Abstract

This paper describes the novel use of an oscilloscope to measure the value of a reactive component (capacitor or inductor). Applications of this technique include measuring unknown component values, measuring known component values for binning/matching purposes, and characterizing component values as a function of frequency.

Measuring reactive component values with an oscilloscope

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Every electronics technician has a multimeter on his bench, but few have an LCR meter. If they have need for a particularly critical capacitor value they usually just pay a premium for smaller tolerances, which is to say they pay a premium to have the manufacturer bin the parts for them. And for those who do have an LCR meter, or who paid that premium for a smaller tolerance, they only know a nominal value based on some *assumed* frequency.

Unfortunately, if a capacitor (or inductor) value is critical, it is usually so at a specific frequency, or over a band of frequencies. And if few technicians have an LCR meter on their bench, even fewer have a network analyzer.

But pretty much everyone has an oscilloscope on their bench. Add to that a signal generator and a known resistor and they have all they need to measure the value of any reactive component, limited only by the precision of their oscilloscope and ohmmeter, at whatever frequencies their signal generator can produce.

With a simple setup a technician can quickly measure unknown component values, bin/match the values of known components, and even characterize those values over a band of frequencies. Indeed, using the technique described in this paper a technician could even analyze the behavior of non-reactive components (e.g. a resistor) at high frequencies where they begin to exhibit reactive characteristics.

This is a recently rediscovered technique the author learned in undergraduate school, one of equal parts utility and simplicity. Though it would rightly be considered “old school,” it is one that every technician would do well to learn and understand.

This paper analyzes and discusses this technique via the specific example of a capacitor, but it can just as easily be applied to an inductor.

Figure 1 shows the simple circuit arrangement used in this example. A sinusoidal signal is applied to a series RC circuit with taps on either side of the capacitor. By using one of these signal taps to drive the vertical axis of the oscilloscope, and the other to drive the horizontal sweep, a lissajous curve will be produced on the oscilloscope’s display.

Recall that in the general case a lissajous curve is a plane curve parametrized by independent

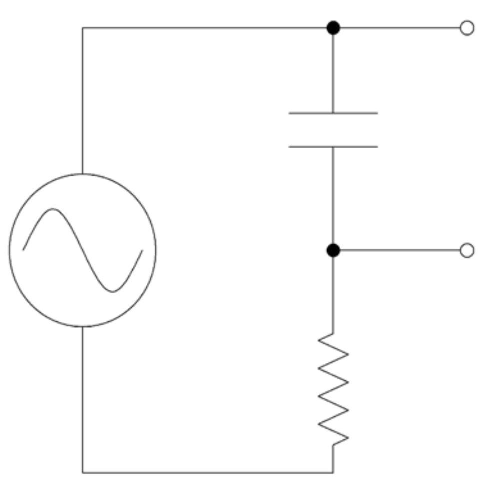

Figure 1

cyclic signals. If the ratio of the signal frequencies is a rational number, which is to say if that ratio is a ratio of integers, the curve is closed.

In our case, since both axes are driven by the same signal, the ratio of the signals will be 1:1 and the lissajous curve will be an ellipse similar to that shown in figure 2. More precisely, the ellipse will be a simple closed curve, parametrized as

$$\begin{aligned} x(t) &= a \cdot Sin(\omega t) \\ y(t) &= b \cdot Sin(\omega t + \theta) \end{aligned} \quad \textbf{(1)}$$

where *a* and *b* are scaling constants, in this case reflecting independent amplifiers for each oscilloscope axis.

Notice immediately that the domain of this curve is limited to

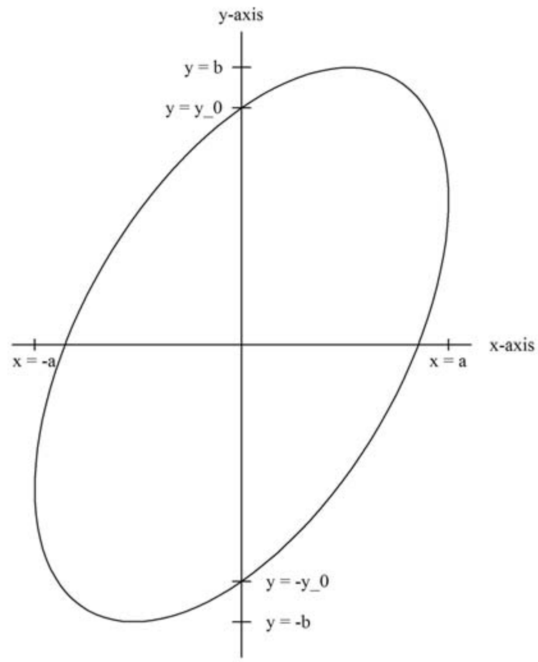

Figure 2

$$\begin{aligned} x(t) = -a \Rightarrow Sin(\omega t) = -1 \Rightarrow \omega t = \frac{3\pi}{2} \\ x(t) = a \Rightarrow Sin(\omega t) = 1 \Rightarrow \omega t = \frac{\pi}{2} \end{aligned} \quad \textbf{(2)}$$

and the range is similarly limited to

$$\begin{aligned} y(t) = -b \Rightarrow Sin(\omega t + \theta) = -1 \Rightarrow \omega t + \theta = \frac{3\pi}{2} \\ y(t) = b \Rightarrow Sin(\omega t + \theta) = 1 \Rightarrow \omega t + \theta = \frac{\pi}{2} \end{aligned} \quad \textbf{(3)}$$

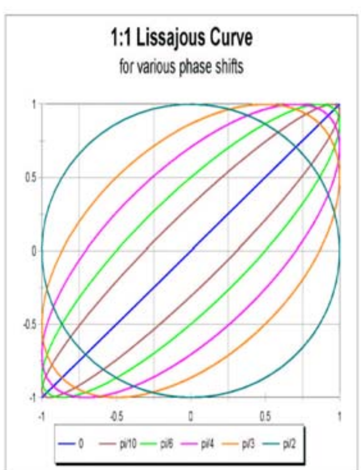

Figure 3

Figure 3 shows the evolution of the curve's aspect ratio with varying phase shift (2). At 2 = 0 the ellipse has an aspect ratio (minor axis:major axis) of 0 (a diagonal line). This reflects a purely resistive circuit. As the phase shift increases, the minor axis increases to a maximum at 2 = B/2. This is shown as a circle in figure 3 because in this example the coefficients a and b are assumed to be equal (see Equation 1).

Note that the ellipse's axes do not rotate with the changing phase shift. (The rotation of the ellipse will vary with the ratio of the coefficients a and b.) It is the eccentricity of the ellipse that we are interested in, not the rotation of its axes. And though there is certainly more than one way to analyze the eccentricity of an ellipse, the following method is chosen for precision's sake. Whether using cursors or a graticule, intercepts and orthogonal extent are more easily, and accurately, measured than the relative lengths of rotated axes.

Consider the y-intercepts in figure 2, labeled $\pm y_0$. Since both occur when x(t) = 0, both occur when a·SinTt = 0, or when Tt is either 0 or B. Thus, using y(t) from equation 1, we can write

$$
\begin{aligned}
y_0 &= b \cdot Sin(\theta) \\
\frac{y_0}{b} &= Sin(\theta) \\
\therefore Sin^{-1}\left(\frac{y_0}{b}\right) &= \theta
\end{aligned}
\qquad \textbf{(4)}
$$

By measuring the maximum y-intercept of the ellipse (y_0), and the maximum vertical extent of the ellipse (b), it is a simple matter to calculate the phase shift 2. Finally, knowing 2 makes it a simple matter to calculate C as follows.

$$
\begin{aligned}
Tan\theta &= \frac{X_c}{R} \\
R \cdot Tan\theta &= X_c = \frac{1}{\omega C} \\
\therefore \frac{1}{\omega \cdot R \cdot Tan\theta} &= C
\end{aligned}
\qquad \textbf{(5)}
$$

Thus, within the precision of your oscilloscope's ability to measure the values of T, b and y_0, and your ability to measure R, you can measure C. Moreover, you can do so for as many frequencies as your signal source, your oscilloscope, and your patience will allow.