

quadrature.

Phase difference using delay time measurement

Phase difference can be measured on an oscilloscope by finding the time delay between two waveforms and their period. You can accomplish that using the oscilloscope's cursors as shown in **Figure 2** where relative cursors measure the time difference between the maxima of the two 10 MHz sine waves. Cursor time readouts in the lower right corner of the screen indicate a delay of 10 ns. The period can also be measured using the cursors. The phase difference, in degrees, can be determined using the equation:

$$\Phi = t_d/t_p \times 360 = 10 \text{ ns}/100 \text{ ns} \times 360^\circ = 36^\circ$$

Where: t_d is the delay between waveforms and t_p is the period of the waveforms.

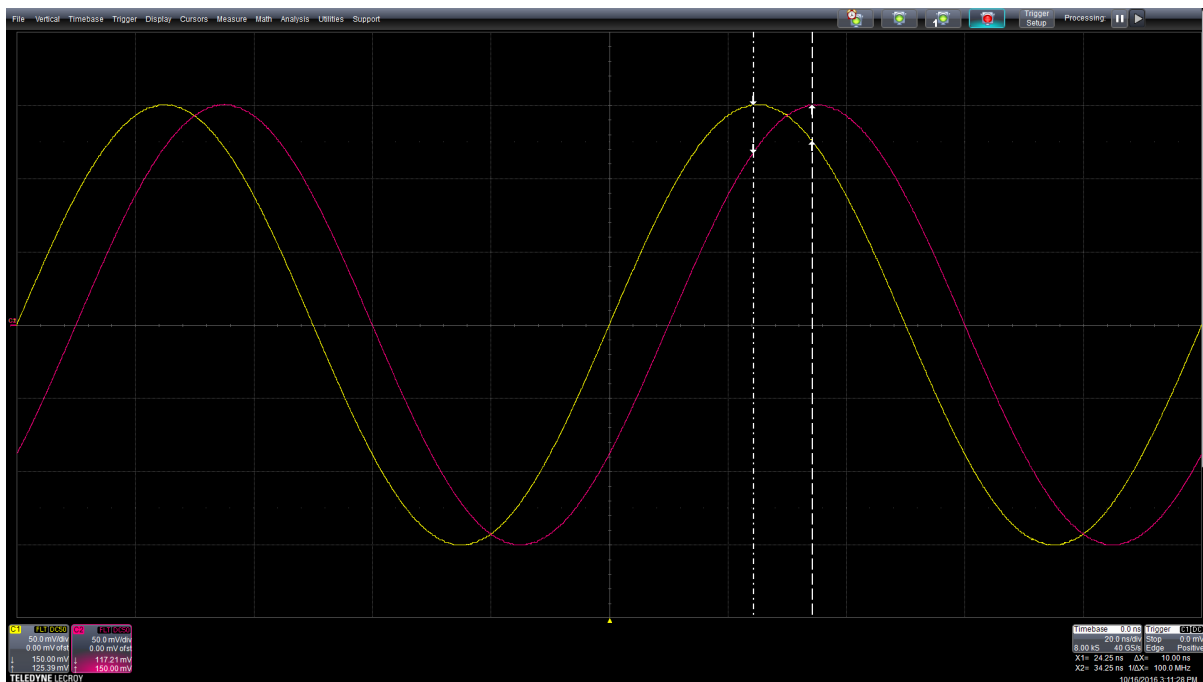


Figure 2 Measuring time delay between the same phase point on two waveforms using oscilloscope cursors

This technique is a remnant of analog oscilloscope measurements. It works on digital oscilloscopes (DSOs), but the measurement accuracy is very dependent on the manual placement of the cursors.

Phase parameters

DSOs simplify phase measurements by offering direct phase measurement, based on measuring the delay and period of the source waveforms. You can select the measurement thresholds and slopes for each waveform. The phase measurement is identical to the method used in the previous section applying an interpolator to assure accurate location of the measured phase points. The advantage of using the oscilloscope's built-in measurement capability is that it removes cursor placement as an error source. Phase can be read out in units of degrees, radians, or percentage of period. **Figure 3** provides an example of a phase measurement.

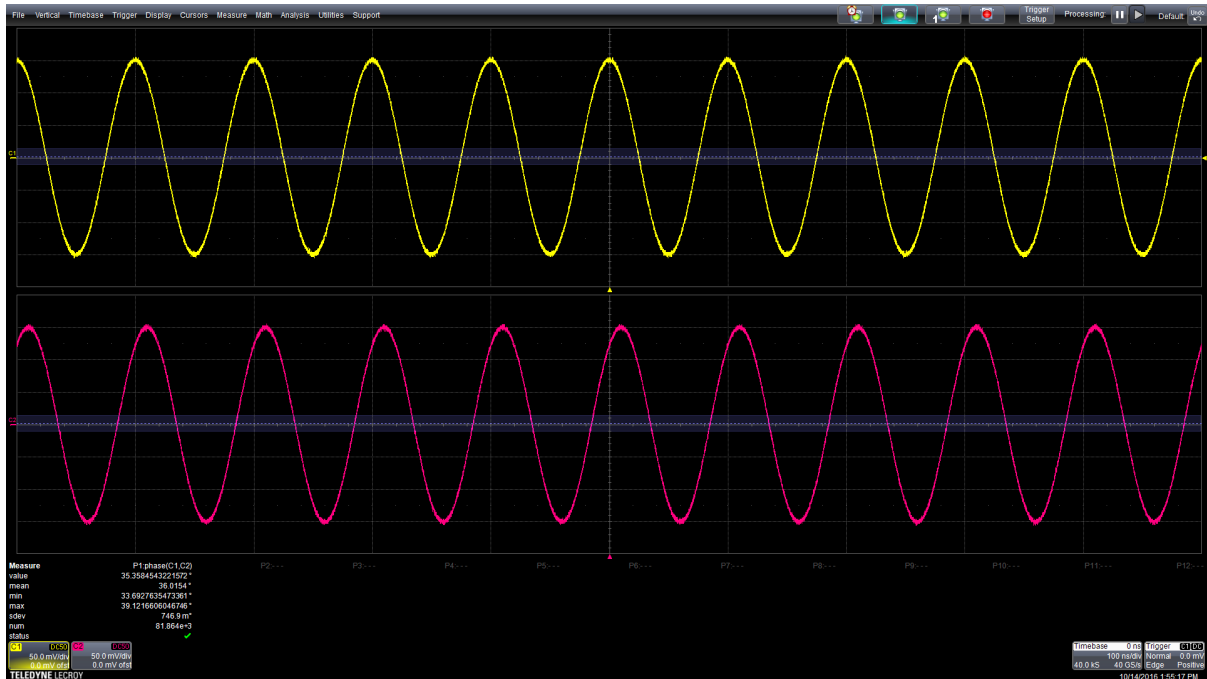


Figure 3 Using the phase measurement parameter: The parameter P1 (lower left) shows the phase parameter with statistics.

The phase measurement is performed using parameter P1 in the lower left corner of the screen image. This oscilloscope makes "all instance" measurements meaning that the phase is measured for every cycle on the screen for each acquisition. The large number of phase measurements available supports measurement statistics, shown in this **Figure 3**. Measurement statistics show the most recent measurement, the mean value of all the measurements, maximum and minimum values encountered, the standard deviation, and the number of measurements included in the statistics. The key statistical readouts are the mean value and the standard deviation. The mean is the average value of all the measurements made. The standard deviation is a measure of the uncertainty in the measurement. In this example the mean value is 36° . The standard deviation is 0.747° . Most of the uncertainty in this measurement is a function of the vertical noise on the waveform. The mean value reduces noise by averaging the measured values. Noise can further be reduced by decreasing the bandwidth of the oscilloscope front end.

Dynamic phase measurements

Sometimes the phase difference isn't static and you need to characterize the phase change of a signal—think phase-modulated carrier. This type of measurement relies on the "All Instance" character of parameter-based timing measurements. Phase is measured for every cycle of the waveform. This information can be displayed using a [trend or a track plot](#). The trend plot strings all the measured values together as a waveform where the horizontal axis is measurement event. The track, on the other hand, plots measured values as a function of time. This maintains synchronicity with the source waveform. So if one of the waveforms is phase modulated, you can get a cycle-b-cycle plot of the instantaneous phase as seen in **Figure 4**.

The upper trace, C1, in **Figure 4** is a 10 MHz carrier, phase modulated (PM) by a 100 kHz sine wave. The trace C2 (second from top) is a 10 MHz sine with no modulation. The phase parameter reads the phase difference between the two waveforms. The measured phase difference for each cycle of the source waveforms is plotted in the third trace from the top (F1) as the track of the phase parameter and shows the phase difference versus time. This has, in essence, demodulated the PM waveform.

Note that in addition to having measurement statistics turned on, the oscilloscope also has a histicon (iconic histogram) of the phase parameter displayed. The histicon shows a miniature version of the histogram of phase values. Pointing at the histicon and clicking results in the full-scale histogram of phase difference being displayed in the bottom trace. The histogram breaks the amplitude range into a user set number of "bins." The number of measured values within each bin (vertical scale) is plotted versus the measured values (horizontal scale). The saddle shaped histogram is typical of a sinusoidal signal. Steps in the track plot and gaps in the histogram are the result of the phase difference values holding at fixed values for each cycle of the source waveform.

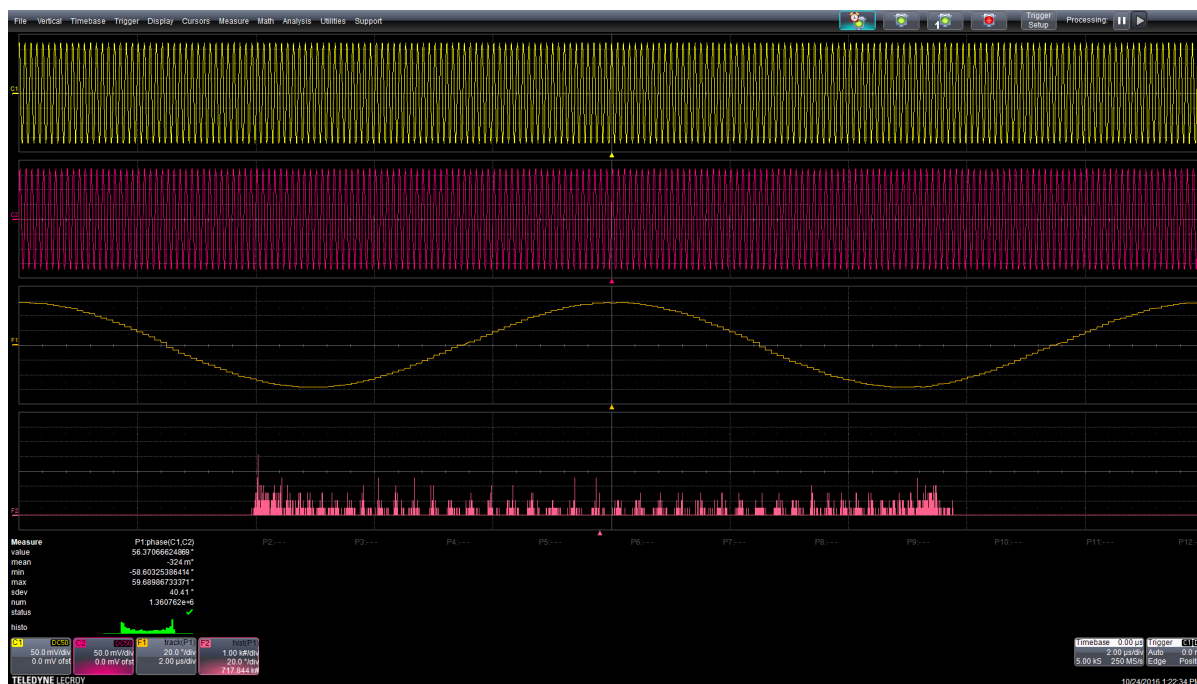


Figure 4 Dynamic phase difference measurement utilizing the parameter track function (trace F1) to show the cycle to cycle variation in phase difference as a function of time.

The min and max values of the phase parameter readout provide the range of the phase excursion over the full modulation cycle.

Editor's note: The equation was updated to fix a typo. Thanks to commenter RonFredericks for the correction.

Other phase measurement techniques

Other phase measurement techniques

The phase parameter measures phase in the time domain and is dependent on detecting waveform transitions across user set voltage thresholds. Additive vertical noise, from the waveform source and the oscilloscope itself, limit accuracy of this measurement. You can improve signal-to-noise level by restricting the oscilloscope's bandwidth, which results in smaller values for the standard deviation of the measurement and thus more accurate readings. Accuracy is further enhanced by taking multiple measurements and using the average or mean values of the phase instead of the instantaneous value.

You can also make phase measurements in the frequency domain by computing a single point Discrete Fourier Transform (DFT) of the input at the signal frequency and reading the phase of the FFT. This is the technique used for the optional measurement parameter narrow band phase (nbph). **Figure 5** shows both the measurement of phase difference using the phase parameter as well as nbph. Nbph reads the phase of a signal at the specified frequency at the first data point between the

parameter cursors in the acquired record. If the parameter cursors are in their default positions it reads the phase of the first point in the record. Since we are interested in the phase difference between two signals it requires two nbph measurements. In **Figure 5**, we measure nbph of both the C1 and C2 waveforms in parameters P2 and P3, respectively. Parameter mathematics lets you to take the phase difference in P4. We see that the nbph difference is 36.000° and the phase parameter reads 35.993° . Note the standard deviation of the nbph measurement is significantly lower than that of the phase parameter. This is because the nbph measurement has a narrower measurement bandwidth (105 kHz) for the 1000 cycle acquisition length. Keep in mind that nbph is an optional parameter and will add to the cost of the oscilloscope.

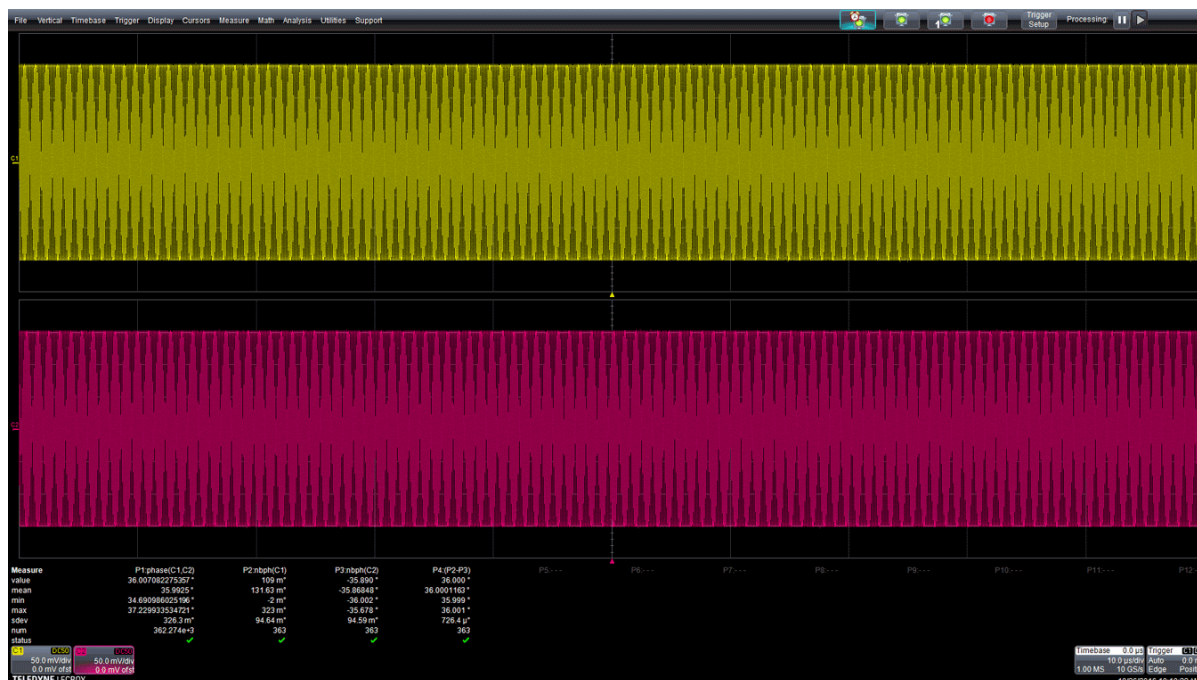


Figure 5 Comparing phase difference measurements between the phase parameter on the difference of nbph measurements showing the slightly better performance of the nbph method

Classic phase measurement - Lissajous pattern

For those romantics who have used an analog oscilloscope, you probably remember using a classic Lissajous patterns to measure phase difference. It can be measured by cross plotting the two waveforms on the X-Y display of the oscilloscope as shown in **Figure 6**. In this figure, the waveform on channel 1 (C1) provides the horizontal or X displacement. Channel 2 (C2) provides the vertical deflection. The Lissajous pattern indicates the phase difference by the shape of the X-Y plot. A straight line indicates a 0° or 180° phase difference while a circle indicates a 90° difference. Phase differences between those values show as ellipses and phase is determined by measuring the maximum vertical deflection and the vertical deflection at zero horizontal deflection. In **Figure 6**, cursors mark these two locations on the X-Y plot.

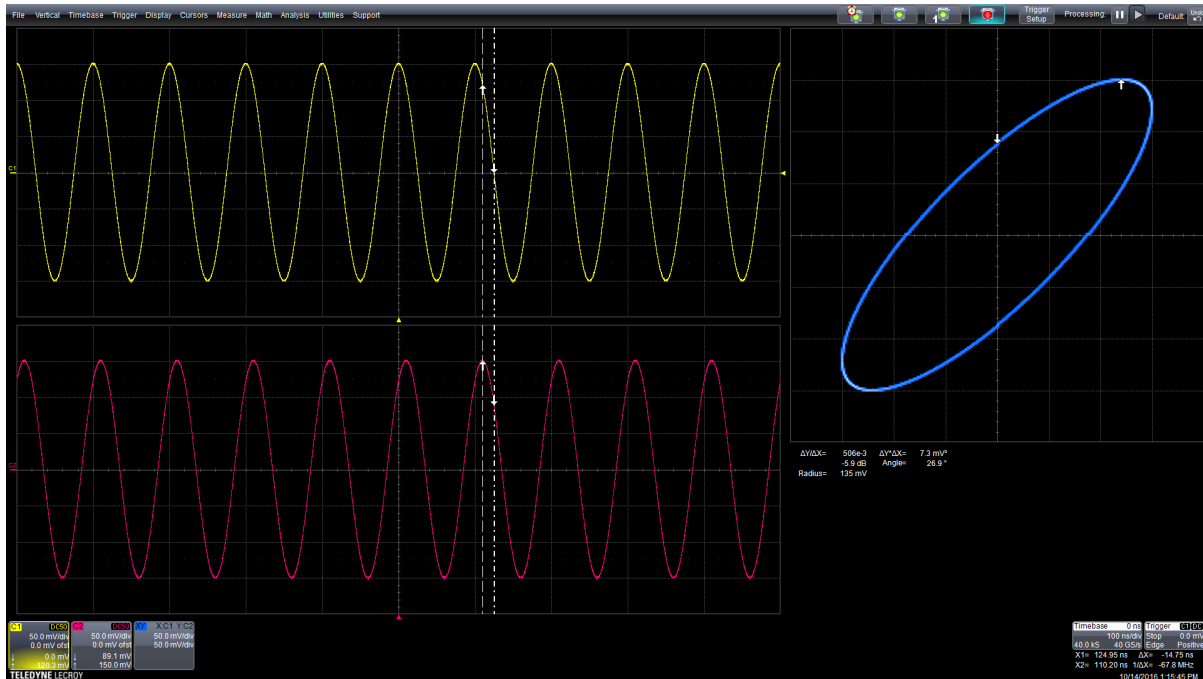


Figure 6 Using a classic Lissajous display lets you measure the phase difference between two sine waves.

The cursors also appear, and track, on the X and Y component waveforms. Cursor readouts in the descriptor box for channel two show the required values for computing the phase difference.

$$\Phi_2 - \Phi_1 = \pm \sin^{-1} (Y_{x=0}/Y_{\max}) \text{ for the top of the ellipse located in quadrant I}$$

$$\Phi_2 - \Phi_1 = \pm [180 - \sin^{-1} (Y_{x=0}/Y_{\max})] \text{ for the top of the ellipse located in quadrant II}$$

The sign of the phase difference is determined by inspecting the dual channel traces.

In our example, the Y_{\max} value is 150 mV, $Y_{x=0}$ is 89.1, and the top of the ellipse is in QI:

$$\Phi_2 - \Phi_1 = \pm \sin^{-1} (89.1/150) = \pm \sin^{-1} (0.594) = 36.44^\circ$$

Lissajous patterns can still be used on modern digital oscilloscopes as seen in **Figure 6**. The accuracy of this method is dependent on the placement of the cursors but it produces reasonable results with a greater artistic panache.

DSOs offer multiple techniques to measure phase. Direct measurement in the time domain supports both static and dynamic measurements of phase. Frequency domain based nbph provides somewhat more accurate results for static phase measurements but require optional software. The next time you need to make a phase measurement keep these techniques in mind.

Arthur Pini has over 50 years' experience in electronics test and measurement.

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