Lab 4: Oscilloscope and Function Generator Operation

Reference reading in text: Chapter 2, sections 2.1, 2.2, 2.3, 2.4, and 2.5.

This exercise will take two lab periods.

Goals:

1. To become familiar with the operation of the lab function generators (Wavetek model FG3B or BK Precision model 4011A, and Instek model AFG-2112) and digital storage oscilloscopes (Tektronix model TDS 2012B).

2. To become familiar with various ways of characterizing signal waveforms: rms vs. peak-to-peak amplitude, period vs. frequency content of periodic signals, etc.

3. To optimize data collection techniques for measuring the frequency response of circuits.

4. To become acquainted with frequency response or Bode plots.

5. To become acquainted with the terminology of decibels as used in standard electronic (and other) applications.

4.1 Introduction

The Wavetek, BK Precision, and GW Instek function generators available in our lab generate a variety of periodic waveforms of varying periods and amplitudes. The Tektronix TDS 2012B digital storage oscilloscopes provide a means of observing these and other periodic waveforms. The 'scopes' do this by digitally recording the time-dependent voltage of the waveform and displaying the result on an LCD screen such that the horizontal axis is (proportional to) time and the vertical axis is (proportional to) the voltage being measured. You can directly select the scale factors that relate distances along the axes to voltage and time. The trickier part is to arrange to have the waveform recording, or 'sweep' repeated in such a way as to generate the same picture of the waveform on each successive sweep – otherwise, you see a confusing jumble on the screen. As described below, the sweep can be "triggered" in several different ways to produce a stable display.

This lab exercise is designed to help you gain familiarity with the function generators and the Tektronix oscilloscope you will be using throughout the semester. Large portions of it follow a similar exercise developed by Curtis Meyer, our textbook author; however, that exercise has been modified to accommodate our signal generating devices, which differ considerably from the ones described in Meyer's exercise, and because there is considerable interaction between the signal sources and the oscilloscope.

4.1.1a Using the Wavetek and BK Precision function generators

The Wavetek FG3B and BK Precision 4011A function generators are similar in many respects, but differ in a few minor ways. Both generate a periodic output waveform which, expressed graphically as a voltage vs. (or as a function of) time has a shape which can be selected to be rectangular, triangular, or sinusoidal. The period, T (or frequency, $=1/\mathrm{T}$), of the waveform can be adjusted over a broad range of values varying from less than a microsecond (corresponding to $f\sim$ a few megahertz or MHz) to many tens of seconds (corresponding to $f\sim 0.01\ \mathrm{Hz}$). The amplitude of the waveform varies from a few tens of millivolts (mV) to about 20 volts peak-to-peak (i.e. from the minimum value to the maximum value of signal voltage). In addition, it is possible to superimpose the periodic waveform on a steady-state DC level analogous to adding a constant voltage to the waveform. While the signal generators mentioned in the Meyer lab exercise digitally synthesize output waveforms, our generators are an older design and use an analog technique. The Instek generator we'll study later is a digital synthesis generator.

The signal generated by the function generator appears at the BNC connector labeled OUTPUT. An auxillary output also appears at the TTL/CMOS BNC connector, but this is a digital signal that is either a high level (typically about 3 to 5 V) or a low level (usually zero V) that is synchronized with the generated signal and is not of immediate interest to us for this exercise.

The controls of both function generators are organized similarly. There is a prominent LED display in the upper left corner of the front panel which displays the generated frequency. This display is actually the indicator for a frequency counter (which counts cycles of a signal); on the BK4011A the signal is that produced by the generator, but on the Wavetek FG3B, the counter can be connected to either the generator or to an external signal source (connected to the EXT CNTR BNC connector). In this case, the source of the frequency reading is determined by the push-button labeled CNTR INP. When the button is in the 'out' position, the counter reads the internal generator; when it is in the 'in' position, it reads the frequency of the signal connected to CNTR INP.

There is a row of push buttons along the upper edge of the front panel; the left-most of these buttons turns the power on and off (push once and it's on; push again and it's off – this type of button is called a 'toggle').

Three push buttons in the upper right corner of the front panel determine the waveform to be generated: rectangular (aka 'square'), triangular, or sinusoidal (aka 'sine'). If these are behaving properly, it should only be possible to push one of them at a time – pushing one in cancels the others – this kind of button-array is sometimes referred to as an array of 'radio buttons.'

Normally, the repetition frequency of the generator is determined by several controls: a row of push buttons (radio buttons) along the top edge of the panel determines the range (essentially the power of ten) of the signal repetition frequency. On the Wavetek, fine control of the frequency is achieved by a knob located at the lower left of the panel. On the BK generator, there are two knobs – one for coarse control, and one for fine control. As discussed in section 2.8 (Fourier Analysis) of the text, a non-sinusoidal signal (such as a 'square wave' or a 'triangle wave') does not have a unique single frequency. This is why 'repetition frequency' was used in the earlier part of this paragraph. This frequency is the inverse of the repetition period of the signal, which *can* be uniquely defined.

We probably will not use an alternate method for controlling the frequency that uses a voltage applied to the VCF/MOD IN connector on the Wavetek; the instrument manual should be read closely before using this input (notice the warning icon next to it). Using this input, one can generate a frequency that is proportional to the applied voltage and within the range selected by the range pushbuttons. Four additional knobs, under the button row and above the row of BNC connectors, control some aspect of the signal that appears at the OUTPUT connector. Although these have very similar functions on the Wavetek and BK generators, the details differ and will be described separately.

On the Wavetek FG3B, these four controls are labeled 'DUTY/INV', 'TTL/CMOS', 'DC OFFSET/ADJ', and 'AMPLITUDE/-20dB ATTN'. Each of these labels indicate control features that vary depending on whether the knob is pushed in or pulled out (there are color-coded front panel icons, and the labels are color coded, to clarify this). For example, the AMPLITUDE knob controls the amplitude of the signal whether it is pushed in or pulled out; however, when pulled out, the voltage amplitude is reduced by an (additional) factor of 10 (corresponding to a 'level' that is 20 decibels (dB) lower). Similarly, the DUTY knob controls the so-called 'duty cycle' of the signal (unless in the fully counterclockwise or CCW position, labeled 'CAL' for CALibrated) in either the 'in' or 'out' position, but in the 'out' position, the signal is INVerted. The TTL/CMOS knob controls the production of a TTL-compatible digital signal at the TTL/CMOS BNC connector when in the 'in' position; in the 'out' position, it controls the level of the high state of a digital signal meeting CMOS specifications. (CMOS stands for Complementary Metal Oxide Semiconductor and is an integrated circuit technology widely used in digital integrated circuits.) Finally, the DC OFFSET/ADJ knob forces the signal to vary symmetrically about zero volts (as a pure sine function varies above and below zero) in the 'in' position but permits adjustment of a variable DC (i.e. time-independent) voltage (or OFFSET) which can be superimposed on the time-varying part of the signal when this control is in the 'out' position.

On the BK generator there are four knobs having functions similar to those described for the Wavetek. These are, from left to right, labeled 'DUTY CYCLE', 'CMOS LEVEL', 'DC OFFSET', and 'OUTPUT LEVEL'. To the left of this bank of knobs, is a corresponding bank of four push buttons, which in effect turn the ability of the knobs to function on and off, with one exception (see the label icon just to the left of the buttons). The exception is that the OUTPUT LEVEL knob is functional independent of the corresponding button position; however, when the button is 'in' the output amplitude is reduced by 20 dB (i.e. by a factor of ten in voltage).

The LED frequency meter display varies between the two generators as well. There are individual LED indicators that specify the units of the display measurement – kHz or MHz in the case of the Wavetek, Hz or kHz in the case of the BK – note that the Wavetek reading always includes a decimal point whereas the BK sometimes does not, or rather has an implicit decimal point at the far right. Note also that both generators have an LED indicator that is labeled GATE and which flashes on and off. When the GATE LED is on, the frequency counter is actively counting the cycles of the signal for a new measurement, and the displayed measurement is the result of the previous gate count. Since the gate period can be as long as 1 second, the display update can be slow, and this can sometimes make adjusting the frequency to a desired value a bit awkward at times.

4.4.4b Using the GW Instek model AFG-2112 arbitrary function generator

While the AFG-2112 is capable of producing an arbitrary periodic waveform, it is somewhat involved to define that arbitrary waveform, and we will ordinarily use it with predefined waveforms, as a sine, square, or triangle, or pulse generator, much like the other generators in the lab. The real advantages of this unit are its wider range of frequencies (up to 12 MHz), the ability to control its operation over a USB cable using a programming environment like LabVIEW (we may use this ability in a later lab exercise), and the convenience of the push-button front panel and display. The push-button front panel, however, can also be a disadvantage at times. Sometimes it's easier to "twiddle" or "twirl" an analog knob.

Pages 10 to 29 of the AFG-2112 operation manual are provided with this handout, and the full manual is posted on the Blackboard site.

At a minimum, you should explore (once you are using the oscilloscope in the next section) setting the frequency, the waveform (sine, square, and triangle), the duty cycle of the waveform, and the amplitude of the output, so that you are familiar with the use of the front panel controls.

4.1.2 Using the Tektronix TDS 2012B Oscilloscope

The user manual for your oscilloscope (‘scope’) is available in the lab as a hard copy manual and on the Blackboard course site in the Course Materials/Manuals folder. You might want to download a copy of the manual to your lab computer if someone already hasn’t done so. To make it easy for others to find, you might consider putting the download copy in a desktop folder named “Manuals”. Pages 1-36 (1-30 in the pdf manuals) cover the basic operational details. The chapter on Application Examples shows how to do various types of measurements, several of which are similar to the laboratory exercises. Most features are documented in the instructions under the ‘HELP’ button, which you can search via the index or by simply pressing ‘HELP’ after pressing a button about which you would like to learn. Below are a few notes to help orient you.

The TDS 2012B is much more than a traditional oscilloscope. The latter would simply show a waveform as it occurs in a circuit. The TDS 2012B is a digital storage scope: it digitizes the waveform and can store a single waveform so that you can analyze it after it occurs. Like a ‘storage scope’, it will display on its screen indefinitely the last trace for which it was triggered. (Warning: this means you may be fooled into thinking the scope is seeing something when it is really displaying an old waveform! In particular, if you press the RUN/STOP button, the scope won’t run normally until you press it again. STOP lights up in red at the top of the screen to warn you if the scope has been stopped.) Of course, the scope can also perform the functions of a traditional real-time oscilloscope. The scope can save waveforms to flash drives so you can do further analysis on a computer. The lab computers also have software that can be used to acquire a screen shot of the oscilloscope’s display and/or to download a complete copy of the display memory of the oscilloscope (via a USB cable). The scope performs a variety of analyses of waveforms (amplitude, period, . . .) and can do so in a continuous way, constantly updating the results. You will probably use this capability extensively. Some measurements (in particular, comparisons of different waveforms) require you to manipulate the cursors and read off values of various quantities.

The controls for the scope are a combination of front panel knobs, buttons, and menus displayed on the screen. Getting familiar with these controls is one of the main points of this lab exercise.

• You select input channel 1 or 2 with the two buttons so-labeled (yellow and blue). After pressing one of these, you can change the settings for the corresponding channel. (Each channel has dedicated control knobs for vertical scale and vertical position, regardless whether that channel is selected or not.) Note that pressing a channel menu button when that channel is already selected turns off the display of that channel. Pressing again turns it back on.

• VERTICAL section: The scale of the vertical axis is controlled by the VOLTS/DIV knob. The calibration, in volts per large grid unit, is displayed on the screen. You can move the zero volt point with the “position” knob. Notice that the vertical scale for each channel is *displayed on your scope screen* (in volts per division, where a division is defined by the large tick marks rather than the smaller ones).

• HORIZONTAL section: The scale of the horizontal axis (time) is controlled by the SEC/DIV knob. The calibration, in time per large grid unit, is displayed on the screen. You can move the track horizontally with the “position” knob. Notice the scope screen *always displays the time scale* (in time per division).

• TRIGGER section: The triggering of the sweep is controlled by this section. When trying to visualize a time-varying but periodic voltage (e.g. a sine wave), the scope needs to start its sweep at the same point on the waveform each time – otherwise, you will just see a jumble of lines on the screen. By starting at the same point, you get a stable pattern. The LEVEL button controls the voltage level at which the sweep will begin. Note that, if this level is outside the range over which your input signal varies, the scope never triggers! (Or, in AUTO trigger mode, it will trigger randomly!) Several other controls are on the Trigger menu screen, accessed by pressing the Menu button. The SLOPE control determines whether the sweep begins when the input crosses the trigger level while rising (increasing in voltage) or while falling (decreasing in voltage). The SOURCE control decides whether channel 1 or 2 is tested for the trigger condition. (Or whether the EXT TRIG input, or the power line is used to trigger the scope.) Notice that the scope screen (on the bottom right) *shows which channel it is triggering on*, whether it is looking for a rising or falling slope, and at what level it will trigger. (It also displays the frequency at which it is being triggered.)

• In the Vertical, Horizontal and Trigger and sections are MENU buttons that bring up on-screen displays with expanded sets of options.

• One important button is the AUTOSET located on the right side of the top row. This generally sets the scope parameters so that the input signal will appear on the screen. When all else fails, try this! However, the settings that result from the AUTOSET function are usually not the best for a particular measurement, they are just close. You can usually do better by tweaking the settings a bit.

• The ACQUIRE button allows you to select ’Sample’ mode (which is typically used) or ’Average’ mode which can be much more confusing, but is useful for cleaning-up a repetitive signal which has non-repetitive noise on it.

• The MEASURE button in the top row allows you to set up a variety of types of automatic measurements. Some measurements you will want to use include: the Frequency and RMS (which is usually more reliable than peak-to-peak which is more noise sensitive).
• The SAVE/RECALL and Print buttons allow you to save (to memories in the scope or to a flash drive) all the settings of the scope and/or a screen image and/or the measured values. If you save the settings, you can then re-adjust the scope for a different job and then return to what you were doing. (Starting next lab, you will use it to save the measured values of the waveform you are looking at. You mustn’t confuse these two different ways of using SAVE!) There are also two memories (REFERENCE A and B) which can save a waveform so you can display it on the screen to compare to what you see later.
• The CURSOR button turns on vertical or horizontal markers (with their exact positions indicated). These are sometimes useful for making measurements ’by hand’ when the automated measurements are not trustworthy. It’s always good to check occasionally to make sure the scope isn’t giving nonsensical values with its automated measurements.
• The DEFAULT SETUP button will turn off any ’crazy’ modes to which the scope may be set (perhaps by the last people who used it).

The scope probes allow you to test the voltage at various points in a circuit. Notice that some of the probes have X1 and X10 settings selected by a switch on the probe body. Be careful to not use the X10 setting unless you also set the scope to multiply its input by 10 by “telling it” about using the probe, or you will be off by a factor of 10 in the measurements you make.

4.2 Procedure

4.2a. Recording waveforms using oscilloscope Take notes of what you do and what you see/measure with the scope as you do this. Visualize each type of waveform from each of the function generators at your workstation on the oscilloscope. Adjust frequency, amplitude, and DC offsets and observe the resultant waveforms. Be sure to try the different input coupling settings (DC or AC set using the channel menu buttons) on the scope as you change things like the DC offset. (*It will be important to*

keep track of the setting of the coupling, especially when measuring at low frequencies or for signals which don't average to zero.
Usually you want the coupling set to 'DC'... except when you don't.) Try (using the Trigger menu) triggering internally and externally using the TTL output from the function generator, connected to the EXT TRIG input of the scope. Try saving you scope settings, messing things up and then recalling the saved settings. If you can observe noise (fuzziness) on a signal, you probably can't trust the amplitude readings of the MEASURE function of the scopes. Often the most accurate measure of size of a signal is the one found "by hand" by positioning the scope's horizontal cursors where you best estimate the top and bottom of the signal (sans noise) to be. You can also tell the scope to make automated measurements of Pk-Pk (Peak-to-peak size) and RMS. Try all these methods and compare the results.

Capture sinewaves at 10 Hz and 10 MHz in computer.

Note: You will always get the best accuracy from the scope if the vertical and horizontal scales are adjusted so one or two cycles of the waveform fills most of the screen! In general, don't forget to adjust your scope whenever the waveform starts to look small.

Compare all of these measurements to your "hand" measurements for sine, square, and triangle waves. Which automated measurements are the most accurate? What does the RMS voltage setting mean when applied to sine, square or triangle waves? Compare calculated RMS values to the waveforms you observe.

4.2b. Measuring frequency response of a voltage divider. Build a voltage divider with R1 = 100 k and R2 = 2.2 k. Measure the exact values of your two resistors so that you will be able to make accurate predictions. Now set your function generator to produce a sine-wave output with a frequency in the range 100 kHz to 1000 kHz. Connect the output of the generator both across your entire divider and to channel one of your scope, using a BNC "Tee". Set the output voltage to be 0.75 V peak-to-peak, using the scope, set to 1V/division.

Measure both the RMS and Peak-to-Peak voltage of the output of the generator, using the MEASURE function. Are these consistent with each other? Also measure the peak-to-peak voltage by "hand" (using the cursors) and compare to the previous measurements. Then adjust the scope to have 0.1 V/division and repeat your measurements. Discuss.

Connect channel two of the scope across R2. Based on what you measured earlier, predict what you should measure on channel 2.

Make the measurements and compare them with your predictions. Which method is the most accurate? What problems do you encounter in your measurements?

4.2c. Frequency response of the voltage divider circuit. Select a 10Vpp sine wave with zero offset voltage (check with the scope to be sure this is what you've got). Measure the amplitude of the voltage at the output of the divider as a function of frequency over the range 1Hz to 2MHz. Take data so that when you make a plot with a logarithmic frequency scale the points are roughly equally spaced (use a 1-2-3-5-10-20-30-50, etc. sequence of frequencies). To verify that the frequency dependence you observe is not a result of a variation in output of the function generator or sensitivity of the scope, use both scope channels with one directly connected to the generator output. Be sure to use DC coupling of the input signal on both channels. Make a Bode plot of the measured frequency response. This is a log-log plot of the relative gain ($V_{\text{out}}(f)/V_{\text{ref}}$)vs. frequency, where V_{ref} is a chosen reference voltage. In this case, use $20\ \log_{10}(V(f)/V(1000\ \text{Hz}))$ for the vertical axis and $\log_{10}(f)$ for the horizontal axis. The vertical axis is referred to as a "decibel" or "dB" scale – it is a standard in electronics.

A 'bel' (named for Alexander Graham Bell) is a factor of 10 change in power. This is commonly used to measure quantities such as amplification and attenuation. For example, the amplification, in bels, is $A_{\text{bel}} = \log_{10}(P_{\text{out}}/P_{\text{in}})$. Then, since $P \propto V^2$ for resistive loads, we have $A_{\text{bel}} = \log_{10}((V_{\text{out}}/V_{\text{in}})^2) = 2 \log_{10}(V_{\text{out}}/V_{\text{in}})$. Then, a decibel is a tenth of a bel, so the numerical value of the amplification in decibels is ten times more than it is in bels, so $A_{\text{decibel}} = A_{\text{dB}} = 20\log_{10}(V_{\text{out}}/V_{\text{in}})$.

On a frequency response plot, the "characteristic frequency", also sometimes called the "break frequency", is that frequency at which the response falls to $1/\sqrt{2}$ (about 0.71) of its nominal or reference value. Remembering that the power delivered to a resistor goes like V^2, this point corresponds to where the power delivered is reduced to ½ that at the reference frequency. Since $\log_{10}(0.707) \approx -0.15$, the vertical scale in the Bode plot is down by 3 dB ($= 20\log_{10}(0.707)$) and this frequency is referred to as a "-3 dB point". Note the -3 dB frequency on your plot. Also (if you have sufficient data range) determine the rate of fall-off of the frequency response in dB/decade (this is called the "roll-off" rate; a decade corresponds to an increase or decrease in frequency by a factor of 10).

If the response falls at a rate of α dB/decade, what does this imply about the functional form of (f)? Is the high frequency behavior what you expect for a device made entirely of resistors? Can you explain what might be happening?

4.2d. AC vs. DC coupling into the oscilloscope. When an input channel is set to "AC coupling", an input blocking capacitor is put in series between the input terminal and the scope's amplifier. This capacitor will reduce the scope's response at low frequency (we will consider this effect quantitatively in a later lab); the input gain is zero at zero frequency or DC. This blocking function is convenient when you want to examine a small AC signal that rides on top of a larger DC offset. By putting the same signal into both channels of the scope and coupling one AC and one DC, measure the frequency response of the AC coupled channel of the scope. At high enough frequency, both channels should yield the same trace – you can overlap the traces so you can see when they start to deviate. Starting at a "high" frequency, measure the frequency response of the two channels and make a Bode plot using the ratios of the two measured signals. Determine the -3 dB point and the roll-off rate. You will need to remain aware of these results when you do measurements throughout the rest of the semester. You'll have to choose whether to use AC or DC coupling for each measurement.