CLEVELAND INSTITUTE OF ELECTRONICS

Electronics and Your Slide Rule

Using the Special Electronic Scales

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In this lesson you will learn...

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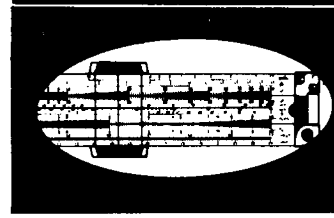
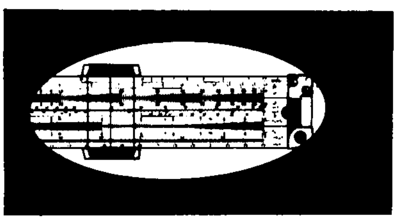


A chat with your instructor

In this lesson you will learn to use the trignometric scales on your slide rule. Also included in this lesson are instructions on how to use the special electronics scales on the CIE slide rule. If you do not have the special scales on your slide rule, you may skip these topics. Practical applications for the use of the trignometric scales will be given in the next lesson.

In studying this lesson be sure to work all the practice problems. Practice is very important in learning slide rule operation. Don't limit your practice to the problems in your slide rule lessons. Always keep your rule handy and use it for any needed calculations—whether business, personal, or electronics—that come up.



Electronics and Your Slide Rule Part III

1 REACTANCE AND RESONANCE DECIMAL POINT LOCATOR ... Resonance-frequency problems and problems concerning inductive and capacitive reactance are among the most commonly occuring problems that electronic technicians are required to work. Because of the rather involved formulas used for these problems and also because of the very large and very small values normally employed, locating the decimal point with certainty is a difficult task. For that reason special scales are provided on the back of the CIE Electronics rule to enable the decimal point to be quickly and surely located in all problems involving reactance and resonance. At the same time, the scales also provide approximate solutions that are close enough for many requirements. When a more accurate answer is required, it can be quickly obtained by the use of the H scale or the 2π scale on the front of the rule. The use of these two scales will be explained later.

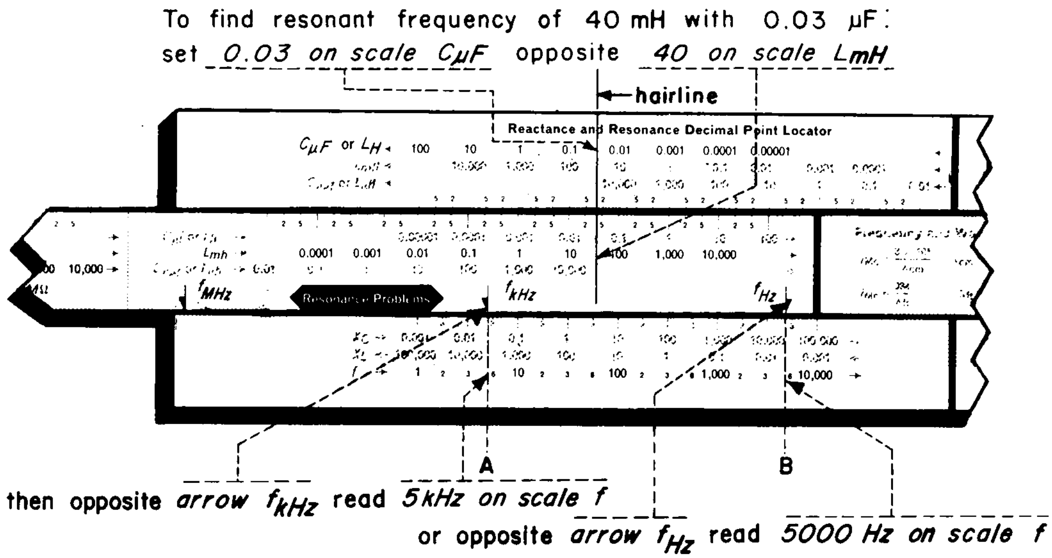


Fig. 1 Showing that 40 mH will resonate with 0.03 μF at approximately 5 kHz or 5000 Hz.

The Decimal Point Locator scales have been designed so that it is unnecessary to convert from one unit to another in using these scales. This not only saves time but also eliminates a common source of errors in decimal point location. The next two topics will provide sufficient examples for you to understand the use of the decimal point locator scales.

2 DECIMAL POINT LOCATOR, RESONANCE PROBLEMS...To locate the decimal point in resonant-frequency problems in which C and L are given, set the value of either C or L (it makes no difference which) on the Resonance Problems Scale of the slide opposite the other given value on the upper-body scale. Then read the approximate frequency on the lower-body scale opposite the appropriate arrow on the slide.

As an example of how the decimal point is located in a resonant-frequency problem, suppose an inductance of 40 mH is connected in parallel with a capacitance of 0.03 μF. At approximately what frequency will this parallel circuit be resonant? Figure 1 shows the setup for working this problem. Set the hairline over 0.03 μF on the upper body of the rule. This is to be found on the scale marked CμF, and it is somewhere between the main division marks 0.01 and 0.1 on that scale.

To assist in locating positions between main division marks, the space between each of the main divisions is marked by two subdivision marks, 2 and 5. For the space between the 0.01 and 0.1 marks on the CμF scale, the 2 and the 5 marks represent 0.02 μF and 0.05 μF, respectively. Therefore, to represent 0.03 μF the hairline is set between the 2 and 5 marks, and closer to the 2 mark than to the 5, as can be seen in Fig. 1.

Now move the slide so that 40 mH on the section of the slide marked Resonance Problems is under the hairline. The scale used for this purpose is the one on the slide marked LmH. 40 on this scale is located between the main division marks 10 and 100. The two subdivision marks, 2 and 5, between these two main divisions represent 20 mH and 50 mH on the LmH scale. To represent 40 mH the hairline should therefore be between the 2 and 5 marks but closer to the 5 than to the 2, see Fig. 1. A high degree of accuracy is never necessary in setting values on the Decimal Point Locator scales.

The approximate resonant frequency is now read on the f scale of the lower body of the rule under the arrow marked f_{kHz} if the answer is wanted in kilohertz or under the arrow marked f_{Hz} if the answer is wanted in hertz. To read the answer in kilohertz, refer to dashed line A of Fig. 1. On scale f the dashed line is between the main divisions 1 and 10, which shows that the frequency lies somewhere between 0 and 10 kHz.

To pin the frequency down closer notice that the dashed line is between the subdivision marks 3 and 6 on scale f. Hence, the resonant frequency of this circuit is between 3 and 6 kHz. Since the dashed line is nearer the 6 subdivision than the 3, the frequency must be in the neighborhood of 5 kHz. This is close enough for locating the decimal point accurately and also for many practical purposes. A more accurate answer can be obtained quickly by the use of the H scale on the front of the rule, as will be explained later.

The dashed line B in Fig. 1 shows where to read if the answer to the problem is wanted in hertz. This dashed line shows that the arrow f_{Hz} lies between 1000 and 10,000 Hz. Narrowing down the range, the arrow is between the subdivision marks 3 and 6, and the frequency is therefore between 3000 and 6000 Hz. Since it is nearer to 6 than to 3, a good estimate of the frequency is 5000 Hz.

In working the problem the value of L could equally well have been set on the upper-body scale and the value of C on the slide. It makes no difference which of the scales is used for L and which for C.

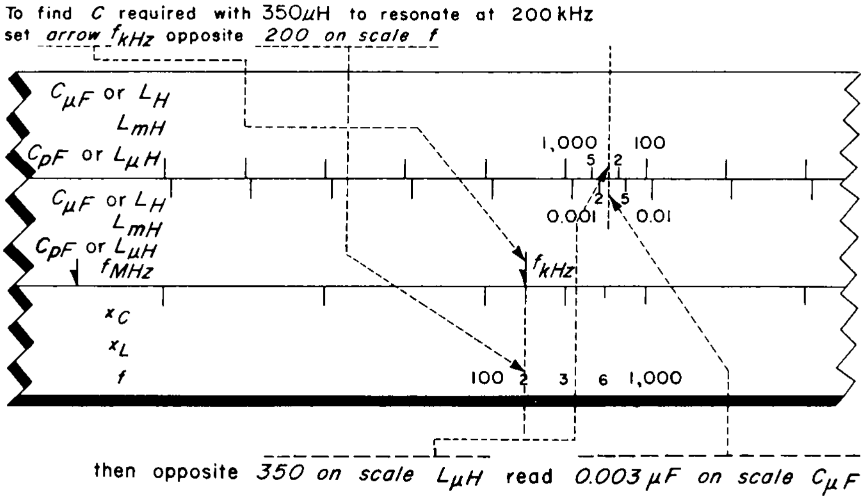


Fig. 2 Showing that, for 350 μH to resonate at 200 kHz, a capacitance of approximately 0.003 μF is required.

Arrows are printed before and after each of the Decimal Point Locator scales. The purpose of these arrows is to indicate the direction of progression of the scales. For example, the values on the X_C scale on the lower part of the body become progressively larger from left to right. Hence, the associated arrows point in that direction. On the other hand, the values on the X_L scale directly below become progressively larger from right to left, so the associated arrows point in the direction opposite from that of the arrows for the X_C scale. Knowing the direction of progression of the scales makes it easier to set and read values.

In the example given in this topic a parallel resonant circuit is involved. If the inductance and capacitance were in series, the problem would have been worked the same way, and the same answer would have been obtained. In working any resonant-frequency problem by using either the Decimal Point Locator or the *LC* scale on the front of the rule the method is exactly the same whether series or parallel resonance is involved.

EXAMPLE . . . Approximately what value of capacitance should be used with an inductance of 350 μh in order to resonate at 200 kc?

SOLUTION . . . Refer to Fig. 2. The steps are as follows:

1. Move the slide so that the slide arrow designated f_{kHz} is opposite 200 on scale f on the lower body of the rule.
2. Place the hairline over 350 on scale $L_{\mu H}$ on the upper body of the rule.
3. Under the hairline read 0.003 on scale $C_{\mu F}$ on the slide. Hence, the answer is 0.003 μF.

In Problems 1 to 4 use the Decimal Point Locator scales to find the approximate frequency at which the given values of L and C will resonate.

1. $L = 3$ mH, $C = 175$ pF
2. $L = 340\ \mu$H, $C = 0.0034\ \mu$F
3. $L = 0.025$ H, $C = 2\ \mu$F
4. $L = 700\ \mu$H, $C = 500$ pF

In Problems 5 to 8 use the Decimal Point Locator scales to find the approximate value of L or C needed to resonate at the given frequency.

5. $f = 240$ kHz, $C = 0.08\ \mu$F
6. $f = 7000$ Hz, $L = 0.5$ H
7. $f = 40$ MHz, $C = 550$ pF
8. $f = 6500$ Hz, $L = 425\ \mu$H

ANSWERS

1. 250 kHz 2. 200 kHz 3. 700 Hz 4. 300 kHz 5. 5.5 μH
6. 0.001 μF 7. 0.03 μH 8. 2 pF

3 REACTANCE PROBLEMS . . . In solving reactance problems, the frequency on the part of the slide marked Reactance Problems is placed opposite the given value of inductance or capacitance on the upper body of the rule. The reactance is then read on the proper scale on the lower body opposite the appropriate arrow of the slide.

EXAMPLE 1 . . . Find the reactance of a 0.005-μF capacitor when used at 3 MHz.

SOLUTION . . . See Fig. 3. The steps are as follows:

1. Set the hairline over 0.005 on scale $C_{\mu F}$ on the upper body.
2. Adjust slide so that 3 on scale f_{MHz} is under the hairline.
3. Opposite the arrow on the slide marked X_C,Ω read 10 Ω on scale X_C on the lower body of the rule. Hence, the reactance of this capacitor at this frequency is approximately 10 Ω.

EXAMPLE 2 . . . What approximate value of inductance will have a reactance of 4 MΩ at a frequency of 3000 kHz?

SOLUTION . . . The steps in the solution are as follows:

1. Move the slide so that the arrow on the slide marked X_L,MΩ is opposite 4 on scale X_L on the lower body of the rule.
2. Set the hairline over 3000 on scale f_{kHz} on the slide of the rule.
3. Under the hairline on the scale marked L_H on the upper body of the rule read 0.3 H, the approximate inductance value required.

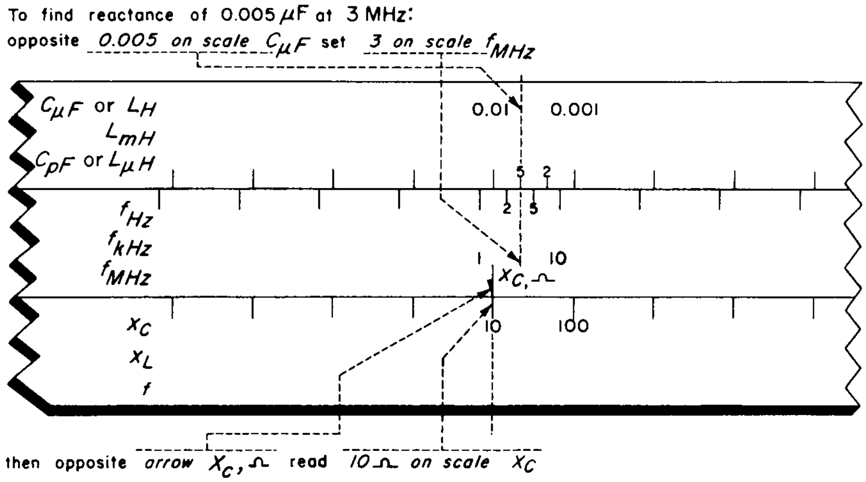


Fig. 3 Finding that the approximate reactance of a 0.005-μF capacitor at 3 MHz is 10 Ω.

EXAMPLE 3 . . . At what frequency will a 200-pF capacitor have a reactance of 25 Ω?

SOLUTION . . . The steps are as follows:

1. Move the slide so that the slide arrow marked X_C,Ω is opposite 25 on scale X_C on the lower body of the rule.
2. Set the hairline over 200 on cale C_{pF} on the upper body of the rule.
3. Under the hairline read 30 on the scale f_{Hz} on the slide. Hence, the required reactance will be obtained at approximately 30 MHz.

WHAT HAVE YOU LEARNED?

In each of the following problems use the Decimal Point Locator scales to find the approximate answer.

1. f = 2300 kHz, L = 250 mH, X_L = ?

2. f = 25 MHz, C = 150 pF, X_C = ?

3. f = 0.8 MHz, L = 0.45 H, X_L = ?

4. f = 7500 Hz, C = 3.5 μF, X_C = ?

5. X_L = 3000 Ω, L = 850 μH, f = ?

6. X_C = 6500 Ω, C = 500 pF, f = ?

7. $f = 480\ \text{kHz}, X_L = 400\ \Omega, L = ?$

8. $f = 2.4\ \text{MHz}, X_C = 30{,}000\ \Omega, C = ?$

ANSWERS

1. $3\ \text{M}\Omega$ 2. $40\ \Omega$ 3. $2\ \text{M}\Omega$ 4. $6\ \Omega$ 5. 700 kHz 6. 60 kHz
7. 0.2 mH 8. 2 pF

4 THE 2π SCALE . . . If the hairline is over a certain value on the 2π scale, 2π times that value will appear under the hairline on the D scale. Conversely, any number under the hairline on the D scale will be divided by 2π by merely reading under the hairline on the 2π scale. This scale is very useful, because the factor 2π occurs widely in electronics.

EXAMPLE 1 . . . How many degrees are there in a radian? 2π radians are equal to 360°.

SOLUTION . . . Set the hairline over 360 on scale D and read 57.3°, the answer, under the hairline on scale 2π.

EXAMPLE 2 . . . The armature of a generator is rotating at 1800 revolutions per minute, which is 30 revolutions per second. What is its angular velocity ω in radians per second? The formula is $\omega = 2\pi r$, where r is revolutions per second.

SOLUTION . . . Set hairline over 30 on the 2π scale. Read 188.8 radians per second, the answer, under the hairline on scale D.

The most important use of the 2π scale is in working capacitive and inductive reactance problems in which better accuracy is required than is possible with the Decimal Point Locator scales. When the 2π scale is used for this purpose, the problem should also be worked on the Decimal Point Locator scales to locate the decimal point.

In working reactance problems in conjunction with the 2π scale, frequency is always set or read on scale 2π. To help you to remember this, the 2π scale is also marked (f_x). Inductance or capacitance is always set or read on scale CI, which is shown by this scale also being identified as L_X or C_X. Capacitive reactance is always set or read opposite the appropriate index of scale D, which you can remember by the arrow at the index labeled X_C. Inductive reactance is always set or read opposite the appropriate index of scale C, which you can remember by the arrow at the index labeled X_L.

EXAMPLE 3 . . . Find accurately the reactance of a 60-mH choke coil at 5000 kHz.

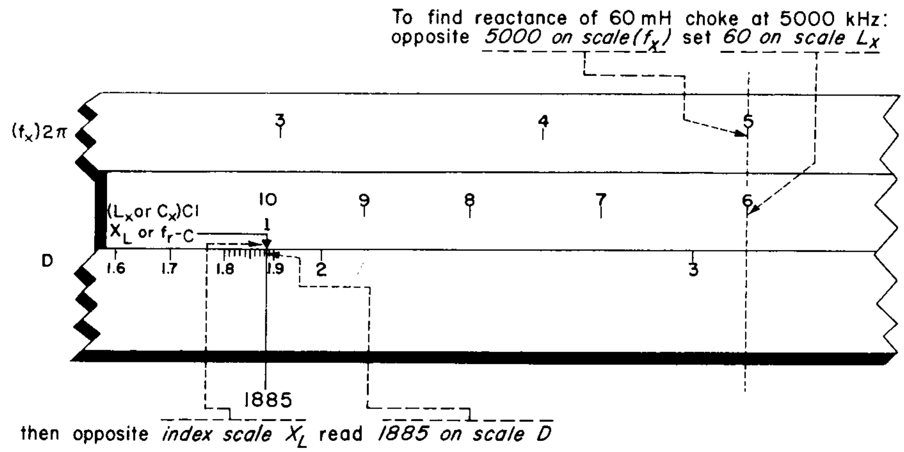


Fig. 4 Finding that a 60-mH choke at a frequency of 5000 kHz has a reactance of 1,885 MΩ.

SOLUTION . . . See Fig. 4. The steps are as follows:

1. Set the hairline over 5000 (which is the frequency) on scale $(f_x)2\pi$.
2. Move the slide so that 60 (which is the inductance) on scale (L_X or C_X)CI is under the hairline.
3. Opposite the index of scale X_L or f_r-C read 1885 (which is the inductive reactance) on scale D.
4. Use the Decimal Point Locator scales on the back of the rule to obtain 1.5 MΩ as the approximate reactance value.

Hence, the accurate reactance of the choke is 1.885 MΩ.

EXAMPLE 4 . . . Find a more accurate value for the reactance of the capacitor in Example 1 of Topic 3.

SOLUTION . . . The steps are as follows:

1. Set the hairline over 3 (which is the frequency) on scale (f_x).
2. Move the slide so that 0.005 (which is the capacitance) on scale C_X is under the hairline.
3. Opposite the left index on scale X_C read 1061 (which is the capacitive reactance) on scale C. The approximate reactance has been found to be 10 Ω. Hence, the exact reactance is 10.61 Ω.

EXAMPLE 5 . . . Find a more accurate value for the inductance in Example 2 of Topic 3.

SOLUTION . . . The steps are as follows:

1. Set the hairline over 3000 on scale (f_x).
2. Move the slide so that the right index of scale X_L is opposite 4 on scale D.
3. Read 212 under the hairline on scale L_X. The approximate inductance was previously found as 0.3 H. Hence, the accurate value of the inductance is 0.212 H.

Any reactance problem can be worked without confusion if you remember these three rules:
1. Frequency is always set or read under the hairline on scale 2π, also marked (f_x).
2. Inductance or capacitance is always set or read under the hairline on scale CI, which is therefore marked (L_X or C_X).
3. Inductive reactance is always set or read opposite the C index on scale D, and this is indicated on the rule by the symbol X_L and an arrow on the C index pointing to the D scale. Capacitive reactance is always set or read opposite the D index on scale C, and this is indicated by the symbol X_C and an arrow pointing to the C scale.

In working any reactance problem set up the known values in the positions on the rule indicated by the two applicable rules above, and then read the unknown value in accordance with the remaining rule.

EXAMPLE 6 . . . Find a more accurate value for the frequency in Example 3 of Topic 3.

SOLUTION . . . Set up the capacitance and the reactance in accordance with rules 2 and 3:

1. By rule 3 set the left index of scale D opposite 25 on scale C.
2. By rule 2 set the hairline over 200 on scale CI.
3. By rule 1 read the frequency, 318, under the hairline on scale 2π. The approximate frequency has previously been found to be 30 MHz. Hence, the accurate frequency is 31.8 MHz.

WHAT HAVE YOU LEARNED?

1–8. Use the 2π scale to obtain accurate answers to the problems in the preceding WHAT HAVE YOU LEARNED? section.

9. The velocity of propagation on a transmission line is given by the formula $v = \frac{\omega}{\beta}$, where v is the velocity of propagation, $\omega = 2\pi f$, and β is the wavelength constant (phase shift per mile). Find v when the frequency is 60 Hz and β is equal to 0.00213.

ANSWERS

1. 3.61 MΩ 2. 42.5 Ω 3. 2.26 MΩ 4. 6.06 Ω 5. 562 kHz
6. 49 kHz 7. 0.133 mH 8. 2.2 pF 9. 177,000 miles/sec

5 USING THE H SCALE...The H scale is used in solving resonant-frequency problems when the accuracy required is greater than that obtainable from the Decimal Point Locator scales. However, the problem must also be worked with the latter scales in order to locate the decimal point. This is much faster than the use of a rough calculation for the purpose. It is well known that the frequency at which a circuit will resonate is determined entirely by the product of the circuit inductance and the circuit capacitance (called the *LC* product). If the hairline is set over the frequency on scale D, the required *LC* product for the circuit to resonate at this frequency is read under the hairline on scale H, and vice versa.

When using the H scale, always set or read frequency opposite the index of scale C, on the D scale. For this reason the symbol f_r and an arrow on the C index pointing to the D scale appear on your rule.

EXAMPLE 1 . . . What must be the *LC* product in order that a circuit will resonate at 20 MHz?

SOLUTION . . . First use the Decimal Point Locator scales on the back of the rule to obtain an approximate answer, as follows:

1. Set the arrow marked f_{MHz} on the slide opposite 20 on scale f on the lower body of the rule.
2. The *LC* product is now found by multiplying together any two opposite values on the upper body of the rule and the Resonance Problems portion of the slide. If 1 is one of the two opposite values, no multiplication is required. If we take 1 on the scale C_{pF} on the upper body of the rule, then the value opposite on scale $L_{\mu H}$ on the slide will be 70. Hence, the approximate value of the *LC* product is 70 when *C* is expressed in picofarads and *L* in microhenrys. Now the front of the rule is used to obtain a more accurate value for the *LC* product.
3. Set the hairline over 20 on scale D, and then read 633 under the hairline on the H scale. Since the approximate value is 70, the accurate value is 63.3, where *C* is in picofarads and *L* is in microhenrys.

EXPLANATION . . . When the hairline is over any frequency value on the D scale, the required *LC* product is under the hairline on the H scale.

The reverse of the problem in the preceding example is to find the frequency of resonance when the *LC* product is known. This, of course, is done by setting the hairline over the *LC* product on scale H and then reading the frequency under the hairline on scale D. However, any value can be set on scale H in two different positions, giving two different frequency readings on scale D.

Obviously only one of these readings can be correct. You should first determine the approximate frequency for the given *LC* product by the use of the Decimal Point Locator scales. Then the correct setting on the H scale is the one that gives a frequency value on the D scale that is near the approximate value previously determined.

The required value of C to go with a given value of L in order to resonate at a certain frequency can be found by dividing the LC product by the given L value. Or if C is known, it can be divided into the LC product to give the required value of L to resonate at a certain frequency. However, the following examples show simpler ways to solve resonant-frequency problems when the LC value is neither known nor wanted, and that is generally the case.

EXAMPLE 2 . . . Find a more accurate value for the capacitance in the example of Topic 2.

SOLUTION . . . The steps are as follows:

1. Set the left index of scale C (which is marked f_r) opposite 200 (which is the frequency) on scale D.
2. Set the hairline over 350 (which is the inductance) on scale (L_r) H.
3. Read 181 (which is the required capacitance) under the hairline on scale B. The approximate value of C has been previously found to be 0.003 μF. Hence, the accurate value is 0.00181 μF.

When C is given and L is to be found, the method is the same as in Example 2. Whether finding L or C, an index of the C scale is placed opposite the frequency on the D scale. Then with the hairline over the given value of L on scale H, the unknown value of C is read on scale B under the hairline. Alternatively, the known value of L or C can be set on scale B and the unknown value then read on scale H. The following example illustrates the method when L and C are known and the frequency is to be found.

EXAMPLE 3 . . . An inductance of 40 mH is connected in parallel with a capacitance of 0.03 μF. At what frequency will this circuit resonate?

SOLUTION . . . The steps are as follows:

1. Find the approximate resonant frequency by using the Decimal Point Locator scales. This was done in Topic 2, and the frequency was found to be 5000 Hz.
2. Set hairline over 40 on scale H.
3. Adjust slide so that 3 on scale B is under the hairline.
4. Read opposite the index of scale C on scale D. Depending upon which halves of scales H and B were used for setting the values, the reading obtained on scale D may be either 1452 or 459. Since the approximate frequency is known to be 5000 Hz, the accurate frequency is 4590 Hz. The value 1452 is spurious, because it is far different from the known approximate frequency. If the reading 1452 is obtained, move the slide so that 3 on the other half of the B scale is under the hairline. Then 459 will read opposite the C index on scale D.

DISCUSSION ... Both the B scale and the H scale are of the repeating type, so any value can be set on either of the two scales in two different positions. In problems in which the frequency is known and L or C is to be found, as in Example 2, the correct answer is obtained no matter which of the possible positions are used on the H and B scales. However, when L and C are known and the frequency is to be found, two different results are possible, depending upon the sections of the H and B scales used.

Only one of the results can be correct. To determine if the result obtained is correct, see if it is in agreement with the approximate value, which should have been previously determined. If it is not, move the slide so that the other half of the B scale is used for setting the B scale value.

WHAT HAVE YOU LEARNED?

1–8. Use the H scale to find accurate answers to the WHAT HAVE YOU LEARNED? section of Topic 2.

9. What LC product is required to resonate at 5 megahertz, L being in microhenrys and C in microfarads?

ANSWERS

1. 220 kHz 2. 148 kHz 3. 710 Hz 4. 269 kHz 5. 5.5 μH
6. 0.00103 μF 7. 0.0287 μH 8. 1.41 pF 9. 0.001014

USING THE TRIGONOMETRIC SCALES

It is necessary to be familiar with logarithms and trigonometry before studying the remainder of this lesson. If you are not familiar with these subjects, your slide rule training is now completed. However, the author hopes you will eventually be able to acquire a knowledge of these subjects and then finish the remainder of this lesson.

6 THE TRIGONOMETRIC FUNCTIONS ... A review of trigonometry, particularly the sections dealing with the right triangle, will help you understand the following sections. The trigonometric functions are defined by the sides of a right triangle. Figure 5 shows a right triangle with sides of length a, b, and c and two acute angles labeled A and B (angles less than 90° are called acute angles), and also the right angle C. The sine, cosine, tangent, and cotangent of angle A are defined as follows: