Chapter 2 Objectives

At the conclusion of this chapter, the reader will be able to…

- Explain the difference between the *frequency* and *time* domains.
- Draw a diagram of a sine wave in both the frequency and time domains.
- Explain how a *complex* waveform (such as a square wave) looks in the frequency domain.
- Define the terms *fundamental* and *harmonic*.
- Define *noise*, and list at least two *internal* and two *external* noise sources.
- Calculate the *signal-to-noise ratio* if the signal and noise voltages (or powers) are known.
- Explain how the *noise Figure* is calculated for an amplifier.

Chapter 2: Signal Analysis

Many different kinds of signals are produced and used by electronic systems. A *signal* is an electrical current or voltage that either represents information (the *information signal*) or performs some useful function (the *carrier signal* in radio). Most signals are alternating-current sine waves, or as we shall see, combinations of sine waves. Signals can be viewed in either the *time* or *frequency* domains.

It's important for technicians to be able to accurately measure electrical signals. We can't see electrons flowing in circuits. Test equipment is our eyes. We will make almost all of our decisions based on what we read from test equipment -- so we must read it accurately!

Many systems have signals that are not wanted. The name for any unwanted signal is *noise*. Noise is produced both inside and outside of circuits. Radio receivers are especially sensitive to noise, as they must amplify extremely tiny signals from receiving antennas.

2-1 Two Domains

Most technicians are very familiar with the instrument of Figure 2-1 below. This is, of course, an oscilloscope. An oscilloscope has a trace that sweeps across the screen from left to right at a selected and calibrated rate. As the voltage of a waveform varies from positive to negative and back, a waveform results.

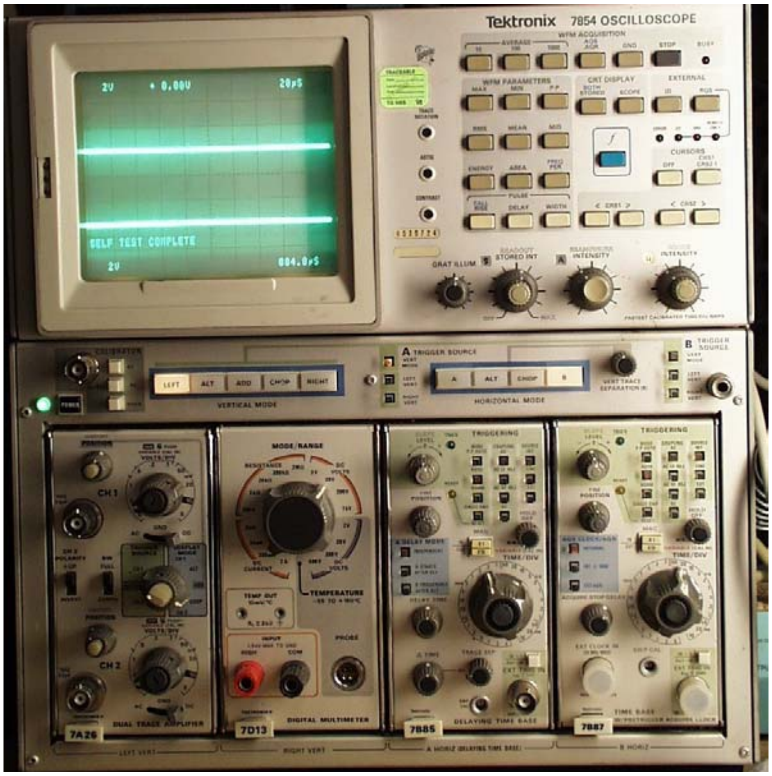

Figure 2-1: A Typical Oscilloscope

A scope works a lot like the popular "Etch-A-Sketch" toy. The *timebase* of a scope moves the dot (horizontal knob on the toy) across the face of the screen at a constant speed. The *vertical deflection* section of the scope moves the dot up and down (same as the vertical knob). Because a scope does this over and over at a rapid rate, our eyes fuse the images together into one continuous line.

We could say that a scope *draws a waveform as it happens*. In other words, an oscilloscope shows pictures of waveforms in the *time domain*. The horizontal axis on an oscilloscope is in units of *time*, in *seconds*.

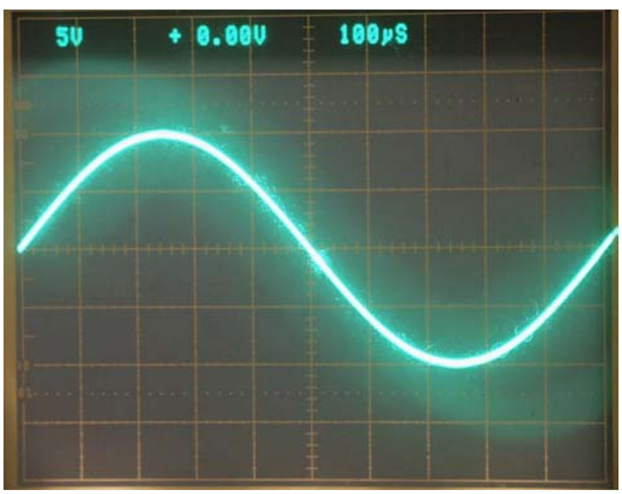

Figure 2-2: Reading the Oscilloscope

Example 2-1

What is the *frequency*, *peak voltage, peak-to-peak voltage*, and *RMS (root mean square or effective) voltage* of the waveform pictured above in Figure 2-2, if the scope settings are as follows:
Horizontal, 100 μS per division.
Vertical, 5 V per division.
If this voltage is being measured across a 50 Ω resistor, what power will result?

Solution:
The frequency can be calculated if the *period* (T) is known:

$$f = \frac{1}{T} = \frac{1}{1ms} = \underline{\underline{1000Hz}} = \underline{\underline{1kHz}}$$

The peak voltage can be calculated by observing that the trace goes two grid squares above (or below) the baseline at the peak of each cycle:

$$Vp = (2divisions)(5V / division) = \underline{\underline{10Vp}}$$

The peak-to-peak voltage is the total height of the waveform:

$$Vpp = (4divisions)(5V / division) = \underline{\underline{20Vpp}}$$

The *RMS* or *effective* value of the waveform can be calculated since the shape is a sine wave:

$$Vrms = \frac{Vp}{\sqrt{2}} \approx 0.707Vp \approx (0.707)(10V) \approx \underline{\underline{7.07V}}$$

Note that many technicians even use 0.7 (rather than 0.707) as an "approximate" factor for calculating an RMS voltage. When reading from an oscilloscope, this is quite valid, since there may be as much as 5% measurement error just from "eyeballing" the display!

Caution: The formula above for RMS voltage is only valid for a sine wave!

The *power* can be calculated using Ohm's law:

$$P = \frac{V^2}{R} = \frac{7.07V^2}{50\Omega} = \underline{\underline{1W}}$$

Caution: To calculate power, an RMS voltage must be used!
(*A Shortcut for Calculating Power)*
If you know the peak-to-peak reading of a *sine wave* waveform, you can also calculate power by using:

$$P = \frac{Vpp^2}{8R} = \frac{20Vpp^2}{(8)(50\Omega)} = \underline{\underline{1\,Watt}}$$

Some techs like this formula, since it avoids the need to convert to RMS first. However, it can only be used for sine waves!

The Frequency Domain

There's another way of looking at electrical signals. An oscilloscope shows signals in the *time domain*, which is fine for many types of measurements. However, many times we're much more interested in what *frequency* or *frequencies* a waveform might contain. An instrument that shows the *frequency domain content* of a signal is called a *spectrum analyzer*.

Being able to measure the *frequency content* of signals is very useful to us for several reasons. You'll recall that one of a radio receiver's tasks is to separate the one desired carrier signal from all the others on the air. This is only possible because each radio transmitter uses a different frequency. *The frequency content of a signal therefore determines whether or not it will be reproduced in a receiver!*

Second, there is only a finite amount of space on the bands in which to operate radio transmitters. Transmitters use up this space in the same way that the parking lot at the local mall fills up with cars. Two radio stations can't share the same frequency, or they'll interfere with each other. *By looking at a radio transmitter's signals in the frequency domain, we can determine its bandwidth. Bandwidth* is the amount of "frequency space" taken up by a signal. It's very much like the width of a motorcycle, car, or truck to be parked in a stall.

Last, we can often tell much more about the quality of a signal by looking at it in the frequency domain. Defects or *distortions* of a waveform are often hard to spot on a scope, especially if the waveform is a sine wave. As you'll see, any distortion in a sine wave will cause new frequencies called *harmonics* to appear. *Distortion of a sine wave (such as an RF carrier) is often much easier to spot on a spectrum analyzer than a scope.*

The Frequency Domain is Nothing New!

Long before the dawn of electronics, humans employed the concept of the frequency domain. Take a look at the notation of Figure 2-3:

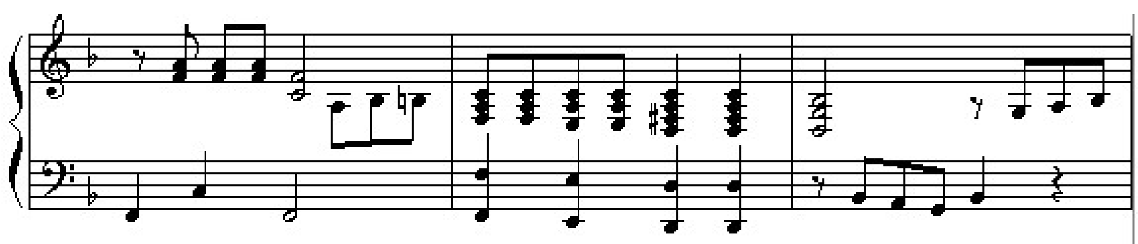

Figure 2-3: Old time frequency domain notation

The music notation of course refers to both *pitch* and *duration* for each note to be played. *Pitch* is really the listener's mental perception of the *frequency* of the note being played. Raise the frequency, and the listener hears a higher pitch. The vertical position of each note gives a precise indication of its pitch. Pitch is related to frequency. Therefore, we're looking at a *frequency-domain* picture here! (There is also time-domain information, because each different type of note plays for a unique time interval.)

The Spectrogram

A *spectrogram* is a graph showing the frequency-domain information of a signal. If the 1 kHz signal of Example 2-1 is perfect, it will look like Figure 2-4 on a spectrogram.

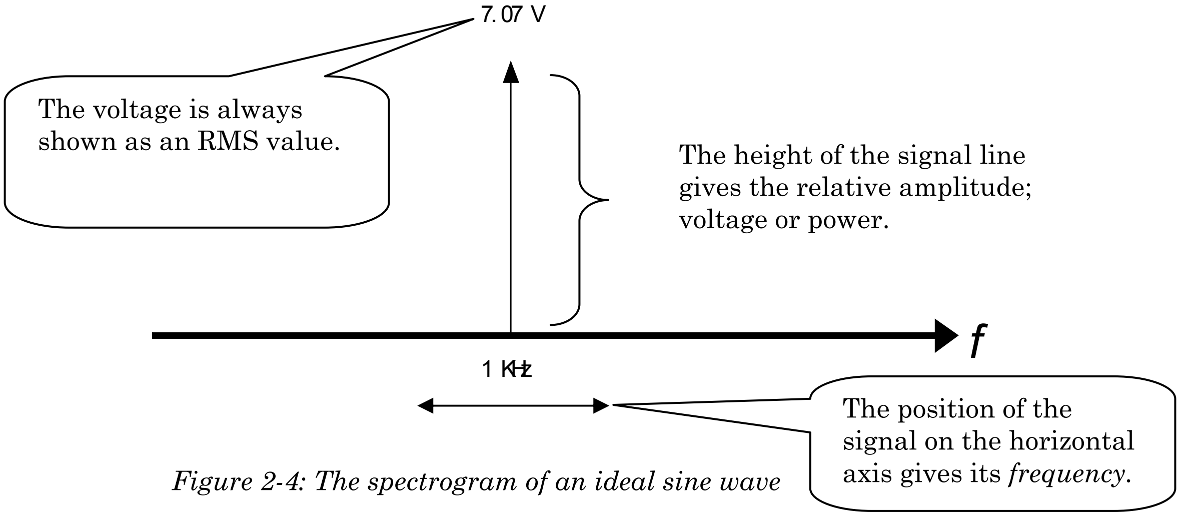

Figure 2-4: The spectrogram of an ideal sine wave

This picture is troubling; it doesn't look *anything* like a sine wave! It's just like the music above; the notation on paper doesn't *look or sound* anything like the music when it's being played, yet it still represents it. Figure 2-5 is the sine wave of Figure 2-1 displayed on a spectrum analyzer display.

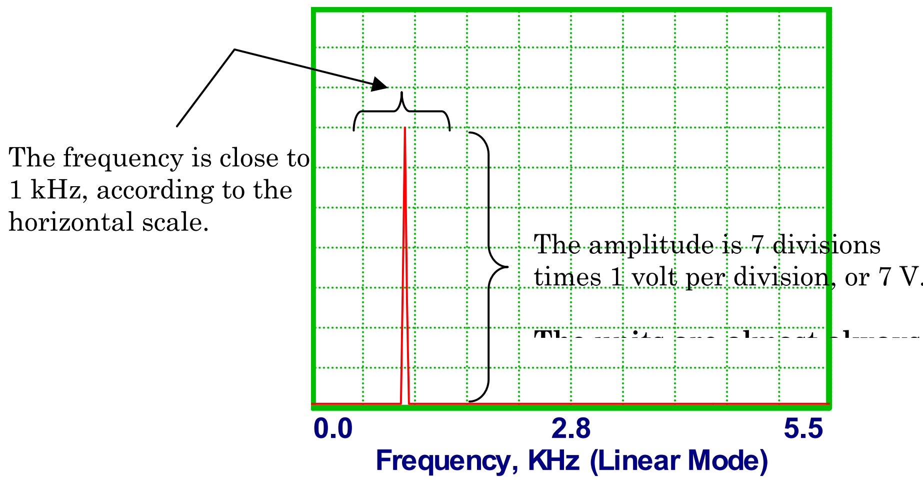

Figure 2-5: Spectrum analyzer display of the pure sine wave
(Vertical setting, 1 V/division)

The sine wave is sometimes referred to as the only "pure" waveform, because a sine wave has only <u>one</u> frequency when it is viewed in the frequency domain.

Example 2-2

What type of waveform is being displayed below in Figure 2-6? What is its *frequency*, *RMS voltage*, and *peak voltage?*

Solution:
The waveform displayed is another *sine wave.* A pure sine wave always shows up as one "line" on a spectrum analyzer display. By reading its position on the horizontal axis, we can see that the frequency is 2.8 kHz. The line is 4 units high, so its voltage is:

$$V = (4 divisions)(1V / division) = \underline{\underline{4V}}$$

This is an RMS voltage. Therefore:

$$Vp = Vrms\sqrt{2} \approx \frac{Vrms}{0.707} \approx \underline{\underline{5.66Vp}}$$

Note that dividing by 0.707 is the same thing as multiplying by 1.41, which is approximately the square root of 2.

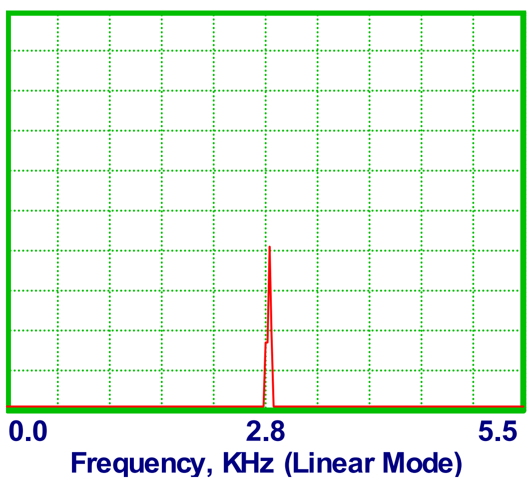

Figure 2-6: A spectrogram display
(Vertical setting, 1 V/division)

Section Checkpoint

2-1 What is a *signal?*
2-2 What are the two *domains* for viewing signals?
2-3 What instrument displays signals in the time domain? What are the units of its horizontal axis?
2-4 What is a spectrogram?
2-5 Give three reasons why technicians need to understand the frequency domain.
2-6 What instrument shows frequency domain information? What are the units on its horizontal axis?
2-7 What does a pure sine wave look like on a spectrogram?