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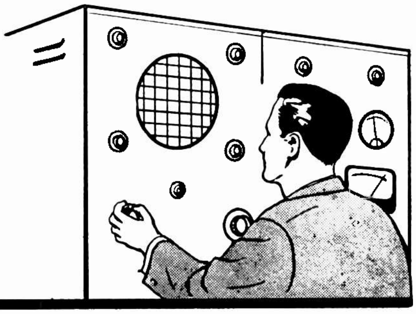

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TO ALL AEROVOX "RESEARCH WORKER" SUBSCRIBERS:

We have been very gratified by the many comments received welcoming the new issues of the long-popular Aerovox "Research Worker" after an absence of some time. Frankly, we are encouraged by the widespread interest in the timely and helpful articles prepared for your benefit by our engineers. Although it has taken considerable time to prepare a new series of technical articles in order to resume our publishing schedule, we now look forward to a continuing program of providing you with practical, up-to-date information on electrical and electronic applications.

We welcome your comments and suggestions so that we can further serve your needs. Write to: Editor, "Research Worker", Aerovox Corporation, New Bedford, Mass.

High-Capacitance Electrolytics in Low-Voltage, High-Current Filters

By the Engineering Department, Aerovox Corporation

SEMICONDUCTOR devices have permitted development of efficient low-voltage, high-current d-c power supplies, both regulated and unregulated. These devices include germanium, selenium, silicon, and silicon carbide rectifiers, silicon controlled rectifiers (solid-state thyratrons), and power transistors. Having no tubes to preheat, the semiconductor-type power supply is instantaneous in operation. It is widely used in electroplating, battery charging, d-c motor operation from a-c power, operation of solenoids, actuators, and brakes, engine starting, transistor servo amplifier supply, and similar heavy-duty applications.

The filter requirements of these power supplies present some problems which are not encountered in design of the high-voltage, low-current supplies more common in electronics. Principally, the filter chokes must be able to carry the large d-c output currents of several amperes. This means that they must be wound with large-diameter wire; and, if the choke is not to be bigger than the rest of the power supply, its inductance therefore will be low. In order to obtain adequate filtering with low inductance, the filter capacitances must be proportionately high. Whereas a conventional filter (for high-voltage, low-current service) might consist of a 10-henry choke and 20-μfd capacitor, a high-current filter would embody an inductance of a few millihenries and a capacitance of several hundred to several thousand microfarads. Such high capacitances are obtainable in small physical size only in electrolytic capacitors.

FUNDAMENTAL FILTER RELATIONSHIPS

Figure 1 shows single-section low-pass filter circuits suitable for use in low-voltage, high-current power supplies. In these circuits, R_L is the equivalent load resistance to which the supply delivers d-c power. The value of this resistance may be determined from the d-c output voltage (E_{dc}) and output current (I_{dc}): $R_L = E_{dc}/I_{dc}$, where R_L is in ohms, E_{dc} in volts, and I_{dc} in amperes. Figure 1(C) illustrates the low-pass response; f_c is the cutoff frequency.

The following equations show the relationship between choke inductance (L, henries), capacitor capacitance (C, farads), load resistance (R_L, ohms), and cutoff frequency

(f_c, cycles per second). The constant π = 3.1416.

(1) $L = R_L/(\pi f_c)$
(2) $C = 1/(\pi f_c R_L)$

Rewriting (1) and (2) and solving for the cutoff frequency, f_c, we find:

(3) $f_c = R_L/(\pi L)$
(4) $f_c = 1/(\pi R_L C)$

Eliminating R_L between equations (1) and (2) and solving for f_c, we find:

(5) $f_c = 1/(\pi \sqrt{LC})$

It is recommended that the cutoff frequency be lower than the rectifier ripple frequency by as much as practicable. (For convenience, Table 2 lists ripple frequency for common rectifier circuits.) For example, a single-phase, full-wave rectifier operated at a frequency (f) of 60 cps delivers a ripple frequency of 2f = 120 cps, and the cutoff frequency ought to be chosen between 40 and 80 cps.

Table 1 is a list of inductance, continuous current rating, and d-c resistance of several typical high-current filter chokes of one manufacturer. In the design of a filter, a good starting point is the choice of a choke to handle the rated d-c output current of the power supply. The capacitors then may be chosen. The following steps are suggested.

DESIGN PROCEDURE

Typical Example. The power supply is to deliver 24 volts at 10 amperes dc and employs a single-phase full-wave rectifier. A capacitor-input filter (Figure 1A) is desired.

1. Select choke: C-2688 (12.5 amp) in Table 1.
2. Note choke inductance: For choke selected in Step 1, L = 10 mh = 0.01 hy.
3. Calculate load resistance from d-c output voltage and current: $R_L = E_{dc}/I_{dc}$ = 24/10 = 2.4 ohms.
4. Calculate cutoff frequency for choke, choosing the filter impedance to match the load resistance. From Equation (3) f_c = 2.4/(3.1416 x 0.01) = 2.4/0.0314 = 76.4 cps.

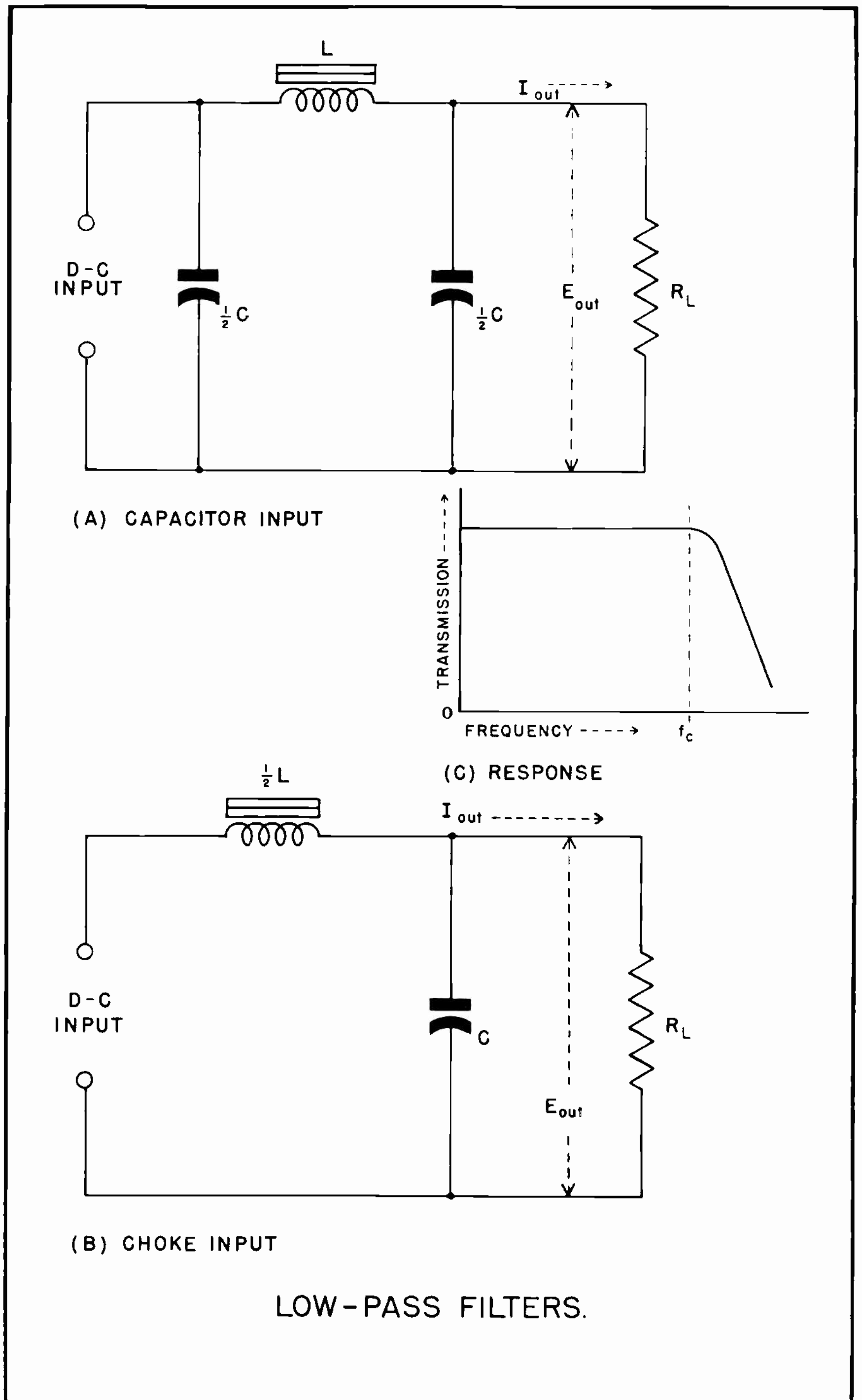

FIG. 1

5. Calculate capacitance: From Equation (2), C = 1/(3.1416 x 76.4 x 2.4 = 1/577 = 0.00173 f = 1730 μfd. From Figure 1(A), we see that each capacitor must have one-half this value; i. e., C = 1730(0.5) = 865 μfd.

Referring to a typical manufacturer's catalogue of Electrolytic Capacitors, we see that a 1000 mfd. capacitor is the closest standard capacitance value available in a 50 volt rating. Although the power supply output voltage is 24 volt, the 50-

volt capacitor was chosen to give a adequate safety factor.

NOTE:—Application of equations (1) through (5) to a choke input filter, does not yield filtering equivalent to the effect of the capacitor input section calculated. Although the filtering effect is reduced, it is still more than sufficient for this type of application.

An alternate procedure (when an exact cutoff frequency is important) is to decide first what cutoff frequency is desirable. Next, select a suitable choke for current-handling capability. Then, from the inductance of the choke, calculate the required capacitance from rewritten Equation (5): $C = 1/(\pi^2 f_c^2 L)$. Divide this C-value by 2 for the capacitor-input filter (Figure 1A) or use the full value (and half the inductance) for the choke-input filter (Figure 1B).

FILTERING ACTION

In many instances, a single filter section will suffice. This is especially true of voltage-regulated semiconductor supplies. However, when one section does not reduce the ripple voltage to the desired level, several sections may be cascaded for additional filtering.

The amount of ripple, compared with the direct component of current or voltage, is a measure of the purity of rectifier output and is called the ripple factor.

$$\text{Ripple factor} = \frac{\text{effective value of all a-c components}}{\text{average, or d-c component}}$$

It can be seen that ripple factor is a function of the waveform of the current in the rectifier load. Table 2 shows that a full wave circuit has less ripple, and is more easily filtered owing to the higher ripple frequency.

The ripple voltage at the filter output is often expressed in percent and is a measure of the effectiveness of the filter. For a choke input filter (Figure 1B) the ripple factor is related to the reciprocal of the filter L_1C_2 product and for a capacitor input filter (Figure 1A) the ripple factor is related to the reciprocal of the product of $C_1 R_L L_2 C_2$.

Where

L_1 = filter section input inductance in Henry

C_1 = filter section input capacitance in Farad

L_2 = filter section inductance in Henry

C_2 = filter section terminating capacitance in Farad

R_L = terminating load resistance in Ohm.

The ripple factor is a function of load on the capacitor-input filter, increasing with current output, while for an inductor-input filter the ripple is independent of the load.

The ripple voltage at the filter input (table 2) is decreased as the nth power of the ripple reduction of a single section, when n filter sections are cascaded.

The filter must perform its function with a minimum of d-c voltage drop. Always important in filter design, the choke resistance is especially crucial in high-current filters, since at high current levels even a low resistance can cause a significant voltage drop. Note from Table 1 that the d-c resistance of the commercial chokes is less than 1 ohm in each instance.

CHOKE TYPE	L (mh)	I (amps)	R (d-c ohms)
C-2685	35	2.0	0.75
C-2686	25	4.0	0.425
C-2687	10	8.0	0.15
C-2688	10	12.5	0.11
C-2689	5	22.5	0.03

TABLE 1. CHARACTERISTICS OF HIGH-CURRENT FILTER CHOKES.

CHARACTERISTIC	RECTIFIER CIRCUIT			
	SINGLE-PHASE		THREE-PHASE	
	Half-Wave	Full-Wave	Half-Wave	Full-Wave
RIPPLE FREQUENCY	f	2f	3f	6f
RIPPLE FACTOR (F)	1.21	0.483	0.183	0.042
RIPPLE VOLTAGE AT FILTER INPUT	$1.21E_{dc}$	$0.483E_{dc}$	$0.183E_{dc}$	$0.042E_{dc}$

f = Frequency of supply voltage
E_{dc} = Average value of d-c output voltage

TABLE 2. RECTIFIER-CIRCUIT CHARACTERISTICS.

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PRS... compact "Dandee" units for trouble-free repair of series-string TV and AC-DC table radios. Aluminum cans with cardboard insulating sleeves. Available in singles, duals, and triples as well as AC rated and non-polarized units.

SRE... "Bantam" metal tubular 'lytics hermetically-sealed in aluminum cans with cardboard insulating sleeves. Smaller than the PRS but capable of handling full size loads to 85°C.

AFH... twist-prong 'lytics featuring 85°C operation... improved sealing... high-purity aluminum foil construction throughout... rugged prongs and mounting terminals. Tops for filter audio bypass applications in TV-radio and amplifier equipment.

HCB... high-capacity-low voltage 'lytics designed especially for applications such as motion picture sound equipment, electric fence controls and other low voltage applications. Feature bakelite case which eliminates need for cardboard outer insulating tubes.

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