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Using The Slide Rule For Radio Calculations

By the Engineering Department, Aerovox Corporation

THERE is no doubt that the slide rule enables one to solve mathematical equations speedily and with sufficient accuracy. Yet it is not being used as much as it might be and its full possibilitics are seldom utilized. This surprising condition is probably due to a lack of familiarity wth short cuts and a lack of practice in using the rule. Very often the product of three factors and even more, can be found by a single setting of the slide while the average man will probably change settings two or three times.

This article aims to show the fastest way of obtaining solutions to typical equations emloyed in the radio art. This is not intended as an elementary text on the use of the slide rule; it is assumed that the reader is familiar with his rule and that he is able to perform the usual computations. It is merely intended to show applications to radio since this field of endeavour never seems to be covered in instruction books.

The question arises: What type of rule appears the most suitable? The examples below will illustrate that considerable time can be saved by the use of folded and inverted scales. Rules having the inverted, folded and inverted-folded scales are the "polyphase-duplex" and the "log-log-duplex". Some work requires log-log scales and trigonometric scales. However, in order to be of universal aid, the following instructions will apply to the "polyphase-duplex" scale and special hints will be given for the benefit of those who have rules with an inverted scale but without folded scales. Such a rule is the "polyphase". The identification of each scale on the rule will be by letter, familiar to all who possess a slide-rule.

OHM'S LAW

$E = IR, \quad I = E/R, \quad R = E/I$

If I and R are given, the result can be obtained in several ways. The first

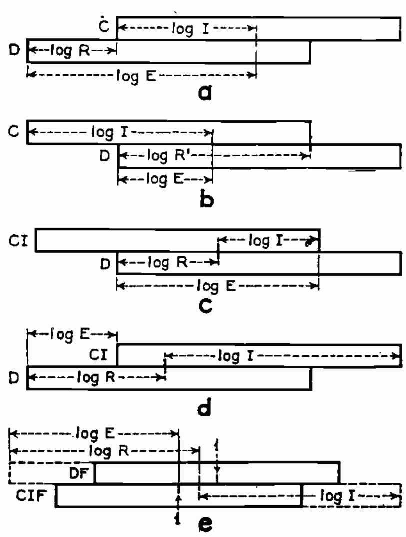


FIG. 1

one is illustrated in Figure 1a. This is ordinary multiplication using the C and D scales. Figure 1b shows the solution for the case when E would fall beyond the limits of the D scale. An alternative way of obtaining the same result is by means of the inverted scale CI and the D scale. This is illustrated in Figures 1c and 1d. Set I on scale CI to R on scale D and read E at either the right or left index of CI on scale D. In some cases this would result in drawing the slide nearly completely out of the stock. It is in such cases that the folded scales serve admirably. For the sake of accuracy and speed the slide should always remain at least half-way in the rule. Whenever the use of scales C or D or CI and D would require a greater movement of the slide, it will be found that the same problem can be solved using CF and DF or CIF and DF without having to move the slide too far. As an illustration, the case of Figure 1d is shown again using scales CIF and DF, Figure 1e. Also, in the case of Figure 1a, when E falls beyond the limit of the scale D, if folded scales are provided it is not necessary to reset the slide to the position of Figure 1b. Instead, find I on scale CF and opposite this mark the answer, E, is found on DF.

In all examples of Ohm's law when E is given together with R or I it will be found most expedient to employ the settings of Figure 1c or 1e. It should be noted also that in certain problems, where it is required to find the current for several different values of resistance across the same voltage, all the answers can be found at a single setting. This would not be true if the settings of Figures 1a and 1b were used; this is the advantage of inverted scales.

TUBE EQUATION

For any vacuum tube, mu, rp and

Gm are related by the following equation

$$mu = rp \times Gm$$

This equation is solved in the same way as Ohm's Law and all the remarks above apply to it. The settings illustrated in Figure 1 can be used if mu is substituted for E, rp for R and Gm for I.

CONVERTING WAVELENGTH TO FREQUENCY

Employing the polyphase slide rule, set the left index of CI to 3 on D. Then find the wavelength corresponding to any frequency on D opposite the frequency on CI or vice versa. This one position of the slide is sufficient to solve all possible conversions from frequency to wavelength and vice versa.

The polyphase-duplex slide rule enables one to employ a folded scale; then the slide need not be moved so far. Set 1 on CIF to 3 on D, then the corresponding values of wavelength and frequency are found opposite each other on the CIF and the D scales. It is also possible to use the CI and DF scales, setting 3 on CI to 1 on DF.

POWER DISSIPATION

The power dissipated in a resistor is given by any one of the following expressions.

$$W = EI \qquad W = E^2/R \qquad W = I^2R$$

The first of the equations is again a simple form such as Ohm's Law, for solutions, see above. The second and third form are similar as far as the method of slide rule manipulation is concerned, therefore we shall discuss only one of them. Figure 2 illus-

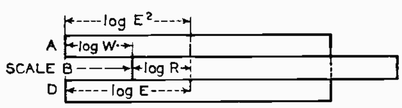


FIG. 2

trates the setting for this case. To W on scale A set the index of scale B, move the indicator to R on scale B and find E at the indicator on scale D. Here it is necessary to be careful that W and R are found on the proper half of the A and B scales. If these quantities have an odd number of digits to the left of the decimal point, they must be located on the left half of the A or B scale, otherwise they are on the right half. Failure to observe this rule will result in incorrect results. If it is found that E will be off scale, move the slide to the left, placing the right index opposite W on scale A. E is then found on D opposite R on scale B as before. Example: The load of an amplifier is a 500 ohm resistor; what voltage should be across this resistor so that the power shall be 15 watts? Set the index of scale B to 5 on scale A. Opposite 15 on scale B (right half of B) find 867 on scale D. 86.7 volts is the answer.

REACTANCE OF AN INDUCTANCE

$$X = 2 \pi f L \text{ ohms}$$

On the polyphase slide rule, set f on CI to 6.28 on D. Opposite L on C find X on D (see Figure 3a). If the result falls off scale, move the indicator to the left index of the slide, move right index of slide to indicator and find X on D opposite L on C.

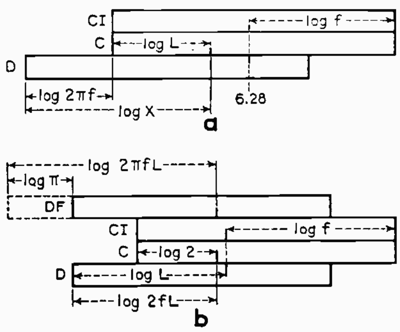


FIG. 3

On the polyphase-duplex slide rule, set f on CI to L on D. Opposite 2 on C find X on DF. If this would require pulling out the slide too far, set f on CIF to L on D. Opposite 2 on C find X on D.

If X is given and either f or L is to be found, proceed as follows. Set 2 on C to X on DF. Opposite f on CI, find L on D or vice versa.

What is the reactance of a 30 henry choke at 60 cycles? Set 3 on CI to 6 on D. Opposite 2 on C, find 1132 on DF. The answer is 11320 ohms.

A choke had a reactance of 5000 ohms at 90 cycles, what is the inductance? This example was chosen to illustrate the second method where the CIF scale must be used. Set 2 on C to 5 on D. Opposite 9 on CIF find 883 on D. The answer is 8.83 henries.

REACTANCE OF A CONDENSER

$$X = \frac{1}{2 \pi f C} \text{ ohms} \quad \text{(C in Farads)}$$

$$X = \frac{159000}{f C} \text{ ohms} \quad \text{(C in Mfd.)}$$

When using a polyphase slide rule, employ $.159 = 1/2\pi$ as guage point. Set f on C to .159 on D. Opposite C on scale CI find X on D. In order to understand this better one may consider that .159 represents $1/2\pi$ and this has to be divided by f, the result again to be divided by C. The inverted scale enables us to do it all in one setting. Figure 4a may make this clear. It can occur occasionally that the result is beyond the right index of scale D. In that case the divisions have to be done one by one.

The polyphase-duplex slide rule obviates the necessity of remembering the number 159 and further simplifies the operation. Set the index of D to twice the frequency on C. Opposite C (mfds) on CIF, find X on D (see Figure 4b). Example: what is the reactance of a 3 mfd. condenser at 120 cycles? Set 24 on C to the left index on D. Opposite 3 on CIF find 442 on D. The reactance is 442 ohms.

In case the slide would have to be pulled out too far, set twice the frequency on CF to 1 on DF. The answer, X, is found on D opposite C (mfds) on CIF. If this result is found to be off scale, it can be found on CIF opposite C (mfds) on D.

In the special case when either f or C is equal to 1, 10, 100, etc., the result can be found direct with but one setting for all values of the remaining independent variable. Align the indices of scales on slide and stock. Set the indicator to 2f or 2C on CIF and find the reactance on D.

LC PRODUCT FOR ANY FREQUENCY

$$f = \frac{1}{2 \pi \sqrt{LC}} \qquad LC = \frac{1}{(2 \pi f)^2}$$

If the product LC alone is required and not the individual values of L and C, the answer is very simply obtained. On the polyphase slide rule set f on C to 159 on D. Opposite the index of C read LC on A. Explanation: .159 equals $1/2\pi$ as stated before. Dividing by f in the normal way find $1/2\pi f$ on D while the square of this which is equal to LC is found on A.

On the polyphase-duplex the answer can be had at once without even setting the slide. Align indices of slide and stock. Opposite 2f on CIF find LC on A. The explanation is a little more difficult and so another drawing has been made (Figure 5). It should be remembered that opposite any number *a* on the CIF scale one finds $1/\pi a$ on the D scale. This will be clear because the CI scale shows the reciprocals of all values on the C scale and the CIF scale has been displaced with respect to the CI scale by π in such a way that any value a on CI is in line with $a\pi$ on CIF.

INDIVIDUAL VALUES OF L AND C

If it is required to find L and C to tune to a given frequency, ordinary division can be performed on the A and B scales. Perhaps many would prefer to employ the scales D and CI which would be more accurate and also would show at one setting all the possible combinations of L and C tuning to the required frequency. This can be done by performing the above described operation twice. On the polyphase slide rule, set f on C to 253 on D. Set the indicator to the index of C. Set f on C to the indicator and find LC on D opposite the index. Also, opposite L on CI find C (mfds) on D and vice versa. Example: what is the required inductance to tune to

550 kc with a condenser of 350 mmfd. Set 5.5 on C to 253 on D. Set the indicator to the index of C and again set 5.5 to the indicator. Opposite 350 on CI find 240 on D. The required inductance is 240 microhenries.

Using the polyphase-duplex, align the indices, set the indicator to 2f on CIF. Set the index of the slide to the indicator and set the indicator again to 2f on CIF. Then again set the index of the slide to the indicator. Opposite C (mfds) on CI find L on D and vice versa. Or, opposite C (mfds) on CIF find L on DF and vice versa. Whenever an index of the slide has to be set to the indicator choose the index which will leave the greater art of the slide in the rule. Explanation: the first setting of the indicator simply gives us $\sqrt{LC}$ which is squared by repeating the process. Thereafter one uses division by means of the inverted scale.

PLACING THE DECIMAL POINT

Equations involving LC may offer difficulties in properly placing the decimal point "by inspection". The following table shows the magnitude of LC for different frequencies. LC decreases when the frequency increases. The table still leaves doubt whether LC is between 1 and 10 or between 10 and 100 for instance. If, on the duplex rule the slide had to be moved to the right, it is the lower of the two values. If it had to be moved to the left it is the higher one of the two. There cannot be any doubt if LC is found on the A scale as in the first example.

ALTERNATING CURRENT BRIDGES

The usual equation for a resistance bridge is of the form:

$$R = \frac{a\,b}{c}$$

This equation is easily solved by any rule. Set a on C to c on D. Opposite

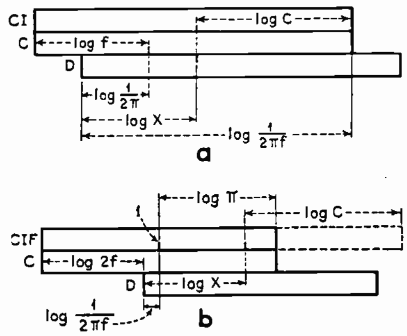


FIG. 4

b on C find R ond D. If the ratio a/c is kept constant one setting of the slide suffices for several measurements involving different values of b.

DECIBELS

Problems involving decibels are also easily solved on the slide rule. Practically every rule has an L scale. Converting any power ratio to decibels is done simply by setting the indicator to the power ratio on D and reading db. on L. Example: the power ratio corresponding to 5 is 6.99

f	LC henries & mfds	LC millihenries & mfds	LC microhenries & mmfd
15.9—159 cycles	100—1	100,000—1000	
159—1590 cycles	1—.01	1,000—10	
1.59—15.9 kc.	.01—.0001	10—0.1	
15.9—159 kc.		0.1—0.001	
159—1590 kc.			1,000,000—10,000
1.59—15.9 mc.			10,000—100
15.9—159 mc.			100—1

Example: In the above example, 550 kc. was used and the LC product was found to be 836. The slide had to be moved to the right so it is the lower one of the two values, LC being between 10,000 and 100,000. Therefore, LC is 83,600.

Another example: What capacity is needed to tune a 30 henry choke to 50 cycles? Align indices of the duplex slide rule, set indicator to 1 (2f = 100) on CIF, set right index of the slide to the indicator. Set the slide to 1 on CIF and find the LC product on D. The answer is 1012; of course it could not be anything but 10.12. Now the required capacity can be found without a further movement of the slide. Opposite 3 on CIF find 338 on D. The required capacity is .338 mfd. This simplified way was possible only because 2f happened to be equal to 100.

db. When the power ratio is higher than 10, divide by 10, 100, etc. until the quotient is less than 10. Find the corresponding gain in db. and add 10 db. for every place the decimal point had to be moved to bring the power ratio within the range 1-10. Example: What is the db. gain corresponding to a power gain of 5530? Moving the decimal point three places to the left we obtain 5.53. Set the indicator to 5.53 on D and read 7.42 on L. Add 30 db. to the result which gives 30 + 7.42 = 37.42 db.

If the power ratio is less than 1 the CI scale and the L scale should be employed.

Finding the db. gain corresponding to voltage ratios—if the impedance is the same in both cases—proceed as described above but multiply the result by 2.

Readers who have a "log-log" rule have an alternate way of finding db. Set the index of the slide to 10 on LL3. Opposite the power ratio on LL2 and LL3 find the gain in db. on C. If the power ratio was more than 10, all values found on C are between 10 and 100: if it was less than 10, the C scale is direct reading.

Finding the db. gain from the voltage ratio, set 2 on scale C to 10 on LL3. Opposite the voltage gain on LL2 or LL3 find db. gain on C. If the voltage gain is between 1 and 3.14 the db. gain is between 1 and 10. If the gain was higher multiply all values on C by 10.

It may be interesting to know that the gain in "nepers" is found by aligning the indices. Opposite the voltage ratio on LL2 and LL3, find the gain in nepers on C. One neper = 8.686 db., one db. = 0.115 neper.

Converting power ratios less than 1 to db., employing the log-log scales, set 1 (middle of B scale) to .10 on the LLO scale. The db. loss is found on B opposite the power ratio on LL0. For voltage ratios set 2 on the B scale to .10 on the LL0 scale and proceed as before.

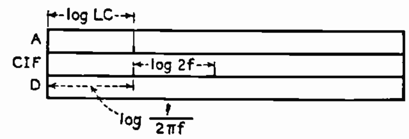


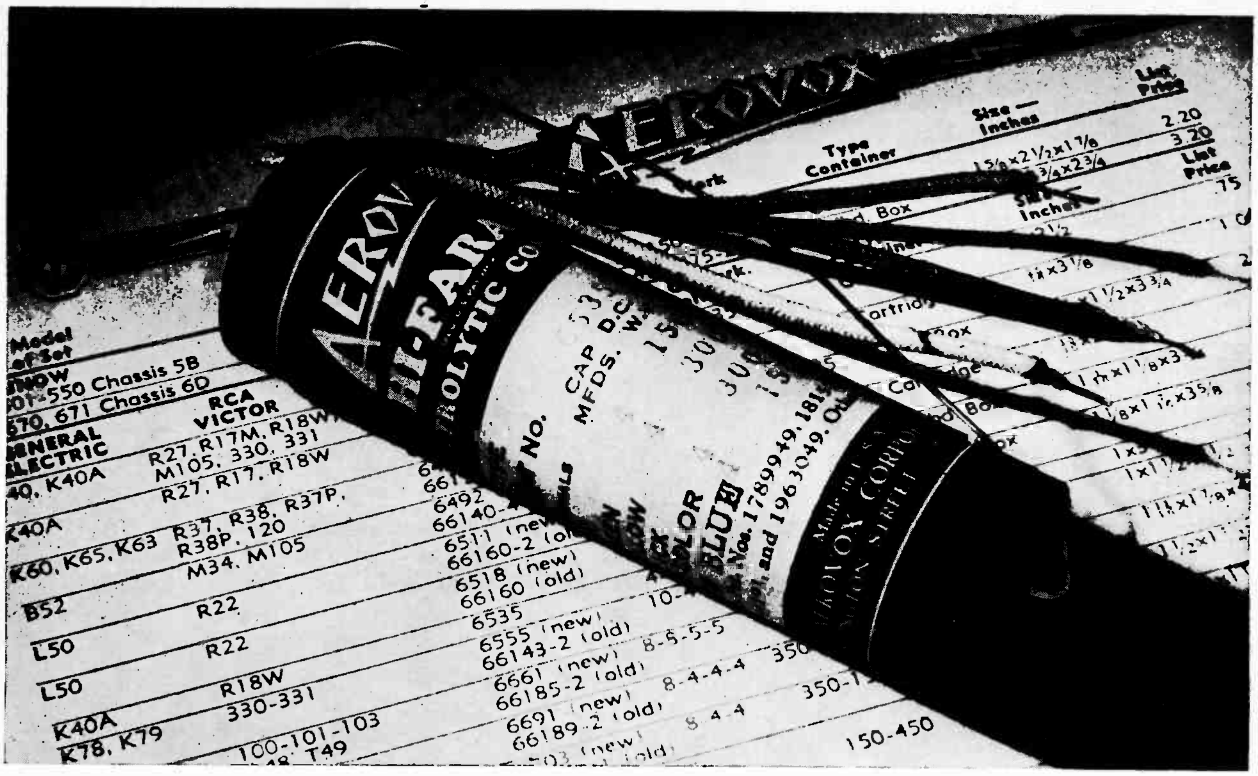
FIG. 5

To find the gain in db. directly from two values of voltages or powers, set P2 (the larger of the two) on D to P1 on C. Opposite the index the index of C find db. on L.

CHARGE AND DISCHARGE OF CONDENSER

A condenser of C microfarads discharges through a resistor of R megohms. The time constant is RC seconds. The condenser will discharge to .368 of its original voltage in RC seconds but how far is it discharged before and after this instant? The log-log scales show the answer at once. Opposite 1 on A set RC on B. Opposite t (time in seconds) on B find the voltage across the condenser on LL0. For instance, suppose RC is .25, then the time constant is .25 second. Set .25 on B to 1 on A. Opposite .1 on LL0 find .57 on B which shows that the voltage dropped to 1/10 the original charge after .57 seconds. Similarly, it drops to .05 of the original charge after .75 seconds.

If it is desired to go beyond the limit of the LL0 scale, for instance in order to find the elapsed time before the voltage has dropped to ½ percent of the original, multiply .005 by 10. Opposite .05 on LL0 find 3 on A. Add 2.3 (which is $\log_e 10$) making 5.3. Opposite 5.3 on A find 1.32 on B. It takes 1.32 seconds to discharge the condenser to .005 of its original charge.



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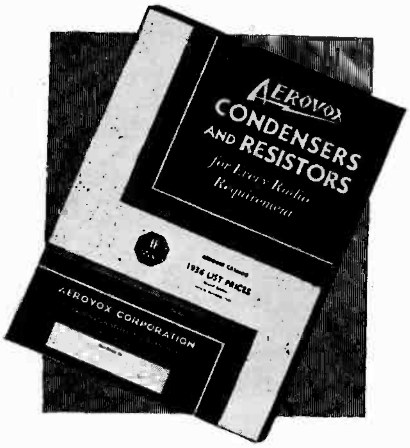

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