The Aerovox Research Worker

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

VOL. 6, NO. 4 APRIL, 1934 50c per year in U. S. A. 60c per year in Canada.

The Proper Use of Condensers in High Voltage Filter Circuits

By the Engineering Department, Aerovox Corporation

IN the design and construction of rectifier filter systems the use of electrolytic condensers for relatively low voltage filter systems in the order of 400 or 500 volts maximum has become almost standard. For these voltages there is little question that electrolytic condensers meet the requirements of such filter circuits as well as any other type of filter condenser. At the same time the electrolytic condenser is cheaper and more compact.

However, the problem of what types of condensers should be used on higher voltage circuits has not been discussed in previous issues of the Research Worker to any considerable extent. Many readers have written us regarding this problem and hence this issue is devoted to a general discussion of this subject of condensers for high voltage filter circuits.

Condensers for filter circuits are of three types. These three types are the electrolytic condenser, the wax condenser and the oil condenser. The following discussion will, we hope, serve to indicate the essential problems connected with the use of these types of condensers.

In the case of electrolytic condensers where voltages higher than 400 or 500 volts are required, the practice is to connect several condensers in series to obtain a combination capable of withstanding higher voltages. The usual practice is to use for this purpose standard 450 volts working voltage 525 volts surge peak condensers, and to figure on the basis of allowing one extra condenser so as to reduce the voltage across the condensers. For example, for 1000 volts, three condensers should be used in series; for 1500 volts, four condensers would be used in series, and etc.

The problem of using a series combination in this manner naturally raises the old problem that always arises when condensers are connected in series across a source of direct current. If several condensers of equal capacity are connected across a.c. voltage then the voltage divides evenly among the several condensers. For example, if three 1 mfd. condensers are connected across 300 volts a.c. then there will appear across each condenser 100 volts. The important point is that the division of voltage, when a series group of condensers are connected across a.c., is determined purely by the capacity of the individual section, and the only time the voltage division will be on equal is when the capacities are unequal. As an example of this take the case of a 1 mfd. condenser and a 2 mfd. condenser both connected in series across 300 volts. In such a case there would be 200 volts a.c. across the 1 mfd. unit and 100 volts a.c. across the 2 mfd. unit. Note that the voltage division is an inverse function of the capacity. The higher the capacity, the lower the voltage.

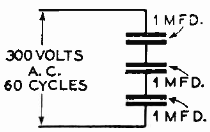


FIG. 1

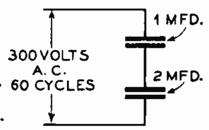


FIG. 2

Although the reason why the a.c. voltage divides in this manner is probably known to most readers nevertheless, it might be worth while to indicate briefly why the a.c. voltage divides as it does in order that the difference between the division of the voltage on a.c. and the division of the voltage on d.c., to be discussed later, will be entirely clear.

Let us, therefore take a typical example and work it through. For example, suppose, as in Fig. 1, three 1 mfd. condensers are connected in series across 300 volts a.c. Assume that the frequency is 60 cycles. By referring to the chart given in the December 1931 issue of the Research Worker (Vol. 5, No. 1) it will be found that a 1 mfd. condenser has at 60 cycles a reactance of approximately 2600 ohms. If we work out this figure accurately it will be found that it is 2654 ohms, but for the purpose of our example, we will take the approximate figure of 2600 ohms obtained from the chart.

Since each 1 mfd. condenser has at 60 cycles a reactance of 2600 ohms then 3 in series will have a reactance three times 2600 or a total of 7800 ohms. The current flowing through the circuit will be equal to the voltage 300 volts divided by the reactance 7800 which gives a current of .0385 amperes.

The voltage across any one of the condensers will then be equal to the reactance of that condenser multiplied by the current. The voltage across any one of the condensers will therefore be equal to 2600 times .0385 which gives 100 volts. Since the same current flows through all the condensers, and furthermore since all the condensers have the same capacity, and therefore the same reactance, it is obvious that there will be 100 volts across each of the three condensers. This indicates that the voltage divides equally among the various condensers, provided they have the same capacity.

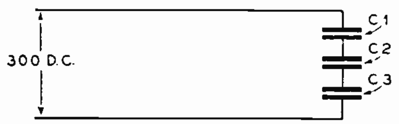


FIG. 3

Now let us take the case of unequal capacities, as shown in Fig. 2. Assume again that the source of voltage is 300 volts a.c. 60 cycles and that we have connected across this voltage one 1 mfd. condenser and one 2 mfd. condenser. The reactance of the 1 mfd. condenser as indicated above is 2600 ohms. By reference to the chart it will be found that a 2 mfd. condenser has one-half the reactance or 1300 ohms. This makes a total reactance of the two in series 3900 ohms. The current through the circuit will therefore be the voltage 300 volts divided by the total reactance 3900 ohms which gives a total of .077 amperes.

The voltage across the condensers will again as in the foregoing example be equal to the reactance of the condenser multiplied by the current. In the case of the 1 mfd. condenser this gives us 2600 x .077 or 200 volts. In the case of the 2 mfd. condenser we have 1300 multiplied by .077 or 100 volts. Note in this case that the voltage division is unequal and that the larger capacity has the lower voltage across it.

The above example indicates what happens when condensers are connected in series on a.c. When condensers are connected in series to a source of d.c. voltage the results are, however, entirely different.

In the case of direct current circuits the division of voltage bears no direct relation to the capacities of the condensers connected in series. In the case of series sections on d.c. the voltage across any one section depends entirely upon the insulation resistance of the condenser.

Let us work through a few examples for series sections on d.c., for in this way we can show most clearly the difference between series sections on d.c., and series sections on a.c. Suppose, we have three sections connected in series on d.c. as shown in Fig. 3 in which the three sections are marked C1, C2, and C3. In the case of d.c. operation we must take into consideration the insulation resistance of the condensers. Assume that the three condensers connected in series for this first example have the following characteristics:

UNIT	CAPACITY	INSULATION RESISTANCE
C-1	1 mfd.	1000 megohms
C-2	1 "	1000 "
C-3	1 "	1000 "

When these three series condensers are connected across d.c. the condensers immediately take a charge but after the initial charging current, the current drawn from the d.c. source will be determined by the insulation resistance of the three sections in series. In this case the insulation resistance of the three sections in series is 3000 megohms. The current through the circuit will therefore be

$$I = \frac{E}{R}$$

$$I = \frac{300}{3000 \times 10^6}$$

$$I = 0.1 \times 10^{-6} \text{ amperes}$$

Therefore, the current is 0.1 microamperes.

The voltage across any one section is equal to the insulation resistance of the section multiplied by the current. Since in this example the sections have the same insulation resistances the voltage across each section will be equal to the insulation resistance 1000 megohms multiplied by the current 0.1 microamperes. This gives

$$E = IR$$

$$= 0.1 \times 10^{-6} \times 1000 \times 10^6$$

$$= 100 \text{ volts}$$

Therefore, in an example of the type given each section will have 100 volts across it, and the voltage will divide equally.

However, in the manufacture of paper condensers the procedure is to check the capacity to be sure that it is within tolerance and to then check the insulation resistance to make certain that it is above a certain minimum value. For example a 1 mfd. condenser might have an insulation resistance of 1000 megohms or it might, as an example have an insulation resistance of 2000 megohms. Both condensers would be considered entirely satisfactory. Suppose, however, we connected three condensers in series which have the following characteristics.

UNIT	CAPACITY	INSULATION RESISTANCE
C-1	1 mfd.	1000 megohms
C-2	1 "	1500 "
C-3	1 "	2000 "

In such a combination the total insulation resistance would be 4500 megohms, and if the voltage was 300 volts d.c. the current would be

$$I = \frac{300}{4500 \times 10^6} = 0.0667 \times 10^{-6} \text{ amp.}$$

The voltages across the individual sections will again be equal to the current 0.0667 microamperes multiplied by the insulation resistance. This gives the following values for the voltages across the sections.

UNIT	VOLTAGE
C-1	66.7 volts
C-2	100 volts
C-3	133.3 volts

It will be noted from the above that while, quite naturally, the total voltage adds up to 300 volts the voltage does not uniformly divide between the various sections due to the fact that the sections have unequal resistances.

Because of the above problem, and the fact that the voltage division may be even more unequal, unless proper care is exercised, it is desirable always to use condensers rated at the proper voltage, rather than for the user to make up a bank out of several individual condensers. If, however, several condensers are used in series then the precaution should be taken to connect across them a group of resistors as shown in Fig. 4. These resistors should have values as low as can be tolerated in the circuit.

These resistors should have values considerably lower than the probable insulation resistances of the condensers. In fact, in the case of paper condensers it will generally be possible in ordinary circuits to use a bank of resistors to give a current drain of 1 mil. This current, while small, is still much greater than the leakage current of the condensers, and the resistor will therefore serve to equalize the voltages.

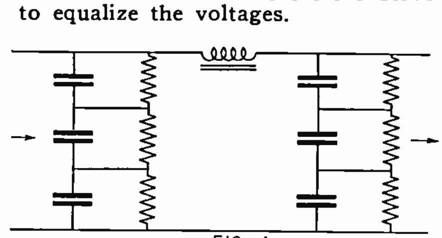


FIG. 4

As a typical example, in the case of a 1000 volt circuit the total value of the shunt resistance connected across the circuit will be 1 megohm, and the bank would consist of as many individual resistors (all equal in value) as there are condensers in series. For two condensers in series there would be two one-half megohm resistors; for three condensers in series there would be used 3 resistors in the order of 330,000 ohms each.

By using such an arrangement, the voltage will divide evenly and thereby greatly reduce the possibility of any condenser failures.

In a future issue of the Research Worker we will carry this discussion forward further with particular reference to the types of condensers especially designed for high voltage circuits.

Some Useful Data on A. F. Characteristics

The tables given below contain considerable information useful to workers in the field of audio engineering. One table indicates various important points in the frequency spectrum from 16 cycles up to 32,768 cycles. The other table indicates the peak audio frequency power developed by various musical instruments, played very loudly. These values for the maximum audio frequency output of musical instruments may be compared with the output of a violin played very softly which is 4 microwatts.

PEAK POWER OF MUSICAL INSTRUMENTS

(Fortissimo Playing)

INSTRUMENT	PEAK POWER, WATTS
Heavy Orchestra	70
Large Bass Drum	25
Pipe Organ	13
Snare Drum	12
Cymbals	10
Trombone	6
Piano	0.4
Trumpet	0.3
Bass Saxaphone	0.3
Bass Tuba	0.2
Bass Viol	0.16
Piccolo	0.08
Flute	0.06
Clarinet	0.05
French Horn	0.05
Triangle	0.05

NOTE	CYCLES PER SECOND	PIPE ORGAN	REMARKS
C^8	32,768		Beyond limit of audibility for average person.
C^7	16,384		Telephone silent with 40 volts on receiver terminals.
	10,000		Considered ideal upper limit for perfect transmission of speech and music.
C^6	8,192	¾ in.	
·	5,000		Highest note on fifteenth stop.
C^5	4,096		Considered as satisfactory upper limit for high quality transmission of speech and music.
E^4	2,560		
G^4	3,072		Highest note of pianoforte.
	3,000		Approximate resonant point of ear cavity.
C^4	2,048		Considered as satisfactory upper limit for good quality transmission of speech.
	2,000		
	1,500		Maximum sensitivity of ear.
A^2	850		Mean speech frequency from articulation standpoint.
$A\flat^2$	800		
E^2	600		Representative frequency telephone currents.
A^1	426⅔		Orchestral tuning. See note below.
C^1	256		
	200		Considered as satisfactory lower limit for good quality transmission of speech.
C^0	128		
	100		Considered as satisfactory lower limit of high quality transmission of speech and music.
E_0	80		Lower note of man's average voice.
C_0	64	8 ft.	Lowest note of 'cello.
B_1	60		
C_1	32	16 ft.	Lowest note of average church organ.
	30		Considered ideal lower limit for perfect transmission of speech and music.
A_2	27		Lowest note of pianoforte.
G_2	25		
C_2	16	32 ft.	Lowest audible sound. Longest pipe in largest organ.

Notes of the "Gamut"	C	D	E	F	G	A	B	C
Vibration frequencies proportional to	1	9/8	5/4	4/3	3/2	5/3	15/8	2
Intervals between successive notes	9/8	10/9	16/15	9/8	10/9	9/8	16/15	

NOTE: Nearest note is indicated. Scale based on Middle C^1 (Physical Pitch)=256 cycles.

Radio Editors of magazines and newspapers are hereby given permission to reprint in whole or in part, with proper credit to the Aerovox 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 Corporation. It is published to bring to the Radio Experimenter and Engineer authoritative, first hand information on condensers and resistances for radio work.

VOL. 6, NO. 5 | MAY, 1934 | 50c per year in U. S. A. 60c per year in Canada.

Resonant Circuit Calculations

By the Engineering Department, Aerovox Corporation

IN view of the present popularity of radio receivers designed to cover relatively wide frequency bands, the following general data on tuned circuits may be of interest.

The tuned circuit consists fundamentally of a coil in series with a condenser as shown in Fig. 1. If we induce a constant voltage into such a circuit and measure the current flow around the circuit as the frequency of the induced voltage is varied we would find a typical resonant characteristic between the current and the frequency, provided the frequency was varied above and below the resonant frequency of the circuit.

The resonant frequency will be that frequency corresponding to the maximum current. The frequency of resonance is determined by the capacity and inductance of the circuit, and is equal to

$$F = \frac{1}{2 \pi \sqrt{LC}}$$

where L is the inductance of the circuit in henries, C is the capacity in farads, and F is the resonant frequency in cycles per second. The derivation of the above formula will be found in standard text books on radio.

In the design of receiver tuning over a wide frequency range, one method whereby a single coil can be made to cover a wider range of frequency is by the use of a switch which cuts a mica condenser into the circuit in series with the main tuning condenser.

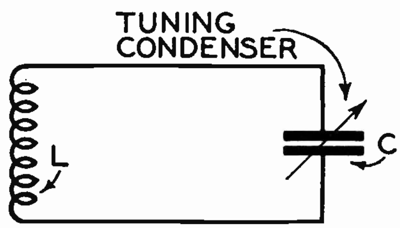


FIG. 1

The effect of the mica condenser in series with the main tuning condenser is to reduce the capacity and thereby to increase the resonant frequency of the circuit.

For example, suppose that the main tuning condenser in a resonant circuit has the maximum capacity of 0.00025 mfd. and that in combination with a coil this capacity will tune to a minimum frequency of 500 kilocycles. If we connected in series with the tuning condenser as shown in Fig. 2 a fixed mica condenser with a capacity of .00025 then the circuit will tune to a minimum frequency of 700 kilocycles.

If we know the range of frequency over which a given circuit will tune then we can determine the frequency range obtained with any given combination of tuning condenser and series fixed condenser by the relationship

$$\frac{F_1}{F_2} = \frac{\sqrt{C_2}}{\sqrt{C_1}}$$

F_1 is the frequency to which the circuit will tune without the series fixed condenser.

F_2 is the frequency to which the circuit will tune with the series fixed condenser.

C_1 is the capacity of the tuning condenser.

C_2 is the capacity of the combination of the fixed condenser in series with the tuning condenser.

For example, suppose a circuit uses a 0.00025 microfarad tuning condenser and tunes from 500 to 1500 kilocycles. The inductance required for such a circuit would be 400 microhenries. In order to tune to a maximum of 1500 kilocycles the equivalent minimum capacity of the entire circuit would have to be approximately 0.0000278 mfd. Assume that we want to change

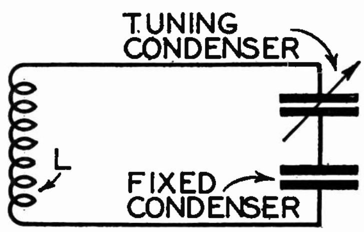


FIG. 2

the frequency range so that the minimum frequency will be 1500 kilocycles instead of 500. This means that with the tuning condenser set at maximum capacity the capacity of the circuit must be 0.0000278.

For two condensers in series the formula is

$$C_1 = \frac{Ct\ C_2}{C_2 - Ct}$$

C_1 is the required capacity for the series fixed condenser.

C_2 is the original capacity for the tuning condenser.

Ct is the required capacity for the two condensers in series.

In this example Ct is 27.8 micromicrofarads. The original capacity C_2 is 250 micromicrofarads. Substituting the formula that we have,

$$C_1 = \frac{27.8 \times 250}{250 - 27.8}$$

$$= \frac{6950}{222.2}$$

$$= 31.3 \text{ micromicrofarads}$$

In other words we would have to connect in series with the tuning condenser a fixed condenser having a capacity of 31.3 micromicrofarads.

It will be noted that the required series capacity 31.3 micromicrofarads is not much different than 27.8 micromicrofarads the minimum capacity of the tuning condenser. Of course, when the circuit is required to tune to higher frequencies, a smaller series condenser will be required.

In the above example as a matter of simplicity we have neglected the distributed capacity of the tuning coil itself in order to simplify the problem. In actual practice, however, the distributed capacity of the coil may be an important factor.

In a future issue we expect to cover in more detail the characteristics of circuits covering wide tuning ranges.

Power Factor Correction with Oil Condensers

The accompanying group of curves, Fig. 1, will prove useful in connection with calculations on condenser capacity required to correct low power factor on motors, power lines, etc.

This group of curves shows the relationship between three factors, the desired power factor, the existing power factor, and the percentage of the kilowatt load required in kv-a of capacitive load.

For example, suppose a system has a power factor of 70% and that the kilowatt load in the system is 1000 kilowatts. Assume that it is desired to correct the power factor to 90%. From the curve it will be noted that the 90% desired characteristic point intercepts the curve of 70% existing power factor at a point corresponding to 53%, as the percentage of kv-a capacity required in capacitive reactive kv-a. In this case the kilowatt load is 1000 and 53% is 530 kv-a. This means that if we connect across the line 530 kv-a of capacitive load then the power factor of the system will become 90%.

The capacity in microfarads required to obtain 530 kv-a can be figured from the following listing:

Low Voltage	Mfds. per Kv-a
110	219.00
220	54.80
440	13.70
550	8.80
1100	2.20
2200	.55
2300	.50

If the system had a voltage of 1100 volts 60 cycles a.c. then the capacity required would be, from the above table, 530 divided by 2.2 or 241 microfarads.

From the chart, Fig. 1, and the table similar examples can readily be worked out.

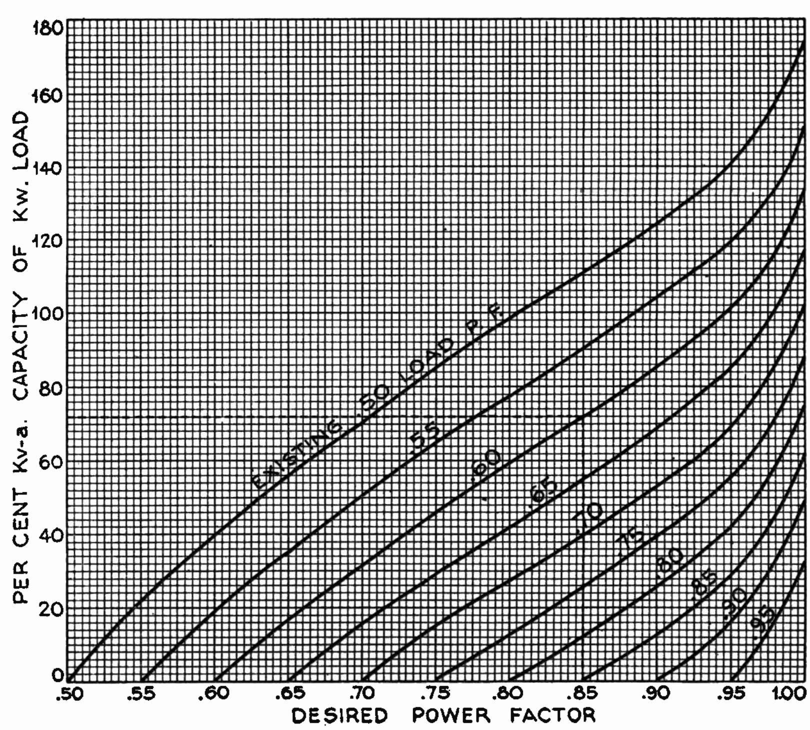
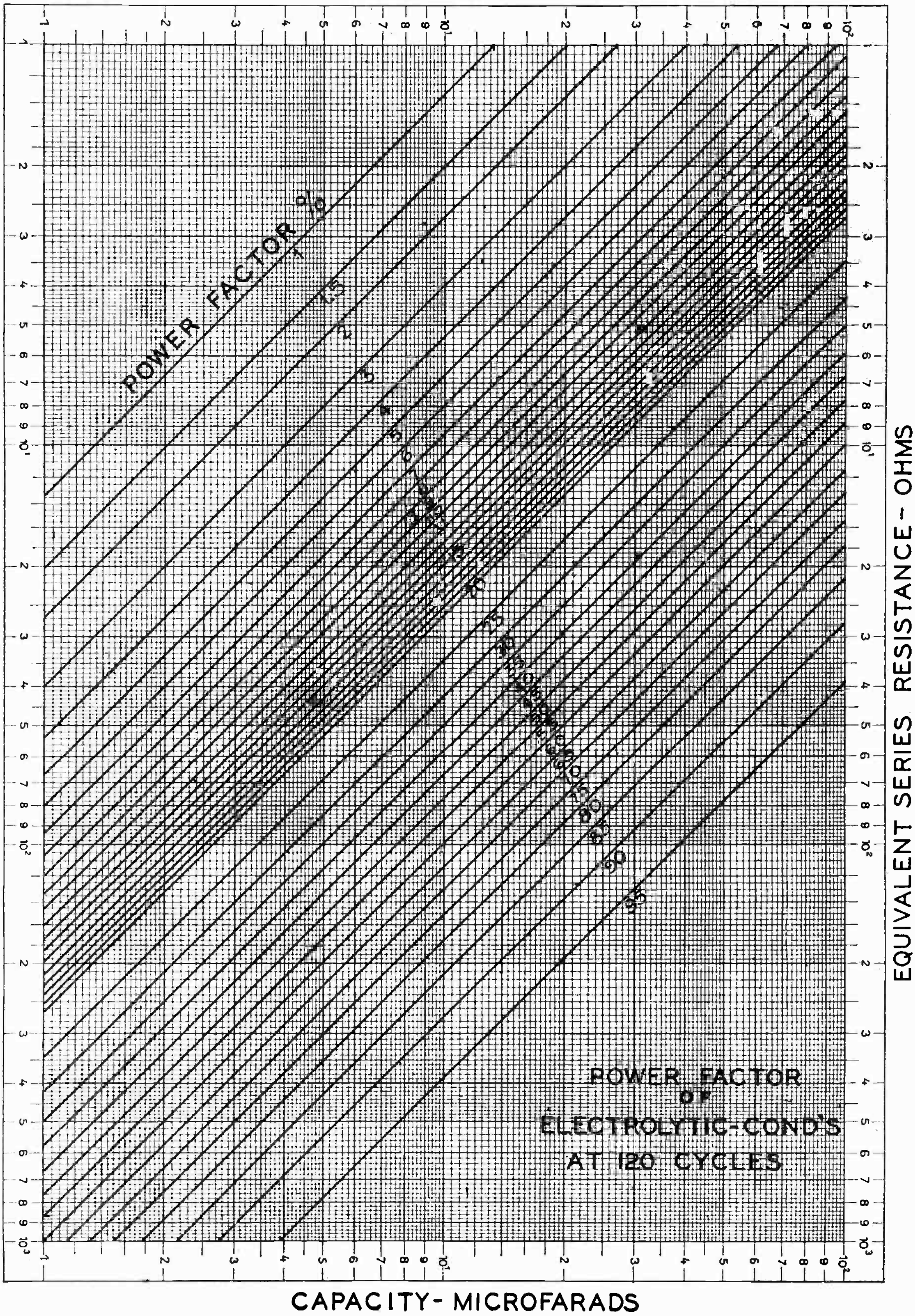


Fig. 1


POWER FACTOR %
POWER FACTOR
OF
ELECTROLYTIC-COND'S
AT 120 CYCLES
EQUIVALENT SERIES RESISTANCE - OHMS
CAPACITY- MICROFARADS

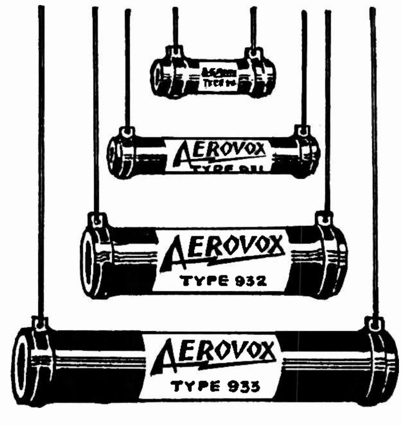
They Can Take It!

AEROVOX

WIRE-WOUND
VITREOUS ENAMELED
RESISTORS

Yes, sir! . . . These small Aerovox wire-wound vitreous enamel coated resistors are rated at 5, 10, 15 and 20 watts, and will even stand overloads without affecting them in the least. Everyone knows the regular Aerovox line of heavy duty Pyrohm resistors, . . . and these little resistors have all the good characteristics of their bigger brothers.

These new resistors are wire-wound and coated with a layer of special vitreous enamel which is fired at very high temperatures. This coating of hard enamel protects the delicate wire winding against moisture and mechanical injury. The resistance wire is brazed to lugs and soft copper wire leads soldered to rugged terminal bands make the unit convenient to use and wire into a circuit.



Types 930, 931, 932 and 933

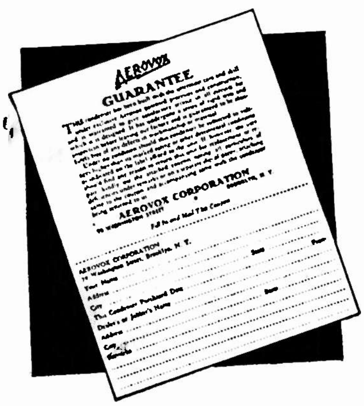
Type 930—5 Watts—Size 1/4" x 1"—Price $.35 each
Resistors in all the following values:
Resist. Ohms—100, 150, 200, 250, 300, 350, 400, 450, 500, 600, 750, 800, 900, 1000, 1500, 2000, 2500, 3000, 4000, 5000, 6000, 7500, 10,000.

Type 931—10 Watts—Size 1/4" x 1 3/4"—Price $.35 each
Resistors in all the following values:
Resist. Ohms—100, 250, 500, 750, 1000, 1500, 2000, 2500, 3000, 4000, 5000, 6000, 7500, 10,000, 15,000 20,000, 25,000, 30,000.

Type 932—15 Watts—Size 7-16" x 2"—Price $.65 each
Resistors in all the following values:
Resist. Ohms—250, 500, 750, 1000, 1500, 2000, 2500, 3000, 4000, 5000, 6000, 7500, 8000, 9000, 10,000, 15,000, 20,000, 25,000, 30,000, 40,000, 50,000, 70,000.

Type 933—20 Watts—Size 7-16" x 3"—Price $.75 each
Resistors in all the following values:
Resist. Ohm—1000, 2500, 5000, 7500, 10,000, 15,000, 20,000, 25,000, 30,000, 40,000, 50,000, 75,000, 100,000.

NOTE: The above resistors are standard values carried in stock. Units of intermediate values, not exceeding the maximum values given above, are usually available.



BEWARE OF SUBSTTITUTES FOR AEROVOX PRODUCTS!

Look for the Aerovox Yellow and Black Label, Box and Guarantee Slip.

All genuine, guaranteed Aerovox products bear the standard Aerovox goldenrod yellow and black label and are packed in boxes of the same color scheme. Each unit is packed with an Aerovox guarantee slip insuring the purchaser of receiving a perfect factory inspected product.

NRA MEMBER U.S. WE DO OUR PART

AEROVOX CORPORATION

70 WASHINGTON STREET, BROOKLYN, N. Y.

Sales Offices in All Principal Cities

RADIO MANUFACTURERS ASSOCIATION RMA MEMBER