is due to the fact that there are two radio frequencies which when heterodyned by the local oscillator frequency will produce the intermediate frequency. An arrangement as shown in the accompanying Figure 6 may be employed as a tunable device in the radio frequency selective stage or stages of a superheterodyne receiver to eliminate such second channel interference.

A development of the circuit shown in Figure 6 is illustrated in the accompanying Figure 8 and it is thought that the arrangement of Figure 8 will be obvious therefrom having regard to the references thereon. The accompanying Figure 9 is the equivalent theoretical circuit corresponding to Figure 8. In the arrangement of Figure 8 M_1C_1 is resonant to one frequency, M_2C_2 is resonant to another and $((L_1-M_1)+(L_2-M_2))C_3$ is resonant to a third which is intermediate the first two, the said third frequency being an "accepted" frequency i. e. a frequency at which maximum response is obtained, and the first two being "rejected" or "dip" frequencies i. e. frequencies at which minimum response is obtained. The characteristic obtained with the circuit of Figure 8 is therefore a "humped" characteristic with steeply sloping sides rising from the two "dip" frequencies.

Figure 12 shows another circuit arrangement in accordance with this invention, and suitable for use for cutting out interference at one side or another of a particular desired frequency—e. g. for eliminating "second channel interference" in a superheterodyne receiver for which purpose the said circuit arrangement would be provided in the radio frequency portion of the receiver as in the case of the circuit shown in the accompanying Figure 6. In the accompanying Figure 12, L_1 are similar inductances coupled together by a mutual inductance M and C_1C_2 are condensers.

The accompanying Figure 13 is the equivalent theoretical circuit correspondence to Figure 12. It is possible to employ in cascade (in separate valve stages) two differently adjusted circuit arrangements, each adapted to cut out interference to one or other side of a given frequency, and thus to produce a band pass effect e. g. two arrangements as illustrated in the accompanying Figure 12 may be so employed.

Figure 14 shows such an arrangement. In the said Figure 14, V_1 and V_2 are thermionic valves in cascade, and it will be observed that there is associated with the plate circuit of the valve V_1 a filter generally designated **1** (said filter being as illustrated in the accompanying Figure 12) while a similar but differently adjusted filter **2** is associated with the valve V_2. *Ch* are chokes. IN are the input terminals and OU are the output terminals. The circuit **1** is so adjusted as to have a response curve as shown at IR in the accompanying Figure 15, while the response curve of circuit **2** is shown at 2R, the resultant overall response curve being shown at OR.

Another simple arrangement in accordance with the invention is shown in the accompanying Figure 16, the accompanying Figure 17 being the theoretical equivalent circuit. In these two figures M is the mutual inductance between inductances L_1 and L_2 and also that between the inductances L_3 and L_4. The arrangement of the said Figure 16 is in effect that of two series resonant circuits in parallel, one of these circuits producing a "dip" at a frequency f_1 and the other producing a "dip" at a frequency f_2, there being a peak resonance at a frequency

$$f_0=\sqrt{f_1 f_2}.$$

This broad principle of using two acceptor circuits to produce a band pass effect is disclosed in British specification No. 19968/32, but whereas in the arrangements shown in the said specification the sharpness of the effect produced is obtained by applying negative resistance by means of valves, the use of mutual inductance in the present case enables the provision of valves for negative resistance to be dispensed with. In the accompanying Figure 16, the interconnection between the mutual shunt arms is made by a condenser which resonates with the inductance (L_2—M) and (L_3—M).

Figures 19 to 24 are illustrative of still further arrangements in accordance with this invention. These further arrangements may be regarded as examples of cases in which the coupling element or elements in a band pass filter circuit arrangement of the kind employing a plurality of circuit elements is so designed as to present substantially varying reactances for different frequencies in the frequency spectrum considered, and the magnitudes of the components in the coupling element relative to the other components of the whole circuit arrangement are so chosen that at resonance the coupling is approximately at or above the value giving optimum coupling condition, continues approximately at or above the said value for that range of frequency over which an approximately flat topped response curve is required and decreases relatively rapidly from the said value after the desired flat topped region is passed. Figure 18 exemplifies the known tunable band pass filters consisting in essence of two elemental circuits coupled together by a coupling impedance, the complex arrangement having a plurality of modes of oscillation and a plurality of resonant frequencies which are the principal factors in determining the response curve of the whole arrangement.

The circuits of Figures 19 to 24 may be regarded as improvements in the type of filter exemplified by Figure 18, although the separate circuit elements in arrangements, as typified by the said Figure 18, may be of relatively complex form, such arrangements in general may be theoretically reduced so as to be represented by the simple theoretical circuit shown in the said Figure 18, in which figure the condenser C, resistance R, and inductance L to one side of the impedance X are the component portions of one circuit element, the corresponding capacity C, resistance R, and inductance L to the other side of the impedance X being the component portions of the other circuit element. X is the coupling impedance between the circuit elements. It may be shown that with a band pass filter of the general type exemplified theoretically by the said Figure 18, whether the circuit elements be coupled directly or by mutual inductance, condenser coupling or in any other way, if the value of the impedance X at any particular frequency be chosen relative to the resistance R at such value as will produce the required substantial flat-topped response curve, that choice will determine the shape of the sides of the response curve and the positions of the cut-off frequencies and in arrangements as hitherto proposed, wherein the coupling impedance X has been designed to be approximately of constant impedance over the frequency spectrum considered the adjustment of X relative to R determines the side cut-off frequencies, and the shape of the sides of the response curve and unless further circuits are introduced sharper cut-off effects cannot be obtained.

The expression "optimum coupling condition" employed above means that condition which is obtained when the value of the reactance presented by the coupling impedance X is equal to the value of the resistance R. So long as the reactance X is equal to or greater than the resistance R the over-all efficiency will be high. The more rapidly the ratio

$$\frac{X}{R}$$

decreases the sharper will be the cut-off effects. Figure 19 shows an arrangement in which the coupling impedance is constituted by a tuned circuit L_2C_2 designed to have a resonant period at the same frequency as those of the side circuits incorporating the reactances L_1C_1. The constants of the circuit L_2C_2 are so chosen that its reactance is comparable to the value of R and preferably greater than R in order to obtain a close approximation to a flat topped response curve. With this arrangement the approximately flat top will be obtained over that region where the reactance presented by the impedance L_2 and C_2 in parallel is greater than R and when this region has been passed the ratio

$$\frac{X}{R}$$

will decrease, producing relatively steep sides to the responsive curve.

A modified and somewhat better form of arrangement is shown in Figure 20, in which it will be seen that a split circuit consisting of reactances L_2C_2 and L_3C_3 replaces the simple tuned circuit L_2C_2 of Figure 19. In the said Figure 20 the constants are such that a high impedance

peak is produced at the frequency at which L_1 and C_1 resonate and very low impedance dips are produced at frequencies on either side. The ratios

$$\frac{L_2}{C_2} \text{ and } \frac{L_3}{C_3}$$

are chosen in a manner analogous to that adopted for Figure 19 to produce an approximately flat topped response curve for a desired width of frequency spectrum. Where very high selectivity is required negative resistance may be applied to the coupling element.

Figure 21 shows a further modified arrangement which may be regarded as closely equivalent to the arrangement of Figure 20, but wherein mutual inductance is utilized, the arrangement of Figure 21 thus presenting the advantage of very low losses. The resemblance between Figure 21 and Figures 8 and 11 will be noted.

In Figure 21 M_1 represents the coupling between L_1 and l_1 and M_2 the coupling between L_2 and l_2. R_1 and R_2 are resistances. The simplest case of an arrangement as shown in Figure 21 is where M_1 equals l_1 and M_2 equals l_2 but good effects can be obtained even if this condition be not complied with. As M_1 and M_2 would not in practice differ very much for cases where high selectivity is required, it will generally be possible to make L_1 equal to L_2.

The equivalent theoretical circuit for the case where M_1 equals l_1 and M_2 equals l_2 is represented in Figure 22. Figure 23 shows a three circuit element arrangement wherein one mutual inductance M_1' is utilized to sharpen the general cut-off effect on one side of the desired response curve and the other mutual inductance M_2' is applied to sharpen the general cut-off effect on the other. In the said Figure 23, as will be seen, there are two coupling impedances, one between each pair of successive circuit elements and, as before, these coupling impedances are so chosen that the reactances presented thereby are approximately equal to and preferably greater than the resistance value R over the range through which a flat topped response curve is required but falls away relatively rapidly on either side of that range.

The diagram in the accompanying Figure 11 shows a circuit arrangement illustrated as energized from a tetrode valve V. In the diagram of Figure 11 the condensers C_1 and C_2 are shown variable, and when the apparatus was adjusted and arranged to give the various values marked on the said diagram the series of characteristic curves shown graphically in Figure 10 were obtained. In the graphs of the said Figure 10 the abscissæ are frequencies in KC and the ordinates response values in decibels and also in voltage ratio (output terminals to input terminals). The three different characteristics were obtained for three different settings of the condensers C_1C_2 and it will be observed that the adjusting of these condensers results in altering the positions of the "dip" frequencies on the frequency scale substantially without altering either the flatness of the top of the curve, the height thereof, or the steepness of the sides; in other words adjustment of C_1 and C_2 results in altering practically only the width of band passed.

It will be observed from the accompanying Figure 11 that the response curve rises outwardly of the "dip" frequencies. This can be avoided by associating with a circuit as shown in the said Figure 11 an ordinary tuned circuit; e. g. an ordinary tuned circuit may be connected in cascade with a filter in accordance with this invention. By suitably dimensioning the tuned circuit and, in particular, the damping thereof so that it has a characteristic of about the same (or somewhat higher) maximum height as the filter characteristic, a combined characteristic generally resembling that of the filter alone, except that it does not rise to any very great extent outwardly of the "dip" frequencies, may be obtained.

As will be apparent to those skilled in the art, careful screening should be adopted in carrying the invention into practice to prevent undesired coupling occurring. The present invention is of general application, but one particularly advantageous use of band pass filters in accordance with the invention is in connection with the intermediate frequency stages of superheterodyne receivers and by providing a band-pass circuit arrangement in accordance with this invention in association with such an intermediate frequency amplifier a very satisfactory band-pass effect may be obtained in the amplifier.

What is claimed is:—

1. In combination with a source of side band modulated carrier energy, a band pass selector network comprising at least three series connected circuits each tuned to the frequency of said carrier, each circuit including a coil and a tuning condenser, mutual inductance between the coils of each pair of adjacent circuits coupling them, each mutual inductance having in series therewith an auxiliary condenser to provide a series resonant path, whereby two such paths are provided, one of the paths being tuned to a frequency differing from the carrier frequency by the width of one side band, and the other path being tuned to a frequency differing from the carrier frequency by the width of the remaining side band.

2. In combination, a source of side band modulated radio frequency carrier energy, a selector network comprising a pair of tuned circuits, each circuit including a coil and a tuning condenser, said circuits being tuned to the carrier frequency, said coils being connected in series and magnetically coupled, an auxiliary condenser being connected in series with the mutual inductance between said coils and providing therewith a series resonant path, an electron discharge tube having its input electrodes coupled to the output of said network, a second network similar in all respects to the first network, coupled to the output electrodes of the tube, the series resonant paths of said networks each being tuned to a frequency, one above and the other below, and differing from said carrier by the width of the side band frequency.

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