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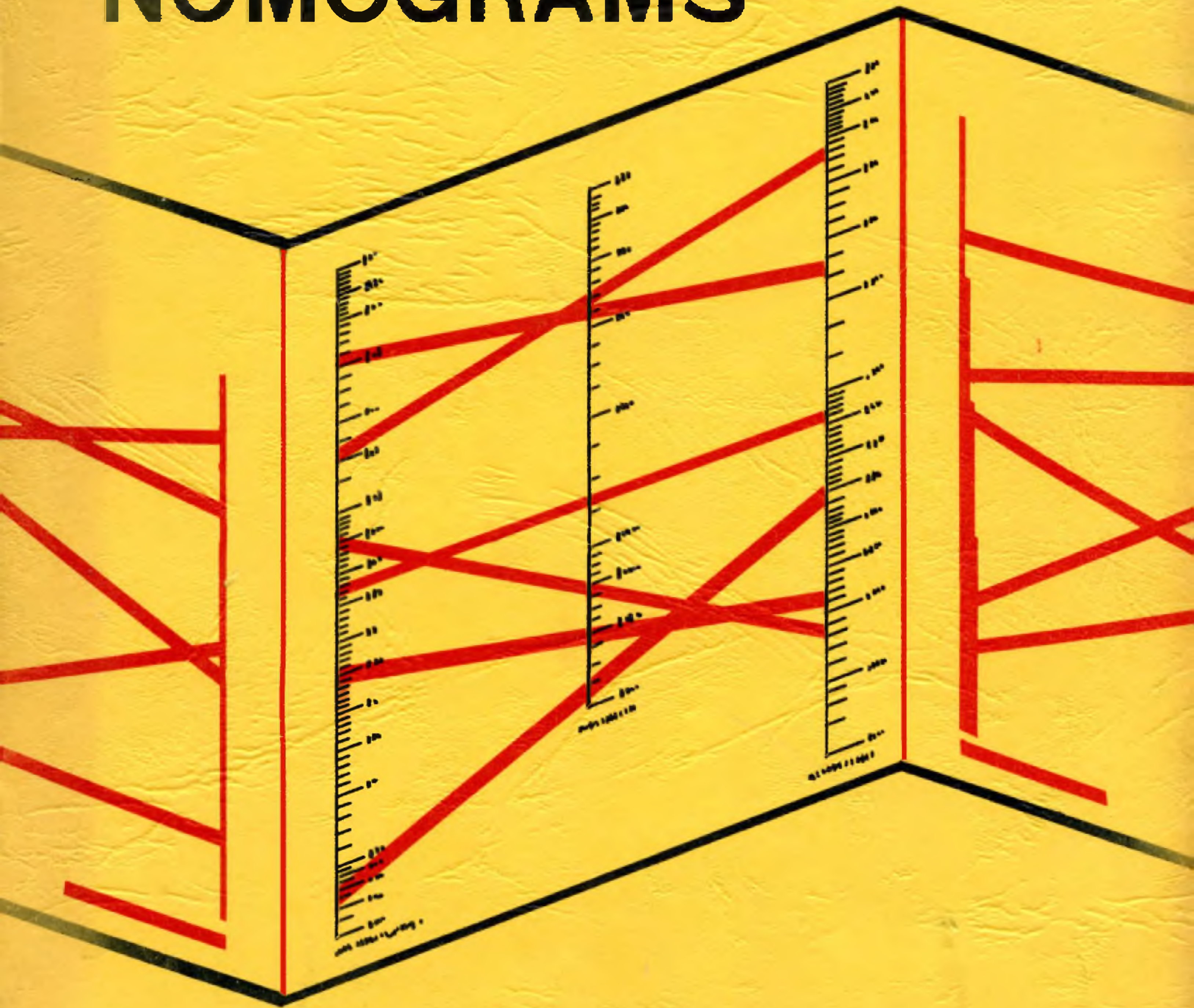
ELECTRONIC ENGINEERING NOMOGRAMS



By Max H. Applebaum

ELECTRONIC ENGINEERING NOMOGRAMS

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Preface

Because of its simplicity, the nomogram or nomograph is often used by members of technical professions. Although computers are being relied upon to obtain rapid solutions to complicated equations which demand a high degree of accuracy, the nomogram has wide usage and will continue to be used for years to come. The nomograms presented in this book are based upon equations commonly used by engineers and technicians. Chapter One consists of simple, often-used equations and conversion charts for quick reference. Chapter Two, the largest section in the book, deals with the design of passive attenuator pads and filters. This chapter has been expanded to include many variations of simplified filters used at higher frequencies.

Characteristics of various types of transmission lines are included in Chapter Three. In addition to the more common lines, balanced shielded and the four-wire balanced lines are dealt with. In Chapter Four, passive electronic components are covered. Some design equations are given and several of the nomograms aid in test procedures. Chapter Five is devoted to vacuum tubes and transistors. An R-C coupled amplifier analysis is presented as a means of solving for component values. Other nomograms relate physical dimensions to component characteristics.

Finally, Chapter Six includes many nomograms which could possibly fit into several other chapters. That they are in the miscellaneous section is not meant to minimize their importance. On the contrary, several are among those most often used.

The author is grateful to the following publications for permission to reprint nomograms which first appeared in their magazines: Circuits Manufacturing, Simplified Inductance Test of Incoming Inspection, May/June 1965; EE (formerly Electronic Industries) A Chilton Publication, Coefficient of Coupling, August 1965—Rise Time Calculations, June 1965; EEE Magazine, Nonsymmetrical Pi and O Pads, June 1966—Low-Pass R-C Filters, April 1966—Low-Pass L-R Filters, August 1966—Low-Pass L-C Filters, May 1966—High-Pass L-R Filters, February 1967—Parallel-T Filters, November 1965—Bypass Capacitors, March 1966; EDN Magazine, Low-Pass Filters: Constant K, March 1967—Low-Pass Filters: M-Derived, April 1967—High-Pass Filters: Constant K and M-Derived (scheduled for publication)—VSWR, September 1965: Electronic Design, Life of Pilot Lights, December 1966; Electronic Products, Finding Characteristic Impedance of Transmission Lines (Nomograms 3-1, 3-4, 3-12,

3-15, 3-16), April 1966; Electronics World, Parallel Resistors, September 1965—Symmetrical Attenuator Pads, September 1966—T and H Attenuator Pads, March 1966 Transformer Turns Ratio, November 1965—Capacitance Measuring, January 1966—Amplifier Gain, August 1965—Power Output, May 1965—Percentage of Modulation, January 1967—UHF-TV Shorting Stub, June 1965; Electro-Technology (A Conover-Mast Publication), Ripple Current in Electrolytic Capacitors, August 1966—Frequency, Ratio of Frequency to Thickness in Quartz Crystals, July/August 1965—Volt/Age (now Electrical Apparatus Service — Volt/Age, Mulville-Barks Publications, Inc.), AC Motor-Starting Capacitor Measurement, April 1966. Special thanks to the following: William A. Stocklin, editor of Electronics World the first to except one of my nomographs for publications; George Rostky, editor of EEE Magazine, who offered encouragement in the writing of the book; all of the engineers at the Thomas Organ Company, who cheerfully took time from their busy schedule to offer help; and Esther Collen, for helping to type the final manuscript.

Special thanks is due Frank Caplan, my brother-in law, for introducing me to nomography, supplying me with reference material in the study of the subject, and helping me in every way possible. Last, but not least, I wish to express loving gratitude to my wife Helen and to my daughters Janet and Wanda. Their cheerful demeanor aided me psychologically during the periods of depression and melancholy which befell this neophyte author. To them, this book is dedicated.

Max H. Applebaum
March 1968

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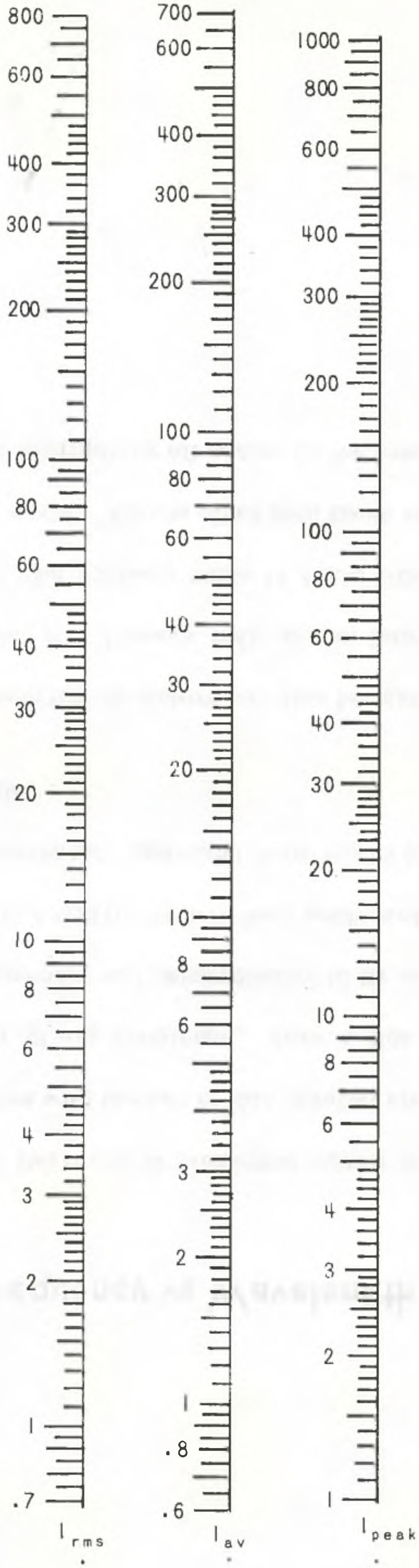
CHAPTER 1

Conversion Charts and Often-Used Nomograms

Peak, Average, and rms Conversion

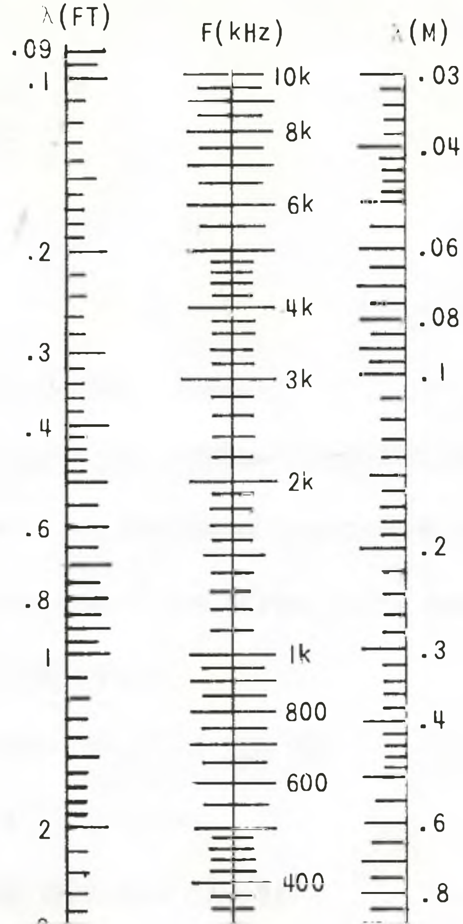
When one of the values of a sine-wave current or voltage is known, the other two may be found simply by drawing a straight line, perpendicular to all three scales, through the value of the known. Values other than those shown may be determined by merely multiplying all scales by the same factor.

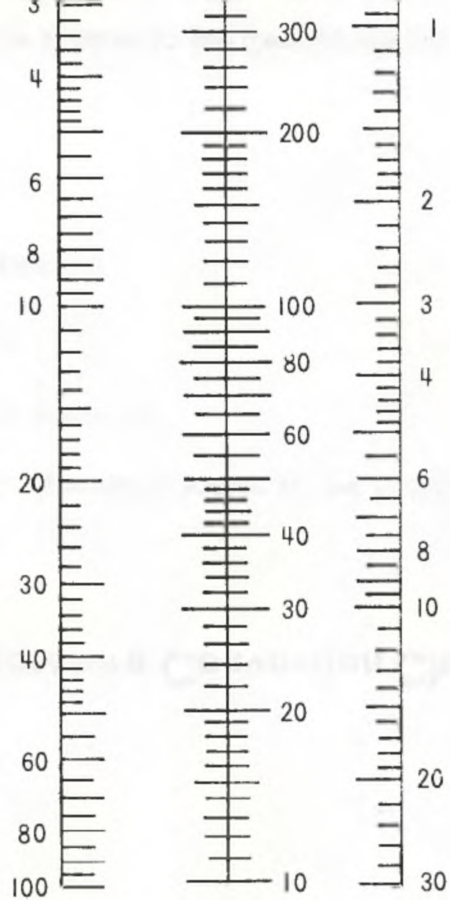

800 600 400 300 200 100 80 60 40 30 20 10 8 6 4 3 2 1 .7
700 600 400 300 200 100 80 60 40 30 20 10 8 6 3 2 1 .8 .6
1000 800 600 400 300 200 100 80 60 40 30 20 10 8 6 4 3 2 1
I_{rms}
I_{av}
I_{peak}

Frequency vs Wavelength

Frequency in Hertz can be converted rapidly to wavelength in meters or feet with the use of this parallel chart. To find the wavelength of any frequency, draw a line through the value of the frequency, and perpendicular to its scale. Wavelength in feet is found on the left-hand scale and wavelength in meters is found on the right-hand scale where the line intersects each scale.

Conversion from feet to meters can also be made by drawing a perpendicular line through both scales intersecting the known value. The unknown value is found where this line intersects its scale. Values other than those shown may be used by merely multiplying all scales by the same factor.


λ(FT)
F(kHz)
λ(M)
.09
.1
.2
.3
.4
.6
.8
1
2
10k
8k
6k
4k
3k
2k
1k
800
600
400
.03
.04
.06
.08
.1
.2
.3
.4
.6
.8


3
4
6
8
10
20
30
40
60
80
100
300
200
100
80
60
40
30
20
10
1
2
3
4
6
8
10
20
30

Temperature Conversion Chart

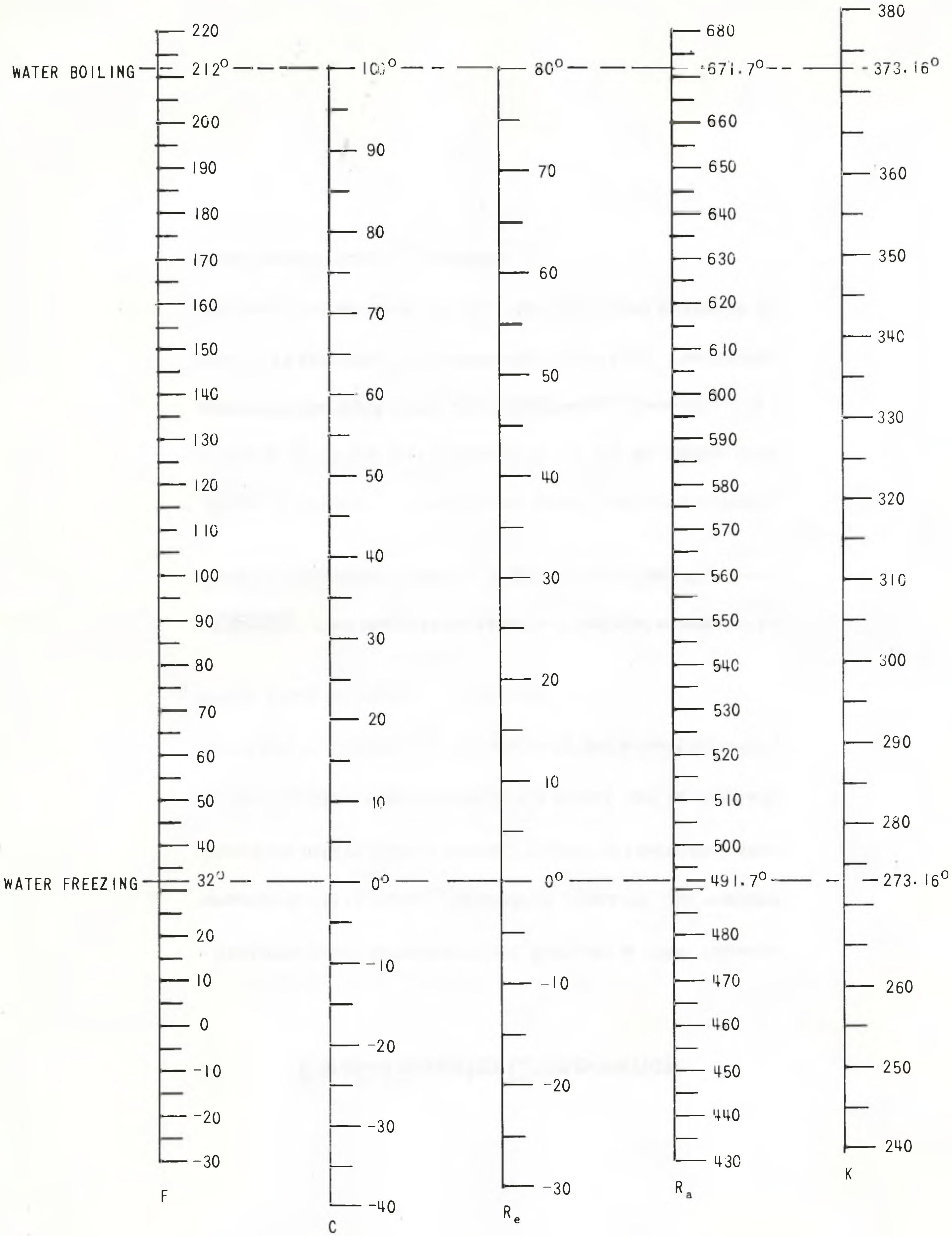
The five major temperature scales in use today are:

1. Centigrade (Celsius)
2. Fahrenheit
3. Kelvin (Absolute)
4. Rankine
5. Reamur

The other four are related to the Centigrade scale as follows:

1. Fahrenheit (F) = (9/5 C) + 32
2. Kelvin (K) = C + 273.16
3. Rankine (Ra) = 1.8 (C + 273.16)
4. Reamur (Re) = 4/5 C

Conversion from any of the scales to all others is easily done by drawing a perpendicular line through all scales simultaneously. The chart includes all temperatures between water boiling and freezing points.

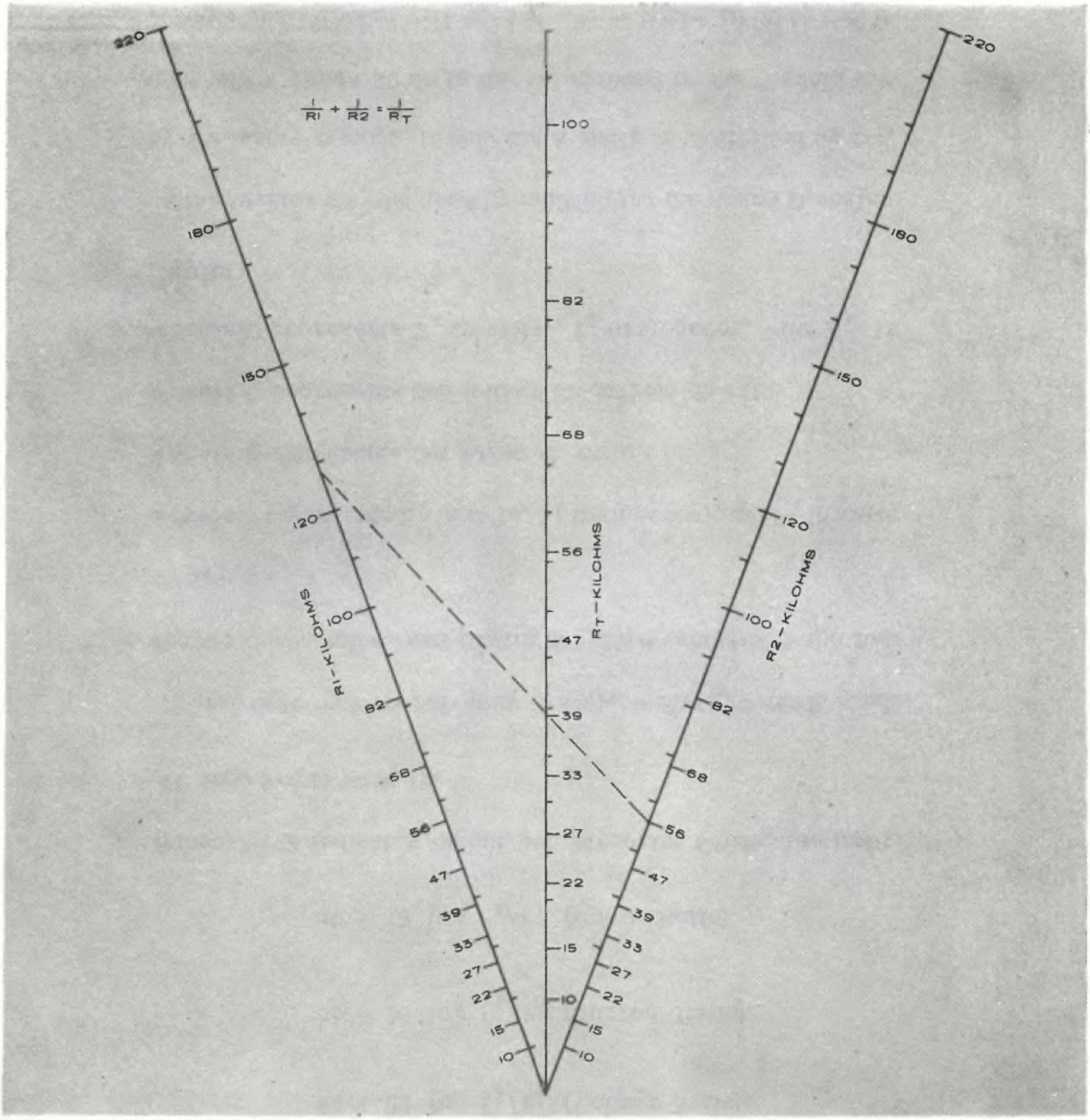

WATER BOILING
WATER FREEZING
212°
32°
100°
0°
80°
0°
671.7°
491.7°
373.16°
273.16°
F
C
R_e
R_a
K

Parallel Resistor Computation

Engineers and technicians will find this a most valuable nomogram. It is unique, insofar as standard EIA resistor values are indicated on all scales. Values of resistors larger or smaller than those shown on the scales can be mentally calculated by multiplying all scales by the same factor 10^n, where n may be positive or negative.

Example: Find the correct value of a resistor necessary to shunt a 560,000-ohm resistor to get a total of 390,000 ohms.

Solution: Place a straight-edge across the three scales, crossing 56 on the R_2 scale and 39 on the R_T scale. The solution is the point where the straight-edge crosses the R_1 scale. In this case, it crosses just below 130. The closest EIA value on the scale is 120. Multiplying all scales by 10 gives an answer of 1.2 megohms.



$\frac{1}{R1} + \frac{1}{R2} = \frac{1}{R_T}$
R1 - KILOHMS
R_T - KILOHMS
R2 - KILOHMS
220
180
150
120
100
82
68
56
47
39
33
27
22
15
10

db Conversion

Decibel gain or loss for voltage, current, and power are found from the following equations:

$$db = 20 \log E_2/E_1 \quad \text{(Voltage Ratio)}$$

$$db = 20 \log I_1/I_2 \quad \text{(Current Ratio)}$$

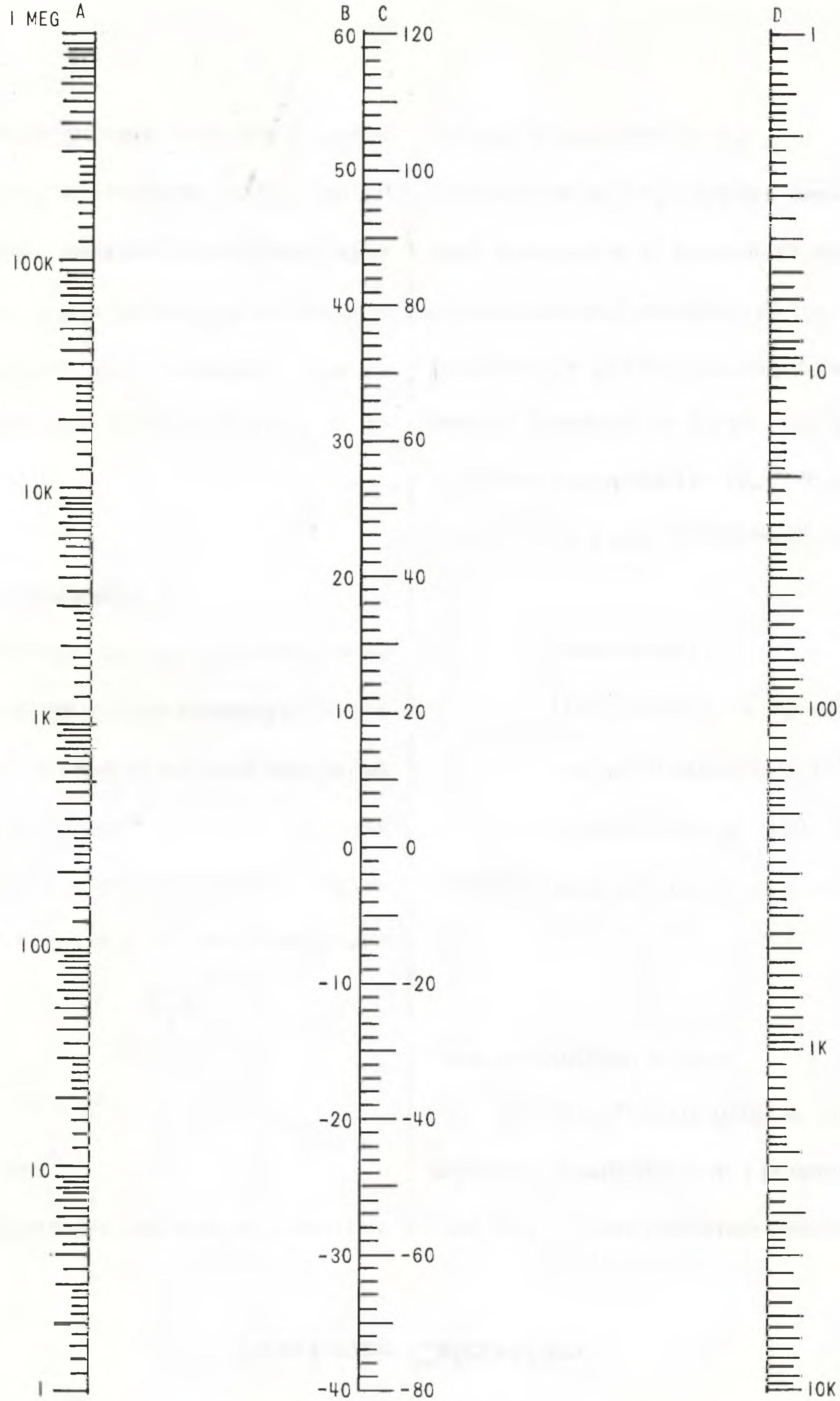
$$db = 10 \log P_2/P_1 \quad \text{(Power Ratio)}$$

Subscript 2 indicates output and subscript 1 indicates input. All logs are to base 10.

These equations are solved by drawing a straight line through the two known values and finding the third value where the line intersects its scale.

- Scale A represents E_2 in volts, I_1 in amperes, and P_2 in watts
- Scale B represents the power db ratio
- Scale C represents the voltage or current db ratio
- Scale D represents E_1 in volts, I_2 in amperes, and P_1 in watts

Other values may be used by multiplying the A and D scales by the same factor. If only the A scale is multiplied by 10^n, then add n times 20 db to the value found on the C scale for voltage and current ratios, and add n times 10 db to the B scale for power ratios.


A
1 MEG
100K
10K
1K
100
10
1
B
C
60
50
40
30
20
10
0
-10
-20
-30
-40
120
100
80
60
40
20
0
-20
-40
-60
-80
D
1
10
100
1K
10K

Reactance Calculation

The equations for inductive and capacitive reactance are:

$$X_L = 2\pi fL$$

and

$$X_C = \frac{1}{2\pi fC}$$

When the values of f, L, and C are known, X_L and X_C are found by drawing two lines between the appropriate values on the given scales. X_L is found on the right side of the center scale for the line extended to L, and X_C is found on the left side of the center scale for the line extended to C.

For values other than those shown on the scales, multiply the appropriate scale by 10^n, where n may be positive or negative. For inductive reactance calculations, when either L or f is multiplied by 10^n, the X_L value found on the chart must also be multiplied by 10^n. For capacitive reactance calculations, when either C or f is multiplied by 10^n, then the X_C value found on the chart must be multiplied by 10^{-n}.

Example: Find X_C for a .0033 microfarad capacitor and X_L for a .15-henry coil at a frequency of 15,750 Hz. (The solution is shown by the broken line.)

NOTE: Since f was multiplied by 10^3, then X_C must be multiplied by 10^{-3}, giving a capacitive reactance of 3.1K. For inductive reactance the L scale was multiplied by 10^1 and the f scale was multiplied by 10^3. Therefore, the value of X_L found on its scale must be multiplied by 10^4, and the inductive reactance is calculated as 15K.

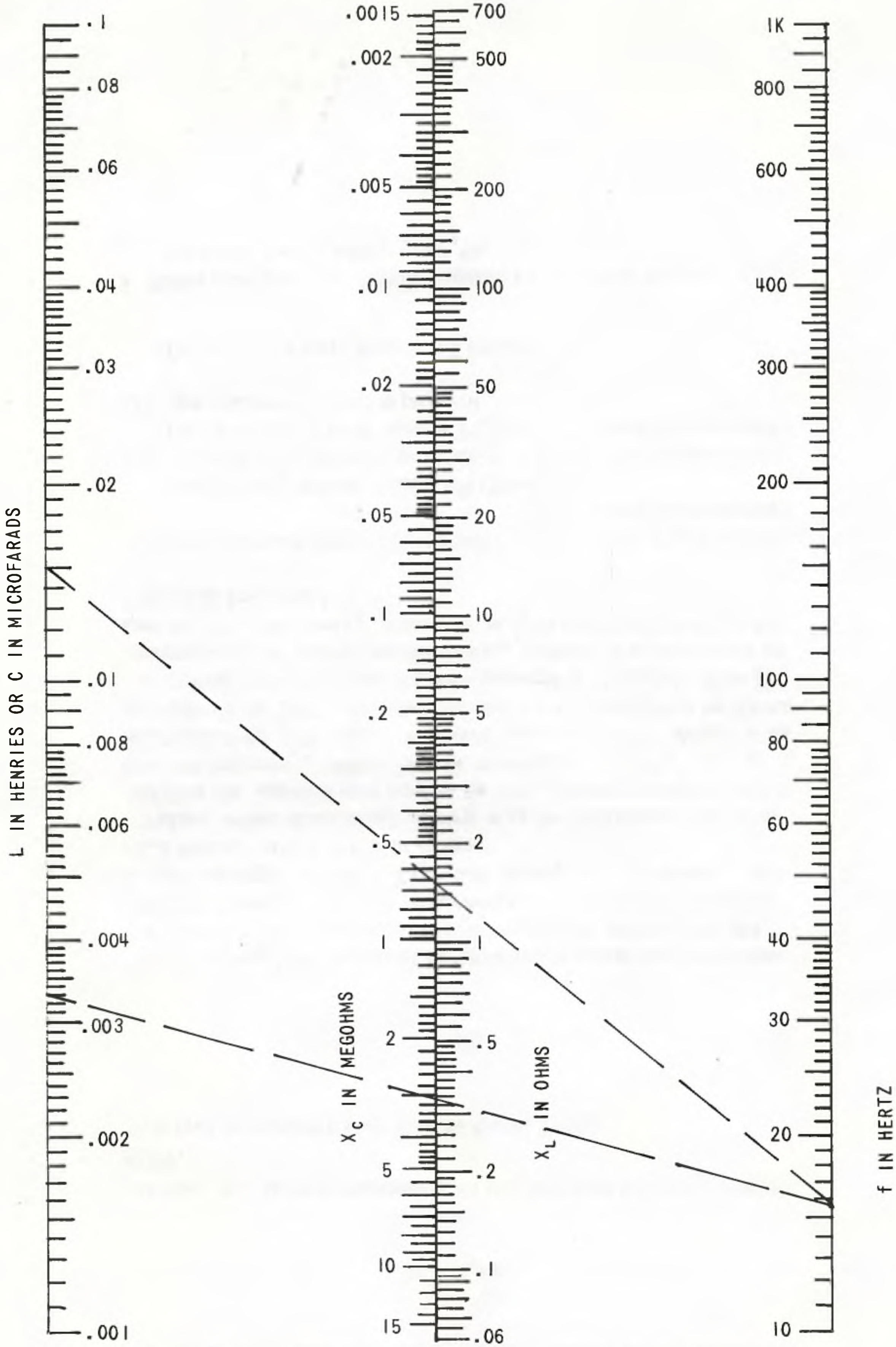

L IN HENRIES OR C IN MICROFARADS
.1
.08
.06
.04
.03
.02
.01
.008
.006
.004
.003
.002
.001
.0015
.002
.005
.01
.02
.05
.1
.2
.5
1
2
5
10
15
700
500
200
100
50
20
10
5
2
1
.5
.2
.1
.06
X_C IN MEGOHMS
X_L IN OHMS
IK
800
600
400
300
200
100
80
60
40
30
20
10
f IN HERTZ

Figure of Merit

The figure of merit (Q) of a coil is defined by the equation:

$$Q = X_L/R$$

Where: X_L is the reactance of the coil and R is its resistance.

The coil impedance can then be found from:

$$Z = QX_L$$

Q and Z can both be found by merely drawing one line from the values of X_L and R on their respective scales. Q and Z are found where the line intersects the appropriate scale. In the example shown, $X_L = 500$ ohms, $R = 40$ ohms, $Q = 12.5$ ohms, and $Z = 6,250$ ohms.

Values other than those shown may be determined by multiplying the appropriate scales by 10^n, where n may be positive or negative. When X_L is multiplied by 10^n, then Q is multiplied by 10^n and Z is multiplied by 10^{2n}. When R is multiplied by 10^n, then both Q and Z are multiplied by 10^{-n}.

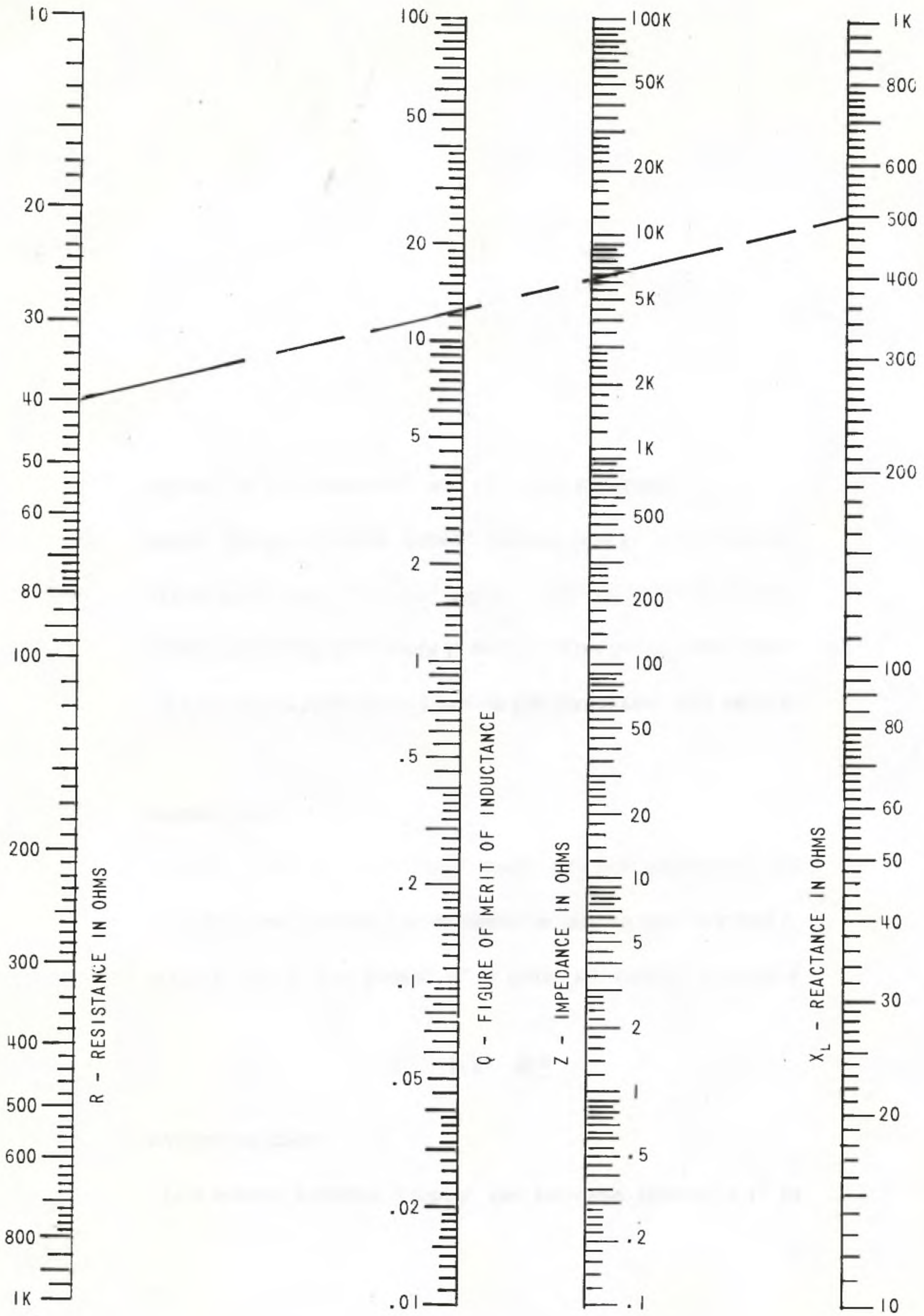
Q values greater than 10 are generally desired. For the convenience of scale modification, values of Q are given as low as .01. However, accuracy of Q is determined from the following factors.*

(1) Approximate error in percent $= -\dfrac{100}{Q^2}$ (for small resistive components)
for $Q = 10$, error equals 1% (low)

(2) Approximate error in percent $= -100\,Q^2$ (for small reactive components)
for $Q = 0.1$, error equals 1% (low)

(3) Approximate error in percent $= +\dfrac{50}{Q^2}$
for $Q = 7$, error equals 1% (high)

* Reference Data for Radio Engineers, second edition, J.J. Little and Ives, 1946, page 70


R - RESISTANCE IN OHMS
Q - FIGURE OF MERIT OF INDUCTANCE
Z - IMPEDANCE IN OHMS
X_L - REACTANCE IN OHMS
10
20
30
40
50
60
80
100
200
300
400
500
600
800
1K
100
50
20
10
5
2
1
.5
.2
.1
.05
.02
.01
100K
50K
20K
10K
5K
2K
1K
500
200
100
50
20
10
5
2
1
.5
.2
.1
1K
800
600
500
400
300
200
100
80
60
50
40
30
20
10

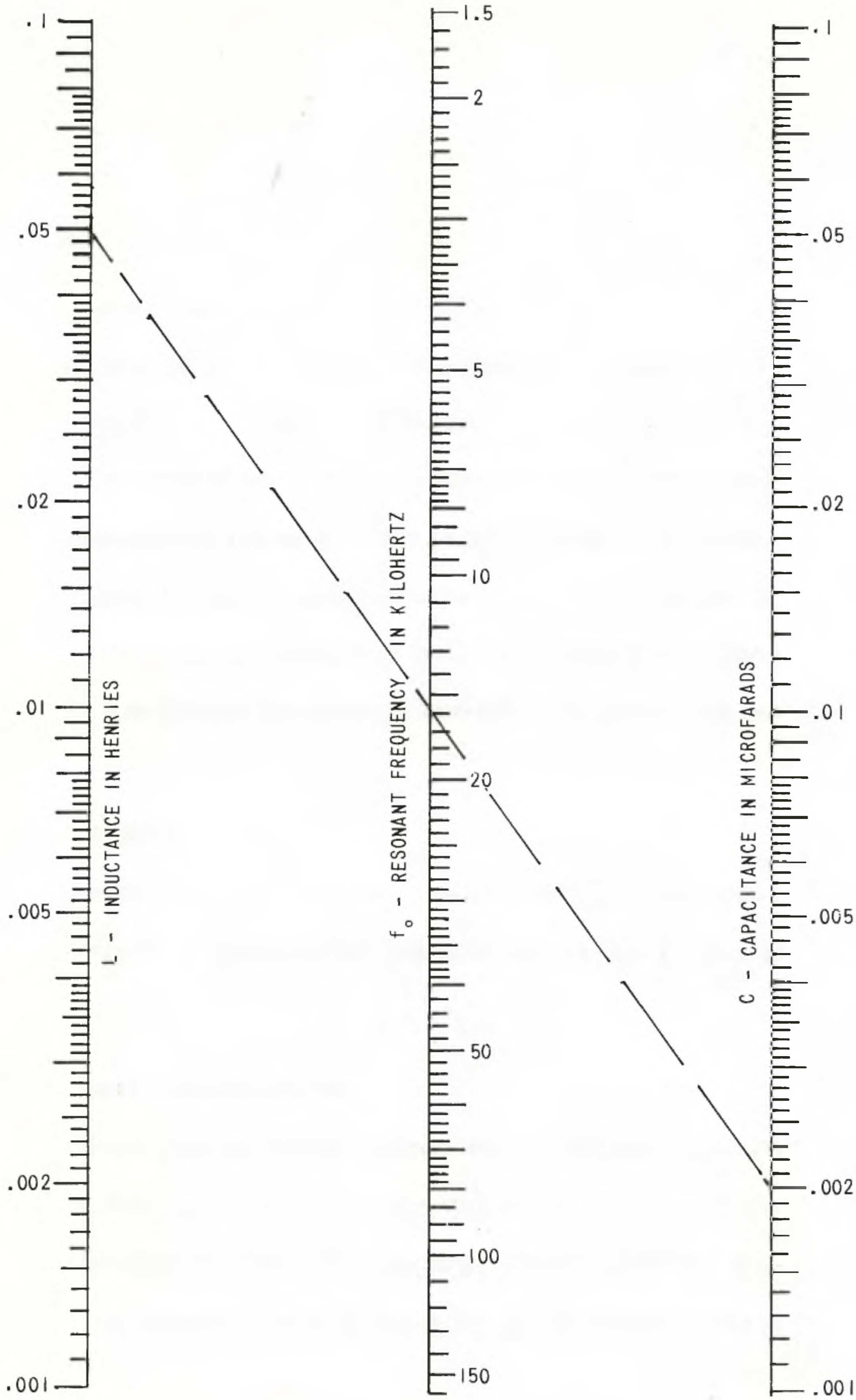
Resonant Frequency Calculation

In a series resonant circuit, the resonant frequency f_o is calculated from:

$$f_o = 1/2\pi\sqrt{LC}$$

When L and C are known, f_o is found by simply drawing a straight line through the appropriate values on the L and C scales. Read the value of f_o where the line intersects the center scale.

Values other than those given on the nomogram may be calculated by multiplying both L and C scales by 10^n and multiplying the f_o scale by 10^{-n}, where n may be positive or negative. In the example shown, broken line C = .002 microfarads, L = .05 henries, and f_o = 15.9 kiloHertz.


L - INDUCTANCE IN HENRIES
.1
.05
.02
.01
.005
.002
.001
f_o - RESONANT FREQUENCY IN KILOHERTZ
1.5
2
5
10
20
50
100
150
C - CAPACITANCE IN MICROFARADS
.1
.05
.02
.01
.005
.002
.001

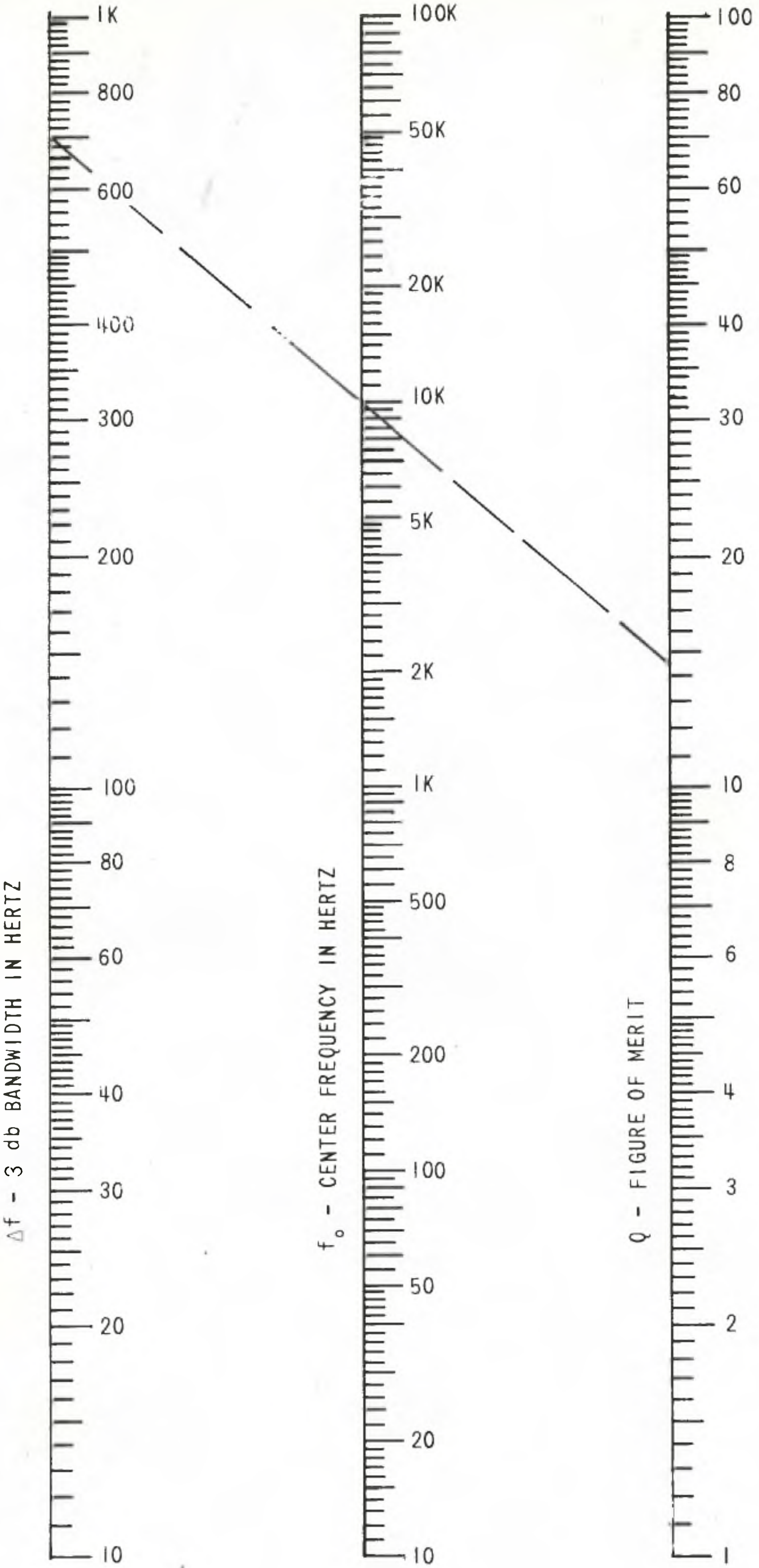
Tuned Circuit "Q" Determination

An accurate method of finding the "Q" of a tuned circuit is to sweep the tuned circuit about its resonant frequency, finding the frequencies above and below resonance which are 3 db down from the voltage at resonance, and calculating the value of Q from the equation:

$$Q = f_o/\Delta f$$

where: f_o is the resonant frequency and $\Delta f = f_H - f_L$ the 3 db bandwidth, (f_H is the upper 3 db point and f_L is the lower 3 db point).

The equation is solved by drawing a line through the two known values and finding the third value where the line intersects its scale. Other values of f_o and Δf may be used by multiplying the scale values by 10^n, where n may be negative or positive. When f_o is multiplied by 10^n, then Q is multiplied by 10^n. When Δf is multiplied by 10^n, then Q is multiplied by 10^{-n}. In the example shown: $\Delta f = 700$ Hz, $f_o = 10$ k Hz, and $Q = 14.5$.



Δf - 3 db BANDWIDTH IN HERTZ
1K
800
600
400
300
200
100
80
60
40
30
20
10
f_o - CENTER FREQUENCY IN HERTZ
100K
50K
20K
10K
5K
2K
1K
500
200
100
50
20
10
Q - FIGURE OF MERIT
100
80
60
40
30
20
10
8
6
4
3
2
1

CHAPTER 2

Attenuators and Filters

Symmetrical Attenuator Pads (T, H, Pi, O)

Resistive pads are a common means of attenuating audio, video, and radio frequencies without disturbing the circuit impedances. These nomograms provide a rapid method of determining the values of resistors to make up such pads. The nomograms are for symmetrical pads in which the impedances looking into the pads from both sides are equal.

Nomogram 2-1 is for the solution of symmetrical T and H pads where $Z_1 = Z_2 = Z$. R_1 and R_3 are the same for both pads and are found in the following manner:

(1) From the value of Z in the left-hand column draw a line to the number of db attenuation desired on the $N(R_3)$ scale. Find the value of R_3 where the line crosses its scale.

(2) From the same value of Z draw a line to the same number of db attenuation in the $N(R_1)$ scale. Find the value of R_1 where the line crosses its scale.

Example: Design a 10 db pad for an unbalanced 75-ohm coaxial cable terminating in its own impedance.

Solution: (1) Extend a line from 75 on the Z scale to 10 on the $N(R_3)$ scale. The line crosses the R_3 scale at 52, which is the value of R_3 in ohms.

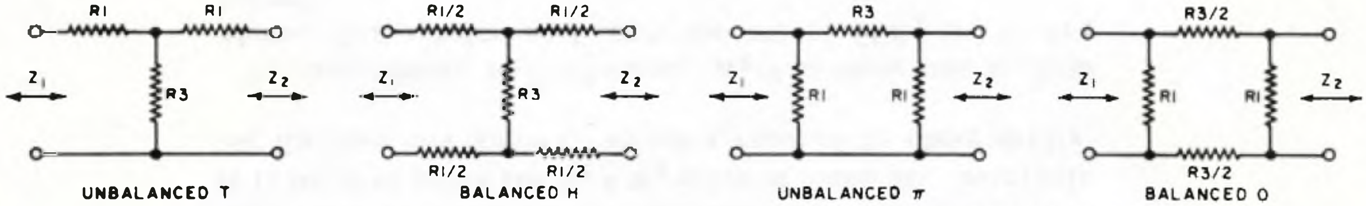
(2) Extend a second line from 75 on the Z scale to 10 on the $N(R_1)$ scale. The line crosses the R_1 scale at 39, which is the value of R_1 in ohms.

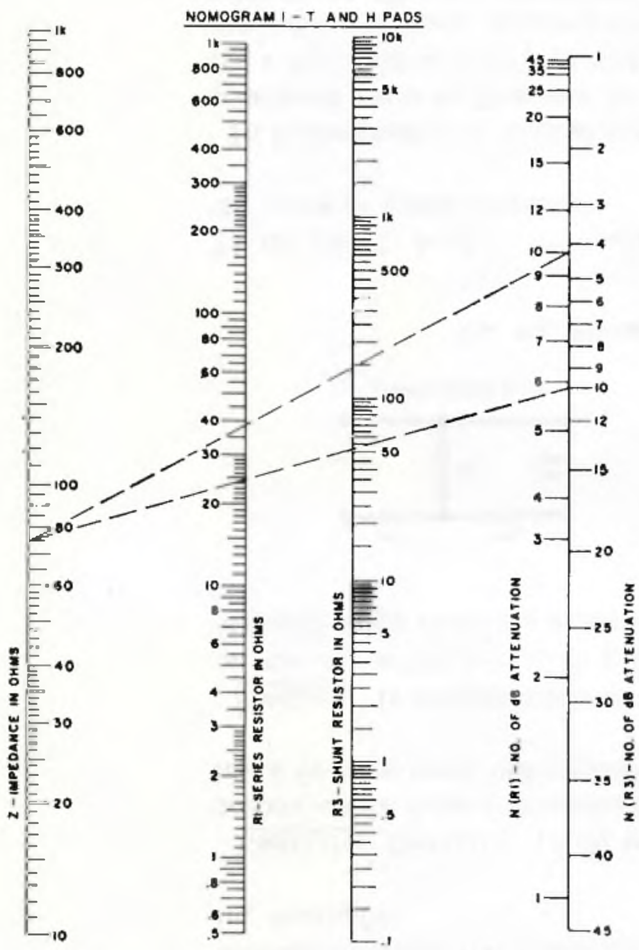
Nomogram 2-2 is for the solution of symmetrical Pi and O pads where $Z_1 = Z_2 = Z$. R_1 and R_3 are the same for both pads and are found in a similar manner to Nomogram 2-1.

Example: Design a 6 db pad (O type) to attenuate a strong signal causing overload on all channels in a TV receiver. The wire used is 300-ohm twin-lead and connects to a balanced 300-ohm input at the antenna terminals of the tuner.

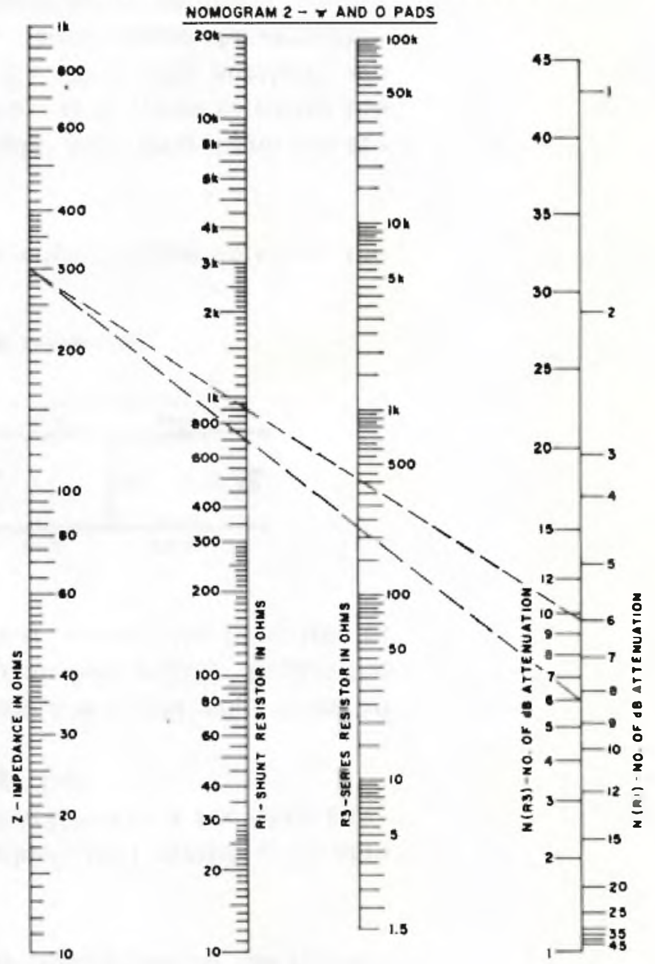
Solution: (1) Extend a line from 300 on the Z scale to 6 on the N (R_1) scale. This line crosses the R_1 scale at 900, which is the value of R_1 in ohms.

(2) Extend a second line from 300 on the Z scale to 6 on the N (R_3) scale. This line crosses the R_3 scale at 225 which is the value of R_3 in ohms.





Nomogram 2-1



Nomogram 2-2

T and H Attenuator Pads

The use of Nomograms 2-3 and 2-4 provide a simplified and rapid means of calculating component values for unbalanced T and balanced H nonsymmetrical attenuator pads for audio or RF applications. These pads have different value impedances looking into and out of the circuit. Schematics of the pads are shown in Fig. 2-3. The formulas used for the nomograms are adaptations of standard equations. The method of using the nomograms is illustrated in the following example.

Example: Design a 12 db pad which will match a 75-ohm coaxial cable from a distribution amplifier to a receiver having a 50-ohm input unbalanced to ground.

Solution: In Nomogram 2-3, extend a straight-edge from 50 on the Z_2 scale to 12 on the attenuation scale. Rotate the straight-edge about the point where it crosses the pivot line to

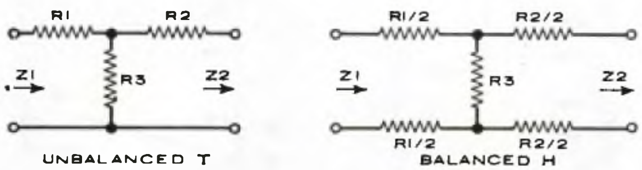


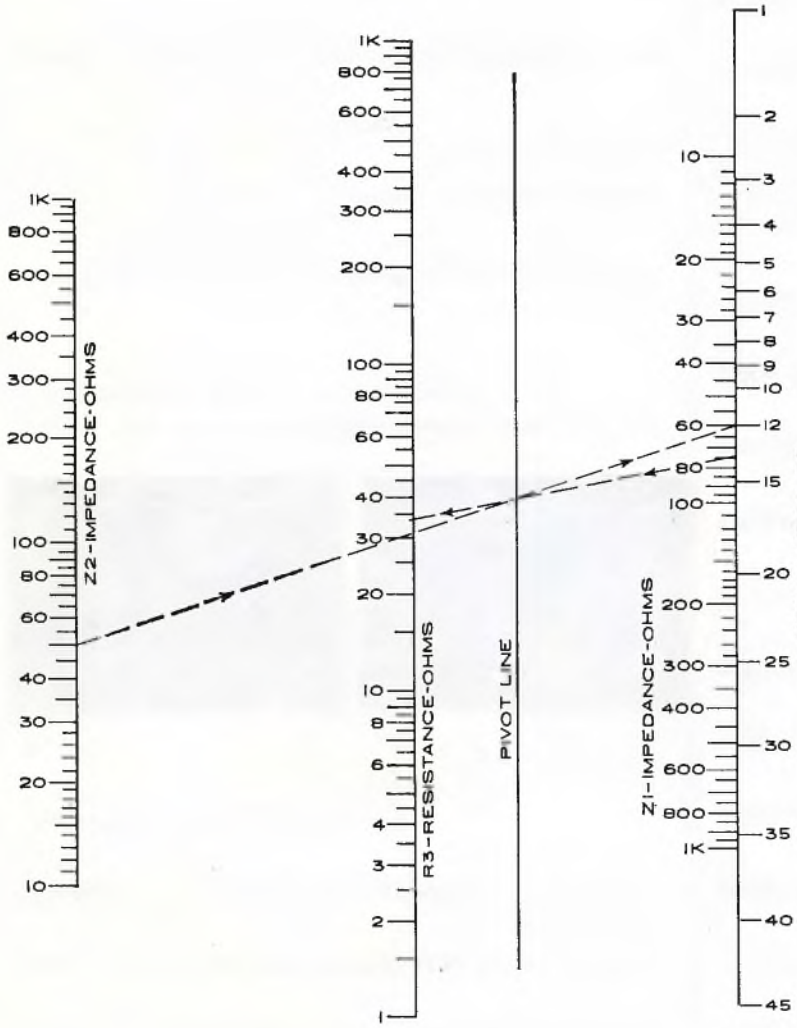
Fig. 2-3. Typical pad schematics.

75 on the Z_1 scale. The straight-edge is found to cross the R_3 scale at about 33 ohms.

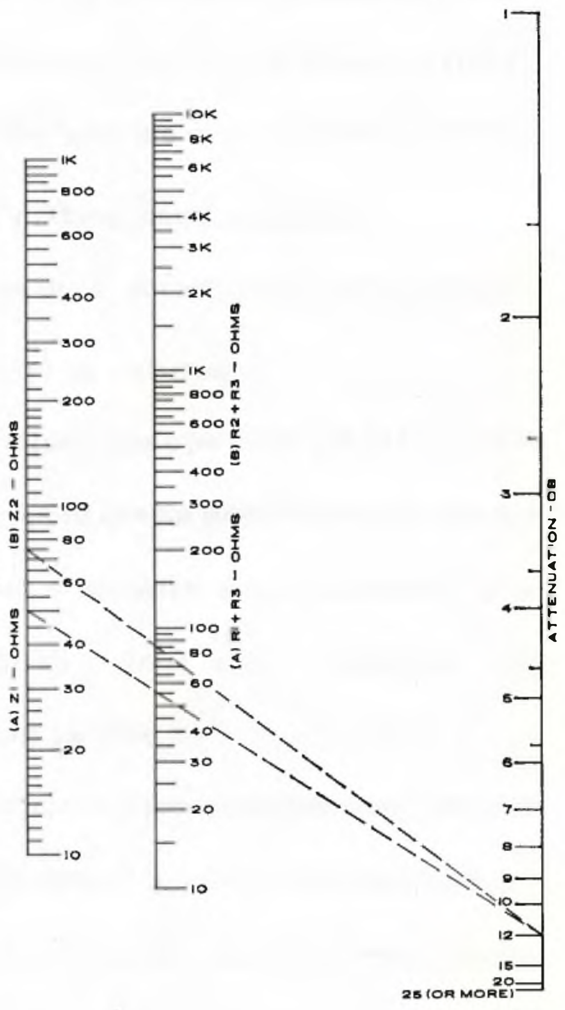
In Nomogram 2-4, extend a straight-edge from 12 on the attenuation scale to 75 on the Z_1 scale. It is found to cross the $R_1 + R_3$ scale at 85. Subtracting R_3 from this number, we get a value of about 52 ohms for R_1. Now extend the straight-edge from 12 on the attenuation scale to 50 on the Z_2 scale. It is found to cross the $R_2 + R_3$ scale at about 56. Subtracting R_3 from this number, we get a value of 23 ohms for R_2.

To summarize, $R_1 \cong 52$ ohms, $R_2 \cong 23$ ohms and $R_3 \cong 33$ ohms. For a balanced H pad, the values of R_1 and R_2 are halved.

NOTE: In Nomogram 2-3, the Z_1 scale is used in conjunction with the $R_1 + R_3$ scale, and the Z_2 scale is used in conjunction with the $R_2 + R_3$ scale.



Nomogram 2-3



Nomogram 2-4

Nonsymmetrical Pi and O Pads

Nonsymmetrical matching pads are called for when a signal must be attenuated between a generator with one impedance and a load with another. Among the simpler and more popular pads, we have the unbalanced Pi (Fig. 2-4A) and the balanced O (Fig. 2-4B). These can be quickly and easily designed with the help of Nomogram 2-5.

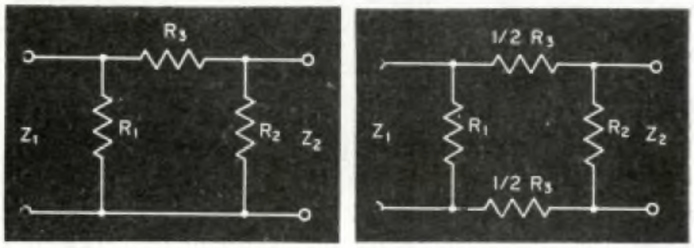


Fig. 2-4. Two very popular matching pads, the unbalanced Pi (a) and the balanced O (b).

In Fig. 2-4, R_1, R_2, and R_3 have the same values for both pads. (These resistors should be noninductive RF typed for best performance.) Their values can be calculated from three equations:

$$R_3 = \frac{N-1}{2}\sqrt{\frac{Z_1 Z_2}{N}} \tag{1}$$

$$\frac{1}{R_1} = \frac{N+1}{Z_1(N-1)} - \frac{1}{R_3} \tag{2}$$

$$\frac{1}{R_2} = \frac{N+1}{Z_2(N-1)} - \frac{1}{R_3} \tag{3}$$

where: N is the ratio of generated power to output power.

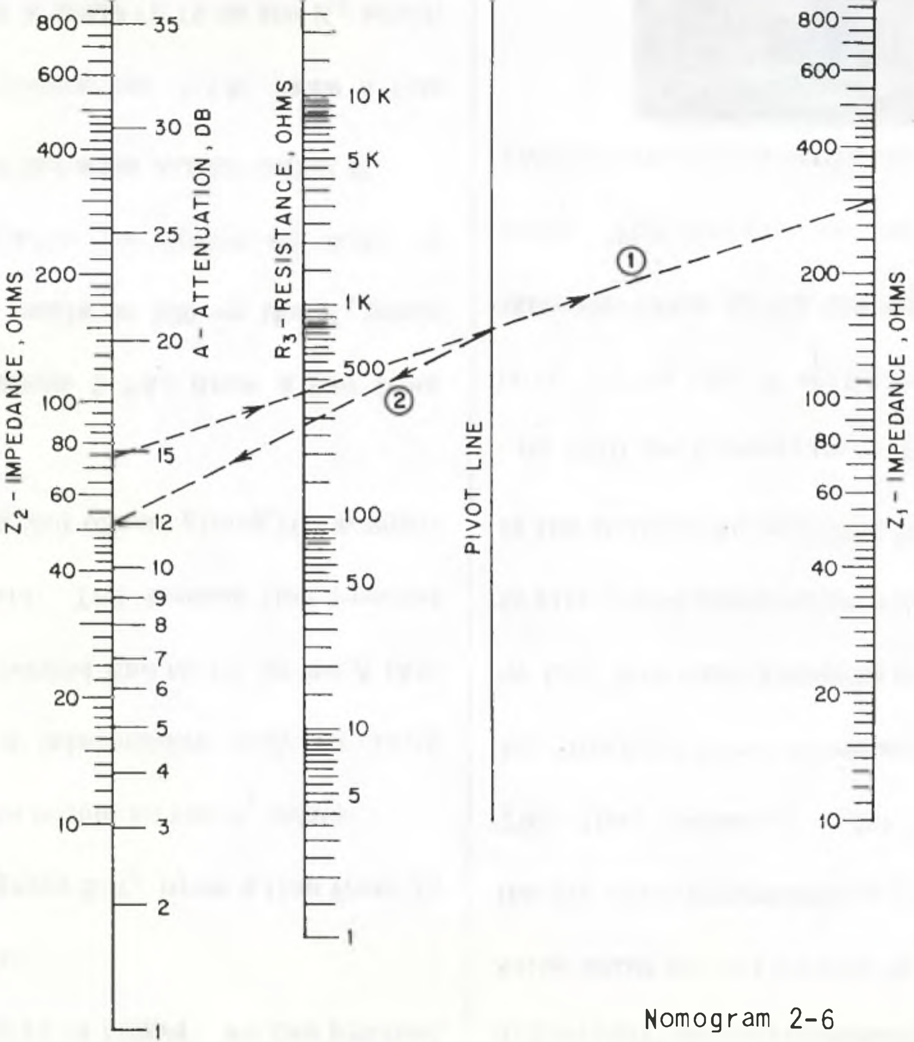
Nomogram 2-5 shows the minimum possible attenuation as a function of the Z_1/Z_2 ratio, where Z_1, always considered larger than Z_2, can represent either the source or the load impedance. When it's necessary to design a minimum-loss matching pad, the loss can never be zero unless of course $Z_1 = Z_2$, which gives a unity ratio. Obviously, for this case a matching pad isn't needed. It is impossible to design these pads with less attenuation than shown because negative resistance would be required.

The use of the nomograms is best illustrated with a typical design problem.

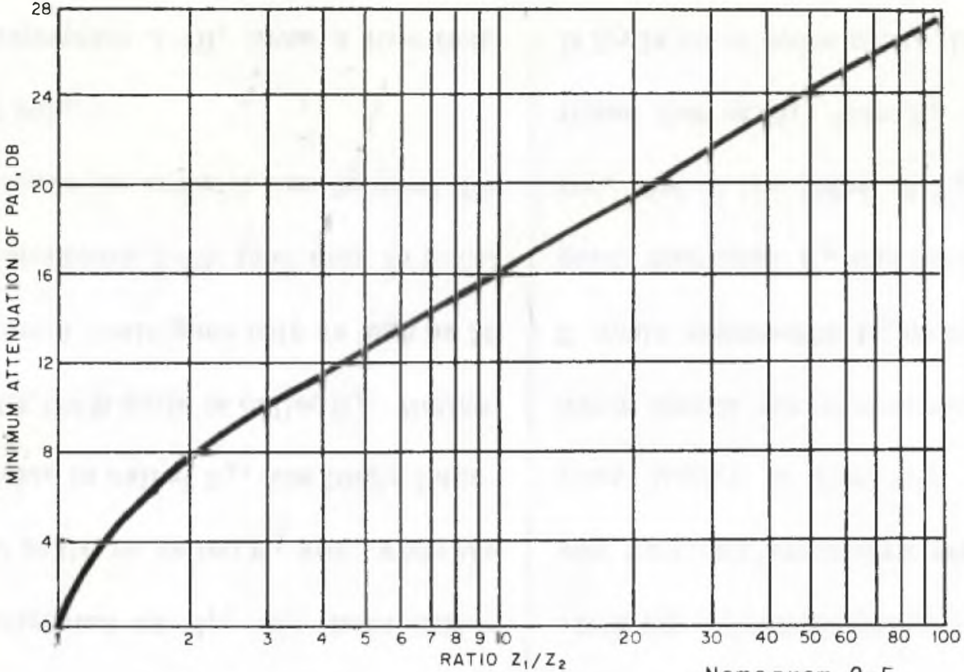
Problem: Assume it is necessary to design a 12 db attenuator to match a 75-ohm line to a 300-ohm TV input using a balanced O configuration.

Solution: First use Nomogram 2-5 and notice that a Z_1/Z_2 ratio of four (from 300/75) has a minimum possible attenuation of

(Continued on next page)

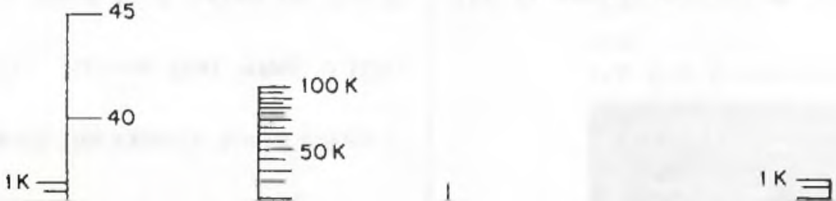

Z_2 - IMPEDANCE, OHMS
A - ATTENUATION, DB
R_3 - RESISTANCE, OHMS
PIVOT LINE
Z_1 - IMPEDANCE, OHMS
800
600
400
200
100
80
60
40
20
10
1
35
30
25
20
15
12
10
9
8
7
6
5
4
3
2
10 K
5 K
1 K
500
100
50
10
5
1
①
②

Nomogram 2-6



MINIMUM ATTENUATION OF PAD, DB
0
4
8
12
16
20
24
28
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
80
100
RATIO Z_1/Z_2

Nomogram 2-5



45
40
100 K
50 K
1K
1K

11.6 db. Since 12 is larger, we can proceed with the design.

(1) In Nomogram 2-6, draw a line from 75 on the Z_2 scale to 300 on the Z_1 scale.

(2) From its intersection with the pivot line, draw a second line to 12 on the A (Attenuation) scale. The second line crosses the R_3 scale at 280 ohms, giving the solution to equation 1.

(3) In Nomogram 2-7A, draw a line from 12 one the A scale to 300 on the Z_1 scale. This line crosses the center (B) scale at 270, the value for what can be called B_1.

(4) Still on Nomogram 2-7A, draw a line from 12 on the A scale to 75 on the Z_2 scale. Its intersection with the center scale gives a value of B_2 of 67. Notice that when a line from the A scale goes to a value on the Z scale, designated as Z_1, the intersection with the B scale is called B_1 and, when the Z scale value is called Z_2, the line's intersection with the B scale is called B_2. Notice, too, that the A scale goes only as high as 30 db. In Nomogram 2-7A (and only in 2-7A) the 30 db mark on scale A can be used for all higher values.

(5) In Nomogram 2-7B, draw a line from 2.8 on the C scale (representing the 280-ohm value found for R_3 in step 2) through 2.7 on the B_1 scale (representing 270 from step 3). This line, extended to the D scale, gives 48. Since the C and B values were multiplied by 100, this value should be multiplied by 100 to give 4,800 ohms as the value for R_1 (which is the solution for equation 2).

(6) Still on Nomogram 2-7B, draw a line from 28 on the D scale (representing the 280-ohm value of R_3) through 6.7 on the B_2 scale. This line crosses the C scale at 8.6. This value should be multiplied by 10 (as were

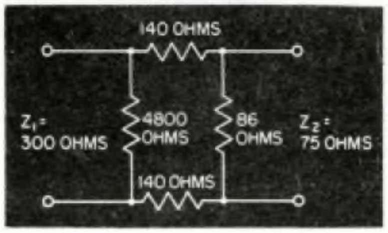
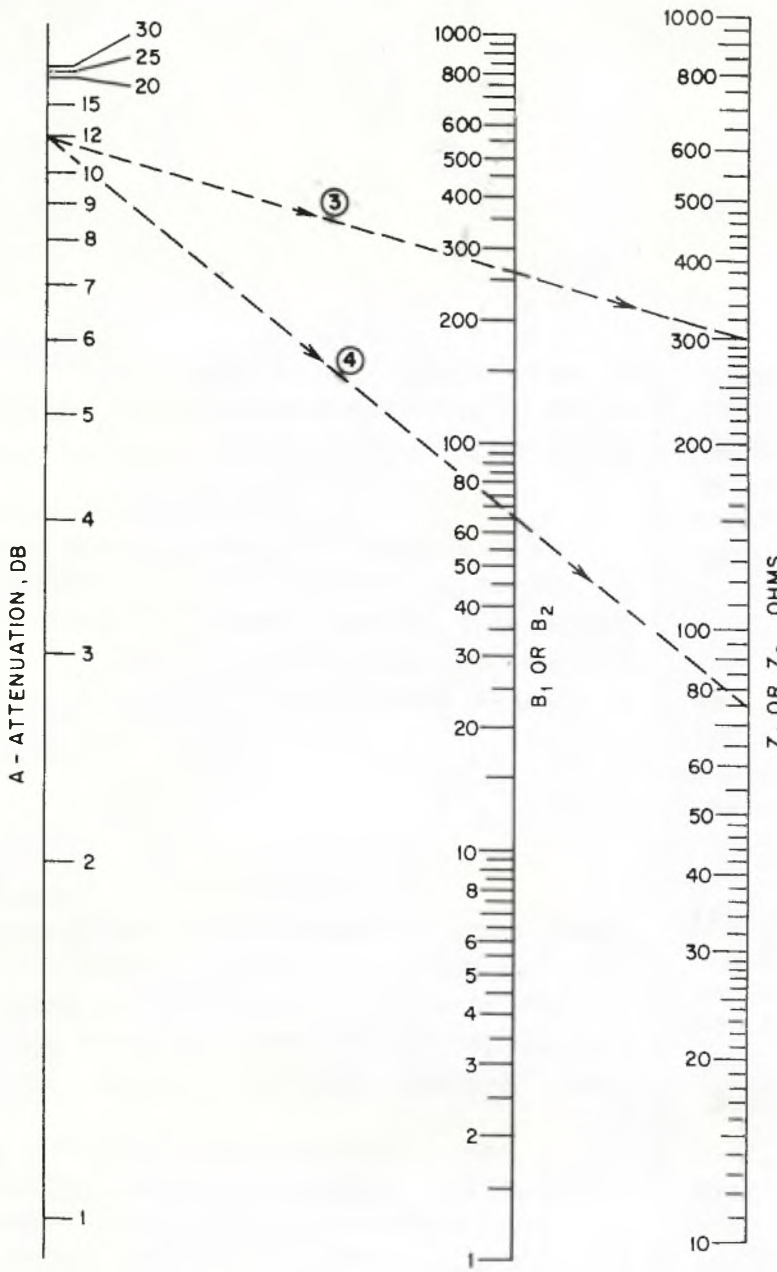
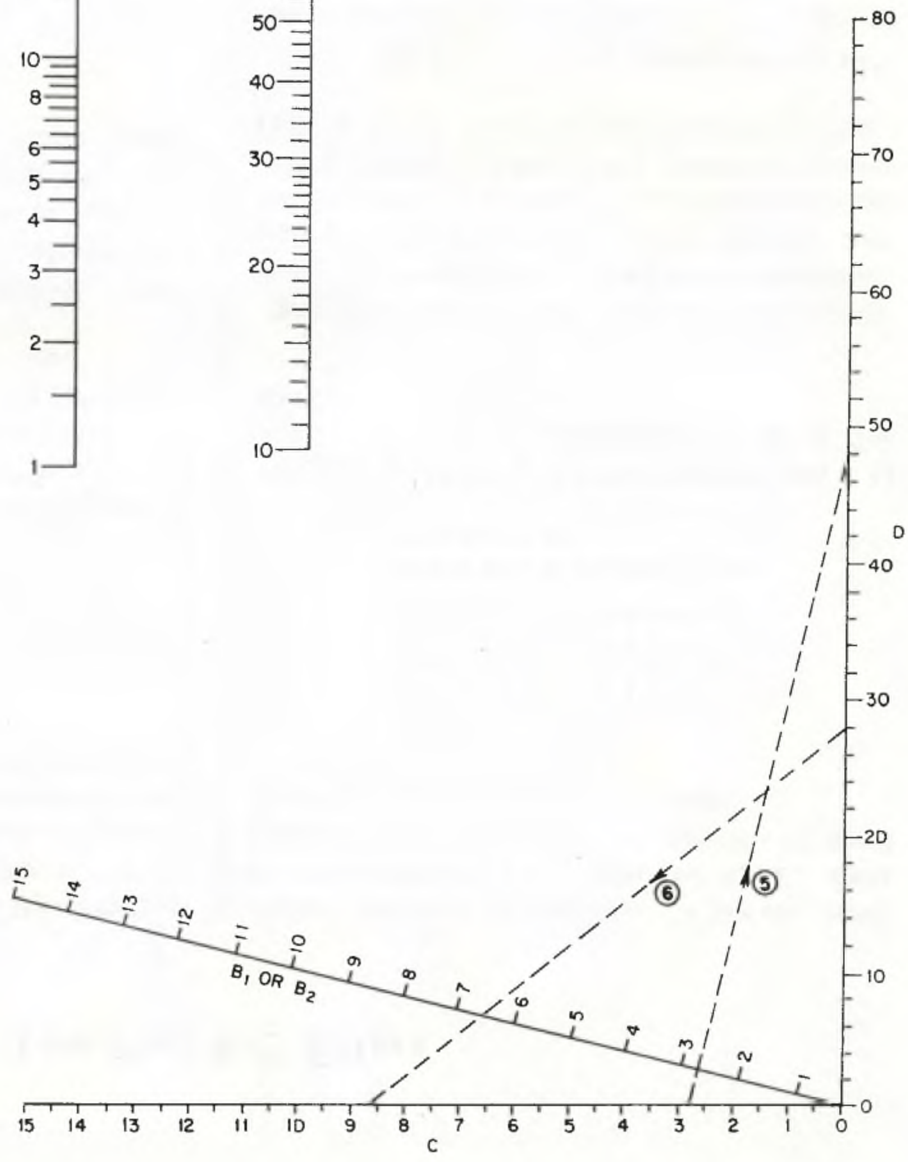


Fig. 2-5. A completely designed pad.

the D and B scales) to give 86 ohms as the value for R_2 (which solves equation 3). We now have all necessary resistance values. They appear in Fig. 2-5. Notice that the outer scales can be reversed. Thus, if the C scale represents R_1 or R_2, the D scale must represent R_3 and vice versa. Notice, too, that if the value of R_3 is 10 or more times that of B_1, then $R_1 = B_1$. Similarly, if R_3 is 10 or more times B_2, then $R_2 = B_2$.



Nomogram 2-7A



Nomogram 2-7B

Low-Pass R-C Filters

Here's a nomogram to speed the design of an elementary R-C filter, or to determine the attenuation of a given elementary R-C filter at any frequency. In the R-C network of Fig. 2-6, the ratio of output to input voltage is given by:

$$\frac{E_o}{E_i} = \frac{1}{\sqrt{1 + \omega^2 T^2}} \tag{1}$$

where: $\omega = 2\pi f$ and $T = RC$. An analysis of the equation shows that as $\omega^2 T^2$ approaches zero, the E_o/E_i ratio approaches unity, and as $\omega^2 T^2$ approaches infinity, the output-to-input voltage ratio approaches zero.

For practical purposes, however, when $\omega^2 T^2$ is much less than one, the voltage ratio equals one, and when $\omega^2 T^2$ is at least 10, the voltage ratio becomes equal to $1/\omega T$. This is the approximation on which Nomogram 2-8 is based:

$$\frac{E_o}{E_i} = \frac{1}{\omega T} \tag{2}$$

It's necessary to bear in mind the fact that the nomogram is accurate only for values of ωT equal to or greater than 10. It is further assumed that the output load impedance is high compared to the impedance of the filter's shunt capacitor.

Values other than those given on the scales for R, C, and f can be used by multiplying the appropriate scale by 10^n, where n can be either negative or positive. When any scale is multiplied by 10^n, then the E_o/E_i ratio must by multiplied by 10^{-n}, and $20n$ db must be added to the adjacent db scale.

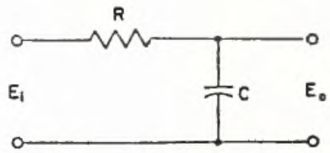


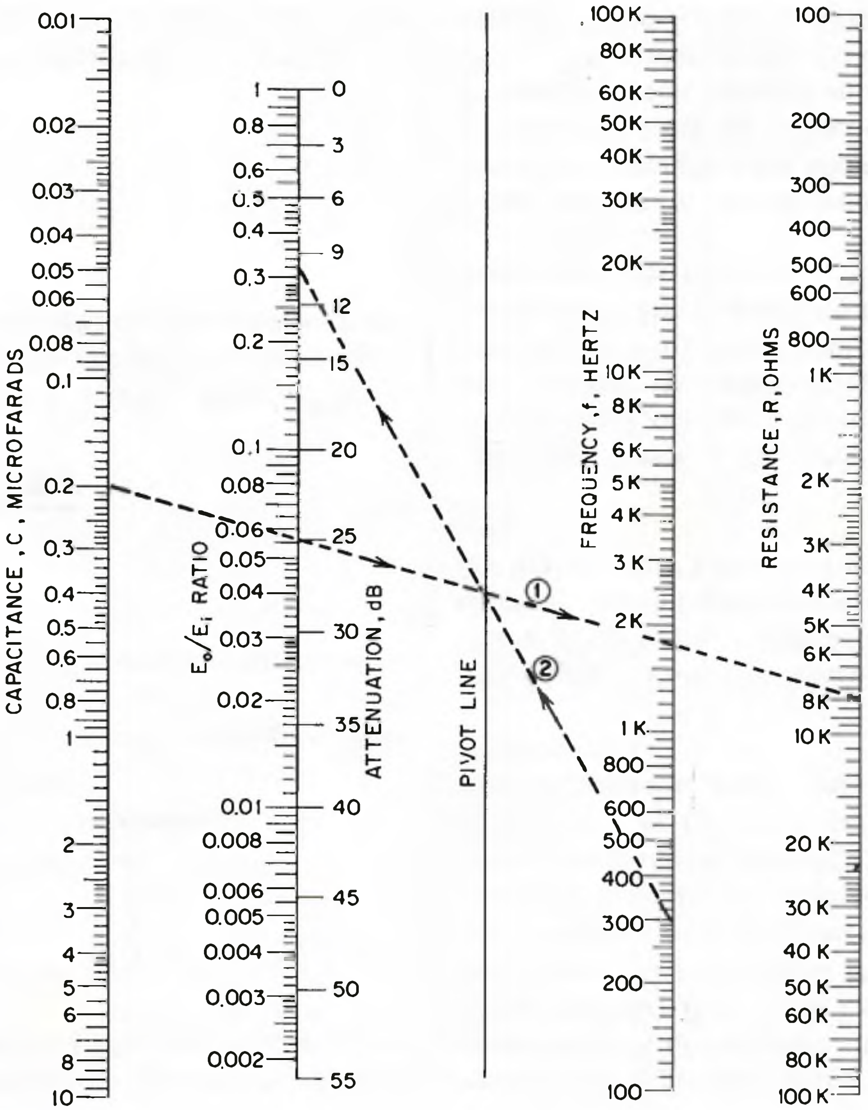
Fig. 2-6. The elementary low-pass RC filter.

Example: If R has a value of 800K and C is 0.2 μf, what is the attenuation in db at 300 Hertz?

Solution: Draw a line from 8K on the R scale to 0.2 on the C scale. Through its intersection with the pivot line, draw another line from 300 on the f scale to the attenuation and voltage-ratio scale. This gives a voltage ratio of 0.33, which is equivalent to 9.7 db.

Since the R scale was multiplied by 10^2, the ratio must be multiplied by 10^{-2}, giving a ratio of 0.0033. To the db reading add 20 times 2, making a total attenuation of 49.7 db. This is verified by checking the db value adjacent to 0.0033 on the ratio scale.

The nomogram can be used in reverse by rotating a straight-edge about the pivot point (on the pivot line) of a line drawn from the frequency to the attenuation or voltage-ratio scale. The rotating line gives a selection of suitable R and C combinations.


CAPACITANCE, C, MICROFARADS
E₀/Eᵢ RATIO
ATTENUATION, dB
PIVOT LINE
FREQUENCY, f, HERTZ
RESISTANCE, R, OHMS
1
2

Low-Pass L-R Filters

Here's a nomogram to help speed the design of an elementary L-R filter or determine

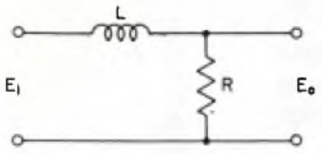


Fig. 2-7. The elementary L-R filter.

the attenuation of a given elementary L-R filter at any frequency. In the L-R network of Fig. 2-7, the ratio of output to input voltage is given by:

$$\frac{E_o}{E_i} = \frac{1}{\sqrt{1 + \omega^2 T^2}} \qquad (1)$$

where: $\omega = 2\pi f$ and $T = L/R$. When $\omega^2 T^2$ is greater than 10, the equation is closely approximated by $1/\omega T$ which gives us to a close approximation:

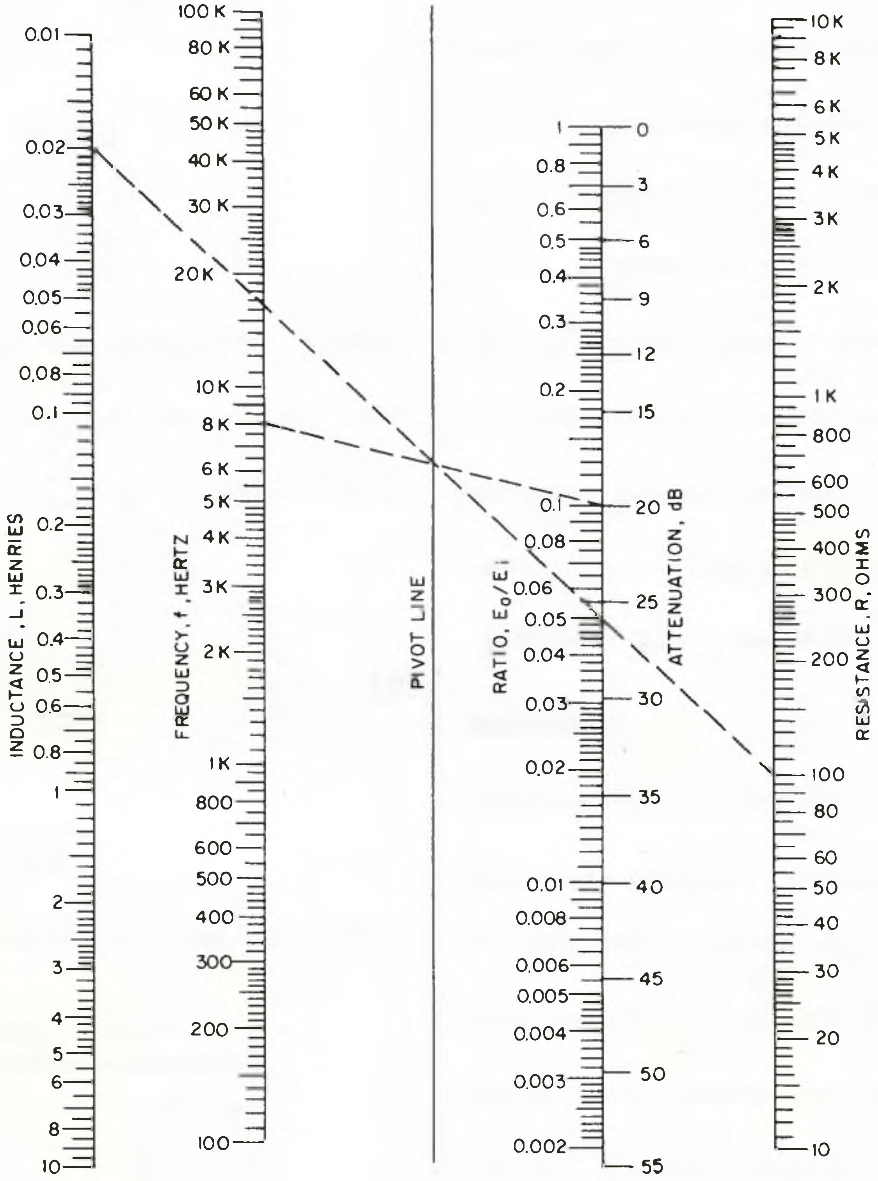
$$\frac{E_o}{E_i} = \frac{R}{\omega L} \qquad (2)$$

The accuracy of Nomogram 2-9 depends on ωT having values of 10 or greater and on the output load impedance being high compared to the shunt R of the filter. Values other than those given for R, L, and f on the nomogram can be used by multiplying the scale value by 10^n, where n can by positive or negative. When the R scale is multiplied by 10^n the voltage ratio must be multiplied by 10^n. When either the L or f scale is multiplied by 10^n, then the voltage ratio scale must be multiplied by 10^{-n}.

Example: Find the attenuation at 8 kHz of an elementary low-pass filter whose series element has an inductance of 0.02 henries and whose shunt element is a 100-ohm resistor.

Solution: Draw a line from 0.02 on the L scale to 100 on the R scale. Draw another line through its intersection with the pivot line from 8,000 on the f scale to the attenuation scale. The attenuation is 20 db and the output-to-input ratio is 0.1.

The nomogram can be used in reverse by rotating a straight-edge about the pivot point (on the pivot line) of a line drawn from the frequency to the attenuation or voltage-ratio scale. The rotating line gives a selection of suitable R and L combinations.


INDUCTANCE, L, HENRIES
FREQUENCY, f, HERTZ
PIVOT LINE
RATIO, E_o/E_i
ATTENUATION, dB
RESISTANCE, R, OHMS

Low-Pass L-C Filters

Nomogram 2-10 helps one check the attenuation characteristics of the elementary low-

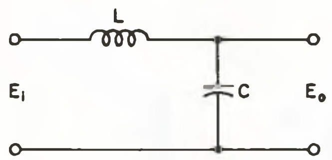


Fig. 2-8. The elementary low-pass L-C filter.

pass L-C filter in Fig. 2-8. The basic equation for this filter is:

$$\frac{E_o}{E_i} = \frac{1}{\frac{f^2}{f_o^2} - 1} \qquad (1)$$

where: $f_o = 1/(2\pi\sqrt{LC})$. For simplification of the voltage-ratio equation, the constant term in the denominator can be dropped, making the equation:

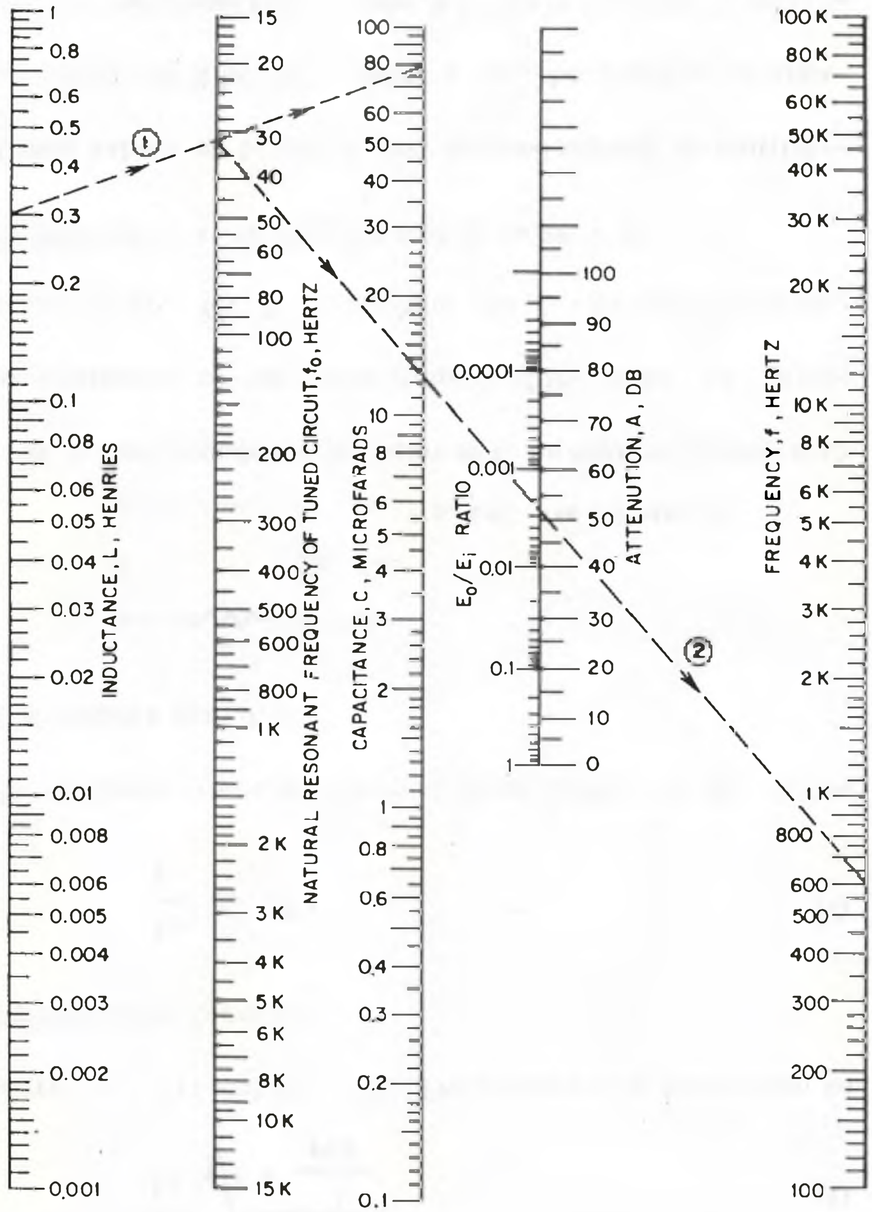
$$E_o/E_i = f_o^2/f^2 \qquad (2)$$

This simplified equation makes the nomogram quite accurate for f values at least five times greater than f_o. It must be assumed that the output load impedance is high compared to the impedance of the filter's shunt capacitor.

For a given filter, the nomogram gives the solution in terms of the E_o/E_i voltage ratio as well as the equivalent attenuation in db. Other values of L, C, and f may be used by multiplying all scales by 10^n, where n can be positive or negative. When this is done, the voltage-ratio and attenuation scales remain unchanged.

Example: For a low-pass filter having an inductor of 0.3 henries and an 80 μf capacitor, find the output-to-input voltage ratio and the attenuation in db at 600 Hertz.

Solution: Draw a line between the L and C values on Nomogram 2-10. From its intersection with the f_o scale (which, incidentally, gives the natural resonant frequency of a series-tuned L-C circuit) draw another line to 600 Hz on the f scale. This line crosses the voltage-ratio and attenuation scale at a ratio of 0.0028, equivalent to an attenuation of 51 db.


INDUCTANCE, L, HENRIES
NATURAL RESONANT FREQUENCY OF TUNED CIRCUIT, f_0, HERTZ
CAPACITANCE, C, MICROFARADS
E_0/E_i RATIO
ATTENUTION, A, DB
FREQUENCY, f, HERTZ

High-Pass R-L Filters

In the R-L network shown in Fig. 2-9, the ratio of output to input voltages is:

$$\frac{E_o}{E_i} = \frac{1}{\sqrt{1 + \frac{1}{\omega^2 T^2}}} \qquad (1)$$

where: $\omega = 2\pi f$ and $T = L/R$. The nomogram is based upon an approximation formula:

$$\frac{E_o}{E_i} \approx \omega T \qquad (2)$$

This approximation formula is accurate within 10% for values of T smaller than 0.5.

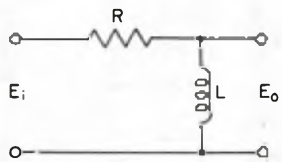
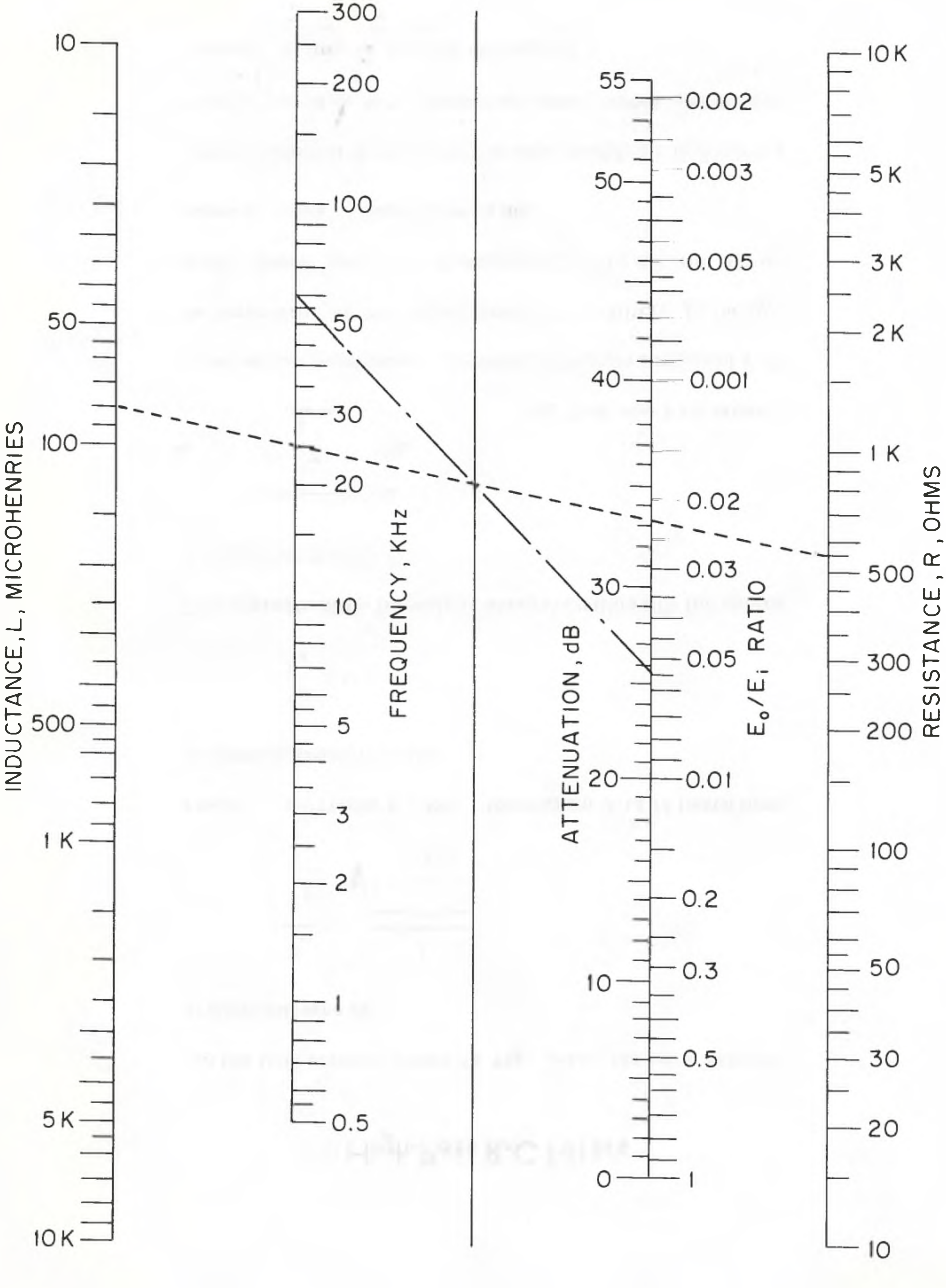


Fig. 2-9. The R-L network.

The output impedance is assumed to be high compared with the impedance of the shunt element of the filter. In the example shown, for R = 550 ohms and L = 80 microhenries, the attenuation at 60 kHz is found to be 25.9 db.

Other values of L and R may be used merely by multiplying both L and R by 10^n, where n may be positive or negative. In the nomogram, scale A is the inductance in microhenries, scale B is the frequency in Hertz, scale C is the attenuation in db, scale D is the ratio E_o/E_i, and scale E is the series resistance in ohms.



INDUCTANCE, L, MICROHENRIES
10
50
100
500
1 K
5 K
10 K
FREQUENCY, KHz
300
200
100
50
30
20
10
5
3
2
1
0.5
ATTENUATION, dB
55
50
40
30
20
10
0
E_o/E_i RATIO
0.002
0.003
0.005
0.001
0.02
0.03
0.05
0.01
0.2
0.3
0.5
1
RESISTANCE, R, OHMS
10 K
5 K
3 K
2 K
1 K
500
300
200
100
50
30
20
10

High-Pass R-C Filters

In the R-C network shown in Fig. 2-10, the ratio of output to input voltages is:

$$\frac{E_o}{E_i} = \frac{1}{\sqrt{1 + \frac{1}{\omega^2 T^2}}}$$

where: $\omega = 2\pi f$ and $T = RC$. Nomogram 2-12 is based upon an approximation formula:

$$\frac{E_o}{E_i} \approx \omega T$$

This approximation formula is accurate within 10% for values of T smaller than 0.5.

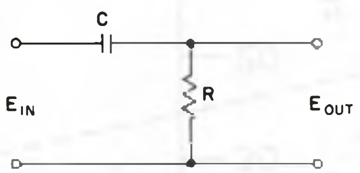
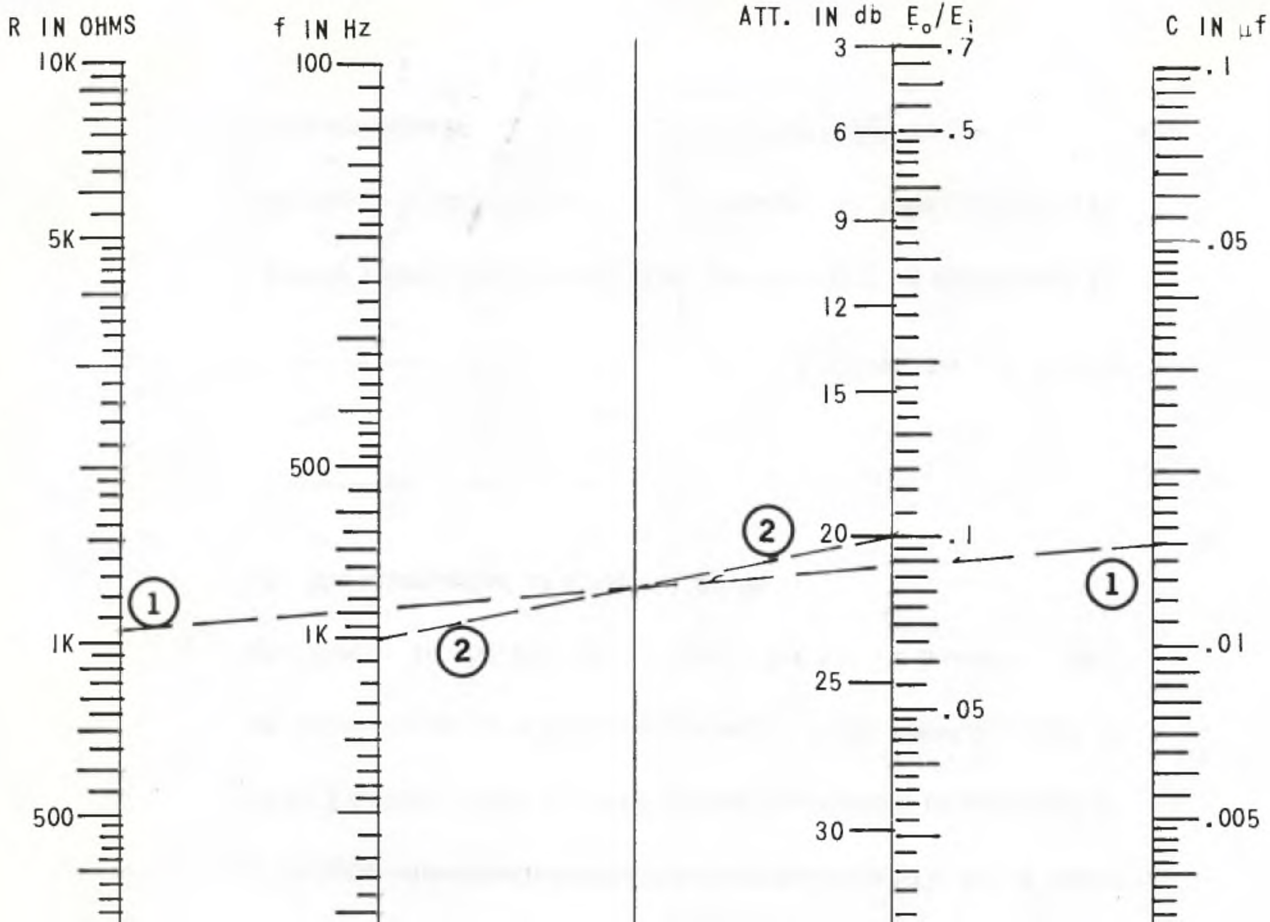


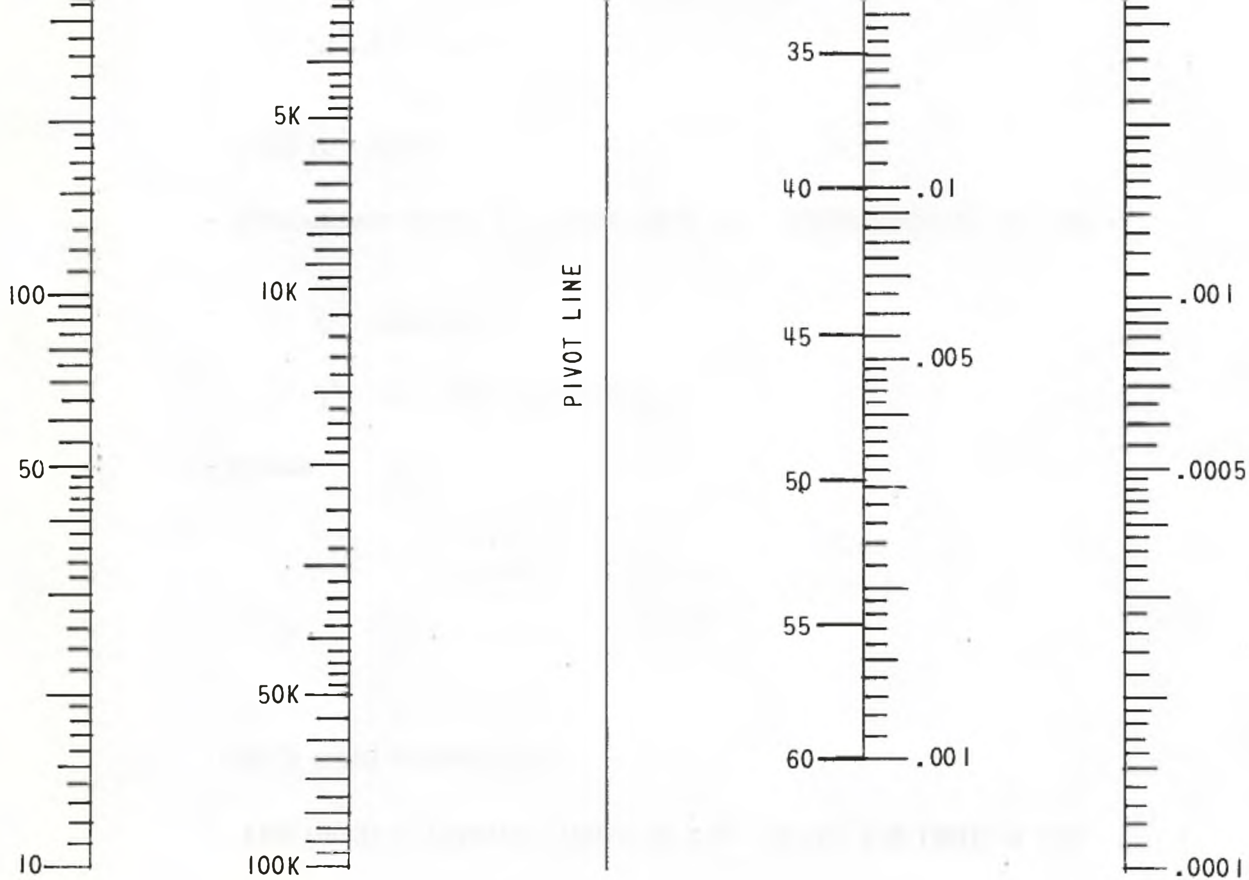
Fig. 2-10. Simple R-C network.

The output impedance is assumed to be high compared with the impedance of the shunt element of the filter. In the example shown, for f - 1,020 ohms and C = .015 μf, the attenuation at 1 kHz is found to be 20 db.

Other values of R and C may be used merely by multiplying C by 10^n and R by 10^{-n}, where all other scales remain unchanged. (n may be positive or negative.)



R IN OHMS
10K
5K
1K
500
f IN Hz
100
500
1K
ATT. IN db
3
6
9
12
15
20
25
30
E_o/E_i
.7
.5
.1
.05
C IN μf
.1
.05
.01
.005
1
2


100
50
10
5K
10K
50K
100K
PIVOT LINE
35
40
45
50
55
60
.01
.005
.001
.001
.0005
.0001

High-Pass L-C Filters

For the L-C network shown in Fig. 2-11, the ratio of output to input voltages is:

$$\frac{E_o}{E_i} = \frac{1}{\frac{1}{\omega^2 LC} - 1} = \frac{1}{\frac{f_o^2}{f} - 1}$$

where: $\omega = 2\pi f$

f_o = resonant frequency

f = frequency

Nomogram 2-13 is based upon an approximation of the above formula:

$$E_o/E_i \approx f^2/f_o^2$$

This approximation formula is accurate within 10% for a ratio of f_o/f greater than 5. The output impedance is assumed to be high compared with the impedance of the shunt element of the filter. In the example shown, for L = .2 h and C = .015 μf, the attenuation at 1 kHz is 20 db.

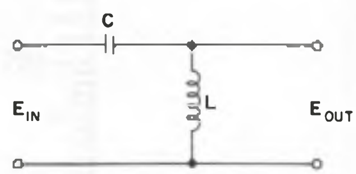
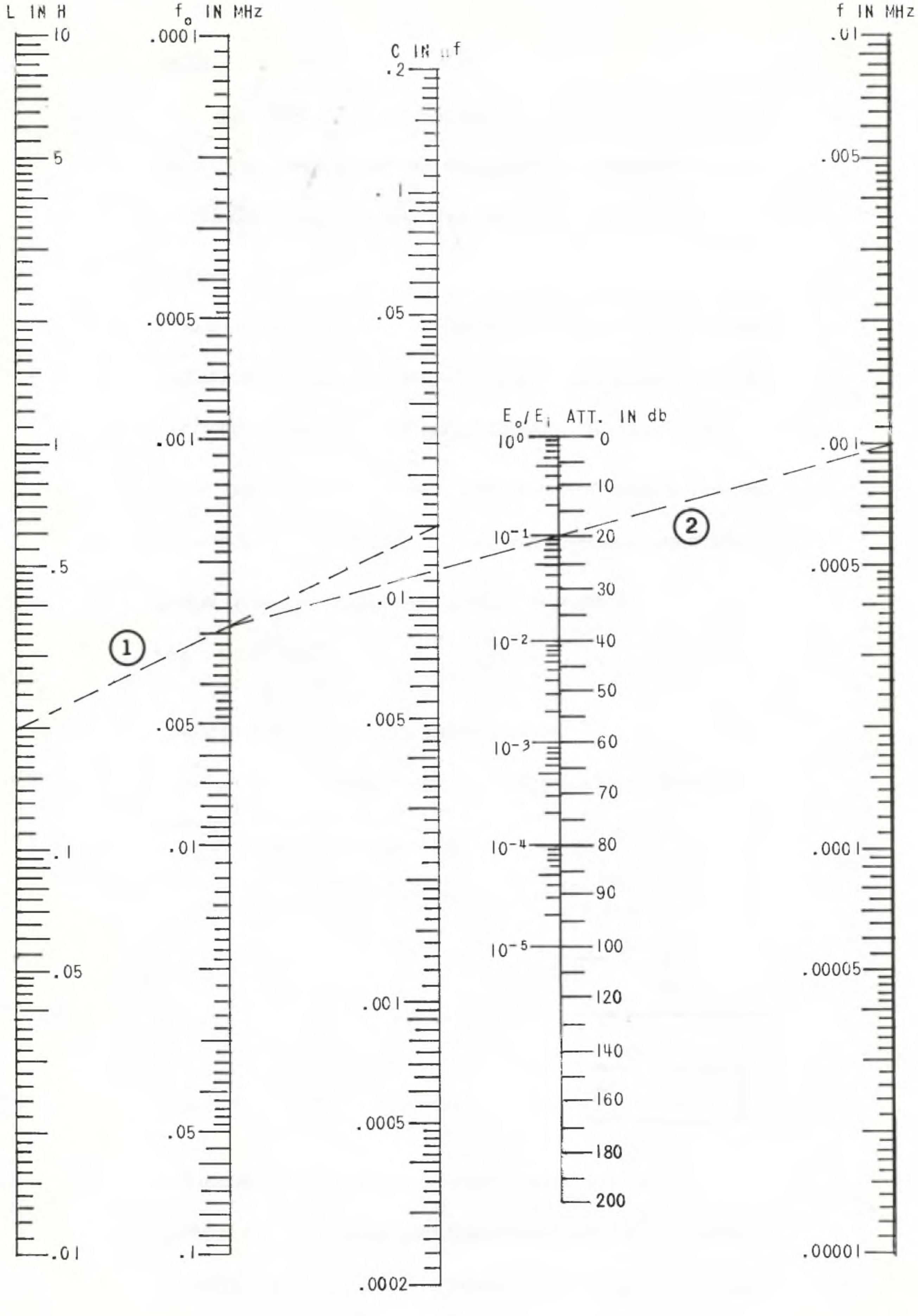


Fig. 2-11. The L-C network.

Other values for L and C may be used if L is multiplied by 10^n and C is multiplied by 10^{-n}, where all other scales remain unchanged. (n may be positive or negative.)


L IN H
10
5
1
.5
.1
.05
.01
f_o IN MHz
.0001
.0005
.001
.005
.01
.05
.1
C IN µf
.2
.1
.05
.01
.005
.001
.0005
.0002
E_o/E_i ATT. IN db
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
10
20
30
40
50
60
70
80
90
100
120
140
160
180
200
f IN MHz
.01
.005
.001
.0005
.0001
.00005
.00001
1
2

Low-Pass Filters: Constant-K Types

The low-pass filter has a passband from DC to the cutoff frequency, f_c. Beyond this frequency, the signal is attenuated excessively as shown by the graph in Fig. 2-12.

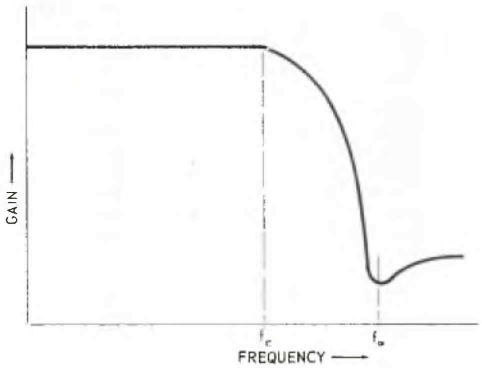


Fig. 2-12. Graph showing attenuation of constant-k low-pass filters.

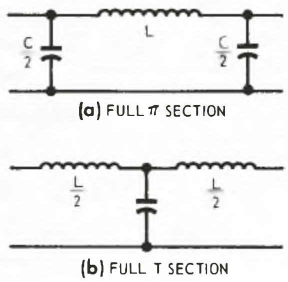


Fig. 2-13. Pi and T filter configurations.

The Pi and T configurations for the constant-k filters are shown in Fig. 2-13. For these circuits:

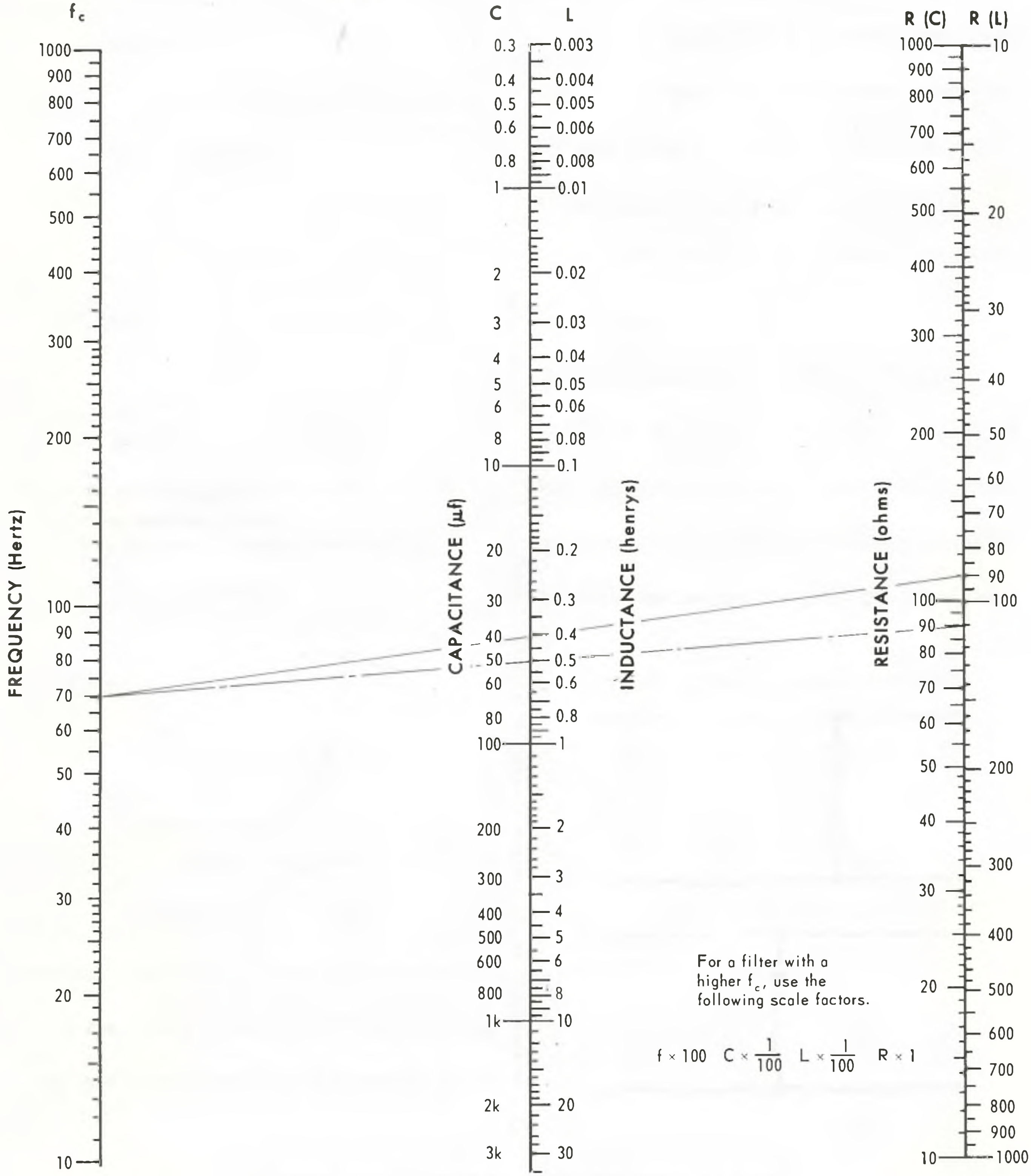
$$L = R/\pi f_c$$

and $$C = 1/\pi R f_c$$

where: R is the nominal terminating resistance.

Nomogram 2-14 provides a graphical solution to these equations. The values of L and C can be determined by aligning a straight-edge from f_c on the left-hand scale to R(L) or R(C), respectively, on the right-hand scale. The values of L and C are found where the straight-edge intersects the center scales.

Example: Design a low-pass constant-k filter with a cutoff of 7 kHz and terminating in 90 ohms. In Nomogram 2-14, $f_c = 7$ kHz, $R = 90$ ohms, values of L and C are: $L = 4.1$mh and $C = 0.51\ \mu$f.



f_c
C
L
R (C)
R (L)
FREQUENCY (Hertz)
CAPACITANCE (µf)
INDUCTANCE (henrys)
RESISTANCE (ohms)
1000 900 800 700 600 500 400 300 200 100 90 80 70 60 50 40 30 20 10
0.3 0.4 0.5 0.6 0.8 1 2 3 4 5 6 8 10 20 30 40 50 60 80 100 200 300 400 500 600 800 1k 2k 3k
0.003 0.004 0.005 0.006 0.008 0.01 0.02 0.03 0.04 0.05 0.06 0.08 0.1 0.2 0.3 0.4 0.5 0.6 0.8 1 2 3 4 5 6 8 10 20 30
1000 900 800 700 600 500 400 300 200 100 90 80 70 60 50 40 30 20 10
10 20 30 40 50 60 70 80 90 100 200 300 400 500 600 700 800 900 1000
For a filter with a higher f_c, use the following scale factors.
$f \times 100 \quad C \times \frac{1}{100} \quad L \times \frac{1}{100} \quad R \times 1$

Low-Pass Filters: M-Derived Types

The low-pass filter has a passband from DC to the cutoff frequency f_c. Beyond this frequency the signal is attenuated considerably to f_∞ as shown by the graph in Fig. 2-14. The T-section configuration used in

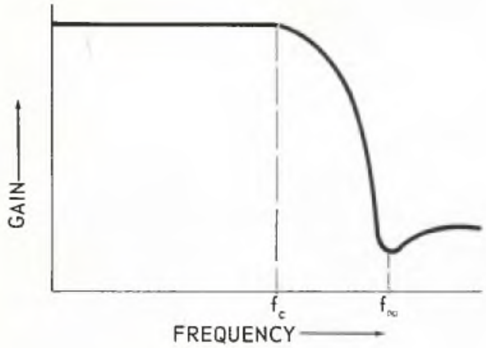


Fig. 2-14. Graph showing attenuation of m-derived low-pass filter.

series m-derived filters is shown in Fig. 2-15. The design formulas for these circuits are:

$L_A = mL$

$L_B = (1-m^2)L/4m$

$C_B = mC$

and $m = \sqrt{1 - (f_c/f_\infty)^2}$

where: f_∞ is the frequency of maximum attenuation.

The correct value of m can be found by using Nomogram 2-15. No units are given for f_c and f_∞ because any frequency can be used,

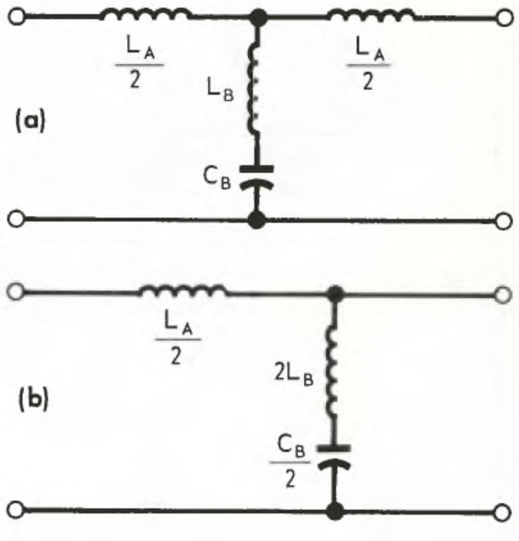
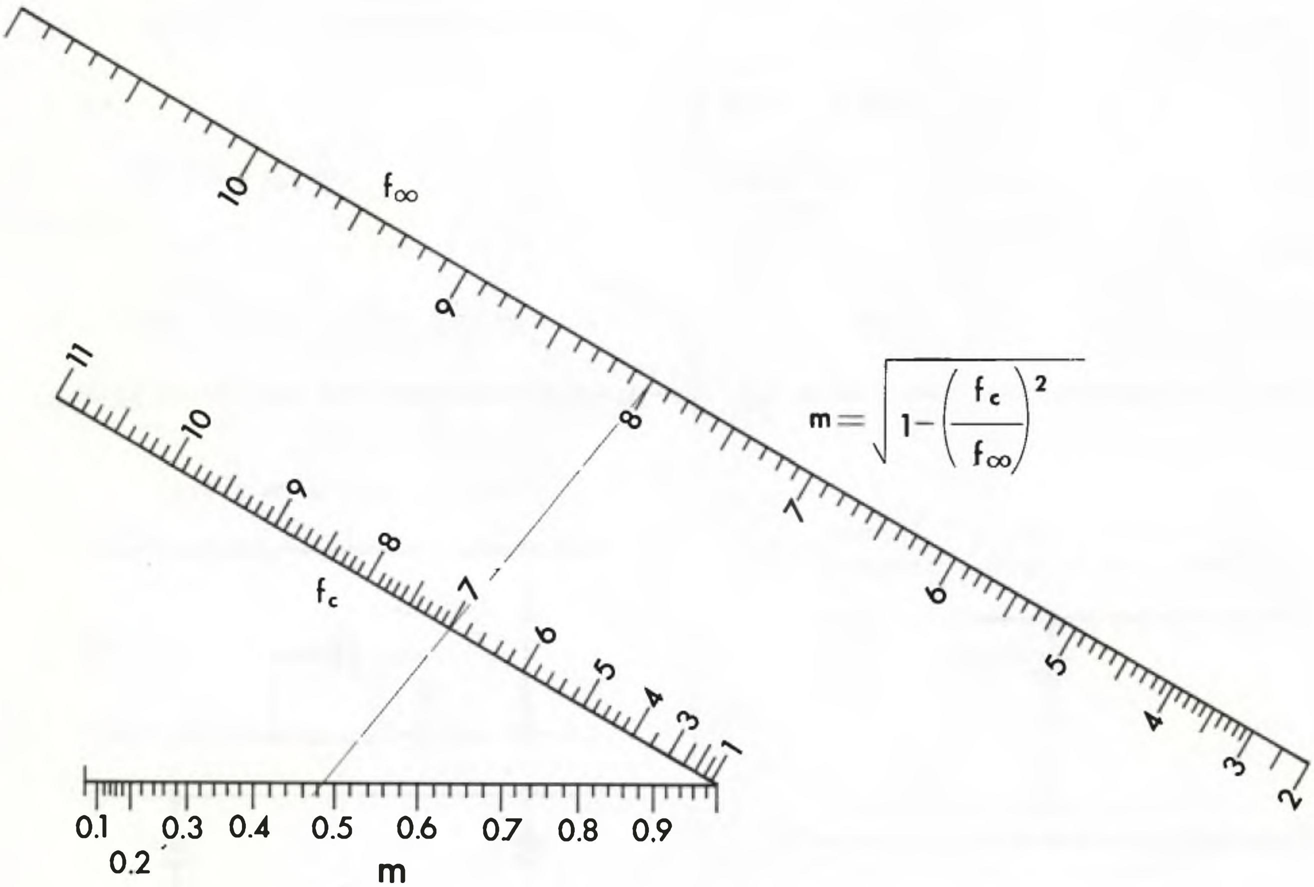


Fig. 2-15. T-section filter configuration.

provided that both scales use the same units. The value of m is found by aligning a straight-edge from the value of f_∞ on its scale through the value of f_c on its scale. The value of m is found where the straight-edge intersects the m scale.

The values of L_A, L_B, and C_B are found by using Nomogram 2-16. Notice that L_A and C_B are found by using the left-hand scales and L_B is found by using the right-hand scales. By extending a straight-edge from either L or C to the value of m (as found in Nomogram 2-15) on their appropriate scales.

(Continued on next page)



Nomogram 2-15

The values of L_A, L_B, and C_B are found where this line intersects the center scale. Any units may be used for C or L, provided that the same units are used for C_B or L_A and L_B, respectively.

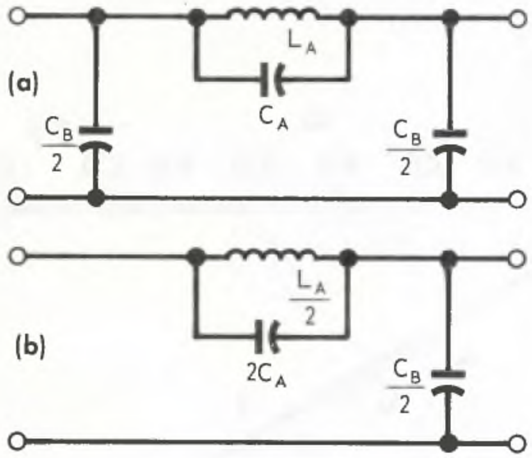


Fig. 2-16. Pi section filter.

The Pi section for the shunt m-derived filter is shown in Fig. 2-16. For this circuit:

$L_A = mL$

$C_A = (1-m^2)\ C/\ 4m$

$C_B = mC$

The values of these components are found by using Nomograms 2-15 and 2-16, just as with the series m-derived filter.

Example: Design a series m-derived low-pass filter with a cutoff frequency of 7 kHz, a maximum attenuation at 8 kHz, and terminating in 90 ohms. Using Nomogram 2-15, m is determined to be 0.485.

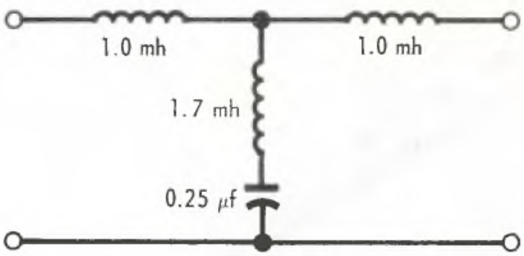
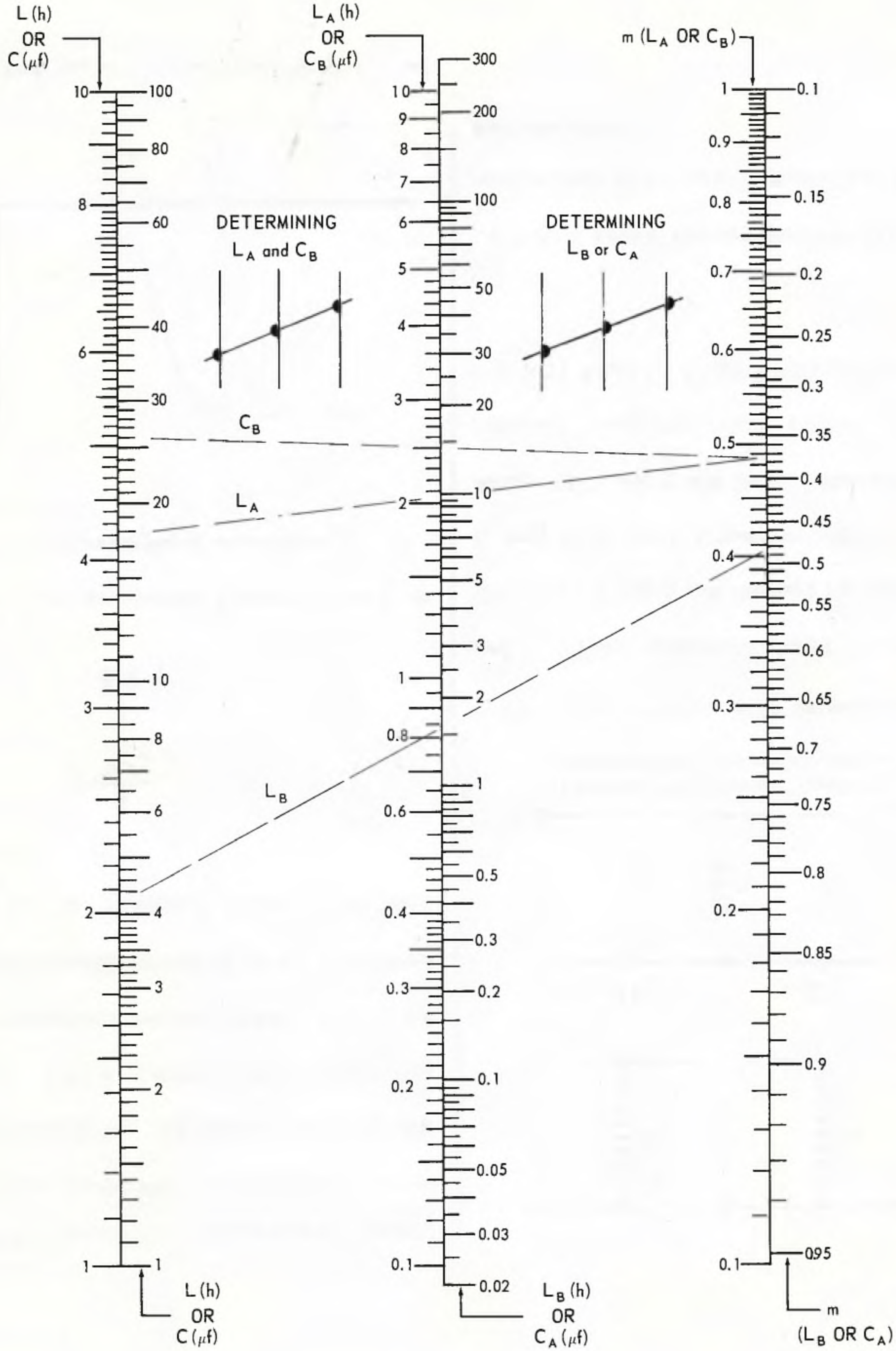


Fig. 2-17. Filters for the example in text.

On Nomogram 2-14 (constant-k), using $f_c = 7$ kHz and R = 90 on both R(C) and R(L) scales, the values of L and C are determined to be: L = 4.1 mh, C = 0.51 μf. Therefore, on Nomogram 2-16, L_A = 2 mh, C_B = 0.25 μf and L_B = 1.7 mh. The final filter is as shown in Fig. 2-17.



Nomogram 2-16

High-Pass Filters

The high-pass filter attenuates all signals in the frequency range from DC up to the cut-off frequency f_c. All signals above f_c are passed. Fig. 2-18 shows a typical high-pass filter frequency response curve. Fig. 2-19 shows the configurations of Pi and T sections used in the constant-k filters. For these circuits:

$$L = \frac{R}{4\pi f_c}$$

$$C = \frac{1}{4\pi f_c R}$$

where: f_c is the cut-off frequency and R is the nominal terminating resistance.

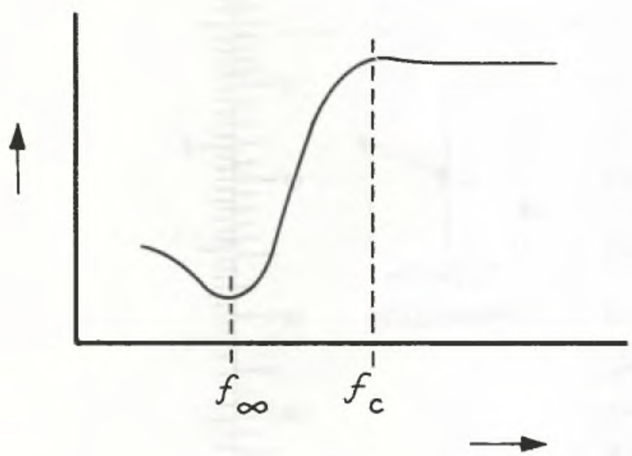


Fig. 2-18. Typical high-pass filter response curve.

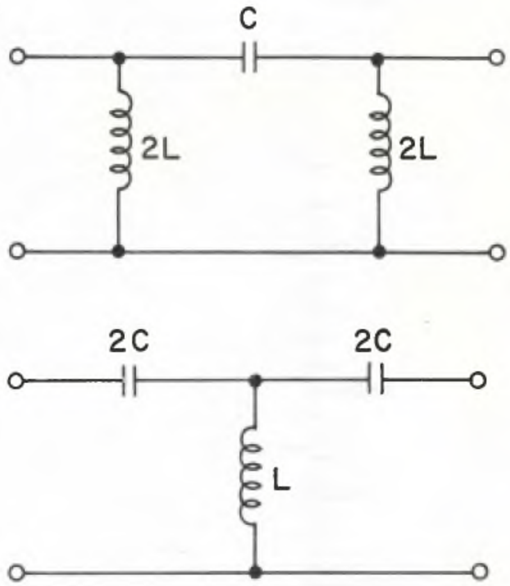
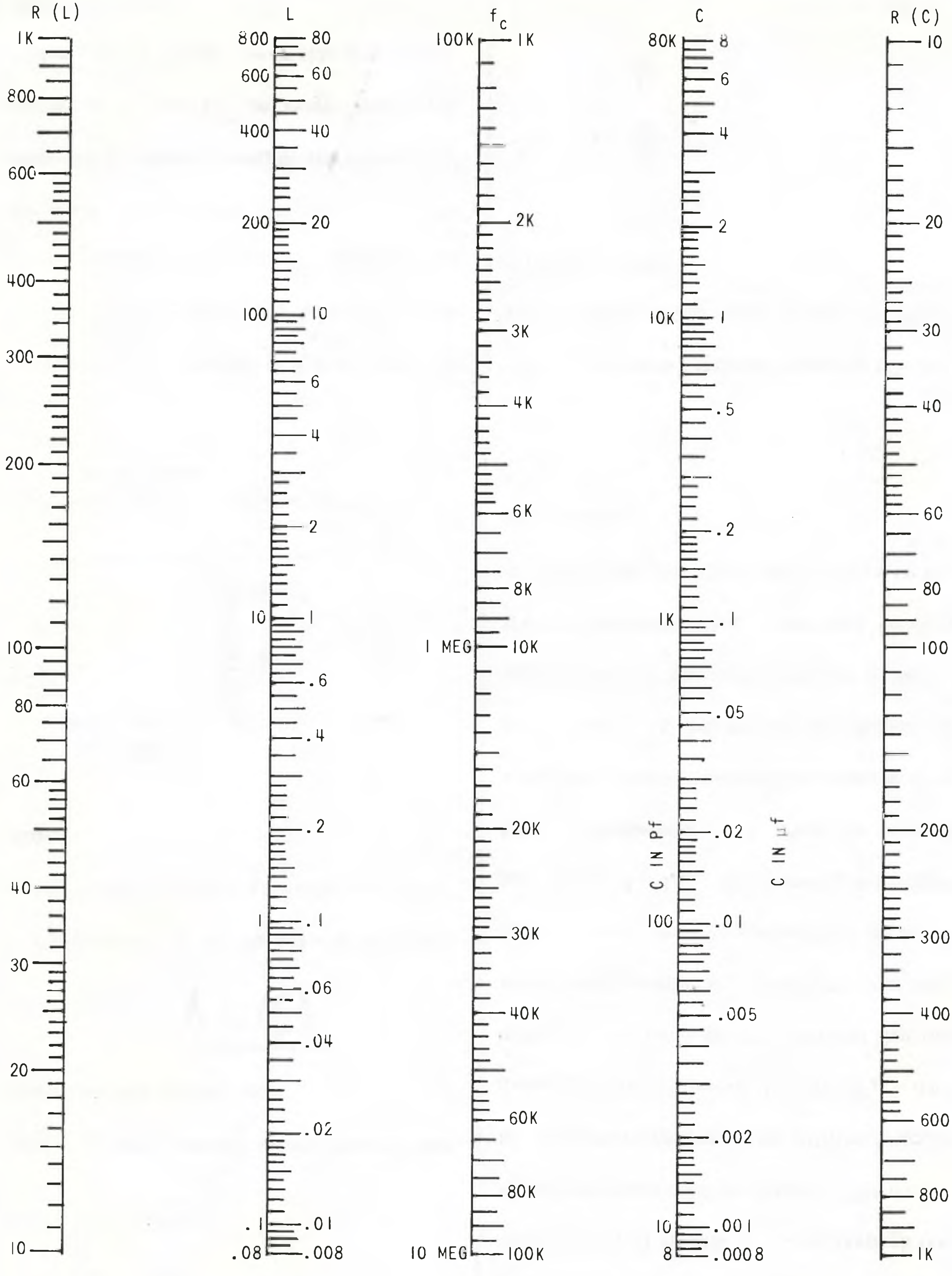


Fig. 2-19. Pi (top) and T (bottom) configurations, constant-k filters.

Nomogram 2-17 is used in the solution of L and C. Their values are found by merely drawing a straight line through the values of f_c and R on their respective scales. The values of L and C are found where the lines intersect their respective scales. NOTE: Use R(C) scale for C and R(L) scale for L.

Fig 2-20 shows the configuration of the T section used in the series m-derived filter. For this circuit:

(Continued on next page)



Nomogram 2-17

$$C_A = \frac{C}{m}$$

$$L_B = \frac{L}{m}$$

$$C_B = \frac{4m}{1-m^2}C$$

Where: L and C are the values found in the constant-k nomogram, and:

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

In this equation f_c is the cut-off frequency and f_∞ is the frequency of maximum attenuation.

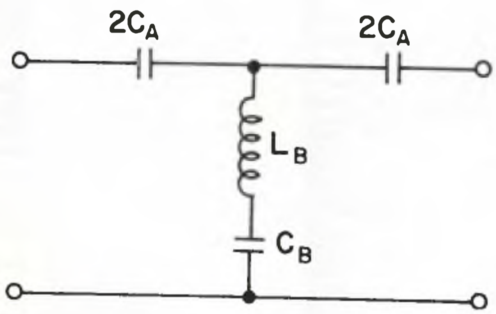


Fig. 2-20. T configuration, series m-derived filter.

Nomogram 2-18 is used to find the value of m. No units are given for f_c or f_∞. Any unit of frequency may be used, provided that the same units are used on both scales. To solve for m, draw a straight line through the values of f_c and f_∞ on their respective scales. m is found where this line intersects its scale.

The values of L_B and C_A are found in Nomogram 2-19 by drawing a straight line from the value of m on the m_1 scale through the values of L and C on the B scale. The points of intersection of these lines with the A scale determine the values of L_B and C_A. Any units may be used for C, provided that the same unit is used for C_A. Similarly, any unit may be used for L, provided that the same unit is used for L_D. By extending a straight line, in Nomogram 2-19, from the value of m on the m_2 scale through the value of C on the C scale, C_B can be found at the point of intersection of this line with the D scale. Values other than those shown may be used by multiplying both the C and D scales by the same factor.

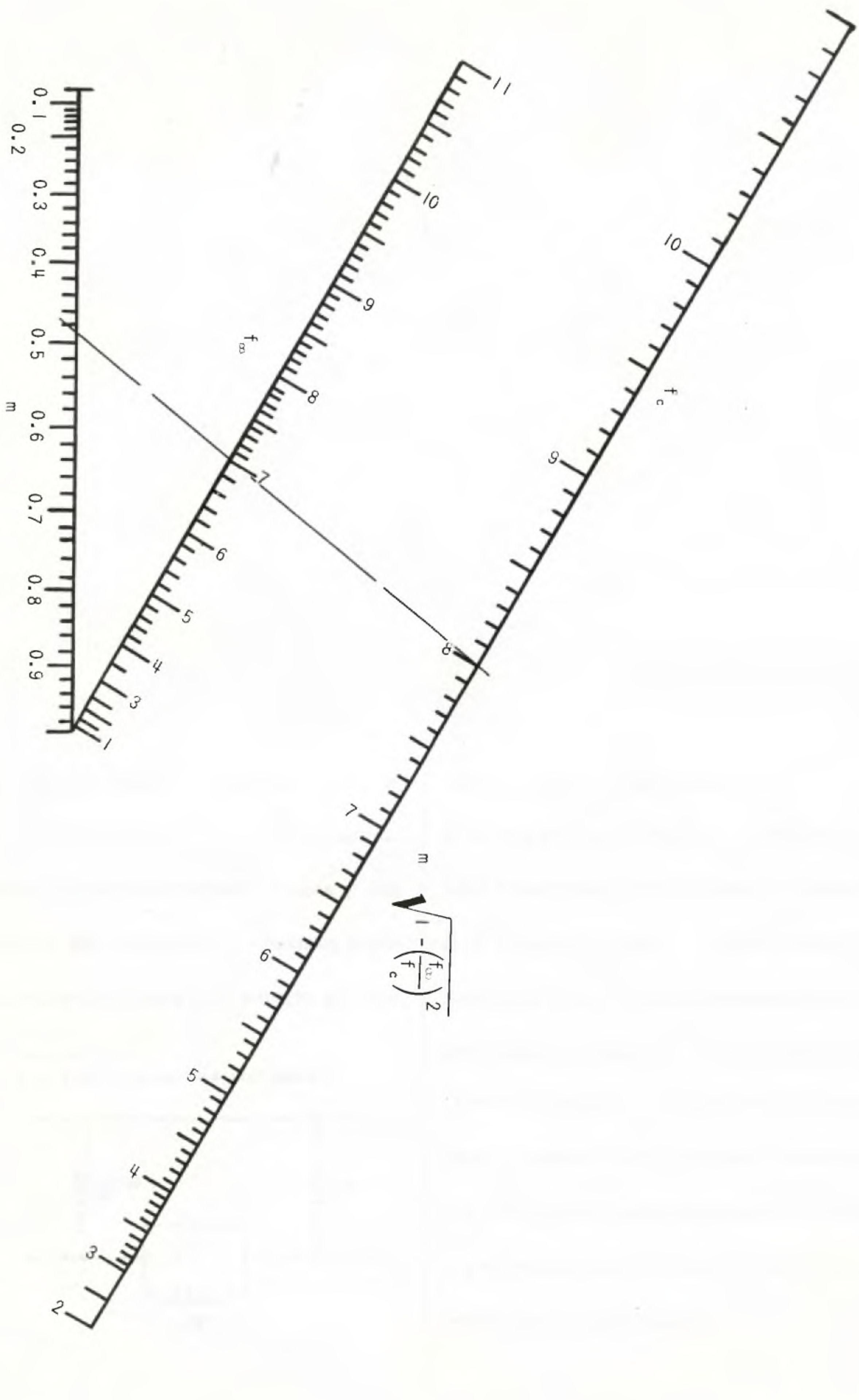
Fig. 2-21 shows the configuration of the Pi section used in the shunt m-derived filter. For this circuit:

$$L_A = \frac{4mL}{(1-m^2)}$$

$$L_B = \frac{L}{m}$$

$$C_A = \frac{C}{m}$$

(Continued on next page)



Nomogram 2-18

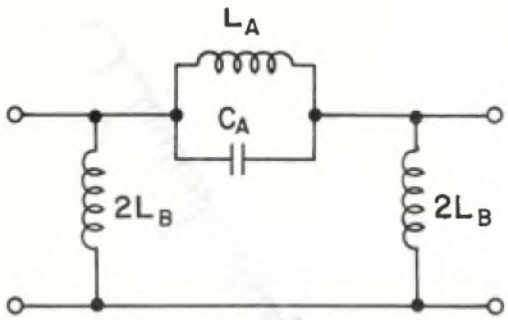
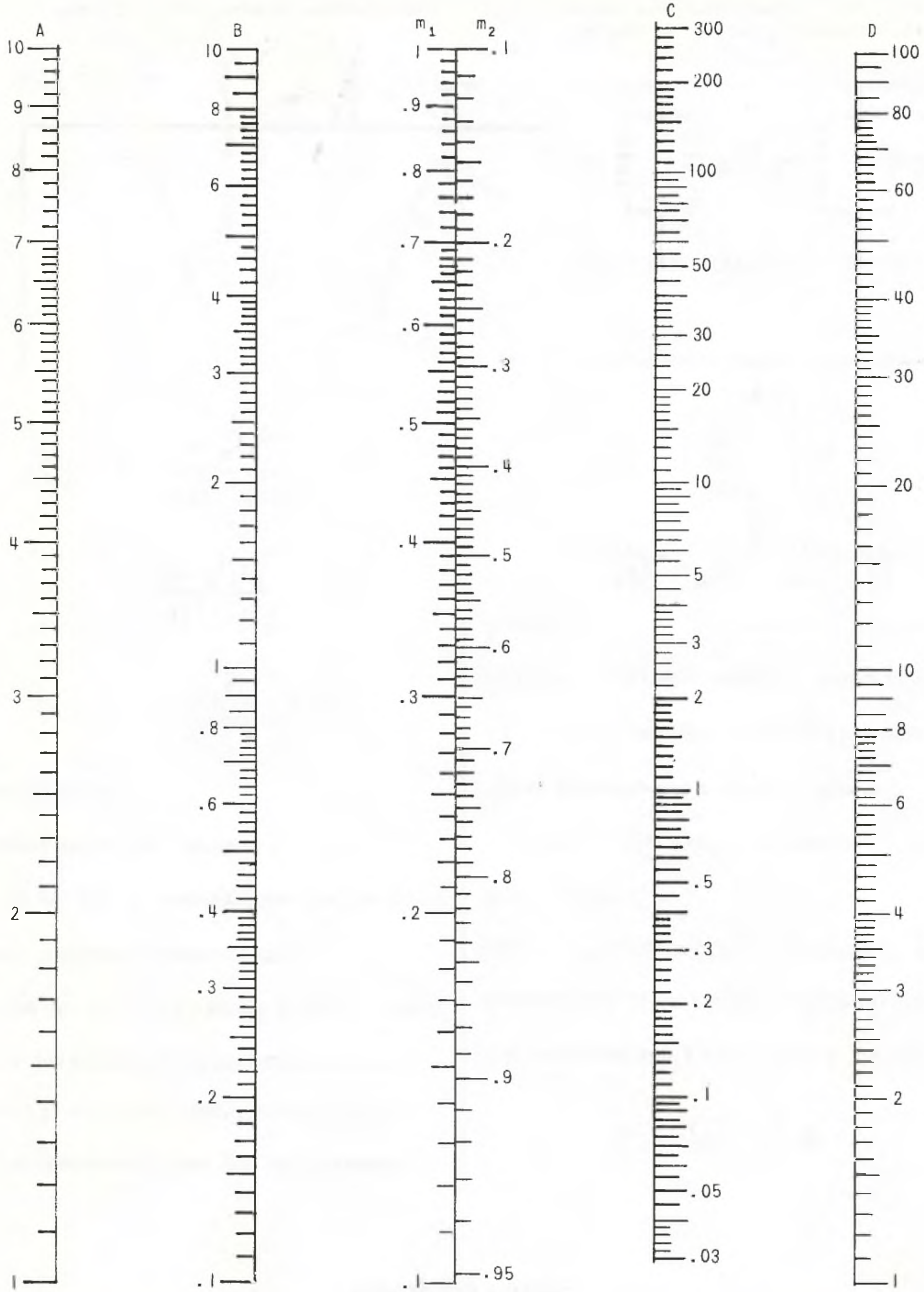


Fig. 2-21. Pi configuration, shunt m-derived filter.

These values are found in a similar manner to that used for the series m-derived filter by using the same nomograms, where L and C are the values found in the constant-k nomogram and m is found as described for the series m-derived filter.

The solution of L_B and C_A was described for the series m-derived filter. L_A is found in Nomogram 2-19 by drawing a straight line from the value of m on the m_2 scale through the value of L on the C scale. Read off the value of L_A at the point of intersection of this line with the D scale. Again, other values than those shown on the scales may be used, provided that the respective equation scales are multiplied by the same factor



Nomogram 2-19

Bandpass Filters

The band-pass filter has the characteristic of transmitting a specific band of frequencies and attenuating all frequencies above and below it. Fig. 2-22 shows a typical band-pass frequency response curve.

The Pi and T configurations for the constant-k filters are shown in Fig. 2-23. For these circuits:

$$L_1 = \frac{R}{\pi (f_2 - f_1)}$$

$$C_1 = \frac{(f_2 - f_1)}{4\pi f_1 f_2 R}$$

$$L_2 = \frac{(f_2 - f_1) R}{4\pi f_1 f_2}$$

$$C_2 = \frac{1}{\pi (f_2 - f_1) R}$$

The equations for L_1 and C_2 are solved in Nomogram 2-14 in the low-pass filter section, with the values of $(f_2 - f_1)$ substituted for the f_c scale.

L_2 and C_1 are found in Nomogram 2-20. These equations are solved as follows:

1. Draw a straight line through the values of f_1 and f_2 on their respective scales to the X scale.

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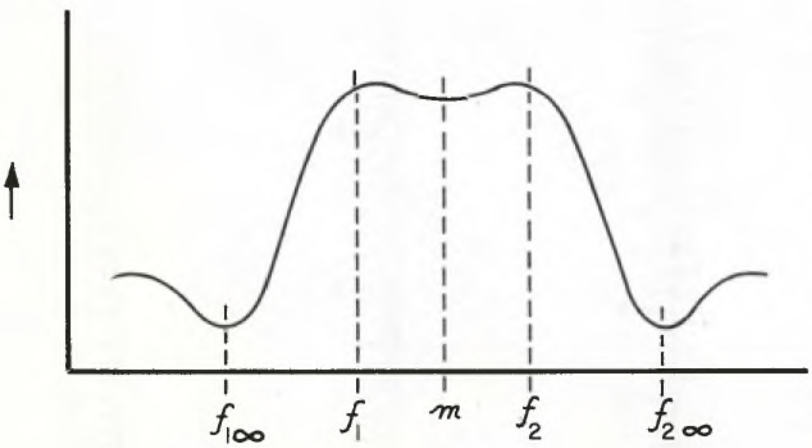


Fig. 2-22. Typical bandpass response curve.

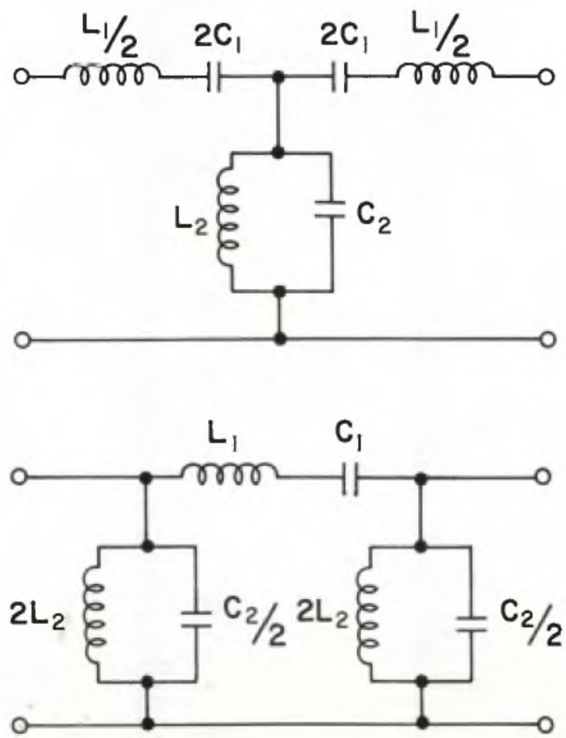
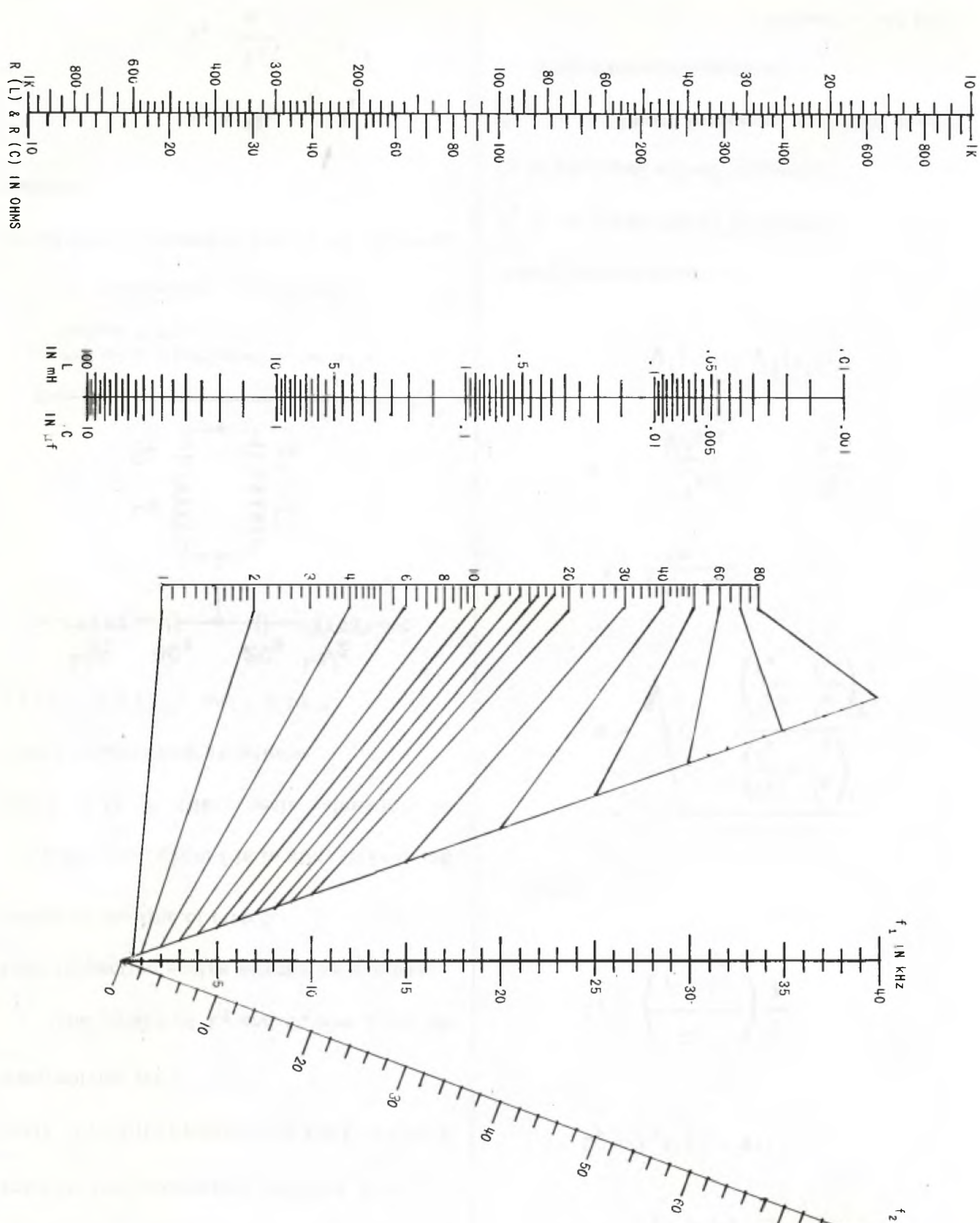


Fig. 2-23. T (top) and Pi (bottom) configurations, bandpass constant-k filter.



Nomogram 2-20

2. Transpose this value to the X_{log} scale as indicated in the nomogram.

3. Draw a straight line from the X_{log} scale to the appropriate value of R on its scale. Use R(L) when solving for L and R(C) when solving for C.

4. The values of L_2 and C_1 are found on their respective scales where they are intersected by the line of step 3.

For this nomogram f is in kHz, L is in mh and C is in μf. Other scale values may be used by multiplying as follows:

f x 10^n, L x 10^{-n}, and C x 10^{-n}.

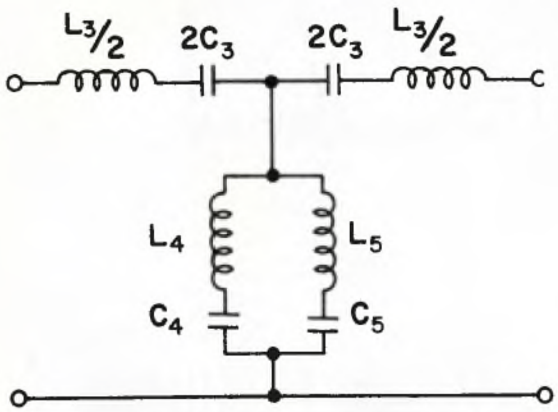


Fig. 2-24. T configuration, series m-derived filter.

The T configuration for the series m-derived filter is shown in Fig. 2-24. For this circuit:

$$L_3 = mL_1$$

$$C_3 = \frac{C_1}{m}$$

$$L_4 = L_1 A\left(1 + \frac{1}{N^2}\right)$$

$$C_4 = \left(\frac{C_1}{1 + N^2}\right)\frac{1}{A}$$

$$L_5 = L_1 A\,(1 + N^2)$$

$$C_5 = \left(\frac{C_1}{1 + \frac{1}{N^2}}\right)\frac{1}{A}$$

Where:

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

$$A = \frac{(1 - m^2)}{4m}$$

$$N = \frac{f_{2\infty}}{\sqrt{f_1 f_2}} = \frac{f_{2\infty}}{f_m}$$

$$f_m = \sqrt{f_1 f_2} = \sqrt{f_{1\infty} f_{2\infty}}$$

For the above equations:

f_1 is the lower cut-off frequency.

f_2 is the upper cut-off frequency.

$f_{1\infty}$ is the lower frequency at which maximum attenuation occurs.

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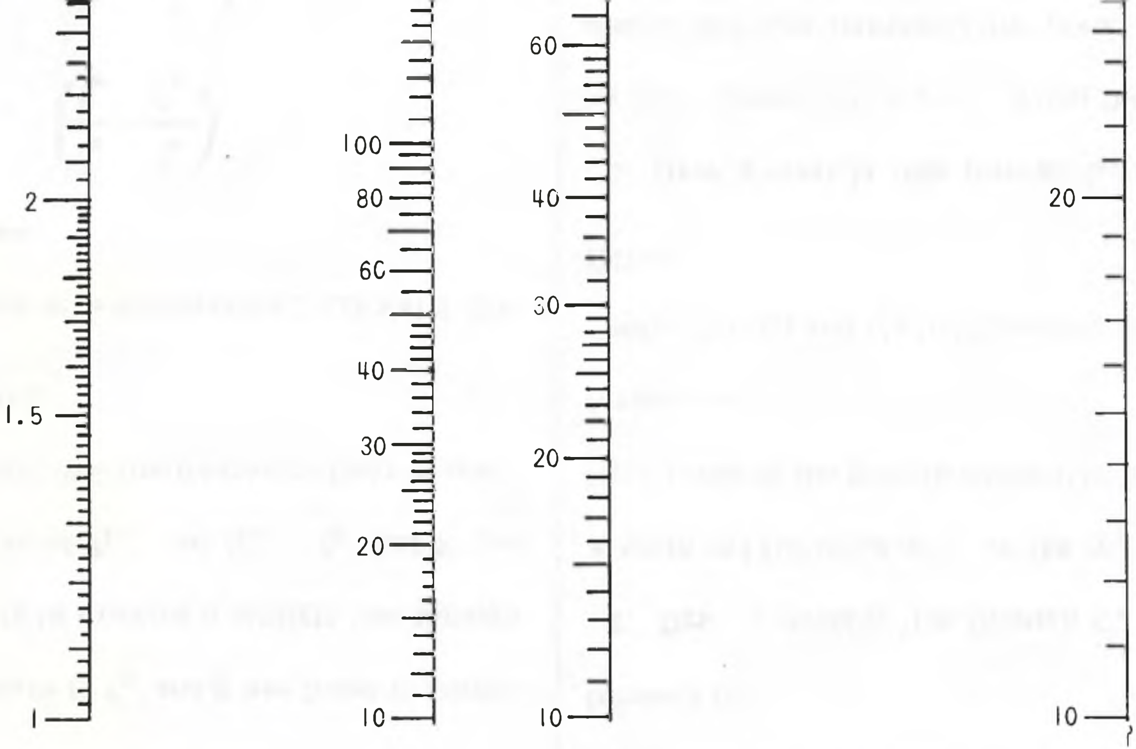
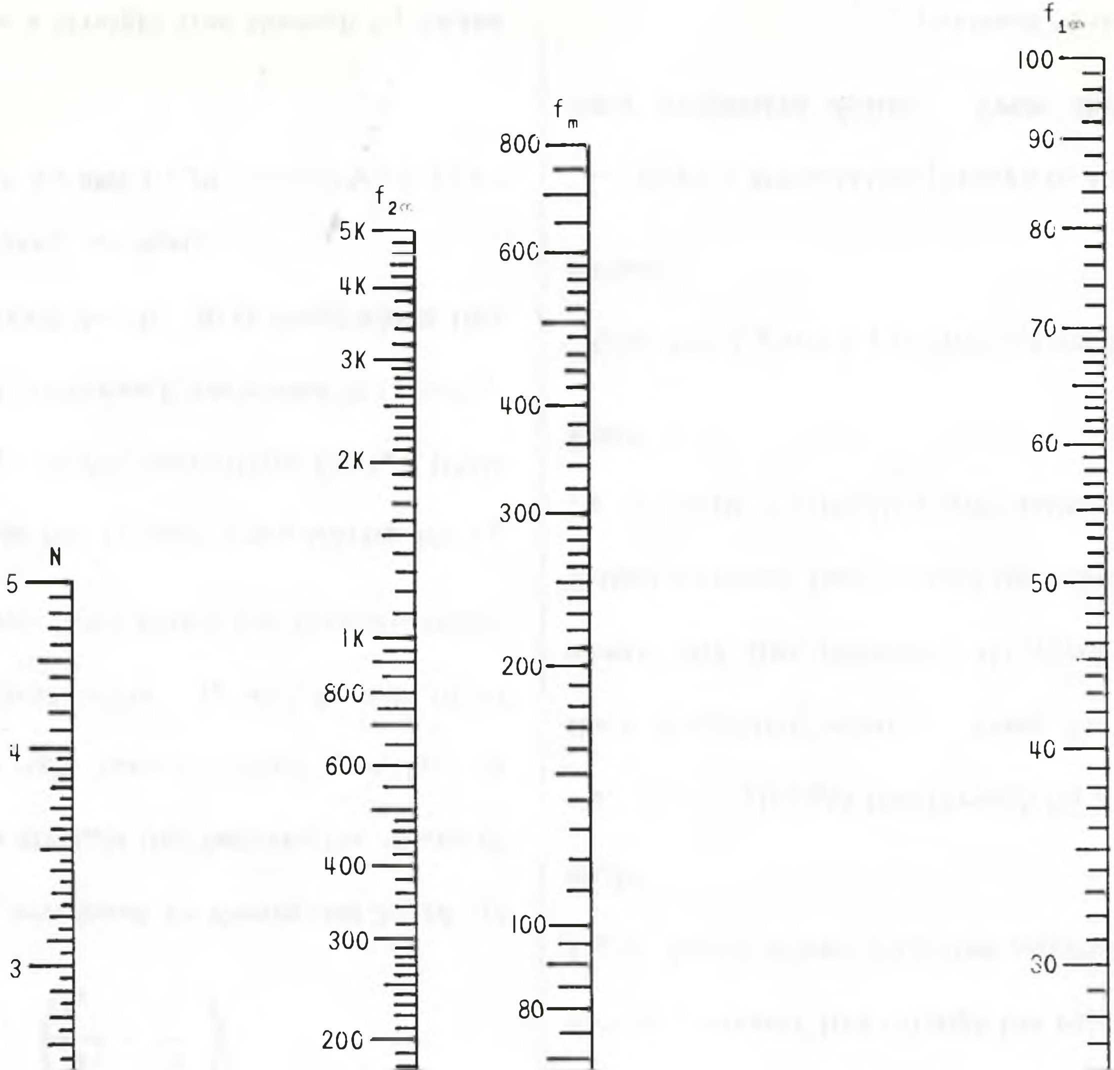


Nomogram 2-21


N
5
4
3
$f_{2\infty}$
5K
4K
3K
2K
1K
800
600
400
300
200
f_m
800
600
400
300
200
100
80
$f_{1\infty}$
100
90
80
70
60
50
40
30

$f_{2\infty}$ is the upper frequency at which maximum attenuation occurs.

The values of f_m and N are found in Nomogram 2-21 by drawing a straight line through the values of $f_{1\infty}$ and $f_{2\infty}$. f_m and N are found where this line intersects their respective scales.

Solve for m in Nomograms 2-22A and 2-22B as follows:

$$\text{Let} \quad f_A = \left(\frac{f_2}{f_m} - \frac{f_m}{f_2}\right)$$

$$\text{and} \quad f_B = \left(\frac{f_{2\infty}}{f_m} - \frac{f_m}{f_{2\infty}}\right)$$

f_A and f_B are found in Nomogram 2-22A by drawing a straight line between the values of f_m on the right-hand scale and f_2 or $f_{2\infty}$ on the left-hand scale. f_A and f_B are found where these lines cross the diagonal scale.

NOTE: Use the f_2 scale when solving for f_A and the $f_{2\infty}$ scale when solving for f_B. Draw a straight line through the values of f_A and f_B in Nomogram 2-22B. m is found where this line intersects its scale.

Solve for L_3 and C_3 in Nomogram 2-19 as follows:

1. Draw a straight line through L_1 on the B scale and the value of m on the m_1 scale. L_3 is found on the A scale where this line intersects it.

2. Draw a straight line through C_1 on the A scale and the value of m on the m_1 scale. C_3 is found on the B scale where this line intersects it.

Solve for L_4 and C_5 in Nomogram 2-23 as follows:

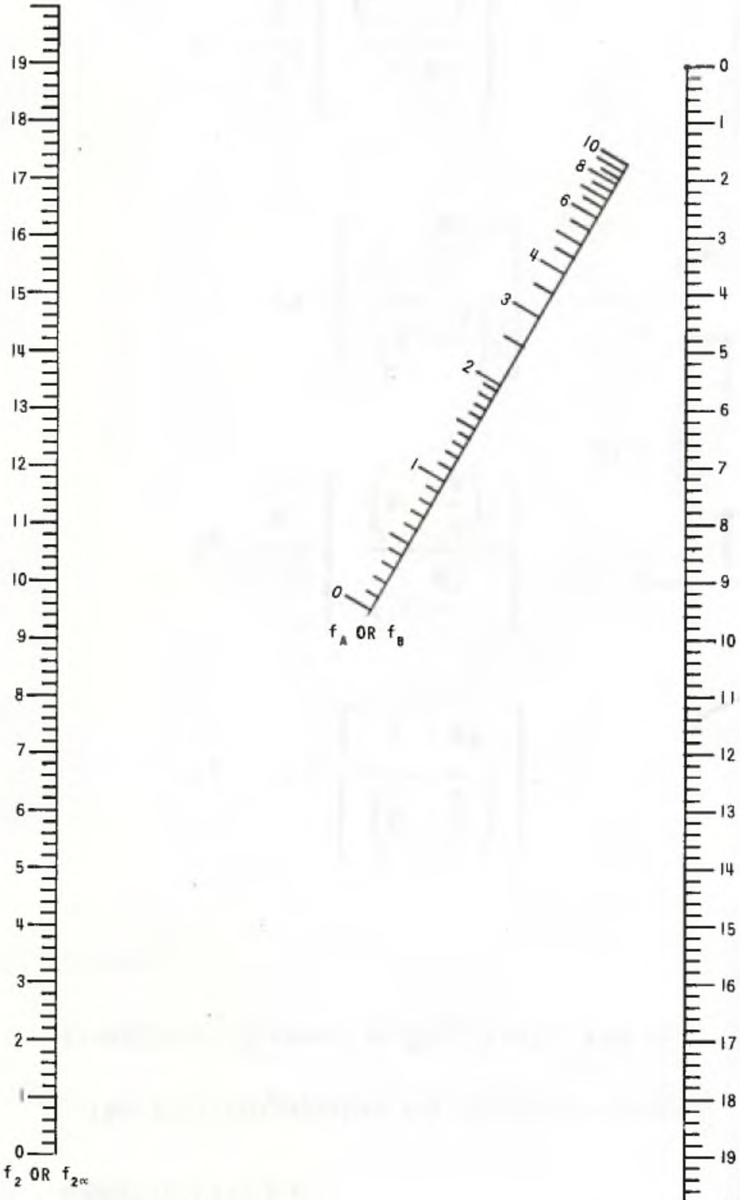
1. Draw a straight line through L_1 and m on their respective scales. From the point where this line intersects the pivot scale, extend a second line through the value of N. L_4 is found where this line intersects its scale.

2. Draw a straight line through C_1 and N on their respective scales. From the point where this line intersects the pivot scale, extend a second line through the value of m. C_5 is found where this line intersects its scale.

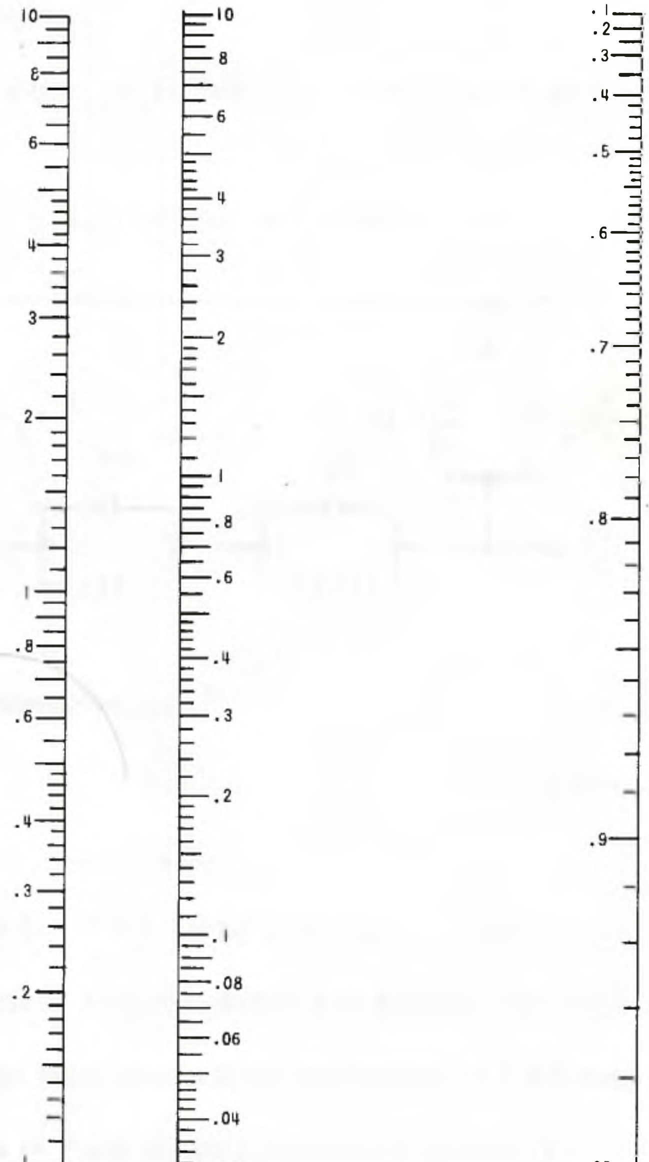
Solve for L_5 and C_4 in Nomogram 2-24 as follows:

1. Draw a straight line through m and N on their respective scales. From the point

(Continued on next page)



Nomogram 2-22A



Nomogram 2-22B

where this line intersects the pivot scale, extend a second line through the value of L_1 on its scale. L_5 is found where the second line intersects the L_5 scale.

2. C_4 is found in a similar manner to that described for L_5.

The Pi configuration for the shunt m-derived filter is shown in Fig. 2-25. For this circuit:

$$L_6 = mL_1\left[\frac{\left(N - \frac{1}{N}\right)^2}{1 + N^2}\right]$$

$$C_6 = \frac{C_1}{m}\left[\frac{1 + \frac{1}{N^2}}{\left(N - \frac{1}{N}\right)^2}\right]$$

$$L_7 = mL_1\left[\frac{\left(N - \frac{1}{N}\right)^2}{1 + \frac{1}{N^2}}\right]$$

$$C_7 = \frac{C_1}{m}\left[\frac{1 + N^2}{\left(N - \frac{1}{N}\right)^2}\right]$$

$$L_8 = \frac{L_2}{m}$$

$$C_8 = mC_2$$

Where: m and N are the same as for the series m-derived filter.

Solve for L_6 and C_7 in Nomogram 2-25 as follows:

1. Draw a straight line through the values of m and N on their respective scales. From the point where this line intersects the pivot scale, extend a second line through the value of L_1. L_6 is found where the second line intersects its scale.

2. C_7 is found in a similar manner to that described for L_6.

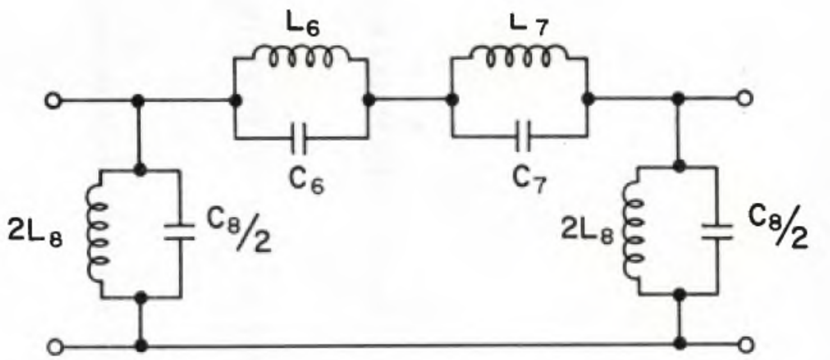
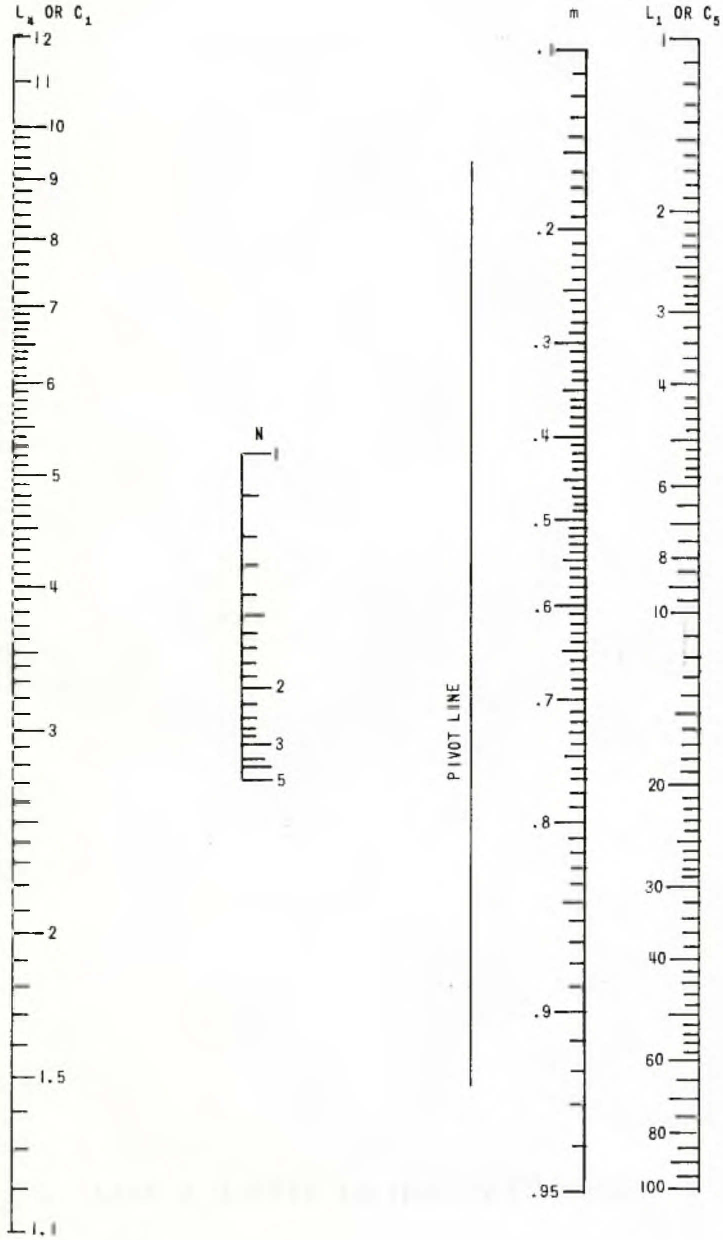


Fig. 2-25. Pi configuration, shunt m-derived filter.

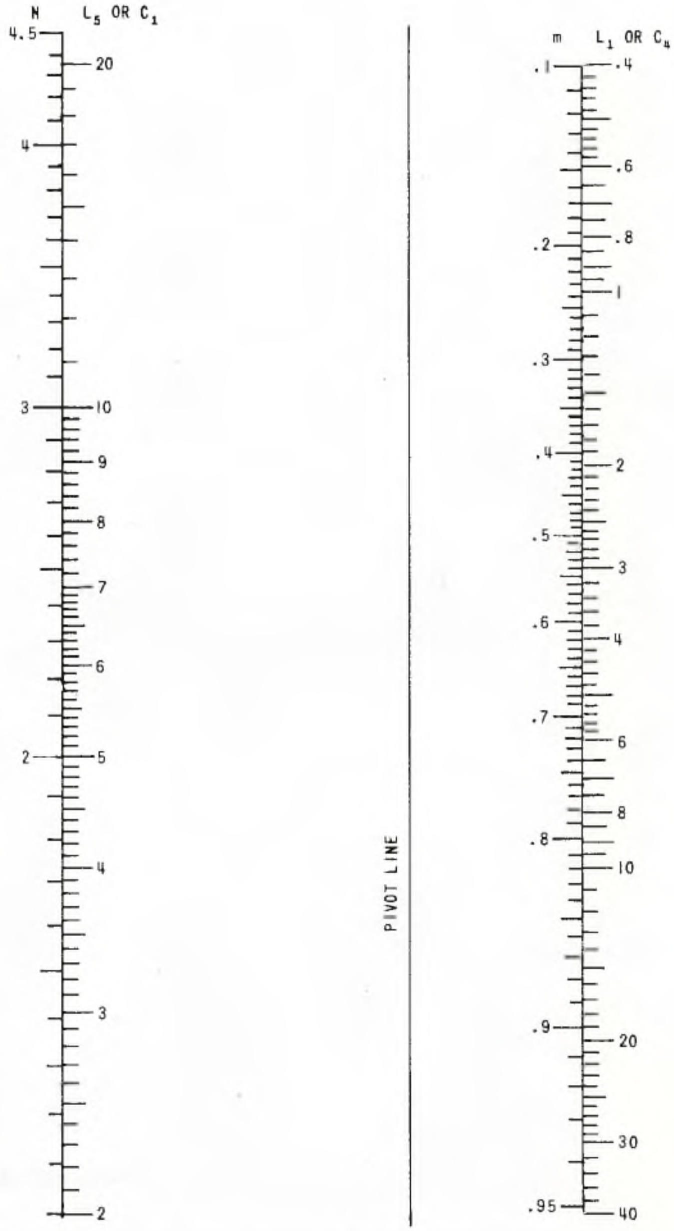
Solve for L_7 and C_6 in Nomogram 2-26 as follows:

1. Draw a straight line through the values of m and N on their respective scales. From the point where this line intersects the pivot scale, extend a second line through the value

(Continued on next page)



Nomogram 2-23



Nomogram 2-24

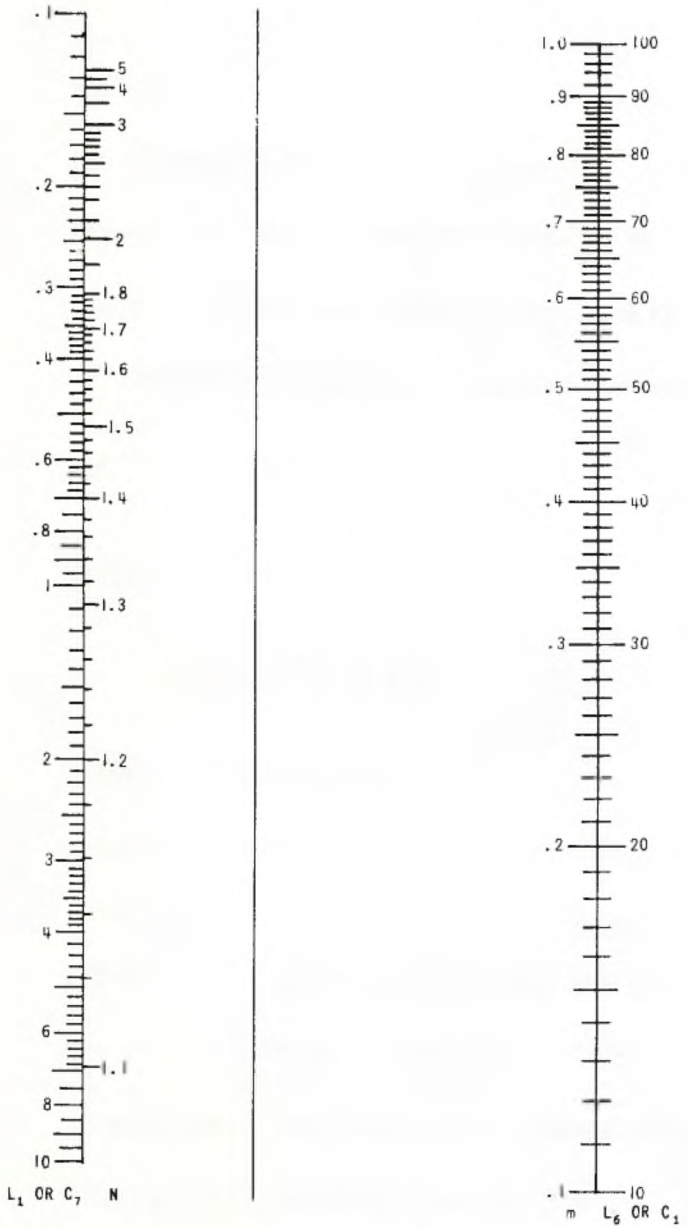
of L_1 on its scale. L_7 is found where this line intersects its scale.

2. C_6 is found in a manner similar to that described for L_7.

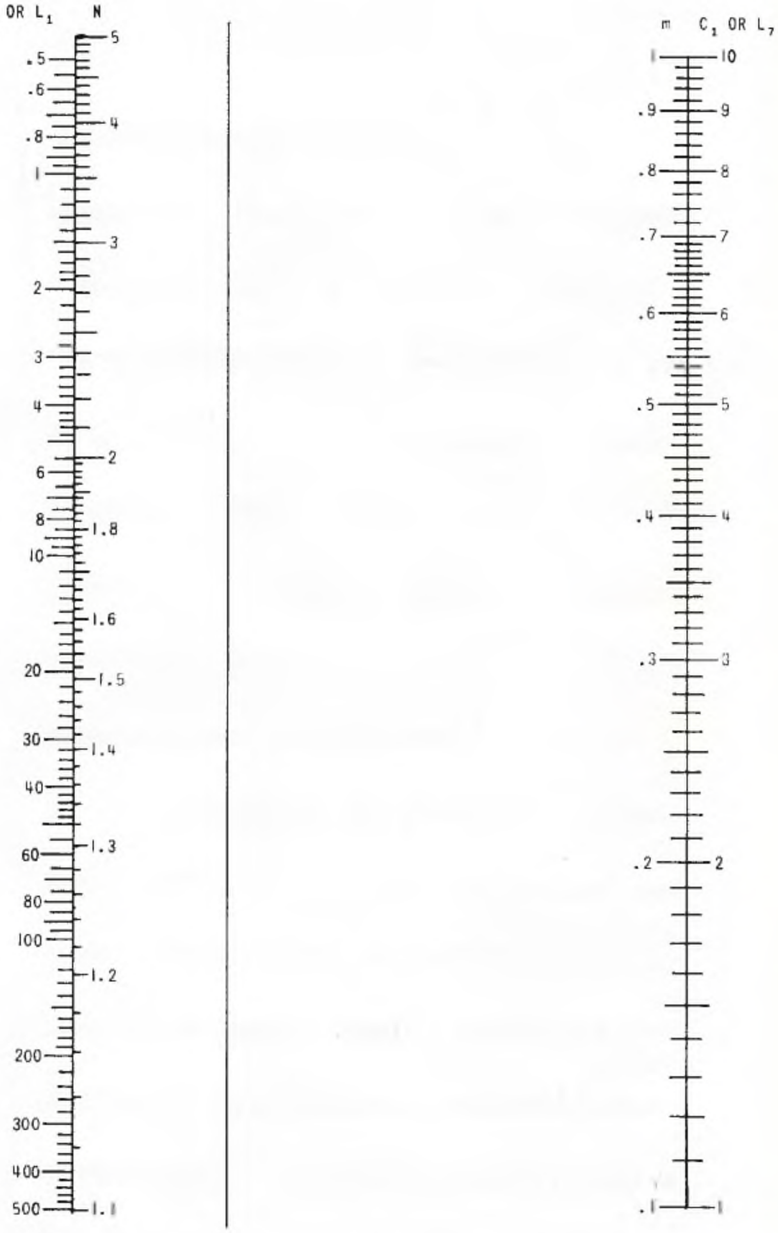
Solve for L_8 and C_8 in Nomogram 2-19 as follows:

1. Draw a straight line through L_2 on the A scale and the value of m on the m_1 scale. L_8 is found on the B scale where this line intersects it.

2. Draw a straight line through C_2 on the B scale and the value of m on the m_1 scale. C_8 is found on the A scale where this line intersects it.



Nomogram 2-25



Nomogram 2-26

Parallel-T Filters

The parallel-T (or twin-T) filter continues to enjoy the wide use that began to greet it since H. W. Augustadt filed his patent for it in May 1936. One of the few limitations of the network is that calculating component values is somewhat cumbersome and time consuming. Nomogram 2-27 eliminates the limitation. The trap or null frequency of the parallel-T shown here is:

$$f_o = 1/[2\pi R_1 C_1]$$

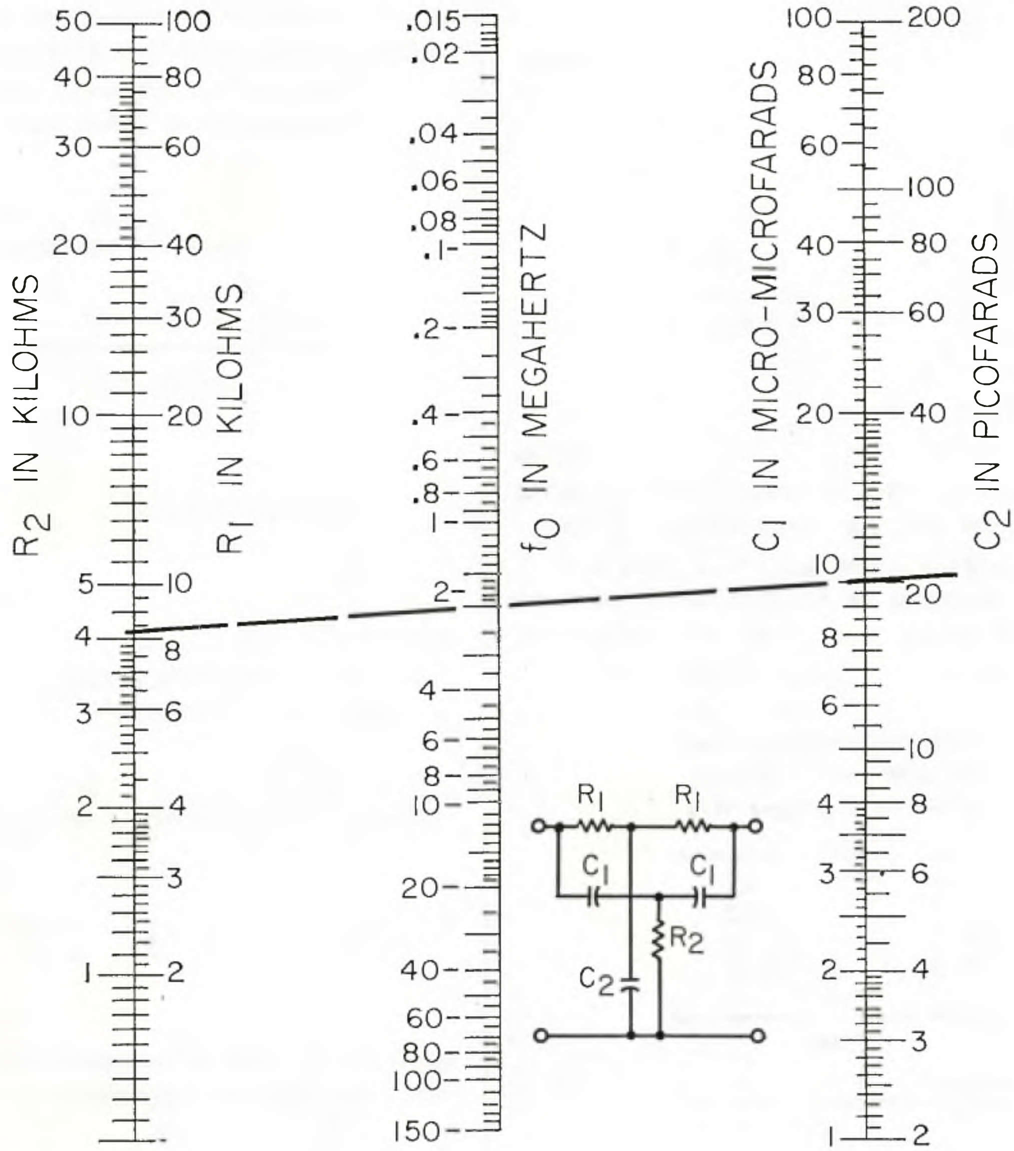
Where: $R_1 = 2R_2$

and $C_2 = 2C_1$

The nomogram gives values for all components so that one can determine the trap frequency for any RC combination involved or RC combinations for any trap frequency required.

For a desired trap frequency, various combinations of components can be found directly by rotating a straight-edge about a frequency pivot point on the center scale. Values of R and C can be found where the straight-edge crosses the outer scales. Values other than those shown can be found by multiplying one scale value by any factor and dividing the other scale value by the same factor. Thus, if the R scales are multiplied by 10, the C scales must be divided by 10. It is recommended that capacitor values be selected first from available stock, since values found on the nomogram may be difficult to procure.

The example shown on the nomogram is for a parallel-T filter with sharp rejection at 2 MHz using 10 pf for C_1. The nomogram gives a value for R_1 of 8.2K.


R2 IN KILOHMS
R1 IN KILOHMS
fO IN MEGAHERTZ
C1 IN MICRO-MICROFARADS
C2 IN PICOFARADS
R1
R1
C1
C1
R2
C2

Band-Elimination Filters

The band-elimination filter has the characteristic of attenuating a specific band of frequencies and transmitting all frequencies above and below it. Fig. 2-26 shows a typical band-elimination frequency response curve.

The Pi and T configurations for the constant-k filters are shown in Fig. 2-27. For these circuits:

$$L_1 = \frac{(f_2 - f_1)\,R}{\pi f_1 f_2} \qquad C_1 = \frac{1}{4\pi\,(f_2 - f_1)\,R}$$

$$L_2 = \frac{R}{4\pi\,(f_2 - f_1)} \qquad C_2 = \frac{(f_2 - f_1)}{\pi\, f_1 f_2 R}$$

The equations for L_2 and C_1 are solved in Nomogram 2-17 of the high-pass filter section with the values of $(f_2 - f_1)$ substituted for the f_c scale.

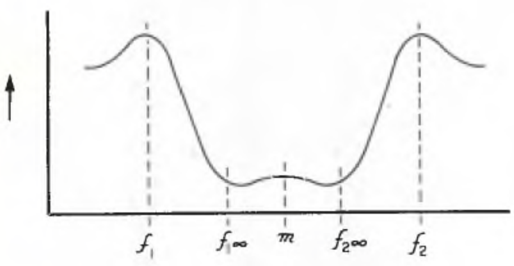


Fig. 2-26. Band-elimination filter response curve.

L_1 and C_2 are found in Nomogram 2-28. Their equations are solved as follows:

1. Draw a straight line through the values of f_2 and f_1 on their respective scales to the X scale.
2. Transpose this value to the X_{log} scale as indicated on the nomogram.
3. Draw a straight line from the X_{log} scale to the appropriate value of R on its scale. Use R(L) scale when solving for L and R(C) scale when solving for C.
4. The values of L and C are found on their respective scales where they are intersected by the line of step 3.

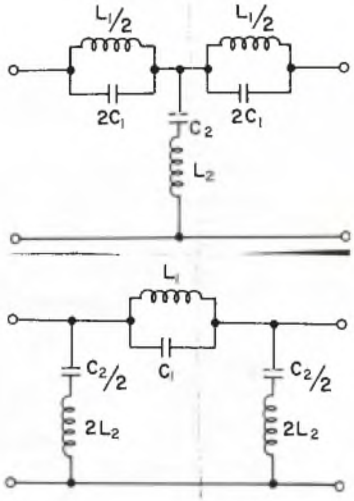


Fig. 2-27. T (top) and Pi (bottom) configuration, band elimination constant -k filter.

For this nomogram, f is in kHz, L is in mh and C is in µf. Other scale values may be used by multiplying as follows:

$f \times 10^n$, $L \times 10^{-n}$ and $C \times 10^{-n}$

The T configuration for the series m-derived filter is shown in Fig. 2-28. For this circuit:

$$L_3 = mL_1 \qquad C_3 = \frac{C_1}{m}$$

$$L_4 = \frac{(1 - m^2)\,L_1}{4m} \qquad C_4 = \frac{4m\,C_1}{(1-m^2)}$$

$$L_5 = \frac{L_2}{m} \qquad C_5 = mC_2$$

Where:

$$m = \sqrt{1 - \frac{\left(\dfrac{f_{2\infty}}{f_m} - \dfrac{f_m}{f_{2\infty}}\right)^2}{\left(\dfrac{f_2}{f_m} - \dfrac{f_m}{f_2}\right)^2}}$$

and $\quad f_m = \sqrt{f_1 f_2} = \sqrt{f_{1\infty} f_{2\infty}}$

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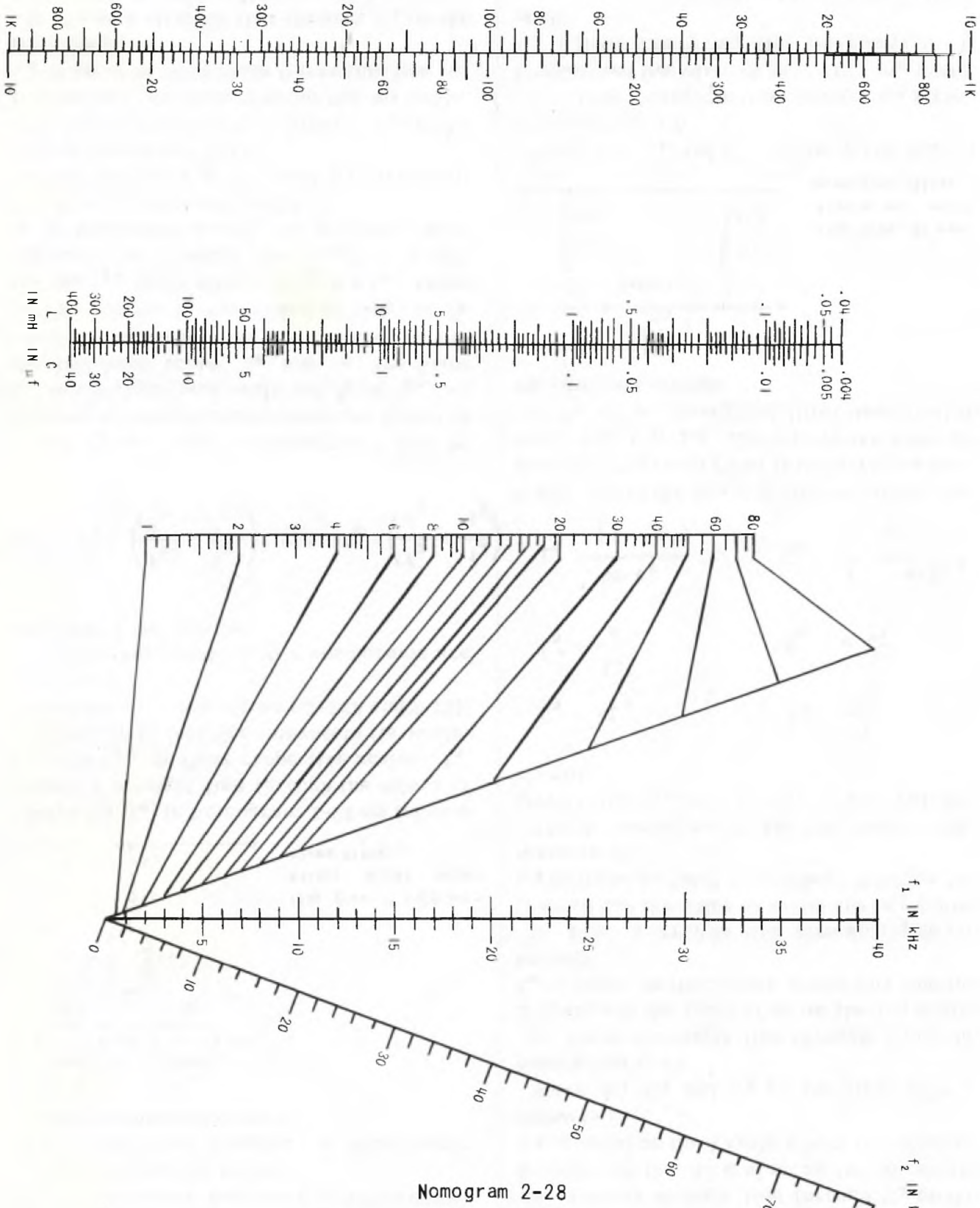


Nomogram 2-28

For the above equations:

f_1 is the lower cut-off frequency.

f_2 is the upper cut-off frequency.

$f_{1\infty}$ is the lower frequency at which maximum attenuation occurs.

$f_{2\infty}$ is the upper frequency at which maximum attenuation occurs.

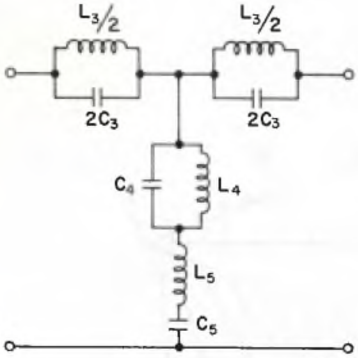


Fig. 2-28. T configuration, series m-derived filter.

Solve for f_m in Nomogram 2-21 as follows: Extend a straight line through the values of $f_{1\infty}$ and $f_{2\infty}$ on their respective scales. f_m is found where this line intersects its scale.

Solve for m in Nomograms 2-22A and 2-22B as follows:

1. For simplification, two nomograms are required in the solution.

Let $f_A = \left(\frac{f_{2\infty}}{f_m} - \frac{f_m}{f_{2\infty}}\right)$ and $f_B = \left(\frac{f_2}{f_m} - \frac{f_m}{f_2}\right)$

f_A and f_B are found in Nomogram 2-22A by drawing a straight line between the values of f_m on the right-hand scale and f_2 or $f_{2\infty}$ on the left-hand scale. f_A and f_B are found where these lines cross the diagonal scale. NOTE: Use the f_2 scale when solving for f_B and the $f_{2\infty}$ scale when solving for f_A. Draw a straight line through the values of f_A and f_B in Nomogram 2-22B. m is found where this line intersects its scale.

Solve for L_3, C_3, L_5, and C_5 on the left side of Nomogram 2-19:

1. Draw a straight line through L_1 on the B scale and the value of m on the m_1 scale. L_3 is found on the A scale where this line intersects it.

2. Draw a straight line through C_1 on the A scale and the value of m on the m_1 scale. C_3 is found on the B scale where this line intersects it.

3. Draw a straight line through L_2 on the A scale and the value of m on the m_1 scale. L_5 is found on the B scale where this line intersects it.

4. Draw a straight line through C_2 on the B scale and the value of m on the m_1 scale. C_5 is found on the A scale where this line intersects it.

Solve for L_4 and C_4 on the right side of Nomogram 2-19:

1. Draw a straight line through L_1 on the D scale and the value of m on the m_2 scale. L_4 is found on the C scale where this line intersects it.

2. Draw a straight line through C_1 on the C scale and the value of m on the m_2 scale. C_4 is found on the D scale where this line intersects it.

The Pi configuration for the shunt m-derived filter is shown in Fig. 2-29. For this circuit:

$$L_3 = mL_1 \qquad C_3 = \frac{C_1}{m}$$

$$L_5 = \frac{L_2}{m} \qquad C_5 = m\,C_2$$

$$L_6 = \frac{4m\,L_2}{(1 - m^2)} \qquad C_6 = \frac{(1 - m^2)\,C_2}{4m}$$

Where: m is the same as for the series m-derived filters described in the previous section. L_3, C_3, L_5, and C_5 are the same as for the series m-derived filter described in the previous section.

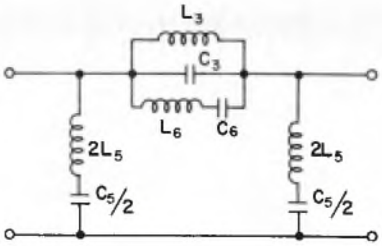


Fig. 2-29. Pi configuration, shunt m-derived filter.

Solve for L_6 and C_6 on the right side of Nomogram 2-19:

1. Draw a straight line through L_2 on the C scale and the value of m on the m_2 scale. L_6 is found where this line intersects the D scale.

2. Draw a straight line through C_2 on the D scale and the value of m on the m_2 scale. C_6 is found where this line intersects the C scale.

CHAPTER 3

Transmission Lines

RF Transmission Lines

When the type of transmission line is known, its characteristic impedance as well as other constants can be found from available charts. However, the type of line is not always known. Therefore, calculations must be made to determine its constants.

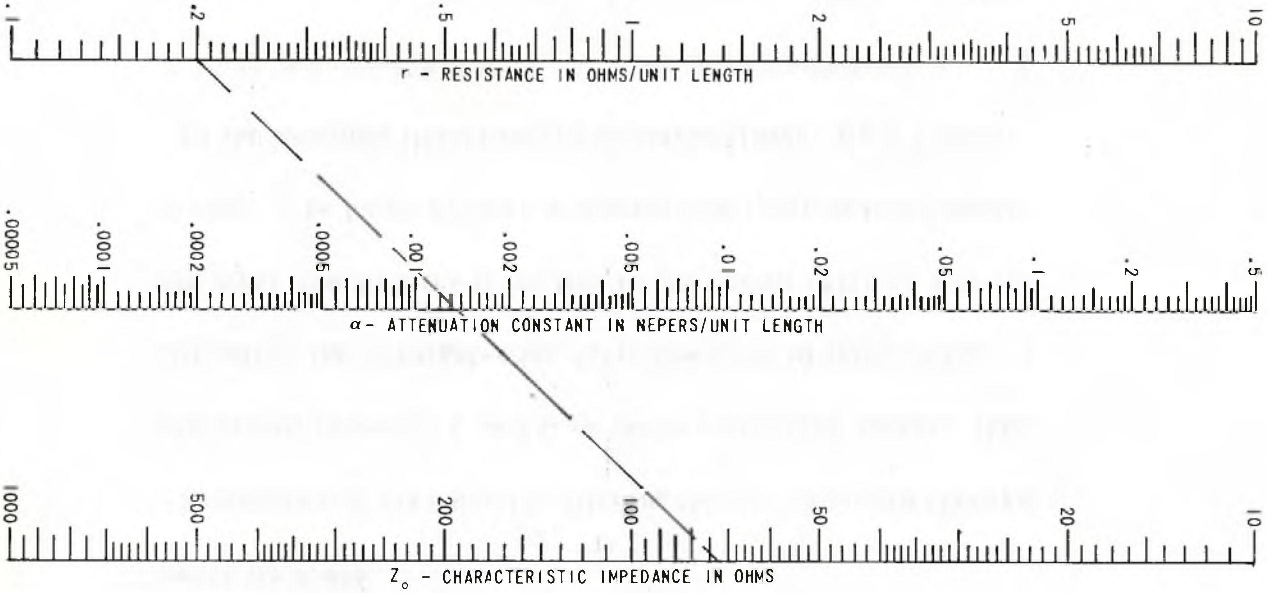
The nomograms in this chapter simplify the calculations of constants for several of the more common types of uniform transmission lines. It must be kept in mind that negligible losses are assumed for all the types presented. The following assumptions are also made:

1. There is skin effect present.
2. Distance between conductors is large compared to the diameter of the conductor.
3. Distance between conductors is small compared to the wavelength.
4. Line length is large compared to distance between conductors.
5. The height of the conductor above ground is large compared to the distance between conductors.

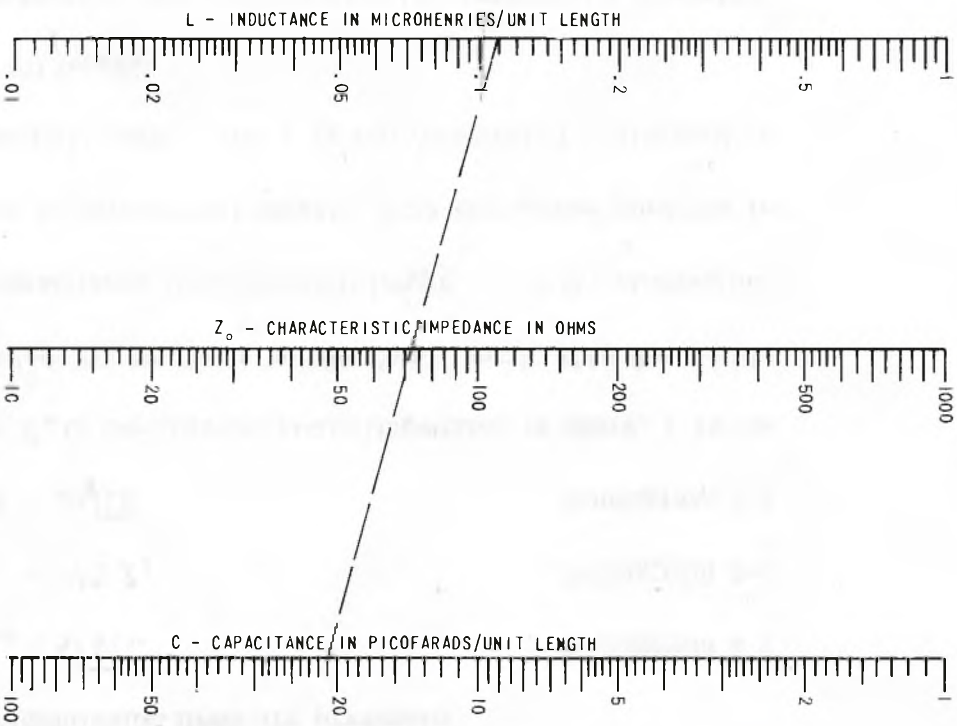
The reader is referred to Landee et al, Electronic Designers Handbook, New York, Mc-Graw-Hill Book Company, 1957.

(Continued on next page)

Nomogram 3-2



Nomogram 3-1



First, some general relationships which apply to parallel-wire transmission lines are presented.

(1) $Z_o = \sqrt{L/C}$ Nomogram 3-1

(2) $\alpha = r/2\ Z_o$ Nomogram 3-2

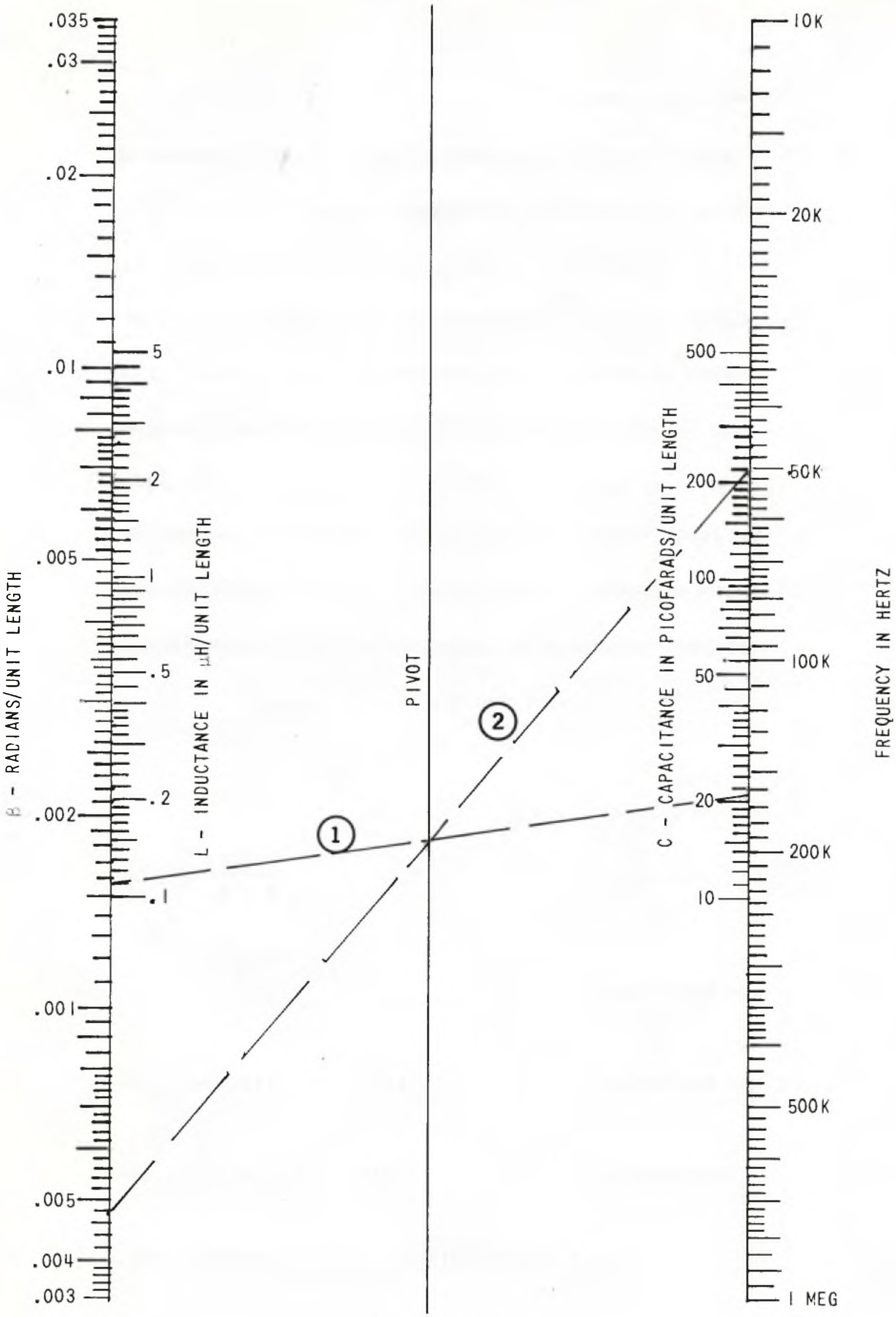
(3) $\beta = \omega\sqrt{LC}$ Nomogram 3-3

Where: Z_o is the characteristic impedance in ohms, L is the distributed inductance in henries/unit length, C is the distributed capacitance in farads/unit length, α is the attenuation constant in nepers/unit length, β is the phase constant in radians/unit length, and r is the distributed resistance in ohms/unit length.

Nomograms 3-1 and 3-2 are solved by extending a straight-edge through the two known values on their respective scales and locating the third value where the straight-edge intersects its scale.

Nomogram 3-3 is solved by aligning the straight-edge through the known values of L and C on their respective scales, then extending the straight-edge from the point of intersection of the first line with the pivot line to the known value of f on its scale. β is found where the second line intersects its scale.

In the example illustrated by the dashed lines, $Z_o = 73$ ohms, L = .11 microhenries/foot, C = 21 picofarads/foot, r = .2 ohms per foot, f = 50 kiloHertz, $\alpha = .00137$, and $\beta = .00477$.



β - RADIANS/UNIT LENGTH
L - INDUCTANCE IN μH/UNIT LENGTH
PIVOT
C - CAPACITANCE IN PICOFARADS/UNIT LENGTH
FREQUENCY IN HERTZ
.035
.03
.02
.01
.005
.002
.001
.005
.004
.003
5
2
1
.5
.2
.1
500
200
100
50
20
10
10K
20K
50K
100K
200K
500K
1 MEG
1
2

Nomogram 3-3

Open Two-Wire Lines

The configuration of this line is shown in Fig. 3-1

(4) $Z_o = 276 \log_{10} 2D/d$ Nomogram 3-4

(5) $L = 0.921 \log_{10} 2D/d$ Nomogram 3-5

(6) $C = \dfrac{12.06}{\log_{10} 2D/d}$ Nomogram 3-5

(7) $r = \dfrac{8.3\sqrt{f}}{(d/2)}$ Nomogram 3-6

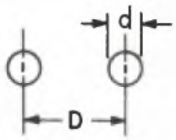
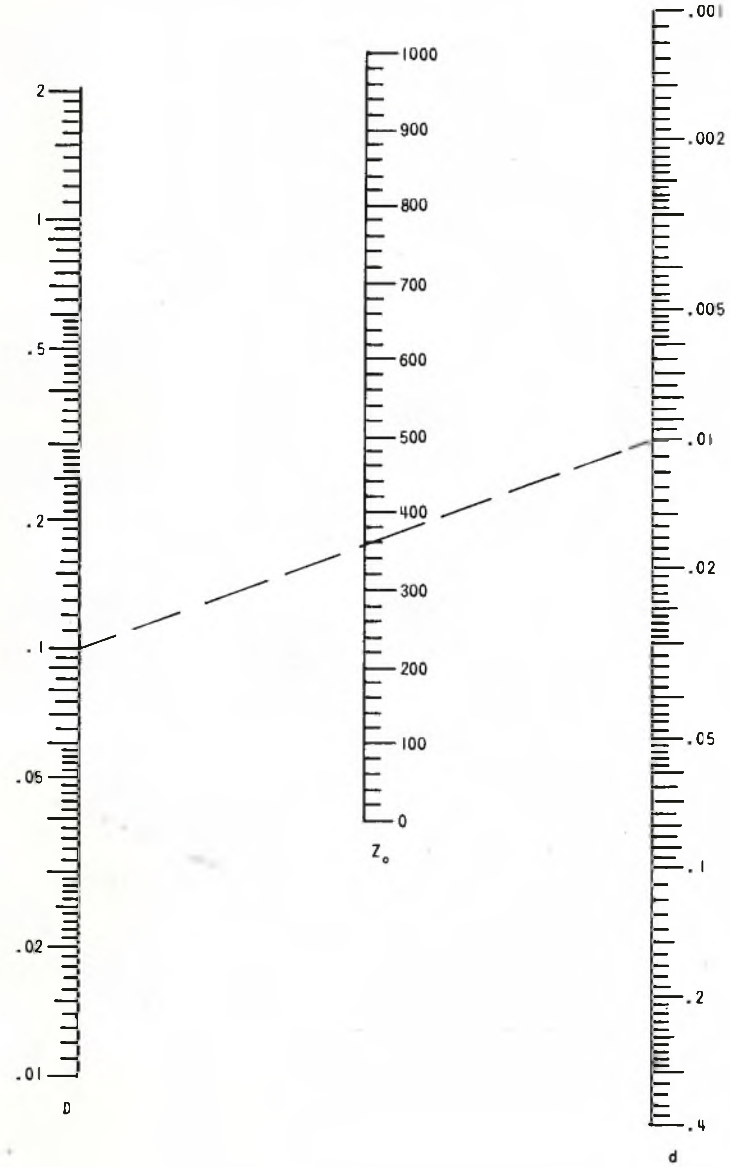


Fig. 3-1. Open two-wire line.

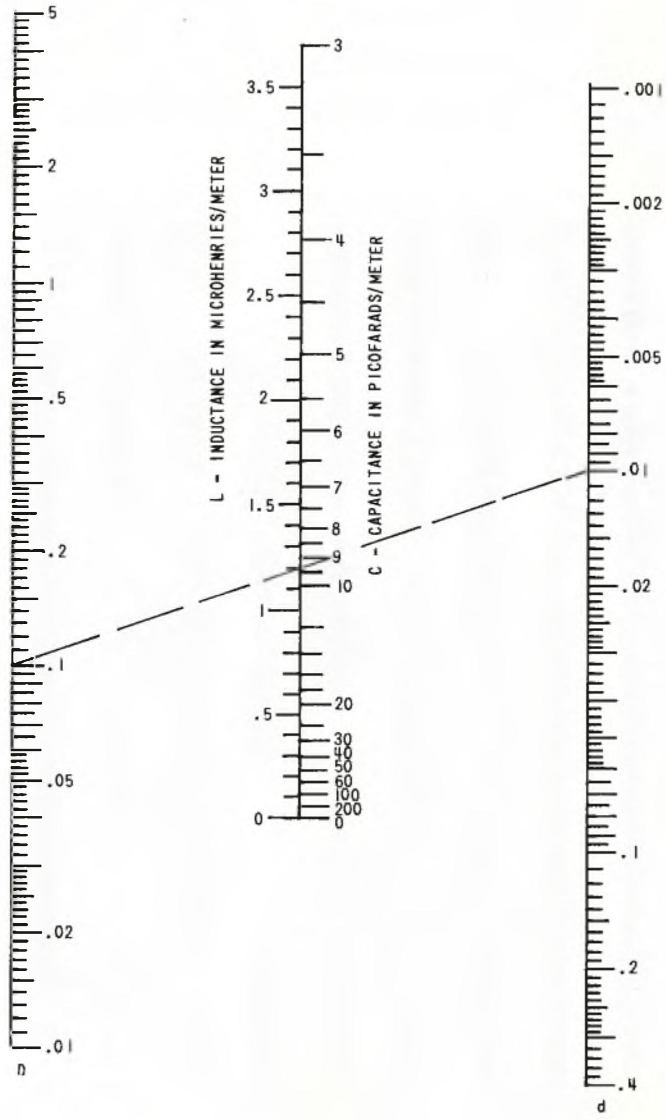
Nomograms 3-4 and 3-5 are solved by extending a straight-edge through the values of D and d on their respective scales and locating the unknown value where this line intersects the center scale. Notice that in Nomogram 3-5, the left side of the centerline is the scale of L and the right side is the scale for C. Values other than those given may be used by simultaneously multiplying the D and d scales by the same factor. The values of the center scales remain unchanged.

Nomogram 3-6 is solved by extending a straight-edge through the values of f and d on their respective scales and locating r

(Continued on next page)



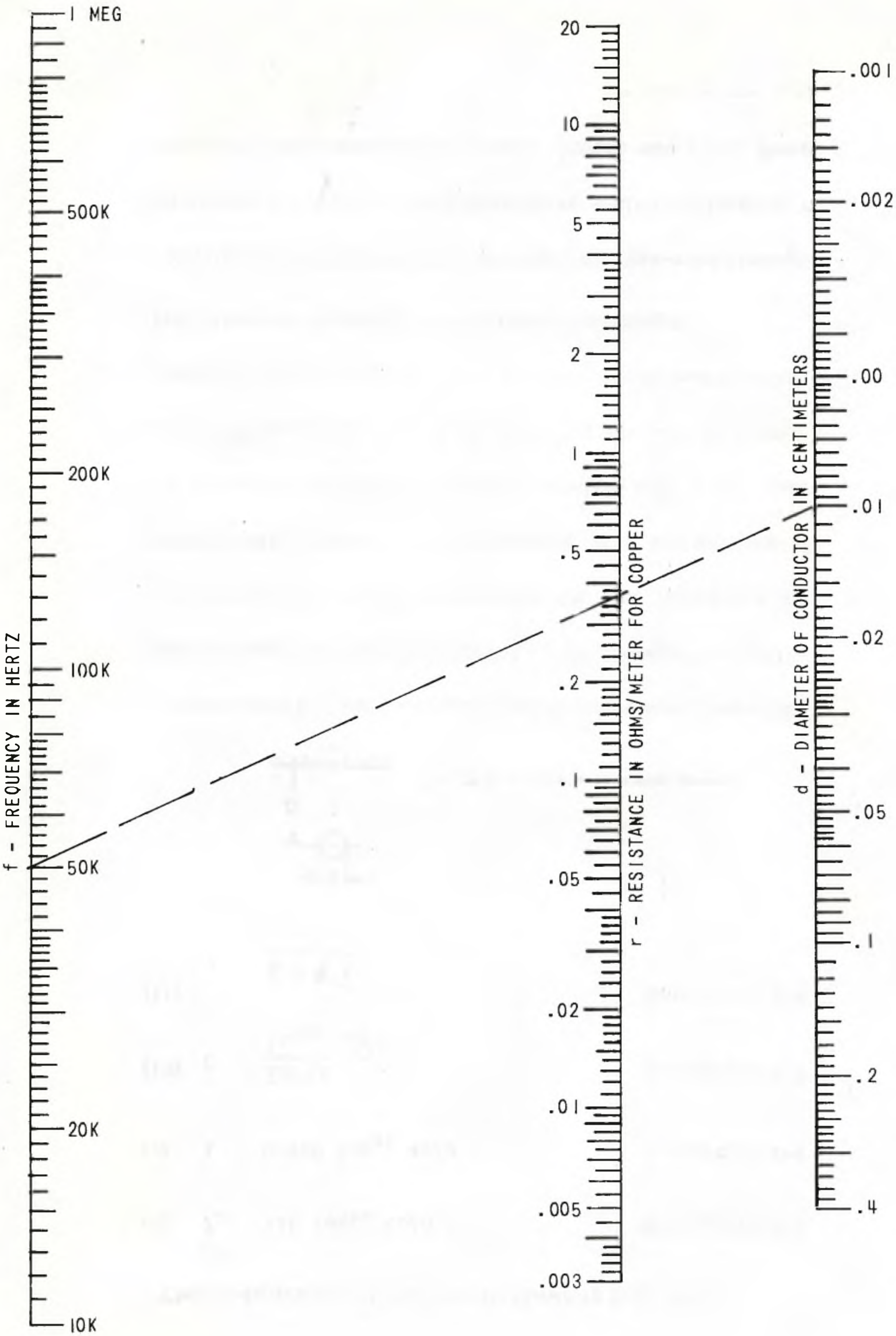
Nomogram 3-4



Nomogram 3-5

where this line intersects its scale. Values other than those shown may be used by simultaneously multiplying the f and d scales by the same factor without changing the values of the r scale. If only d is multiplied by 10^n, then r must be multiplied by 10^{-n}. If only f is multiplied by 10^n, then r must be multiplied by $10^{n/2}$. (n may be positive or negative.)

In the example illustrated by the dashed lines, D = .1 cm, d = .01 cm, Z_0 = 359 ohms, L = 1.2 microhenries/meter, c = 9.3 picofarads/meter, and r = .37 ohms/meter.



f - FREQUENCY IN HERTZ
1 MEG
500K
200K
100K
50K
20K
10K
r - RESISTANCE IN OHMS/METER FOR COPPER
20
10
5
2
1
.5
.2
.1
.05
.02
.01
.005
.003
d - DIAMETER OF CONDUCTOR IN CENTIMETERS
.001
.002
.005
.01
.02
.05
.1
.2
.4

Nomogram 3-6

Single-Wire Above Ground

The configuration of this line is shown in Fig. 3-2.

(8) $Z_0 = 138 \log_{10} 4D/d$ Nomogram 3-7

(9) $L = 0.460 \log_{10} 4D/d$ Nomogram 3-8

(10) $C = \dfrac{24.12}{\log_{10} 4D/d}$ Nomogram 3-8

(11) $r = \dfrac{8.3 \sqrt{f}}{d}$ Nomogram 3-9

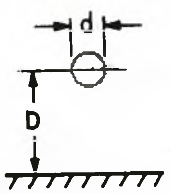
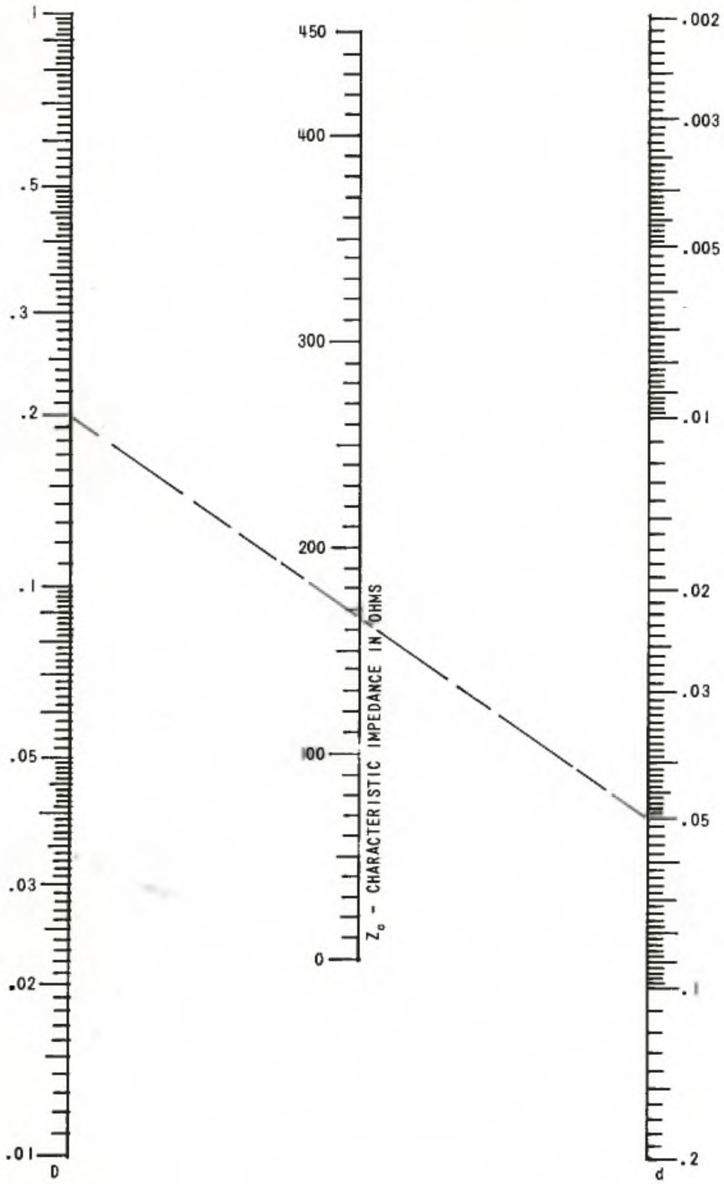


Fig. 3-2. Single wire above ground.

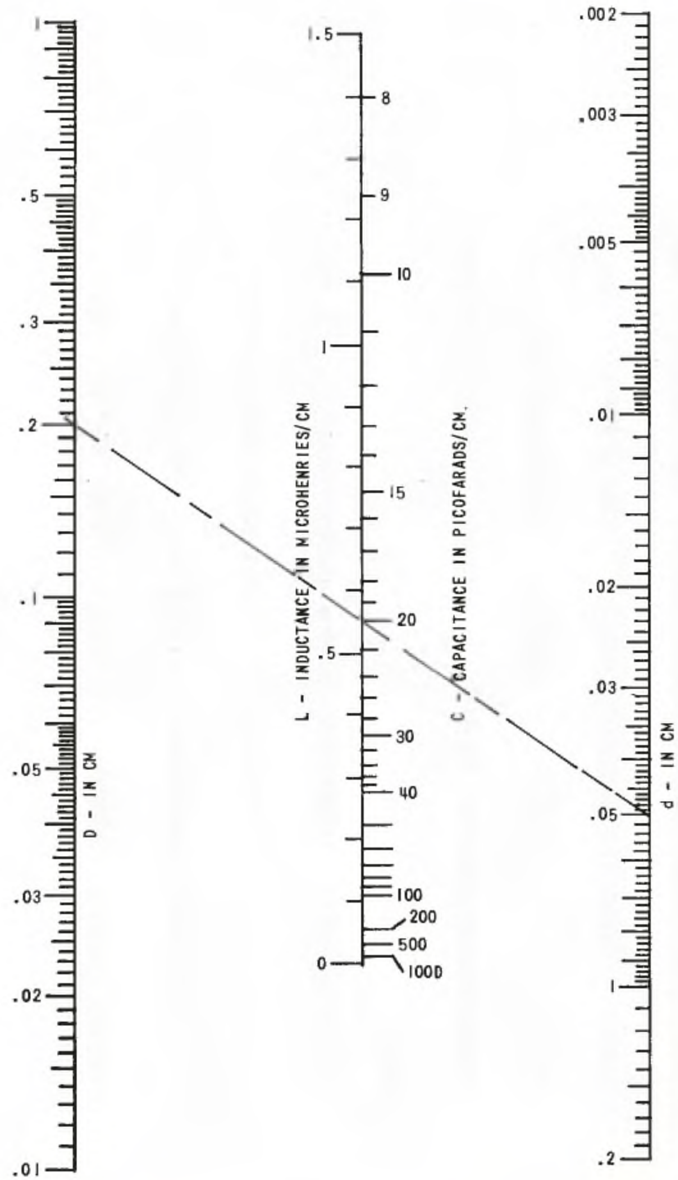
Nomograms 3-7 and 3-8 are solved by extending a straight-edge through the values of D and d on their respective scales and locating the unknown value where the line intersects the center scale. Notice that in Nomogram 3-8, the left side of the centerline is the scale for L and the right side is the scale for C. Values other than those given may be used by simultaneously multiplying the D and d scales by the same factor. The values of the center scales remain unchanged.

Nomogram 3-9 is solved by extending a straight-edge through the values of f and d on their respective scales and locating r where this line intersects its scale. Values other than those

(Continued on next page)



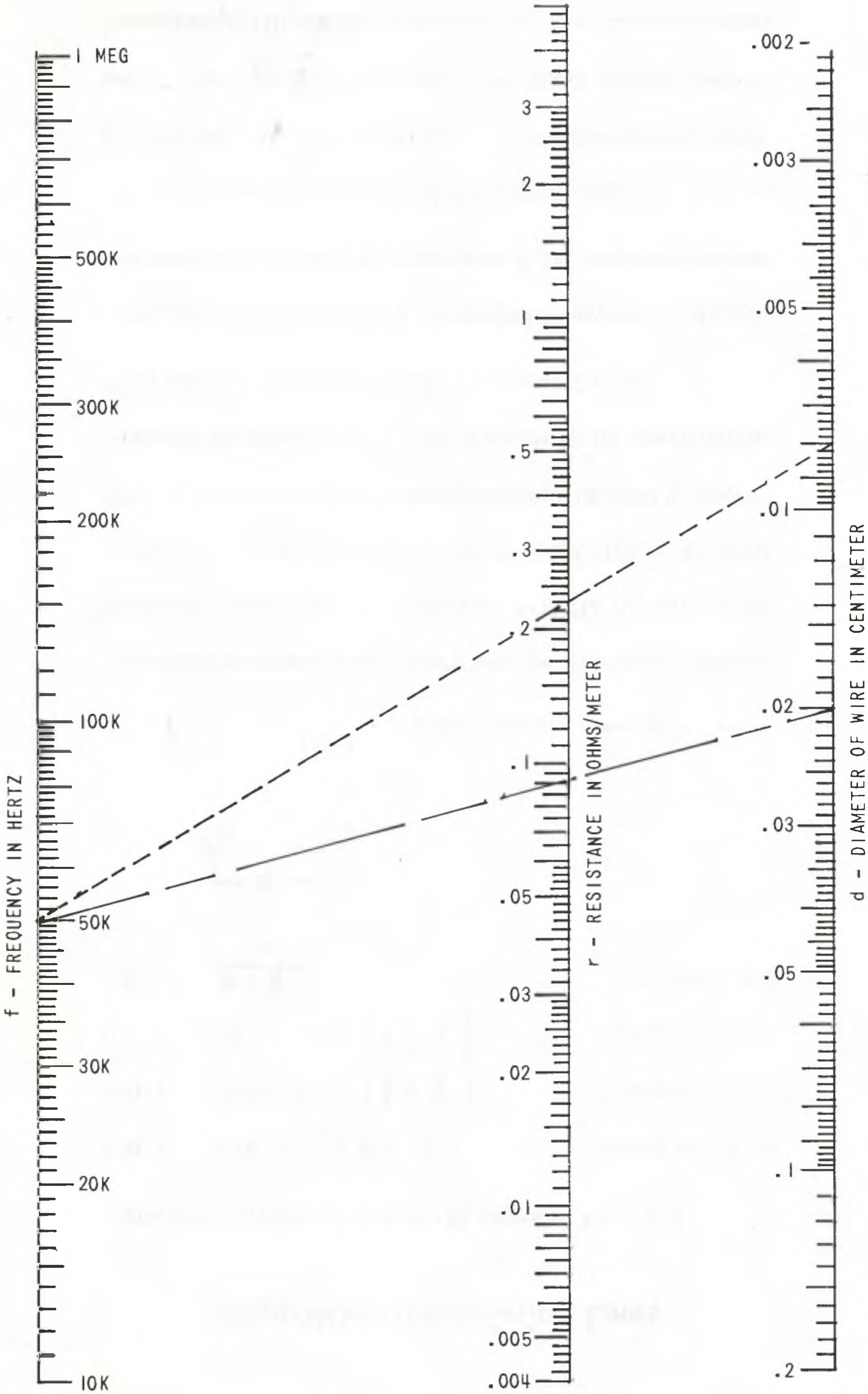
Nomogram 3-7



Nomogram 3-8

shown may be used by simultaneously multiplying the f and d scales by the same factor without changing the values of the r scale. If only d is multiplied by 10^n, then r must be multiplied by 10^{-n}. If only the f scale is multiplied by 10^n, then r must be multiplied by $10^{n/2}$. (n may be positive or negative.)

In the example illustrated by the dashed lines D = .2 cm, d = .05 cm, Z_o = 166 ohms, L = .554 microhenries/meter, and c = 20 picofarads/meter. In the example illustrated by the large dashed lines d = .02 cm, f = kHz, and r = .092 ohms/meter for copper.



I MEG
500K
300K
200K
100K
50K
30K
20K
10K
f - FREQUENCY IN HERTZ
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.004
r - RESISTANCE IN OHMS/METER
.002
.003
.005
.01
.02
.03
.05
.1
.2
d - DIAMETER OF WIRE IN CENTIMETER

Nomogram 3-9

Four-Wire Transmission Lines

The configuration of this line is shown in Fig. 3-3.

(12) $Z_o = 138 \log_{10} \left(\sqrt{2}\ \frac{D}{d} \right)$ Nomogram 3-10

(13) $L = 0.460 \log_{10} \left(\sqrt{2}\ \frac{D}{d} \right)$ Nomogram 3-11

(14) $C = 24.1 / \log_{1c} \left(\sqrt{2}\ \frac{D}{d} \right)$ Nomogram 3-11

(15) $r = \frac{8.3 \sqrt{f}}{d}$ Nomogram 3-9

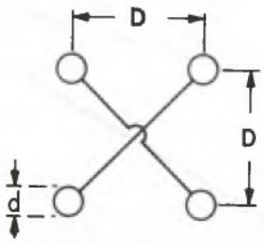
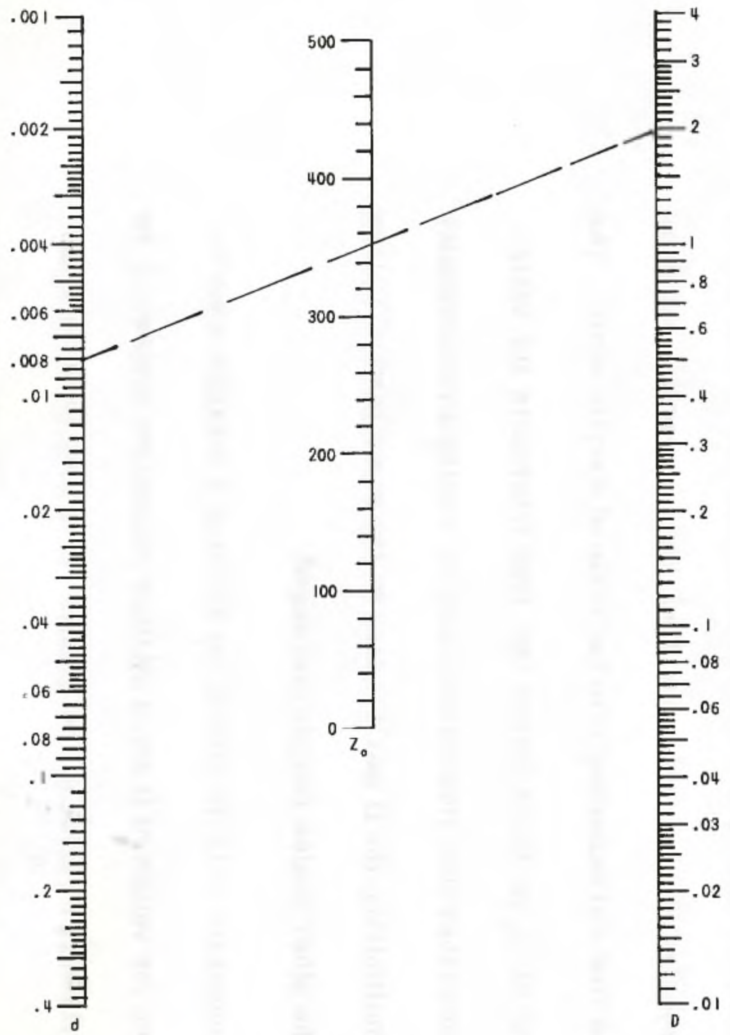


Fig. 3-3. Four-wire transmission line.

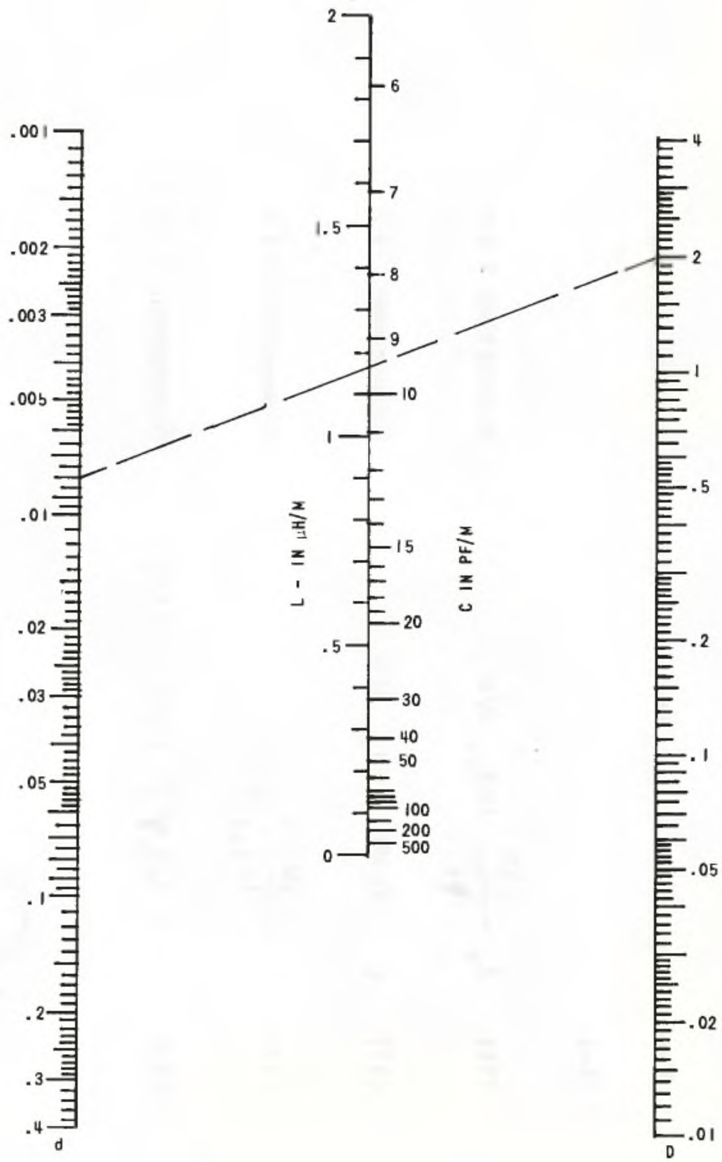
The unknown value is found where the line intersects the center scale. Notice that in Nomogram 3-11 the left side of the center line is the scale for L and the right side is the scale for C. Values other than those given may be used by simultaneously multiplying the D and d scales by the same factor. The values of the center scales remain unchanged.

Nomograms 3-10 and 3-11 are solved by drawing a straight line through the values of D and d on their respective scales.

In the example illustrated by the dashed lines, D = 2 cm, d = .008 cm, Z_o = 352 ohms, L = 1.17 microhenries/meter, and c = 9.4 picofarads/meter. The short dashed lines in Nomogram 3-9 illustrate the solution for r = .23 ohms/meter at f = 50 kHz.



Nomogram 3-10



Nomogram 3-11

Coaxial Cable

The configuration of this transmission line is shown in Fig. 3-4.

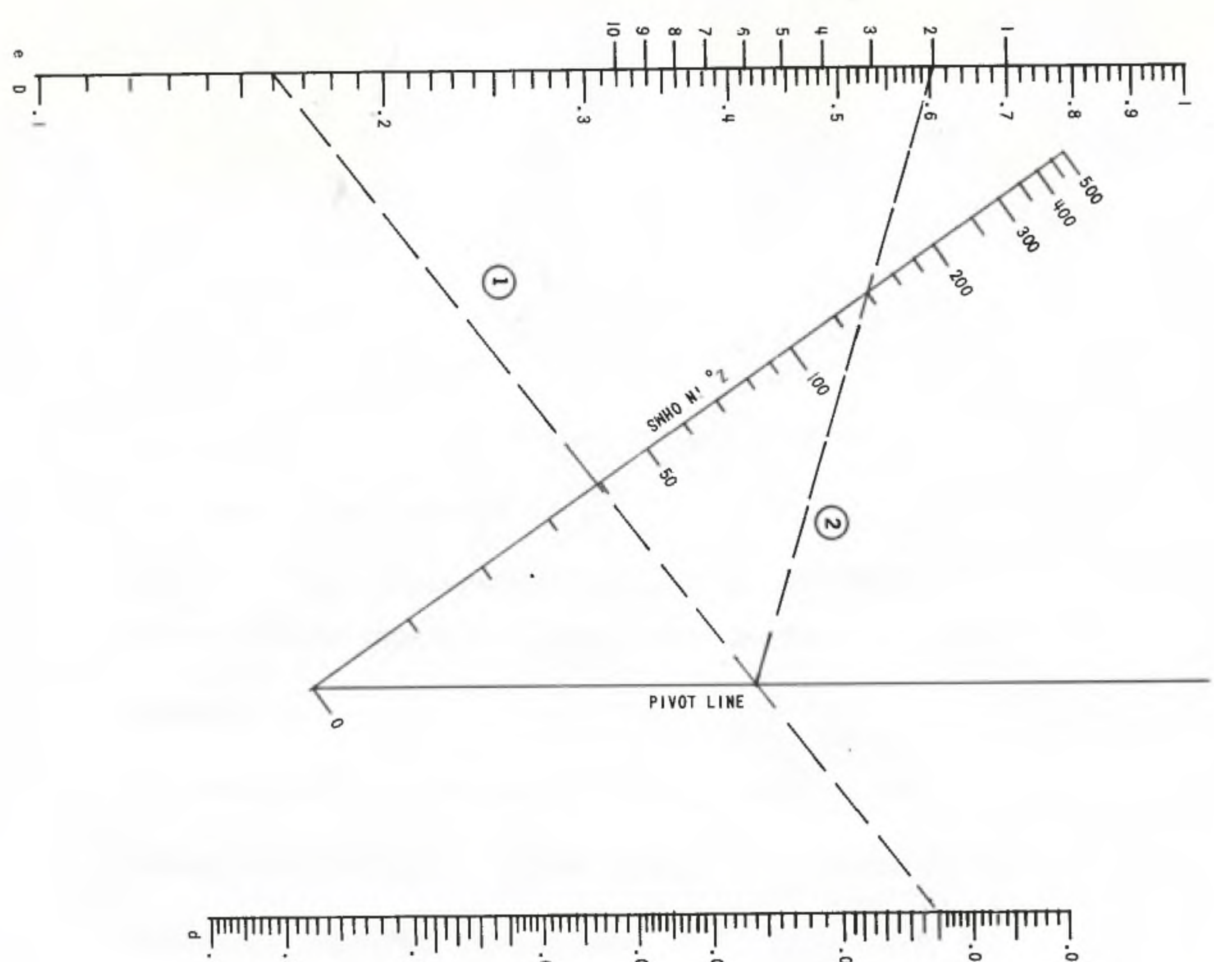
(16)	$Z_o = \frac{138}{\sqrt{e}} \log_{10} D/d$	Nomogram 3-12
(17)	$L = 0.460 \log_{10} D/d$	Nomogram 3-13
(18)	$C = \frac{24.1 e}{\log_{10} D/d}$	Nomogram 3-13
(19)	$r = 8.3 \sqrt{f} \; (1/D + 1/d)$	Nomogram 3-14

Fig. 3-4. Coaxial cable.

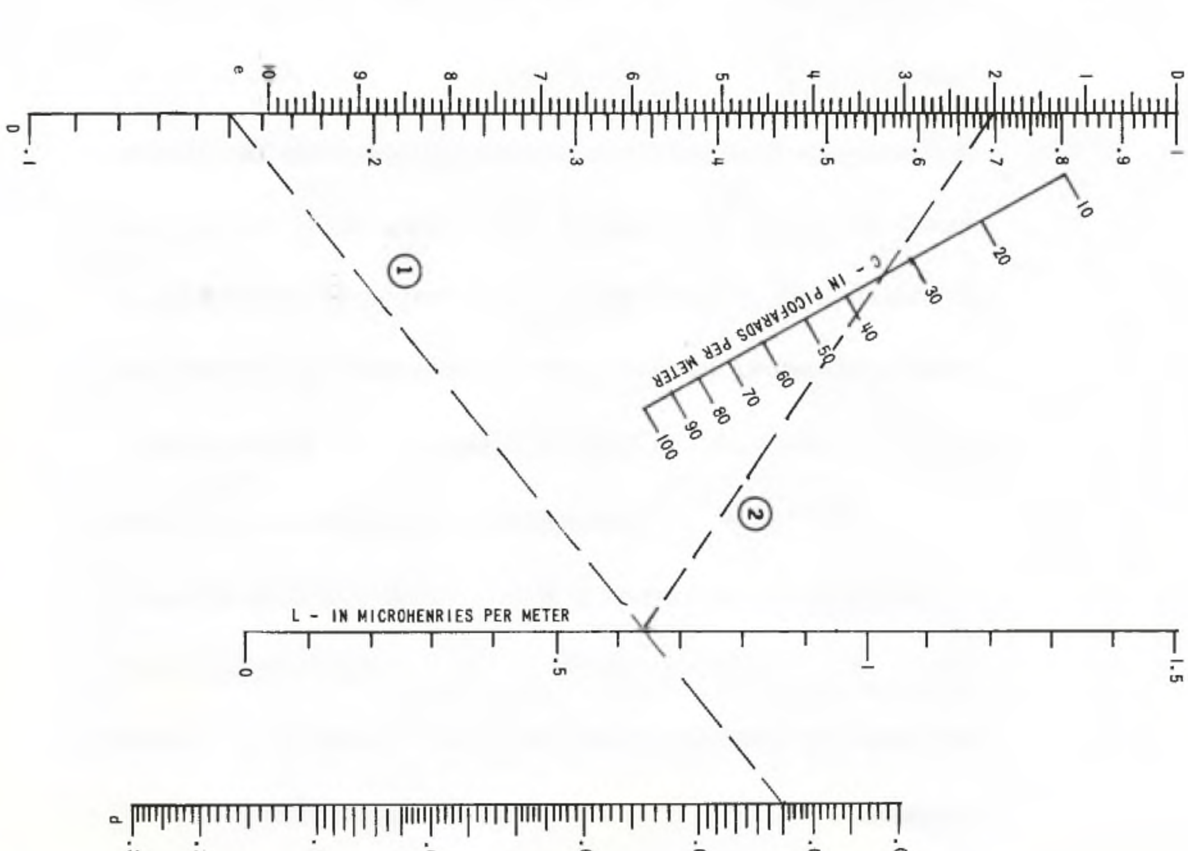
Nomogram 3-12 is solved by aligning a straight-edge between the values of D and d on their respective scales, then by rotating the straight-edge about the intersecting point on pivot line and extending it to the value of e on its scale. The value of Z_o is found where this line intersects its scale. Values other than those shown may be used by simultaneously by multiplying the D and d scales by the same factor. Values of the other scales remain unchanged.

Nomogram 3-13 is solved by aligning a straight-edge between the values of D and d on their respective scales. L is found where its scale is intersected. C is then found by align-

(Continued on next page)



Nomogram 3-12

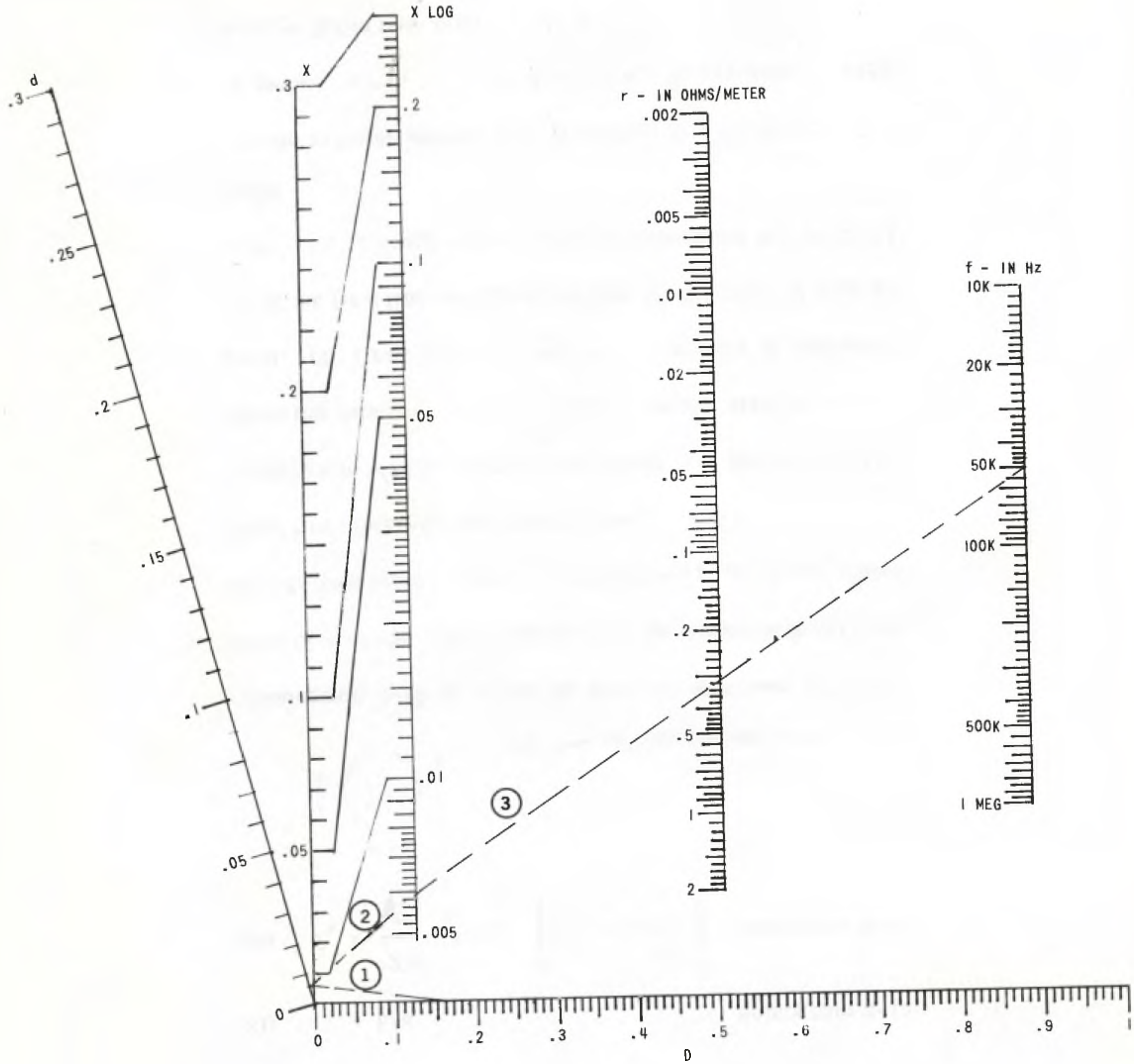


Nomogram 3-13

ing the straight-edge between L and e on their respective scales. C is found where this line intersects the diagonal scale. Values other than those shown may be used by simultaneously multiplying the D and d scales by the same factor. Other scale values remain unchanged.

Nomogram 3-14 is solved as follows: (a) Draw a straight line between the values of D and d on their respective scale. (b) Transpose the value of X from the point of intersection of the first line to the same value on the log X scale. (c) Draw another line from the point on the log X scale to the value of f on its scale. r is found where this line intersects its scale. Values other than those given may be used by simultaneously multiplying the D and d scales by 10^n. When this is done, r must be multiplied by 10^{-n}. If the value of f is multiplied by 10^n, then r must be multiplied by $10^{n/2}$. (n may be positive or negative.)

In the examples shown, D = .16 cm, d = .006 cm, Z_o = 140 ohms, L = .655 microhenries/m, C = 33 picofarads/m, e = 2, and r = .31 ohms/m.



Nomogram 3-14

Balanced Shielded Lines

The configuration of this line is shown in Fig. 3-5.

(20) $\sigma = h/D$ Nomogram 3-15

(21) $\nu = h/d$ Nomogram 3-15

(22) $^{*}Z_0 = \dfrac{276}{\sqrt{e}} \log_{10}\left[2\nu \dfrac{1-\sigma^2}{1+\sigma^2}\right]$ Nomogram 3-16

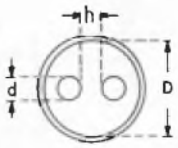


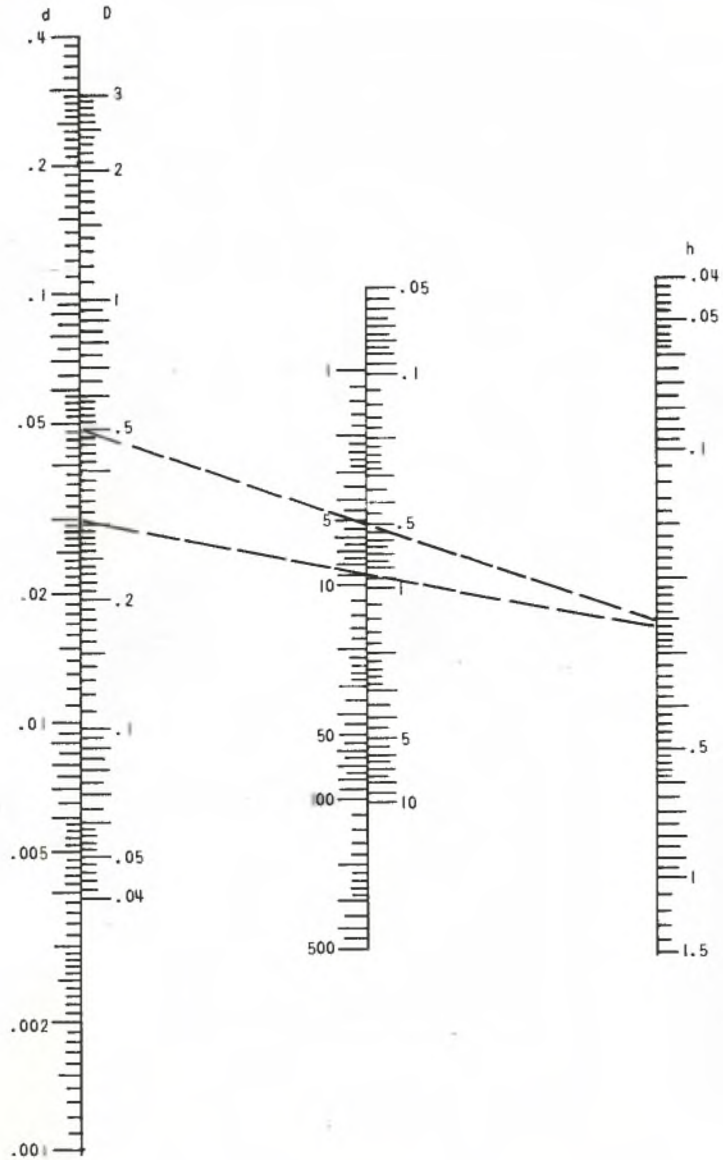
Fig. 3-5. Balanced shielded line.

Nomogram 3-15 is solved by drawing two lines from the value of h on the right-hand scale to the values of d and D on the left-hand scale. ν and σ, respectively, are found where these lines intersect the center scale.

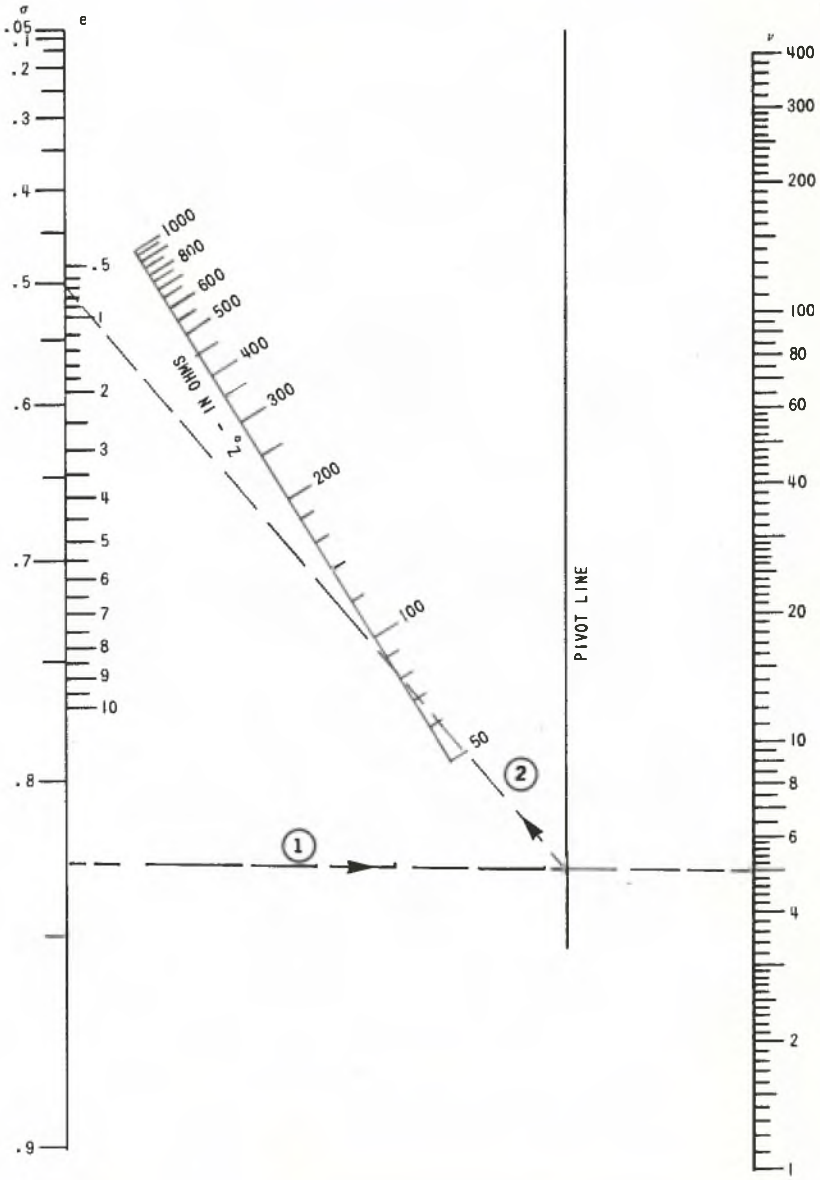
Nomogram 3-16 is solved in two steps. (1) Draw a line between the values of ν and σ, found from the previous nomogram. (2) Draw a second line, from the point of intersection of the first line with the pivot line, to the value of e on its scale. Z_0 is found where this line intersects the diagonal scale.

In the example shown: h = .25 inches, d = .05 inches, D = .3 inches, $\nu = 5$, $\sigma = .83$, e = .7, and $Z_0 = 84$ ohms. This equation holds true for D >> d, h >> d.

* Reference Data for Radio Engineers, J. J. Little & Ives Company, New York, 1946.



Nomogram 3-15



Nomogram 3-16

CHAPTER 4

Passive Components

Single Layer Air-Core Coil

The design of a single layer air-core coil is simplified with the use of this nomogram. Nagoaka's formula is expressed by:

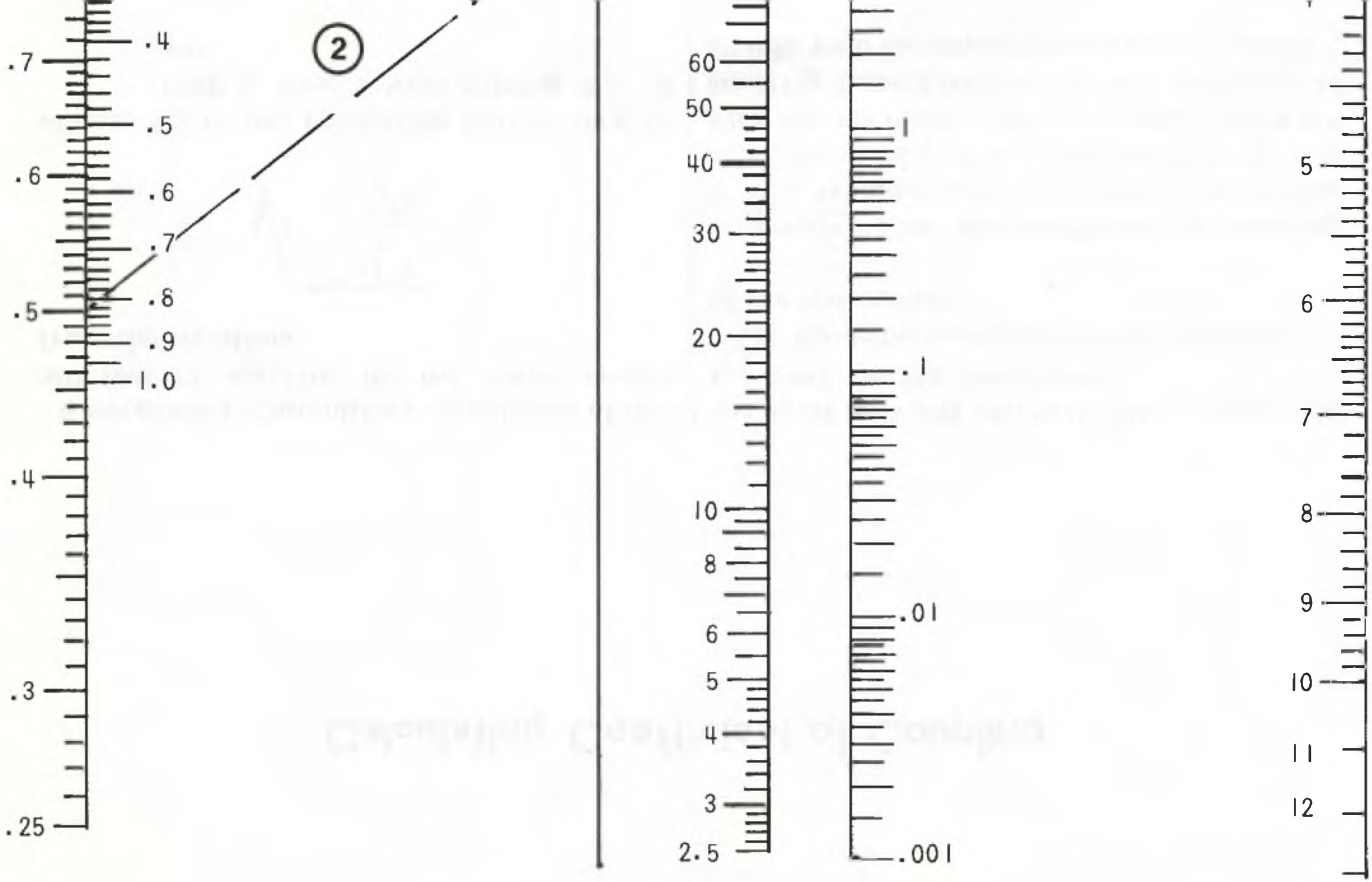
$$L = \frac{.03948\ a^2 n^2 k}{b}$$

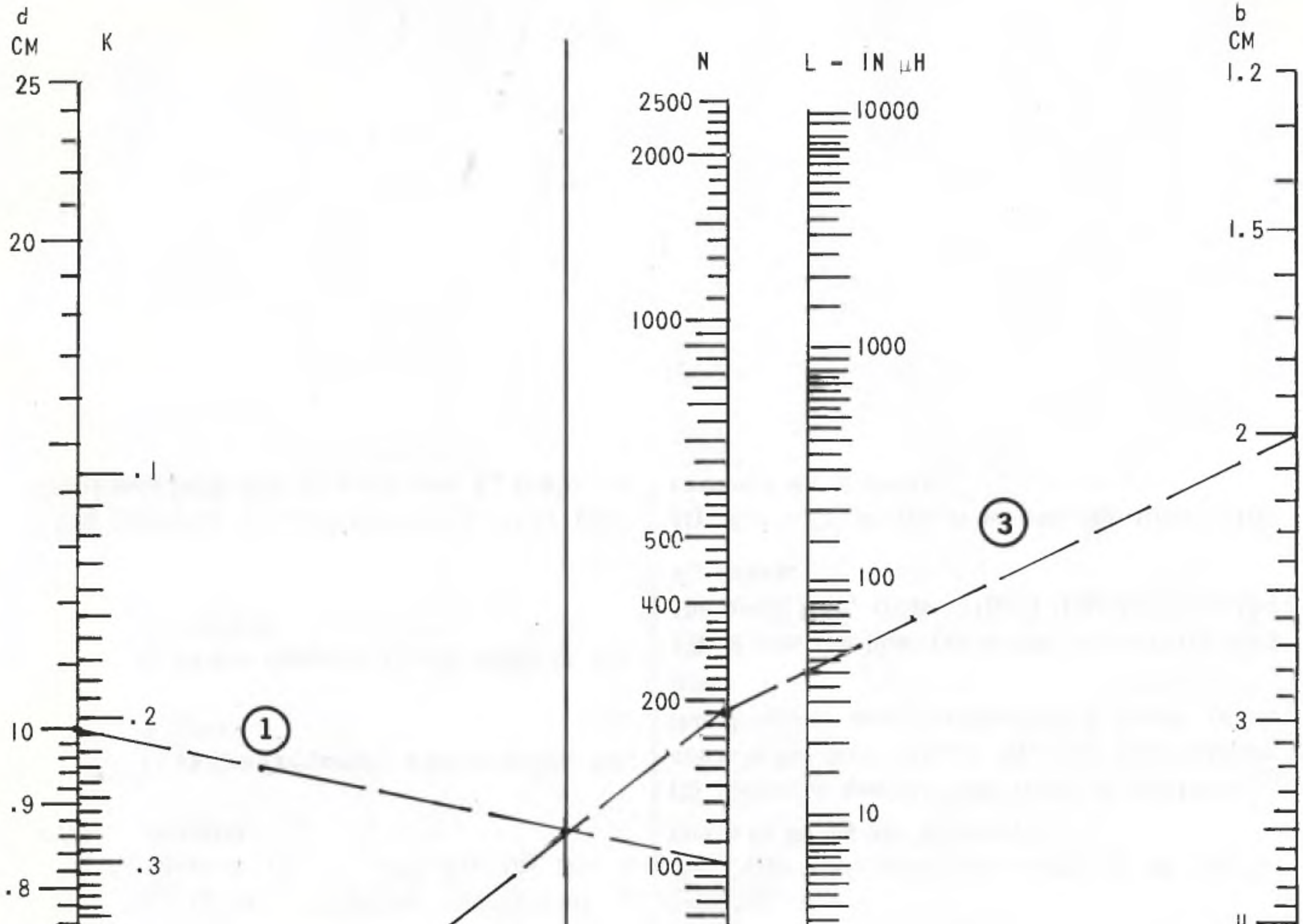
Where: L is the inductance in microhenries,
a is the radius of the coil in cm
b is the length of the coil in cm
n is the number of turns, and
k is Nagoaka's constant (a function of d/b. See Table.)

In the example illustrated by the dashed lines: b = 2 cm, n = 100, a = .5 cm, $\therefore$ d = 1 cm (from the table, k = .8181 for d/b = .5) L = 40.4 microhenries.

TABLE OF VALUES FOR K IN NAGOAKA'S FORMULA

Ratio d/b	K	Ratio d/b	K
0.05	0.979	3.8	0.376
0.1	0.959	4.0	0.365
0.2	0.92	4.2	0.355
0.3	0.884	4.4	0.346
0.4	0.850	4.6	0.336
0.5	0.818	4.8	0.328
0.6	0.789	5.0	0.320
0.7	0.761	5.2	0.312
0.8	0.735	5.4	0.305
0.9	0.711	5.6	0.298
1.0	0.688	5.8	0.292
1.1	0.667	6.0	0.285
1.2	0.648	6.2	0.280
1.3	0.629	6.4	0.274
1.4	0.612	6.6	0.269
1.5	0.595	6.8	0.263
1.6	0.580	7.0	0.258
1.7	0.565	7.2	0.254
1.8	0.551	7.4	0.249
1.9	0.538	7.6	0.245
2.0	0.526	7.8	0.241
2.2	0.503	8.0	0.237
2.4	0.482	8.5	0.227
2.6	0.463	9.0	0.219
2.8	0.445	10.0	0.203
3.0	0.429	11.0	0.190
3.2	0.415	12.0	0.179
3.4	0.401	13.0	0.169
3.6	0.388		


.7
.6
.5
.4
.3
.25
.4
.5
.6
.7
.8
.9
1.0
2
60
50
40
30
20
10
8
6
5
4
3
2.5
1
.1
.01
.001
5
6
7
8
9
10
11
12



d CM
K
N
L - IN μH
b CM
25
20
10
.9
.8
.1
.2
.3
2500
2000
1000
500
400
200
100
10000
1000
100
10
1.2
1.5
2
3
1
3

Calculating Coefficient of Coupling

Nomogram 4-2 simplifies calculation of coefficient of coupling (K) for transformers from the equation:

$$K = \sqrt{1 - \frac{f_o^2 C_o}{f_s^2 C_s}}$$

Where: C_o is the resonating capacitance of winding No. 1 with winding No. 2 open.

C_s is the resonating capacitance of winding No. 1 with winding No. 2 shorted.

f_o is the frequency with winding No. 2 open.

f_s is the frequency with winding No. 2 shorted.

Any unit may be used for the scales, provided that both the f_o scale and f_s scale use the same unit and that both the C_o scale and C_s scale use the same unit.

The following example will illustrate the use of the nomogram.

Example: Find the coefficient of coupling K of a transformer which has a resonating capacitance of 3 pf at a frequency of 90 kHz with the secondary winding open, and a resonating capacitance of 9 pf at a frequency of 80 kHz with the secondary winding shorted.

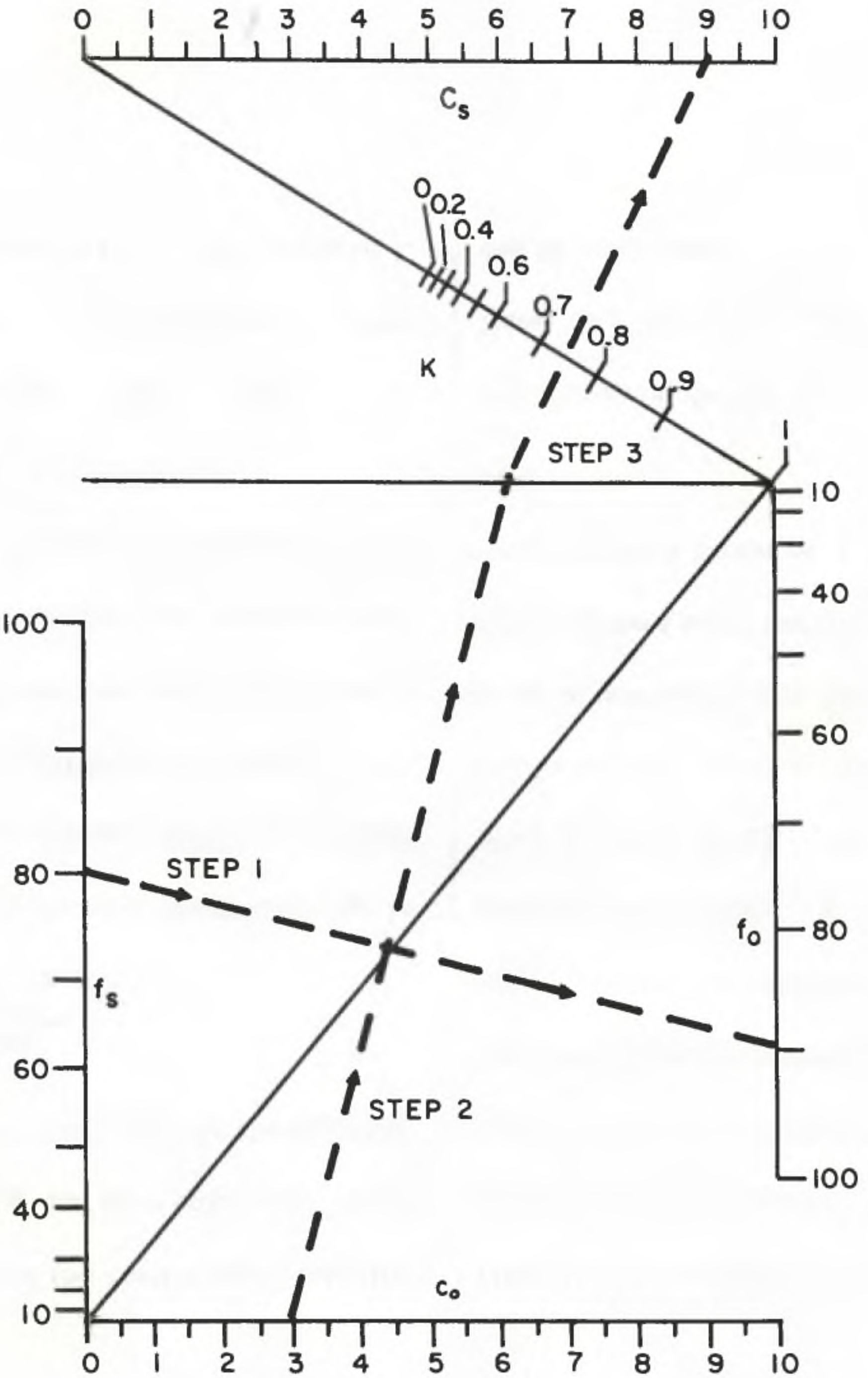
Solution:

(1) Draw a straight line from 80 on the f_s scale to 90 on the f_o scale.

(2) Draw a second line from 3 on the C_o scale to the point where the first line crosses the diagonal scale and extend it to the pivot line.

(3) From the junction of the second line and the pivot line, draw a third line to 9 on the C_s scale.

(4) K = 0.76 is found where the third line crosses the K scale.



0 1 2 3 4 5 6 7 8 9 10
C_s
0
0.2
0.4
0.6
0.7
0.8
0.9
1
K
STEP 3
10
40
60
80
100
f_o
100
80
60
40
10
f_s
STEP 1
STEP 2
c_o
0 1 2 3 4 5 6 7 8 9 10

Mutual Inductance

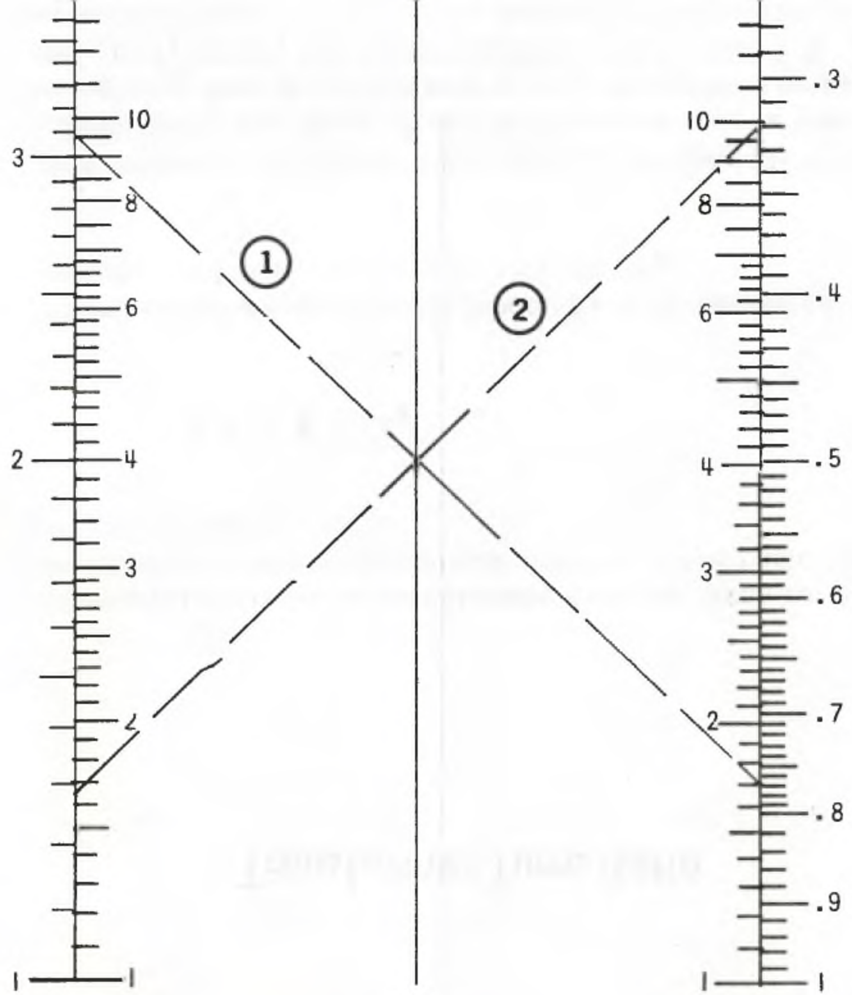
The calculation of the coefficient of coupling can be frustrating and time consuming, even with the use of the slide rule. In the equation:

$$K = \frac{M}{\sqrt{L_1 L_2}}$$

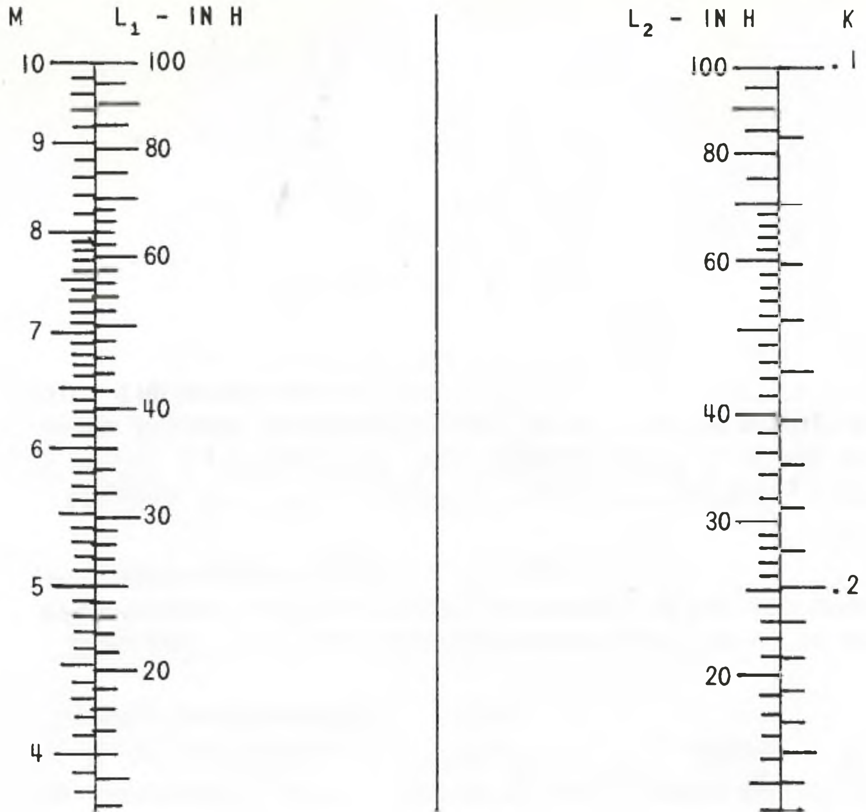
Where: L_1 is the primary inductance, L_2 is the secondary inductance, and M is the mutual inductance. The coefficient of coupling K can be found rapidly with the use of this nomogram by simply drawing two straight lines. The method of solution is illustrated in the example shown in the nomogram.

For loose coupling, where values of K are between .01 and .1, both the K and M values must be multiplied by 10^{-1}. For values of L other than those shown, the L_1, L_2, and M scales must all be multiplied by 10^n, where n may be positive or negative. When this is done the values of K remain unchanged. When only L_1 and L_2 are multiplied by 10^n and M remains unchanged, K must by multiplied by 10^{-n}. NOTE: The M and L_1 scales can be used for finding squares and square roots of numbers where the L_1 scale is equivalent to the A scale and the M scale is equivalent to the D scale on a normal 10" slide rule.

In the example illustrated by the dashed lines, $L_1 = 9.5$ mh, L_2 is 1.7 mh, $k = .32$, and $M = 1.28$ mh.



10
3
8
1
6
2
4
3
2
1
1
.3
10
8
2
.4
6
4
.5
3
.6
2
.7
.8
.9
1
1



M
L1 - IN H
10
9
8
7
6
5
4
100
80
60
40
30
20
L2 - IN H
K
100
80
60
40
30
20
.1
.2

Transformer Turns Ratio

Nomogram 4-4 aids in the computation of the turns ratio for transformers used for impedance matching. The basic equation for the turns ratio is:

$$T.R. = \sqrt{Z_1/Z_2}$$

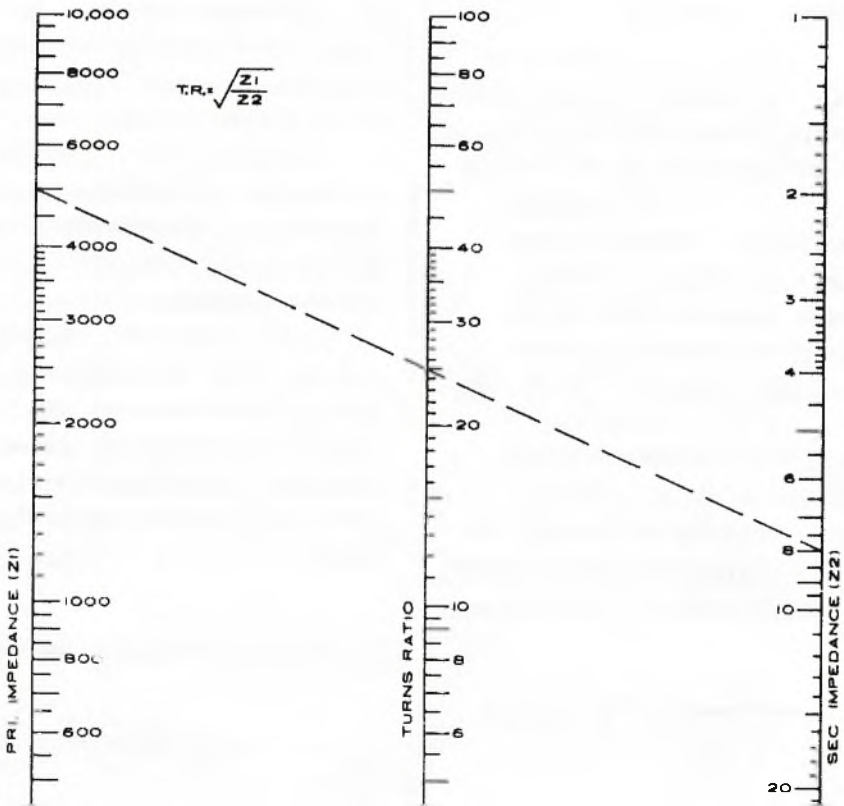
Where: Z_1 is the primary impedance, Z_2 is the secondary impedance, and T.R. is the turns ratio N_1/N_2.

The method of solution is illustrated in the example below. Values other than those shown on the scales may be used by multiplying them by 10^n, where n may be positive or negative. If Z_1 and Z_2 are both multiplied by 10^n, then T.R. remains unchanged. If only Z_1 is multiplied by 10^n, then T.R. is multiplied by $10^{n/2}$. If only Z_2 is multiplied by 10^n, then T.R. is multiplied by $10^{-n/2}$. Using even values of n will simplify the conversion of scales.

Example: Find the turns ratio required for an audio output transformer to match a plate impedance of 500,000 ohms to a speaker where impedance is 8 ohms.

Solution: Draw a straight line from 5,000 on the Z_1 scale to 8 on the Z_2 scale. The line crosses the T.R. scale at 25. Since Z_1 was multiplied by 100, T.R. must be multiplied by 10. The turns ratio is 250/1.


400
300
200
100
4
3
2
1
30
40
60
80
100



$T.R. = \sqrt{\frac{Z1}{Z2}}$
PRI. IMPEDANCE (Z1)
10,000
8000
6000
4000
3000
2000
1000
800
600
TURNS RATIO
100
80
60
40
30
20
10
8
6
SEC IMPEDANCE (Z2)
1
2
3
4
6
8
10
20

Impedance Test Procedure for Incoming Inspection

With the use of this procedure and the included nomogram, nonskilled operators may be employed in the incoming inspection testing of low-frequency chokes and transformers for radios, television receivers, and other consumer products. The procedure described is a general test method for impedance measurements and originality is not implied. However, simplified methods are described which allow the use of unskilled help, resulting in a labor cost saving.

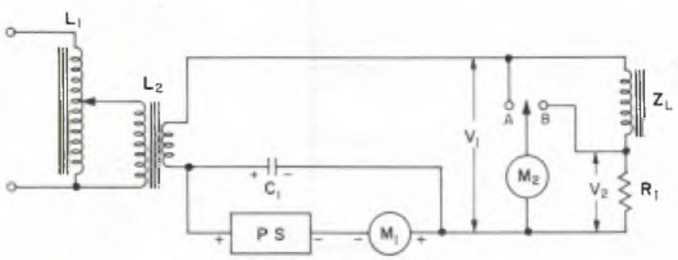


Fig. 4-1. Impedance test procedure test setup.

The engineering prints for the components may specify certain conditions for the tests which should be strictly adhered to. In most cases, 60 Hz will be specified as the test frequency; therefore, the illustration is shown using a variable transformer that is fed from a 120-volt source. Isolation is obtained with the use of a 12-volt stepdown transformer when low voltages are specified and a 1:1 ratio isolation transformer for higher voltages. Where other frequencies are specified, an audio oscillator may be used. In those cases where a DC bias is required as a prerequisite for the test, a low impedance DC supply should be used as illustrated. (Refer to Fig. 4-1.) The accuracy of the test is dependent upon the following conditions:

(1) R_1 should be selected so that its resistance is very much smaller than the impedance of the inductor under test.

(2) R_1 should be smaller than the DC resistance of the inductor.

(3) R_1 should be within 5% accuracy.

With the circuit hooked up as shown in the illustration, proceed with the test as follows:

(1) Starting from zero, adjust the variable transformer for the test voltage specified.

(2) Starting from zero, adjust the DC supply for the required DC bias if specified.

(3) Readjust the variable transformer if necessary. (This reading is V_1).

(4) Throw the meter switch to position "B" and read V_2).

(5) The impedance Z_L can be calculated from the following equation:

$$Z_L = \frac{V_1 R_1}{V_2}$$

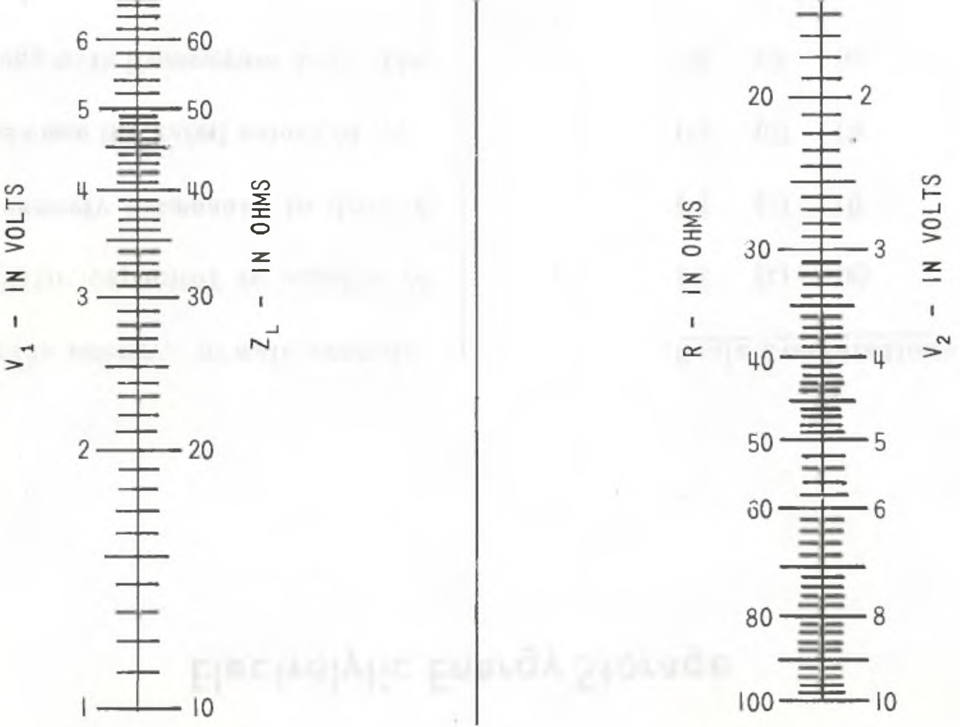
With the use of Nomogram 4-5, Z_1 can be rapidly found as follows:

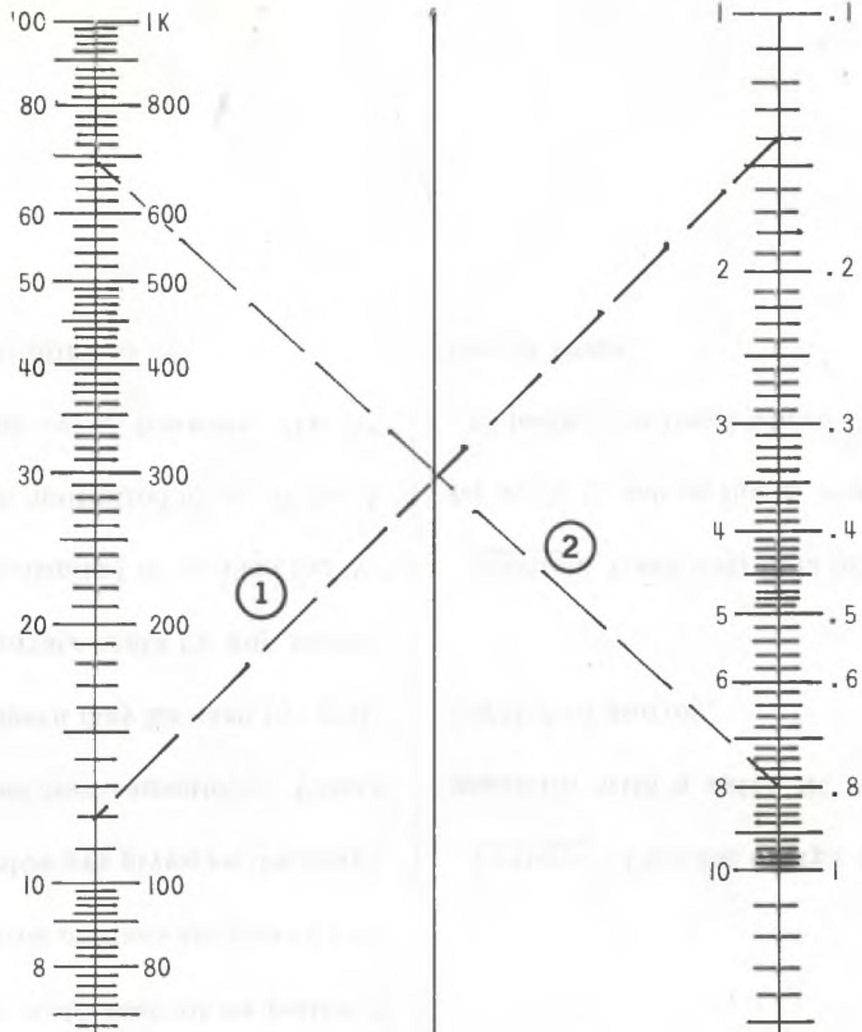
(1) Draw a straight line from the measured value of V_1 on the left-hand scale to the measured value of V_2 on the right-hand scale.

(2) Draw a second line from R_1 on its appropriate scale to the point where the first line crosses the pivot line, and extend the line to the Z_L scale where the unknown impedance can be read directly.

Example: In the test of an audio output transformer primary, find the impedance where $R_1 = 8$ ohms, $V_1 = 12$ volts, and $V_2 = .14$ volts.

Solution: (1) Draw a straight line from 12 on the V_1 scale to .14 on the V_2 scale. (2) Draw a second line from 8 on the R_1 scale through the point where the first line crossed the pivot line and extend it to the Z_L scale. Read 680 ohms on the Z_L scale. This is the impedance. (The answer is within slide rule accuracy.)


V1 - IN VOLTS
ZL - IN OHMS
R - IN OHMS
V2 - IN VOLTS
1
2
3
4
5
6
10
20
30
40
50
60
20
30
40
50
60
80
100
2
3
4
5
6
8
10


100
1K
80
800
60
600
50
500
40
400
30
300
20
200
10
100
8
80
1
2
1
.1
2
.2
3
.3
4
.4
5
.5
6
.6
8
.8
10
1

Electrolytic Energy Storage

To determine the energy, in watt-seconds, that an electrolytic capacitor is capable of storing, it is merely necessary to draw a straight line between the rated values of capacity and voltage with Nomogram 4-6. The energy storage in watt-seconds or joules is found where this line crosses the center column. Several scales are given on the chart, which should include most capacitors. Values other than those shown may be used by multiplying the appropriate scale by any factor. If the C scale is multiplied by n, then the WS scale must also be multiplied by n. If the E scale is multiplied by n, however, the WS scale must be multiplied by n^2.

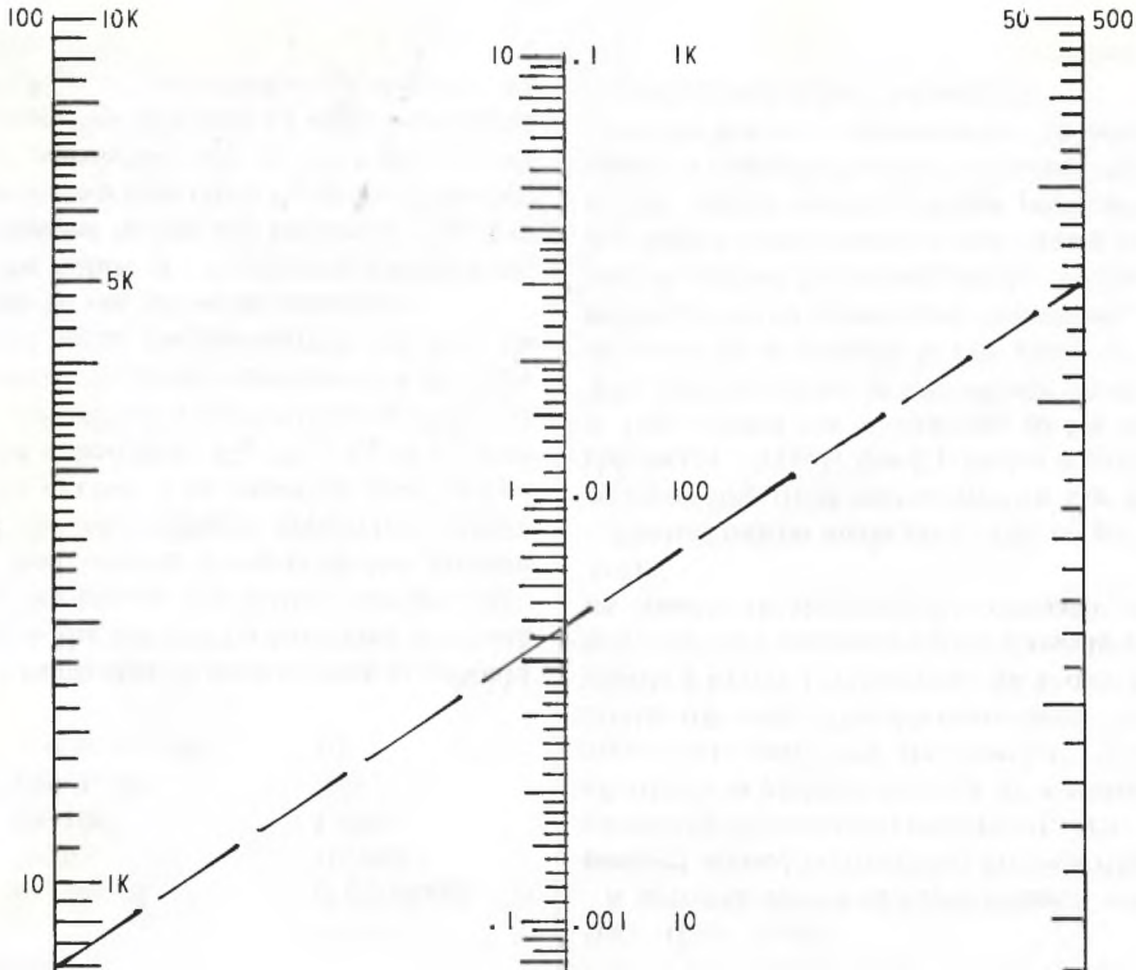
Scale Combinations

(a)	(c)	(g)
(b)	(c)	(f)
(a)	(d)	(f)
(b)	(e)	(g)

Example: Find the energy an 8-microfarad capacitor with a rated DC voltage of 350 is capable of storing.

Solution: Draw a straight line from 8 on the (a) scale to 350 on the (g) scale. The answer, .49 joules, is found where this line crosses the (c) scale.


C - CAPACITY IN MICROFARADS
500
100
WS - ENERGY STORAGE IN WATT/SECONDS OR JOULES
.01
.0001
1
.00001
.1
E - DC VOLTS
10
100
5
50
(a)
(b)
(c)
(d)
(e)
(f)
(g)


100
10K
5K
10
1K
10
.1
1K
1
.01
100
.1
.001
10
50
500

Capacitance Measurement

This capacitance test will find its maximum usefulness when applied to incoming inspection testing of electrolytics.

Fig. 4-2 shows the basic circuit of the tester. An AC voltage, equal to the product of the nominal rated AC ripple current and the approximate reactance resulting from the sum of the reactances of the capacitors at 60 Hz, is applied to the circuit. (In most cases approximately 30 volts rms may be used. Slightly higher voltage may be used for large values of capacitance.) E_{DC} is a polarizing potential equal to the rated DC working voltage of the unknown capacitor (C_X). This potential is applied across C_X through the series resistor R to prevent C_X from being shorted by the DC supply. R should have a value of about 20 times the reactance at 60 Hz. The limiting factor in determining the maximum value of R is the capacitor charging time, which should be short for rapid testing. The following chart shows some suggested values of resistance for various ranges of capacitance:

C_X (in µf)	R (in ohms)
1-10	10, 000
10-100	1, 000
100-1, 000	100
1, 000-10, 000	10

C_K is a capacitor of known value and should be close to the value of C_X for more accurate results. By taking the ratio of the two capacitors and setting it equal to the inverse ratio of the AC voltages appearing across them, we arrive at an equation from which C_X can be calculated. $C_X/C_K = E_K/E_X$ The task of calculating C_X can be done quickly and conveniently by using Nomogram 4-7. The method of using the nomogram can best be described by the following example:

Find the value of an unknown electrolytic (C_X) measured in the test fixture of Fig. 4-3 when the known capacitor C_K is 10 µf the AC voltages measured are 9 volts across the known capacitor (E_K) and 11 volts across the unknown (E_X). The solution is obtained in two steps.

(1) Align a straight-edge from 9 on the E_K scale to 11 on the E_X scale, and

(2) Align a straight-edge from 10 on the C_K scale and the point where the straight-edge crosses the pivot line in step 1. Extend this line. The answer, 8.2 µf, can be found on the C_X scale where the second line crosses it. For higher values of capacitance than those shown on the scales, merely multiply both C scales by 10^n.

The need for calculation of C_X can be eliminated and the value can be read off directly from the meter in the following manner:

(1) Adjust the AC input voltage until E_X appearing across C_X is equal to C_K in microfarads. Whether E_X is in volts or millivolts doesn't matter, as long as E_X and E_K are both in the same unit.

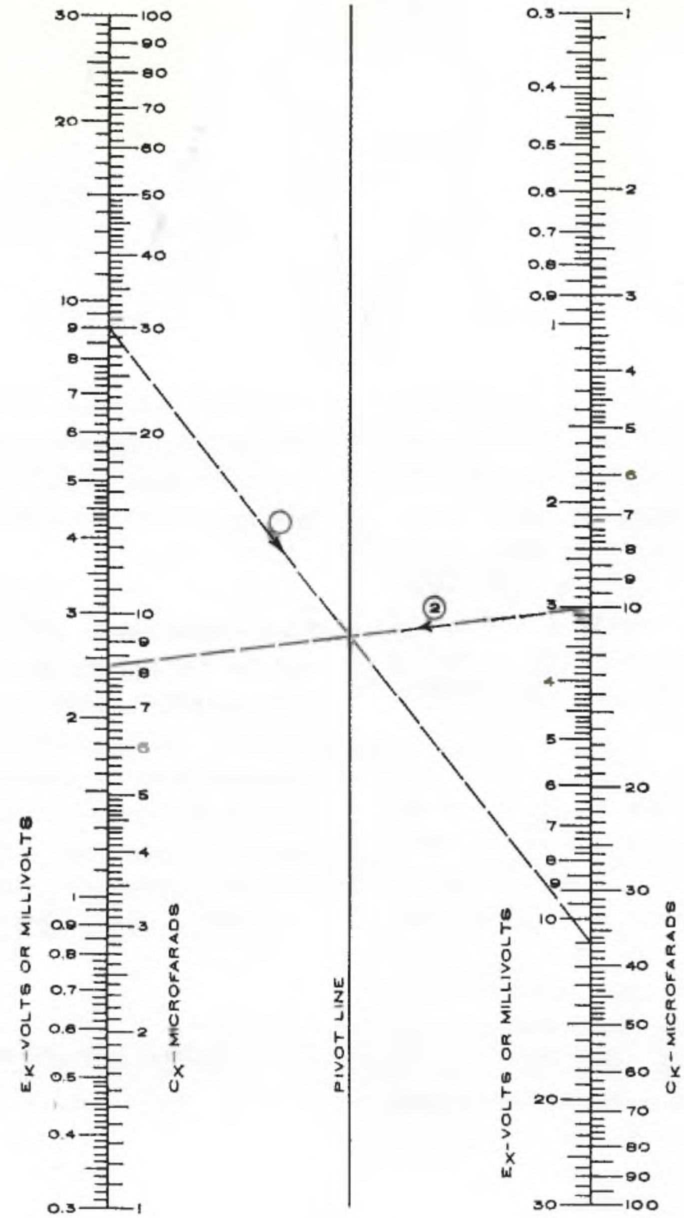
(2) Read E_K across C_K. This value in volts is equal to C_X in microfarads.

When it is necessary to measure large quantities of electrolytic capacitors, as in the case of incoming inspection departments, a test fixture can be constructed for rapid testing. (Fig. 4-3.)

A suitable means of rapid connect and disconnect should be provided for inserting and removing the capacitor under test. The meter should be a reliable type of AC vacuum-tube voltmeter, such as the Hewlett - Packard Model HP 400. The decision must be made whether to use two meters, as shown in Fig. 4-3, or only one meter with a toggle switch, as shown in the partial schematic of Fig. 4-2B.

The test can be made on a "go/ no go" basis by providing limit indications on the face of the meter. First, the E_X meter should have a line drawn on it parallel to the needle. This line should be on the voltage point which is equal in magnitude to the value of C_K in microfarads as previously described. This can be called the set-up point. Second, the E_K meter should have a line drawn parallel to the needle at the voltage point which is equal in magnitude to the minimum value acceptable for C_X. Another can be added for the maximum value if specified.

(Continued below)



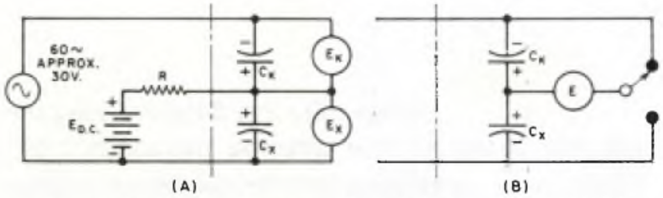


Fig. 4-2. (A) Basic circuit and (B) meter-switching arrangement.

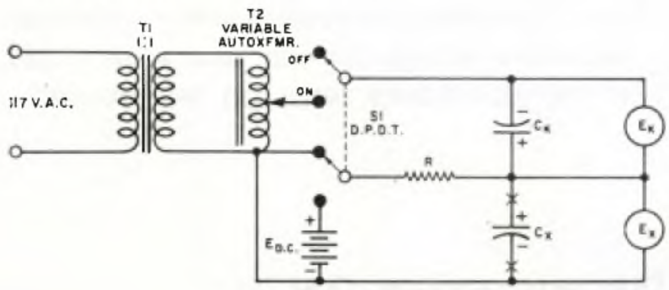


Fig. 4-3. Circuit diagram of the electrolytic test fixture.

The test for each capacitor can now be made in a matter of seconds by using the following procedure:

(1) Insert the capacitor into its holder, observing the proper polarity.

(2) Turn the "on-off" switch to its "on" position.

(3) Adjust the variable transformer until the needle on the E_X meter comes to the set-up mark.

(4) Observe the position of the needle on the E_K meter. It should fall on or between the two limit marks. If not, reject the capacitor.

(5) Turn the "on-off" switch to the "off" position.

(6) Remove the capacitor.

AC Motor-Starting Capacitance Chart

Commercial DC filter electrolytic capacitor testers are not capable of accurately checking AC motor-starting capacitors. This test should be made under simulated actual working conditions. In other words, they should be tested at line voltage by measuring the impressed voltage across them and the current passing through them.

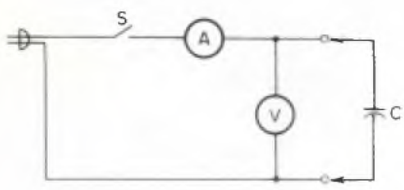


Fig. 4-4. Capacitor test circuit.

Fig. 4-4 shows the circuit for the suggested test. The switch should be of the thermal type that will release itself in case of a short. To obtain accuracy of less than one microfarad, care should be taken in the selection of the voltmeter and the ammeter. It is also recommended that the unit under test be maintained at a temperature of 25° C for two hours just prior to testing. Proceed with the test as follows:

(1) Connect the capacitor to the test leads.

(2) Throw the switch to the "on" position. Do not allow the capacitor to remain connected for more than 5 seconds.

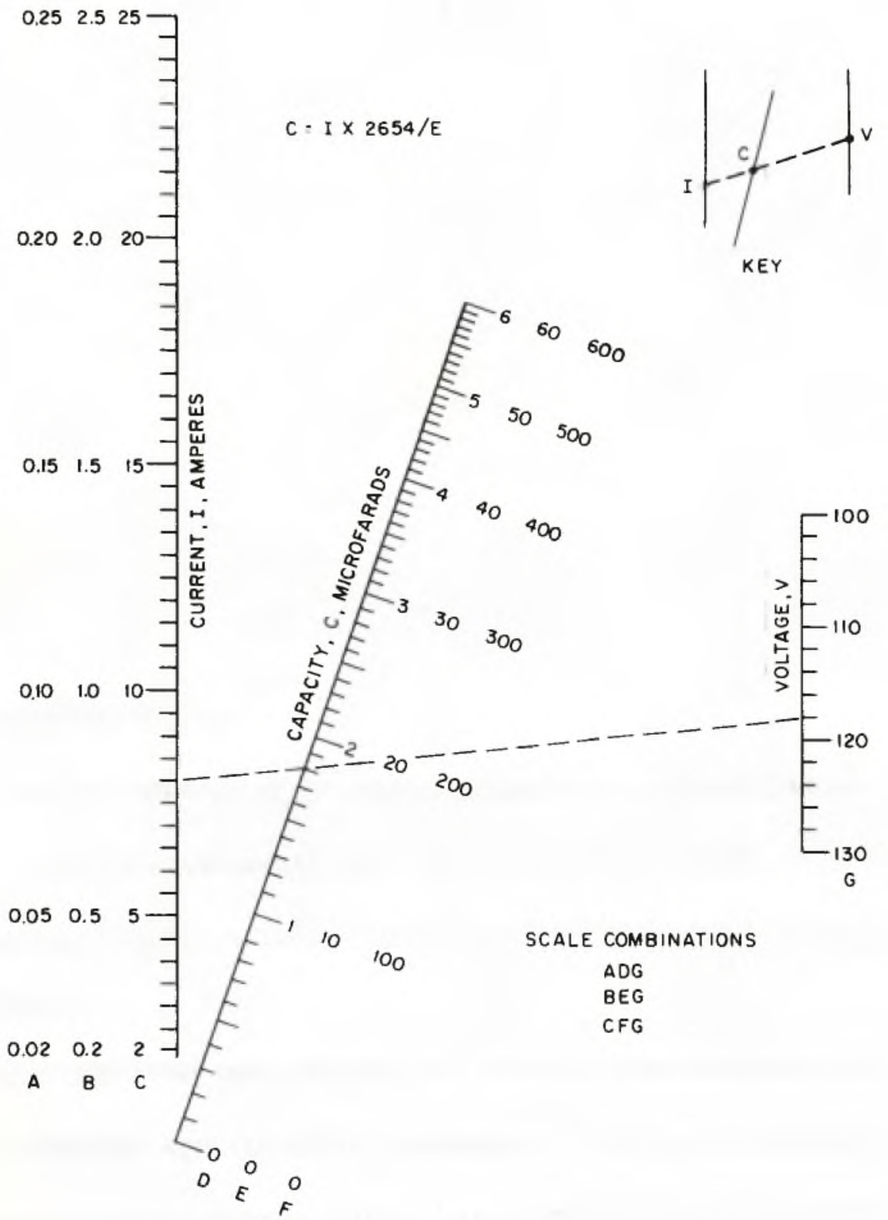
(3) Record the readings taken from the ammeter and voltmeter during the 5-second period.

(4) Throw the switch to the "off" position and compute the capacity from the formula: $C = I \times 2,654/\text{volts}$.

The capacity is rapidly computed with the use of the nomogram by merely extending a straight-edge through the recorded values of current and voltage on their respective scales. The value of capacity is found on the appropriate capacity scale where this line crosses it. Several scales are given for current and capacity and the proper scale combinations to be used are shown on the nomogram. Values other than those shown on the various scales may be used merely by multiplying the desired scale by n. If current scales are multiplied by n, capacity scales must also be multiplied by n. If voltage scales are multiplied by n, capacity scales must be divided by n. n may be any number, either whole or fraction.

Example: Determine the capacity of a unit tested as described above where the current reading is 8 amperes and the voltage is 118.

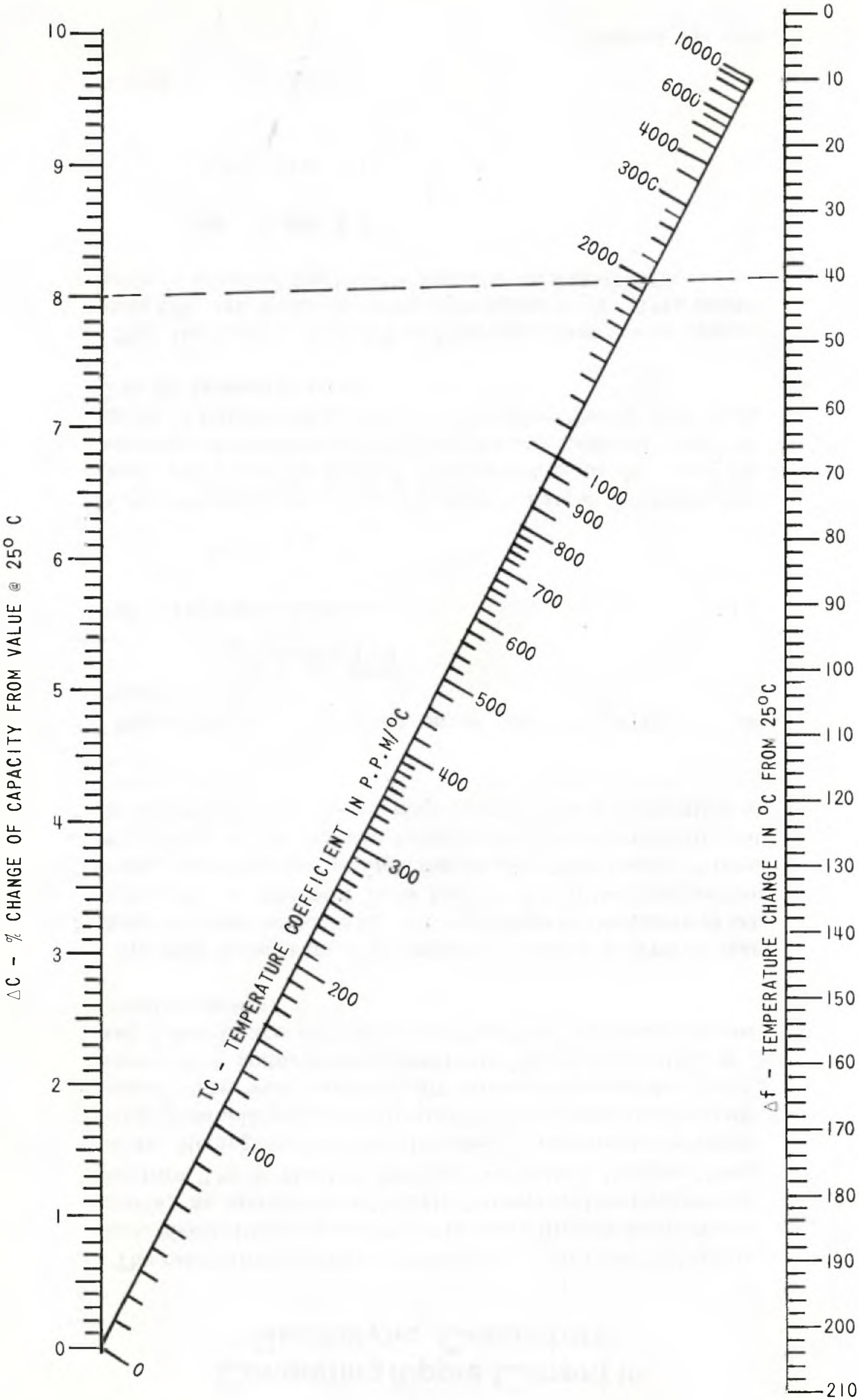
Solution: Extend a straight-edge from 8 on the C scale of the left-hand column to 118 of the G scale on the right-hand column. The answer, 180 microfarads, is found where this line crosses the F scale of the diagonal column.


C = I X 2654/E
KEY
I
C
V
CURRENT, I, AMPERES
0.25 2.5 25
0.20 2.0 20
0.15 1.5 15
0.10 1.0 10
0.05 0.5 5
0.02 0.2 2
A B C
CAPACITY, C, MICROFARADS
6 60 600
5 50 500
4 40 400
3 30 300
2 20 200
1 10 100
0 0 0
D E F
VOLTAGE, V
100
110
120
130
G
SCALE COMBINATIONS
ADG
BEG
CFG

Capacitor Temperature Coefficient

The temperature coefficient of a capacitor is related to its temperature stability. That is, it is a measurement of change in capacity with change in temperature. For this nomogram it is assumed that the test was made at room temperature (25^{o}C).

In the example illustrated by the dashed line, there is a 40^{o} change in temperature from 25^{o} C for an 8% capacity change from its value at 25^{o}C, which results in a temperature coefficient of 2,000.


ΔC - % CHANGE OF CAPACITY FROM VALUE @ 25° C
TC - TEMPERATURE COEFFICIENT IN P.P.M/°C
Δf - TEMPERATURE CHANGE IN °C FROM 25°C
0
1
2
3
4
5
6
7
8
9
10
100
200
300
400
500
600
700
800
900
1000
2000
3000
4000
6000
10000
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210

Computing Ripple Current in Electrolytic Capacitors

The calculation of ripple current in a polarized DC aluminum electrolytic capacitor can be simplified by using nomograms, as discussed in "Ripple Current in Electrolytic Capacitors," by J. Meek in Electro-Technology (January 1964, p104). Nomogram 4-10 can be used to determine the maximum allowable power dissipation W within the capacitor container. The basic equation for the nomogram is $W = 2A/T$, where T is ambient temperature in ^{o}C, $A = 2\pi r (L + r)$, and r and L are the radius and length of the capacitor container in inches.

To read Nomogram 4-10 properly, extend a straight line from the point on scale L, corresponding to the length of the container, to intersect pivot line P. From the intersection point, extend another straight line to the point of scale T corresponding to the ambient temperature. The intersection of the line with scale W is the maximum allowable dissipation in watts.

Nomogram 4-11 is based on on equation in MIL-C-62B where:

$$I_{ma} = 0.003 \sqrt{CV}$$

and on the power formula:

$$W_{dc} = I_{ma} V$$

It can be used to determine DC watts. Extend a straight line from the point on scale A corresponding to the rated DC working volts to the point on scale D corresponding to the capacity in microfarads. The intersection of the line with scale C is the leakage current.

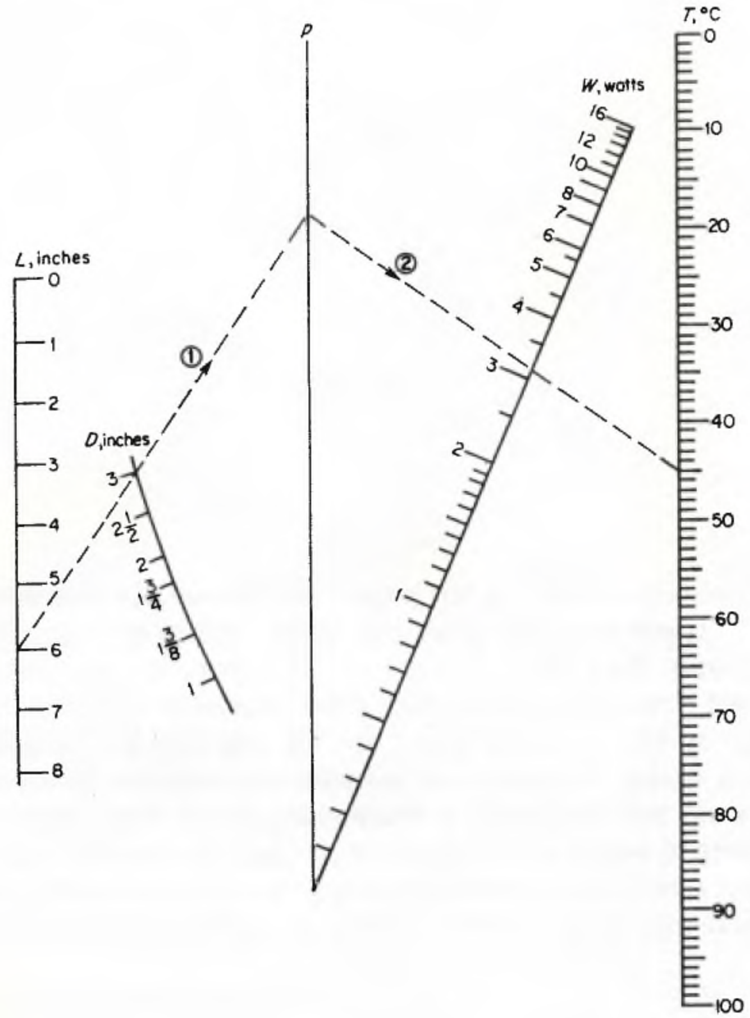
The dissipation factor DF and the equivalent series resistance ESR are found by using Nomogram 4-12. This nomogram is based on the 120-Hz formulas in MIL-C-62B:

$$DF = 0.006 \sqrt{C}$$

$$ESR = 1326\ DF/C$$

Where: C is in microfarads.

(Continued on next page)

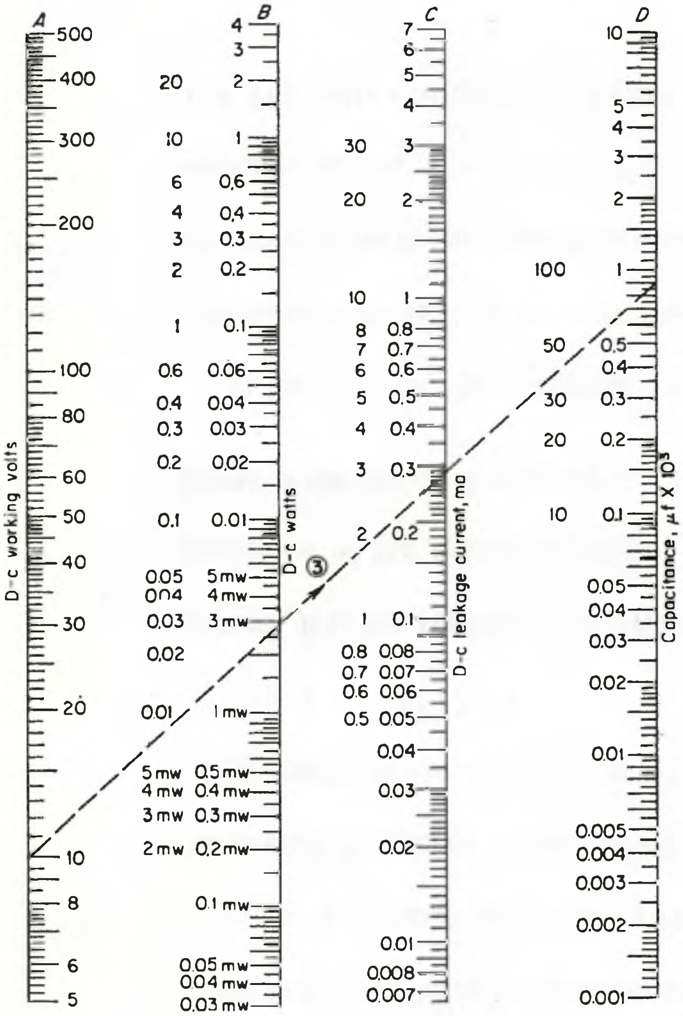


Nomogram 4-10

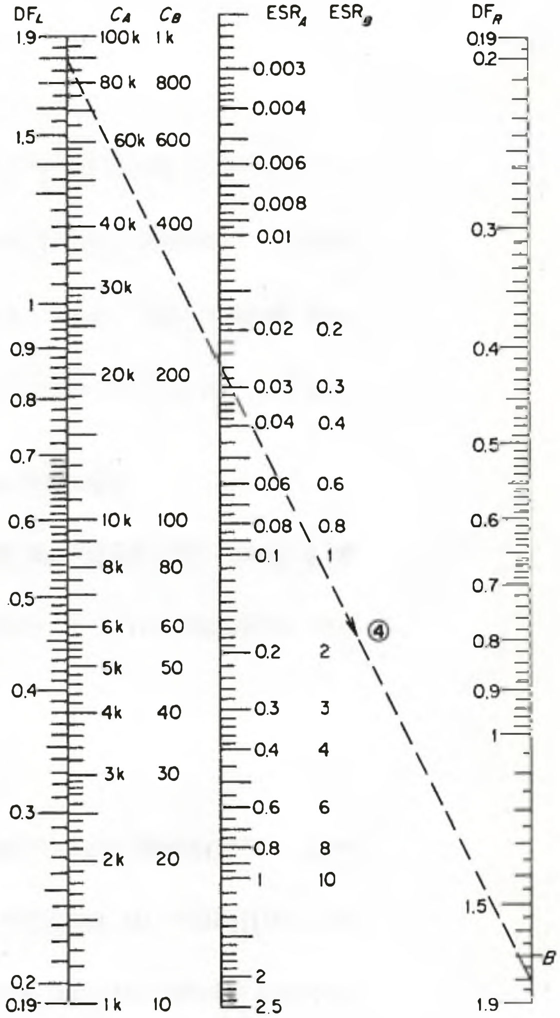
The procedure for using the nomogram depends on the value of the capacitor. If the capacitance is less than 1,000 μf, extend a straight line from the point on scale C_B, corresponding to the capacitance, to point B on scale DF_R. The intersection of the line with scale ESR_B is the equivalent series resistance.

If the capacitance is greater than 1,000 μf, locate its value on scale C_A. This point also corresponds to the dissipation factor on the adjacent scale DF_L. Extend a straight line from the capacitance value on C_A to the point on scale DF_R that corresponds to the value of dissipation factor found on scale DF_L. The intersection of the line with scale ESR_A is the equivalent series resistance.

Consider the example in Meek's article: A 90,000-microfarad capacitor rated at 10 working volts DC is to be subjected to an ambient of 45°C. The container is 3 inches in diameter x 6 inches long. From Nomogram 4-10 we find that the maximum allowable power dissipation is 3.18 watts. From Nomogram 4-11 we find that W_{dc} is 0.029 watts. Then $W - W_{dc} = W_{ac} = 3.151$ allowable watts. In Nomogram 4-12, the line from 90,000 on scale C_A to 1.8 on scale DF_R intersects scale ESR_A at 0.026. Since we know the ESR and W_{ac}, we can use Meek's nomogram to find the AC ripple current.



Nomogram 4-11



Nomogram 4-12

Bypass Capacitor Determination

Though Nomogram 4-13 is based on an equation derived originally for use in vacuum-tube audio amplifier design, it is useful in many bypass applications. A prime use of the nomogram is to determine the nominal value of capacitance needed to bypass a cathode (or emitter) resistor of an amplifier so the lowest frequency to be down 3 db can be specified. The nomogram is based on the equation:

$$C = 10^7/2\pi fR$$

Where: R is the resistor to be bypassed, C is the nominal capacitance of the bypass capacitor in microfarads, and f in Hertz is the lowest frequency to be bypassed.

C is found simply by extending a straight-edge from f in the left-hand scale to R in the right-hand scale, and noting the intersection with the capacitance scale in the center. In the example shown, f is 60 Hz, R is 180 ohms, and C is 146 μf. The AHI scale combination is used.

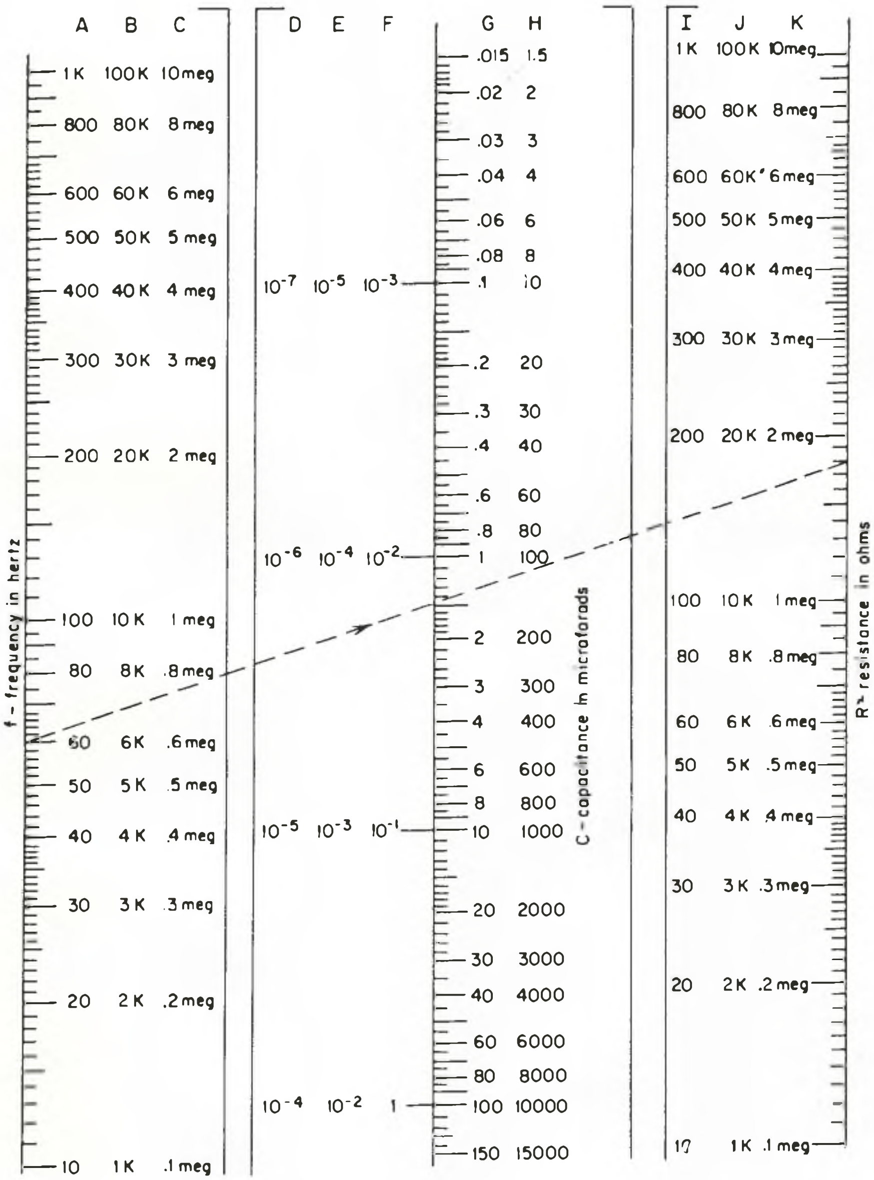


Chart of Scale Combination

AFK	BEK	CDK
AGJ	BFJ	CEJ
AHI	BGI	CFI

CHAPTER 5

Vacuum Tubes and Transistors

R-C Coupled Amplifier Analysis

These nomograms will be found, by engineers and technicians alike, to be of time-saving value in the analysis and design of R-C coupled amplifiers. They do not eliminate the trial and error method normally encountered in such designs, but they do eliminate the calculation of many equations which are tedious and repetitious. Although they are based on vacuum tube design, many analogies and direct applications can be made to transistor circuitry.

Fig. 5-1(a) is a schematic of a simple triode R-C coupled amplifier, and Fig. 5-1(b) is its equivalent circuit from which we may more readily analyze the amplifier. From Thevenin's theorem the tube was replaced by an AC voltage source with an output equal to μ (the amplification factor) times the input signal e_s. The AC plate resistance of the tube, r_p, is shown in series with the signal source. The amplified signal voltage is developed across R_L, the plate load resistor of the triode stage. This signal is in turn coupled through C_c to the grid of the following stage. Gridleak resistor R_g of the following stage is included, since the output voltage e_o appears across it. C'_p is the output shunt capacitance of the tube under analysis and includes C_{pk} (the plate-to-cathode interelectrode capacitance) plus stray wiring capacitances. C'_g is the input shunt capacitance of the tube of the following stage. If the voltage is being delivered to a pentode, C'_g is equal to the sum of C_{gk} (grid-to-cath-

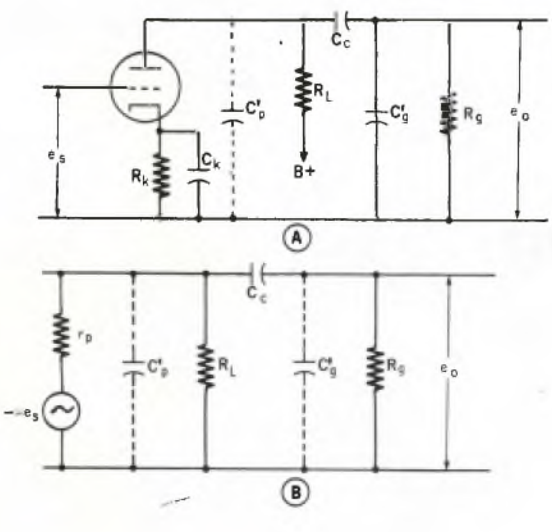


Fig. 5-1. (a) Triode R-C coupled amplifier.
(b) Equivalent circuit of a.

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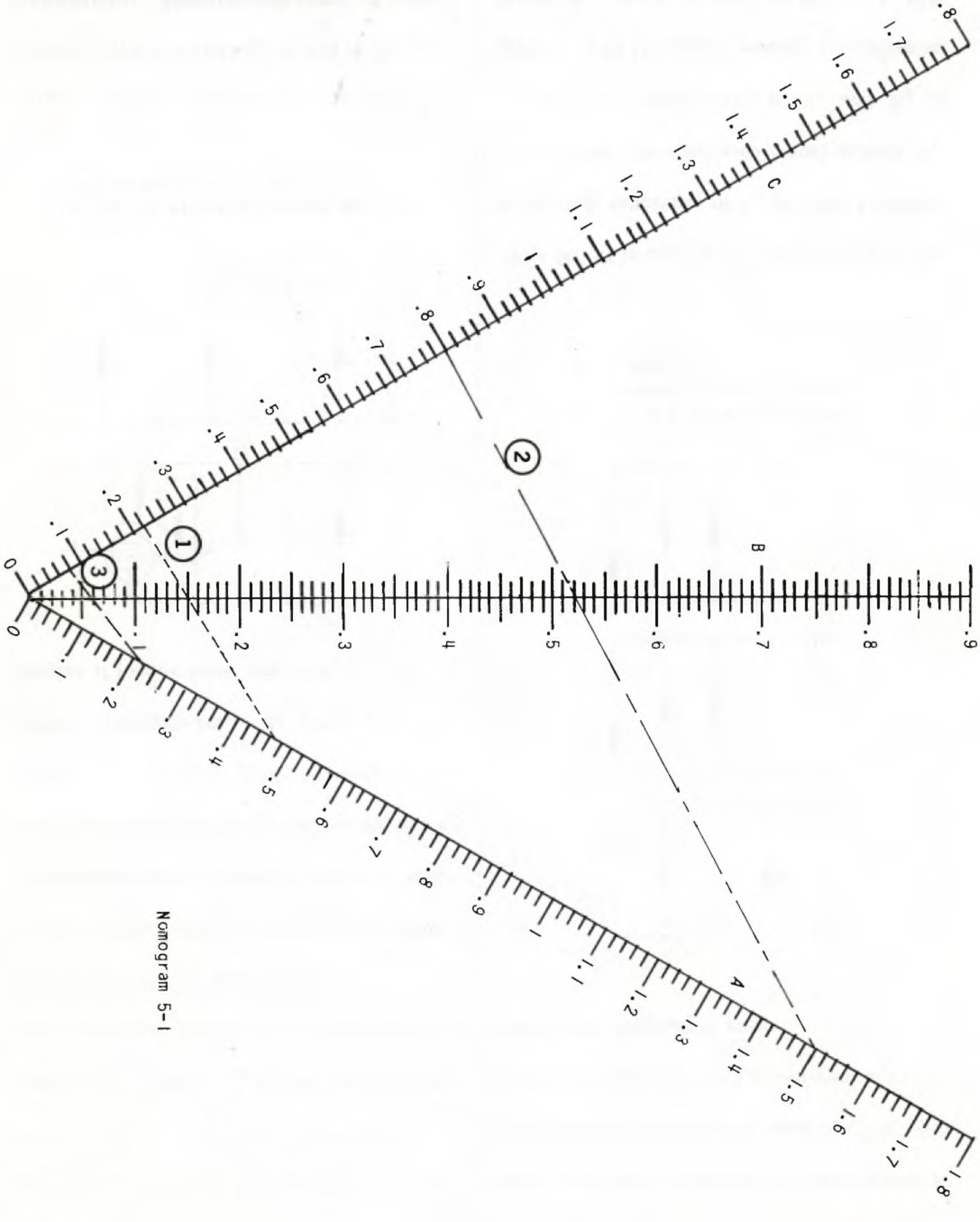


Nomogram 5-1

ode capacitance), C_{gs} (grid-to screen capacitance), and stray wire capacitances. If the voltage is being delivered to a triode, then $C'_g = C_{gk} + C_{gp}(1+A)$ + stray wire capacitances, where C_{gp} is the grid-to plate capacitance and A is the gain of the stage and will normally be at least 1/2 times μ. The interelectrode capacitances are built into the tube and we have no control over them. However, the stray wiring capacitances can be kept down to between 4 and 10 picofarads by careful arrangement. (It could be much greater if longer leads are used.)

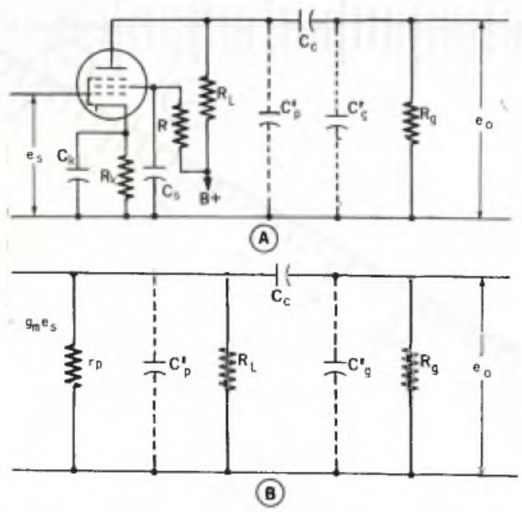


Fig. 5-2. (a) Pentode R-C coupled amplifier. (b) Equivalent circuit of a.

Fig. 5-2(a) is a schematic of a pentode R-C coupled amplifier and Fig. 5-2(b) is its equivalent circuit. Since pentode tubes have higher plate resistance and amplification factors it is simpler to use the constant-current generator form, while the constant-voltage generator is more convenient to use for triodes. For simplification of this analysis, Fig. 5-3 shows the equivalent circuit broken down for the various frequency ranges.

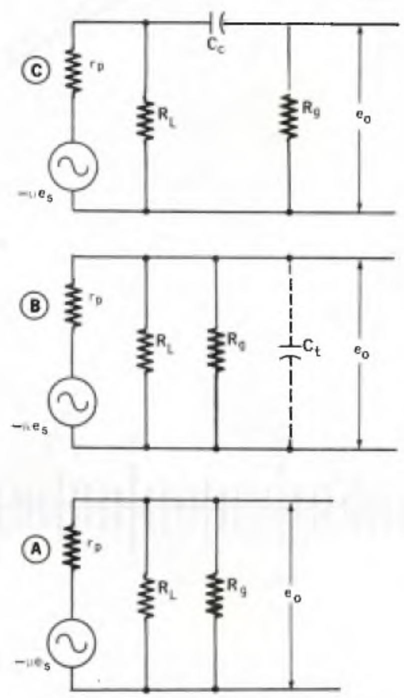
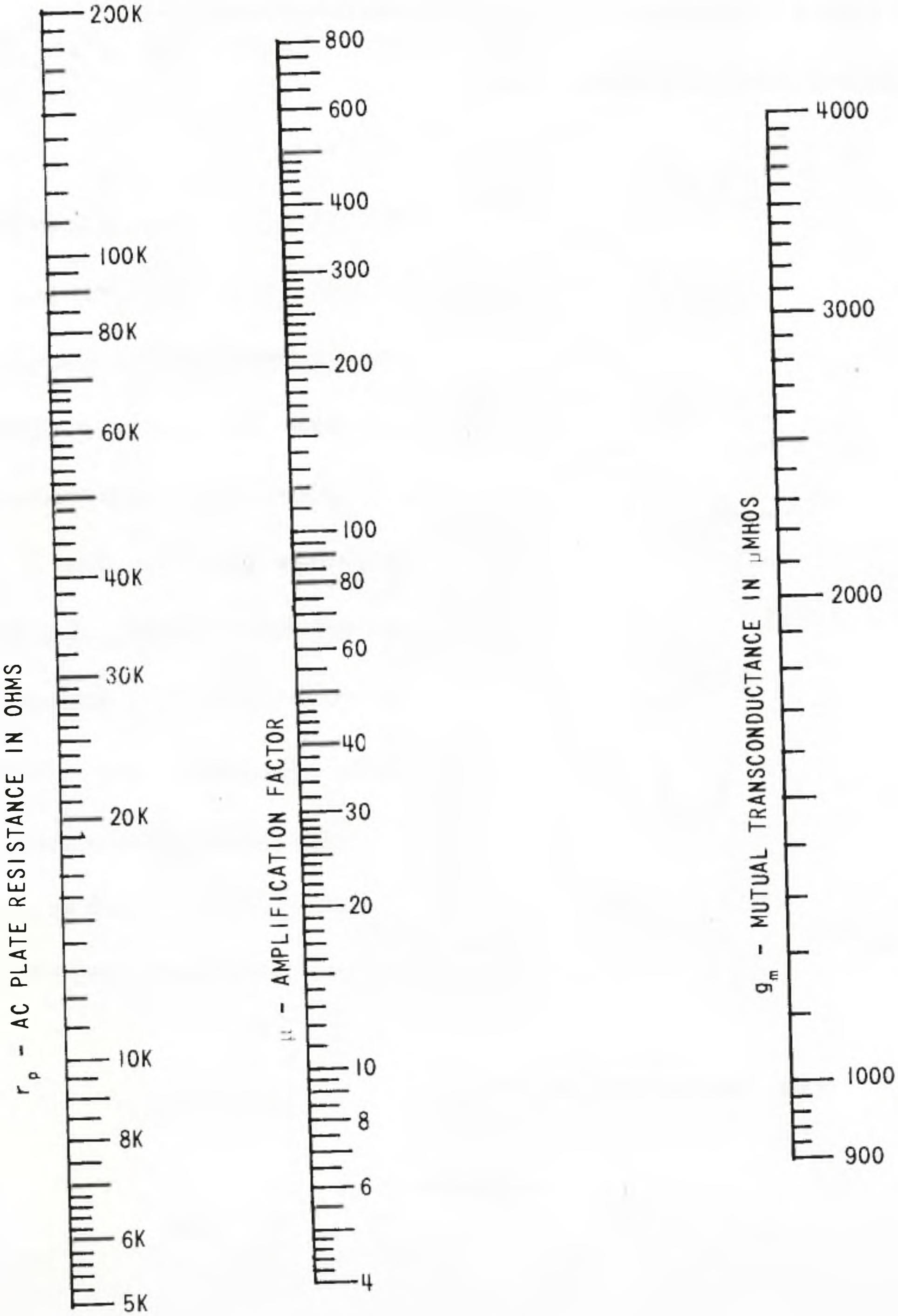


Fig. 5-3. (a) Mid-frequency. (b) High-frequency. (c) Low-frequency.

The falloff in gain at low frequencies is due to the high reactance of C_c at these frequencies. Since the developed signal across R_L is fed to the combination of C_c and R_g in series, with the output voltage e_o appearing across R_g, it can be seen in Fig. 5-4 that

(Continued on next page)


200K
100K
80K
60K
40K
30K
20K
10K
8K
6K
5K
r_p - AC PLATE RESISTANCE IN OHMS
800
600
400
300
200
100
80
60
40
30
20
10
8
6
4
μ - AMPLIFICATION FACTOR
4000
3000
2000
1000
900
g_m - MUTUAL TRANSCONDUCTANCE IN μMHOS

Nomogram 5-2

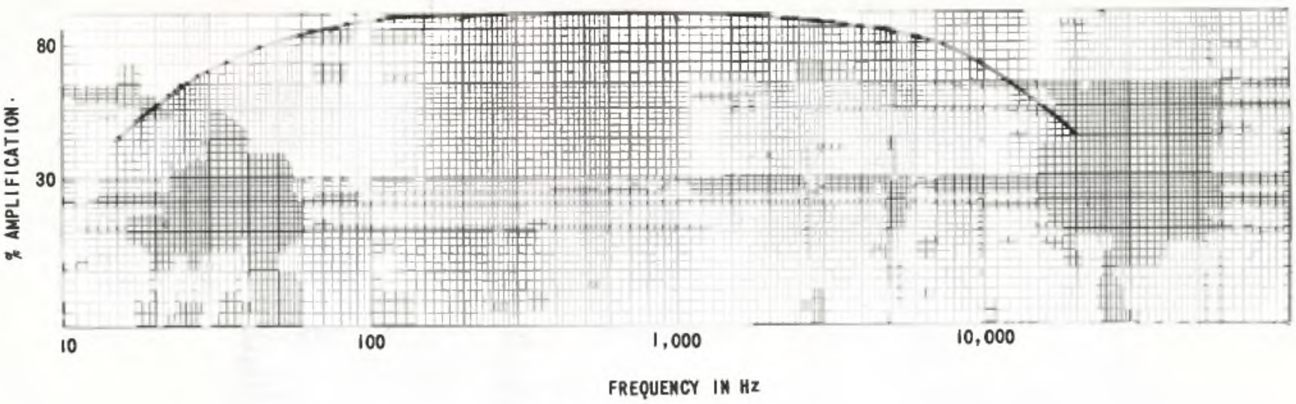


Fig. 5-4. Typical response curve of a pentode R-C coupled amplifier.

the larger X_c becomes, the smaller e_o will be. The fall-off in gain at high frequencies is due to the lumped shunt capacitance, previously discussed, which effectively shunts R_g, thereby lowering the effective load impedance. At the mid-frequency range the reactance of C_c is very small with respect to R_g and may be considered to be a short circuit. The reactance of C_t is very high with respect to R_g and may be considered to be an open circuit. The stage gain A is given for the various frequency ranges by the following equations:

(1) $A_m = \mu R/(R + r_p)$ Medium frequencies for triode amplifiers

(2) $A_m = g_m r$ Medium frequencies for pentode amplifiers

(3) $A_h = \dfrac{A_m}{\sqrt{1 + (r/X_t)^2}}$ High frequencies for both amplifiers

(4) $A_L = \dfrac{A_m}{\sqrt{1 + (X_c/\rho)^2}}$ Low frequencies for both amplifiers

(5) Where: $R = R_L R_g / (R_L + R_g)$

(6) $r = Rr_p / (R + r_p)$
$= r_pR_LR_g / (r_pR_1 + r_pR_g + R_LR_g)$

(7) $\rho = R_g + \dfrac{R_L r_p}{R_L + r_p}$

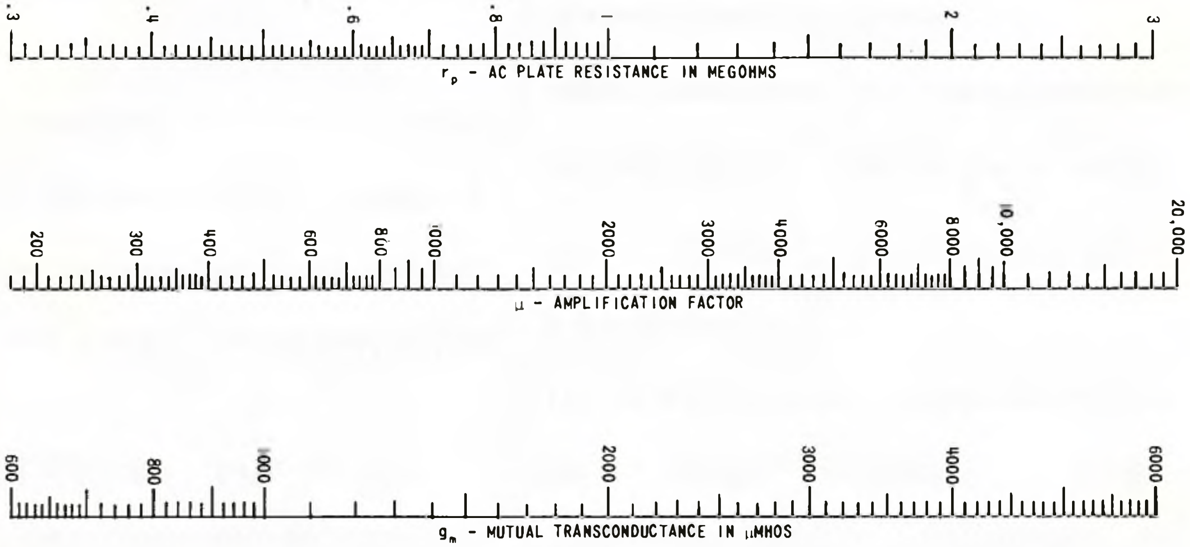
(8) $X_t = 1/(\omega C_t)$

(9) $C_t = C'_p + C'_g$

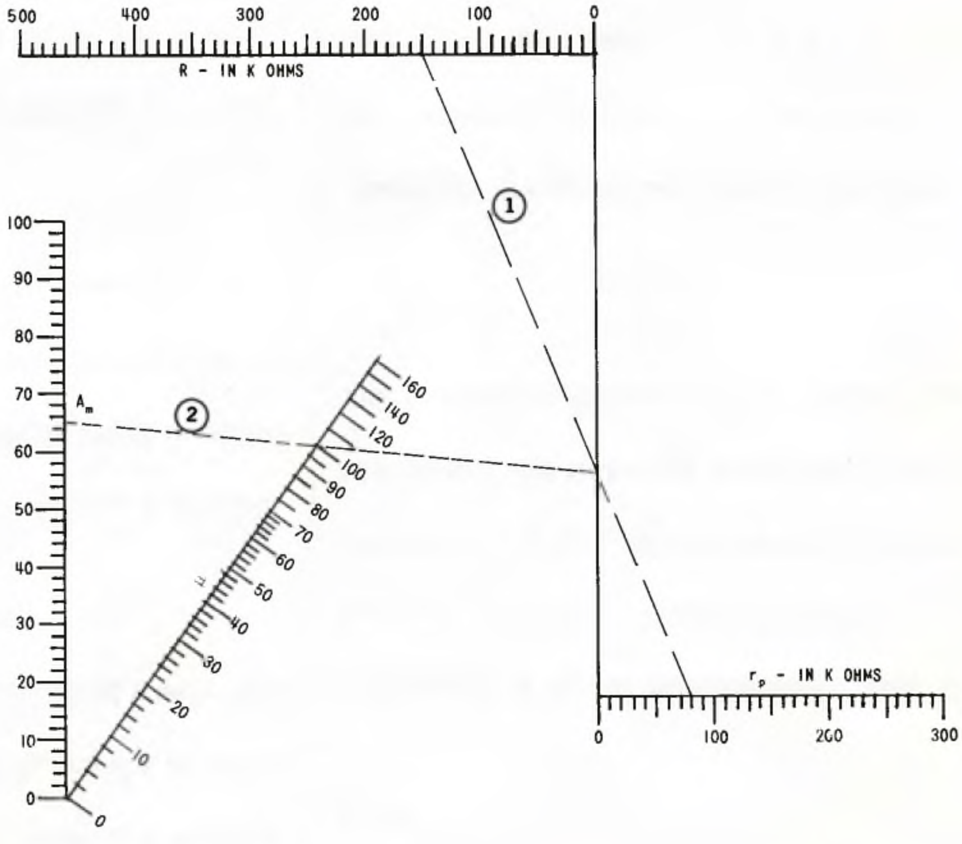
(10) $X_c = 1/(\omega C_c)$

In the analysis of pentode amplifiers, where r_p is very much greater than R_L and R_g, it may be assumed that $r \approx R_L$, and A_m is approximately equal to $g_m R_L$. Only a very small error is introduced by this assumption.

(Continued on next page)



Nomogram 5-3



Nomogram 5-4

Nomogram 5-1 is for the solution of parallel resistors.

Equation (5) is solved by drawing a straight line through the values of R_L on the A scale and R_g on the C scale. R is found where this line intersects the B scale.

Equation (6) is solved by drawing a straight line through the values of R (as found in equation 1) on the A scale and r_p on the C scale. r is found where this line intersects the B scale.

Equation (7) is solved by drawing a straight line through the values of R_L on the A scale and r_p on the C scale. Mentally add the value of R_g to the value found where the line intersects the B scale. This is the value of ρ.

Nomograms 5-2 and 5-3 may be used to find the third tube characteristic when only two are given in the tube manual. Nomogram 5-2 is for triodes and Nomogram 5-3 is for pentodes.

Mid-frequency gain A_m is found in Nomogram 5-4 for triode amplifiers and in Nomogram 5-5 for pentode amplifiers.

High-frequency gain A_h is found in Nomograms 5-6A and 5-6B, while the low-frequency gain A_L is found in Nomograms 5-7A and 5-7B.

<u>Example</u>: Find the mid-frequency gain A_m and the 3 db falloff frequencies for the circuit of Fig. 5-1(a), where the tube used is a 12AV6 and the following stage uses a 50C5. The component values are R_L = 220K, R_g = 470K, and C_c = .006 mfd.

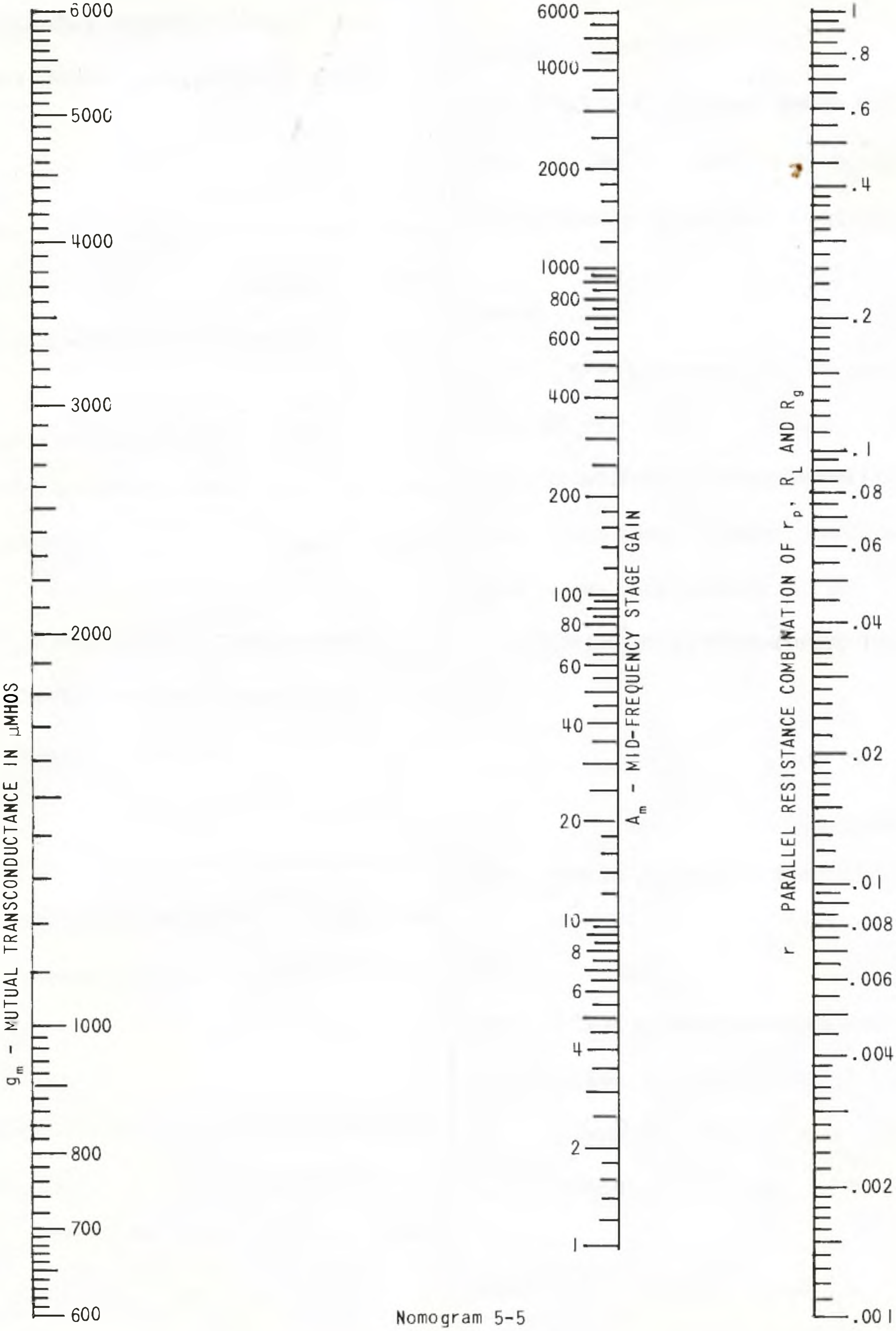
Solution: From the tube manual the following constants are found for the 12AV6: μ = 100, r_p = 80K, and C_{pk} = .8 pf. For the 50C5: C_{gs} = 13 pf and C_{gk} = 13 pf.

Stray capacitance is estimated as 10 pf each for C'_g and C'_p; therefore: C_t = .8 + 10 + 13 + 13 + 10 = 46.8 pf. In Nomogram 5-1 we find the values of:

(a) $R = R_L R_g/(R_L + R_g)$ as follows: Draw a straight line from 220K on the C scale to 470K on the A scale. R = 150K is found where this line crosses the B scale.

(b) $r = Rr_p/(R + r_p)$ as follows: Draw a straight line from 150K on the C scale to 80K

(Continued on next page)



g_m - MUTUAL TRANSCONDUCTANCE IN μMHOS
6000
5000
4000
3000
2000
1000
800
700
600
A_m - MID-FREQUENCY STAGE GAIN
6000
4000
2000
1000
800
600
400
200
100
80
60
40
20
10
8
6
4
2
1
r PARALLEL RESISTANCE COMBINATION OF r_p, R_L AND R_g
1
.8
.6
.4
.2
.1
.08
.06
.04
.02
.01
.008
.006
.004
.002
.001

Nomogram 5-5

on the A scale. $r = 52K$ is found where the line crosses the B scale.

(c) $\rho = R_g + R_L r_p / (R_L + r_p)$ as follows: Draw a straight line from 80K on the A scale to 220K on the C scale. Find 58K where this line crosses the B scale. Add to 470K and $\rho = 525K$.

In Nomogram 5-4 the mid-frequency gain A_m is found as follows: Draw a straight line from 150K on the R scale to 80K on the r_p scale. Now draw a straight line from the point where the first line crosses the pivot scale through 100 on the μ scale. $A_m = 65$ is found where this line crosses its scale.

In Nomogram 5-6A we can find the high frequency at which the gain falls off to 3 db below that of the mid-frequency gain.

Analyzing equation (3), it can be seen that when $r = X_t$, $\omega C_t r - 1$, the ratio A_h/A_m is equal to .707 and A_h is 3 db down from A_m.

Draw a straight line from 46.8 on the C_t scale through 1 on the $\omega C_t r$ scale. Draw a second line from the point where the first line intersected the pivot line to 52K on the r scale. $f_{3db} = 65$ kHz is found where the second line crossed the f scale.

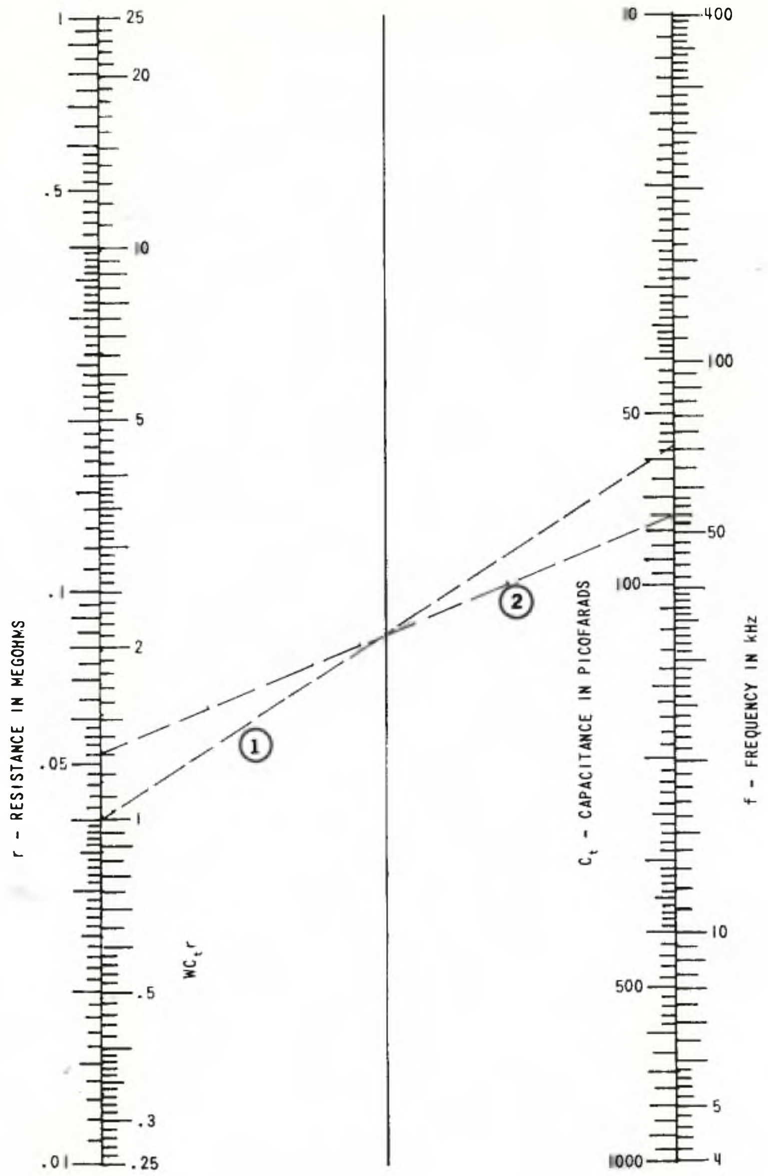
In Nomogram 5-6B we find the gain at the 3 db frequency by drawing a straight line from 1 on the $\omega C_t r_2$ scale to 65 on the A_m scale. $A_h = 46$ is found where this line crosses the A_{h2} scale.

From equation (4) it can be seen that when $\rho = X_c$, the ratio $A_L / A_m = .707$, and A_L is 3 db down from A_m.

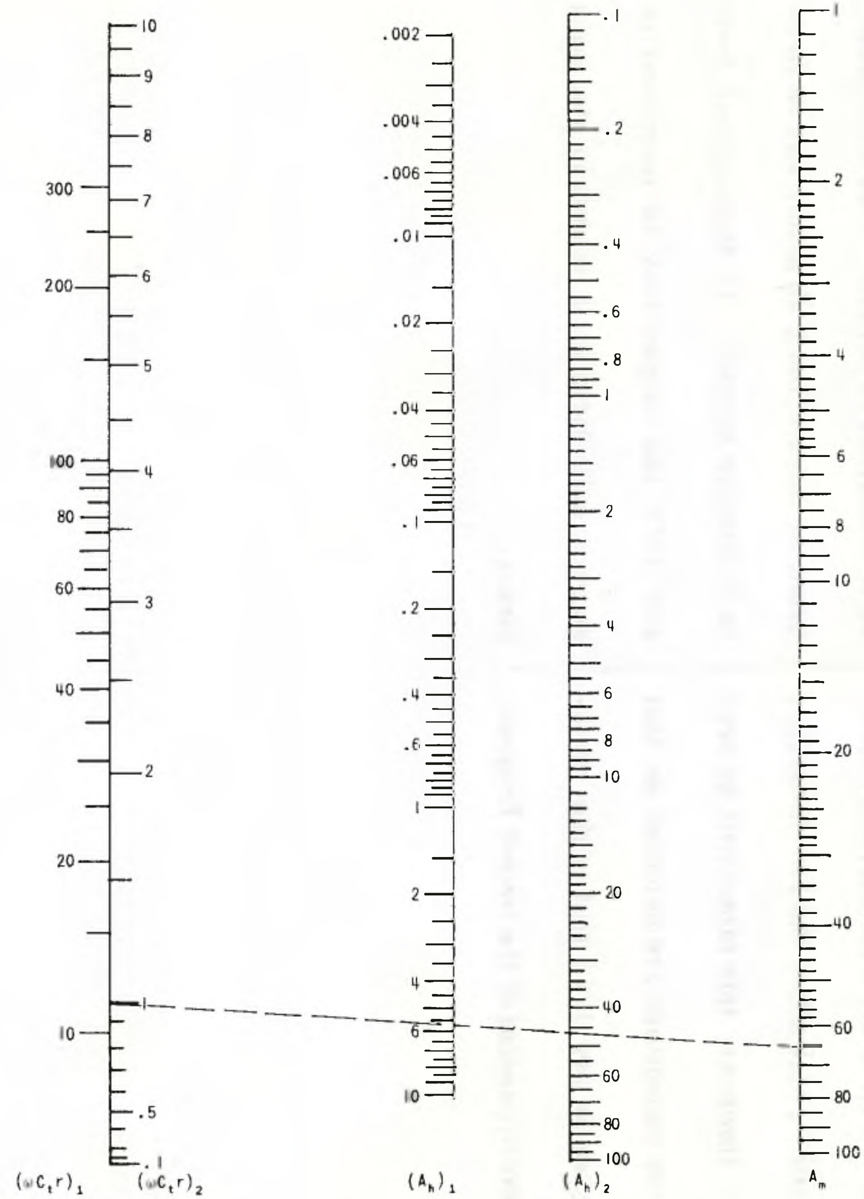
In Nomogram 5-7A draw a straight line from 520K on the ρ scale through 1 on the $\omega c \rho$ scale. Now draw a straight line from the point where the first line intersected the pivot scale through .006 on the C scale. $f_{3db} = 47$ Hz is found where this line intersects the f scale.

In Nomogram 5-7B draw a straight line from 1 on the $\omega c \rho$ scale to 65 on the A_m scale. $A_L = 46$ is found where this line crosses the A_{L2} scale.

(Continued on next page)

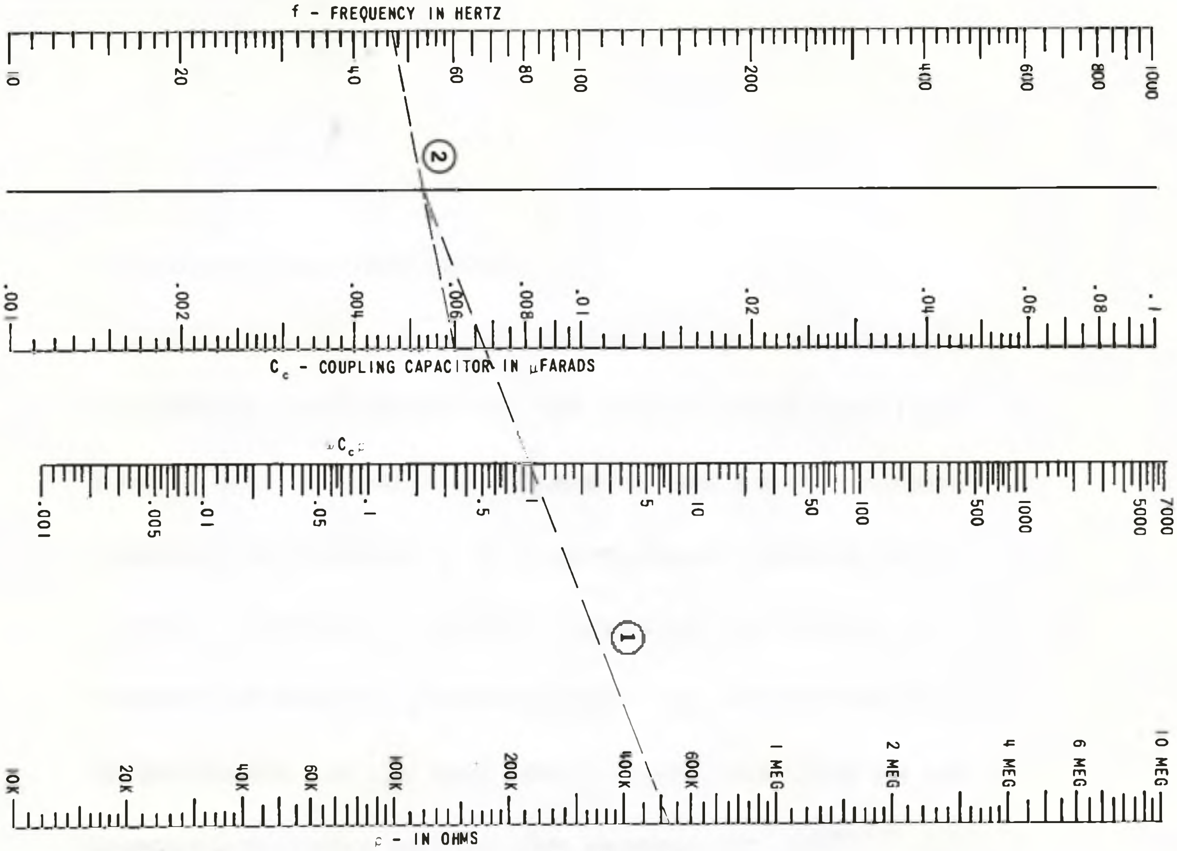


Nomogram 5-6A

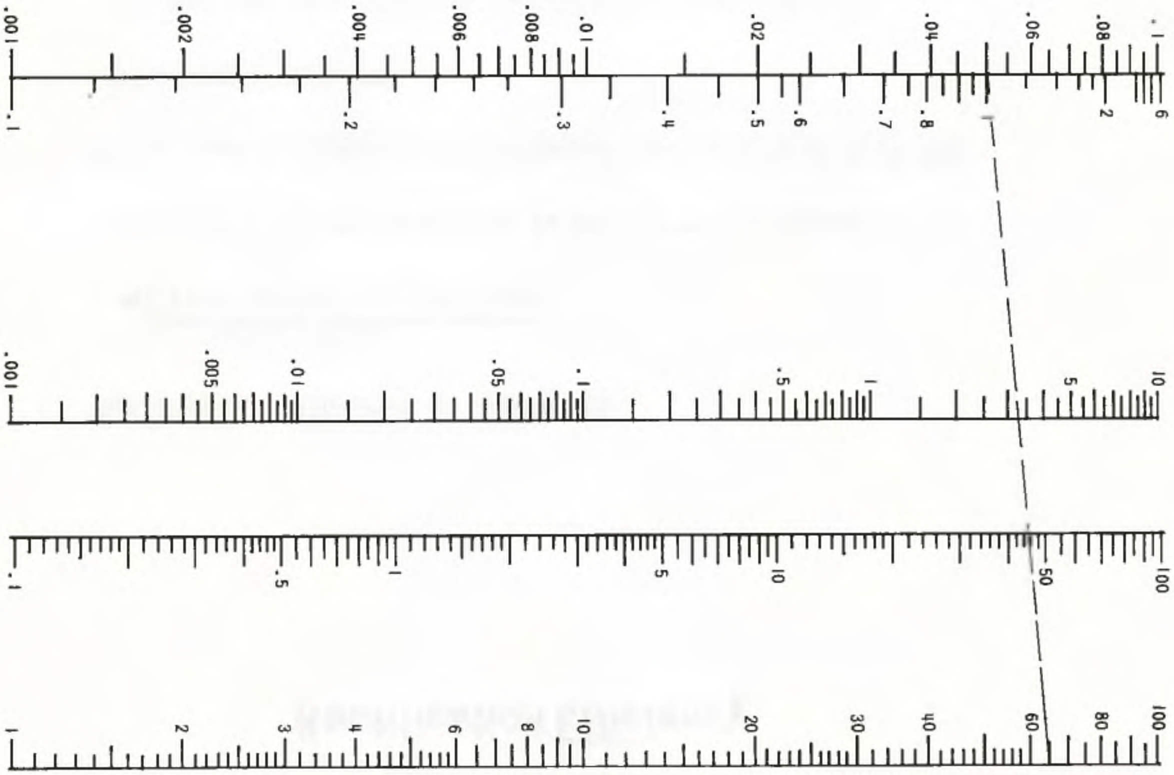


Nomogram 5-6B

It should be kept in mind that bypass capacitors C_k and C_s will affect the low-frequency response. However, this effect will be negligible if the capacitors are selected so that their reactances are 1/10 that of the resistors they are bypassing at the lowest frequency it is desired to bypass. This gain at frequencies beyond the 3 db points can be found in a similar manner. In Nomograms 5-6B and 5-7B the ranges may be increased by merely multiplying all A scales by the same factor.



Nomogram 5-7A



Nomogram 5-7B

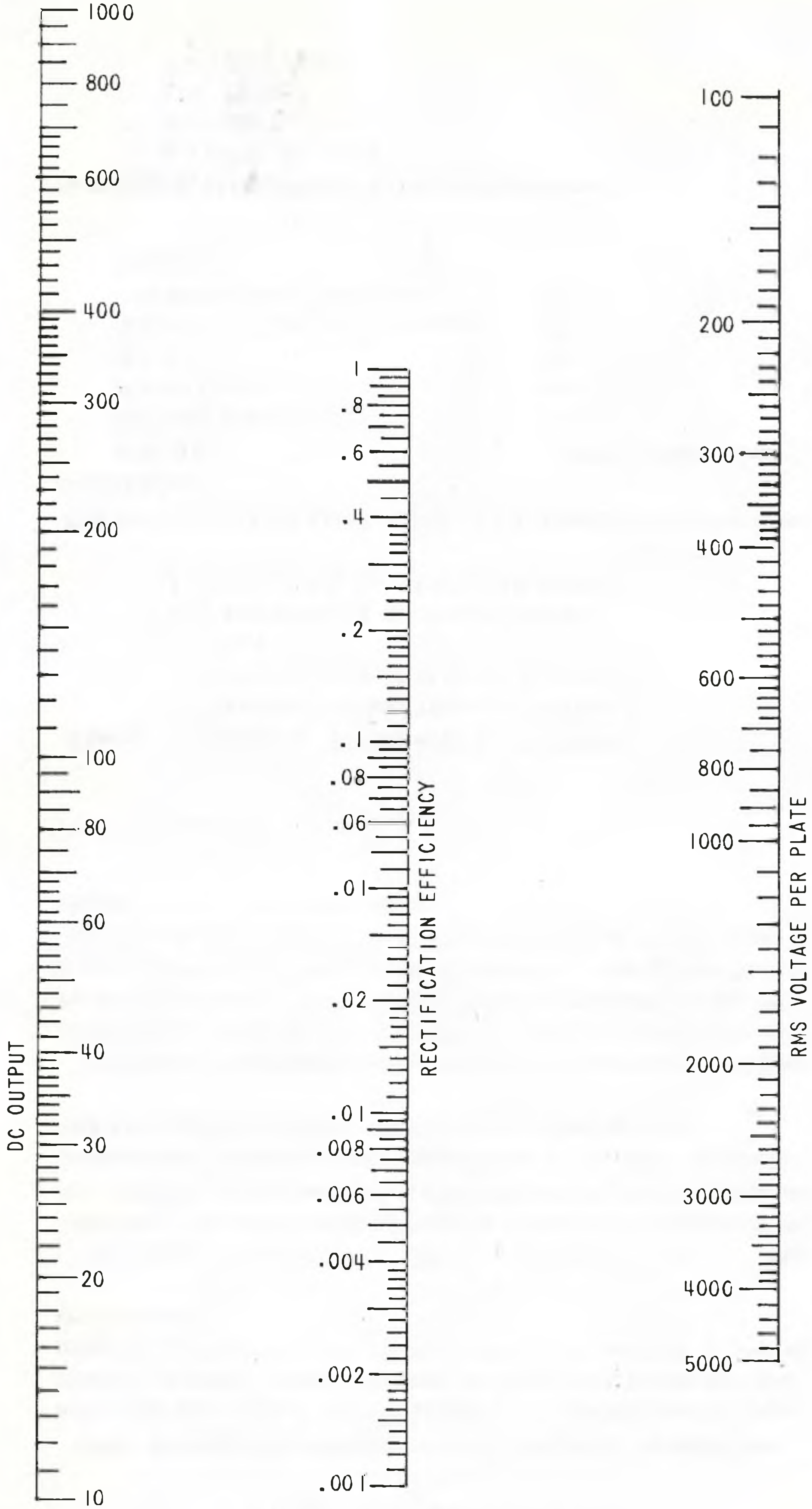
Rectification Efficiency

Rectification efficiency is defined as:

$$\frac{\text{DC output voltage}}{\sqrt{2}\ (\text{rms supply voltage/plate})}$$

Where: The DC output voltage is measured at the input to the filter, and the plate supply voltages are measured with the transformer unloaded.

To find the efficiency of the rectifier tube, it is merely necessary to draw a straight line between the values of DC output voltage and the rms supply voltage per plate on the appropriate scales in Nomogram 5-8. The rectification effi-iciency is found where this line intersects the center scale. This may be expressed in % if the efficiency scale is multi-plied by 100. This equation is found on page 1 of 5 in Sylvania Engineering Data Service for the 5AS4A, dated April 1959. For other values, both voltage scales may be simultaneously multiplied by the same factor.


DC OUTPUT
1000
800
600
400
300
200
100
80
60
40
30
20
10
RECTIFICATION EFFICIENCY
1
.8
.6
.4
.2
.1
.08
.06
.01
.02
.01
.008
.006
.004
.002
.001
RMS VOLTAGE PER PLATE
100
200
300
400
600
800
1000
2000
3000
4000
5000

Heat Sink Calculation

When the engineer designs a power amplifier he must consider the problem of "heat sinking" in the selection of transistors. In many cases, the cost of a heat sink could far surpass the savings obtained in the selection of certain types of transistors.

The power transistor is often mounted directly to the chassis. This allows heat from the transistor to transfer to the chassis. Heat transfer can be improved by using a metallic oxide-filled silicone grease which fills in the tiny scratches and air gaps between the case and mounting surface.

This topic is thoroughly covered by Wayne Goldman, of Wakefield Engineering Inc., in an article entitled "9 Ways to Improve Heat Sink Performance," which appeared in the October 1966 issue of Electronic Products. Nomogram 5-9 is based upon the equation for thermal resistance which appears in the article. The equation is:

$$\theta = \frac{\rho t}{A}$$

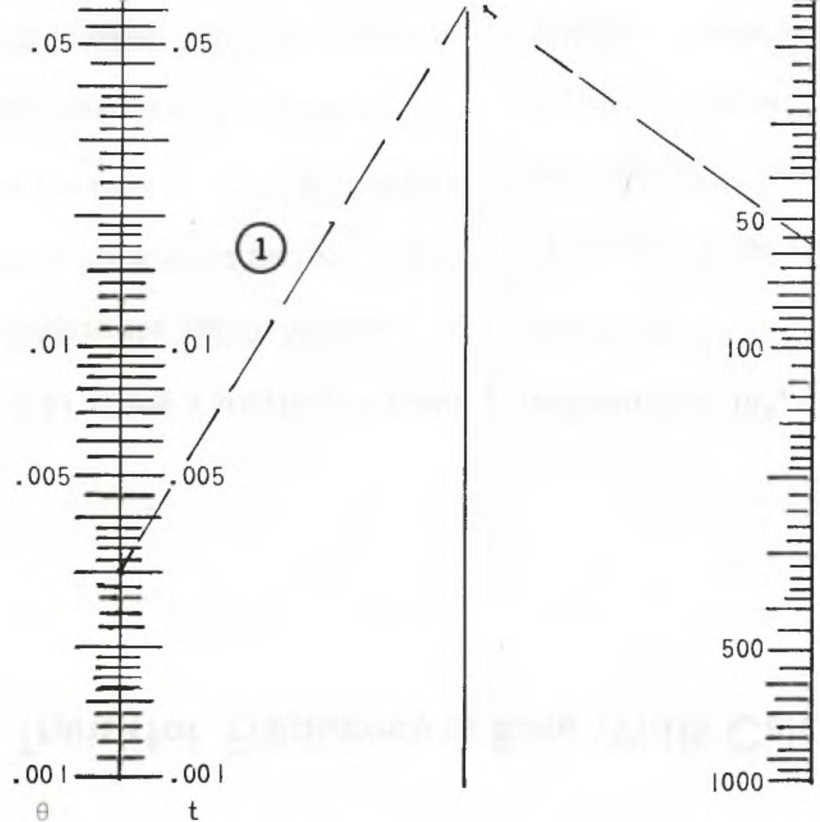
Where: θ = thermal resistance in $^{\circ}$C/watt
ρ = specific thermal resistance of the interface material in $^{\circ}$C inches/watt
t = thickness of the film in inches
A = area of the film in square inches

The following chart gives values of ρ for some commonly used materials:

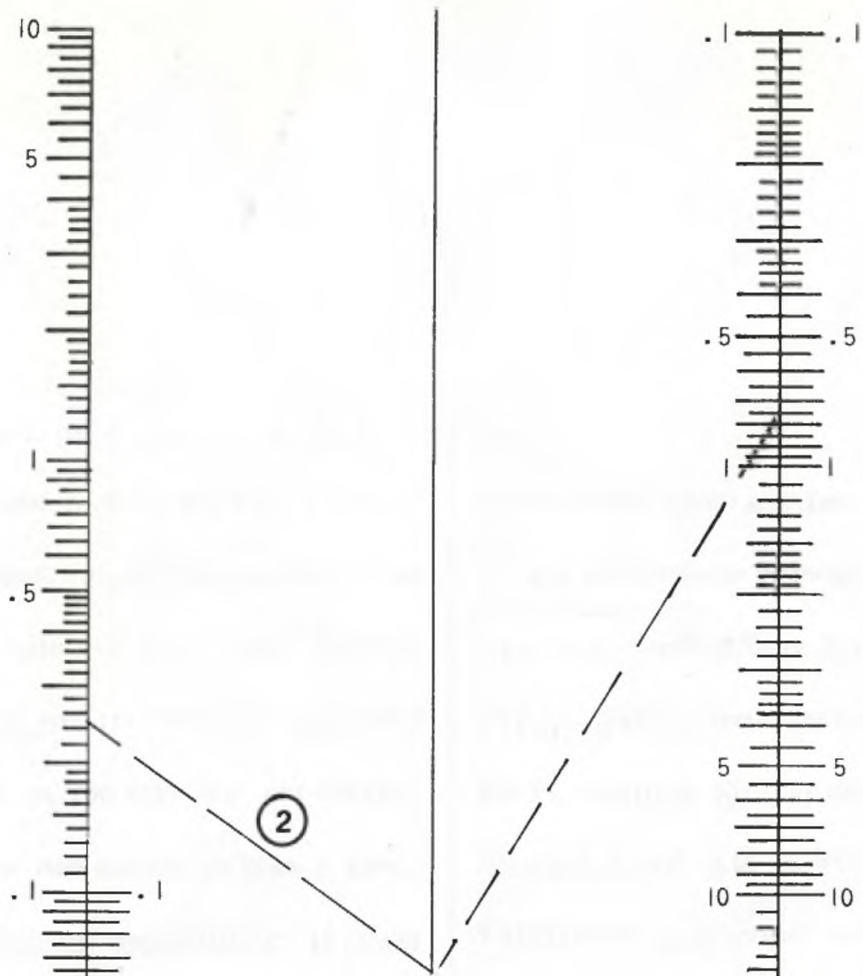
Still Air	1200°C	inches/watt
Silicone Grease	204	"
Mylar Film	236	"
Mica	66	"
Wakefield Type 120 Compound	56	"
Wakefield Delta Bond 152	47	"
Anodize	5.6	"

In the example illustrated by the dashed lines:

ρ = 56°C in./watt
t = .003 in.
A = .75 in.^{2}
θ = .25°C/watt



.05
.05
.01
.01
.005
.005
.001
.001
θ
t
1
50
100
500
1000


10
5
1
.5
.1
.1
.1
.1
.5
.5
1
1
5
5
10
10
2

Transistor Frequency vs Base Width Calculations

Nomogram 5-10 offers a simple and rapid means of calculating the cutoff frequency of a transistor when the width of the base region is known. The formula* is: $f_\alpha = C/W^2$, where f_α is the cutoff frequency, W is the width of the base region in mils, and C is a constant which was empirically determined. It is not the intent of this nomogram to give a theoretical analysis of the formula, but merely to provide a tool for its solution. Although the nomogram shows a base width range of .1 to 1 mils, other widths can be substituted by multiplying the W scale by 10^n, where n may be negative or positive. When W is multiplied by 10^n, then f_α must be multiplied by 10^{-2n}.

Example: Find the cutoff frequency of a germanium NPN transistor whose base width region is 4.8 mils.

Solution: Extend a straight-edge from the germanium NPN point on the C scale to .48 on the W scale. The straight-edge will cross the f_α scale at 25. Since W was multiplied by 10^1, then f_α must be multiplied by 10^{-2}. The cutoff frequency is therefore .25 mHz.

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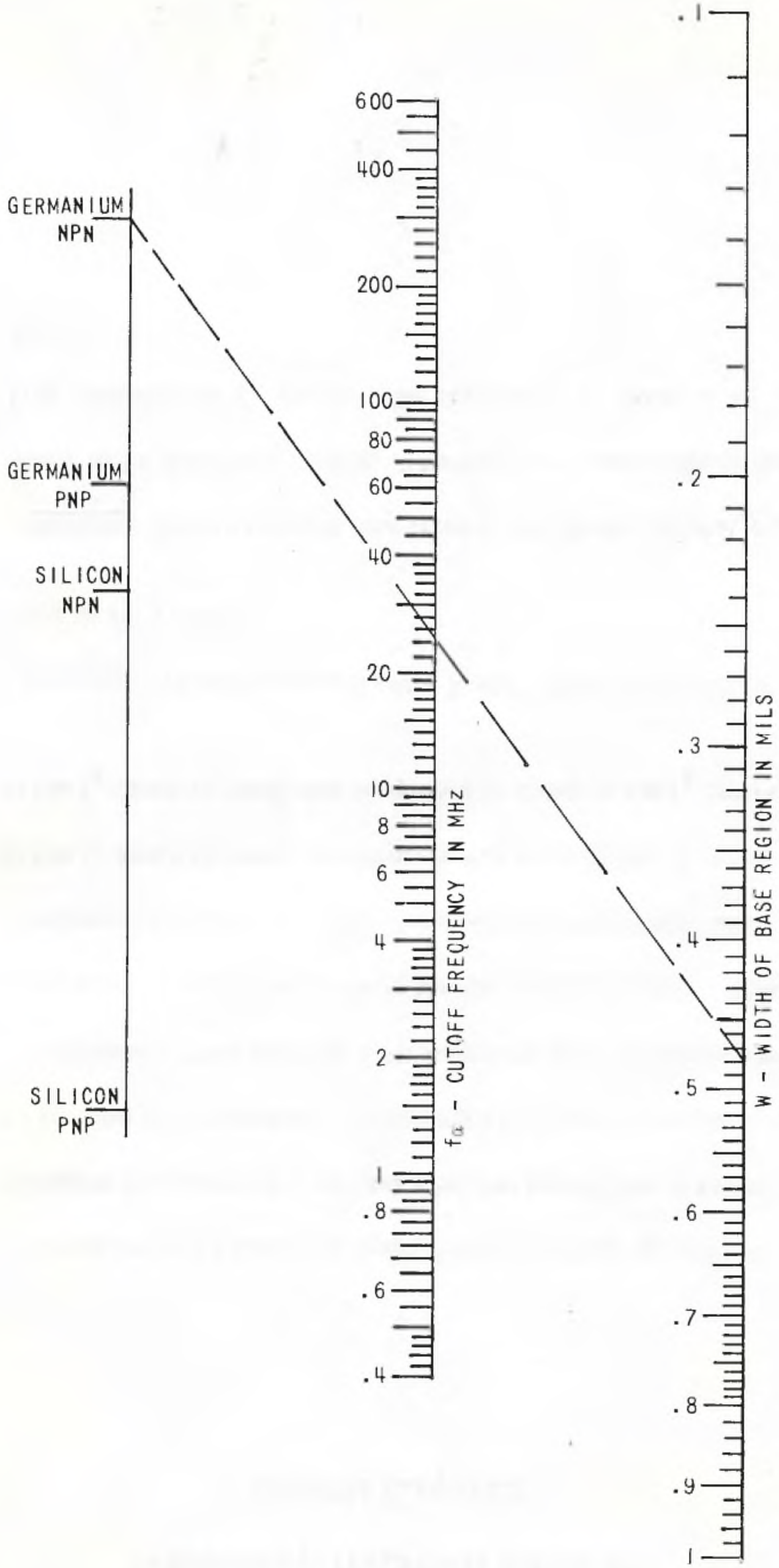
* This formula can be found in the 4th edition of Reference Data for Radio Engineers, page 497.

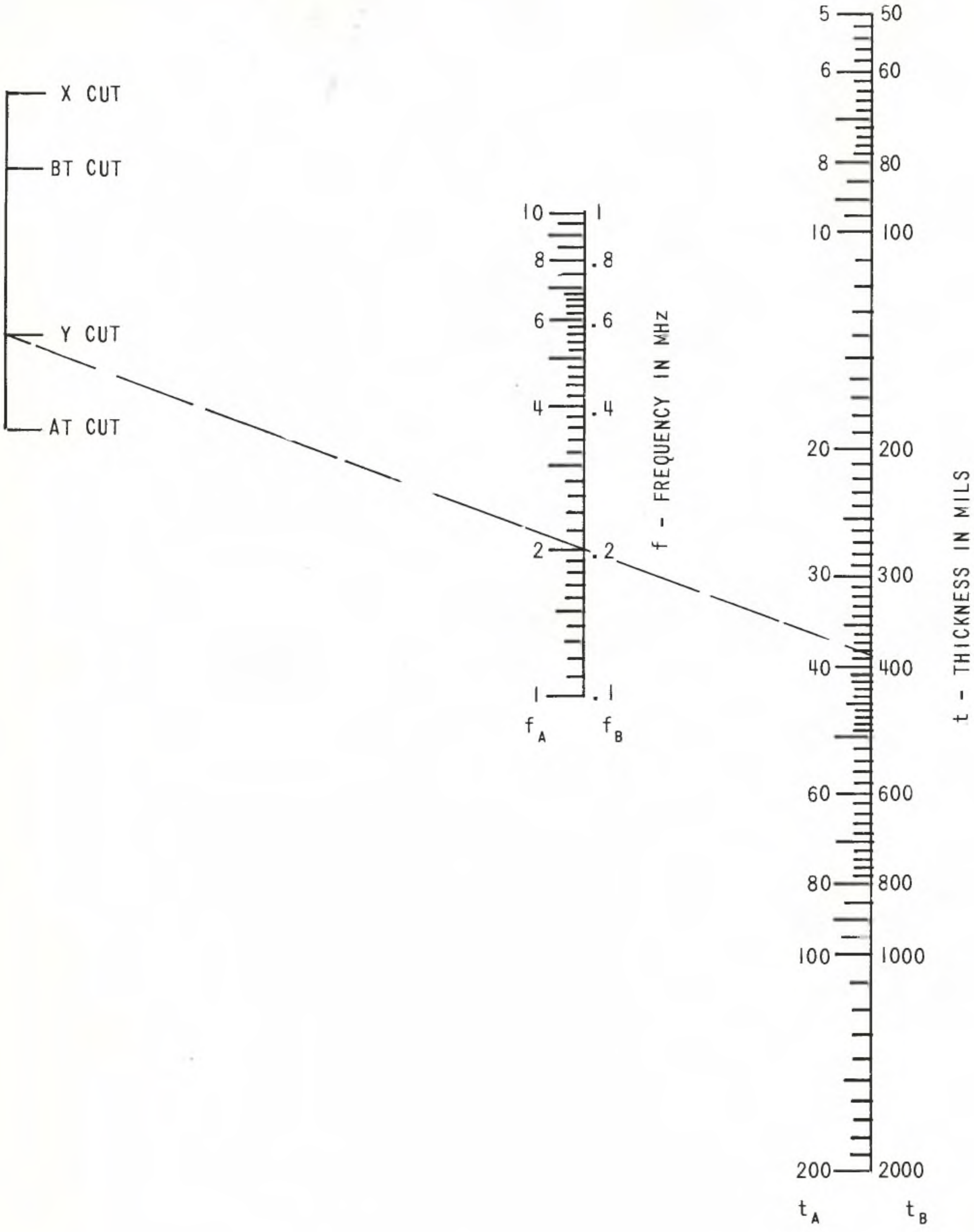

GERMANIUM NPN
GERMANIUM PNP
SILICON NPN
SILICON PNP
fα - CUTOFF FREQUENCY IN MHz
600
400
200
100
80
60
40
20
10
8
6
4
2
1
.8
.6
.4
W - WIDTH OF BASE REGION IN MILS
.1
.2
.3
.4
.5
.6
.7
.8
.9
1

Frequency-Thickness Ratio for Quartz Crystals

Nomogram 5-11 comes in handy for calculating the primary resonant frequency of a crystal when the type of cut is known. It is done by measuring the thickness of the crystal with a micrometer, then drawing a straight line from the thickness scale to the crystal cut scale at the appropriate points. The frequency is found where this line intersects the center scale. If the t_A scale is used, the frequency is found in the f_A scale. If the t_B scale is used, the frequency is found in the f_B scale.

Example: Find the frequency of a Y-cut crystal whose thickness is 38.5 mils.

Solution: Draw a straight line from Y-cut on the crystal cut scale to 38.5 on the t_A scale. The answer is found where the line crosses the f_A scale. The frequency is found to be 2 mHz.


X CUT
BT CUT
Y CUT
AT CUT
f - FREQUENCY IN MHz
f_A
f_B
t - THICKNESS IN MILS
t_A
t_B

CHAPTER 6

Miscellaneous

Nyquist Noise Voltage

One of the more important types of noise that the electronics engineer must deal with is termed thermal noise. A random motion of free electrons sets up a thermal agitation in any conductor. This causes small random voltages, called thermal or Johnson noise, to appear across the terminals of the conductor. The energy spectrum of noise is uniform over all frequencies—i. e., the voltage has a "flat" or "white" characteristic which is independent of frequency. Thermal noise voltage is expressed by:

$$E_n = \sqrt{4kTRB}$$

Where: E_n is the rms value of the thermal noise in volts

k is Boltzman's constant = 1.372×10^{-23} joules/°K

T is the temperature in °K (Degrees Kelvin)

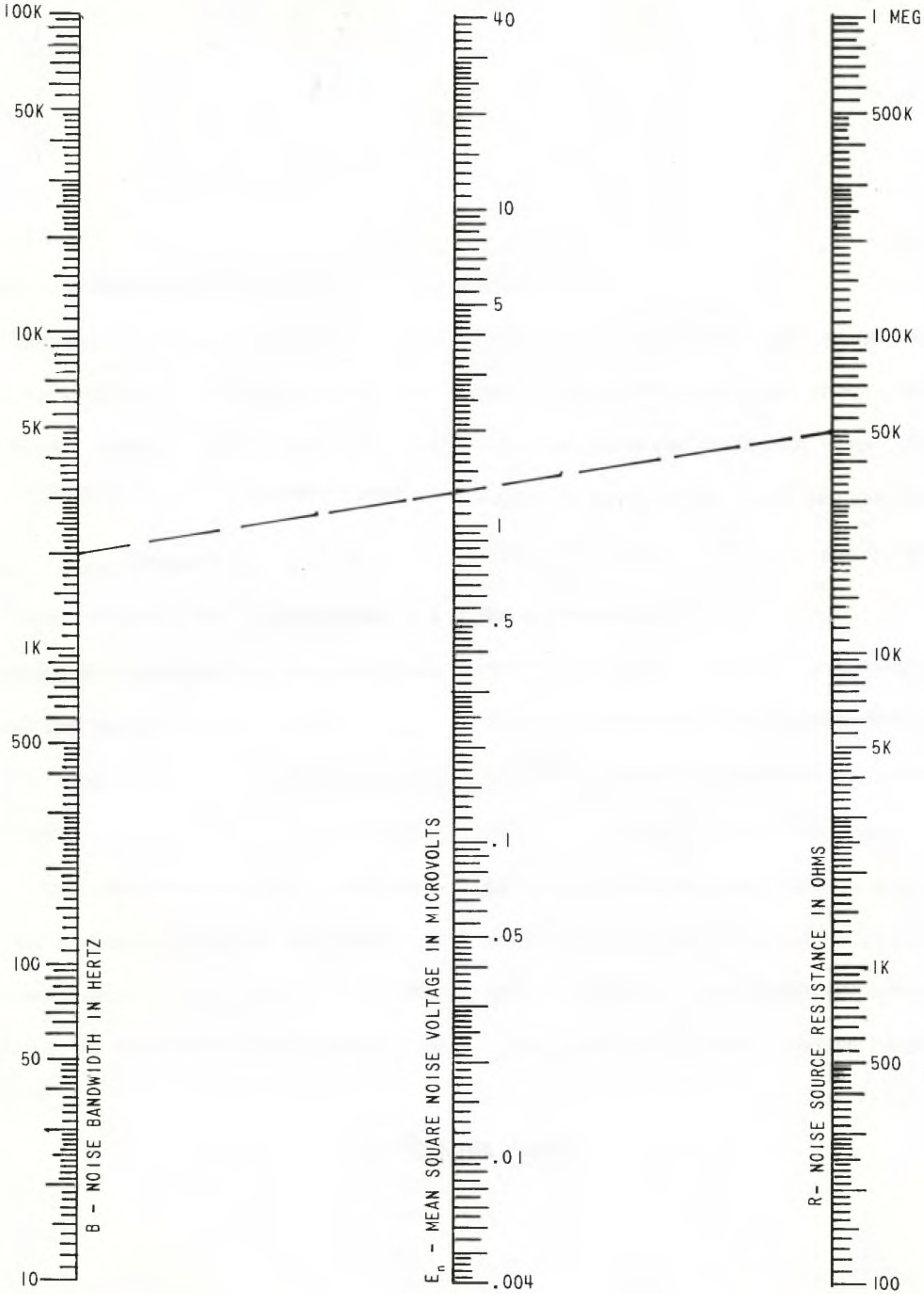
B is the noise bandwidth in Hz

R is the resistance in ohms

At room temperature, T = 25°,C = 298.16°K. The noise equation then becomes:

$$E_n = \sqrt{1.636 \times 10^{-20}\ BR}$$

Values other than those shown on the scales may be used by multiplying all scales simultaneously by 10^n, where n may be either positive or negative. If only the B or R scale is multiplied by 10^n, then the E_n scale must be multiplied by $10^{n/2}$. In the example illustrated by the dashed line, B = 2 kHz, R = 50 K and E_n = 1.28 μv.


100K
50K
10K
5K
1K
500
100
50
10
B - NOISE BANDWIDTH IN HERTZ
40
10
5
1
.5
.1
.05
.01
.004
E_n - MEAN SQUARE NOISE VOLTAGE IN MICROVOLTS
1 MEG
500K
100K
50K
10K
5K
1K
500
100
R- NOISE SOURCE RESISTANCE IN OHMS

Amplifier Gain

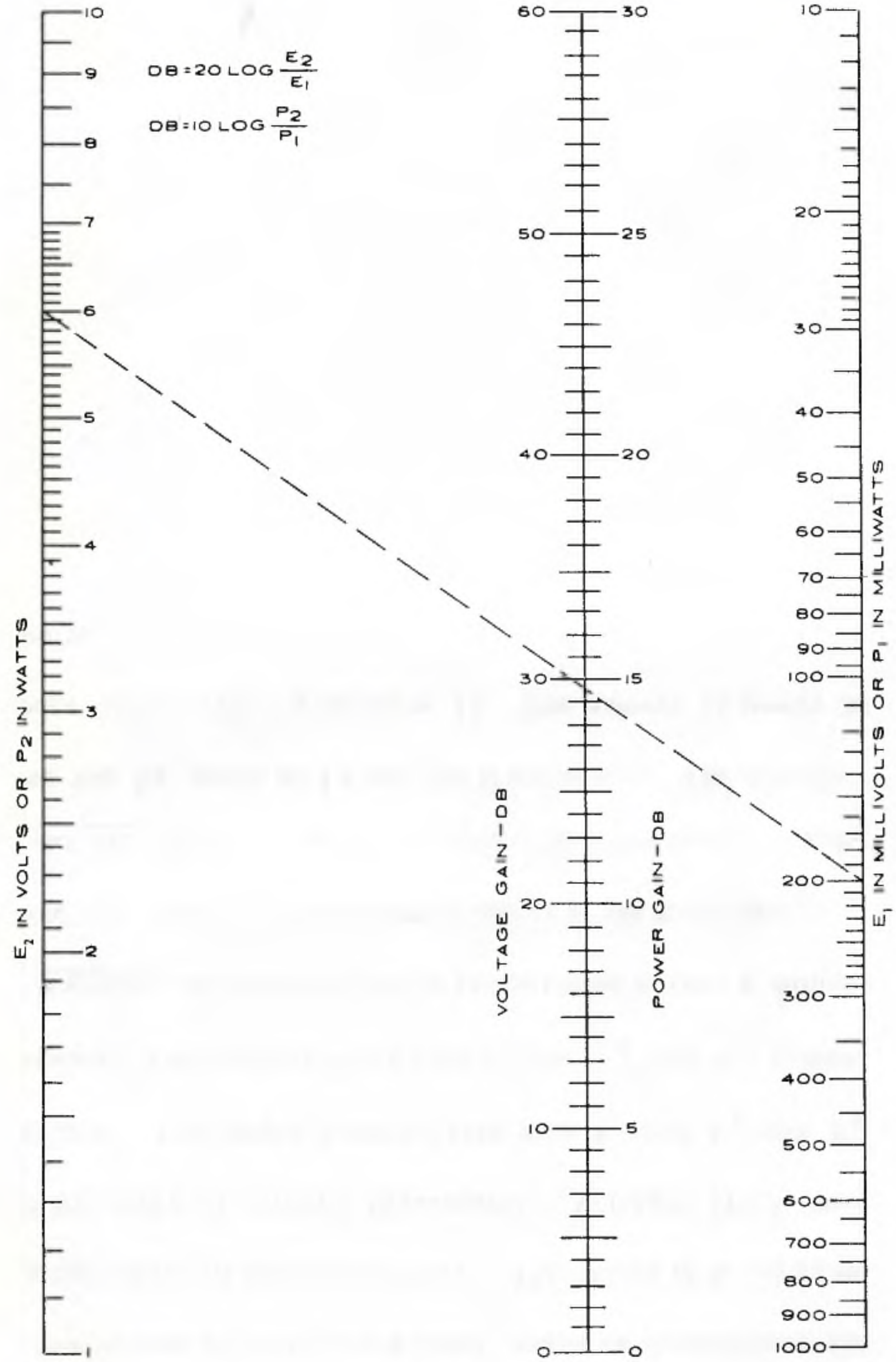
To find the power gain of an amplifier, it is necessary to compute the ratio of its output to input power (take the log and multiply by 10). When the input and output resistances are equal, the voltage gain of the amplifier can be calculated by multiplying 20 times the log of the output to input voltages. Nomogram 6-2 eliminates the tedious calculations involved, and gain can be determined in a much simpler manner.

For values of 10^n or 10^{-n} times those on E_1 scale, subtract or add respectively, n times 20 db from or to the values on the voltage gain scale. (n times 10 db from or to the power gain scale when the P_1 scale is used.)

For values of 10^n or 10^{-n} times those on the E_2 or P_2 scales, add or subtract, respectively, n times 20 db to or from the values on the voltage gain scale and n times 10 db to or from the values on the power gain scale.

Example: Find the voltage gain of an amplifier whose input and output resistances are equal when 6 volts output is measured for 200 millivolt input.

Solution: Place one end of a straight-edge over 6 on the left-hand scale and the other end over 200 on the right-hand scale. Find 29.6 at the point where the straight-edge crosses the center scale. This is the voltage gain in db.

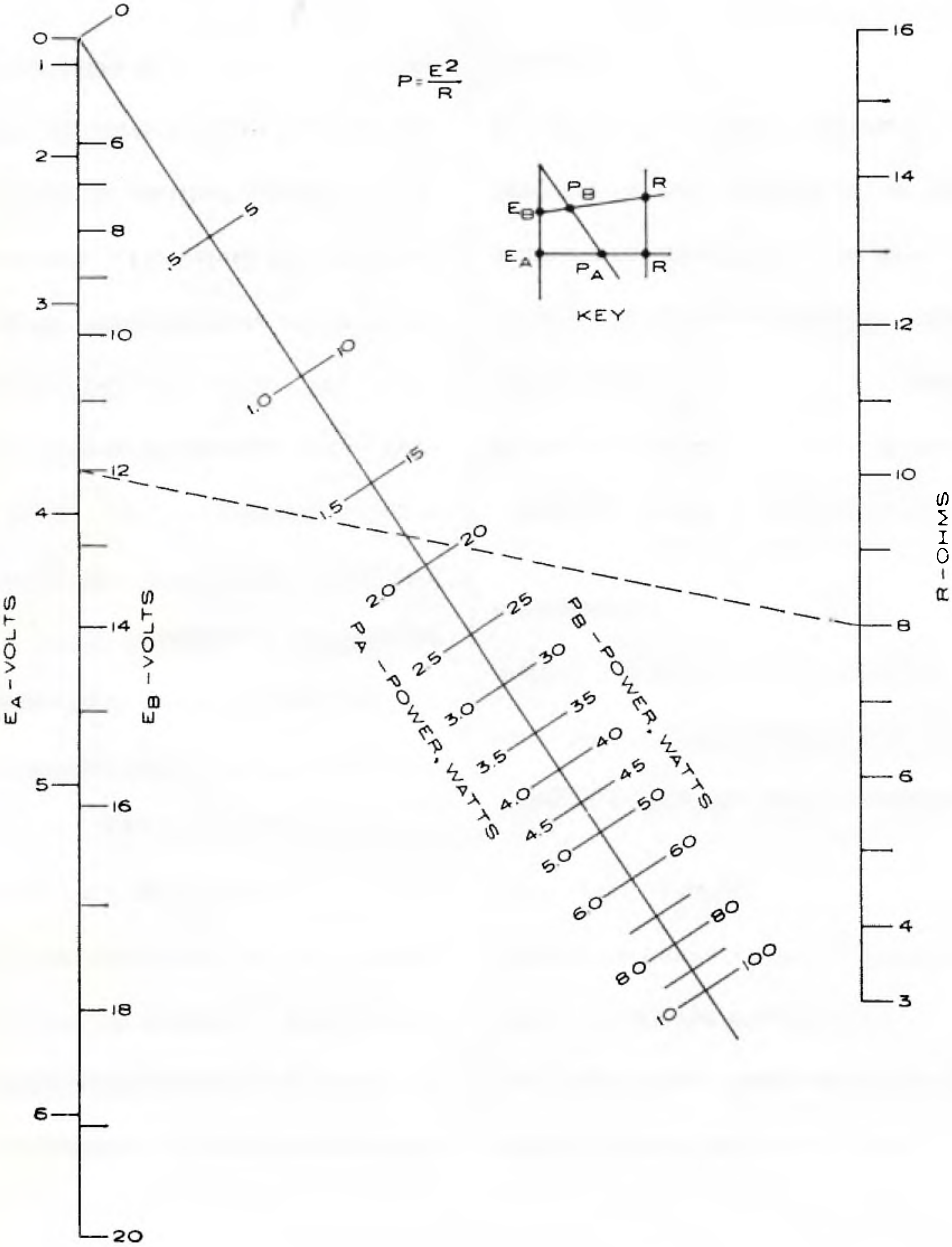

DB = 20 LOG $\frac{E_2}{E_1}$
DB = 10 LOG $\frac{P_2}{P_1}$
E_2 IN VOLTS OR P_2 IN WATTS
VOLTAGE GAIN – DB
POWER GAIN – DB
E_1 IN MILLIVOLTS OR P_1 IN MILLIWATTS

Amplifier Power Output

Nomogram 6-3 provides a rapid means of determining the output power of audio amplifiers. The values of R are given in the range of speaker impedances. Voltages are in rms values. For output voltages less than 6, use E_A and P_A scales. For voltages more than 6, use E_B and P_B scales.

Example: An amplifier has a 12-volt drop across a dummy load of 8 ohms. Find the power output of the amplifier.

Solution: Lay a straight-edge across the three scales, touching the E_B scale at 12 and the R scale at 8. The straight-edge crosses the P_B scale at 18. The answer is power in watts.


P = E2/R
KEY
EA - VOLTS
EB - VOLTS
R - OHMS
PA - POWER, WATTS
PB - POWER, WATTS

Modulation Percentage

In AM transmitters, it is necessary to check the modulation percentage so that limits set by the FCC are not exceeded. The methods of obtaining the waveforms are not discussed here since they can be found in any standard text. Nomogram 6-4 does, however, offer a simplified means of determining the percent modulation from the waveforms.

Fig. 6-1 shows a series of oscilloscope patterns of an RF carrier being modulated by a sine wave. Fig. 6-2 shows a series of trapezoidal patterns of the same waves. Percent Modulation (M) = ((A-B/(A + B)) x 100, where A is the crest amplitude and B is the trough amplitude. The values of A and B are measured from the oscilloscope patterns. M is found by extending a straight-edge from the measured value of A on its scale to the measured value of B on its scale. The percent modulation is found where the straight-edge crosses the diagonal scale. A and B may be in any units as long as both are measured in the same units.

Example: Find the percent modulation of a wave whose crest amplitude is 6.3 centimeters and whose trough amplitude is 2.7 centimeters.

Solution: Extend a straight-edge from 6.3 on the A scale to 2.7 on the B scale. The straight-edge crosses the M scale at 40, which is the percent modulation. Note: For symmetrical modulation, the above equation produces the same results as the equations: M = (A-C)/C or (C-B)/C, where C = carrier amplitude.)

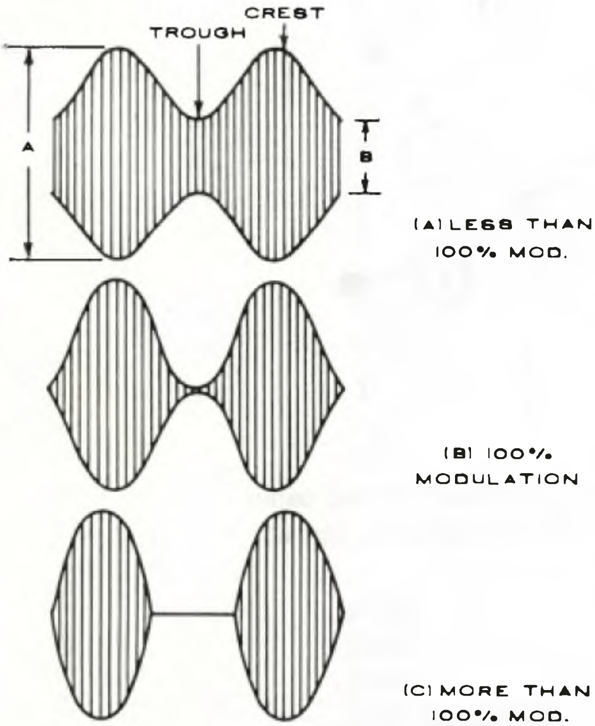


Fig. 6-1. Amplitude modulated RF carrier waveforms.

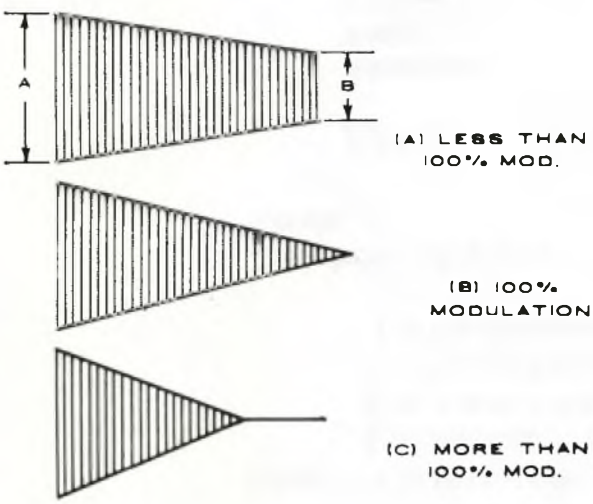
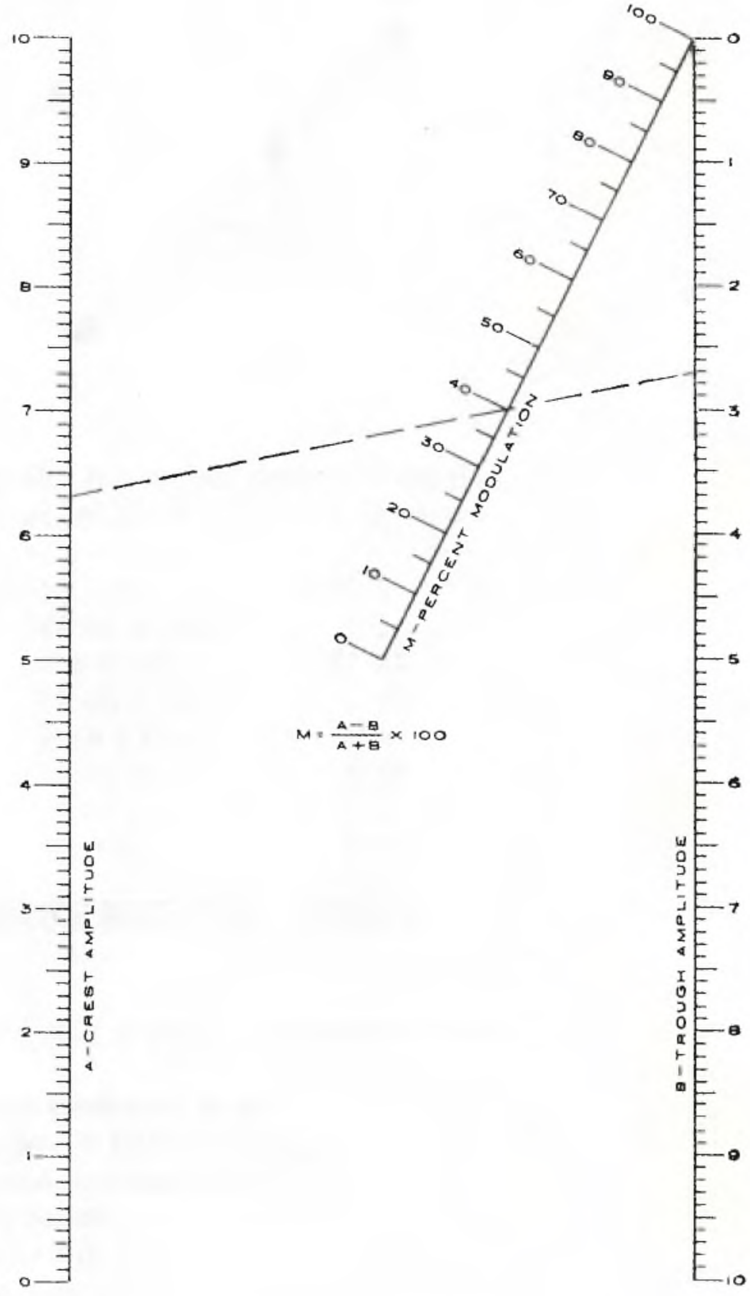


Fig. 6-2. Trapezoidal modulation patterns seen on scope.



Tuning Fork Frequency

The physical dimensions of a tuning fork resonator determine its natural resonance frequency which is given by the equation:

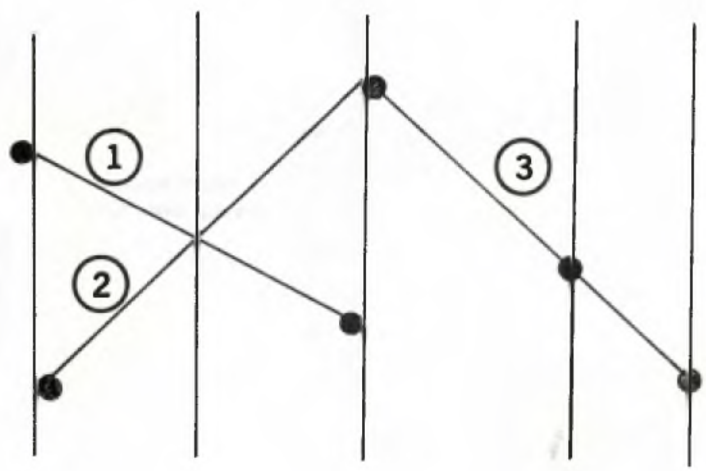
$$f = \frac{0.55966\ d}{L^2}\sqrt{\frac{E}{12\rho}}$$

Where: d is the tine thickness in cm
L is the tine length in cm
E is Young's Modulus in dynes/cm^2
ρ is the material density in grams/cm^3
f is the fundamental frequency in Hz.

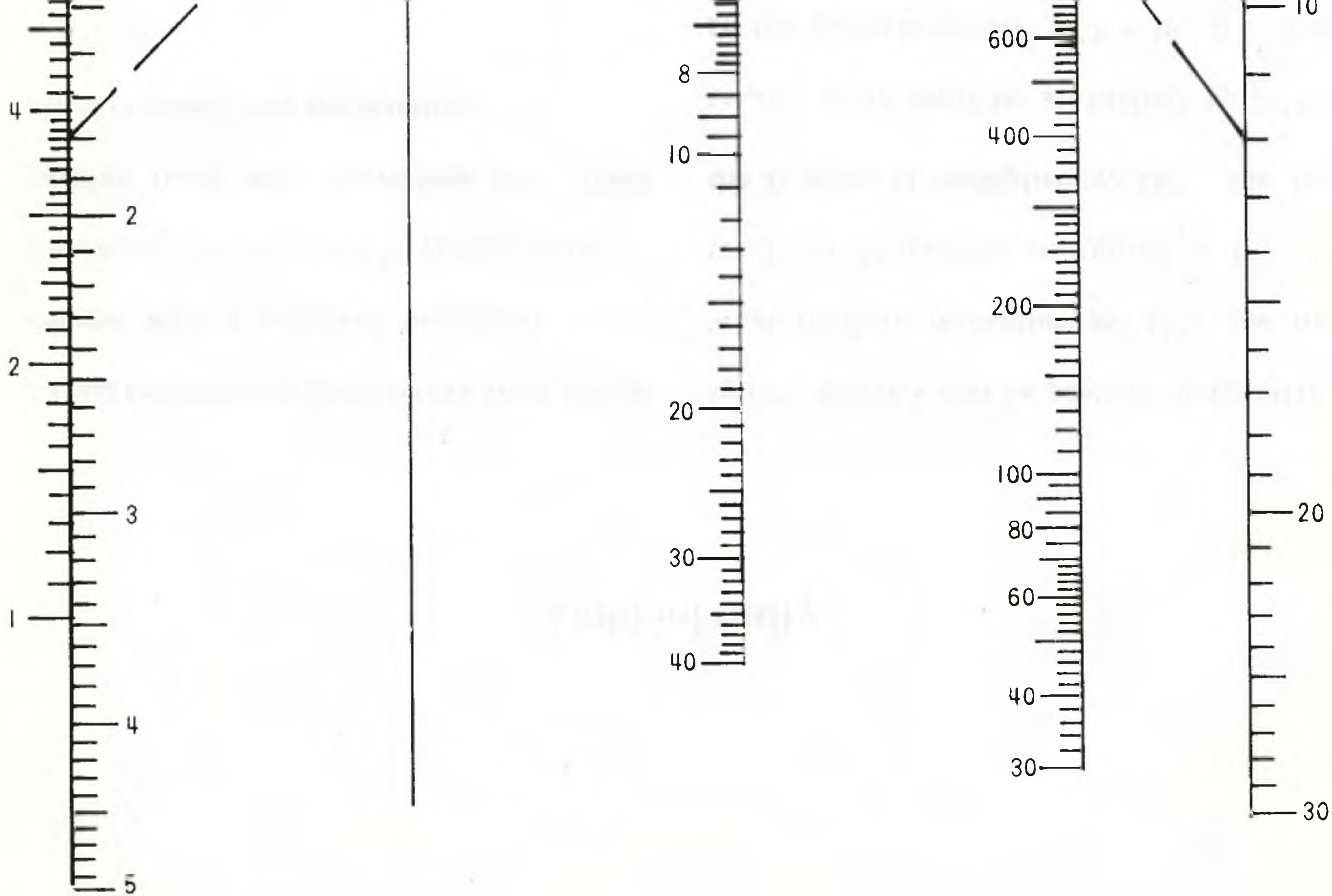
The chart below gives values of E and ρ for some common metals.

METAL	YOUNG'S MODULUS	DENSITY
Aluminum	7×10^{11}	2.699
Brass	9.2×10^{11}	8.6
Copper	$10\text{-}12 \times 10^{11}$	8.89
Iron (Cast)	$8\text{-}10 \times 10^{11}$	7.2
Iron (Wrought)	$18\text{-}20 \times 10^{11}$	7.85
Lead	1.5×10^{11}	11.37
Steel	$19\text{-}21 \times 10^{11}$	7.7
Nickel	22×10^{11}	8.9

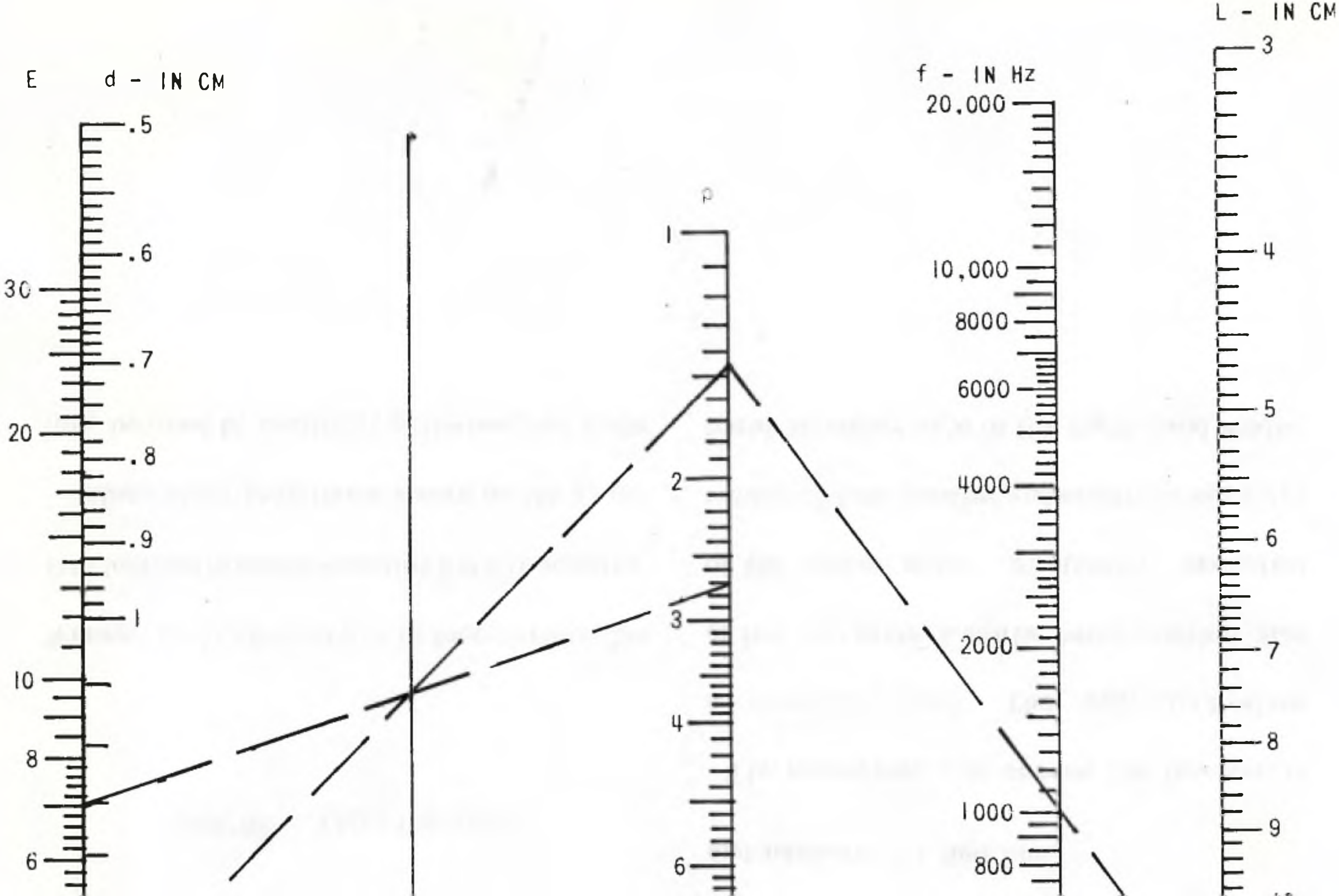
In the example illustrated by the dashed lines for an aluminum tuning fork: d = 1.8 cm, L = 12 cm, and f = 1020 Hz.



Key



4
2
2
3
1
4
5
8
10
20
30
40
600
400
200
100
80
60
40
30
10
20
30


E
d - IN CM
f - IN Hz
L - IN CM
p
.5
.6
.7
.8
.9
1
30
20
10
8
6
1
2
3
4
6
20,000
10,000
8000
6000
4000
2000
1000
800
3
4
5
6
7
8
9

Light Intensity

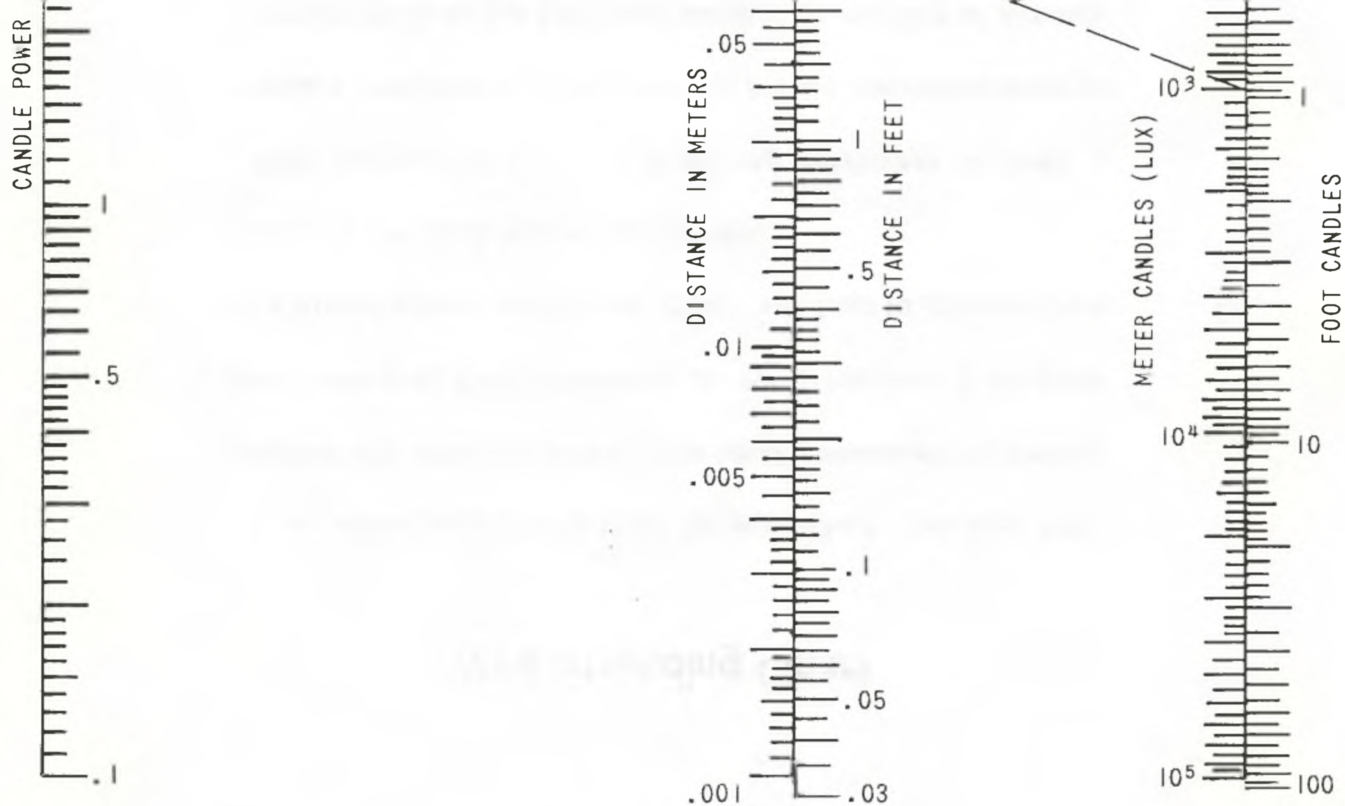
Light intensity to a given object from a light source with a signified horizontal candle power may be found in foot-candles or meter-candles (Lux) with Nomogram 6-6. This chart is based upon the equation:

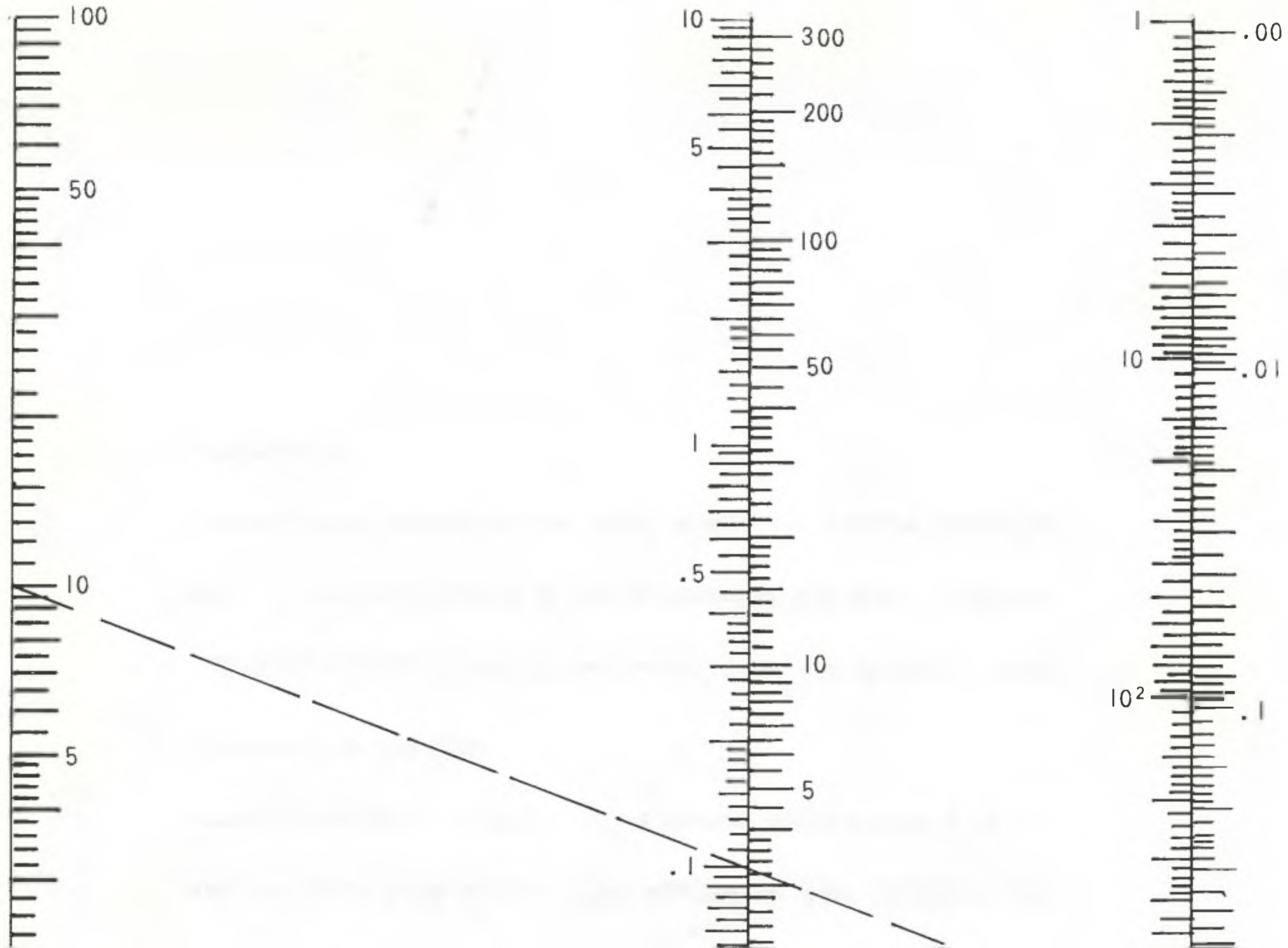
$$HCP/D^2 = \text{Light Intensity}$$

Where: Light intensity is in foot-candles for D in feet and in meter-candles for D in meters.

Values other than those shown on the graph may be used by multiplying the desired scale by 10^n, where n may be positive or negative. When HCP is multiplied by 10^n, the intensity scale must be multiplied by 10^n. If the D scale is multiplied by 10^n, the intensity scale must be multiplied by 10^{-2n}. In the example shown: HCP = 10, D = .1 m and intensity = 1,000 Lux.

The nomogram also serves the function of a conversion chart. The equivalent values of feet and meters can be found on either side of the center scale. Similarly, equivalent values of foot-candles and meter-candles are found on either side of the right-hand scale.


CANDLE POWER
1
.5
.1
DISTANCE IN METERS
.05
.01
.005
.001
DISTANCE IN FEET
1
.5
.1
.05
.03
METER CANDLES (LUX)
10^3
10^4
10^5
FOOT CANDLES
1
10
100



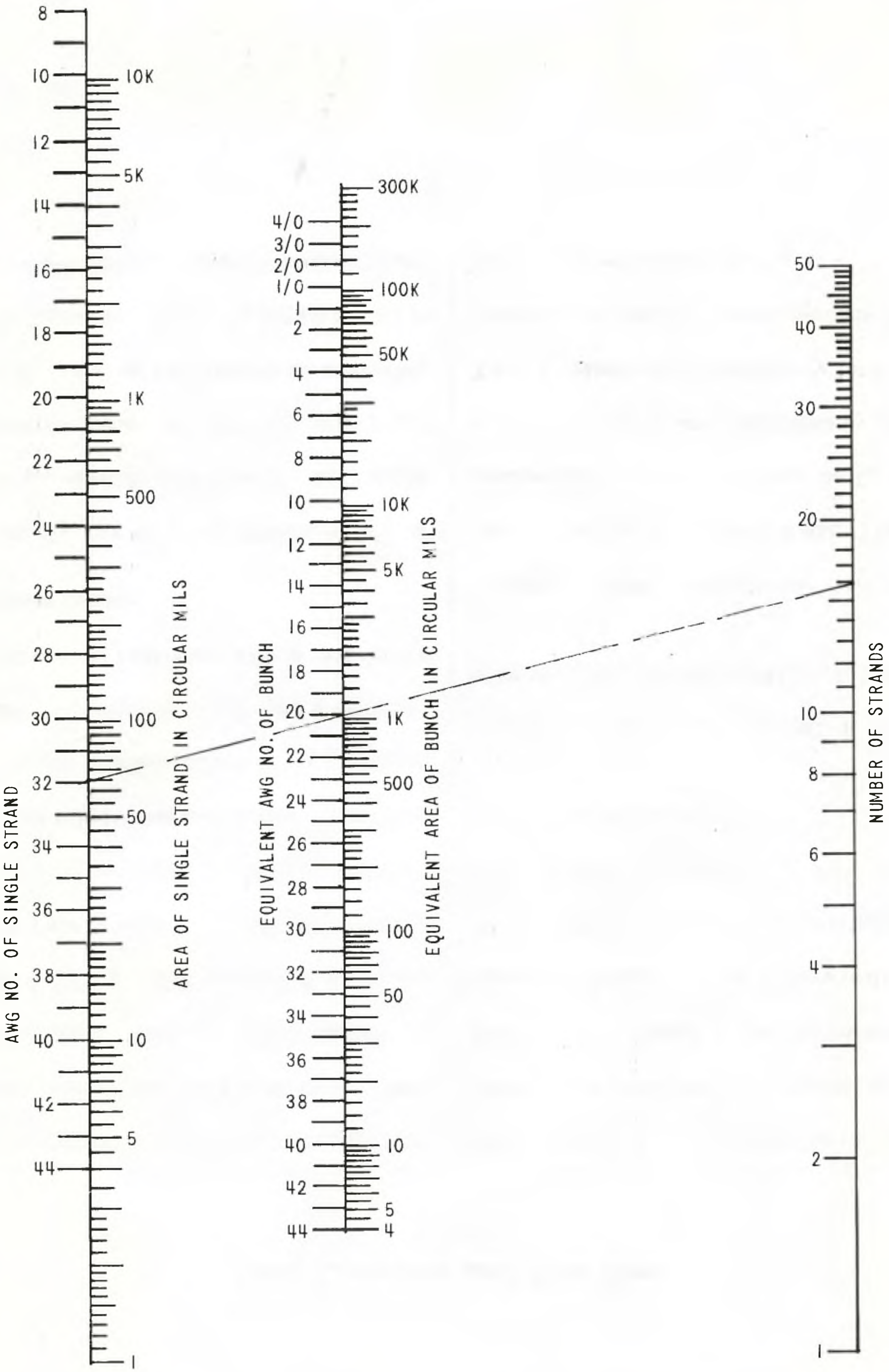
100
50
10
5
10
5
1
.5
.1
300
200
100
50
10
5
1
10
10^2
.001
.01
.1

Wire Stranding Chart

It is often desirable to know the equivalent area and AWG number of a stranded cable. The usual procedure for finding this value is to first determine the AWG number or the area of a single strand in circular mils, and then to multiply this figure by the total number of strands,

With Nomogram 6-7, it is merely necessary to draw a straight line from the AWG number (or its equivalent area in circular mils) on the left-hand scale to the number of strands on the right-hand scale. The equivalent AWG number and area of the bunch is found on the center scale where it is intersected by the line.

In the example shown by the dashed line: 16 strands of #32 wire is the equivalent of a single strand of #20 wire. Use the closest AWG number to the point where the center scale is intersected.


AWG NO. OF SINGLE STRAND
AREA OF SINGLE STRAND IN CIRCULAR MILS
EQUIVALENT AWG NO. OF BUNCH
EQUIVALENT AREA OF BUNCH IN CIRCULAR MILS
NUMBER OF STRANDS

Time Constant and Rise Time

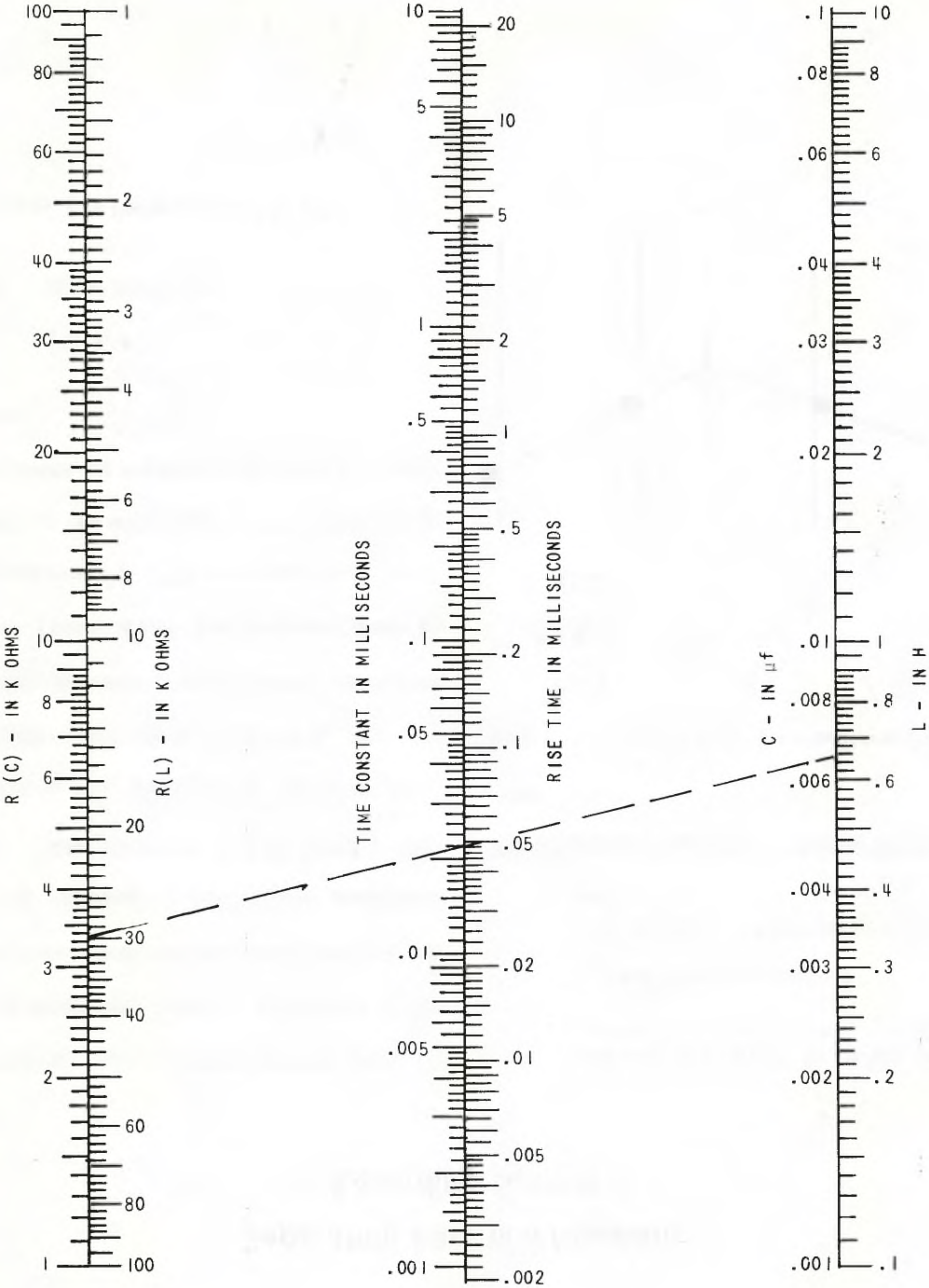
Time constant and rise time are rapidly calculated for both R-C and L-R circuits with Nomogram 6-8. Only one step is needed. In the R-C circuit, time constant T is defined as the time it takes to charge the capacitor to 63.2% of the maximum voltage. In the L-R circuit it is defined as the time it takes for the current to reach 63.2% of its maximum value. Rise time T_R is the time it takes for the charge to rise from 10% to 90% of its maximum value.

T and T_R can be found simultaneously by drawing a straight line from R_L to L at the respective values for the L-R circuit and from R_C to C at the respective values for the R-C circuit. T and T_R for each case is found where this line crosses the center scale.

Other values of L, C, and R can be substituted in the nomogram by multiplying any value by 10^n, where n may be positive or negative. When L, C, or R_C are multiplied by 10^n, then T and T_R are also multiplied by 10^n. When R_L is multiplied by 10^n, then T and T_R are multiplied by 10^{-n}.

Example: Find T and T_R of an L-R circuit, when R_L is 300,000 ohms and L is .65 henries.

Solution: Draw a straight line from 30 on the R_L scale to .65 on the L scale. The line crosses the T scale at 0.022 and the T_R scale at 0.048. Since R_L was multiplied by 10^1 the T and T_R values are multiplied by 10^{-1}. The answers are then 2.2 micro-seconds for T and 4.8 micro-seconds for T_R.


R (C) - IN K OHMS
R(L) - IN K OHMS
TIME CONSTANT IN MILLISECONDS
RISE TIME IN MILLISECONDS
C - IN µf
L - IN H
100
80
60
40
30
20
10
8
6
4
3
2
1
1
2
3
4
6
8
10
20
30
40
60
80
100
10
5
1
.5
.1
.05
.01
.005
.001
20
10
5
2
1
.5
.2
.1
.05
.02
.01
.005
.002
.1
.08
.06
.04
.03
.02
.01
.008
.006
.004
.003
.002
.001
10
8
6
4
3
2
1
.8
.6
.4
.3
.2
.1

Separation Loss in a Magnetic Recording System

Magnetic tape recorders require precision tape resolution. This is so because of the high frequencies that are being recorded. A slight variation in tape-to-head separation may cause excessive loss in signal. This problem was discussed in "Magnetic Tape Trends" published by Ampex Corp. Two formulas appeared in Bulletin #10, September 1965 Issue, which are presented here as Nomogram 6-9. The first one is used to determine the wavelength of the signal being recorded and the second calculates the signal loss.

(1) $\lambda = S/f$

(2) Signal loss $= 55d/\lambda$

Where: λ is the wavelength in mils

S is the tape speed in inches per second

f is the frequency in Hertz

d is the tape-to-head separation in mils

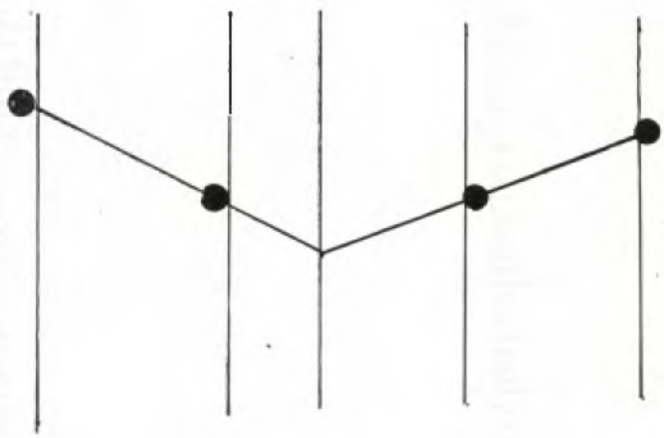
The nomogram is solved by following the Key below.

<u>Note</u>: A & C scales are used simultaneously

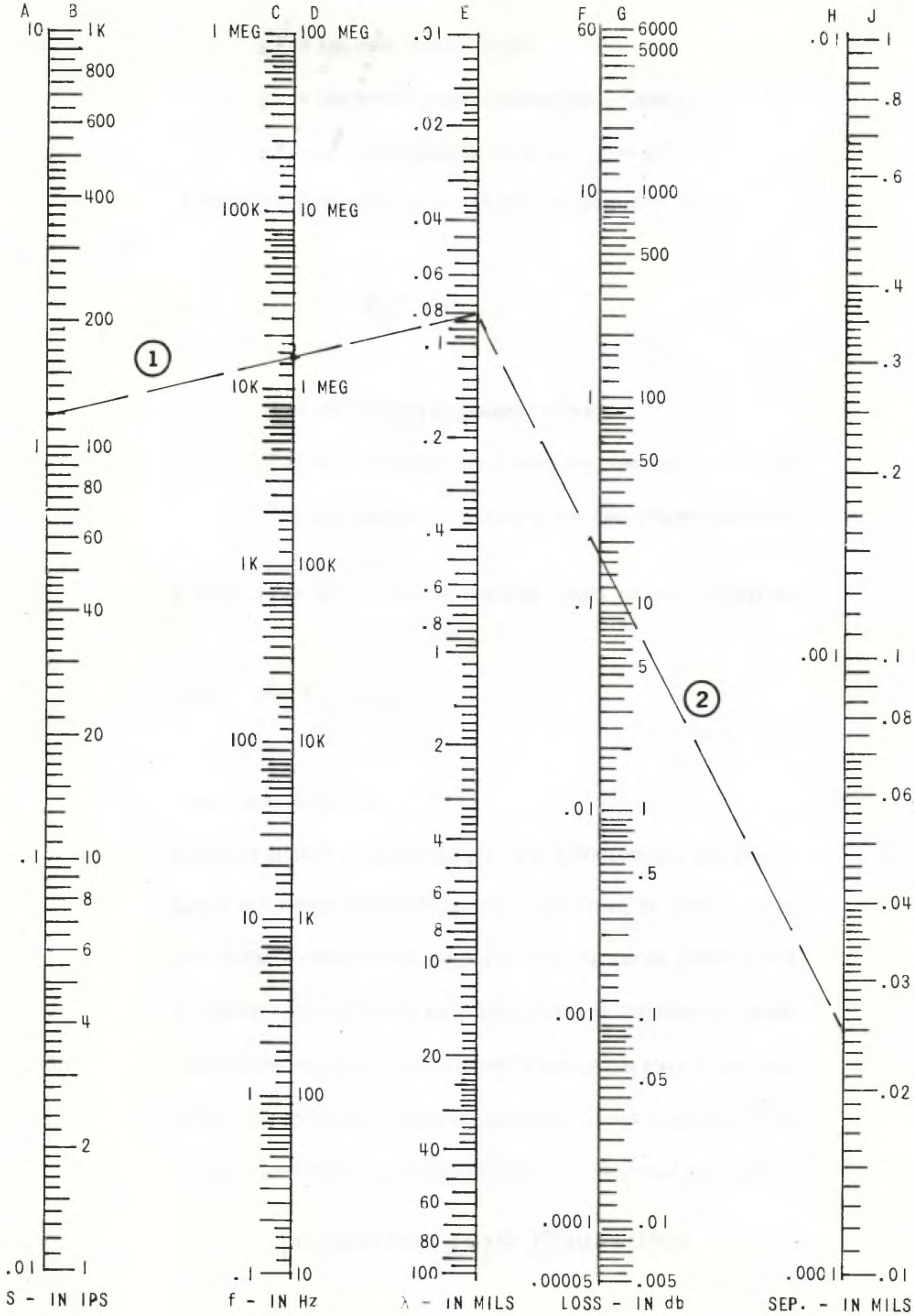
B & D " " " "

F & H " " " "

G & J " " " "



Key


A B
10 1K
800
600
400
200
1 100
80
60
40
20
.1 10
8
6
4
2
.01 1
S - IN IPS
C D
1 MEG 100 MEG
100K 10 MEG
10K 1 MEG
1K 100K
100 10K
10 1K
1 100
.1 10
f - IN Hz
E
.01
.02
.04
.06
.08
.1
.2
.4
.6
.8
1
2
4
6
8
10
20
40
60
80
100
λ - IN MILS
F G
60 6000
5000
10 1000
500
1 100
50
.1 10
5
.01 1
.5
.001 .1
.05
.0001 .01
.00005 .005
LOSS - IN db
H J
.01 1
.8
.6
.4
.3
.2
.001 .1
.08
.06
.04
.03
.02
.0001 .01
SEP. - IN MILS
1
2

Deflection Yoke Conversion

Deflection yoke specifications generally include yoke inductance, sweep current, and acceleration anode potential, as well as the deflection angle through which the CRT beam will be swept. The engineer may make precise departures from the given specifications with the use of these nomograms which are based upon information described in CELCO Application Notes, Data Sheet Y2G. The equations for the nomograms are as follows:

6-10: $I_2/I_1 = \theta_2/\theta_1$

Where: I_1 is the deflection current listed in the specifications at θ_1.

I_2 is the deflection current at the new deflection angle.

θ_1 is the deflection angle from the specification sheet.

θ_2 is the desired deflection angle.

6-11 $I_2/I_1 = \sqrt{E_2/E_1}$

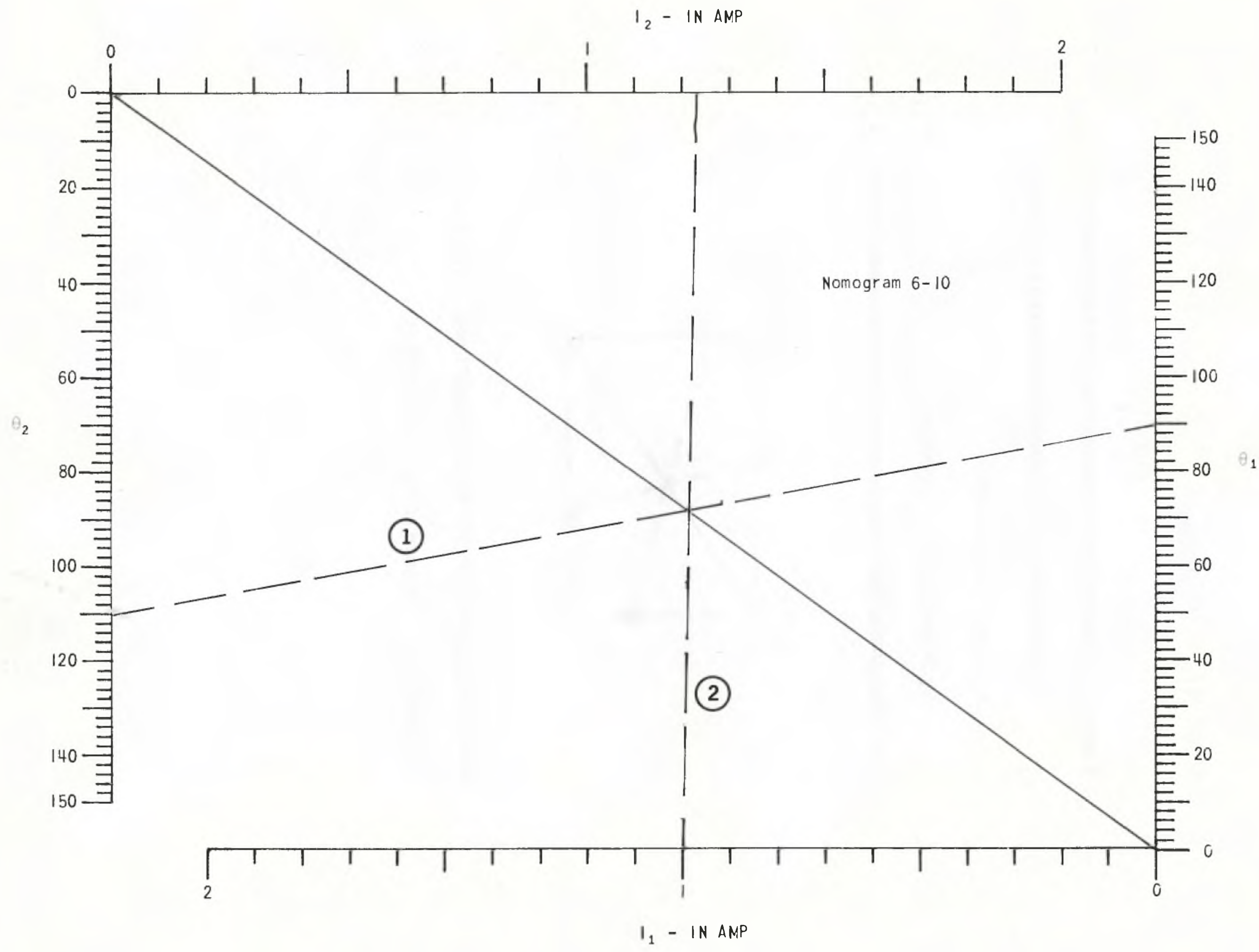
Where: I_1 is the deflection current listed for θ_1 at E_1.

I_2 is the deflection current for θ_1 at E_2.

E_1 is the anode voltage listed for θ_1 and I_1.

E_2 is the new anode voltage.

(Continued on next page)



Nomogram 6-10

6-12 $(I_2/I_1)^2 = L_1/L_2$

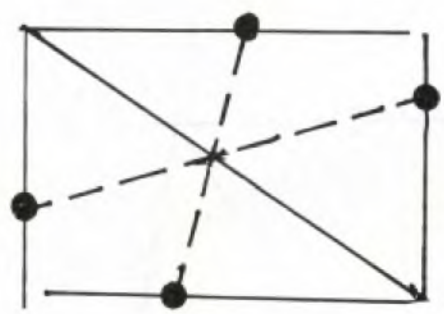
Where: I_1 is the deflection current from the specifications.

I_2 is the deflection current at the desired inductance.

L_1 is the inductance at I_1.

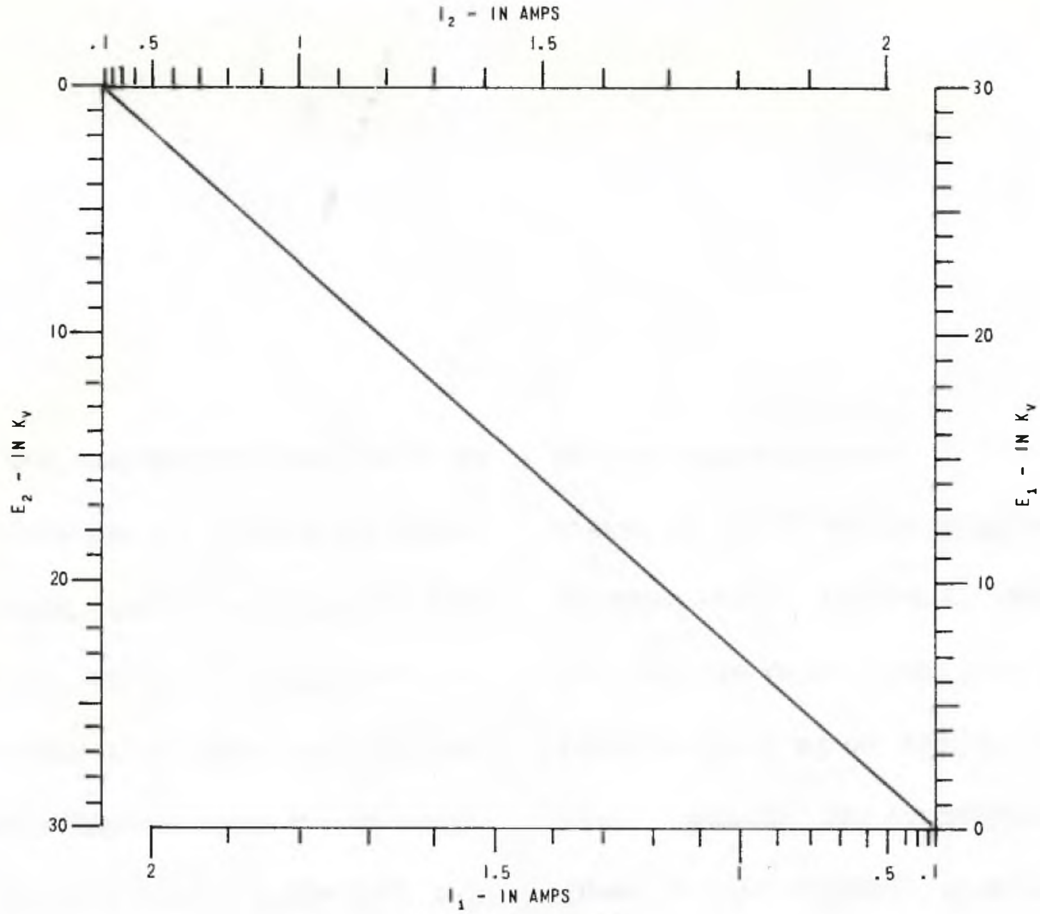
L_2 is the desired yoke inductance.

All three nomograms are similarly solved as shown in the Key below.

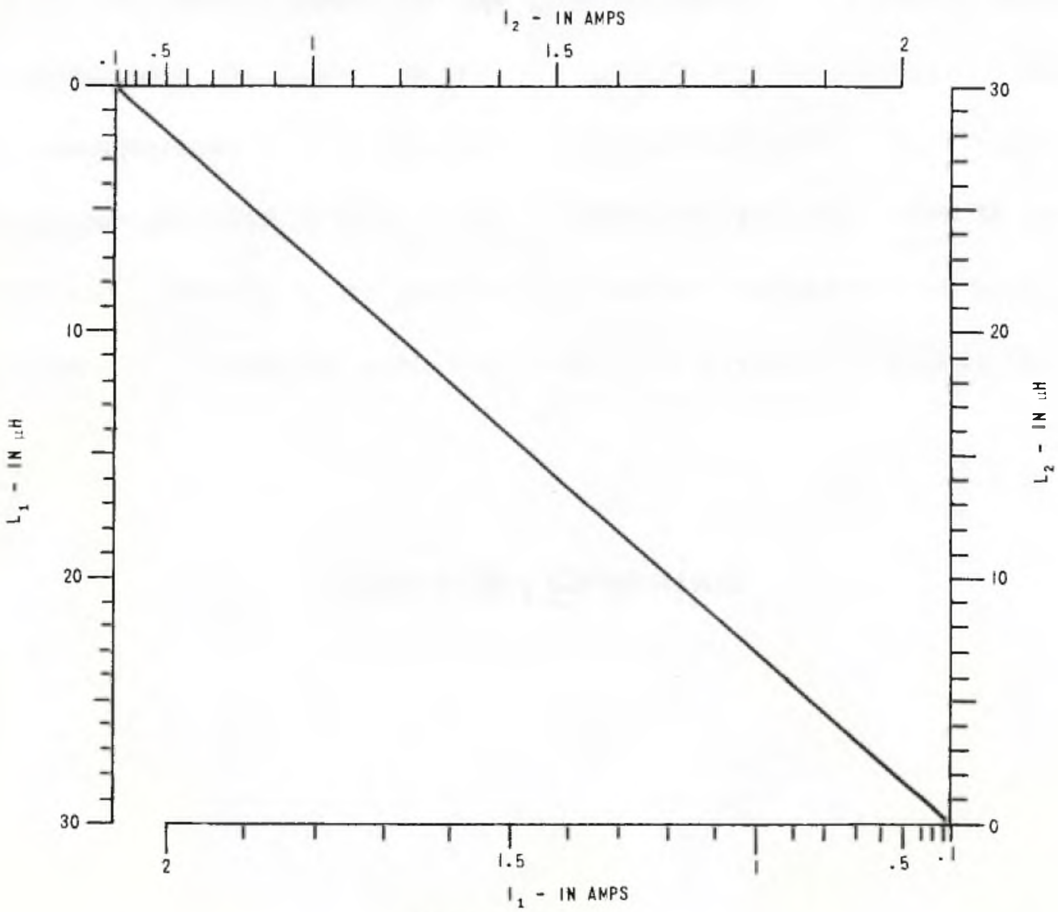


Key

For the example illustrated by the dashed lines: $\theta_2 = 110^{o}$, $\theta_1 = 90^{o}$, $I_1 = 1$ ampere and $I_2 = 1.22$ amperes.



Nomogram 6-11



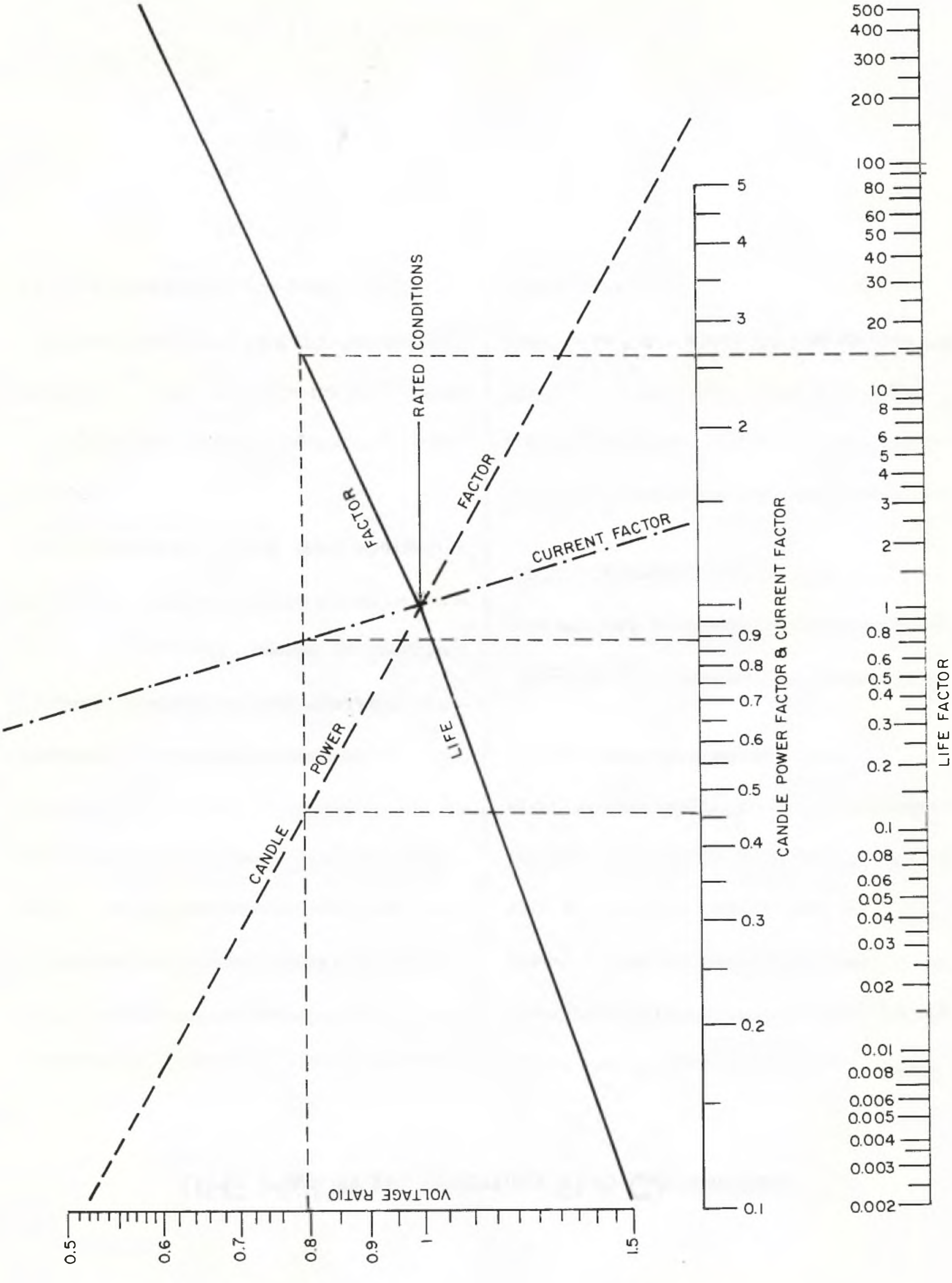
Nomogram 6-12

Pilot Light Evaluation

Even the humble incandescent lamp may create intriguing problems if its lifetime must be evaluated rigorously in terms of its operating characteristics. The questions are: To what degree do the voltage, the current, and the candlepower change the life factor of the pilot light? Nomogram 6-13 supplies the answers in a few simple steps.

Manufacturers recommend that the rated voltage of the lamps be 10 to 20% higher than intended applied voltage. This obviously does not apply where the duty cycle of the applied voltage is such that the lamp will be on for only short periods, where brightness is not important, and where blue lenses are used, since the blue light output is low for low-temperature lamps.

To illustrate the use of the charts, consider this problem. A lamp is operated at 0.8 times its rated voltage. How will the life factor, current, and candlepower change? From the graph we can read off the following: The life factor increase to 14.5 times its rated value, the current decreases to 0.88 of its rating and the candlepower drops to 0.46 of the rated value.


RATED CONDITIONS
LIFE FACTOR
CANDLE POWER FACTOR
CURRENT FACTOR
VOLTAGE RATIO
CANDLE POWER FACTOR & CURRENT FACTOR
0.5
0.6
0.7
0.8
0.9
1
1.5
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
4
5
0.002
0.003
0.004
0.005
0.006
0.008
0.01
0.02
0.03
0.04
0.05
0.06
0.08
0.1
0.2
0.3
0.4
0.5
0.6
0.8
1
2
3
4
5
6
8
10
20
30
40
50
60
80
100
200
300
400
500

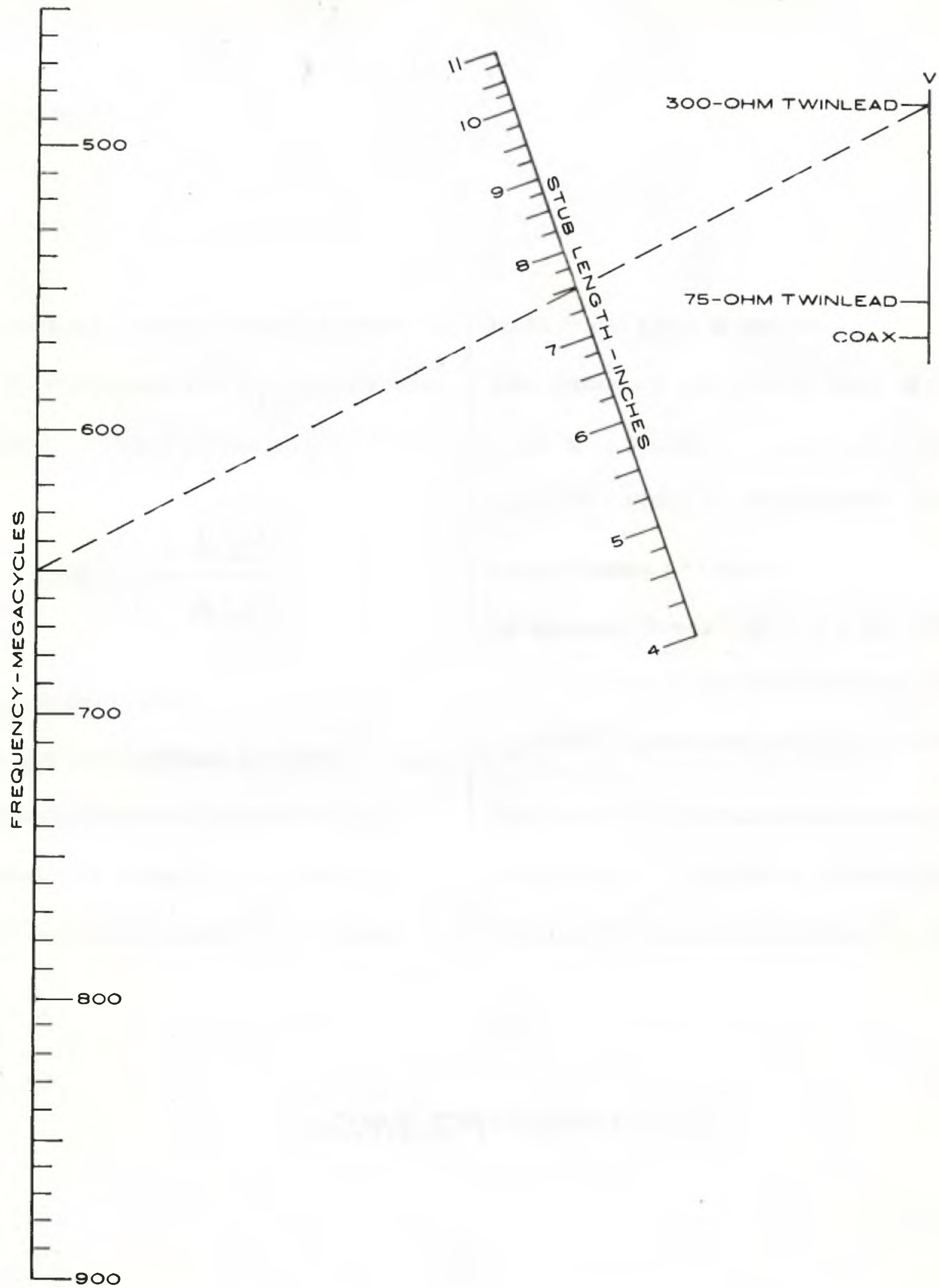
UHF Half-Wave Shorting Stub Calculation

Nomogram 6-14 permits rapid determination of the length of half-wave shorting stubs to eliminate interference in the UHF television range. Most technicians are acquainted with the method of making these stubs and probably know the exact length of 300-ohm twinlead required to eliminate interference on VHF channels. However, with the increasing number of UHF channels opening up throughout the country, they may have to resort to some fancy guesswork or else start sharpening pencils.

Assuming that the technician knows his service area, he will also know the frequencies of potential sources of UHF-TV interference. With this information, the length of the required stub is found by drawing a straight line through all three scales, from the frequency in the left-hand scale to the "V" column at the point indicated for the type of lead-in wire used to construct the shorting stub. The stub length is found in the diagonal column where the line crosses it.

Example: Find the length of a piece of 300-ohm twinlead necessary to eliminate an interference frequency of 650 MHz.

Solution: Draw a straight line from 650 on the frequency scale to the 300-ohm twinlead point on the "V" scale. The stub length is found to be 7.45" where the line crosses the center scale.


FREQUENCY - MEGACYCLES
500
600
700
800
900
STUB LENGTH - INCHES
11
10
9
8
7
6
5
4
V
300-OHM TWINLEAD
75-OHM TWINLEAD
COAX

VSWR Calculations

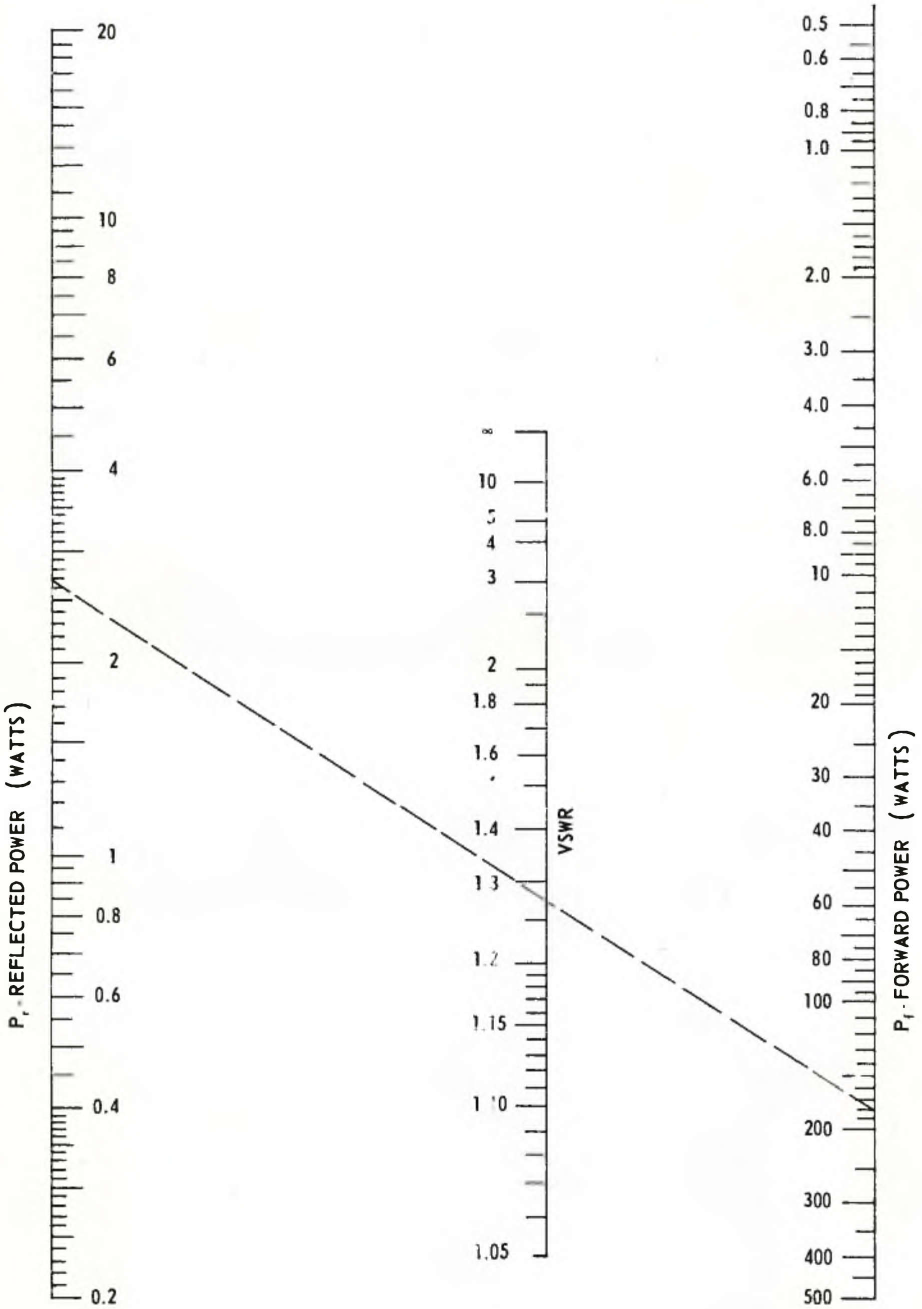
Nomogram 6-15 permits a rapid means of calculating the VSWR of a transmission line after having measured the powers of the incident (P_f) and reflected (P_r) waves. The solution of the equation:

$$\text{VSWR} = \frac{1 + \sqrt{P_r/P_f}}{1 - \sqrt{P_r/P_f}}$$

is cumbersome even with the use of a slide rule. By using Nomogram 6-15, the equation can be solved by merely aligning a straight-edge through the measured points on the P_r and P_f scales. The VSWR is located where the straight-edge intersects the center scale.

Example: Determine the VSWR of a transmission line for the following recorded power; (a) reflected power, $P_r = 2.7$ w, and (b) forward power $P_f = 180$ w.

Solution: Align a straight-edge through points $P_r = 2.7$ and $P_f = 180$. The straight-edge intersects the center scale at 1.27, which is the VSWR of the line.


P_r - REFLECTED POWER (WATTS)
20
10
8
6
4
2
1
0.8
0.6
0.4
0.2
VSWR
∞
10
5
4
3
2
1.8
1.6
1.4
1.3
1.2
1.15
1.10
1.05
P_f - FORWARD POWER (WATTS)
0.5
0.6
0.8
1.0
2.0
3.0
4.0
6.0
8.0
10
20
30
40
60
80
100
200
300
400
500