Radio Editors of magazines and newspapers are hereby given permission to reprint in whole or in part, with proper credit to the Aerovox Wireless Corporation, the contents of this issue of the Aerovox Research Worker.

The AEROVOX Research Worker

The Aerovox Research Worker is a monthly house organ of the Aerovox Wireless Corporation. It is published to bring to the Radio Experimenter and Engineer authoritative, first hand information on condensers and resistances for radio work.

Vol. 1 July 25, 1928 No. 7

Notes on the Design of Filters

PART 2

By Sidney Fishberg
Research Engineer, Aerovox Wireless Corp.

IN the last issue of the "Research Worker," we considered the voltage regulating and operating characteristics of the component condensers of a filter. In this article we shall examine the effect of the component condensers in removing the hum from the rectifier output.

The result of this investigation may be summarized briefly by saying that the filtering action of Condenser "C1" of Fig. 1 (shown again in this issue for reference) when plotted against its capacity is represented by a set of hyperbolae, and the effect of subsequent filter sections is to bring these curves in, closer and closer to the co-ordinate axes.

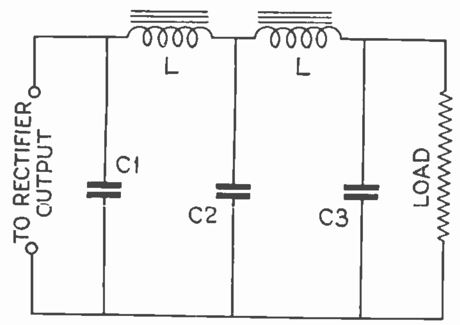


Fig. 1

A simple mathematical calculation shows that the filtering action of "C1" of Fig. 1 may be represented by the formula shown in Fig. 7. In the case of a full wave rectifier, the frequency of "f" is twice that of the power supply line, whereas in a half wave rectifier, it is equal to the frequency of the power supply.

$$\Delta E_1 = \frac{1}{R f C_1}$$

ΔE_1 = VOLTAGE FLUCTUATION AT TERMINALS OF "C_1"
R = LOAD RESISTANCE IN OHMS
f = FREQUENCY OF RECTIFIED WAVE
C_1 = CAPACITY OF FILTER CONDENSER IN FARADS

Fig. 7

This formula tells us several interesting facts. The first one is that the voltage fluctuation is related to the capacity of "C1" by a function of the type shown in Fig. 8, that is,

$$XY = K \qquad \text{(Fig. 8)}$$

an hyperbola. This signifies that if we increase the capacity of "C1" uniformly, the voltage fluctuation will be reduced far more by the first few increments of capacity than by succeeding increments. To make this statement more concrete, let us assume an eliminator which supplies 50 mils at 220 volts, and see how the capacity of "C1" affects the hum. Substituting in the formula shown in Fig. 7 and plotting the results, we obtain the curve of Fig. 9. A voltage fluctuation of ¼ to ½ of one percent is just about tolerable. The futility of attempting to remove any appreciable portion of the hum by means of "C1" is readily apparent because the curve of Fig. 9 shows that even 10 mfds. will only reduce the hum to ten percent. As we have remarked before, the only purpose of "C1" is to raise the available output voltage.

The second fact shown by the formula of Fig. 7 is that the filtering action of "C1" is inversely proportional to the current drain. This is due to the fact that the voltage fluctuation increases with the current drain, as explained previously. Hence a filter which is perfectly satisfactory when delivering 75 milliamperes may hum badly when called upon to deliver 100 or 120 milliamperes. In a majority of cases where a filter hums at a heavy load, it is due to the inherent nature of the load, and not to saturation of

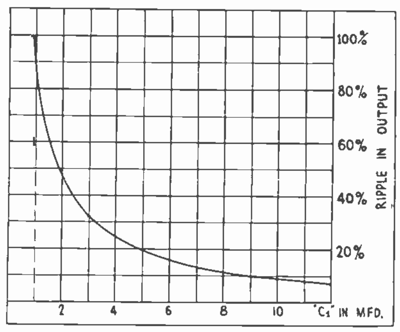


Fig. 9

the filter chokes. This phenomenon will be discussed in greater detail below.

Another little heeded characteristic of this type of filter is the fact that the filtering action varies inversely with the frequency. That is, a filter will remove only half as much hum from a half wave rectifier as from a full wave rectifier. Furthermore, the succeeding filter sections act in the same way as regards frequency, so that finally, a given filter will remove but one-quarter as much hum from a half wave rectifier as from a full wave rectifier.

The attenuation that the following filter sections introduce is expressed by the formula

$$\Delta E_2 = \frac{1}{1 + \left[\frac{\omega L (1 + R\omega C_2)}{R}\right]}$$

ΔE_2 = VOLTAGE FLUCTUATION AT TERMINALS OF "C_2"
L = INDUCTANCE OF SECTION IN HENRIES
C_2 = CAPACITY OF SECTION IN FARADS
R = LOAD RESISTANCE IN OHMS
ω = 2π TIMES THE FREQUENCY OF THE RECTIFIED WAVE = $6.2832 f$

Fig. 10

It is seen that the formula contains terms for the load resistance and for the square of the frequency. For this reason, a given filter is much less effective at heavy loads than at light loads, and less efficient with half wave rectifiers than with full wave rectifiers. The actual effectiveness of the filter section consisting of the first choke and condenser "C2" (Fig 1) for various values of "C2" is shown by Fig. 11. In plotting this curve, "R" was assumed to be 4400 ohms, and "L" to be 15 henries. (This latter value corresponds more nearly to the facts than the nominal value of 30 henries, at which most filter chokes are rated.)

The value of the ripple voltage at the terminals of "C2" is given by the product of delta E_1 and delta E_2 of Figs. 7 and 10. The effectiveness of adding a condenser and an inductance to cut down the hum, instead

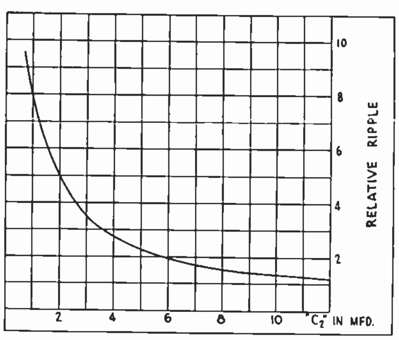


Fig. 11

of merely adding capacity at "C1" is brought out vividly by comparing Figs. 9 and 12. Altho the ripple voltage is now reduced to a small value, it is still sufficiently large to introduce an annoying hum into the loud-speaker. For this reason, a third filter section is usually employed, which removes almost completely all traces of hum. The attenuation caused by this section is the same as that of the second section.

To check these conclusions, a vacuum tube voltmeter study was made of the filter circuit of Fig. 1 for the following conditions:

1. Current varying from 25 to 150 milliamperes.
2. "C2" constant, "C3" varying from 0 to 10 microfarads.
3. "C3" constant, "C2" varying from 0 to 10 microfarads.
4. Half wave and full wave rectifiers.

In this study, "C1" was kept constant at 2 microfarads while all other conditions were being varied. The graphs showing the results of these tests are presented in figures 13 to 16 inclusive.

Examining these curves in succession, Fig. 13 shows how the degree of filtering varies with the current drawn from the eliminator, and the capacity of the sections.

All the curves vary hyperbolically, the filtering action decreasing greatly at large currents. However, by

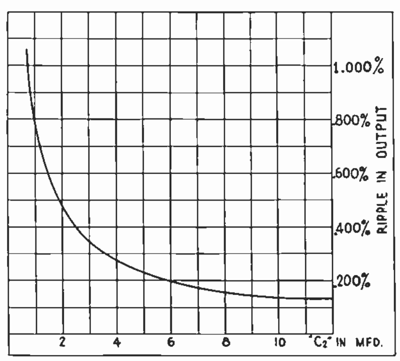


Fig. 12

employing sufficient capacity, the hum may be reduced to a tolerably small value for any desired current drain. For medium-powered eliminators, such as those using Raytheon or CX-380 tubes, a total filter capacity of 8 to 10 microfarads is ample: but, in high powered amplifiers, where the current drain ranges from 100 to 150 milliamperes, the total filter capacity has to run up to twice this amount for the same degree of filtering.

The next set of curves, given in Fig. 14, show the filtering action of "C3." The most striking thing about this family of curves is the mode of their variation. Referring to the diagram, suppose we have a filter in which "C1" is 2 mf., "C2" is 0, and "C3" is 0; and we wish to improve the filtering action by adding two microfarads. The curves tell us at once that much more benefit will be obtained by adding the capacity at "C2" rather than at "C3." Now suppose we wish to improve the filtering action by adding an additional two microfarads unit. This time, better filtering will be obtained by adding the unit at "C3" rather than at "C2."

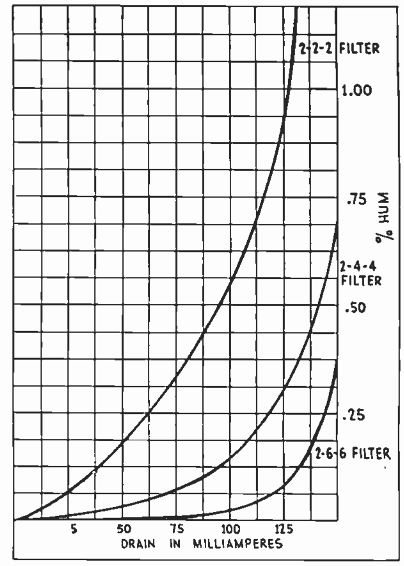


Fig. 13

The curves of Fig. 15, showing the filtering action of "C2" are of exactly the same nature as those discussed in the previous paragraph. Studying the two curves together, it is obvious that for a given amount of capacity, the best filtering is obtained when "C2" = "C3."

The ideal manner in which to add a given capacity is to split it between the two sections adding an equal amount to each section, but if this cannot be done, the next best results will be obtained by adding the extra capacity at "C3" rather than at "C2."

This conclusion, derived here in a graphic way, may be derived more

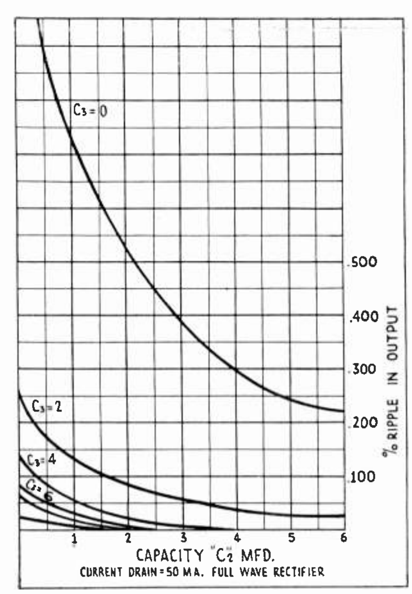


Fig. 14

elegantly in mathematical form. Readers interested in this proof are referred to the General Electric Review, Vol. 19, p. 177, 1916.

In Figs. 14 and 15, a horizontal line at 0.1% ripple intersects the various curves. This line represents a value of ripple voltage which just produced an audible hum, under the conditions obtaining when these tests were made. The percentage ripple which just produces an audible hum varies widely with different factors, such as the amplification of the transformers at the hum frequency, the response of the loudspeaker at the same frequency, and even the auditory sensitivity of the operator. The points of intersection of this line with the various curves give the values of "C2" and "C3" necessary to reduce the hum to a tolerable value. The considerations governing the choice of any particular combination of "C2" and "C3" are as follows: 1. Maximum filtering. 2. Minimum cost. 3. Sufficient capacity at "C3" to preserve tone quality.

We have seen that when "C2" = "C3," the maximum filtering action for a given amount of capacity is obtained. This arrangement also provides sufficient capacity at "C3," for then the addition of extra capacity at "C3" will not improve quality appreciably. At the same time this filter is the cheapest of all tolerable combinations. This is so because when one condenser is smaller than the other, the cost is not smaller in the same proportion.

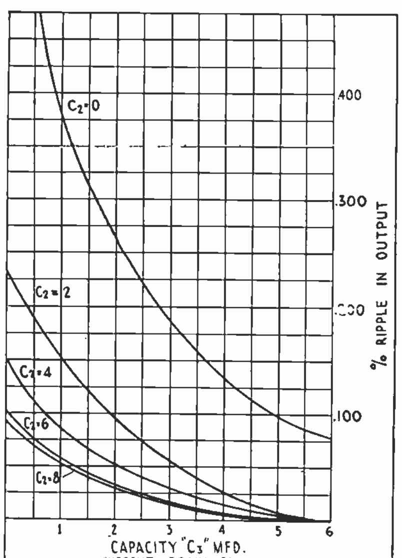


Fig. 15

Turning, now, to a consideration of half wave filters, it must be realized that the only reason for their existence is their cheaper cost. Taking average retail prices, a half wave eliminator which will give the same output as a full wave eliminator will cost about twenty-five percent less than the latter. This is a very appreciable saving, especially since half wave units are used only in high powered sets and amplifiers, where the cost is considerable.

On the other hand, there are several factors which go to counterbalance this lower cost. The first is the fact that the filtering is much poorer than with a full wave rectifier. Curves showing the ripple in the output of a half wave rectifier are shown in Fig. 16. A comparison of Fig. 16 with Fig. 15 reveals the great difference in filtering between the two types of rectifiers. To reduce the hum to the same value as we have chosen for full wave rectifiers would require approximately three to four times as much capacity. Fortunately, however, the frequency of this hum is 60 cycles instead of 120, and it is amplified and reproduced so poorly that a much greater ripple is tolerable. Due to this saving fact, the filter capacity does not have to be increased excessively on the average set. When transformers and loudspeakers which amplify this low frequency well are used however, the ripple of a half wave unit is intolerable, and either a larger filter, or a full wave rectifier must be used.

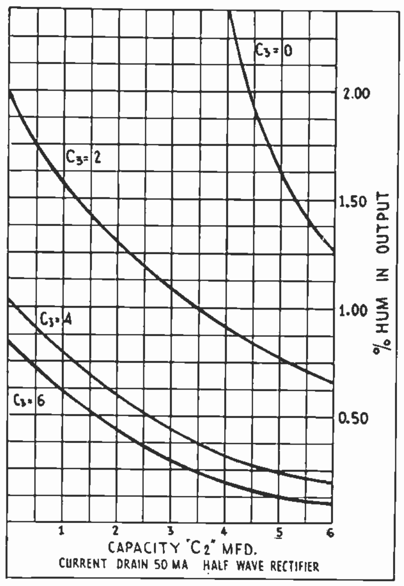


Fig. 16

The second disadvantage of a half wave rectifier is the fact that its single tube has to carry twice the load that the two tubes of a full wave rectifier do, and its life is correspondingly shortened. The final disadvantage of a half wave rectifier is its objectionable voltage regulation, which is much poorer than that of a full wave rectifier. This is shown graphically in Fig. 17, which shows the output of two eliminators each of which supplies 80 mils at 550 volts. While both of these units supply the same current and voltage at this one point, the half wave unit has far less reserve power than the full wave unit. In view of these disadvantages, it may be said that a half wave unit should not be chosen except when cost is a major consideration.

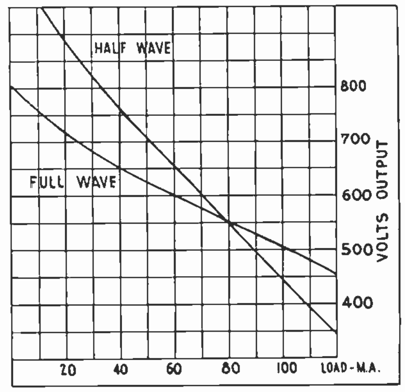


Fig. 17

Aerovox Plant Expands

The increased demand for Aerovox condensers and resistors has made necessary the addition of 10,000 square feet of floor space to the Aerovox plant at 70 Washington Street, Brooklyn, N. Y.

The Aerovox Wireless Corporation takes this opportunity of thanking its many friends whose confidence and patronage has made possible its rapid progress from a comparatively small plant occupying only about 4,000 square feet in 1924 to its present large plant of over 30,000 square feet.

A cordial invitation to visit the Aerovox plant is extended to editors, engineers, manufacturers and others who are interested in seeing how condensers and resistors are made.

It is gratifying to see that the pioneer efforts of the Aerovox Wireless Corporation for ruggedly built, conservatively rated, thoroughly tested and absolutely safe condensers and resistors are now bearing fruit. The steadily increasing business garnered as a result of a steadfast pursuance of a rigid policy of manufacturing only the best condensers and resistors that can be made is proof positive that it pays to manufacture products that stand the most rigid tests.

The National Short Wave Receiver Using Screen Grid Tube R. F. Amplifier

THE arrival of the screen grid tubes solved several problems that have heretofore given serious trouble to the designers of short-wave receivers for either broadcast or television signal reception.

The eagerness which receiver designers have displayed in adapting their circuits for use with this new member of the vacuum tube family, as a means of increasing tremendously the efficiency of such circuits, speaks well for its really remarkable characteristics.

In the first place, the greater sensitivity of the screen grid tube makes the reception of long distance signals much simpler. In the second place, the very small interelectrode capacity of this type of tube also makes it possible to use a stage of radio frequency amplification without all the ticklish adjustments which were formerly necessary to neutralize or balance the radio frequency stage.

In the third place the use of a stage of tuned R. F. with a screen grid tube ahead of the regenerative detector eliminates the radiation nuisance which would otherwise soon make reception on short waves unbearable.

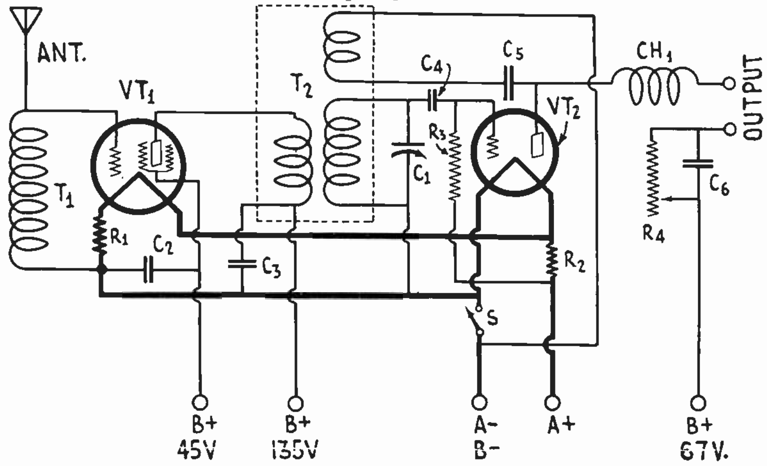
The National Screen Grid Five employs interchangeable transformers to cover the band of 100 to 15 meters (3 to 20 megacycles).

The use of short waves for broadcast reception opens up a wonderful field for long distance reception which is unusually free from the static and fading nuisances which usually hamper the DX hound on the regular broadcast band of approximately 200 to 600 meters. It is not uncommon to receive foreign stations such as ANE, Java, 3LO Melbourne, Australia, 5SW, London, England, and PCJJ, Holland in the United States on the short waves.

In addition to broadcast reception, which is sent out on short waves, most of the television signals which are being transmitted on short waves can be received on this receiver.

The additional equipment necessary for television reception is a special resistance coupled amplifier to build up the signal to sufficient intensity and finally a means for converting the signal into an image.

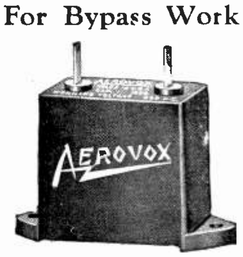
Aerovox Resistoformers are ideally suited for use in such resistance coupled audio amplifiers.



LIST OF PARTS REQUIRED

C1: National, 125 mmfd. short wave type variable condenser.
C2, C3: Aerovox Type 250, .5 mfd. non-inductive condensers.
C4: Aerovox Type 1450, .00025 mfd. moulded mica condenser.
C5: Aerovox Type 1450, .001 mfd. moulded mica condenser.
C6: Aerovox Type 200-S, 1 mfd. non-inductive condenser.
CH1: National No. 90 R. F. Choke coil.
R1: Lynch No. 15 Equalizor.
R2: Lynch No. 2 Equalizor.
R3: Aerovox Metalohm, 6 megohms.
R4: Carter No. 5 "Hi-Ohm" volume control.
S: Carter battery switch.
T1: National No. 10 H. F. impedance.
T2: National Short Wave transformer coil (set of 4 coils required to cover the range from 15 to 100 meters).
VT1: Cunningham CX-322 screen grid radio tube.
VT2: Cunningham CX-112A radio tube.
One National foundation unit for Screen Grid short wave receiver, which includes Westinghouse Micarta, drilled panels and hardware.
One National Type E dial with No. 28 Illuminator.
Eight Eby binding posts.

POPULAR
For Bypass Work



Attractive, compact and efficient, these Type 250, 450, 650 and 1051 non-inductive, paper wound condensers encased in bakelite cases have proven very popular with the best known set designers of the country.

They are available in working voltages of from 200 to 1000 volts and in capacities ranging from .05 to 1 mfd. to suit all bypassing requirements.

Construction Folders—Free

It is of course impossible to give a detailed description of this receiver in the limited space available in this folder. A complete description giving photographs and layout of parts is contained in a folder which may be had free on request by sending in the coupon below.

AEROVOX WIRELESS CORP.,
70 Washington Street,
Brooklyn, N. Y.

I am interested in the National Screen Grid Short Wave Receiver and would like to have you send me free the detailed folder on its construction.

Name ....

Address ....

City .... State..........

EFFICIENT
For Use in R. F. Circuits

The Type 1450 bakelite moulded mica condensers are by far the most efficient fixed condensers available for use in radio frequency circuits, where permanence, accuracy and compactness are the prime essentials.

These condensers, moulded in bakelite and available in a wide range of capacities from .00004 to .02 mfds. are the choice of the leading set designers and manufacturers.

Complete Catalog of Aerovox Products May Be Had Free on Request to

Aerovox Wireless Corporation, 70 Washington Street, Brooklyn, N. Y.