

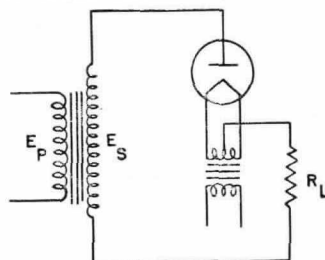
APPLICATIONS # (CONT'D)

Rectifiers

The switching action of the simple diode is most widely used in power supplies. Fig. 16 and Figs. 17 through 26, illustrate some of the most popular rectifier circuits with companion wave forms, and the accompanying table on page 18 provides useful conversion ratios.

The single-phase, half-wave rectifier, Fig. 16, has the obvious advantages of simplicity and low cost. However, these gains may be materially reduced by the increased cost of filter components resulting from the comparatively low fundamental ripple frequency, and the ten-

dency of the transformer core to saturate due to the unidirectional current flow in its secondary.

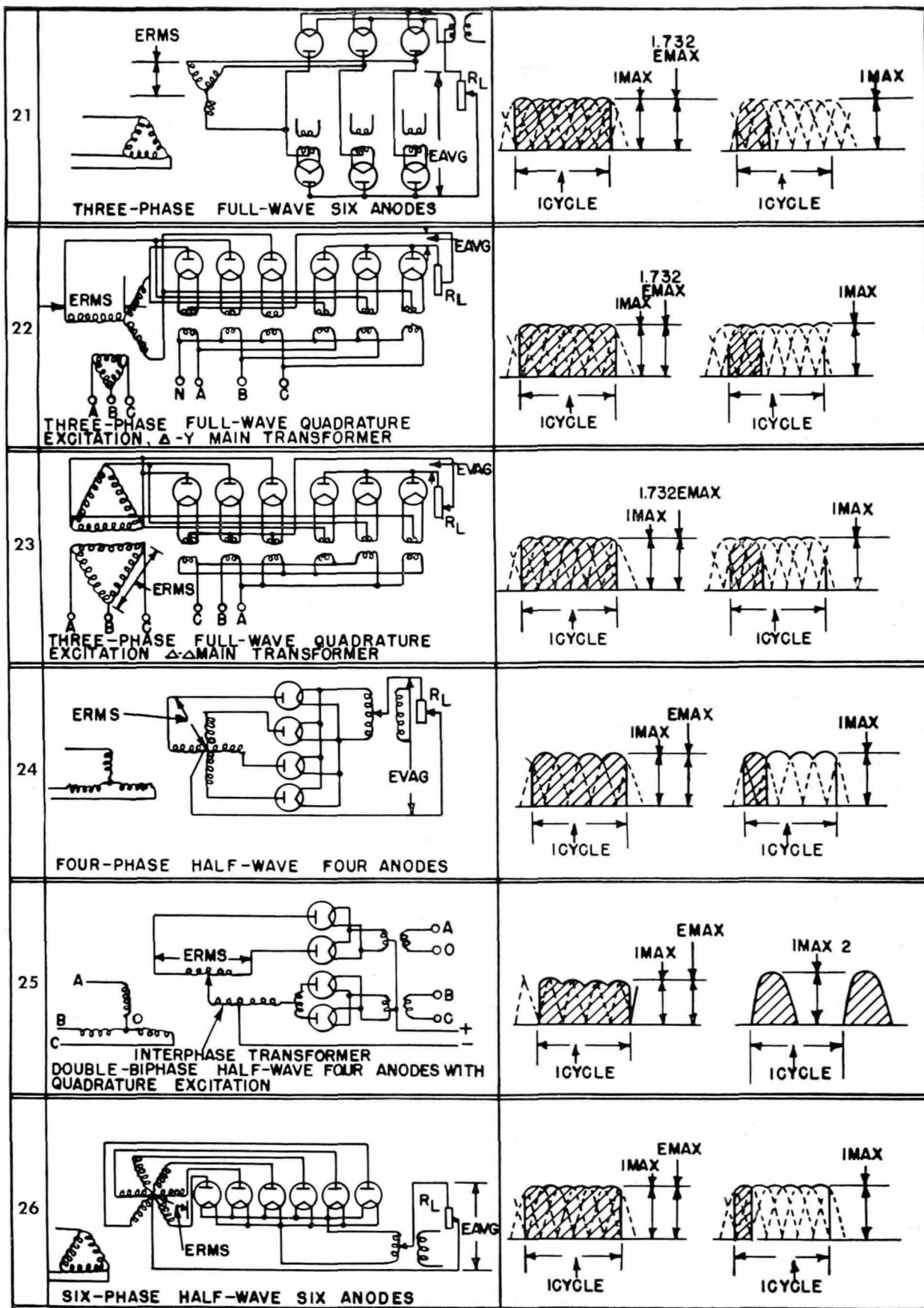


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Fig. 16—Single-phase, Half-wave Rectifier

NO	FIGURE	WAVE FORM
17	BIPHASE HALF-WAVE TWO ANODES	
18	BIPHASE FULL-WAVE FOUR ANODES	
19	THREE-PHASE HALF-WAVE THREE ANODES	
20	DOUBLE THREE-PHASE HALF-WAVE WITH INTERPHASE TRANSFORMER SIX ANODES	

Figs. 17 through 26

Circuits shown in ETX-108 are examples of possible tube applications and the description and illustration of them does not convey to the purchaser of tubes any license under patent rights of General Electric Company.



APPLICATIONS (CONT'D)

USEFUL RATIOS

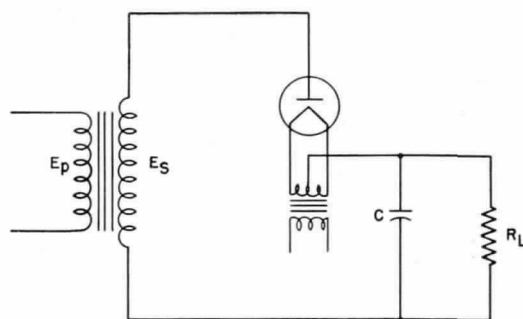
Fig. No.	Tube 1 (Avg.) Load 1 (Avg.)	E—Avg.	E—Inverse	I—Avg.
17	0.500	0.318 E—Max 0.450 E—Rms	E—Max 3.140 E—Avg.	0.636 I—Max
18	0.500	0.636 E—Max 0.900 E—Rms	E—Max 1.570 E—Avg.	0.636 I—Max
19	0.333	0.827 E—Max 1.170 E—Rms	$\sqrt{3}$ E—Max 2.090 E—Avg.	0.827 I—Max
20	0.167	0.827 E—Max 1.170 E—Rms	$\sqrt{3}$ E—Max 2.090 E—Avg.	0.827 I—Max
21	0.333	1.650 E—Max 2.340 E—Rms	$\sqrt{3}$ E—Max 1.050 E—Avg.	0.955 I—Max
22	0.333	1.650 E—Max 2.340 E—Rms	$\sqrt{3}$ E—Max 1.050 E—Avg.	0.955 I—Max
23	0.333	0.955 E—Max 1.340 E—Rms	E—Max 1.050 E—Avg.	0.955 I—Max
24	0.250	0.900 E—Max 1.274 E—Rms	2.220 E—Avg.	0.900 I—Max
25	0.250	0.318 E—Max 0.450 E—Rms	3.140 E—Avg.	0.318 I—Max
26	0.167	0.955 E—Max 1.350 E—Rms	2.090 E—Avg.	0.955 I—Max

The biphas half-wave rectifier, Fig. 17, of page 16 is a popular system in most applications. Compared to the single-phase system, its double frequency ripple voltage, with characteristically lower amplitude, represents the more desirable approach to power-supply design. Supplies intended to deliver high voltages at very low currents, i.e. peak rectifiers, are exceptions and do employ the single-phase half-wave rectifier. Inspection of the various circuit wave forms, and the table of ratios above, will convey to the reader the complexity and applicability of each of the circuits.

Voltage Multipliers: In the many applications requiring a high-voltage, low-current power supply, the voltage multiplier often represents the most economical and compact design. Some preliminary discussion of the action of capacitor filters will serve to clarify the principles involved.

Fig. 27 shows a simple single-phase, half-wave rectifier with capacitor output.

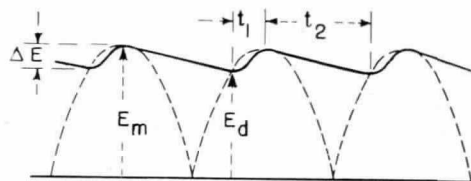
On the assumption that the voltage wave shown in Fig. 28 is a sawtooth (a good approximation at light loads) it may be shown that the fundamental ripple amplitude approaches ΔE ,



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Fig. 27—Single-phase, Half-wave Rectifier with Capacitor Output



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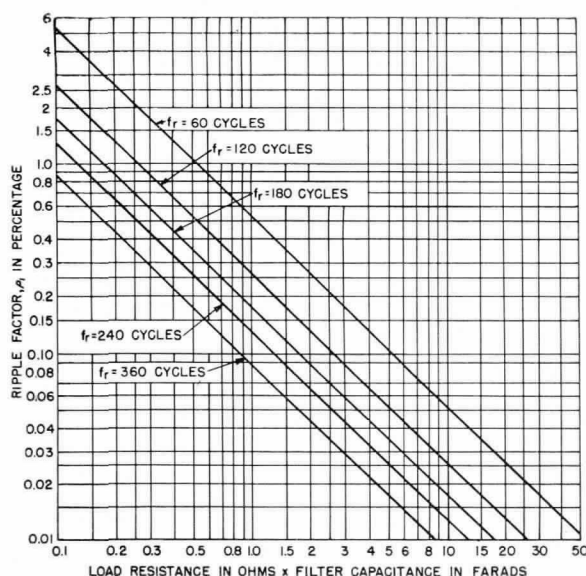
Fig. 28—Wave Form of the Capacitor Voltage under Light Load

where ΔE is the total voltage excursion, and that the ripple factor is P .

$$P = \frac{1}{\pi f R C}$$

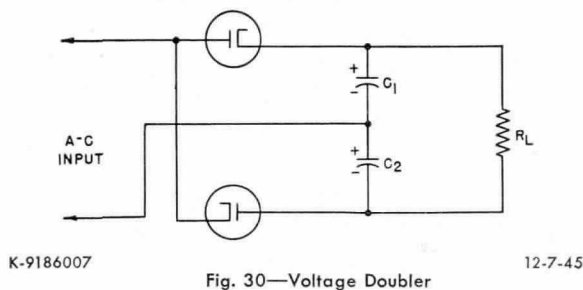
The expression, under the assumptions made, is valid only when p is small, at most a few per cent.

At heavy loads, the problem can be solved by a series of successive approximations, but the process is fairly tedious. Fig. 29, graphically representing the expected ripple factor for a number of resistance-capacitance combinations at various frequencies, can be used both for the simple single-phase half-wave supply and for the more complex multipliers.



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Fig. 29—Ripple Factor for Resistance Load Shunted by a Capacitor

A form of voltage doubler is shown in Fig. 30. Its operation depends on the ability of the circuit to charge each of two capacitors in series to the peak voltage of the transformer. On the half cycle when point A goes positive C_1 is charged to full transformer voltage (less tube drop). C_2 charges on the alternate half cycle and the output voltage across R_L thus becomes

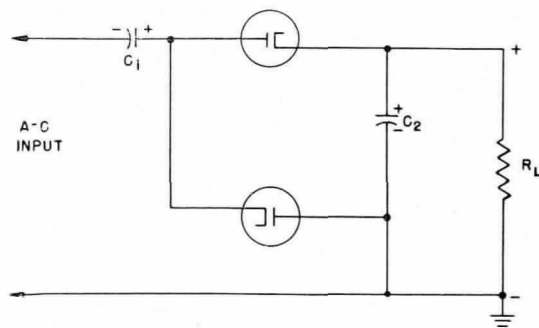


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Fig. 30—Voltage Doubler

Fig. 29—H. J. Reich, Theory and Application of Electron Tubes p. 542, Fig. 14-9; McGraw-Hill Book Co., Inc., 1939

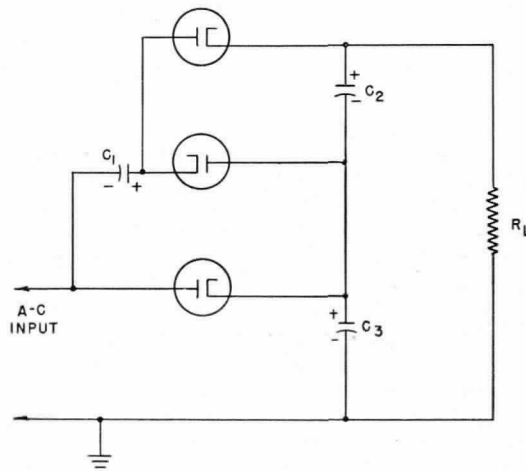
the instantaneous sum of the two capacitor voltages. Obviously the fundamental ripple frequency has become twice the line frequency of the input transformer.

Fig. 31 is another form of the doubler which allows grounding one end of the transformer secondary.



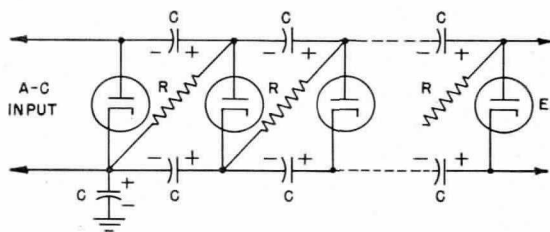
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Fig. 31—Voltage Doubler for Grounded Input

Fig. 32 shows an extension of the doubler system to provide a d-c voltage almost equal to three times the peak transformer voltage.



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Fig. 32—Voltage Tripler

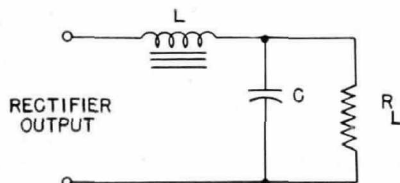
An interesting multiplier is shown in Fig. 33. It is especially adaptable to high-frequency rectifiers.



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Fig. 33—Voltage Multiplier

APPLICATIONS (CONT'D)

Filters for Rectifiers: The single-section inverted L filter shown in Fig. 34 is subject to simple analysis. The standard definition of ripple factor is taken to be the ratio of the rms value of the ripple voltage to the algebraic average value of the total voltage, expressed in percentage.



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Fig. 34—Single-section Inverted L Filter

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Inspection will show that the smoothing factor is equal to the total input impedance of the filter divided by the impedance of the capacitor and load resistance in parallel. In a well designed choke, the resistance of the choke is inconsequential compared to the reactance and, with the further assumption that the reactance of the capacitor is small compared to the resistance of the load, the expression for the smoothing factor becomes:

$$= \frac{X_1 - X_c}{X_c} = W^2 LC - 1$$

In a multi-stage filter such as shown in Fig. 35, simple cumulation of smoothing factors for each section gives a good but somewhat conservative approximation of actual conditions.

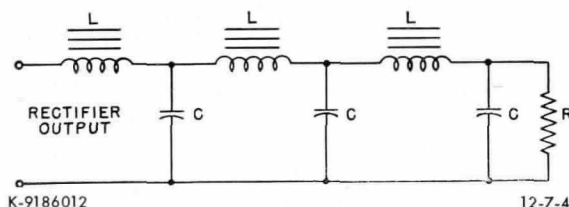


Fig. 35—Multi-stage Filter

Since it may be shown that for a given total amount of capacitance and reactance, maximum filtering is achieved when all sections are alike, a working formula for the design of rectifier filters may be taken as

$$LC = \frac{\sqrt[n]{\mathcal{L} + 1}}{40 f_r^2}$$

where N is the number of sections

$\mathcal{L}$ is the smoothing factor

f_r is the fundamental ripple frequency

The value of $\mathcal{L}$ is simply the ratio of the input ripple factor, as determined from Fig. 29, to the desired factor at the load.

The relative values of L and C for optimum performance are:

$$C = \frac{\sqrt{1 + \sqrt[n]{\mathcal{L}}}}{2 \pi f_r R}$$

$$L = R \sqrt{1 + \sqrt[n]{\mathcal{L}}}$$

Precaution should be taken to avoid LC combinations which will resonate at fundamental or harmonic frequencies of the supply voltage or load.

Filter Charts

Fig. 36 and Fig. 37 present a simple graphical means of designing choke input filter systems for power supplies. These apply to full-wave, single-phase circuits only (60-cycle sine-wave supply). When the supply is a 50-cycle source, multiply the selected values of inductance and capacitance by 1.2. When the supply is a 25-cycle source, multiply the filter values by 2.4.

Erms = Maximum volts (RMS) per plate applied to rectifier tube.

RL = Load Resistance.

Er₁ = Percentage ripple in d-c output voltage from (1) the first section of a double-section filter, or (2) a single-section filter.

Er₂ = Percentage ripple in d-c output voltage from second section of a double-section filter.

Erms = Maximum volts (RMS) per plate applied to rectifier tube.

RL = Load Resistance.

Er₁ = Percentage ripple in d-c output voltage from (1) the first section of a double-section filter, or (2) a single-section filter.

Er₂ = Percentage ripple in d-c output voltage from second section of a double-section filter.

General Rules for Selection of Filter Constants

SINGLE-SECTION FILTER (FIG. 36)

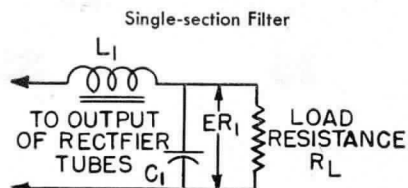
Select Inductance Values

- (1) above proper **RL** Curve
- (2) to left of proper **ERMS** Curve
- (3) along desired **Er₁** Curve

For each selected inductance value, use corresponding value of filter capacitance.

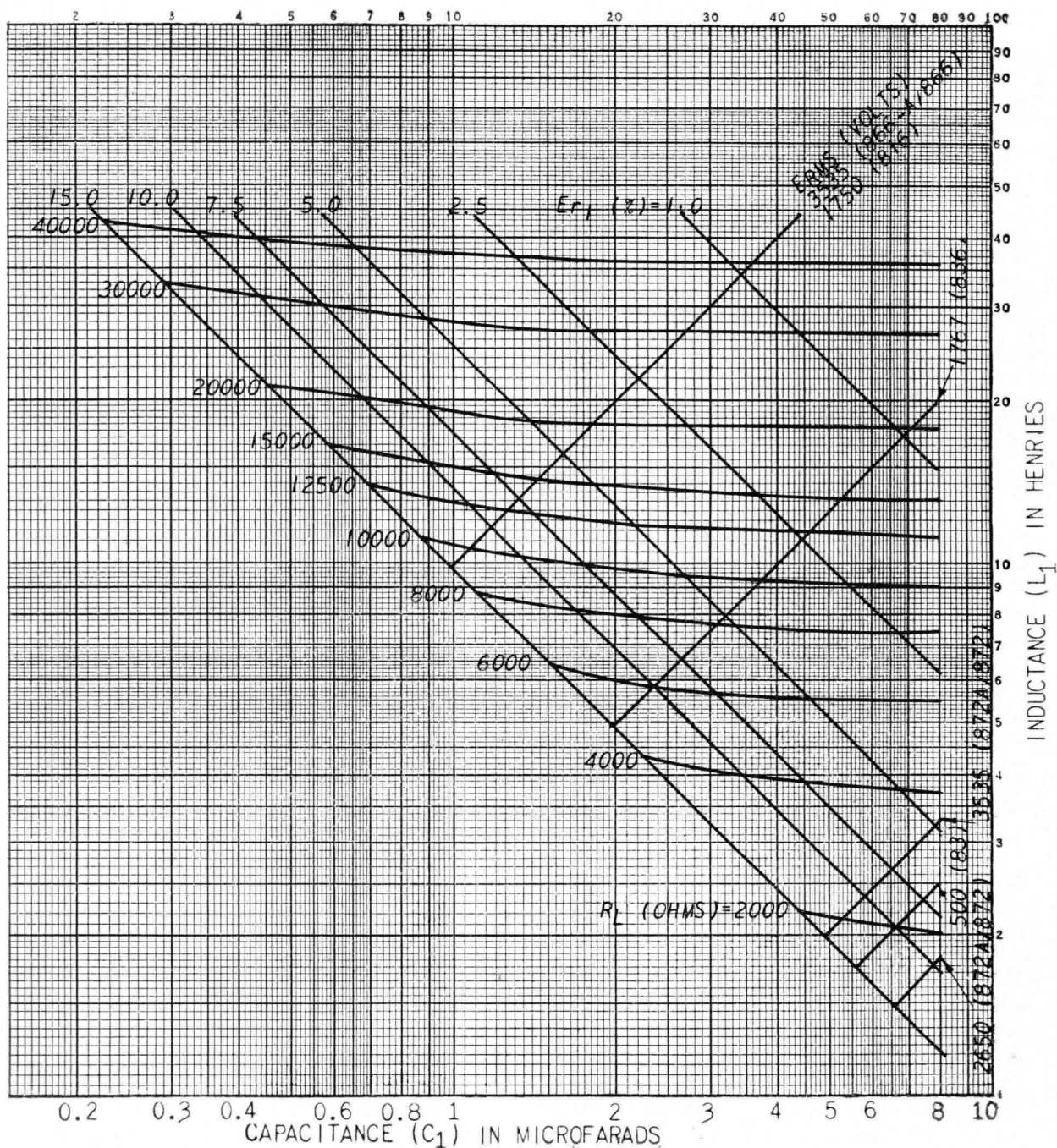
DOUBLE-SECTION FILTER (FIG. 37)

- (1) Select desired percentage of output ripple voltage **Er₂** on appropriate curve of **Er₁**.
- (2) Read corresponding **L₂ C₂** product.
- (3) To satisfy this product, choose convenient values of **L₂** and **C₂**.
- (4) Check value of selected **L₂** to make sure that it is greater than $3(C_1 + C_2) + 2C_1 C_2$.



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Fig. 36—Design Chart for Single-section Filter