The Oscilloscope and Function Generator

Required Equipment

1. A Digital Phosphor Oscilloscope (Tektronix TDS3024B)
2. Function Generator (Agilent 3322A)
3. DC Power Supply
4. Potentiometer
5. Protoboard and various resistors
6. TDS3000 Series Digital Phosphor Oscilloscopes Reference Manual

Introduction

The aim of this lab is to familiarize you with the TDS3024B 200-MHz oscilloscope that you will use repeatedly during the course. While earlier (analog) oscilloscopes employed beams of electrons in cathode ray tubes to "paint" voltage waveforms, this Digital Phosphor Oscilloscope (DPO) uses fast Analog to Digital Converters (ADC's) to take samples of the voltage as a function of time, store it in memory and then display it on a color LCD screen. This fully digital design results in a lighter instrument with expanded capabilities due to its fully digital circuitry.

Oscilloscope Overall

Each DPO has its own Internet Protocol (IP) address.   That address is taped to the DPO's top. Copy it into your lab notebook, as you will need it later in this lab as well as in others.

There is a Reference Manual that you can use to become familiar with the instrument's features.

- *Quick Menu.* Simple measurements of waveforms can be performed with this feature, without resort to more advanced features
- *Acquire Menu.* This menu controls the data acquisition features of the DPO, that are activated by pushing the Run/Stop button. The status of the acquisition is indicated on the upper left hand corner of the screen.
- *Cursor Menu.* This gives you control over both horizontal and vertical cursors used in making timing and voltage measurements.
- *Display Menu.* The features are self-explanatory.
- *Measure Menu.* Numerical values of the period, frequency and amplitude of the input signal are given on the screen. Also obtainable are rise or fall times, defined as the times for the signal to change between 10% and 90% of its maximum range, in upward or downward direction.
- *Trigger Menu.* On an analog oscilloscope, the trigger initiates the sweep of the trace from left to right, starting at a particular user-selected value of the input signal. On a digital oscilloscope the "trigger" simulates a sweep. The trigger can be assigned to a channel and can be AC coupled or DC coupled.

Setting the Function Generator

Turn on the function generator and the 'scope and attach the function generator output to the CH1 input of the 'scope using a BNC Tee and a BNC cable.

Set the function generator to produce a 1-kHz sine wave with 5 volts peak to peak. Remember to turn the output ON. (Be aware that the function generator has an output resistance of 50 ohms.)

Push AUTOSET on the 'scope to display the sine wave on the screen.

Problem: As it is turned on, the function generator voltage display is based on the assumption that the generator will be loaded by an external device with a 50-ohm input resistance. Because the output resistance is also 50 ohms, the voltage display on the function generator shows half of the true output voltage as seen by a high-impedance device such as a digital voltmeter or 'scope. (To read more about this curious state of affairs consult the Appendix.)

Your first task is to get the function generator to display the correct output voltage. Press "Utility" then "Output setup." Then set Load to "High Z" and press "Done." You will see that the voltage display now reads 10 volts peak-to-peak while the output voltage has not changed at all – as evident from the unchanged trace on the 'scope. In this operation you have told the function generator to expect to look into a high impedance load.

Getting Familiar with the Oscilloscope

Push AUTOSET on the 'scope if needed to display the sine waveform.

Push OFF (VERTICAL column) to turn off the trace. Then bring it back with CH1 yellow button.

Note the x-axis calibration 400 μs/div. Change the scale with the knob (HORIZONTAL column).

Note the y-axis calibration 2 v/div. Change the scale with the knob (VERTICAL column), e.g. 1 v/div. or 5 v/div. Change the y position.

Go to Trigger Menu and see Trigger Source on the right side of the screen.
Set the trigger source to "CH2" and see the trace roll.

With the trace still rolling, go to Acquire Menu and see options.
Select "Average 512" and see the trace shrink because of averaging all those out-of-phase traces.
Remove the averaging function by pushing "Sample" to return to a normal display.

Return to Trigger Menu and set the trigger source back to "CH1."

Press the CURSOR button to bring up the cursor options on the side.
Select "H Bars" to get horizontal cursor bars. You will be measuring voltages.

One bar is solid and you can adjust it with the unmarked knob to match the waveform peak.
The other bar is dashed, but you can make it solid and adjustable by pushing the SELECT button. Use the knob to adjust the cursor to measure the valley voltage.

From the side options, select "V Bars" to get vertical cursor bars. Again, you can select and adjust bars. You will be measuring time.

Set the two bars to be three periods apart. Use negative-going zero crossings.
You expect the "Delta" measurement on the screen to indicate 3 ms.

You can identify the zeros by the numerical voltage display on the screen. Observe that the reading jumps around preventing you from finding the zeros accurately.
Solve that problem by going to the Acquire Menu and selecting "Average 512." Return to the Cursor menu and observe that the voltage reading is much more stable.

Return to the Acquire Menu and select SAMPLE for a normal display.

Go to the QUICK MENU (upper right) and note the DC and AC coupling options. There are varieties of coupling, and the final option is to disconnect the input from the 'scope and short the 'scope inputs to ground.

Lab 2 begins

Basic functions

0A. [1 p] Record the IP address in your notebook.

Go to the DISPLAY menu (upper middle)

0B: [3 p] Using the Tee, connect both CH1 and CH 2 to the function generator and select "Triggered XY" mode. Draw the pattern in your lab notebook

Go to the MEASURE menu (upper middle)

0C: [3 p] Measure the frequency and period. Are they consistent? Do they agree with the setting of the function generator?

0D: [4 p] Calculate the expected rise time. It is the time for the steepest 80% of the rise to occur. To do this you find t1 and t2, where

$$-4.0 = 5 \sin(2\pi\ 1000\ t1 + \phi)$$
$$+4.0 = 5 \sin(2\pi\ 1000\ t2 + \phi)$$

Then t2-t1 is the rise time. Record it in your lab notebook

0E: [4 p] Go to the measurement menu and cycle among the options to bring up "Rise Time." Read the rise time from the 'scope display. Compare the calculated rise time with the measured value.

0F. [3 p] Recall your experience triggering on the wrong channel. Describe.

DC Offset

1A. [4 p] Use the offset function on the function generator to add a voltage to the sine wave. An example is shown in Fig. 1. Describe the effect of AC vs DC coupling. Write an equation to describe the signal shown in Fig. 1.

1B. [3 p] Use the 'scope to measure the offset that you have set on the function generator. Does it agree with the function generator display? Write an equation to describe your own offset signal.
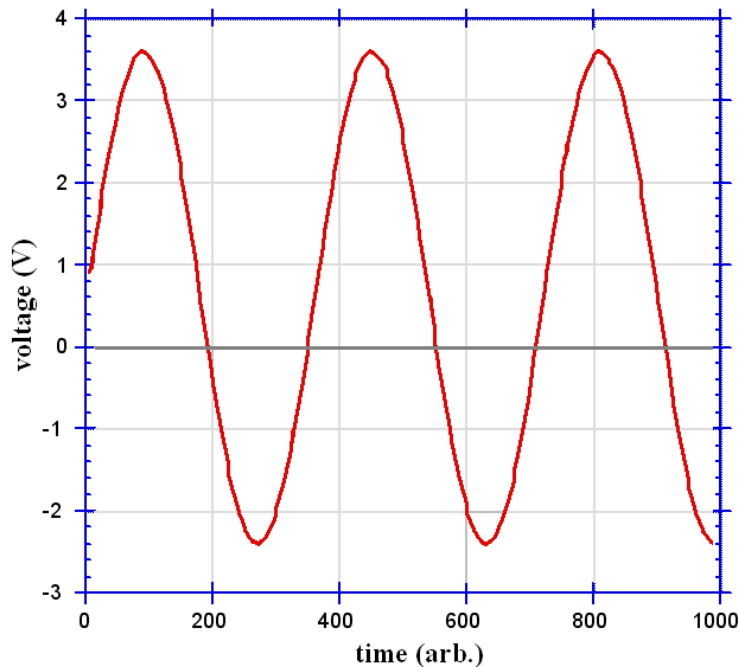
**Figure 1: A 3-V sine wave (6 V peak-to-peak) with 0.6 V DC offset.**

Comparing input and output

For this, and subsequent measurements, you will use the 'scope probes. They make the input impedance of the 'scope even higher.

2A. [4 p] Use clip leads and a potentiometer to construct the AC level control circuit shown in Fig. 2. The input to this circuit is the output of the function generator. Measure it with CH1. The output of this circuit is the signal on the wiper arm of the potentiometer (center terminal on the pot). Measure it with CH2, as shown in Fig. 2. Draw the circuit in your notebook.

2B. [4 p] Adjust the potentiometer so that the output amplitude is about half the input, and **print the display showing input and output and paste it into your lab notebook.** This circuit is the essence of an audio volume control.

The DPO display can be printed to the color printer in the lab by opening a Web browser and entering the DPO's IP address. You should see the 'scope display on the computer monitor screen. Then print the page. **When printing, select "print preview" from your browser's printing options.**
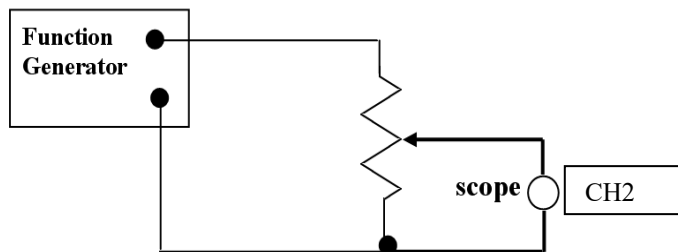

Figure 2: AC level control.

Passive Summer
The passive summer shown in Fig. 3 adds the DC voltage from the power supply to offset the AC voltage from the function generator. Suppose the function generator creates a sine wave voltage of $V_{AC} = 5 \sin (2\pi ft)$, where f is the frequency and the amplitude is 5 V (the peak-to-peak amplitude would be 10 V), and that the DC power supply provides a voltage of 10 V. Assuming that voltage sources are ideal, it can be shown that $V_{out} = V_{AC}/2 + V_{DC}/4$. Hence that the output will always positive and it should look like the curve in Fig. 4, below.

3A [4 p] Draw the circuit and do the algebra to prove the above equation.

3B. [4 p] Build the passive summer circuit as described above. Verify all the function generator and power supply settings via measurements (DC and AC) with the DPO. Again display the function generator output on CH1 and display the summer output on CH2.

Print the resulting waveform and paste it into your lab notebook.
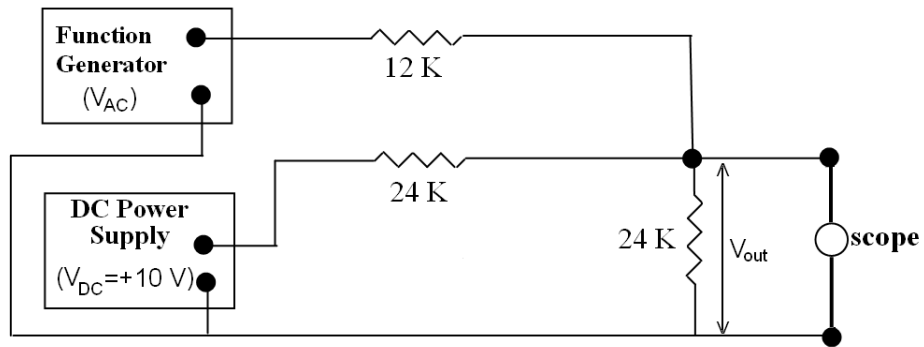
Fig. 3 Passive summer adds DC and AC

3C.[4 p] Have your instructor check your passive summer circuit and initial the drawing with expected voltages in your lab notebook.
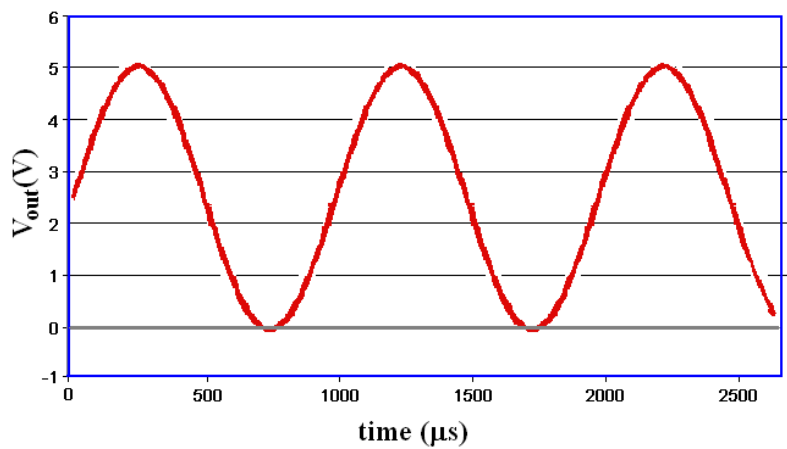
Figure 4: Output of Passive Summer.

APPENDIX

Hello there!

I am your friendly Agilent 3322A function generator. Some people call me unreliable because I report my output voltage *creatively*. For instance, I may say that my output voltage is 5 volts peak-to-peak when the truth is that my output voltage is 10 volts peak-to-peak.

But I am not really unreliable; I'm just too smart for my own good (and your own good). I will explain:

First, know that my output resistance (impedance) is 50 ohms. No matter what any other setting may be, my output resistance is 50 ohms, and that is that.

Next, know that when you first turn me on, I will expect to be looking into a load of 50 ohms. In the terms of your previous lab, I am an output box with an output resistance of 50 ohms, and I expect to be connected to an input box with an input resistance of 50 ohms. [I expect that because of misguided notions about impedance matching.] Therefore, I imagine a voltage divider situation, and if my open-circuit (Thevenin equivalent) voltage is 10 volts, my display will tell you that the voltage is 5 volts. It is 5 volts because that is what you would read at my output terminals as loaded by 50 ohms.

But suppose you don't connect me to a 50-ohm load. Suppose you connect me directly to a 'scope. The 'scope (or voltmeter) has very high input resistance and then you will find that my output is 10 volts (the open-circuit voltage), even though my display still indicates only 5 volts.

You may think that my display is misleading, and it is, but I have thought about that, and I have a work-around. I am willing to change my mind and believe that I am looking into a high-resistance load if you press the right buttons. Just press Utility, then Output Setup, then select High-Z load. Go through that sequence and you will find that my display suddenly reads 10 volts while my output voltage has not changed at all.

I am even more versatile. I am willing to believe that I am looking into whatever load you want. Just press the buttons Utility and Output Setup and use my knob to dial up a load resistance that you want me to believe. I will change the display accordingly. For instance, if my open-circuit voltage is 10 volts, and you tell me that I will be looking into a 100-ohm load, my display will read $10*[100/(50+100)]=6.667$ volts. Nevertheless, my open-circuit output voltage will remain 10 volts.

Now that you understand me, I hope you will no longer think that I am a compulsive liar. Of course, it is true that if my makers at Agilent had given me a digital voltmeter across my output terminals instead of my computed display, then I could have told you the true output voltage under any load conditions and saved us both all this trouble.