





# UNITED STATES PATENT OFFICE

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## WAVE FILTER

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A principal object of my invention is to provide a new and improved adjustable wave filter for alternating electric currents of a variety of frequencies. Another object of my invention is to provide a wave filter that may be adjusted to pass any one of several different frequency ranges as desired. Another object of my invention is to provide a wave filter in which by a simple adjustment it can be made to pass only a low frequency range, or an intermediate frequency band or a high frequency range. Still another object of my invention is to provide a wave filter adapted for use in connection with telephone subscribers' lines by which they can receive as they please any one of several different messages put on their lines simultaneously. All these and various other objects of my invention will be apparent on consideration of a limited number of specific embodiments thereof which I have chosen to disclose in the following specification by way of example. It will be understood that the specification relates to these examples and that the invention will be defined in the appended claims.

Referring to the drawings, Figure 1 is a diagram showing one embodiment of my invention. Fig. 2 is a diagram showing a modification, and Fig. 3 is a diagram showing attenuation as a function of frequency for the apparatus of Fig. 1.

To disclose an example of utility of my invention as well as to disclose an example of the invention itself, I have shown in Fig. 1 a telephone system adapted for ordinary subscribers' service by connection of individual lines at a central station, on which is superposed a wire broadcasting system to which the subscriber may listen in by making simple adjustments at his subscriber's station. The various subscribers' lines 11, 12 and 13 extend from the respective switchboard jacks 14, 15 and 16.

The numeral 20 indicates carrier current generating and transmitting apparatus which sends out music or monologue or other suitable broadcast sounds in the form of modulated carrier current comprised within a range of 5 to 10 kilocycles per second. An

appropriate band filter for these frequencies is indicated at 21 and the modulated carrier currents within this range go through the transformer 17 to the main conductors 22 and thence in multiple to the various lines 11, 12 and 13, through the respective pairs of condensers 8, 9 and 10. At 23 there is another carrier current broadcast generating and transmitting equipment involving a range of frequencies from 22 to 27 kilocycles per second and an appropriate filter 24 is interposed as shown. At 18 is a third equipment for the range 60 to 65 kilocycles with the appropriate filter at 19. The modulated carrier currents within these ranges 22 to 27 and 60 to 65 kilocycles are also put on the main conductors 22 and then in multiple on the lines 11, 12 and 13.

The ordinary subscriber's set terminating a line such as 12 is indicated at S. Branch conductors 12' go through the high pass filter 26 with critical frequency at 5 kilocycles per second. The output of filter 26 goes to the adjustable filter indicated generally by the numeral 27 which will now be described in detail.

The adjustable filter here employed is of the so-called "ladder type", comprising like series elements in succession and alternately disposed like shunt elements. The proper terminations at the ends of such a ladder type filter to minimize reflection effects may be understood to be interposed where the dotted lines are shown at 28 and 29. The switches 30, 30' and 31 all move together and have three positions of adjustment 1, 2 and 3, under the control of the subscriber by means of a handle 36. Assume first that the adjustment is at position 1 as shown in Fig. 1. In this position it will be seen that the series elements consist of the inductance coils 32, the series condensers 33 being shunted out by the switches 31. Also, the shunt elements each consist of the condensers 34, the inductance coils 35 being disconnected at this position of the switches 30. With the series coils 32 and the shunt condensers 34 effectively connected as shown, the system 27 constitutes a low-pass wave filter. Its cut-off frequency being 10 kilocycles per second, the broadcast



receiving apparatus 25 will receive only the modulated carrier currents sent from the apparatus 20 within the range 5 to 10 kilocycles per second.

By pushing the handle 36 to its second or intermediate position, the switches 30 and 30' will make contact with both the coil 35 and the condenser 34, and each switch 31 will break connection with both of the two opposed contacts with which it is adapted to co-act. This will put the coil 32 and condenser 33 in series in each filter section and the coil 35 and condenser 34 in shunt in each filter section, and the filter 27 will become a band-pass filter, subject to the condition that  $L_1 C_1 = L_2 C_2$ . As will be explained presently, the constants for the coils and condensers have been chosen in this specific example to make the range 20 to 30 kilocycles, which comprehends the range of apparatus 23 and filter 24, but not any part of the ranges of apparatus 20 and filter 21 and apparatus 18 and filter 19. At this adjustment only the output from apparatus 23 will be received at the subscriber's apparatus 25.

Let the subscriber shift the handle 36 to its third position and the switches 30' will disconnect the condensers 34, the switches 30 will connect with coils 35, and the switches 31 will make connection to shunt out the coils 32. In this condition the only effective series elements will be the condensers 33 and the only effective shunt elements will be the coils 35, and the filter 27 will be a high-pass filter with its critical frequency at 60 kilocycles per second. The subscriber's apparatus 25 will in this case receive only the output from the apparatus 18, and both the output from the apparatus 20 and apparatus 23 will be shunted out by the wave filter 27.

The formulas for cut-off frequencies of the different kinds of filters are as follows:

For the low-pass wave filter (corresponding to 27 with switch 36 at position 1),

$$f_L = \frac{1}{\pi \sqrt{L_1 C_2}} \quad (1)$$

where  $L_1$  is the series inductance and  $C_2$  is the shunt capacity.

The values for the two cut-off frequencies  $f_1$  and  $f_2$  of the band filter (obtained with switch 36 at position 2) are determined by the formulas:

$$L_1 C_1 = L_2 C_2 = \frac{1}{4\pi^2 f_1 f_2} \quad (2)$$

and

$$\frac{L_2}{L_1} = \frac{(f_2 - f_1)^2}{4f_1 f_2} \quad (3)$$

where  $L_1$ ,  $L_2$ ,  $C_1$  and  $C_2$  are identified on Fig. 1 and  $k$  is a constant.

The formula for the critical or cut-off fre-

quency for the high-pass filter (with switch 36 at its third position) is

$$f_H = \frac{1}{4\pi \sqrt{L_2 C_1}} \quad (4)$$

From these formulas it can readily be deduced that

$$f_L = f_2 - f_1 \quad (5)$$

and that

$$f_H = \frac{f_1 f_2}{f_2 - f_1} \quad (6)$$

Accordingly, by designing the band-pass wave filter at the outset for a range from 20 to 30 kilocycles per second, it follows from Equation (5) that the low-pass wave filter will cut off at 10 kilocycles per second and from Equation (6) that the high-pass wave filter will cut off at 60 kilocycles per second.

It will be seen that the number of coils and condensers is far less in my adjustable filtered than would be required for three several filters to be used alternatively. I secure either a low-pass filter or a high-pass filter merely by changing the connections of the elements of a band-pass filter.

Voice frequency currents on any line such as 11 are prevented from getting across to another line such as 12, by the condensers 8 and 9 which have high impedance for low frequency. All voice frequency currents are kept out of the subscriber's broadcast receiving apparatus by the high-pass filter 26. High frequency currents go to the subscriber's ordinary telephone set S, but they produce no noticeable effect there.

Referring to Fig. 3, the dotted line gives the attenuation-frequency characteristic of the low-pass filter 26. However, the adjustment is made at 36, only frequencies above 5 kilocycles per second are passed. At position 1, the attenuation characteristic designated (1) is in effect, at position 2, the characteristic designated (2) and (2') is in effect and at position 3, the characteristic designated (3) is in effect.

At zero frequency the characteristic impedance of the low-pass filter of Fig. 1, at adjustment 1, is

$$Z_L = \sqrt{\frac{L_1}{C_2}} \quad (7)$$

At the geometrical mean frequency of its range, that is at frequency  $\sqrt{f_1 f_2}$ , the characteristic impedance of the band filter of Fig. 1 at adjustment 2 is

$$Z_B = \sqrt{\frac{L_1}{C_2}} = \sqrt{\frac{L_2}{C_1}} \quad (8)$$

And at infinite frequency the characteristic impedance of the high-pass filter of Fig. 1 at adjustment 3 is

$$Z_H = \sqrt{\frac{L_2}{C_1}} \quad (9)$$

Thus it will be seen that for the three filters



at the respective adjustments, the characteristic impedances at respective representative frequencies are the same and are pure resistances. Hence a design that fits the connected apparatus in respect to characteristic impedance at one adjustment is also a good fit at all adjustments.

Referring to Fig. 2, this shows a modification 37 for the filter 27 of Fig. 1. It will be apparent from the diagram that at position 1 there is a low-pass filter of the type having inductances as series elements and inductances and capacities in series as shunt elements. At position 2 there is a band-pass filter of the same type as in Fig. 1, and at position 3 there is a high-pass filter of the type having a condenser for its series element and a condenser and coil in series for its shunt element. In this case, if  $f_1$  and  $f_2$  are the cut-off frequencies for the band-pass filter then for the low-pass filter

$$f_L = \frac{f_2 - f_1}{\sqrt{1 + a}} \quad (10)$$

where

$$a = \frac{(f_2 - f_1)^2}{f_1 f_2} \quad (11)$$

and for the high-pass filter

$$f_H = \frac{f_1 f_2}{f_2 - f_1} \sqrt{1 + a} \quad (12)$$

Thus if in Fig. 3,  $f_1 = 10,000$  and  $f_2 = 15,000$ , then  $f_L = 4620$  and  $f_H = 32,400$ . The filter of Fig. 3 has the advantage over that of Fig. 1 in that it gives a sharper cut-off at the low-pass and high-pass adjustments.

What is claimed is:

1. A wave filter having successive recurrent sections with at least one coil and at least one condenser per section and means to change the connections of at least one kind of said reactance elements to adjust the free transmitting range of the filter to a desired frequency range, certain of said coils and condensers being operatively connected in on each of several different adjustments.

2. A wave filter having successive recurrent sections with at least one reactance element per section in series and at least one reactance element per section in shunt and means to change the connections of the series reactances and the shunt reactances to adjust the free transmitting range of the filter to a desired frequency range, certain of said reactances being operatively connected in at several different adjustments.

3. A wave filter having successive recurrent sections with at least one coil and at least one condenser per section, and means to change the connections of at least one kind of said reactance elements to adjust the free transmitting range of the filter to a desired frequency range, the elements of the combination being determined to make the character-

istic impedance substantially the same at each adjustment within the respective corresponding free transmitting range, certain of said coils and condensers being operatively connected in on each of several different adjustments.

4. A wave filter having successive recurrent sections with at least one coil and at least one condenser per section, and means to change the connections of at least one kind of said reactance elements to adjust the free transmitting range of the filter to a desired frequency range, the range at each adjustment being exclusive of the ranges at other adjustments, certain of said coils and condensers being operatively connected in on each of several different adjustments.

5. A wave filter having successive recurrent sections with a coil  $L_1$  and a condenser  $C_1$  adapted to be connected in series per section and a coil  $L_2$  and a condenser  $C_2$  adapted to be connected in shunt per section subject to the condition  $L_1 C_1 = L_2 C_2$ , whereby when so connected the filter is a band-pass filter, and means to change the connections of said coils and condensers to convert the filter into a low-pass filter or a high-pass filter.

6. A wave filter having successive recurrent sections with a coil  $L_1$  and a condenser  $C_1$  adapted to be connected in series per section and a coil  $L_2$  and a condenser  $C_2$  adapted to be connected in shunt per section subject to the condition  $L_1 C_1 = L_2 C_2$ , whereby when so connected the filter is a band-pass filter, and means to change the connections of said coils and condensers to convert the filter into a low-pass filter of range lying considerably below the range of the band-pass filter or to convert it into a high-pass filter of range lying considerably above the range of the band-pass filter.

7. A wave filter having successive recurrent sections with a plurality of reactance elements per section, and means to connect said elements in three different ways so that one way the filter will be a low-pass filter, another way it will be a band-pass filter of higher range and the third way it will be a high-pass filter with its cut-off frequency higher than the band-pass range, certain of said reactances being operatively connected in at several different adjustments.

8. A wave filter having successive recurrent sections with a plurality of reactance elements per section and means to connect said elements in three different ways so that one way the filter will be a low-pass filter, another way it will be a band-pass filter of higher range and the third way it will be a high-pass filter with its cut-off frequency higher than the band-pass range, the values of said reactances being chosen so that at representative frequencies within each of the said ranges the characteristic impedance will have substantially the same pure resistance



value, certain of said reactances being operatively connected in at several different adjustments.

5 9. A wave filter having successive recurrent sections with at least one coil and at least one condenser per section, switches to change the connections of said coils and condensers within each section to adjust the free transmitting range of the filter to a desired frequency range and a handle to operate said  
10 switches simultaneously and in coordination, certain of said coils and condensers being operatively connected in on each of several different adjustments.

15 10. A wave filter having successive recurrent sections with a coil and a condenser per section available for series connection and with a coil and a condenser per section available for shunt connection, and means to connect said coils and condensers to make the  
20 filter have different free transmitting ranges of frequency, certain of said coils and condensers being operatively connected for different ranges.

25 11. A wave filter having successive recurrent sections with a coil and a condenser per section available for series connection, and with a coil and a condenser per section available for shunt connection, and means to connect said coils and condensers to make a low  
30 pass filter or a band pass filter or a high pass filter, with the free transmitting range of the band pass filter between the critical frequencies of the low pass and the high pass  
35 filters.

In testimony whereof, I have signed my name to this specification this 3rd day of October, 1923.

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