Using an Oscilloscope for Car Audio Tests
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The advantage of using an oscilloscope is, of course, that one can see and measure exactly what is occurring electrically in a circuit in real time. (Digital storage scopes permit us to dissect the past, but we will save that topic for a future article.) Crunching numbers taken from assorted meter measurements cannot compare to a visual graphic display. From a car audio perspective, a view of an oscilloscope waveform quickly demonstrates the quality and integrity of a "linear" amplifier or any other audio component.

Let's begin our exploration into waveforms, and along the way we will learn how to correlate the display on the oscilloscope with the physical properties of the circuitry under test.

**Sinewaves**

Examining a sinewave yields excellent results when checking amplitude and phase distortion. One of the first waveforms to be studied with a scope is usually the sinewave and one of the easiest measurements that can be taken of a sinewave would be the frequency. In the past, I have discussed the repetitiveness of motion and how that single quality defined a wave. The time for a sinewave to complete one full cycle is known as the period and it is measured in seconds. The frequency of the sinewave is known as the reciprocal of the period. (This means that $f = 1/P$, where $f$ = frequency and $P$ = period (in seconds).

By imputing a known sinewave frequency into the scope's horizontal input and then feeding an unknown sine wave into the vertical input we can visualize the relationship between the two: i.e. (2 to 1, 3 to 1, etc.). This can be accomplished by counting the number of peaks in the display. Even before we had oscilloscopes, such measurements were taken with mechanical instruments and smoked plates.

Such methods were fine for our grandparents, but today the abundance of inexpensive frequency counters has outmoded this tedious method of measuring the frequency of a particular signal. For illustrative purposes, we included a visual example of this older method in **Figure 1**.
These waveforms are named after the man who developed them. They are called Lissajous waveforms or Lissajous figures.

**Dual Channel Scopes**

Nearly all of the later model oscilloscopes have two inputs, or channels, for taking measurements. Such scopes are often called "dual probe" devices. Using two probes makes it quite easy to make many comparative measurements — particularly phase shift or the delay between two waveforms. **See Figure 2 and Figure 3.** When we apply a pure audio sine wave to the input of an amplifier (or any other component under test) we usually set the sine wave amplitude for the normal level of the input of the device under test.

Connect the probe from the scope's Channel 1 to the input of the unit under test and then connect the probe from the scope's Channel 2 to the output of the unit as shown in **Figure 2.**
Using the vertical positioning features for both Channel 1 and Channel 2, position the two sinewaves so that they can be visually compared for a shift in phase as illustrated in Figure 3. One word of caution here is to make sure that the output of the unit under test has the proper load. Without a load the characteristics of the circuit under test may change.

The amount of delay between the input and the output of the component under test can be read on the horizontal axis of the scope. Check the time base settings and make the measurement. Since the time base of most oscilloscopes is calibrated in seconds, milli-seconds, and micro-seconds, some very basic math may be required. To convert the seconds into degrees of shift, recall that one complete waveform represents 360 degrees. A half wave represents 180 degrees, and a quarter wave represents 90 degrees. If a particular output waveform is delayed one quarter of a waveform with respect to the input
Change the frequency of the audio signal generator and again make the measurement. Notice how some audio components have a continuously variable phase shift with respect to changes in frequency. For crossovers and equalizers, this is a fact of life.

**Single Channel Scopes**

If your oscilloscope is not dual channel device, you may test for phase shift by referring to the diagram in **Figure 4** and the display illustrated in **Figure 5**.

![Figure 4. Test diagram using a single channel oscilloscope.](image1)

![Figure 5. Waveforms for the test set-up shown in Figure 4.](image2)
Connect a pure audio sine wave from an audio signal generator to the input of the component to be tested. Adjust the amplitude of the test signal for the proper level at the input and the output of the component under test. The single probe of the oscilloscope should be connected to the input of the unit under test. The output of the component under test should then be connected to the external horizontal input of the oscilloscope.

The vertical dimension of the scope's display can be adjusted by moving the volts/division knob and the horizontal dimension can be adjusted by moving the seconds (or milliseconds) per division knob. The amount of phase shift between the two signals (input and output) can be measured by viewing the resulting waveform. See Figure 5. For our mathematically inclined readers, the formula for calculating the phase angle is shown in Figure 6.

Although this method of determining the phase shift between the input and the output of a device may be somewhat more complicated, it can be just as accurate and revealing.

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Figure 5. Waveforms for the test set-up shown in Figure 4.

Figure 6. Phase shift calculation.
Square Waves

While a sinewave may be useful in testing something such as an amplifier's performance, it only tells us what is happening at a particular frequency. We usually want to know about all the frequencies within the audio bandwidth ---- and sometimes both above and below the audio bandwidth.

A square wave signal can provide a quick check of an amplifier, or other component, at many frequencies simultaneously. A square wave of a given frequency contains a large number of odd harmonics (the fundamental frequency multiplied by 3, 5, 7, 9, etc.) of that frequency. If a 500 Hz square wave is applied to the input of a circuit, there will also be applied many odd harmonics of the fundamental 500 Hz: i.e. 1500 Hz, 2500 Hz, 3500 Hz, and so on.

Most solid-state amplifying devices are inherently non-linear. Many other audio components are also non-linear because their response to electrical signals is, well, non-linear. To design a perfect component that can provide all frequencies with equal amplification and can faithfully reproduce even the most complex waveform with no distortion and no phase shift is yet to be achieved.

Because a single square wave contains so many frequencies it can quickly reveal even the slightest of problems. Harmonic frequencies as high as the 21st harmonic (21 times the fundamental square wave frequency) must pass through the amplifier in order for the square wave to remain undistorted. Failure of an amplifier, or any other device, to perform in this manner is easily visible with an oscilloscope. Please refer to Figure 2 for the wiring diagram used when performing a square wave test on a component.
Testing With Square Waves

Refer to Figure 7 to view the diagram for square wave testing. The short rise time, which occurs at the beginning of the first half cycle of a square wave, is created by the in-phase sum of all the medium and high frequency sine wave components. Please refer to the waveform illustration in Figure 8. The same holds true for the rapid drop at the end of the first half cycle from the maximum amplitude to the minimum amplitude at the 180-degree or half cycle point.

Therefore, a theoretical reduction in amplitude of the high frequency components should produce a rounding of the square corners of the waveform at all four points of one square wave cycle. Figure 8 represents the response of a component with reduced high frequency amplitude and no phase shift.
When there is a high frequency loss plus a phase shift, the square wave looks like the drawing in Figure 9A. In the waveform at Figure 9B, we see an overshoot each time the wave changes direction (vertical amplitude). This indicates a high frequency boost in amplitude.

Figure 9A represents a high frequency loss with a phase shift. Figure 9B is the result of a high frequency boost.

Shown in Figure 10A is the result of a low frequency loss with no phase shift. The waveforms shown in Figure 10B and 10C demonstrate tilts in the square wave. These tilts or slopes are due to phase distortion. The influence of the square wave's third harmonic, either leading or lagging, the fundamental (10B leads, 10C lags) shows up as tilt. Very slight shifts in phase are easily detected by viewing a tilt in the square wave.

Figure 10A depicts a low frequency loss and no phase shift. Figure 10B and Figure 10C show the effects of low frequency phase shift. See Text.

When both a low frequency loss in amplitude and a phase shift occur, the resultant waveform is shown in Figure 11. Low frequency loss is often accompanied by a reactive component (transformer inductance, crossover network, etc.) causing a resultant phase shift. Figure 11 illustrates such a strong tilt.
Figure 11 is a combination of Figure 10A and Figure 10B. It is also true that a combining of Figure 10A and 10C and would appear as the waveform in Figure 11; however, the display would be angled in the opposite direction.

![Figure 11. Low frequency loss accompanied by phase shift.](image)

It is a fact of car audio life that various amplifiers, pre-amplifiers, crossovers, and cabling can cause the output of a square wave to differ from the original signal. The important waveforms previously discussed are summarized in Figure 12.
Figure 12. Copy and clip this chart for future reference.