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Design Data for *m*-Derived Type Filters

PART I

By the Engineering Department, Aerovox Corporation

THE leading advantage of the *m*-derived type of wave filter over the simpler prototype is the sharper cutoff afforded by the former. For this keener tool, however, must be paid the price of increased complexity.

Since we first published design data on constant-K type filters[1], there has been insistent demand that the Research Worker offer similar information regarding the *m*-derived filter. We are accordingly presenting a new series of articles, beginning in this issue, which will cover the design of *m*-type filters for low-pass, high-pass, band-pass, and band-suppression applications.

[1] *Aids in Filter Designing. Aerovox Research Worker.* March 1940

NOMENCLATURE

The *m*-derived section receives its name from the fact that its impedance members are *derived* from those of the simpler prototype, constant-K section and that its behavior depends upon some factor which is a function of a constant *m*. Additional impedances are inserted into the *m*-type section, and the circuit position of these extra elements determines the specific nomenclature of the section. It is the presence of these additional impedances that sharpens the cutoff of the section by providing infinite attenuation at a frequency beyond cutoff.

TYPES

If the additional impedances are added to the series arm of a section, the latter is said to be *shunt-derived*: if they are added to the shunt arm, the section is said to be *series-derived*. Series-derived *m*-type filter sections are shown in Figures 1, 3, 5 and 7. Shunt-derived sections are shown in Figures 2, 4, 6 and 8.

Like constant-K sections, *m*-derived sections may be laid out for low-pass, high-pass, band-pass, and band-suppression. These four configurations are shown in the schematic diagrams referred to above.

m

The constant *m* (which has a positive value between 0 and 1 and is a function of the ratio of the frequency of infinite attenuation to the cutoff frequency) appears in all derived-type filter calculations. The impedances in any *m*-derived section are related to those in corresponding constant-K sections by some factor which is a function of *m*.

If constant-K values are obtainable, *m*-section values may thus be derived from them. Some constant-K impedance values must be multiplied by *m*-factors while others must be divided by *m*-factors in order to obtain impedance values for *m*-type sections. Factors commonly encountered are *m*, $1\text{-}m^2$, $4m/1\text{-}m^2$, $1\text{-}m^2/4m$, and $4\pi m$. Chart II lists the numerical values of these factors for values of *m* between 0.1 and 0.9.

Sharpness of cutoff in the *m*-type filter section is influenced by the value of *m*. It will be seen from Chart I that sharpness of cutoff increases as *m* decreases. This graph depicts the response of the low-pass section but is indicative of other configurations as well. The curve for the high value of $m = 1$ duplicates that of a constant-K section, showing that *m* must approach zero in value if the full attributes of the *m*-derived section are to be realized.

For *m*-values between 0.1 and 1.0, the characteristic impedance of a given filter section is not constant over an appreciable frequency band, except near the middle of this range. When *m* equals 0.6, the characteristic impedance of the derived-type filter is approximately constant over most of the range of transmission. This is desirable in order to prevent reflections.

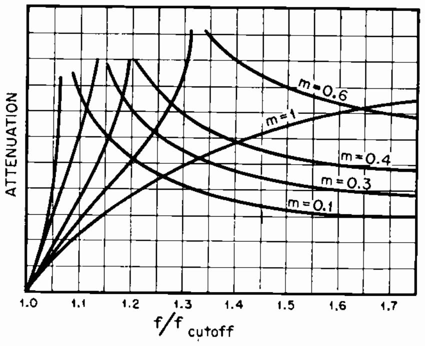
An *m*-value of 0.6 is widely employed in practical filter design, and this value will be the basis of coil and capacitor data tables which will appear later in this series.

Typical transmission-vs-frequency curves for low-pass, high-pass, band-pass, and band-suppression sections are shown respectively by Figures 1-A, 3-A, 5-A and 7-A.

CONFIGURATIONS

Figure 1 shows a series-derived low-pass *m*-type section. The additional impedance is L_2 introduced into the shunt arm. In the shunt-derived low-pass section of Figure 2, the additional impedance is C_1 in the series arm. Figure 3 shows the arrangement for a series-derived high-pass section, and here C_2 in the shunt arm is the additional impedance. In the shunt-derived high-pass section of Figure 4, L_1 in the series arm is the additional impedance. Figure 5 is the circuit for a series-derived band-pass section; and here, as in the case of the

CHART I



AFTER HENNEY, RADIO ENG HANDBOOK P 170 3rd EDITION (McGRAW-HILL)

series-derived band-suppression section of Figure 7, the L_3-C_3 combination in the shunt arm is the additional impedance. Figure 6 shows a shunt-derived band-pass section with the L_3-C_3 combination in the series arm as the additional impedance, as is also the case in the shunt-derived band-suppression section of Figure 8.

FORMULAE

Two types of formulae are given with the circuit diagrams. One set termed *basic formulae* is to be employed when calculating from fundamental data; the other set termed *derivations from K-Values* may be employed when it is desired to calculate *m*-sections from known constant-K values. The latter values are available in numerous tables and from nomographic charts.

In the formulae, constant-K values are designated by the subscript "K" whenever they appear. An example is $C_{1(K)}$ or $L_{2(K)}$ in which C_1 and L_2 are as listed for constant-K sections.

CHART II

NUMERICAL VALUES OF m-MULTIPLIERS AND m-DIVISORS

m	$1-m^2$	$\frac{4m}{1-m^2}$	$\frac{1-m^2}{4m}$	$4\pi m$
0.10	0.990	0.404	2.475	1.256
0.15	0.978	0.613	1.630	1.884
0.20	0.960	0.833	1.200	2.512
0.25	0.938	1.066	0.938	3.140
0.30	0.910	1.318	0.758	3.768
0.35	0.878	1.593	0.627	4.396
0.40	0.840	1.904	0.525	5.024
0.45	0.798	2.255	0.443	5.652
0.50	0.750	2.666	0.375	6.280
0.55	0.698	3.151	0.317	6.908
0.60	0.640	3.593	0.266	7.536
0.65	0.578	4.498	0.222	8.164
0.70	0.510	5.490	0.182	8.792
0.75	0.438	6.849	0.146	9.420
0.80	0.360	8.888	0.112	10.048
0.85	0.278	12.230	0.081	10.676
0.90	0.190	18.940	0.052	11.304

I. LOW-PASS FILTERS

A. SERIES-DERIVED TYPE

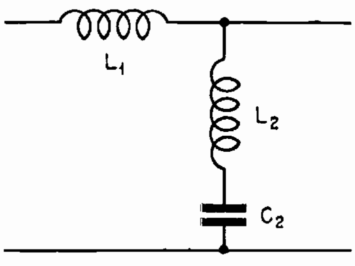


FIG. 1

BASIC FORMULAE	DERIVATIONS FROM K-VALUES
$L_1 = \frac{mR}{\pi f_2}$	$L_1 = mL_{1(K)}$
$L_2 = \frac{(1-m^2)R}{4\pi m f_2}$	$L_2 = \frac{1-m^2}{4m} L_{1(K)}$
$C_2 = \frac{m}{\pi f_2 R}$	$C_2 = mC_{2(K)}$

B. SHUNT-DERIVED TYPE

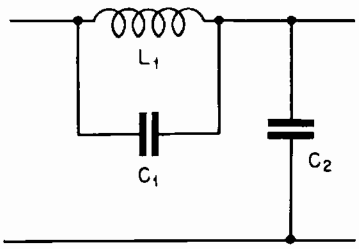


FIG. 2

BASIC FORMULAE	DERIVATIONS FROM K-VALUES
$L_1 = \frac{mR}{\pi f_2}$	$L_1 = mL_{1(K)}$
$C_1 = \frac{1-m^2}{4\pi m f_2 R}$	$C_1 = \frac{1-m^2}{4m} C_{2(K)}$
$C_2 = \frac{m}{\pi f_2 R}$	$C_2 = mC_{2(K)}$

RESPONSE CURVE FOR SERIES AND SHUNT TYPES

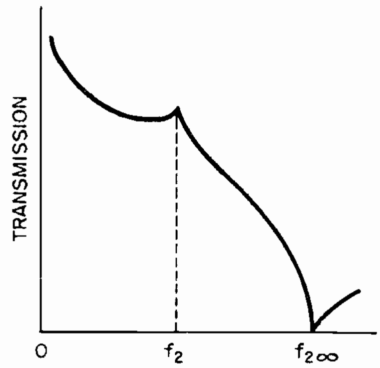


FIG. 1-A

FOR BOTH SERIES AND SHUNT TYPES:

$$m = \sqrt{1 - \frac{f_2^2}{f_{2\infty}^2}}$$

II. HIGH-PASS FILTERS

A. SERIES-DERIVED TYPE

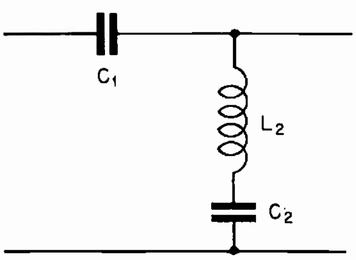


FIG. 3

BASIC FORMULAE	DERIVATIONS FROM K-VALUES
$L_2 = \frac{R}{4\pi m f_1}$	$L_2 = \frac{L_{2(K)}}{m}$
$C_1 = \frac{1}{4\pi m f_1 R}$	$C_1 = \frac{C_{1(K)}}{m}$
$C_2 = \frac{m}{(1-m^2) f_1 \pi R}$	$C_2 = \left(\frac{4m}{1-m^2}\right) C_{1(K)}$

B. SHUNT-DERIVED TYPE

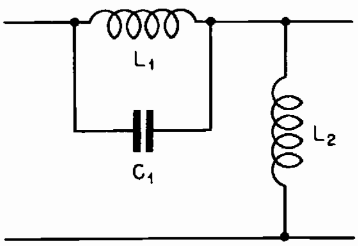


FIG. 4

BASIC FORMULAE	DERIVATIONS FROM K-VALUES
$L_1 = \frac{mR}{(1-m^2)\pi f_1}$	$L_1 = \left(\frac{4m}{1-m^2}\right) L_{2(K)}$
$C_1 = \frac{1}{4\pi m f_1 R}$	$C_1 = \frac{C_{1(K)}}{m}$
$L_2 = \frac{R}{4\pi m f_1}$	$L_2 = \frac{L_{2(K)}}{m}$

RESPONSE CURVE FOR SERIES AND SHUNT TYPES

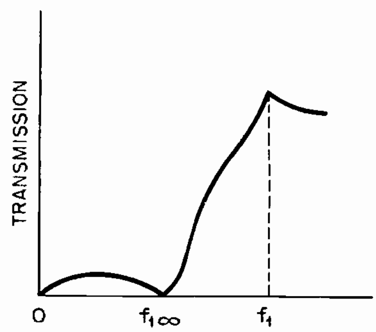


FIG. 3-A

FOR BOTH SERIES AND SHUNT TYPES:

$$m = \sqrt{1 - \frac{f_\infty^2}{f_1^2}}$$

III. BAND-PASS FILTERS

A. SERIES-DERIVED TYPE

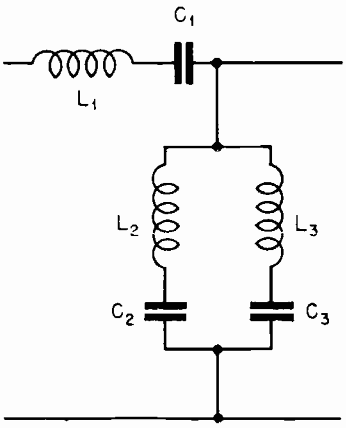


FIG. 5

BASIC FORMULAE	DERIVATIONS FROM K-VALUES
$L_1 = \frac{mR}{\pi(f_2 - f_1)}$	$L_1 = mL_{1(K)}$
$L_2 = \frac{bR}{\pi(f_2 - f_1)}$	$L_2 = L_{1(K)}\left\{\frac{1-m^2}{4m}\left[1+\left(\frac{f_m}{f_{2\infty}}\right)^2\right]\right\}$
$L_3 = \frac{aR}{\pi(f_2 - f_1)}$	$L_3 = L_{1(K)}\left\{\frac{1-m^2}{4m}\left[1+\left(\frac{f_{2\infty}}{f_m}\right)^2\right]\right\}$
$C_1 = \frac{f_2 - f_1}{4\pi m f_1 f_2 R}$	$C_1 = \frac{C_{1(K)}}{m}$
$C_2 = \frac{f_2 - f_1}{4\pi f_1 f_2 a R}$	$C_2 = \left[\frac{C_{1(K)}}{1+\left(\frac{f_{2\infty}}{f_m}\right)^2}\right]\frac{4m}{1-m^2}$
$C_3 = \frac{f_2 - f_1}{4\pi f_1 f_2 b R}$	$C_3 = \left[\frac{C_{1(K)}}{1+\left(\frac{f_m}{f_{2\infty}}\right)^2}\right]\frac{4m}{1-m^2}$

RESPONSE CURVE FOR SERIES AND SHUNT TYPES

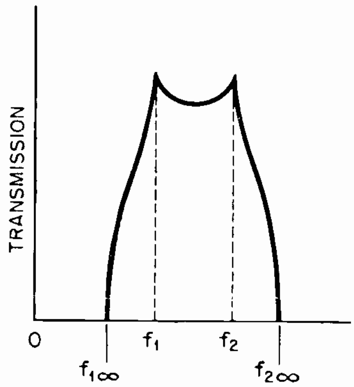


FIG. 5-A

B. SHUNT-DERIVED TYPE

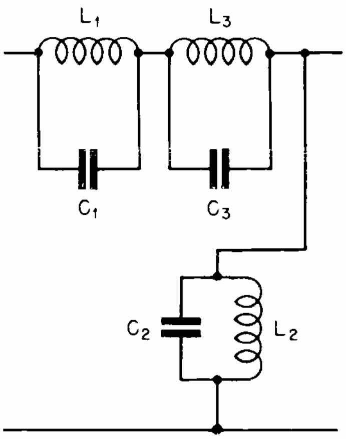


FIG. 6

BASIC FORMULAE	DERIVATIONS FROM K-VALUES
$L_1 = \frac{(f_2 - f_1)R}{4\pi b f_1 f_2}$	$L_1 = mL_{1(K)}\left[\frac{\left(\frac{f_{2\infty}}{f_m} - \frac{f_m}{f_{2\infty}}\right)^2}{1+\left(\frac{f_{2\infty}}{f_m}\right)^2}\right]$
$L_2 = \frac{(f_2 - f_1)R}{4\pi m f_1 f_2}$	$L_2 = \frac{L_{2(K)}}{m}$
$L_3 = \frac{(f_2 - f_1)R}{4\pi a f_1 f_2}$	$L_3 = mL_{1(K)}\left[\frac{\left(\frac{f_{2\infty}}{f_m} - \frac{f_m}{f_{2\infty}}\right)^2}{1+\left(\frac{f_m}{f_{2\infty}}\right)^2}\right]$
$C_1 = \frac{a}{\pi R(f_2 - f_1)}$	$C_1 = \frac{C_{1(K)}}{m}\left[\frac{1+\left(\frac{f_m}{f_{2\infty}}\right)^2}{\left(\frac{f_{2\infty}}{f_m} - \frac{f_m}{f_{2\infty}}\right)^2}\right]$
$C_2 = \frac{m}{\pi R(f_2 - f_1)}$	$C_2 = mC_{2(K)}$
$C_3 = \frac{b}{\pi R(f_2 - f_1)}$	$C_3 = \frac{C_{1(K)}}{m}\left[\frac{1+\left(\frac{f_{2\infty}}{f_m}\right)^2}{\left(\frac{f_{2\infty}}{f_m} - \frac{f_m}{f_{2\infty}}\right)^2}\right]$

FOR BOTH SERIES AND SHUNT TYPES:

$$h = \sqrt{\left(1 - \frac{f_1^2}{f_{2\infty}^2}\right)\left(1 - \frac{f_2^2}{f_{2\infty}^2}\right)}$$

$$a = \left[\frac{(1-m^2)\, f_1 f_2}{4h f_{1\infty}^2}\right]\left(1 - \frac{f_{1\infty}^2}{f_{2\infty}^2}\right)$$

$$b = \left[\frac{(1-m^2)}{4h}\right]\left(1 - \frac{f_{1\infty}^2}{f_{2\infty}^2}\right)$$

$$m = \frac{h}{1 - \left(\frac{f_1 f_2}{f_{2\infty}^2}\right)}$$

$$f_m = \sqrt{f_1 f_2}$$

IV. BAND-SUPPRESSION FILTERS

A. SERIES-DERIVED TYPE

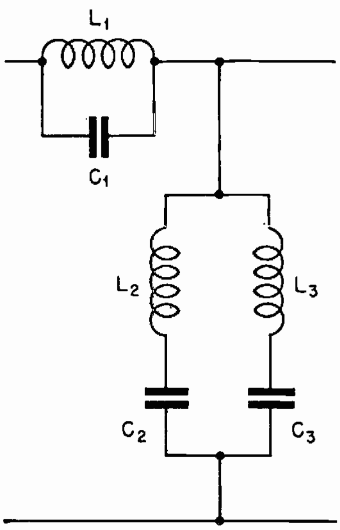


FIG. 7

BASIC FORMULAE	DERIVATIONS FROM K-VALUES
$L_1 = \dfrac{mR(f_1 - f_0)}{\pi f_0 f_1}$	$L_1 = m L_{1(K)}$
$L_2 = \dfrac{R\left[\frac{1}{m}\left(1 + \frac{f_0 f_1}{f_{1\infty}^2}\right)\right]}{4\pi(f_1 - f_0)}$	$L_2 = \dfrac{L_{2(K)}}{m}$
$L_3 = \dfrac{R\left[\frac{1}{m}\left(1 + \frac{f_{1\infty}^2}{f_0 f_1}\right)\right]}{4\pi(f_1 - f_0)}$	$L_3 = L_{2(K)}\left[\frac{1}{m}\left(1 + \frac{f_{1\infty}^2}{f_0 f_1}\right)\right]$
$C_1 = \dfrac{1}{4\pi m(f_1 - f_0)R}$	$C_1 = \dfrac{C_{1(K)}}{m}$
$C_2 = \dfrac{f_1 - f_0}{\left[\frac{1}{m}\left(1 + \frac{f_{1\infty}^2}{f_0 f_1}\right)\right]\pi R f_0 f_1}$	$C_2 = \dfrac{C_{2(K)}}{\frac{1}{m}\left(1 + \frac{f_{1\infty}^2}{f_0 f_1}\right)}$
$C_3 = \dfrac{f_1 - f_0}{\left[\frac{1}{m}\left(1 + \frac{f_0 f_1}{f_{1\infty}^2}\right)\right]\pi R f_0 f_1}$	$C_3 = \dfrac{C_{2(K)}}{\frac{1}{m}\left(1 + \frac{f_0 f_1}{f_{1\infty}^2}\right)}$

RESPONSE CURVE FOR SERIES AND SHUNT TYPES

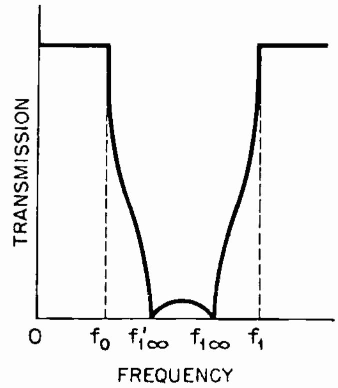


FIG. 7-A

FOR BOTH SERIES AND SHUNT TYPES:

$$m = \sqrt{\frac{\left(1 - \frac{f_0^2}{f_{1\infty}^2}\right)\left(1 - \frac{f_{1\infty}^2}{f_1^2}\right)}{1 - \frac{f_0}{f_1}}}$$

B. SHUNT-DERIVED TYPE

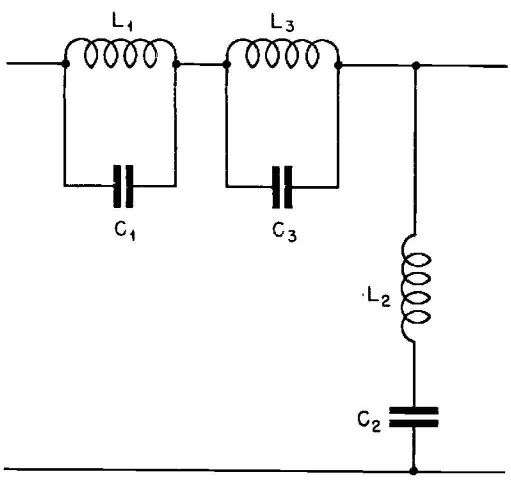
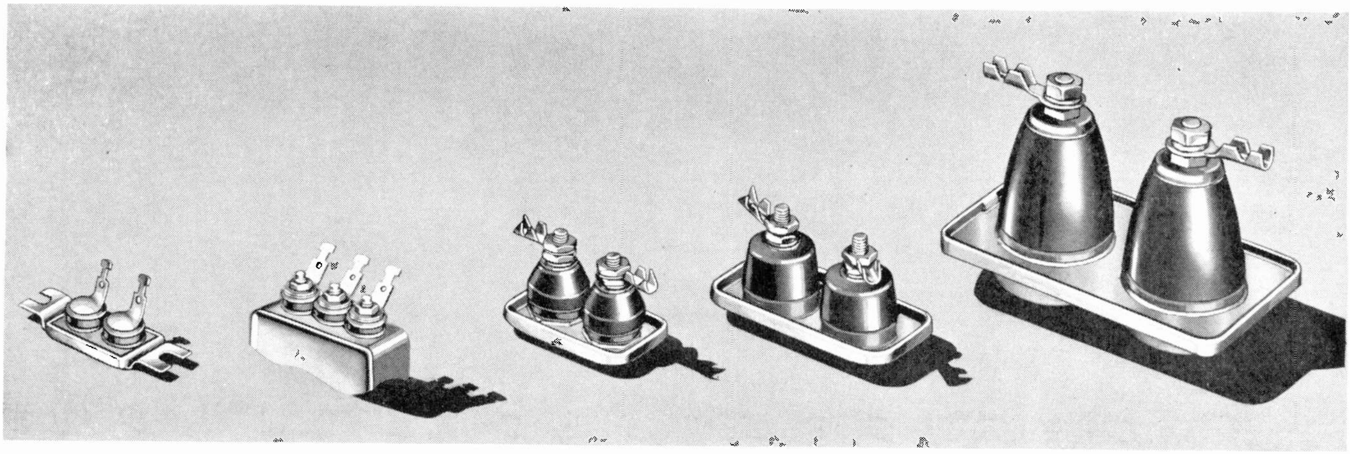
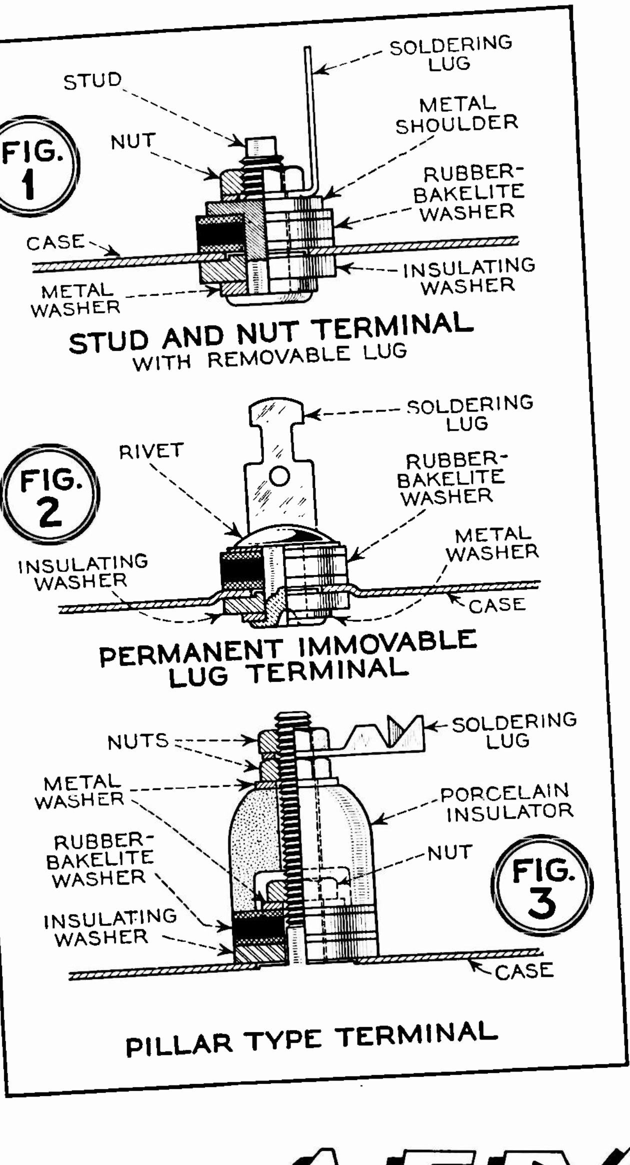


FIG. 8

BASIC FORMULAE	DERIVATIONS FROM K-VALUES
$L_1 = \dfrac{R(f_1 - f_0)}{\left[\frac{1}{m}\left(1 + \frac{f_{1\infty}^2}{f_0 f_1}\right)\right]\pi f_0 f_1}$	$L_1 = \dfrac{L_{1(K)}}{\frac{1}{m}\left(1 + \frac{f_{1\infty}^2}{f_0 f_1}\right)}$
$L_2 = \dfrac{R}{4\pi m(f_1 - f_0)}$	$L_2 = \dfrac{L_{2(K)}}{m}$
$L_3 = \dfrac{R(f_1 - f_0)}{\left[\frac{1}{m}\left(1 + \frac{f_0 f_1}{f_{1\infty}^2}\right)\right]\pi f_0 f_1}$	$L_3 = \dfrac{L_{1(K)}}{\frac{1}{m}\left(1 + \frac{f_0 f_1}{f_{1\infty}^2}\right)}$
$C_1 = \dfrac{\frac{1}{m}\left(1 + \frac{f_0 f_1}{f_{1\infty}^2}\right)}{4\pi(f_1 - f_0)R}$	$C_1 = C_{1(K)}\left[\frac{1}{m}\left(1 + \frac{f_0 f_1}{f_{1\infty}^2}\right)\right]$
$C_2 = \dfrac{m(f_1 - f_0)}{\pi f_0 f_1 R}$	$C_2 = m C_{2(K)}$
$C_3 = \dfrac{\frac{1}{m}\left(1 + \frac{f_{1\infty}^2}{f_0 f_1}\right)}{4\pi(f_1 - f_0)R}$	$C_3 = C_{1(K)}\left[\frac{1}{m}\left(1 + \frac{f_{1\infty}^2}{f_0 f_1}\right)\right]$





A *Choice of* TERMINALS

● Certain types of capacitors must withstand special immersion tests required by Governmental and other rigid specifications. For such requirements Aerovox engineers have developed the "double rubber bakelite" type of terminal assembly. Designed to withstand all voltages normally applied in radio and electronic work, this terminal is available in three types:

(1) The terminal in Fig. 1 is a riveted stud-type terminal with soldering lug held in position by a nut. The lug may be turned any way most convenient for wiring purposes without loosening the terminal insulator assembly.

(2) The terminal and soldering lug in Fig. 2 are permanently riveted to the case, making a fixed riveted assembly with the lug in permanent position. This terminal assembly is preferred because it is firm, comparatively inexpensive and quickly manufactured.

Both terminals can be used for voltages up to and including 1000v. D.C. Working.

(3) For higher voltage applications, the terminal in Figure 3 is supplied on all Aerovox Type 09 capacitors up to and including 3000 volts D.C.W. This is the double rubber bakelite construction combined with porcelain pillar insulator. The terminal shown at the extreme right in the picture above is used in the construction of all 4000 to 7500-volt Type 09 units.

In the matter of terminals, as in every other detail, Aerovox capacitors are *fitted to the application.* State your exact requirements. Our engineers will do the fitting. Literature on request.

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