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Basic Oscilloscope Measurements: Dual-trace and X-Y Phase

Technique brief

Introduction

At one time or another, you probably watched the marching routines performed by a band during the half-time ceremonies of a football game. Whether you watched the band from the stadium bleachers or from a comfortable chair is unimportant. In either case, you noticed that the relationship of the band's columns changed during these various routines, but that they each maintained a common tempo or number of steps per minute.

Now let's imagine that a band like that one marches the length of a football field. Its columns are physically aligned, and each column is marching at the same tempo. As the band marches, every column passes each 5-yard line at the same time. In other words, the columns are marching "in phase." If, when the band reaches the 50-yard line, all but one of the columns march in place for a moment and then resume marching, one column will be leading the rest of the band. Thus, as the band continues marching down the football field, the leading column will pass each of the remaining 5-yard lines sooner than the rest of the band's columns. That is, the leading column and the rest of the band are now "out of phase."

In electronics, the phrases "in phase" and "out of phase" describe the time relationship between two electrical signals. The measurement of phase differences is important in both electronic design and in troubleshooting electronic equipment. More than likely, you'll use an oscilloscope to measure the phase differences between two electrical signals.

Using an oscilloscope, you can make a phase measurement in two different ways. The method you use depends upon what type of oscilloscope you're using and what you're measuring. The first method of phase measurement, dual-trace, is accomplished more easily than the second. However, you need a dual-channel oscilloscope to make it. The second, X-Y, has more steps, and requires a more careful setup, but can be accomplished on any single channel oscilloscope with an external horizontal (or X) input.

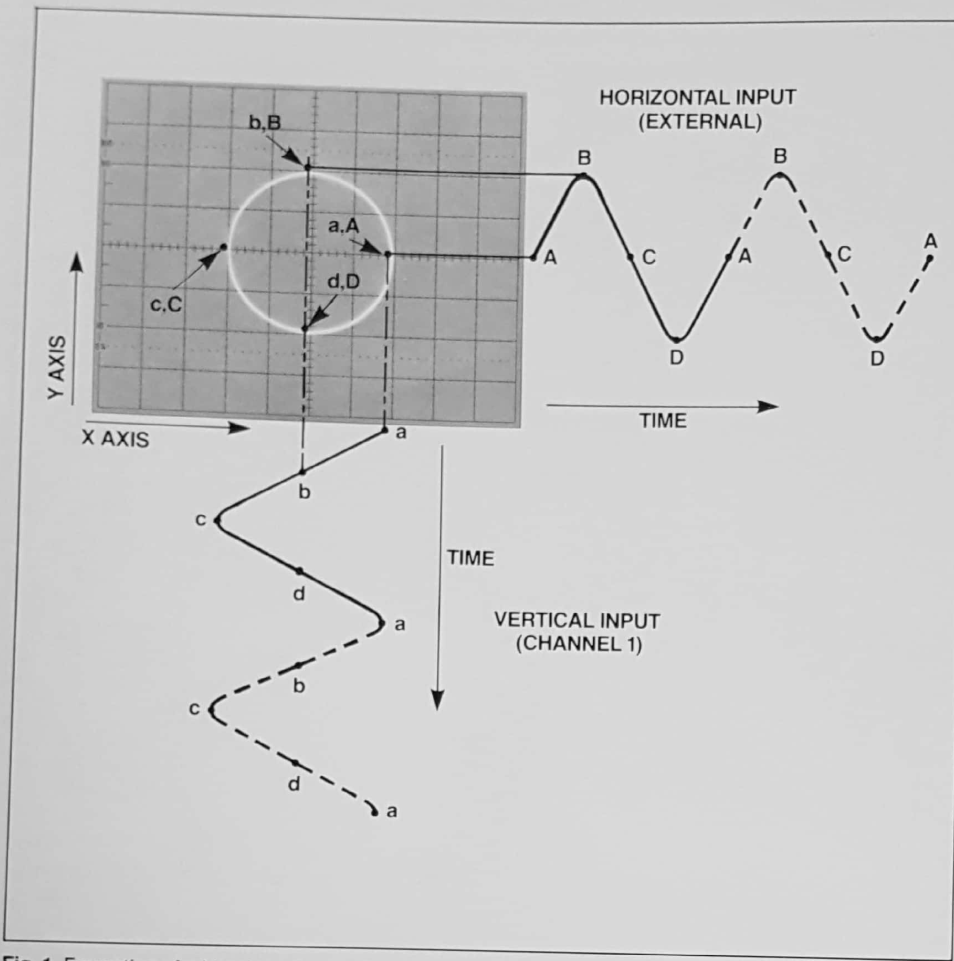

Fig. 1. Formation of a Lissajous figure. (Two sine waves 90° out of phase).

Using the dual-trace method, you'll see two time-shared traces concurrently displayed on the crt screen. Using the X-Y method, you'll see a graph, called a Lissajous (lē' sə zhoo') figure, representing the vertical (or Y) input signal as it is plotted against the external horizontal (or X) input signal. The formation of this graph is explained by figure 1.

The shape of a Lissajous figure depends upon the phase difference between the two input signals, the frequency of the two input signals, and the amplitude of the two input signals. Figures 2, 3, and 4 show the effects of phase difference, frequency, and amplitude on a Lissajous figure.

Phase measurements, whether dual-trace or X-Y, are made when the input signals on both the external horizontal (X) and the vertical (Y) input channels are the same frequency. In fact, differences between the two frequencies become readily apparent in both dual-trace and Lissajous displays. In a dual-trace display, if different frequencies are on both channels, then the triggering channel's display will be stable and the other channel's display will be moving. If you measure phase differences using the X-Y method and there are different frequencies on each channel then you'll see the Lissajous figure begin to roll, or its symmetry change.

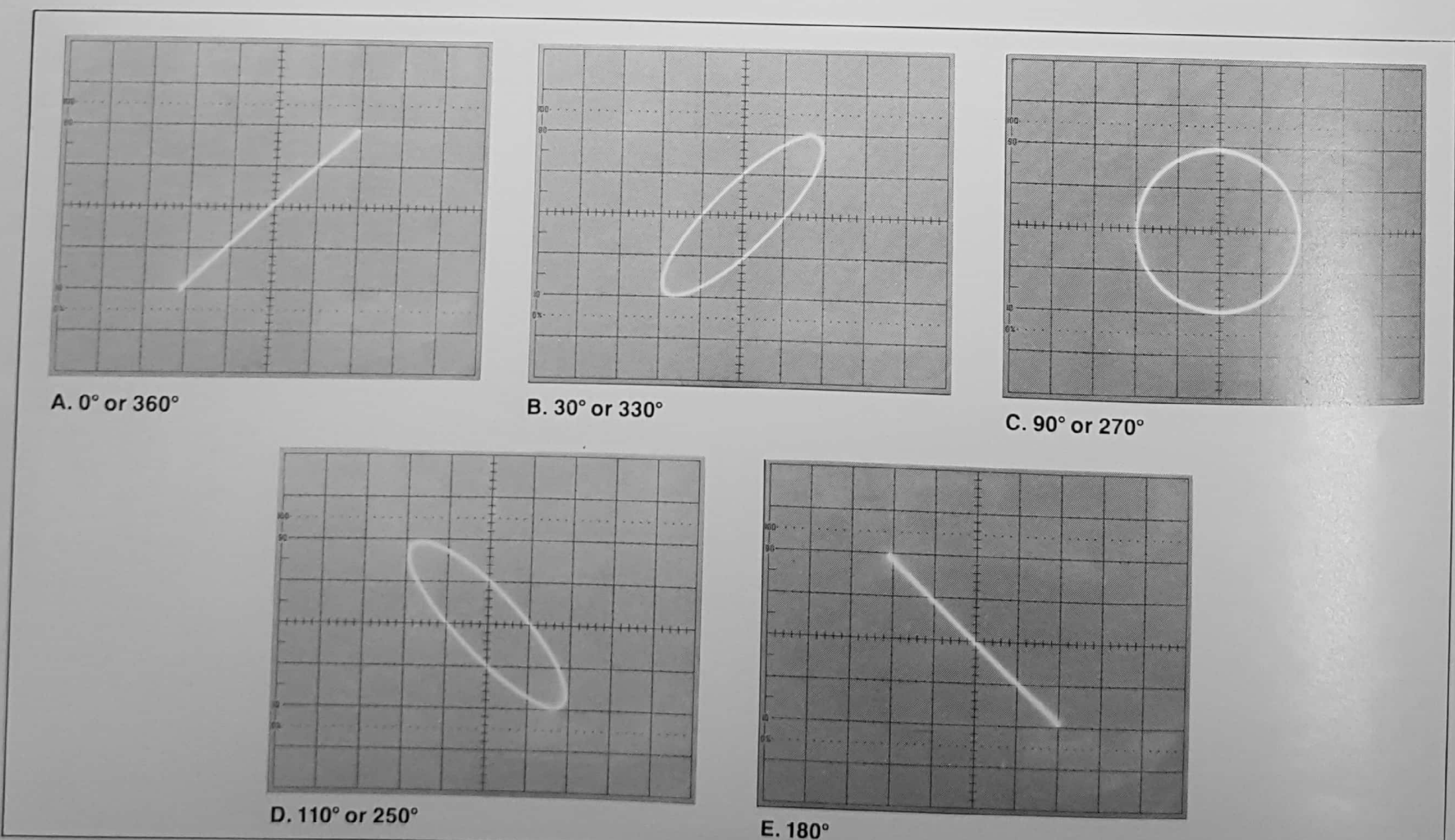

Fig. 2. Effect of phase differences on a Lissajous figure.

Now change the vertical mode to DUAL TRACE. Both waveforms should appear on the crt screen. (If necessary adjust the INTENSITY for an easily viewed display.) If the two waveforms are of unequal amplitude, adjust the VOLTS/DIV and VAR controls to obtain signals of equal amplitude. This will not affect the accuracy of your measurement, but will make your analysis of the signal easier. Align the bottom peaks of each waveform with the same horizontal graticule line by using the vertical POSITION controls. Adjust the SEC/DIV (or its VAR control if it has one) to display one waveform period (that is one cycle or 360°) in no more than eight center horizontal graticule divisions. Once you've aligned the reference waveform (in this case channel 1) with the intersection of the center horizontal graticule line and the first vertical graticule line (see figure 5), you're ready to compute the phase difference between the two waveforms.

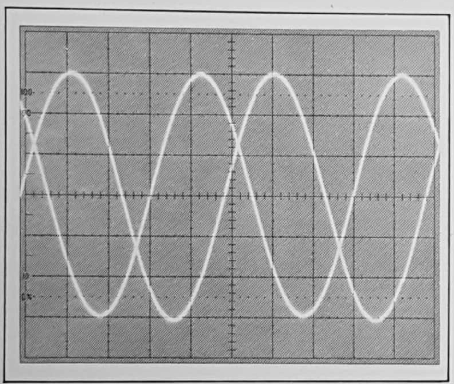

Fig. 5. Align the bottom peaks of each waveform with a horizontal graticule line.

Analyzing Phase Difference

Analyzing phase difference on a dual-trace oscilloscope requires three steps: (1) determining the number of degrees per graticule division, (2) counting the number of divisions between the reference waveform and the second waveform, and (3) computing the phase difference in degrees between the two waveforms.

Notice how many graticule divisions it takes for one complete waveform period to occur. In figure 6, for example, one waveform period occurs in 5.0 graticule divisions. To determine the number of degrees per graticule division, use the following formula.

NUMBER OF DEGREES PER DIVISION
= 360° ÷ Number of Divisions in One Period

Thus, in figure 6,
360° ÷ 5.0 Divisions
= 72° per Division.

When you count the number of horizontal divisions between the two waveforms in figure 6, you should count 1.8. To determine the phase difference between the two waveforms, you'll need to use this formula:

PHASE DIFFERENCE
= Horizontal Difference in Divisions x Degrees per Division

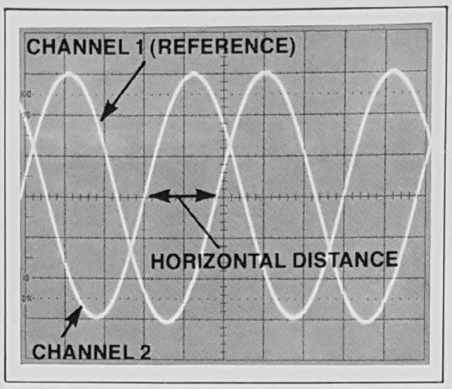

Fig. 6. Determine phase differences—Multiply the number of degrees per division by the number of horizontal divisions between the two waveforms.

Now, using the information you've already derived from figure 6, you can compute the phase difference of the two waveforms.

PHASE DIFFERENCE
= 1.8 Divisions x 72° per Division
= 129.6°

High Resolution Phase Measurements

When the horizontal distance between two waveforms is less than one division, you might find it difficult to make accurate phase measurements. Oscilloscopes equipped with a horizontal magnification (X1-X10) control help make these measurements more accurate. Making high resolution phase measurements is no more difficult than making a regular dual-trace phase measurement. The principle is the same. It just requires a few more steps.

The initial measurement setup is identical, but once you have two waveforms displayed on the crt screen with less than a division between them, you should probably decide to make a high resolution phase measurement. Before doing this, be sure that you compute the number of degrees per division using the method explained above. To make a high resolution phase measurement, set the X1-X10 magnification control to its X10 position. Then rotate the horizontal POSITION control until the display on the crt screen "appears" to be two diagonal lines that cross the center horizontal graticule line. See that at least one of the traces crosses the intersection of a vertical and the center horizontal graticule line, as shown in figure 7.

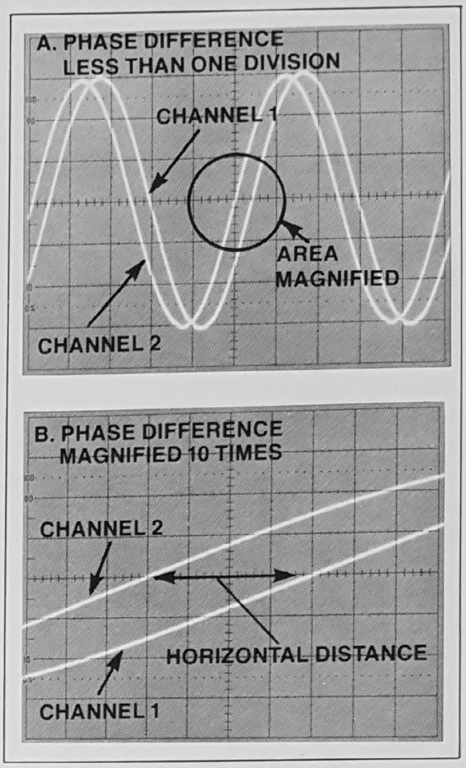

Fig. 7. High resolution phase measurement.

The X10 magnification example merely expands the waveforms without changing their phase relationships. But, whenever you change to a X10 magnified display, the number of degrees per division decreases. In figure 7A, there are 72° per division. When you put the oscilloscope in the X10 magnification mode, there are 7.2° per division (72 ÷ 10 ≌ 7.2° per division). To determine the phase difference between the two waveforms, you still use the formula for phase difference described in the previous section. By substituting these new values into that formula, you can determine the phase difference between the two waveforms in figure 7B.

PHASE DIFFERENCE
= 4 Divisions x 7.2° per Division
= 28.8°

X-Y Phase Measurements

Although you won't see two traces on the crt screen when you make an X-Y phase measurement, what you do see, a Lissajous figure, can help you determine phase relationships.

Setup

On some oscilloscopes, preparing to make X-Y phase measurements takes more steps than on others. If you've just completed the dual-trace phase measurement, then you can use one of the following procedures to quickly make an X-Y phase measurement. The procedure you use will depend upon the type of oscilloscope you're using.

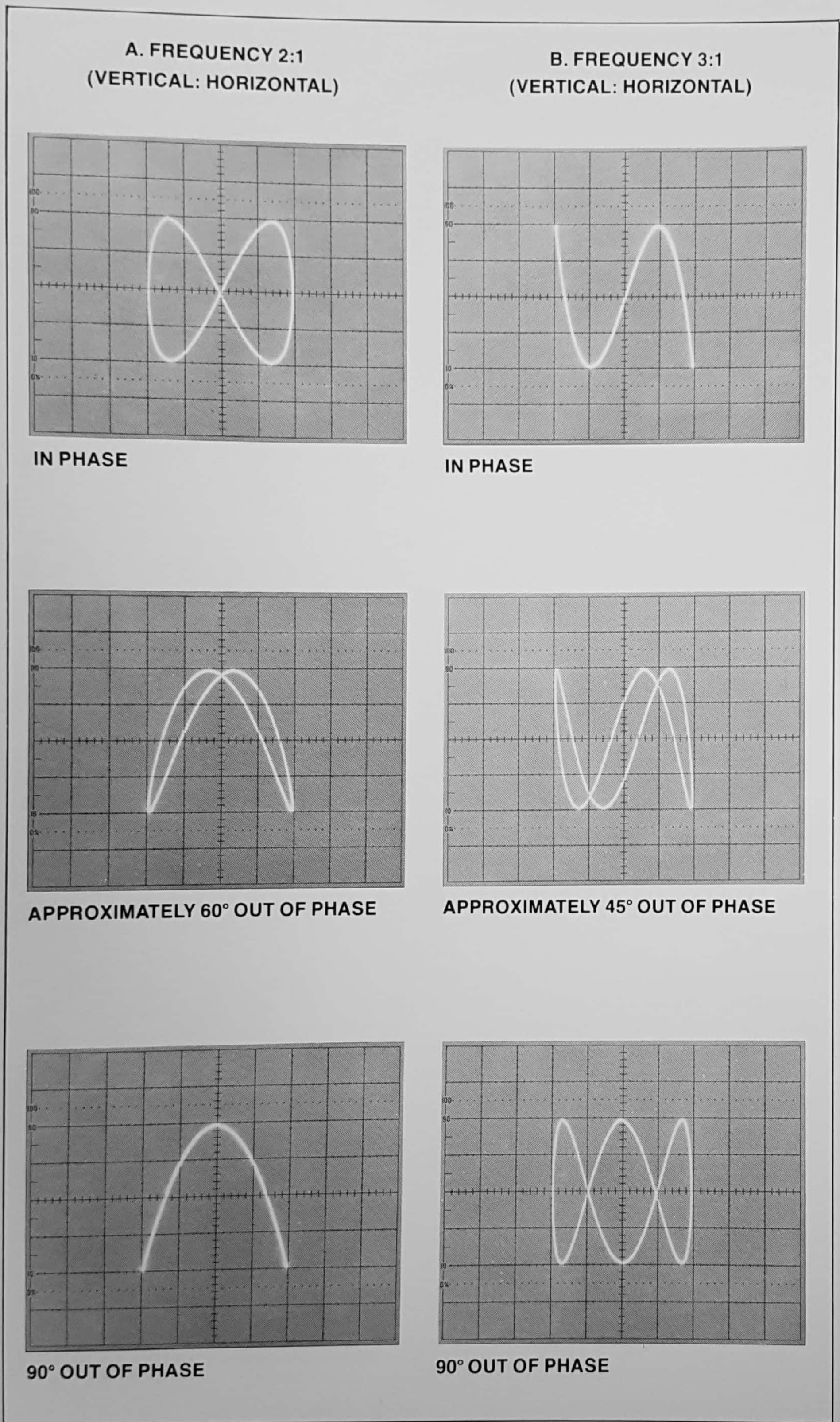

Fig. 3. Effect of frequency on a Lissajous figure at various phase differences.

Even though this technique brief concerns itself with phase measurements, you might be interested in knowing something more about Lissajous figures. Although you can't make a phase measurement with a Lissajous figure when different frequencies exist on the horizontal and vertical input channels, you can find harmonic frequencies. (Harmonic frequencies are integral multiples of a fundamental frequency. For example, a basic frequency of 60 hertz has a second harmonic of 120 hertz, a third harmonic of 180 hertz, and so forth.) Figure 3 illustrates the Lissajous figures which appear when the vertical to horizontal frequency ratio is 2:1 and 3:1. (If the vertical to horizontal ratio is reversed, the figures will rotate 90°.)

Although different frequencies on the horizontal and vertical inputs prohibit you from making phase measurements, different amplitudes do not. You can easily make either type of phase measurement when different amplitudes exist on both channels by making the necessary adjustment (usually the variable control on the VOLTS/DIV control) to compensate for the difference in amplitude.

The following sections contain procedures which give you the ability to setup, make, and analyze phase measurements easily. If you're using a dual-trace oscilloscope, begin with the section that immediately follows; if you're using a single-trace oscilloscope, begin with the section entitled "X-Y Phase Measurements."

Dual-Trace Phase Measurements

Setup

To setup your oscilloscope, verify that it is common grounded with the system to be tested, verify that the system to be tested is grounded, and obtain a free-running trace according to the procedures described in *Basic Oscilloscope Measurements: Setup and Analysis* (AX-3841). The same technique brief describes how to compensate oscilloscope probes. For phase measurements, you'll need to vary that compensation procedure slightly. Connect two identical probes whose cables are of equal lengths to the channel 1 (CH 1) and channel 2 (CH 2) inputs. Select the appropriate vertical mode (CH 1 or CH 2), and follow the procedure described in the above technique brief to compensate both probes. Then set the vertical mode to CH 1.[1]

After you input signals to an oscilloscope, one channel has to be selected as the triggering or reference channel. On some oscilloscopes, this is done for you and you have no control over it, but on more sophisticated dual-trace oscilloscopes you can select either channel as the trigger channel. If your oscilloscope allows you to select the triggering channel, select channel 1. (You could use either channel, but throughout this technique brief let's use channel 1 which is the triggering channel on most oscilloscopes without trigger selection).

If your dual-trace oscilloscope has a CHOP (chopped) or ALT (alternate) switch, set the oscilloscope to either CHOP or ALT. Whether you select a chopped or alternate display depends upon the SEC/DIV control setting. A general rule of thumb is to select the alternate display mode when the SEC/DIV setting is faster than 0.5 ms, and to select a chopped display mode when the setting is slower than 0.5 ms. If your dual-trace oscilloscope doesn't have this control, it probably selects the chopped or alternate display mode for you automatically.

When you're ready to input the signals you want to display, connect the channel 1 probe tip to one test point (the channel 1 probe will provide the triggering or reference waveform on the crt screen), and connect the channel 2 probe tip to a second test point. Then with the vertical mode set to CH 1, perform these steps:

1. Obtain a stable display by using the LEVEL control.
2. Use the vertical POSITION control to approximately center the waveform on the crt screen.
3. Set the VOLTS/DIV and its VAR (variable) control to display a waveform an even number of divisions high.
4. Repeat steps 1, 2, and 3 with the vertical mode set to CH 2.

[1] Either ac or dc coupling may be used. Be aware, however, that using ac coupling at low frequencies will introduce phase shift.

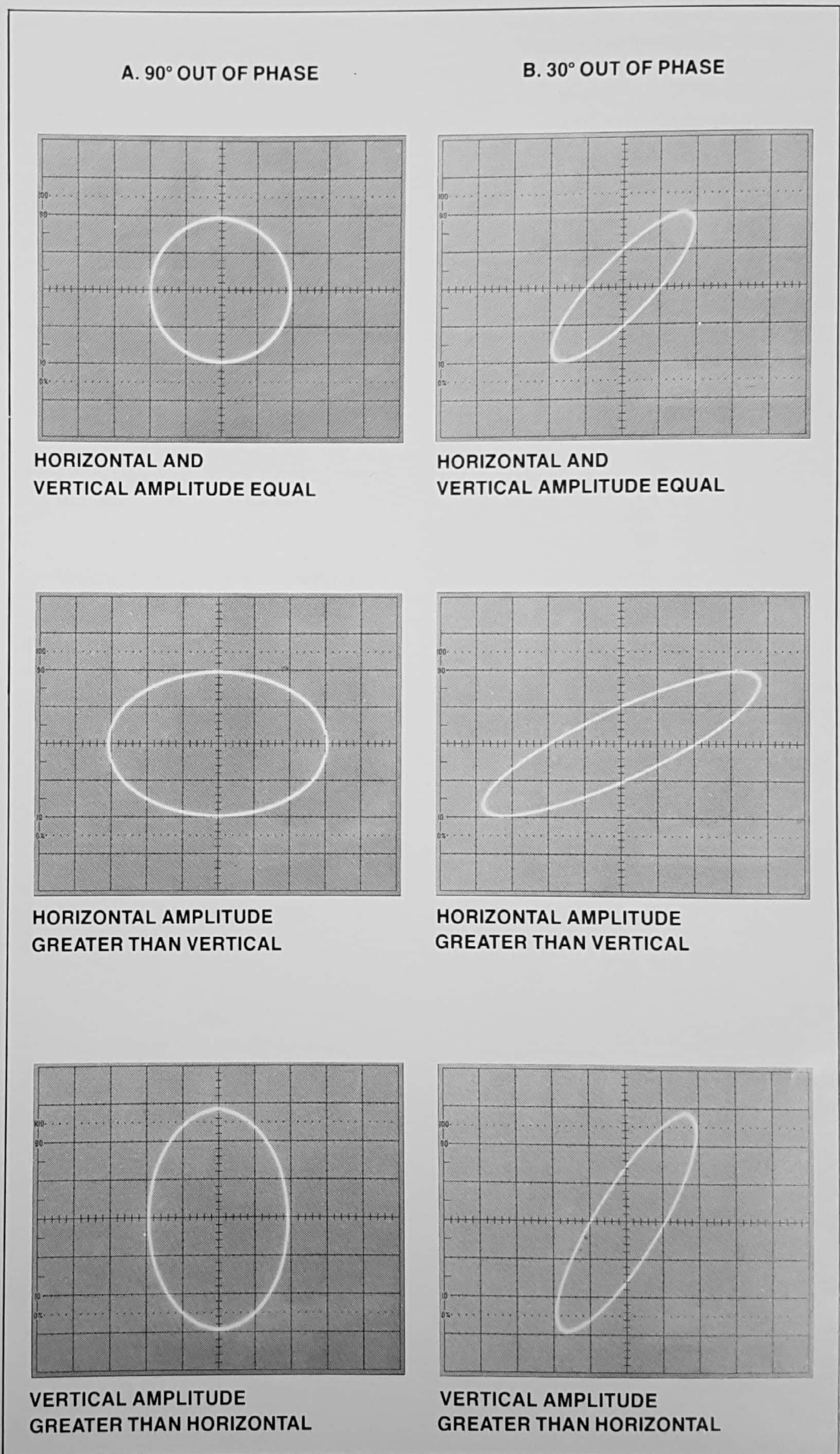

Fig. 4. Effect of amplitude on a Lissajous figure of constant phase.

Procedure 1:

When you use an oscilloscope with an external horizontal input, disconnect the channel 2 probe and connect it to the external input. Select CH 1 as the vertical display mode, switch the oscilloscope into its X-Y mode, and adjust the INTENSITY for an easily viewed display.

Procedure 2:

If your oscilloscope doesn't have an external input, simply set the vertical mode to CH 1 or CH 2, switch the oscilloscope into its X-Y mode and adjust the INTENSITY for an easily viewed display.

When you use a single channel oscilloscope with an external horizontal (X) input, however, you'll need to follow the procedure already described in *Basic Oscilloscope Measurements: Setup and Analysis* (AX-3841) to verify that your oscilloscope is common grounded with the system to be tested, and that the system to be tested and the oscilloscope are both grounded. To compensate two identical probes with equal cable lengths, also follow the above technique brief. After you've compensated both probes, connect one channel 1 (vertical) and the other to the external horizontal input. Once you change the mode of the oscilloscope to X-Y, you should see a Lissajous figure. If you don't, use the BEAM FINDER and the POSITION controls to locate the pattern. After you have a Lissajous figure, adjust the INTENSITY for just enough brightness to view the display easily.[2,3]

By using the POSITION controls, align the Lissajous figure so that one of the edges of its circumference touches the corner formed by a vertical and a horizontal graticule line. (See figure 8.) This adjustment centers the figure and aligns it so that you can easily analyze it.

Analyzing a Lissajous Figure

A Lissajous figure might appear to be difficult to analyze. It's not. Whether you're using a dual-trace or a single-trace oscilloscope, the method is the same: simply count the number of horizontal divisions between the intersections of the Lissajous figure and the center horizontal graticule

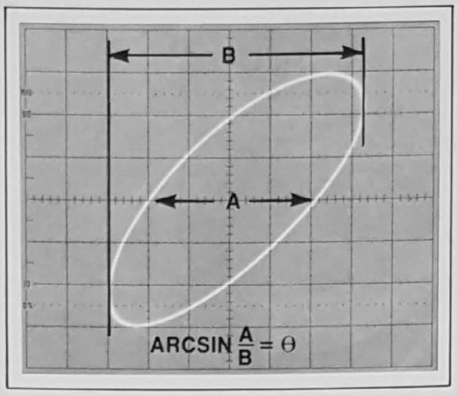

Fig. 8. Determining phase difference using a Lissajous figure.

line (distance A in figure 8), and then count the number of horizontal divisions between the two points on the Lissajous figure with the widest horizontal separation (distance B in figure 8).[4]

After determining the distances shown in figure 8, use the arcsine formula below to determine the number of degrees of phase difference between two signals.

$$\text{Arcsin } (A \div B) = \Theta$$

Thus, in figure 8, you can see that the phase difference can be determined by the following substitutions.

$$\text{Arcsin } (4.1 \div 6.3) = \Theta$$
$$\text{Arcsin } 0.6508 = \Theta$$

By consulting a sine table, you can see that the arcsine 0.65082 falls roughly between 40° and 41°. Through interpolation, you'll find that this arcsine corresponds to an angle of about 40.6° (or 40° 36″).

Applications and Summary

Although phase measurements aren't frequently made in basic electronics, don't overlook their usefulness, particularly in audio, and video tape recorder applications.

Whenever you remove and replace the stereo cartridge on the tone arm of your turntable, you have a good chance of replacing it incorrectly. To check your new hookup, you can use an oscilloscope setup for an X-Y phase measurement. This measurement lets you compare the right and left outputs of the audio amplifier in both stereo and monaural modes. If you have hooked up your stereo cartridge incorrectly, you'll see an irregular elipse similar to that in figure 2D when the equipment is set up for stereo operation and a figure like that in figure 2E when the equipment is setup for monaural operation. These figures indicate that the speakers will be operating out of phase. To correct the condition merely reverse one set of the connections going to the + and − pins on the stereo cartridge. Switching these connections should give you an irregular Lissajous figure like the one in figure 2B for stereo operation and the one in figure 2A for monaural operation. These figures indicate that the speakers will be operating in phase.

Electro-mechanical equipment requires periodic service adjustments. One service adjustment required by video tape recorders (vtr's) assures that the magnetic playback heads are in phase. (If the heads aren't aligned, the vtr audio won't sound clear.) The mechanical adjustment that places the playback heads in phase is aided by the use of an oscilloscope. By setting up the oscilloscope for an X-Y phase measurement and connecting the probes and their grounds to the connections of the playback heads designated by the vtr's service manual, you can quickly tell if the heads are operating in phase. If they are you'll see a Lissajous figure like that in figure 2A. If the heads are out of phase, then you'll see an ellipse similar to that in figure 2B, and you'll have to make the necessary mechanical adjustment to place the playback heads back in phase.

This technique brief explained how to make phase measurements using the dual-trace or X-Y measurement methods, and introduced you to the use of Lissajous figures. It is a part of a growing program dedicated to educating potential users about the capabilities and applications of TEKTRONIX Instrumentation. To obtain the other technique briefs and application notes in this program, or for information about TEKTRONIX Products, contact your Tektronix Field Engineer, Distributor, or Representative.

[2] Either ac or dc coupling may be used. Be aware, however, that ac coupling introduces phase differences at low frequencies.

[3] X-Y phase measurements are limited to low frequencies due to the electrical differences between the vertical and horizontal amplifier at an oscilloscope.

[4] If you want, you can use the vertical distances which correspond to distances A and B in figure 8, but remember not to mix the horizontal and vertical distances in the same measurement.

References:

1. Rider, John F. 1970. *Obtaining and Interpreting Test Oscilloscope Traces*. New York: John F. Rider Publishing, Inc.
2. Lenk, John D. 1971. *Handbook of Electronic Test Equipment.* Englewood Cliffs, N.J.: Prentice-Hall, Inc.
3. Lenk, John D. 1968. *Handbook of Oscilloscopes: Theory and Application.* Englewood Cliffs, N.J.: Prentice-Hall, Inc.