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COOKE RADIO

Slide Rule

A SUPPLEMENTARY MANUAL

BY

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NOTE: This booklet is written primarily for the radio or electrical student. It explains only special applications of basic scales, and the uses of scales found only on the Cooke Radio Slide Rule. A discussion of the powers of ten is also included. The booklet is a supplement to the instructions covering the Polyphase Duplex Decitrig Slide Rule No. 4071. *Be sure that you receive the manual for No. 4071, which explains the general use of this slide rule.*

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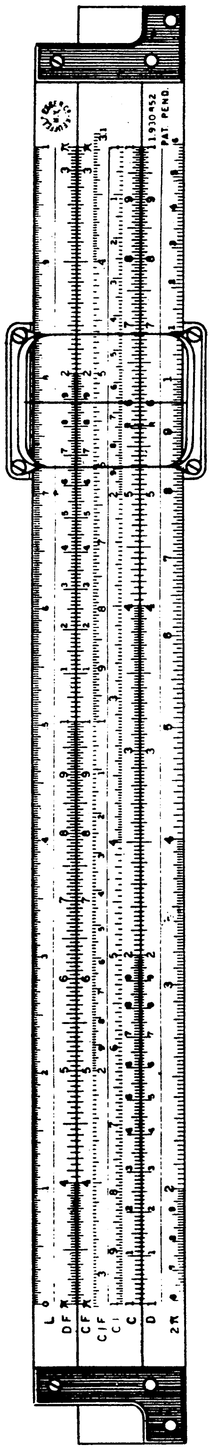

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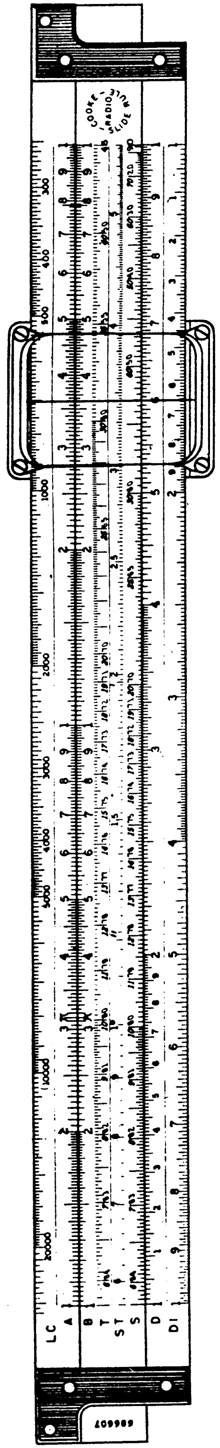

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THE COOKE RADIO SLIDE RULE

KEUFFEL & ESSER CO.

-- C O N T E N T S --

INTRODUCTION

The Cooke Radio Slide Rule has all of the scales of the Polyphase Duplex Decitrig Slide Rule with the exception of scale K, which hass been replaced by scale LC. In addition, on the Cooke Radio Slide Rule, scale 2π occupies the space of scale L; the latter having been placed on the front face of the rule.

It is recommended that learners become thoroughly proficient in computations employing the basic scales through much practice and thorough study of the instruction manual on the Polyphase Duplex Decitrig Slide Rule. The latter, which is also supplied with the Cooke Radio Slide Rule, includes a thorough treatment of the right triangle on which vector calculations are based. In addition, it is urged that the student adopt the habit of utilizing the powers of ten as an aid in properly fixing the decimal point. This subject is discussed in the following pages.

In connection with the above, attention is invited to the fact that slide rule proficiency is attained by thoroughly understanding the operation of the rule for any desired problem. When the particular operation is understood, enough practice should follow so that the principle of making the corresponding slide rule "set up" becomes automatic. For these reasons a large number of exercises have been included in the instruction pamphlets.

At this point the student should begin to acquire the habit of never closing his rule upon the completion of any slide rule operation. When the rule is no longer needed for a particular calculation *carefully lay it down with the same setting on it that was last used.*

There are two good reasons for the above. First, it might be desirable to check the last answer obtained and this is readily accomplished if the slide and indicator have not been moved. Second, the last answer obtained may be needed for carrying out further calculations. If this answer is already on the rule, the time of reset is saved and also the chance of making an error on the reset.

Slide rule accuracy is discussed on page 6 of the instruction book for the No. 4071 slide rule. However, it is desired to emphasize that from a practical radio or electrical viewpoint, the accuracy of a slide rule leaves nothing to be desired.

When practical radio or electrical circuits are taken into consideration it is evident that careful slide rule calculations are more accurate, in general, than the circuit components. For example, the tolerance allowed resistors used in the average radio receiver is plus or minus ten per cent. Other circuit components vary much in the same manner and when temperature effects and other variations are taken into account, slide rule results meet all practical needs. Very few technicians have access to electrical instruments that will read correct to one-tenth of one per cent throughout their operating ranges.

Answers to all exercises will be found in the back of this booklet.

PLACING THE DECIMAL POINT

SIGNIFICANT FIGURES

For the foregoing reasons a slide rule answer to three significant figures is sufficiently accurate for practical results. The student should not confuse three significant figures with the third decimal place. Counting from the left, the first significant figure of any number is the first figure that is not zero.

Examples:
0.00345 is correct to *three* significant figures.
3.1416 is correct to *five* significant figures.
0.4825 is correct to *four* significant figures.
15 is correct to *two* significant figures.
15.0 is correct to *three* significant figures.
0.00000023 is correct to *two* significant figures.
0.000000230 is correct to *three* significant figures.
98,400 is correct to *three* significant figures.

Because the slide rule gives only the significant figures of the result of a mathematical operation, it becomes necessary for the operator to fix the decimal point. The operator must determine the *approximate* answer in order that he may use the more accurate figures taken from the slide rule scales.

POWERS OF TEN

Unfortunately, electrical engineers and particularly radio engineers, are required to handle cumbersome numbers. These numbers range from very small decimal parts of electrical units to extremely large numbers as represented by radio frequencies. The fact that these wide limits of numbers are encountered in the same problem does not simplify the matter. This situation is becoming more complicated owing to the trend to the ultra-high radio frequencies with attendant smaller fractions of units represented by circuit components and larger numbers represented by the frequencies used.

For these reasons the decimal point *cannot* be fixed "by inspection" except in the most simple computations. This important item has been neglected by many writers of slide rule instruction books. Accordingly, many beginners who were interested in the slide rule from a radio or electrical viewpoint have become discouraged by the difficulty of placing the decimal point due to this wide range of numbers encountered in the average problem. This, however, presents little difficulty to the man who has a working knowledge of the powers of ten.

The powers of ten are sometimes termed the "engineers shorthand". A thorough knowledge of the powers of ten and the ability to apply the theory of exponents will greatly assist in determining an approximation, as in general it reduces the average calculation to the usual slide rule operations plus simple mental arithmetic, or at most, in more complicated problems, to simple addition, subtraction, multiplication, or division.

The student will find the use of powers of ten of great assistance in solving problems in alternating currents and general radio circuits. This is especially true of those formulas dealing with inductance and capacity. For example, most of these formulas are expressed in terms of their respective units, i.e., the Henry (the unit of inductance), the Farad (the unit of capacity), and the cycle (the unit of frequency). The actual values of inductance and capacity used in circuits are usually very small decimal portions of the whole units, with the result that when these values are substituted in formulas, unless great care is taken, the student will misplace the decimal point in the final result.

Some of the multiples of ten may be represented as follows:

$.000001 = 10^{-6}$ = ten to the negative sixth power.
$.00001 = 10^{-5}$ = ten to the negative fifth power.
$.0001 = 10^{-4}$ = ten to the negative fourth power.
$.001 = 10^{-3}$ = ten to the negative third power.
$.01 = 10^{-2}$ = ten to the negative second power.
$.1 = 10^{-1}$ = ten to the negative first power.
$1 = 10^{0}$ = ten to the zero power.
$10 = 10^{1}$ = ten to the first power.
$100 = 10^{2}$ = ten to the second power.
$1000 = 10^{3}$ = ten to the third power.

$10000 = 10^{4}$ = ten to the fourth power.
$100000 = 10^{5}$ = ten to the fifth power.
$1000000 = 10^{6}$ = ten to the sixth power.

From the above it is seen that any decimal may be expressed as a whole number times some negative power of ten. *When expressing a decimal as a whole number times a power of ten, place the new decimal point to the right and count the number of places to the former decimal point. The number of places counted will give the proper negative power of ten.*

Examples. $0.00256 = 2.56 \times 10^{-3}$
$0.08735 = 8.735 \times 10^{-2}$
$0.000097 = 9.7 \times 10^{-5}$
$0.000675 = 6.75 \times 10^{-4}$
0.00025 microfarad = 2.5×10^{-4} microfarad = 2.5×10^{-10} farad.
0.15 millihenry = 1.5×10^{-1} millihenry = 1.5×10^{-4} henry.

Also, it is evident that any large number may be expressed as some smaller number times the proper positive power of ten. *When expressing a whole number times a power of ten, place the new decimal point to the left and count the number of places to the former decimal point. The number of places counted will give the proper positive power of ten.*

Examples. $872 = 8.72 \times 10^{2}$
$4368.4 = 4.3684 \times 10^{3}$
$943,000 = 94.3 \times 10^{4}$
$186,000,000 = 1.86 \times 10^{8}$
1440 kc = 1.440×10^{3} kc = 1.440×10^{6} cycles.
128 mc = 1.28×10^{2} mc = 1.28×10^{5} kc = 1.28×10^{8} cycles

MULTIPLICATION IN EXPONENTS

In the general form, the law of exponents in multiplication is given by $A^{m} \cdot A^{n} = A^{m+n}$

Examples. $10^3 \times 10^8 = 10^{3+8} = 10^{11}$

$10 \times 10^4 = 10^{1+4} = 10^5$

$34000 \times 8000 = 3.4 \times 10^4 \times 8 \times 10^3 = 27.2 \times 10^7$

$.000023 \times 800 = 2.3 \times 10^{-5} \times 8 \times 10^2 = 2.3 \times 8 \times 10^{-5+2}$
$= 18.4 \times 10^{-3}$

The student will find that by using a whole number that may be roughly multiplied mentally, such as choosing 2.3×8 as in the above example, placing the decimal will *then* become a matter of inspection.

DIVISION IN EXPONENTS

The law of exponents in division is given by

$$\frac{A^m}{A^n} = A^{m-n} \quad \text{or} \quad \frac{A^m}{A^{-n}} = A^{m+n}$$

Examples.

$$\frac{10^4}{10^2} = 10^{4-2} = 10^2 \quad \text{or} \quad 10^4 \times 10^{-2} = 10^2$$

$$\frac{32000}{.004} = \frac{32 \times 10^3}{4 \times 10^{-3}} = \frac{32}{4} \times 10^{3+3} = 8 \times 10^6$$

$$\text{Or,} \quad \frac{32 \times 10^3 \times 10^3}{4} = 8 \times 10^6$$

$$\frac{33 \times 10^4}{3 \times 10^4} = 11 \times 10^{4-4} = 11 \times 10^0 = 11 \times 1 = 11$$

It follows that like powers of ten occuring as factors in numerator and denominator may be cancelled. The student will also note that when powers of ten are transferred from denominator to numerator and vice versa, it is necessary to change only the sign of the exponent.

Examples.

$$\frac{82 \times 10^5}{41 \times 10^2} = \frac{82 \times 10^5 \times 10^{-2}}{41} = 2 \times 10^3$$

$$\frac{.00047}{.00000032} = \frac{47 \times 10^{-5}}{32 \times 10^{-8}} = \frac{47 \times 10^{-5} \times 10^8}{32} = 1.47 \times 10^3$$

THE POWER OF A POWER IN EXPONENTS

In finding the power of a power the exponents are multiplied. That is, in general

$$(A^m)^n = A^{mn}$$

Examples.

$(10^6)^3 = 10^{6\times 3} = 10^{18}$

$(2100)^3 = (2.1 \times 10^3)^3 = 9.261 \times 10^9$

$(0.002)^4 = (2 \times 10^{-3})^4 = 16 \times 10^{-12}$

THE POWER OF A PRODUCT IN EXPONENTS

The power of a product is the same as the product of the powers of the factors, that is, in general

$$(ABC)^m = A^m B^m C^m$$

Examples.

$(10^4 \times 10^6)^3 = 10^{4\times 3} \times 10^{6\times 3} = 10^{30}$

Or, $10^{12} \times 10^{18} = 10^{12+18} = 10^{30}$

Or, $(10^{10})^3 = 10^{30}$

THE POWER OF A FRACTION IN EXPONENTS

The power of a fraction equals the power of the numerator divided by the power of the denominator. That is:

$$\left[\frac{A}{B}\right]^m = \frac{A^m}{B^m}$$

Example.

$$\left[\frac{10^4}{10^3}\right]^2 = \frac{10^{4\times 2}}{10^{3\times 2}} = \frac{10^8}{10^6} = 10^2$$

The above may be solved by first clearing the exponents inside the parentheses and then raising to the required power. Thus:

$$\left[\frac{10^4}{10^3}\right]^2 = (10^{4-3})^2 = (10^1)^2 = 10^2$$

THE ROOT OF A POWER IN EXPONENTS

The root of a power in exponents is given by

$$\sqrt[n]{A^m} = A^{m \div n}$$

Example. $\sqrt{25 \times 10^8} = \sqrt{25} \times \sqrt{10^8} = 5 \times 10^{8 \div 2} = 5 \times 10^4$

$$\sqrt[3]{125 \times 10^6} = \sqrt[3]{125} \times \sqrt[3]{10^6} = 5 \times 10^{6 \div 3} = 5 \times 10^2$$

$$\sqrt{36 \times 10^{-10}} = \sqrt{36} \times \sqrt{10^{-10}} = 6 \times 10^{(-10) \div 2} = 6 \times 10^{-5}$$

In the above cases where the power of ten is evenly divisible by the index of the root, the process of extracting roots is comparatively simple. When the power of ten is not evenly divisible by the index, the result of the extraction of the root is a fractional power. For example,

$$\sqrt{10^5} = 10^{\frac{5}{2}} = 10^{2.5}$$

Such fractional powers are encountered in various phases of engineering mathematics and are conveniently solved by the use of logarithms. However, when using the powers of ten, the fractional exponent is cumbersome when arriving at a final answer. It becomes necessary, therefore, to devise some means of extracting a root in order to obtain a result with a whole number as an exponent.

This is accomplished by expressing the number, the root of which is desired, as some number times the proper power of ten; the power of ten being evenly divisible by the index of the required root. For example, suppose it is desired to extract the square root of 200,000. While it is true that

$$\sqrt{200{,}000} = \sqrt{2 \times 10^5} = \sqrt{2} \times \sqrt{10^5} = 1.414 \times 10^{2.5}$$

we have a fractional exponent that is not readily reduced to actual figures. If, however, we express the number differently we obtain an integer as an exponent. For example

$$\sqrt{200{,}000} = \sqrt{20 \times 10^4} = \sqrt{20} \times \sqrt{10^4} = 4.47 \times 10^2$$

It will be noted that there are a number of ways of expressing the above problem; such as

$$\sqrt{200{,}000} = \sqrt{0.2 \times 10^6} \text{ or } \sqrt{2000 \times 10^2} \text{ or } \sqrt{0.002 \times 10^8} \text{ etc.}$$

When extracting roots, with the aid of powers of ten, the student should try to write the problem in a form that will allow

a rough mental approximation in order that the decimal point may be properly placed with respect to the significant figures.

EXERCISES I

(See answers Pg. 58)

Express the following numbers as a number between 1 and 10, times the proper power of 10:

(1) 5,876,000,000 (2) 56,720,000

(3) 576 (4) 2594

(5) 672,000 (6) 203

(7) .00000781 (8) .463

(9) .0004 (10) .000000008765

Solve and express as above:

(11) $374{,}000 \times .000025$ (12) $64 \times 10^8 \times 43 \times 10^{-3}$

(13) $613 \times 10^{-3} \times 42 \times 10^{-6}$ (14) $\dfrac{.000068 \times .00025}{47 \times 10^{-8}}$

(15) $.000025 \times .00000008 \times .042$

(17) $837 \times 10^3 \times 10^{-8} \times 46 \times 10^4$ (16) $\dfrac{482 \times 10^3 \times 682 \times 10^4}{26 \times 10^8 \times 67 \times 10^6}$

(19) $(3 \times 10^{-2})^2$ (18) $\dfrac{.0047 \times .000872}{.0000069}$

(21) $(7 \times 10^{-3})^3$ (20) $(5 \times 10^4)^2$

(22) $(8 \times 10^3 \times 2 \times 10^6)^2$

(23) $\dfrac{14 \times 10^6 \times .00006}{.0028 \times 87 \times 10^{-5}}$ (24) $\sqrt{.0036 \times .0004}$

(25) $\dfrac{63 \times 10^3 \times 46 \times 10^{-8}}{6 \times 10^6}$ (26) $\sqrt{.00064 \times .009}$

(27) $\sqrt{64 \times 10^{-3} \times 25 \times 10^5}$ (28) $\dfrac{1}{6.28\sqrt{6 \times 10^3 \times 8 \times 10^{-6}}}$

APPLICATIONS TO ELECTRICAL PROBLEMS *

SCALE 2π

Reactance and other problems in alternating current and radio circuits involving the constant 2π and ω ($2\pi F$) constitute a large part of the problems encountered by the electrician and radioman. It is apparent that some method of reducing the number of slide rule settings when solving such problems would be highly desirable. Scale 2π was devised for this purpose. This scale may be considered as an ordinary D scale folded at $1/2\pi$ or 0.159.

When the indicator is set to any number on scale 2π, that number multiplied by 2π will appear under the indicator on scale D.

Example. Multiply 2π by 60.

Solution. Set indicator to 60 on scale 2π.
Under indicator on D read 377.
(Note that the reciprocal of 377 which is 0.00265 appears under the indicator on DI.)

Example. What is the inductive reactance (X_L) of an AC circuit of 0.08 henry, if the frequency is 60 cycles?

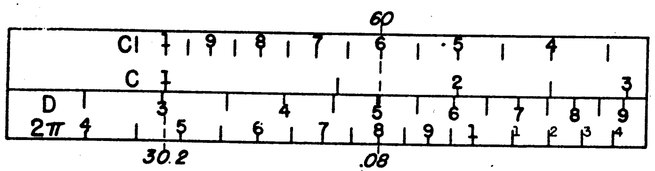
Solution.

$$X_L = 2\pi FL$$

Where F = Frequency in cycles per second
L = Inductance in henrys.

(1) Set indicator to 60 (F) on scale 2π
(2) Set 0.08 (L) on scale CI to indicator.
Opposite index of C read X_L = 30.2 ohms on D.

In step (1) above we multiplied 2π by 60, the product 377 appearing under the indicator on D. Step (2) multiplied 377 by 0.08 by the method of multiplication described for CI in conjunction with D. The above problem is illustrated in Fig. 1.



* See the author's "Mathematics for Electricians and Radiomen", McGraw-Hill Book Co., New York, N. Y., for a thorough treatment of mathematics applied to electrical circuits.

Example. What is the capacitive reactance (X_C) of an AC circuit containing 13 microfarads capacitance, if the frequency is 25 cycles?

Solution.

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

Where F = Frequency in cycles per second.
C = Capacitance in farads.

(Note that 13 microfarads = 13×10^{-6} farad, therefore the equation in arithmetical form would be:

$$X_C = \frac{1}{2\pi \times 25 \times 13 \times 10^{-6}} = \frac{10^4}{2\pi \times 2.5 \times 1.3}$$

(1) Set the indicator to 25 on scale 2π.
(2) To indicator set 13 on CI.
Opposite index of D read X_C = 490 ohms on C. This problem is illustrated in Fig. 2.

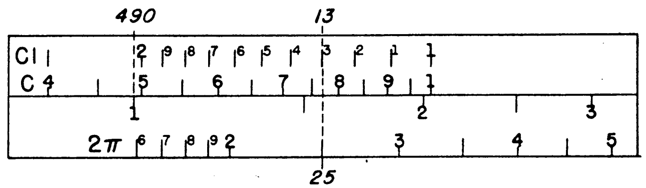


Fig. 2

In step (1) 2π was multiplied by 25, the significant figures of the product 157 appearing under the indicator on scale D, as in the two previous examples. In step (2) we multiplied this product by 13 (the capacitance) by the method of using CI and D. Actually, this product, the significant figures of which are 204, appears on scale D opposite the index of C. What is wanted, however, is the reciprocal of this product which we find on C opposite the index of D. Applying the powers of ten as above allows easy determination of the reactance figure.

Most alternating current problems involve calculating both inductive and capacitive reactances. This may be accomplished with a minimum number of slide rule settings if all reactances are calculated one after the other. If this is done the indicator may be left setting on $2\pi F$ (which is common to both reactances) thus giving each reactance by one setting of the slide.

Example. What is the reactance of a 60 cycle AC circuit containing an inductance of 0.4 henry in series with a capacitance of 80 microfarads?

Solution. (1) To 60 (F) on scale 2π set the indicator.

(2) To indicator set 4 (L) on CI.

Opposite index of C read X_L = 151 ohms on D.

(3) To indicator set 8 (C) on CI.

Opposite index of D read X_c = 33.2 ohms on C.

$$X = X_L - X_c$$
$$= 151 - 33.2$$
$$= 117.8 \text{ or } 118 \text{ ohms.}$$

EXERCISES 2

(See answers Pg. 58)

Fill in the blanks in the following table:

F	L	C	X_L	X_c	X
25	4.2 H	56 µF	[illegible]	[illegible]	
50	2.3 H	43 µF	[illegible]	74	
60	.15 H	27 µF	[illegible]	[illegible]	
1000	.01 H	2.3 µF	[illegible]	[illegible]	
1000 KC	165 µH	170 µµF	[illegible]	[illegible]	
355 KC	225 µH	920 µµF	[illegible]	[illegible]	
2744 KC	63 µH	52 µµF	[illegible]	[illegible]	
6190 KC	24 µH	27 µµF	[illegible]	[illegible]	
215 KC	276 µH	1950 µµF	[illegible]	[illegible]	
500 KC	160 µH	605 µµF	[illegible]	[illegible]	

SCALES A AND B

Scales A and B are used for extracting square roots and squaring numbers when used in conjunction with scales C and D.

To square a number, set the indicator to that number on scale D and read the square under the indicator on scale A. The same procedure applies to squaring numbers on scale C except that the squares are read on scale B. Naturally, all four scales work together if the indices are in alignment.

By combining the operations of squaring and multiplying, many formulas may be solved with a minimum number of settings.

The power in any electrical circuit is given by the square of the current multiplied by the effective resistance, or

$$P = I^2R.$$

Where P = Power in watts,

I = Current in amperes,

and R = Effective resistance in ohms.

The power is obtained by one setting of the slide and one setting of the indicator.

Example. A current of 8.5 amperes is flowing through a resistance of 5.3 ohms. Find the power.

Solution. (1) To 8.5 (I) on D, set index of C.

(2) To 5.3 (R) on B, set indicator.
Under indicator read 383 watts on A.

In step (1), setting the index of C to 8.5 on D, gave the current squared on scale A opposite the index of B. In step (2) the current squared was multiplied by the resistance by using scales A and B.

The above example is illustrated in Fig. 3.

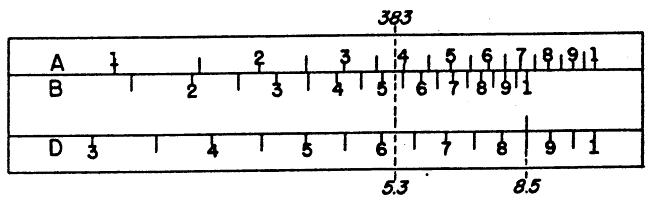


Fig. 3

EXERCISES 3

(See answers Pg. 59)

I	R	E = IR	P = I^2R	I	R	E = IR	P = I^2R
5	10	50	250	2.5	12.2	30.5	76.4
3.2	31	99.1	318	4.69	73	342	1600
6.82	87.6	597	4060	5.2	5.86	30.5	158
0.62	10^3	620	385	8.73	1.73	15.1	132
13.5	2.42	32.7	440	0.76	4.5		
9.2	0.56	5.15	475	1.5	93		

The power in an electrical circuit may be found by dividing the square of the voltage drop across the resistance by the resistance, or

$$P = \frac{E^2}{R}$$

Where P = Power in watts,

E = Voltage across resistance,

and R = Resistance in ohms.

Again the power can be solved for by one setting of the indicator and one setting of the slide.

Example. A potential of 16 volts is impressed across an 18 ohm resistor. What is the power expended in the resistor?

Solution. (1) To 16 (voltage) on D, set indicator.

(2) To indicator, set 18 (resistance) on B.

Opposite index of B read 14.2 watts on A.

Step (1) above, by setting the indicator to the voltage on D, gave the voltage squared under the indicator on A. In step (2) the voltage squared was divided by the resistance by using scales A and B.

The above example is illustrated in Fig. 4.

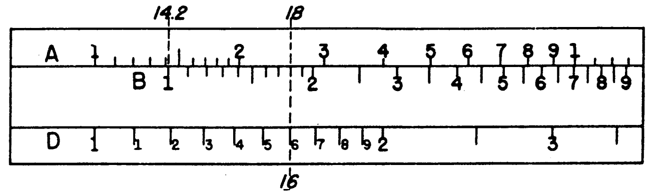


Fig. 4

EXERCISES 4

(See answers Pg. 59)

E	R	$I = \frac{E}{R}$	$P = \frac{E^2}{R}$	E	R	$I = \frac{E}{R}$	$P = \frac{E^2}{R}$
6	12	.5	3	10^3	.367		
32	36	.89	28.5	115	11.3	10.18	1170
110	98.3	1.12	123	12	69	.174	2.08
220	10^4			110	6.73		
550	3.82	144	79300	14	125	.112	1.57

To extract the square root of a number the process of squaring is reversed. The indicator is set to the number on scales A or B and the square root is read under the indicator on scales D or C respectively.

Note that scales A and B consist of two complete scales end to end. This construction is necessary because when a number is squared the logarithm of that number is multiplied by 2, and when extracting the square root of a number its logarithm is divided by 2. To the beginner there is the possibility of confusion as regards which scale, right or left, to use when extracting square roots on scales A and B.

All numbers greater than unity are located, as to their proper scales, (right or left), by the number of integers to the left of the decimal point. Those having an *even* number of integers to the left of the decimal point are located on the *right* scales of A and B. Those having an *odd* number of integers to the left of the decimal point are located on the *left* scales of A and B.

Thus the square root of 25 is found by setting the indicator to the right hand scale, of A or B, while the square root of 2.5 would be found by setting the indicator to 2.5 on the left hand scale.

Numbers less than unity are located by the *number of zeros* between the decimal point and the first significant figure. Those having an even number of zeros will be found on the right hand scale, and those having an odd number will be found on the left hand scale. Decimals having no zeros between the decimal point and the first significant figure are located on the right hand scale.

This apparent difficulty of remembering the proper scales for decimals may be overcome by changing the decimal to a whole number times some even power of ten.

Example. Find $\sqrt{0.00000687}$

Solution.
$$\sqrt{0.00000687} = \sqrt{6.87} \times \sqrt{10^{-6}}$$
$$= 2.62 \times 10^{-3}$$
$$= 0.00262$$

SCALE LC

Any circuit containing inductance and capacity will be resonant at some frequency. This resonant frequency is determined by the values of inductance and capacity and is given by

$$F = \frac{1}{2\pi\sqrt{LC}} \quad \text{or} \quad F = \frac{159 \times 10^3}{\sqrt{LC}}$$

In the latter F = Resonant frequency in *kilocycles*,

L = Inductance in *microhenrys*,

and C = Capacity in *micromicrofarads*.

Inspection of the above formula shows that the frequency varies inversely as the square root of the LC product, and that for *any one frequency*, an infinite number of combinations of L and C values may be used provided the LC product remains the same.

By application of the remainder of the formula, which is a constant, it is a simple task to construct a table of LC products from which resonant frequencies may be obtained.

Scale LC was devised to give directly the LC products of frequencies from 1,000 kc to 10,000 kc, when frequencies between these limits are set on scale D. The LC products thus obtained on the slide rule are for values of L in *microhenrys* and C in *micromicrofarads*. Conversely, any LC product of the above units, when set on scale LC will give the resonant frequency on scale D.

Example. Find LC when F = 1500 kc.

Solution. To 1500 on D, set indicator.
Under indicator read 11,200 on LC.

A study of the basic formula will show the variation of frequency with LC, and familiarity with this variation will be of value when working with scale LC.

Calculations with the LC scale are not restricted to frequencies within the band from 1,000 kc to 10,000 kc. This portion of the spectrum was chosen as a reference calibration because of its present wide use. Scale LC, used in conjunction with scale D, is readily adaptable for use with any frequency.

In the preceding formula, if F is multiplied by 10 it is necessary to divide LC by 100 in order to maintain the equality of the equation. This is because *F varies inversely as the square root of LC*. In like manner if F is divided by 10, LC must be multiplied by 100 to maintain equality. It follows, therefore, that regardless of the power of 10 that is applied to the basic calibration of scale D, it is necessary that the calibration of scale LC be changed inversely by the square of that particular power of ten. This is illustrated in the following examples.

Example. Find the LC product of 24,000 kc.

Solution. To 24,000 on D, set indicator.
Under indicator read significant figures 4400 on scale LC.
In this example scale D was *multiplied* by 10. This was

done in order to change its range from 10,000 kc to 100,000 kc so the desired frequency (24,000 kc) would be within the limits of the scale. Therefore, in order to maintain equality, scale LC must be *divided* by 100. Then the LC product for 24,000 kc is 44. This example is illustrated in Fig. 5.

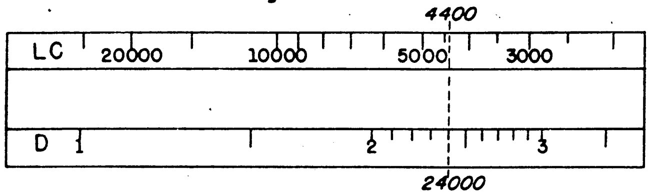


Fig. 5

Example. Find the LC product of 800 kc.

Solution. To 800 on D, set indicator.

Under indicator read 396 on LC.

In order that this frequency fit the calibration of the rule, it is necessary to divide the basic calibration of scale D by 10; thereby making its range from 100 to 1,000 kc. Scale LC is therefore multiplied by 10^2 to maintain equality. Then for 800 kc the LC product is 396×10^2.

The foregoing examples show that all the student must remember is that when scale D is affected by any power of 10, the calibration of scale LC must be changed inversely by the square of that particular power of ten.

In case of doubt it is well to remember that as frequency is increased, inductances and capacities become smaller, thereby reducing the LC product. The opposite is true of the low frequencies; larger values of inductances and capacities being necessary, thereby resulting in larger LC products.

It has been shown that scale LC can be operated on *only in steps of 100,* or *even* powers of 10. It follows then that when the calibration of scale LC is changed by an even power of 10, scale D must accordingly be changed inversely by the square root of that particular power of ten.

Example. LC = 49000. Find the resonant frequency.

Solution. LC = 490×10^2 (operate on basic calibration of LC in multiples of 10^2). To 490 on LC set indicator.

Under indicator read 7200 kc on D.

Scale LC (basic calibration) was multiplied by 10^2, therefore, the calibration of scale D calibration must be divided by $\sqrt{10^2}$, or 10, which gives a frequency of 720 kc.

Example. LC = 88. Find the resonant frequency.

Solution. (Basic calibration 8800 must be used.)

To 8800 on LC set indicator.

Under indicator read 1700 on D.

Scale LC (basic) was divided by 10^2, therefore scale D must be multiplied by 10 which gives 17,000 kc.

EXERCISES 5

(See answers Pg. 59)

μH	μμF	LC	F in kc	μH	μμF	LC	F in kc
180	250	45000	750	9.85	150	1478	4140
242	350	84700	547	400	500	200000	356
14.3	100	1430	4205	25.5	150	3825	2575
2530	1000	2530000	100	701	600	421000	245
7.5	50	375	8210	450	400	180000	375

Because the resonant frequency varies inversely as the square root of LC, it is possible to calculate values of inductance and capacity on scale LC. This is accomplished by making use of scale B.

Example. What value of inductance must be used with a 250 μμF condenser to resonate at 1250 kc?

Solution. To 1250 kc on D set index of C.

To 250 on B set indicator.

Under indicator read 65 μH on LC.

In the above solution a glance at the position of the index of the rule shows the LC value to be roughly 16,000. Setting the indicator to 250 on scale B divided the capacity value into the LC product and gave the significant figures on scale LC, it being necessary to place the decimal by mentally dividing 16,000 by 250. This example is illustrated in Fig. 6.

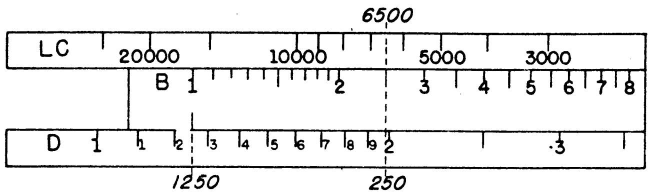


Fig. 6

Example. It is desired to build a trap for 4205 kc. There is on hand a coil with a known inductance of 15 μH. What value of capacity is required?

Solution. To 4205 on D set index.

To 15 on B set indicator.

Under indicator read 95.2 μμF on LC.

In the above solution the decimal was placed as in the preceding example. Inspection shows the LC value to be roughly 1500. (Without the use of the indicator.) A mental division by the inductance value shows that the capacity must be near 100 μμF.

EXERCISES 6

(See answers Pg. 60)

F in kc	μμF	μH	F in kc	μH	μμF
355	1000	200	225	500	1000
375	1000	180	610	200	340
500	500	203	1000	150	169
544	500	172	1750	66	125
795	350	115	3750	18	100

EXERCISES 6 (Contd.)

F in kc	μμF	μH	F in kc	μH	μμF
2575	150	25.5	7200	9.52	52.4
4135	100	14.8	14,000	3.7	34.8
4205	100	14.3	28,200	1.19	26.7
8270	50	7.4	56,500	.54	14.7
17,000	35	2.5	128,000	.31	.498

Example. What are the maximum and minimum capacities of a variable condenser necessary for a frequency range of from 2,000 to 3,000 kc using an inductance of 50 μH?

Solution. Set indicator to 50 on LC. (Remembering that scale LC must be operated on in steps of 100, this means setting the indicator to 5000.)

To 2,000 kc on D set index of C.

Under indicator read 126 μμF on B.

To 3,000 kc on D set index of C.

Under indicator read 56 μμF on B.

Example. A coil of 45 μH is used in a circuit with a variable condenser having a minimum capacity of 50 μμF and a maximum capacity of 250 μμF. What is the frequency range?

Solution. To 45 on LC set indicator.

To indicator set 250 on B.

Opposite index of C read 1500 kc on D.

To indicator set 50 on B.

Opposite index of C read 3350 kc on D.

No difficulty is encountered in the above solution if it is remembered that the proper scales, right or left, are to be used on scale B.

EXERCISES 7

(See answers Pg. 60)

μH	C (max)	C (min)	Coverage in kc	
400	250	50	503	1125
400	350	50		
400	500	50		
200	1000	75		
25.5	150	25		
14.8	100	25		
14.3	100	15		
14.8	100	10		
14.3	100	5		
7.1	50	10		

ALTERNATING CURRENT SERIES CIRCUITS

Instead of using the conventional lettering for the right triangle as shown in Fig. A, we will use the method of lettering as shown in Fig. B. This will enable the student of alternating currents to become more familiar with the impedance triangle, or vector.

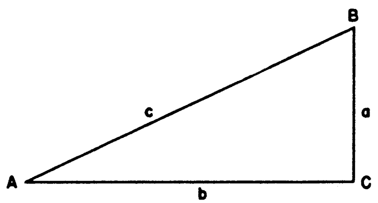


Fig. A

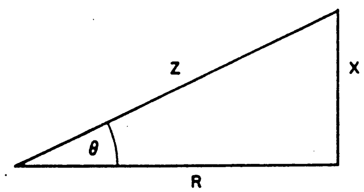


Fig. B

Given X and R - to find Z and θ

A typical alternating current problem is the simple series circuit wherein resistance (R) and reactance (X) are in series as illustrated in Fig. 7. The problem is to find the impedance (Z) and the phase angle (θ).

Because R and X operate at right angles to each other and Z is their vector sum, the three may be plotted as shown in Fig. 8.

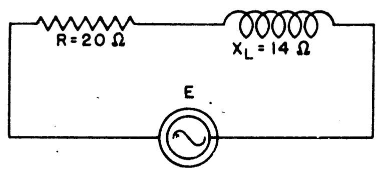


Fig. 7

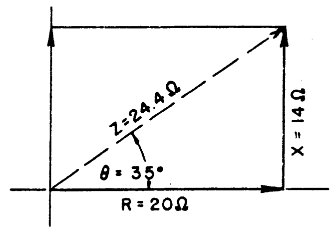


Fig. 8

Solution for Z may be accomplished by making use of the familiar relations between the sides of a right triangle; that is, the square on the hypotenuse is equal to the sum of the squares on the other two sides. Stated as an equation:

$$Z^2 = R^2 + X^2 \quad \text{or} \quad Z = \sqrt{R^2 + X^2}$$

Substituting the circuit values of Fig. 7:

$$Z = \sqrt{20^2 + 14^2} = 24.4 \text{ ohms.}$$

The phase angle θ may be found by its tangent which is

$$\frac{X}{R} = \frac{14}{20} = 0.7 = \tan 35^\circ$$

The above method is cumbersome for slide rule computations because of the number of settings involved. This triangle is conveniently solved by making use of the trigonometric functions. By this method we first solve for θ by taking $\frac{X}{R} = \frac{14}{20} = 0.7 = \tan 35^\circ$ as before. Now that one of the acute angles of the triangle has been found, Z may be found by utilizing a relation which contains Z (the unknown), one of the known sides (X or R), and some function of θ. The sine meets these requirements because

$$\sin\theta = \frac{X}{Z}, \quad \text{or} \quad Z = \frac{X}{\sin\theta} = \frac{14}{0.5736} = 24.4 \text{ ohms.}$$

It now becomes necessary to find a method whereby this solution may be accomplished on the slide rule with a minimum number of settings. As before, we must first find the phase angle θ, and because R and X are the known sides of the right triangle, it follows that the tangent or cotangent must be used because they are the only functions employing both R and X. It is also desirable, as will be seen in the final slide rule operation, to have the numerical value of the particular function on the slide.

Solution.
(1) To 20 on D set index of S
(2) To 14 on D set indicator.
Under indicator read θ = 35° on T *black*.
(3) To indicator set *same angle* (35°) on S *black*.
Opposite index of S read Z = 24.4 ohms on D.

Steps (1) and (2) of the above solution are illustrated in Fig. 9, while step (3) is illustrated in Fig. 10.

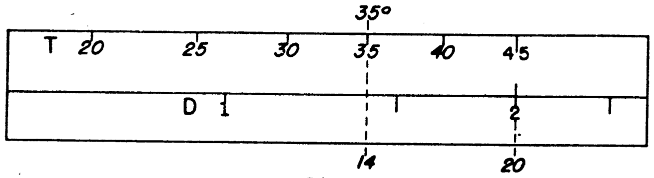


Fig. 9

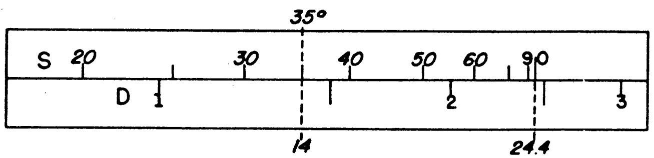


Fig. 10

Steps (1) and (2) divided 14 by 20 (X ÷ R) to give the quotient 0.7 which appeared under the indicator on scale C. The tangent of 35° = 0.7 and this angle therefore appears under the indicator on scale T *black* to give the phase angle θ. Step (3) divided 14 by sin θ, which resulted in Z = X ÷ sin θ = 14 ÷ 0.5736 = 24.4 ohms on scale D opposite the index of S.

At this point the student might wonder why, in step (2) of the solution, 55° T *red* was not chosen as θ instead of 35° on scale T *black*. Here a knowledge of the variation of the various functions becomes an asset. A mental division of X ÷ R showed the quotient, and therefore the tangent value, to be a *decimal and greater than* 0.1, hence an angle between the limits of 5.73° and 45°. By remembering the construction of the right triangle the following rule becomes apparent and should be memorized.

RULE. If X is less than R the phase angle θ is less than 45°.

In the circuit of Fig. 11 a different situation exists. The reactance is greater than the resistance.

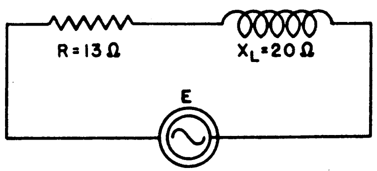


Fig. 11

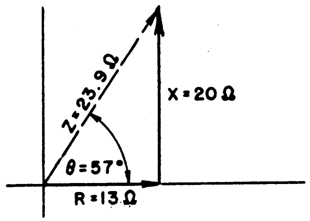


Fig. 12

Again it becomes desirable, in order to complete the solution with a minimum number of slide rule operations, to have the actual numerical value of the particular function used on scale C. It can be seen that the phase angle θ, in this example, is greater than 45° because X is greater than R. Then in order to utilize scale C for the value of the function it follows, because X and R *must* be used to find the angle, that the cotangent must be used. The reason for this, as previously stated, is that scale T *red* calibrated right to left gives the angles whose cotangents are on scale C. Then to get the cotangent value of scale C, R must be divided by X because $\cot \theta = \frac{R}{X}$.

Solution. (1) To 20 on D set index of S

(2) To 13 also on D set indicator.

Under indicator read $\theta = 57^{\circ}$ on T *red* ($X>R \therefore \theta>45^{\circ}$)

(3) To indicator set 57° on S *red*.

Opposite index of S read Z = 23.9 ohms on D.

As before, note that steps (1) and (2) above divided 13 by 20 giving a cotangent value of 0.65 which may be found under the indicator on scale C. Because 13, which is the R value is still on scale D under the indicator, it is desirable to use some function by which Z may be found with a minimum of slide rule settings. This is accomplished by the use of cos θ because

$$\cos \theta = \frac{R}{Z} \quad \text{or} \quad Z = \frac{R}{\cos \theta}$$

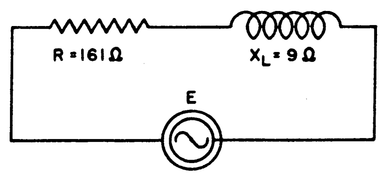
Step (3) placed $\cos 57^{\circ}$ (.545) on scale C under the indicator, thereby dividing 13 (R) by cos θ to give Z = 23.9 ohms.

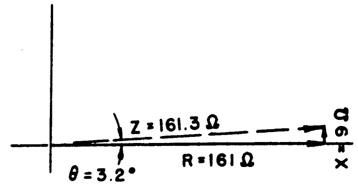
The foregoing explanations should not confuse the student and lead to the belief that there is too much for him to remember in order to become proficient in solutions of impedance triangles. The explanations have been written in an attempt to show the student the actual mechanics of the rule because once these principles are understood, operations on the slide rule cease to be purely mechanical and, as such, difficult to remember.

The solution of the impedance triangle, or vector, for the resultant Z can be stated in one simple

RULE. Always set the index of S to the larger side of the triangle (X or R) on scale D and set the indicator to the smaller side also on scale D. If X is less than R, θ is less than 45°, therefore use scale T *black*. If X is greater than R, θ is greater than 45°, therefore use scale T *red*. *When shifting to scale S, use same color angle that was used on scale T.*

Example. Solve for the impedance and phase angle of a series AC circuit containing a resistance of 161 ohms and an inductive reactance of 9 ohms.





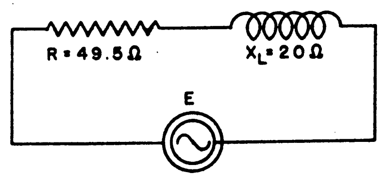
Solution. To 161 (larger side) on D set index of S.

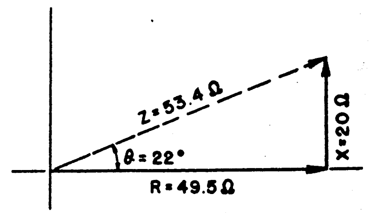
To 9 also on D set indicator.

Under indicator read $\theta = 3.2^{\circ}$ on ST.

It is seen by inspection that the tangent value $\frac{X}{R}$ is less than 0.1 which represents an angle less than 5.73°; hence the use of scale ST. This is permissible because, for all practical purposes the sine, tangent, and radian values on scale ST are equal. Also, for such small angles, Z is very nearly equal to R and vector addition in this case is hardly practicable on the slide rule scales. The actual value of Z in this example is 161.3 ohms.

Example. An AC circuit contains a resistance of 49.5 ohms in series with an inductive reactance of 20 ohms. Solve for the impedance, phase angle and power factor.





Solution. To 49.5 (larger side) on D set index of S.

To 20 also on D set indicator.

Under indicator read $\theta = 22^{\circ}$ on T *black*.

To indicator set 22° on S *black* (same color).

Opposite index of S read Z = 53.4 ohms on D.

To 22° on S *red* set indicator.

Under indicator read power factor = 92.7% on C (PF = 100 × cos θ).

Note: In solving AC problems of this nature it is always desirable to determine the power factor as was done in the above solution. The power factor, when expressed as a percentage, is equal to 100 × cos θ. When the indicator is set to θ on scale S *red*, cos θ appears under the indicator on scale C.

Example. Find the impedance, phase angle, and power factor of a series AC circuit containing a resistance of 17 ohms and a reactance of 55.6 ohms.

Solution. Since the type of reactance is not specified, it may be due to an inductance as shown in Fig. 13, or a condenser as in Fig. 14.

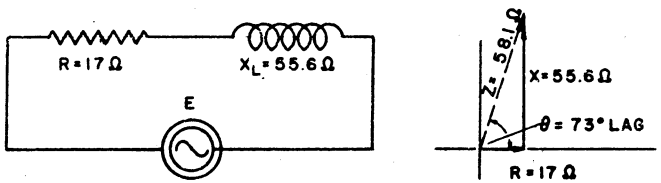


Fig. 13

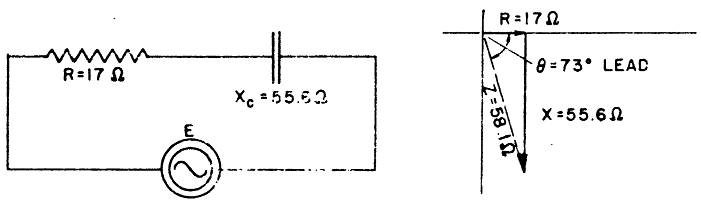


Fig. 14

To 55.6 (larger side) on D set index of S.

To 17 also on D set indicator.

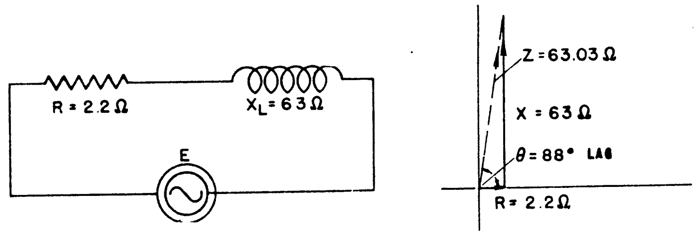
Under indicator read θ = 73° on T *red*.

To indicator set 73° on S *red* (same color).

Opposite index of S read Z = 58.1 ohms on D.

Under indicator read power factor = 29.2 per cent on C.

Example. Solve for the phase angle and power factor in an AC series circuit where the resistance is 2.2 ohms and the inductive reactance is 63 ohms.



Solution. To 63 (larger side) on D set index of S.

To 2.2 also on D set indicator.

Under indicator read 2° on ST. Then θ = 90° - 2° = 88°.

Under indicator read PF = 3.49 per cent on C.

In the foregoing example inspection shows that the tangent value (X ÷ R) is greater than 10; thus denoting an angle greater than 84.28°. Tan θ = 28.6 will be found on scale CI under the indicator.

For such large angles Z is very nearly equal to X and vector addition in this case is not practicable using the trig scales. The actual value of the impedance in this example is 63.03 ohms.

EXERCISES 8

(See answers Pg. 61)

Fill in the blanks in the following table.

X	R	θ	Z	PF	X	R	θ	Z	PF
95.3	50				170.4	100			
39.6	25				507	200			
35.7	15				86	50			
291	150				53.4	30			
396	250				979	500			
46.3	28				102	12.3			
9	63				12	96			

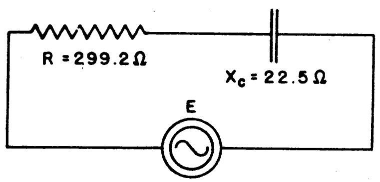
Given Z and θ - to find X and R

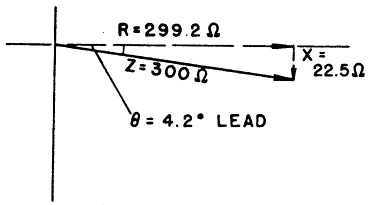
When the hypotenuse (impedance) and one acute angle of a right triangle are known it is possible, by trigonometry, to determine the values of the other two sides (reactance and resistance) of the triangle. By following certain procedure on the slide rule these solutions become relatively simple operations.

The following examples of the cases utilize but two simple formulas when solving for X and R with Z and θ known. These are:

$X = Z \sin \theta$ and $R = Z \cos \theta$.

Example. The impedance of an AC circuit is 300 ohms and the phase angle is 4.3° leading. Find the reactance, resistance, and power factor.



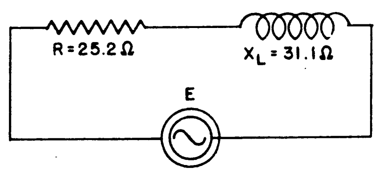


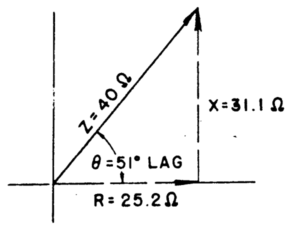
Solution. To 300 (impedance) on D set index of S.
To 4.3° on ST set indicator.
Under indicator read X = 22.5 ohms on D.

The value of X was found by taking $X = Z \sin \theta$. $\sin \theta = 0.075$ will be found under the indicator on scale C. The decimal point is placed by inspection because sines of angles on scale ST vary from 0.01 to 0.1.

Due to the construction of scale S, the resistance and power factor are not obtainable with accuracy for such small phase angles. The actual value of the power factor is 99.7%, while the resistance is 299.2 ohms.

Example. The impedance of a circuit is 40 ohms and the phase angle is 51° lagging. Find the resistance and the reactance.





Solution. (1) To 40 (impedance) on D set index of S.
(2) To 51° on S *red* set indicator.
Under indicator read R = 25.2 ohms on D.
(3) To 51° on S *black* set indicator.
Under indicator read X = 31.1 ohms on D.

Steps (1) and (2) multiply 40 (the impedance) by cos θ to obtain the resistance. These steps are shown in Fig. 15. $\cos \theta = 0.629$ will be found under the indicator on scale C.

Step (3) multiplied the impedance by sin θ to obtain the reactance as shown in Fig. 16. $\sin \theta = 0.777$ will be found under the indicator on scale C.

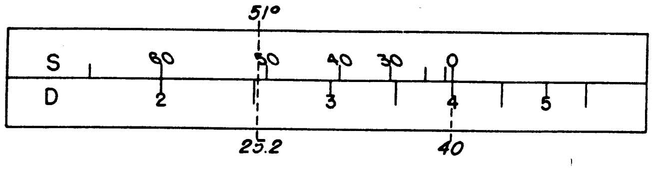


Fig. 15

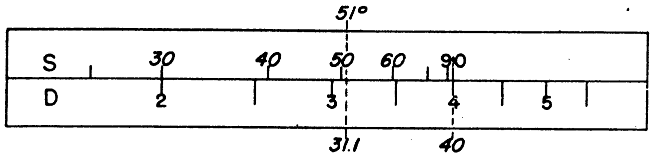


Fig. 16

Example. A circuit has a power factor of 82.9 per cent and an impedance of 26.2 ohms. Solve for the effective resistance and the reactance.

Solution. PF = 100 cos θ ∴ cos θ = 0.829

(1) To 26.2 (impedance) on D set index of S.

(2) To 0.829 on C set indicator.

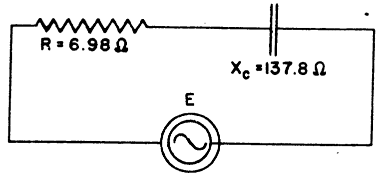
Under indicator read θ = 34° on S *red*, and R = 21.7 ohms on D.

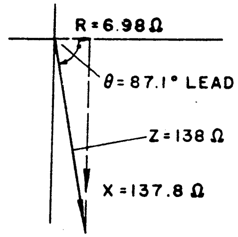
(3) To 34° on S *black* set indicator.

Under indicator read X = 14.65 ohms on D.

Steps (1) and (2) in this solution consisted of multiplying 26.2 (impedance) by cos θ to obtain the resistance, while step (3) multiplied the impedance by sin θ to give the reactance.

Example. The impedance of a circuit is 138 ohms and the power factor is 5.06% leading. Find the effective resistance and the reactance.





Solution. PF = 100 cos θ cos θ = 0.0506 = cos 87.1°.

Cos 87.1° = sin (90° - 87.1°) = sin 2.9°.

(1) To 138 (impedance) on D set index of S.

(2) To 2.9° on ST set indicator.

Under indicator read R = 6.98 ohms on D.

The value of X, for such large angles, is not obtainable with accuracy because in this example X is very nearly equal to Z. The actual value of X is 137.8 ohms.

EXERCISES 9

(See answers Pg. 61)

Fill in the blanks in the following table:

Z	θ	R	X	PF	Z	θ	R	X	PF
1162	58.9°				171	62.1°			
35.2	44.8°				97.9	59.3°			
129.5	39.45°				718	56.1°			
0.563	54.86°				1124	44.55°			
1205	65.5°				942	64.9°			
106	23°				23	36°			

Given Z and R - to find θ and X

When the hypotenuse (impedance) and the base (resistance) of a right triangle are known, the solution for the phase angle θ and the resistance R is made easy by the use of the slide rule.

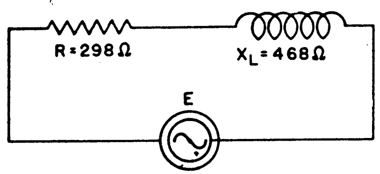
In order to find θ it becomes necessary to utilize some trigonometric function that may be computed with the known values. With Z and R known this function is the cosine because $\cos\theta = \frac{R}{Z}$.

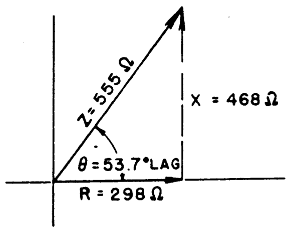
Scale S *red*, calibrated right to left from 0° to 84.28°, gives the angles whose cosines (1 to 0.1) are on scale C. Then if the result of R ÷ Z, which is cos θ, can be placed on scale C at the completion of the division; θ may be read directly from the cosine scales.

The above is accomplished in the usual manner by setting the index of S to the divisor Z (larger known side) on scale D and the indicator to the dividend R (smaller known side) also on scale D. The quotient (cos θ) will then be under the indicator on scale C. The choice of reading the angle θ on scale S or ST depends on the value of the cosine and hence the magnitude of the angle.

Due to the calibration of scale S, only two cases are necessary as examples to illustrate these solutions.

Example. An AC circuit has an impedance of 555 ohms with an effective resistance of 298 ohms. The power factor is lagging. Find the reactance and the power factor.





Solution. (1) To 555 on D set index of S.

(2) To 298 also on D set indicator.

Under indicator read PF = 53.7 per cent on C.

Under indicator read θ = 57.5° on S *red*.

(3) To 57.5° on S *black* set indicator.

Under indicator read X_L = 468 ohms on D.

In steps (1) and (2) cos θ on scale C, and therefore θ on S *red*, was placed under the indicator by dividing R by Z. These steps are illustrated in Fig. 17.

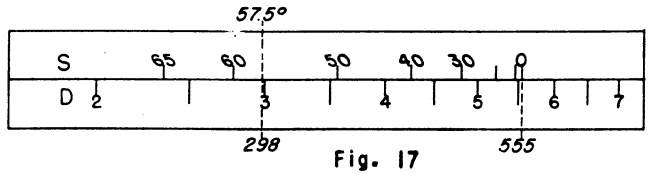


Fig. 17

Step (3) multiplied the impedance (555) by sin 57.5° to give the reactance of 468 ohms on D. Sin 57.5° = 0.843 will be found on scale C under the indicator. Step (3) of this solution is shown in Fig. 18.

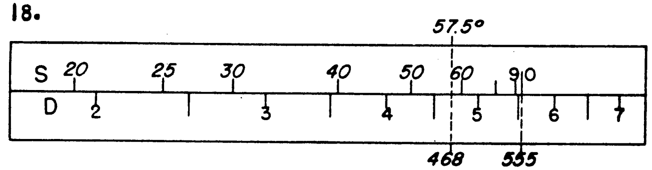
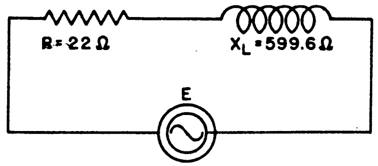
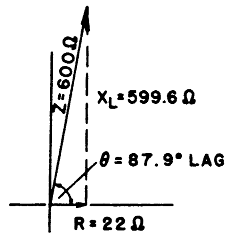


Fig. 18

Example. The impedance of a lagging circuit is 600 ohms and the effective resistance is 22 ohms. Find the reactance and the power factor.





Solution. Inspection shows cos θ to be less than 0.1 and therefore an angle greater than 84.28°.

(1) To 600 on D set index of S.

(2) To 22 also on D set indicator.

Under indicator read 2.1° on ST.

Then θ = $90^\circ - 2.1^\circ = 87.9^\circ$.

PF = 100 cos θ = 3.66 per cent will be found under the indicator on scale C.

Due to the limited space between such large angles on scale S *black* accurate solution for X is impracticable. The actual value of X in this example is 599.6 ohms. It is apparent, as previously explained, that for these large angles X is very nearly equal to Z for all practical purposes.

EXERCISES 10

(See answers Pg. 61)

Fill in the blanks in the following table:

Z	R	θ	X	PF	Z	R	θ	X	PF
1761	800				71.3	45			
1339	500				152.8	85			
1792	800				39.2	15			
1586	1200				98.7	55			
2370	900				1029	500			

Given Z and X - to find θ and R

With the hypotenuse (impedance) and one side (in this case the reactance) of a right triangle known it becomes necessary, in order to solve for the other side (resistance), to utilize some trigonometric function that may be computed with the above known values.

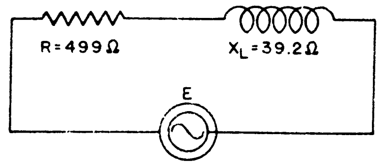
With Z and X given this function is the sine because:

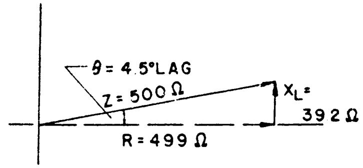
$$\sin \theta = \frac{X}{Z}.$$

As previously explained scales ST and S *black* are the sine scales. The sines of angles on these scales are to be found on scale C. Then if the quotient of X ÷ Z, which is sin θ, can be placed on scale C at the completion of the division, θ may be read directly on the proper scale.

Due to the calibration of scales ST and S *black*, only two cases are necessary as examples to illustrate this type of solution.

Example. The impedance of a line is 500 ohms and the inductive reactance is 39.2 ohms. What is the resistance?





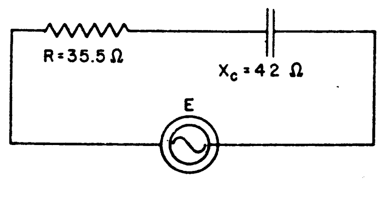
Solution. (1) To 500 (larger known side) on D set index of S.
(2) To 39.2 also on D set indicator.
Under indicator read θ = 4.5° on ST.

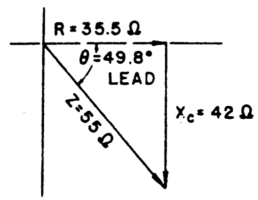
Scale ST was chosen because, by inspection, the division X ÷ Z shows the sine value to be less than 0.1; thus denoting an angle less than 5.73°. Sine 4.5° = 0.0785 will be found under the indicator on scale C.

(3) To 4.5° on S *red* set the indicator.
Under the indicator read R = 499 ohms on D.

As previously explained, due to the limited space between such small angles on scale S *red*, accurate solution for R is impracticable. For such small angles it is apparent that R is equal to Z for all practical purposes.

Example. The impedance of an AC circuit is 55 ohms and the capacitive reactance is 42 ohms. Find the effective resistance and the power factor.





Solution. (1) To 55 (larger known side) on D set index of S.
(2) To 42 also on D set indicator.
Under indicator read θ = 49.8° on S *black*.

(3) To 49.8^{o} on S *red* set indicator.

Under indicator read R = 35.5 ohms on D.

Under indicator read PF = 64.6 per cent on C.

Steps (1) and (2) divided X by Z to obtain sin θ = 0.764 which will be found on scale C under the indicator. These two steps are shown in Fig. 19.

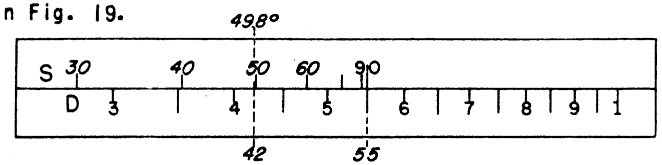


Fig. 19

Step (3) multiplied the impedance (55) by cos 49.8^{o} to give the resistance of 35.5 ohms on D. Cos 49.8^{o} = 0.646 will be found under the indicator on scale C. Step (3) of this solution is shown in Fig. 20.

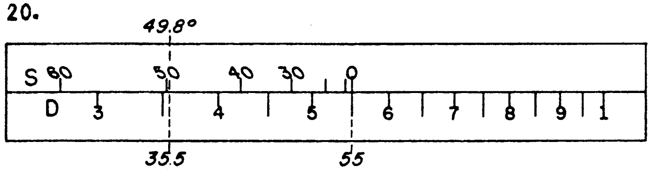


Fig. 20

EXERCISES II

(See answers Pg. 62)

Fill in the blanks in the following table:

Z	X	θ	R	PF	Z	X	θ	R	PF
1802	1615				1065	985			
1459	1330				10.29	2.43			
3060	2928				78	63.7			
1980	1811				384	328			
5040	4977				185	155.6			

PARALLEL CIRCUITS

The solution of parallel AC circuits becomes a relatively simple matter when using the slide rule. This is especially true if the student is able to make full use of the various slide rule operations previously explained.

The method described herein is an adaption of the familiar "total current" method; modified to permit full utilization of the capabilities of the rule. This method has proven tobe more straightforward and simple than any other; at the same time allowing solution in a minimum of time.

The following example is worked out and each step numbered. The slide rule solutions then follow; the numbered steps corresponding to the steps in the first explanatory solution.

Example. Given the circuit of Fig. 21. Solve for the total impedance and equivalent series circuit.

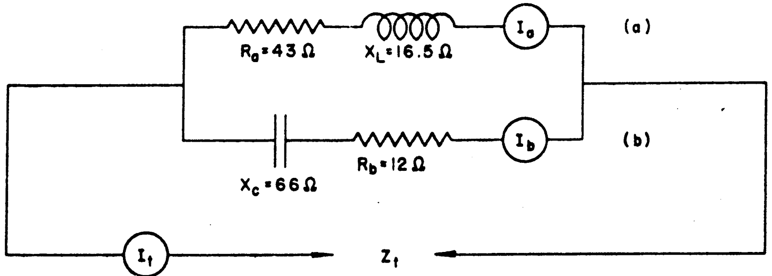


Fig. 21

Solution. First assume a voltage across the parallel combinatio Z_t. In order to facilitate slide rule solution this voltage should always be some power of ten in order that we may make full use of reciprocal operations on the rule. Also, the assumed voltage should be high enough so that it can be divided by the highest branch impedance without the quotient (current) resulting in a decimal.

In this example let the assumed voltage across Z_t be 1000 volts. The phase angle of branch (a) will be:

(1) $\tan \theta_a = \frac{X_L}{R_a} = \frac{16.5}{43} = 0.384 = \tan 21^\circ$ (lag).

(2) $Z_a = \frac{X}{\sin \theta} = \frac{16.5}{\sin 21^\circ} = 46$ ohms.

The assumed current, due to the assumed voltage, through branch (a) is:

(3) $I_a = \frac{E}{Z_a} = \frac{1000}{46} = 21.7$ amperes lag.

I_a is then resolved into its resistive (in-phase) component and reactive (out-of-phase) component.

The resistive component is:

(4) $I_{aR} = I_a \cos \theta_a = 21.7 \cos 21^\circ = 20.3$ amperes.

The reactive component is:

(5) $I_{aX} = I_a \sin \theta_a = 21.7 \sin 21^\circ = 7.77$ amperes.

The phase angle of branch (b) will be:

(6) $\tan \theta_b = \frac{X_c}{R_b} = \frac{66}{12} = 5.5 = \tan 79.7^\circ$ (lead).

(7) $Z_b = \frac{R}{\cos \theta} = \frac{12}{\cos 79.7^\circ} = 67.1$ ohms.

The assumed current through branch (b) is:

(8) $I_b = \frac{E}{Z_b} = \frac{1000}{67.1} = 14.9$ amperes lead.

The resistive component of I_b is:

(9) $I_{bR} = I_b \cos \theta_b = 14.9 \cos 79.7^\circ = 2.66$ amperes.

The reactive component of I_b is:

(10) $I_{bX} = I_b \sin \theta_b = 14.9 \sin 79.7^\circ = 14.7$ amperes.

The components of the two currents are now added to give the components of the total current I_t:

$I_a = 20.3 + j\ 7.77$ amperes

$I_b = 2.66 - j\ 14.7$ amperes

$I_t = 22.96 - j\ 6.93$ amperes

The phase angle of I_t is found in the usual manner by dividing the reactive component by the resistive component:

(11) $\tan \theta_t = \frac{6.93}{23} = 0.302 = \tan 16.8^\circ$ (lead)

The total current I_t is then found by dividing its reactive component by $\sin \theta_t$, or

(12) $I_t = \frac{6.93}{\sin 16.8^\circ} = 24$ amperes

The total impedance is obtained by dividing the total current into the assumed voltage, or

(13) $Z_t = \frac{1000}{24} = 41.7$ ohms.

The current vector is shown in Fig. 22.

The phase angle θ_t of the impedance is the same in magnitude but of different sign as that for the total current; 16.8° lead. The equivalent series circuit of the parallel combination is found by resolving Z_t into its resistive and reactive components, or

(14) $R = Z_t \cos \theta = 41.7 \cos 16.8^\circ = 39.9$ ohms.

(15) $X_c = Z_t \sin \theta = 41.7 \sin 16.8^\circ = 12$ ohms.

The impedance vector is shown in Fig. 23.

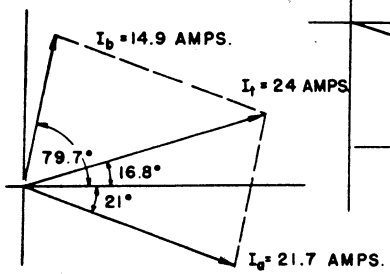


Fig. 22

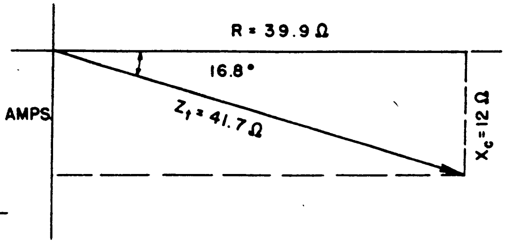


Fig. 23

The foregoing solution may seem rather long. This is because each step has been explained in order to aid the student in understanding this method. Actually when one has become familiar with the solution by slide rule, the entire solution may be written as follows:

Assume 1,000 volts

Z_a = 43 + j 16.5 = 46 ohms, 21° lag. I_a = 21.7 a = 20.3 - j 7.77

Z_b = 12 - j 66 = 67.1 ohms, 79.7° lead. I_b = 14.9 a = 2.66 + j 14.7

I_t = 22.96 + j 6.93

= 24 a, 16.8° lead

Z_t = 41.7 ohms, 16.8° lead = 39.9 - j 12 ohms.

The following slide rule solution steps are numbered to correspond with the steps in the foregoing solution.

(1) To 43 on D set index of S.
To 16.5 on D set indicator.
Under indicator read θ_a = 21° lag on T *black*.

(2) To indicator set 21° on S *black*.
Opposite index of S read Z_a = 46 ohms on D.

(3) Opposite index of D read I_a = 21.7 amperes on C.

(4) To 21.7 on D set index of S.
To 21° on S *red* set indicator.
Under indicator read I_{aR} = 20.3 amperes on D.

(5) To 21° on S *black* set indicator.
Under indicator read I_{aX} = 7.77 amperes.

(6) To 66 on D set index of S.
To 12 on D set indicator.
Under indicator read θ_b = 79.7° lead on T *red*.

(7) To indicator set 79.7° on S *red*.
Opposite index of S read Z_b = 67.1 ohms on D.

(8) Opposite index of D read I_b = 14.9 amperes on C.

(9) To 14.9 on D set index of S.
To 79.7° on S *red* set indicator.
Under indicator read I_{bR} = 2.66 amperes.

(10) To 79.7° on S *black* set indicator.
Under indicator read I_{bX} = 14.7 amperes.

The total current components are found as before, because this is not a slide rule operation.

(11) To 23 on D set index of S.
To 6.93 on D set indicator.
Under indicator read θ_t = 16.8° lead on T *black*.

(12) To indicator set 16.8° on S *black*.
Opposite index of S read I_t = 24 amperes on D.

(13) Opposite index of D read Z_t = 41.7 ohms on C.

(14) To 41.7 on D set index of S.
To 16.8° on S *red* set indicator.
Under indicator read R = 39.9 ohms on D.

(15) To 16.8° on S *black* set indicator.
Under indicator read X_c = 12 ohms on D.

EXERCISES 12

Given the circuit as shown in Fig. 24. Fill in the blank spaces by solving for the total impedance and power factor.

(See answers Pg. 62)

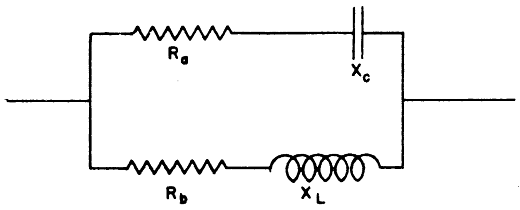


Fig. 24

R_a	X_c	R_b	X_L	Z_t	PF
51	26	21	91		
6	26	72	45		
73	15	4	13		
20	45	705	137		
175	78	40	110		

Example. Given the circuit of Figure 25, solve for the total impedance and power factor.

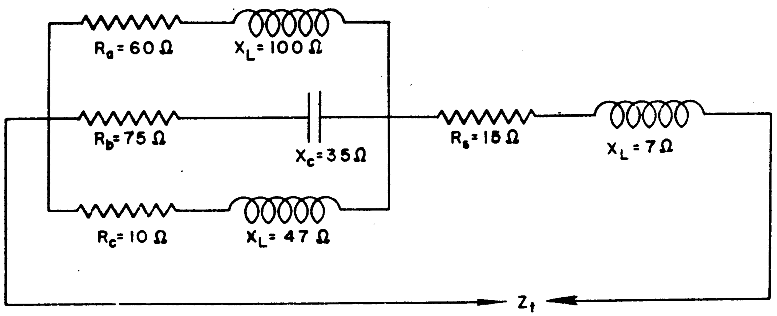


Fig. 25

Solution. Assume 1000 volts across the parallel branches.

Branch (a)

(1) $\text{Tan } \theta_a = \frac{X_L}{R_a} = \frac{100}{60} = 1.66 = \tan 59^\circ$ (lag).

(2) $Z_a = \frac{R}{\cos \theta_a} = \frac{60}{\cos 59^\circ} = 116.5$ ohms.

(3) $I = \frac{E}{Z_a} = \frac{1000}{116.5} = 8.58$ amperes lag.

(4) $I_{aR} = I_a \cos \theta_a = 8.58 \cos 59^\circ = 4.42$ amperes.

(5) $I_{aX} = I_a \sin \theta = 8.58 \sin 59^\circ = 7.35$ amperes.

or, $I_a = I_{aR} + j\, I_{aX} = 4.42 - j\, 7.35$ amperes.

Branch (b)

(6) $\text{Tan } \theta_b = \frac{X_c}{R_b} = \frac{35}{75} = 0.466 = \tan 25^\circ$ (lead).

(7) $Z_b = \frac{X_c}{\sin \theta_b} = \frac{35}{\sin 25^\circ} = 82.8$ ohms.

(8) $I_b = \frac{E}{Z_b} = \frac{1000}{82.8} = 12.1$ amperes lead.

(9) $I_{bR} = I_b \cos \theta_b = 12.1 \cos 25^\circ = 10.9$ amperes.

(10) $I_{bX} = I_b \sin \theta_b = 12.1 \sin 25^\circ = 5.1$ amperes.

or $I_b = I_{bR} + j\, I_{bX} = 10.9 + j\, 5.1$ amperes.

Branch (c)

(11) $\text{Tan } \theta_c = \frac{X_L}{R_c} = \frac{47}{10} = 4.7 = \tan 78^\circ$ (lag).

(12) $Z_c = \frac{R}{\cos \theta_c} = \frac{10}{\cos 78^\circ} = 48.1$ ohms.

(13) $I_c = \frac{E}{Z_c} = \frac{1000}{48.1} =$ 20.8 amperes lag.

(14) $I_{cR} = I_c \cos \theta_c = 20.8 \cos 78^\circ = 4.33$ amperes.

(15) $I_{cX} = I_c \sin \theta = 20.8 \sin 78^\circ = 20.4$ amperes.

or $I_c = I_{cR} + j\, I_{cX} = 4.33 - j\, 20.4$ amperes.

The components of the currents are now added to give the total current through the parallel branches:

$I_a = 4.42 - j\, 7.35$ amperes.

$I_b = 10.9 + j\, 5.1$ amperes.

$I_c = 4.33 - j\, 20.4$ amperes.

$I_{abc} = 19.65 - j\, 22.65$ amperes.

The phase angle of I_{abc} is found in the usual manner by dividing the reactive component by the resistive component.

(16) $\theta_{abc} = \frac{22.65}{19.65} = \tan 49^\circ$ (lag).

(17) $I_{abc} = \frac{19.65}{\cos 49^\circ} =$ 30 amperes lag.

The impedance of the parallel branches is found by dividing the assumed voltage by the total current:

(18) $Z_{abc} = \frac{1000}{30} = 33.3$ ohms.

The phase angle of Z_{abc} is the same as for I_{abc}. Then the equivalent series circuit of the parallel combination is found by resolving Z_{abc} into its resistive and reactive components, or:

(19) $R_{abc} = Z_{abc} \cos \theta = 33.3 \cos 49^\circ = 21.9$ ohms.

(20) $X_{abc} = Z_{abc} \sin \theta = 33.3 \sin 49^\circ = 25.2$ ohms.

or $Z_{abc} = 21.9 + j\, 25.2$ ohms.

Since Z_s is in series with this equivalent circuit we may obtain the total impedance by adding their components:

$Z_{abc} = 21.9 + j\, 25.2$ ohms

$Z_s = 15 + j\, 7$ ohms

$Z_t = 36.9 + j\, 32.2$ ohms

The phase angle of Z_t is found in the usual manner:

(21) $\tan \theta_t = \frac{X_t}{R_t} = \frac{32.2}{36.9} = \tan 41.1^\circ$ (lag).

(22) $Z_t = \frac{X_t}{\sin \theta} = \frac{32.2}{\sin 41.1^\circ} = 49$ ohms.

(23) PF $= 100 \cos \theta_t = 100 \cos 41.1^\circ = 75.4$ per cent.

The current vectors for the parallel branches and the total impedance vector are shown in Figure 26.

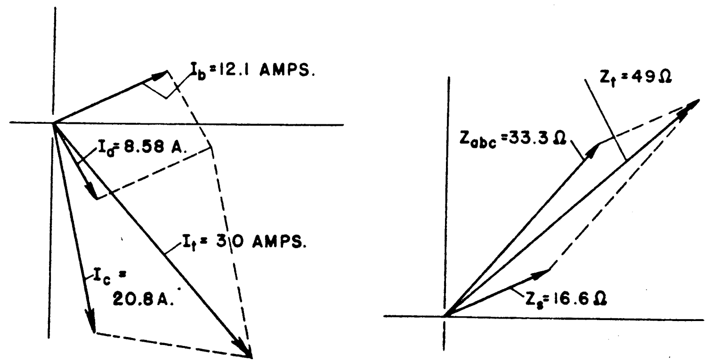


Fig. 26

As in the previous example, the foregoing solution may seem rather long. Actually when one is familiar with the slide rule solution, the entire solution may be written as follows:

Z_a = 60 + j 100 = 116.5 ohms, 59° lag. I_a = 8.58 a = 4.42 - j 7.35 amp.

Z_b = 75 - j 35 = 82.8 ohms, 25° lead. I_b = 12.1 a = 10.9 + j 5.1 amp.

Z_c = 10 + j 47 = 48.1 ohms, 78° lag. I_c = 20.8 a = 4.33 - j 20.4 amp.

I_t = 19.65 - j 22.65 amp.

= 30 a, 49° lag.

Z_{abc} = 33.3 ohms, 49° lag = 21.9 + j 25.2 ohms.

Z_s = 15 + j 7 ohms.

Z_t = 36.9 + j 32.2 ohms.

= 49 ohms, 41.1° lag

PF = 75.4 per cent.

In the following slide rule solution, steps are numbered to correspond with the steps in the explanatory solution.

(1) To 100 on D set index of S.
To 60 on D set indicator.
Under indicator read θ_a = 59° lag on T *red*.

(2) To indicator set 59° on S *red*.
Opposite index of S read Z_a = 116.5 ohms on D.

(3) Opposite index of D read I_a = 8.58 amperes on C.

(4) To 8.58 on D set index of S.
To 59° on S *red* set indicator.
Under indicator on D read I_{aR} = 4.42 amperes.

(5) To 59° on S *black* set indicator.
Under indicator read I_{aX} = 7.35 amperes on D.

(6) To 75 on D set index of S.
To 35 on D set indicator.
Under indicator read θ_b = 25° lead on T *black*.

(7) To indicator set 25° on S *black*.
Opposite index of S read Z_b = 82.8 ohms on D.

(8) Opposite index of D read I_b = 12.1 amperes on C.

(9) To 12.1 on D set index of S.
To 25° on S *red* set indicator.
Under indicator read I_{bR} = 10.9 amperes on D.

(10) To 25° on S *black* set indicator.
Under indicator read I_{bX} = 5.1 amperes on D.

(11) To 47 on D set index of S.
To 10 on D set indicator.
Under indicator on T *red* read θ_c = 78° lag.

(12) To indicator set 78° on S *red*.
Opposite index of S read Z_c = 48.1 ohms on D.

(13) Opposite index of D read I_c = 20.8 on C.

(14) To 20.8 on D set index of S.
To 78° on S *red* set indicator.
Under indicator read I_{cR} = 4.33 on D.

(15) To 78° on S *black* set indicator.
Under indicator read I_{cX} = 20.4 on D.

The total current components are found as before, because this is not a slide rule operation.

(16) To 22.7 on D set index of S.
To 19.7 on D set indicator.
Under indicator read θ_{abc} = 49° lag on T *red*.

(17) To indicator set 49° on S *red.*
Opposite index of S read I_{abc} = 30 amperes.

(18) Opposite index of D read Z_{abc} = 33.3 ohms.

(19) To 33.3 on D set index of S.
To 49° on S *red* set indicator.
Under indicator read R_{abc} = 21.9 ohms on D.

(20) To 49° on S *black* set indicator.
Under indicator read X_{abc} = 25.2 ohms on D.

As before, the impedance components are added.

(21) To 36.9 on D set index of S.
To 32.2 on D set indicator.
Under indicator read θ_t = 141.1° on T *black*

(22) To indicator set 41.1° on S *black*
Opposite index of S read Z_t = 49 ohms on D.

(23) To 41.1° on S *red* set indicator
Under indicator read PF = 75.4 per cent on C.

EXERCISES 13
(See answers Pg. 62)

Given the circuit as shown in Fig. 27. Fill in the blank spaces by solving for the total impedance.

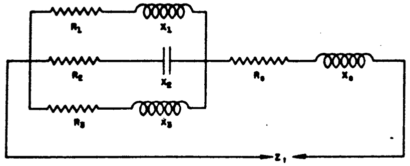


Fig. 27

R_1	X_1	R_2	X_2	R_3	X_3	R_s	X_s	Z_t	θ
97	56	10.5	100	80	50	10	15		
300	140	180	200	15	4.3	5	20		
120	72	4.4	25	35	6.8	50	65		
100	90	125	16	90	150	250	300		
25	4	20	50	75	60	25	40		

SUMMARY OF CONVENIENT SETTINGS AS APPLIED TO RADIO AND ELECTRICAL FORMULAS

There are generally several different methods by which an equation may be solved on a slide rule. However, there is usually one method that is easier and more simple than the others.

The slide rule settings for the formulas contained herein are to teach the student short and convenient methods, most of which have been covered in the instruction pamphlets. Every time a quantity is set up on a slide rule, read from the rule, or transferred to another scale, there is a possibility of making an error. The use of two operations, where one would suffice, increases the possibility of making an error.

In all probability the student, upon becoming more familiar with his slide rule, will discover "set-ups" for certain formulas more to his liking than the following. The choice of such "set-ups" rests entirely with the student because, after all, the *answer* is the important thing.

$P = I^2R$

(1) To current (I) on D set index of slide.
(2) To resistance (R) on B set indicator.
Under indicator read power (P) on A.

$P = \frac{E^2}{R}$

(1) To voltage (E) on D set indicator.
(2) To indicator set resistance (R) on B.
Opposite index of B read power (P) on A.

$I = \sqrt{\frac{P}{R}}$ (1) To power (P) on A set indicator.
(2) To indicator set resistance (R) on B.
Opposite index of slide read current (I) on D.

$R = \frac{P}{I^2}$ (1) To current (I) on D set index of slide.
(2) To power (P) on A set indicator.
Under indicator read resistance (R) on B.

$E = \sqrt{PR}$ (1) To power (P) on A set index of B.
(2) To resistance (R) on B set indicator.
Under indicator read voltage (E) on D.

$e = E_m \sin \theta$ (1) To E_m on D set index of slide.
(2) To θ on S *black* set indicator.
Under indicator read e on D.

$PF = 100 \cos \theta$ (1) To θ on S *red* set indicator.
Under indicator read cos θ on C. Mentally multiply cos θ by 100 to obtain PF in per cent.

$P = EI \cos \theta$ (1) To voltage (E) on D set indicator.
(2) To indicator set current (I) on CI.
(3) To θ on S *red* set indicator.
Under indicator read power (P) on D.

$X_L = 2\pi FL$ (1) To frequency on scale 2π set indicator.
(2) To indicator set inductance (L) on CI.
Opposite index of C read inductive reactance (X_L) on D.

$F = \frac{X_L}{2\pi L}$ (1) To inductance (L) on scale 2π set indicator.
(2) To indicator set index of C.
(3) To inductive reactance (X_L) on D set indicator.
Under indicator read frequency (F) on C.

$F = \frac{X_L}{2\pi L}$ (1) To X_L on D set index of C.
(2) To L on scale 2π set indicator.
Under indicator read F on CI.

$L = \frac{X_L}{2\pi F}$ (1) To frequency (F) on scale 2π set indicator.
(2) To indicator set index of C.
(3) To inductive reactance (X_L) on D set indicator.
Under indicator read inductance (L) on C.

$L = \frac{X_L}{2\pi F}$ (1) To F on scale 2π set indicator.
(2) To X_L on D set index of C.
Under indicator read L on CI.

$X_c = \frac{1}{2\pi FC}$ (1) To frequency (F) on scale 2π set indicator.
(2) To indicator set capacity (C) on CI.
Opposite index of D read capacitive reactance (X_c) on C.

$F = \frac{1}{2\pi C X_c}$ (1) To capacity (C) on scale 2π set indicator.
(2) To indicator set X_c on CI.
Opposite index of D read F on C.

$\omega = 2\pi F$ (1) To F on scale 2π set indicator.
Under indicator read 2πF on scale D.

$X_L = 2\pi FL$

(1) To frequency (F) on scale 2π set indicator.

(2) To indicator set inductance (L) on CI.

Opposite index of C read X_L on D.

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

(3) To indicator set capacity (C) on CI.

Opposite index of D read X_C on scale C.

* $F = \frac{159 \times 10^3}{LC}$

(1) Find product of LC by any convenient method of multiplication.

(2) To LC product on scale LC set indicator.

Under indicator read F in kc on scale D.

* $C = \frac{(159 \times 10^3)^2}{F^2 L}$

(1) To frequency (F) on D set index of slide.

(2) To inductance (L) on B set indicator.

Under indicator read capacity (C) on scale LC.

* $L = \frac{(159 \times 10^3)^2}{F^2 C}$

(1) To frequency (F) on D set index of slide.

(2) To capacity (C) on B set indicator.

Under indicator read inductance (L) on scale LC.

$DB = 10 \log_{10} \frac{P_1}{P_2}$

(1) To P_1 on D set index of C.

(2) To P_2 on scale CI set indicator.

Under indicator read the Mantissa of $\log_{10} \frac{P_1}{P_2}$ on scale L.

Mentally multiply by 10 to obtain DB.

* (Holds true when F is in kc., L is in μH, and C is in μμF.)

$Q = \frac{2\pi FL}{R}$

(1) To F on scale 2π set indicator.

(2) To indicator set L on CI.

(3) To R on CI set indicator.

Under indicator read Q on D.

$Z_r = \frac{(2\pi FL)^2}{R}$

(Where Z_r is the impedance of a resonant parallel circuit.)

(1) To frequency (F) on scale 2π set indicator.

(2) To indicator set index of C.

(3) To inductance (L) on C set indicator.

(4) To indicator set resistance (R) on B.

Opposite index of C read impedance (Z) on A.

$\theta = \arcsin \frac{X}{Z}$

(1) To impedance (Z) on D set index of S.

(2) To reactance (X) on D set indicator.

Under indicator read θ on ST, or S *black*, as applicable. (If $\sin \theta < 0.1$, $\theta < 5.73°$.)

Under indicator read $\sin \theta$ on C.

$\theta = \arccos \frac{R}{Z}$

(1) To impedance (Z) on D set index of S.

(2) To resistance (R) on D set indicator.

Under indicator read θ on S *red*, or ST, as applicable.

$\theta = \arctan \frac{X}{R}$

(1) To the larger value (X or R) on D set index of S

(2) To smaller value on D set indicator.

Under indicator read θ on proper T scale, or ST, (If $\tan \theta < 0.1$, $\theta < 5.73°$.) (If $\tan \theta < 1$, $\theta < 45°$.)

$R = Z \cos \theta$

(1) To impedance (Z) on D set index of S.

(2) To θ on S *red* set indicator.

Under indicator read resistance (R) on D.

$X = Z \sin \theta$	(1)	To impedance (Z) on D set index of S.
	(2)	To θ on ST, or S *black*, as applicable, set indicator.
		Under indicator read reactance (X) on D.
$Z = \dfrac{X}{\sin \theta}$	(1)	To reactance (X) on D set indicator.
	(2)	To indicator set θ on ST, or S *black*.
		Opposite index of S read impedance (Z) on D.
$Z = \dfrac{R}{\cos \theta}$	(1)	To resistance (R) on D set indicator.
	(2)	To indicator set θ on S *red*.
	(3)	Opposite index of S read impedance (Z) on D.
$Z = R \pm j X$	(1)	To larger value (R or X) on D set index of S.
	(2)	To smaller value on D set indicator.
		Under indicator read phase angle θ on proper T scale.
	(3)	To indicator set *same color* phase angle on S.
		Opposite index of S read impedance (Z) on D.
$I_p = K(E_b)^{3/2}$	(1)	To E_b on A set index of B.
	(2)	To E_b on C set indicator.
	(3)	To indicator set K on CI.
		Opposite index of C read I_p on D.

ANSWERS TO EXERCISES

EXERCISES 1

1. 5.876×10^{9}
2. 5.672×10^{7}
3. 5.78×10^{2}
4. 2.594×10^{3}
5. 6.72×10^{5}
6. 2.03×10^{2}
7. 7.81×10^{-6}
8. 4.63×10^{-1}
9. 4×10^{-4}
10. 8.765×10^{-9}
11. 9.35
12. 2.752×10^{8}
13. 2.57×10^{-5}
14. 3.62×10^{-2}
15. 8.4×10^{-14}
16. 1.89×10^{-5}
17. 3.85×10^{3}
18. 5.94×10^{-1}
19. 9×10^{-4}
20. 2.5×10^{9}
21. 3.43×10^{-7}
22. 2.56×10^{20}
23. 3.45×10^{8}
24. 1.2×10^{-3}
25. 4.83×10^{-9}
26. 2.4×10^{-3}
27. 4×10^{2}
28. 7.28×10^{-1}

EXERCISES 2

F	L	C	X_L	X_C	X
25	4.2 H	56 µF	660	114	546 (X_L)
50	2.3 H	43 µF	723	74	649 (X_L)
60	.15 H	27 µF	56.6	98.2	41.6 (X_C)
1000	.01 H	2.3 µF	62.8	69.2	6.4 (X_C)
1000 kc	165 µH	170 µµF	1036	935	101 (X_L)
355 kc	225 µH	920 µµF	502	487	15 (X_L)
2744 kc	63 µH	52 µµF	1085	1114	29 (X_C)
6190 kc	24 µH	27 µµF	933	953	20 (X_C)
215 kc	276 µH	1950 µµF	373	380	7 (X_C)
500 kc	160 µH	605 µµF	503	526	23 (X_C)

EXERCISES 3

I	R	E = IR	P = I²R	I	R	E = IR	P = I²R
5	10	50 v	250 w	2.5	12.2	30.5 v	76.3 w
3.2	31	99.2 v	317 w	4.69	73	342 v	1610 w
6.82	87.6	597 v	4075 w	5.2	5.86	30.5 v	158.5 w
0.62	10^3	620 v	385 w	8.73	1.73	15.1 v	131.9 w
13.5	2.42	32.7 v	441 w	0.76	4.5	3.42v	2.6 w
9.2	0.56	5.15v	47.4 w	1.5	93	139.5 v	209 w

EXERCISES 4

E	R	$I = \frac{E}{R}$	$P = \frac{E^2}{R}$	E	R	$I = \frac{E}{R}$	$P = \frac{E^2}{R}$
6	12	.5 a	3 w	10^3	.367	2725 a	2725 kw
32	36	.89 a	28.4 w	115	11.3	10.2 a	1170 w
110	98.3	1.12 a	123 w	12	69	.174 a	2.09 w
220	10^4	.022 a	4.84 w	110	6.73	16.35a	1800 w
550	3.82	144 a	7.92×10^4 w	14	125	.112 a	1.57 w

EXERCISES 5

μH	μμF	LC	F in kc	μH	μμF	LC	F in kc
180	250	45,000	750	9.85	150	1478	4140
242	350	84,700	547	400	500	2×10^5	356
14.3	100	1430	4205	25.5	150	3825	2575
2530	1000	2.53×10^6	100	701	600	420,600	245
7.5	50	375	8210	450	400	180,000	375

EXERCISES 6

F in kc	μμF	μH	F in kc	μH	μμF
355	1000	200	225	500	1000
375	1000	180	610	200	340
500	500	203	1000	150	169
544	500	171	1750	66	125
795	350	114	3750	18	100
2575	150	25.5	7200	9.52	51
4135	100	14.8	14,000	3.7	35
4205	100	14.3	28,200	1.19	26.8
8270	50	7.4	56,500	.54	14.6
17,000	35	2.5	128,000	.31	5

EXERCISES 7

μH	C (max)	C (min)	Coverage in kc	
400	250	50	503	1125
400	350	50	425	1125
400	500	50	356	1125
200	1000	75	356	1300
25.5	150	25	2575	6300
14.8	100	25	4135	8270
14.3	100	15	4205	10,880
14.8	100	10	4135	13,080
14.3	100	5	4205	18,820
7.1	50	10	8440	18,900

EXERCISES 8

X	R	θ	Z	PF %	X	R	θ	Z	PF %
95.3	50	62.3°	108	46.5	170.4	100	59.8°	199	50.3
39.6	25	57.7°	46.8	53.5	507	200	68.5°	545	36.6
35.7	15	67.2°	38.7	38.8	86	50	59.8°	99.4	50.3
291	150	62.7°	327	45.9	53.4	30	60.7°	61.3	49.0
396	250	57.7°	46.8	53.5	979	500	62.9°	1100	45.5
46.3	28	58.8°	54	51.8	102	12.3	83.12°	103	12.0
9	63	8.13°	63.6	99.0	12	96	7.13°	96.7	99.0

EXERCISES 9

Z	θ	R	X	PF %	Z	θ	R	X	PF %
1162	58.9°	600	995	51.7	171	62.1°	80	150.2	46.8
35.2	44.8°	25	24.8	71.0	97.9	59.3°	50	84.1	51.1
129.5	39.45°	100	82.3	77.3	718	56.1°	400	596	55.7
0.563	54.86°	.324	.46	57.5	1124	44.55°	800	790	71.1
1205	65.5°	500	1097	41.5	942	64.9°	400	853	42.4
106	23.0°	97.6	41.4	92.0	23	36.0°	18.6	13.5	80.9

EXERCISES 10

Z	R	θ	X	PF %	Z	R	θ	X	PF %
1761	800	63.0°	1570	45.4	71.3	45	50.8°	55.3	63.2
1339	500	68.0°	1240	37.5	152.8	85	56.2°	127	55.8
1792	800	63.5°	1600	44.8	39.2	15	67.5°	36.2	38.3
1586	1200	40.8°	1038	75.6	98.7	55	56.1°	82	55.8
2370	900	67.7°	2190	38.0	1029	500	60.9°	900	48.6

EXERCISES 11

Z	X	θ	R	PF %	Z	X	θ	R	PF %
1802	1615	63.6°	800	44.5	1063	985	68.0°	398	37.5
1459	1330	65.8°	598	41.0	10.29	2.43	13.7°	10	97.2
3060	2928	73.1°	885	28.9	78	63.7	54.8°	44.9	57.6
1980	1811	66.2°	890	29.1	384	328	58.6°	200	52.1
5040	4977	82.0°	700	13.9	185	155.6	57.5°	99.4	53.7

EXERCISES 12

R_a	X_c	R_b	X_L	Z_t	PF %
51	26	21	91	54.7	96.9
6	26	72	45	28.4	52.3
73	15	4	13	13.16	45.7
20	45	705	137	48.4	46.7
175	78	40	110	103.7	80.0

EXERCISES 13

R_1	X_1	R_2	X_2	R_3	X_3	R_s	X_s	Z_t	θ
97	56	10.5	100	80	50	10	15	67.8	12.8°
300	140	180	200	15	4.3	5	20	30.3	50.9°
120	72	4.4	25	35	6.8	50	65	84.8	38.9°
100	90	125	16	90	150	250	300	441	47.6°
25	4	20	50	75	60	25	40	58	41.6°