Advanced Skills with Oscilloscopes

*A Hands-On Laboratory Guide
to Oscilloscopes using the
Rigol DS1104Z*

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Advanced Oscilloscope Lab

Before beginning, you should have completed the Introduction to Oscilloscopes Lab

Objectives
- Understand advanced function of oscilloscope
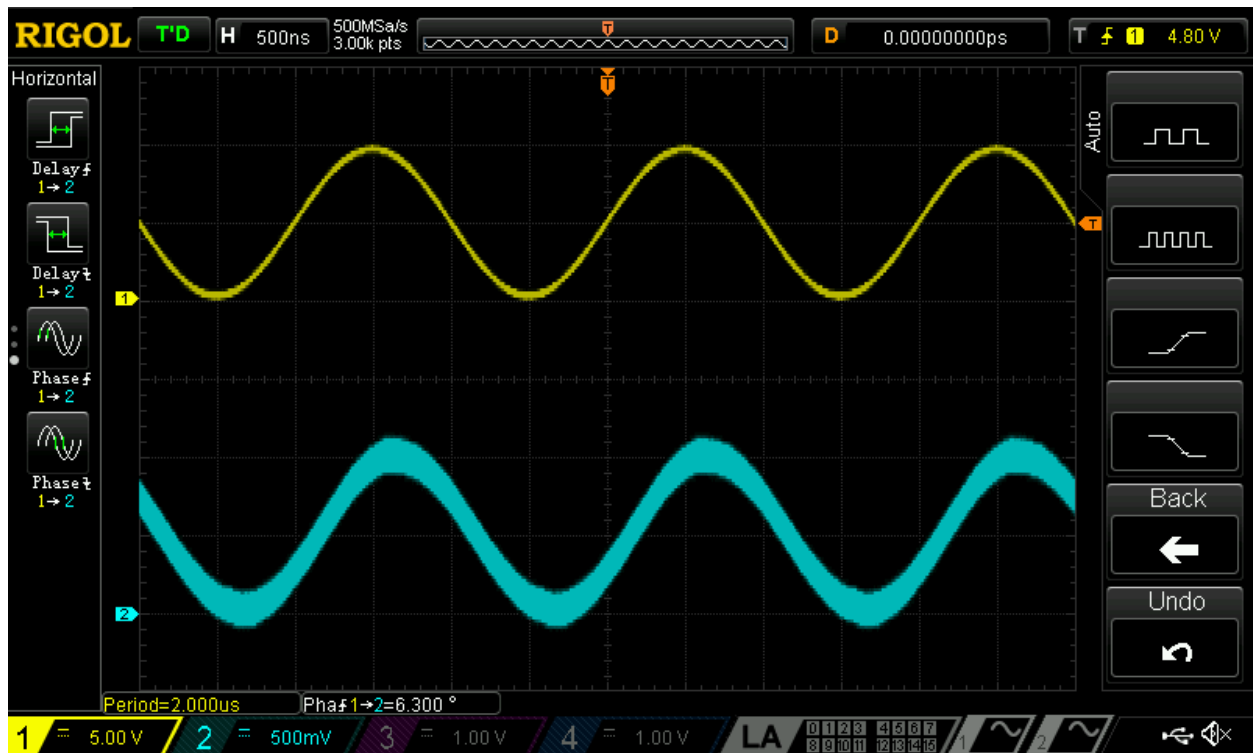- Use on-board features to analyze one or more signals

Equipment List
- One Rigol DSO1140-Z or MSO1104-Z Oscilloscope
- Two Rigol RP2200 Passive 1x/10x probes
- One Rigol DS6K Demo Board w/ USB connector
- One PC with USB host
- One USB thumb drive to save captured images, formatted to FAT32

Analyze Noise in Sine Wave

The DSK6K board has two sine wave outputs, labeled SINE and NOISY_SINE. In this lab, you will follow steps to measure the noise component in the sine wave.

1. Connect the DS6K demo-board's USB cable to a power source (e.g. PC)
2. Insert a USB disk into the oscilloscope, turn the device on.
3. Connect the BNC end of two RP2200 probes on channels 1 and 2
4. Connect the two ground clips to any GROUND loop on the DS6K
5. Connect the spring-clip of the CH1 probe onto the SINE loop on the DS6K
6. Connect the spring-clip of the CH2 probe onto the NOISY_SINE loop on the DS6K
7. Press the "Auto" button to auto-set the scope. The result should look like the following:

Coupling

The two sine-waves have a "DC bias" - that is, the sine wave has an amplitude of 1V, but the range goes from 0VDC to 1VDC, not -500mVDC to +500mVDC. We can say that the signal has a 500mVDC bias.   Recall from basic electronics that capacitors "block" DC but "pass" AC. As a result, we can change how the scope's channels are *coupled* and eliminate the DC bias.

Most oscilloscopes have three coupling modes:
- DC Coupled - passes DC, input to amplifier is directly connected to channel
- AC Coupled - blocks DC, channel input passes through an in-line capacitor
- Ground Coupled - blocks both AC and DC, draws a line at 0V, useful as a reference to detect grounding issues.

Couple Input Signals Lab
1. *Continue from the Analyze Noise lab (previous)*
2. Press CH1 button
3. Press the Coupling soft-key
4. Use multi-function knob to select AC, and press button.
5. Repeat for CH2
6. Notice that both signals are now -500mV to +500mV, centered about 0V.

Phase Delay

The two sine waves are at the same the same frequency, but may be out of phase with each other. This lab step uses the scope to detect and adjust the phase delay.
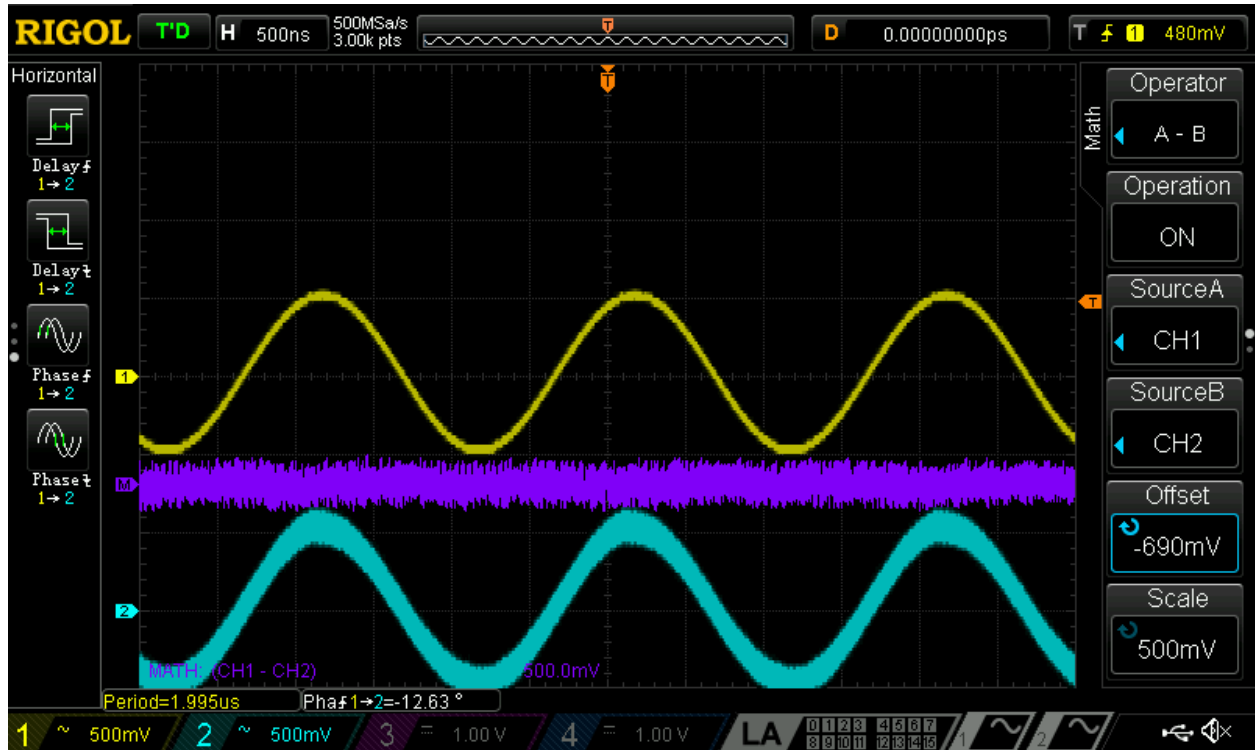
1. *Continue from the Coupling Lab (previous)*
2. Use the measurement menu button to select Horizontal
3. Use the left up and down keys to select the soft-keys for *Phase Rising*
4. Add the measurement to the screen, make sure it says Phase 1->2
5. How many degrees out of phase are the two signals?

6. Look at the display (zoom in / out) as needed to determine which signal is behind the other. In this lab, we assume (without loss of generality) that channel 2 is behind channel 1.
7. Make sure CH2 is selected
8. Use the down-arrow on the right soft-keys to get to Delay-Cal
9. Use the function knob to adjust the delay to minimize the phase mesaurement - it should not get right to 0 because there is noise in one of the sine waves that will cause it to trigger sooner or later.
10. You can use the Vertical Position knob to move the two waves on top of each other to determine how accurate the delay is if you like. Press the position button to recenter the waveform when you are satisfied. The picture should look as follows:

Math

The Rigol scope can perform real-time math on the captured data. We can use this to analyze the data on-screen.
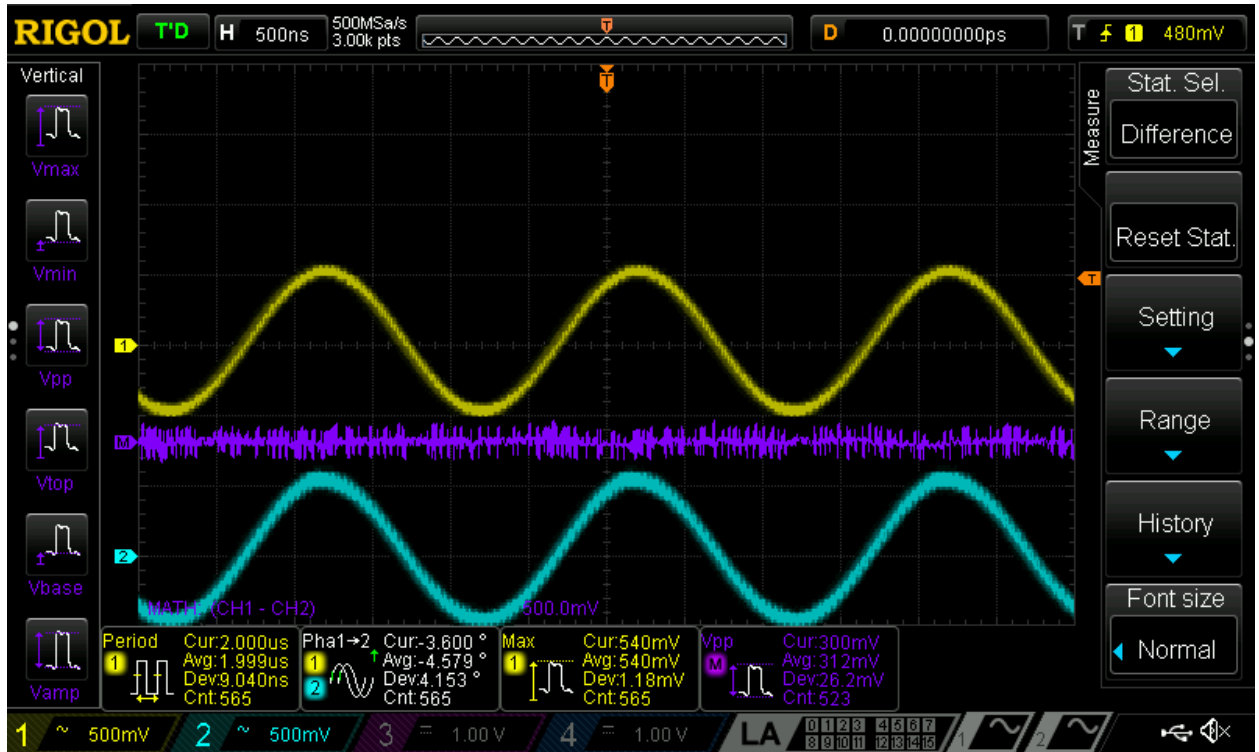
1. *Continue from the Phase Delay lab (previous)*
2. Press the MATH button
3. Use the soft-keys to:
   a. Operator: A-B
   b. SourceA: CH1
   c. SourceB: CH2
   d. Offset: adjust to your preference
   e. Operation: ON
4. The result should appear similar to the following picture.

Measurement / Statistics

The Rigol scope can now analyze the data, in real-time.

1. *Continue from the Math lab (previous)*
2. Press the MEASURE button
3. Use the Right soft-keys to:
      a.   Source: MATH
4. The left-side soft-keys will now display measurements that can be displayed on the computed math signal. Find the Vertical / Vpp measurement and add that to the display.
5. Use the Right soft-keys to turn on statistics, and use the page down to use Stat. Sel to set "Difference". The result will appear as the following figure:

6. Record:
   a. Current Vpp:
   b. Avg Vpp:
   c. Dev: Vpp:
   d. Cnt:

Using this method, you have now determined the amount of random noise added to the signal by the DS6K demo board.

Bandwidth Limit

Sometimes a low-frequency signal has high-frequency noise. For example, consider the noisy sine-wave in this example. The base frequency is 500KHz with some higher-frequency noise injected into it by the DS6K board.

Recall from the previous lab that scopes typically have a -3dB roll-off as they reach their upper-bandwidth limit. We can use this fact to artificially limit the bandwidth of the scope channel to act as a *low-pass-filter*, and use the attenuation to eliminate the high-frequency noise.

1. *Continue from the Measurement and Statistics Lab (previous)*
2. Select CH2 (the noisy sine-wave)
3. Add a *Frequency measurement* to the display
4. Record the frequency:
    a. Average:
    b. Deviation:
5. Engage the BW Limit softkey on CH2
6. Record the full stats:

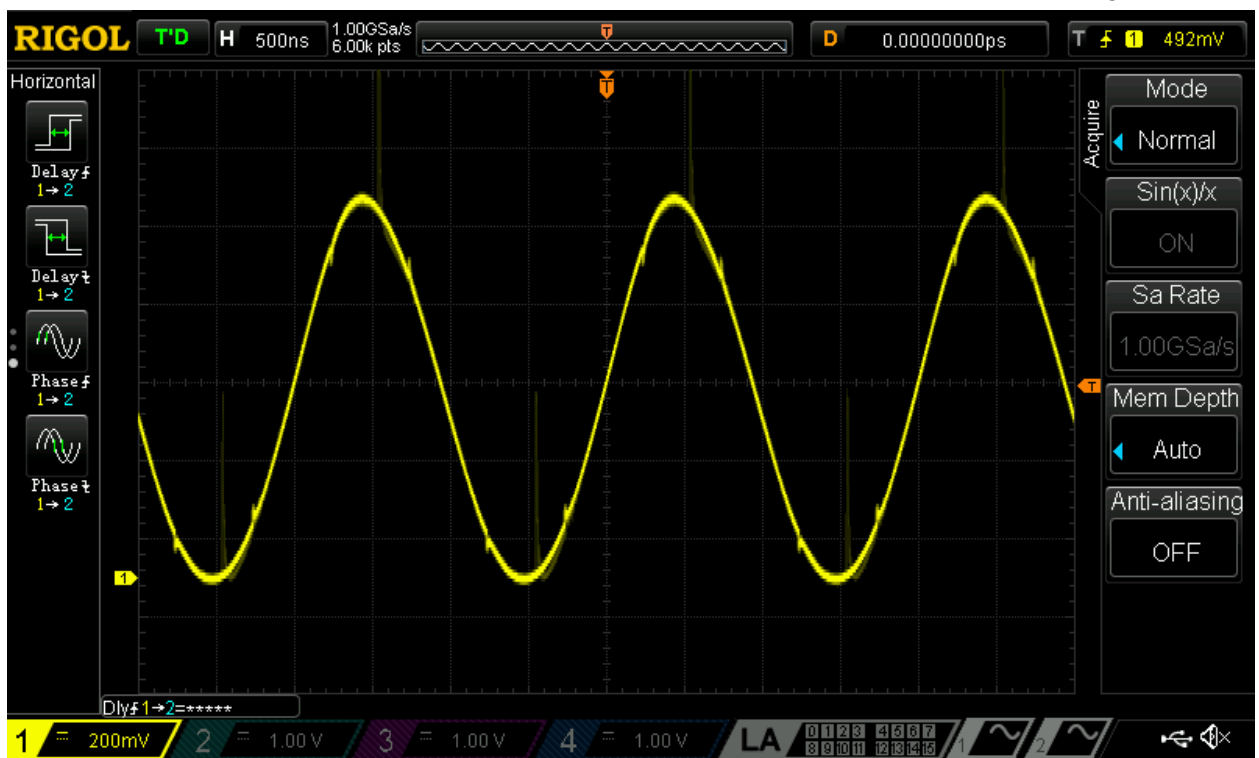|	Vpp (Math)	Frequency (CH2)
Current:		
Average:		
Deviation:		
Count:		

7. Compare these statistics to the previous results - what impact did engaging the bandwdith limit have on your results?

8. What might be a disadvantage to using the bandwidth limit function when debugging a broken system?

Signal Averaging

Another technique used to eliminate noise from the display of a signal is to use an "averaging" technique. In this mode, the scope will read multiple waveforms and average them together. Spurious noise will be averaged out leading to cleaner signals. As before, this improves the display of the signal but ignores the fact that the signal is noisy.

1. Connect the DS6K demo-board's USB cable to a power source (e.g. PC)
2. Insert a USB disk into the oscilloscope, turn the device on.
3. Connect the BNC end of one RP2200 probes on channel 1.
4. Connect the ground clip to any GROUND loop on the DS6K
5. Connect the spring-clip of the CH1 probe onto the GLITCH_SINE loop on the DS6K
6. Press the "Auto" button to auto-set the scope. The result should look like the following:

7. Press the Acquire mode button
8. Use the softkeys to select:
   a. Mode: Average
   b. Averages: 2
9. Screen shot your results / summarize them here:

10. Change the number of averages to 16

11. Screen shot your results / summarize them here:

12. Change the number of averages to 256
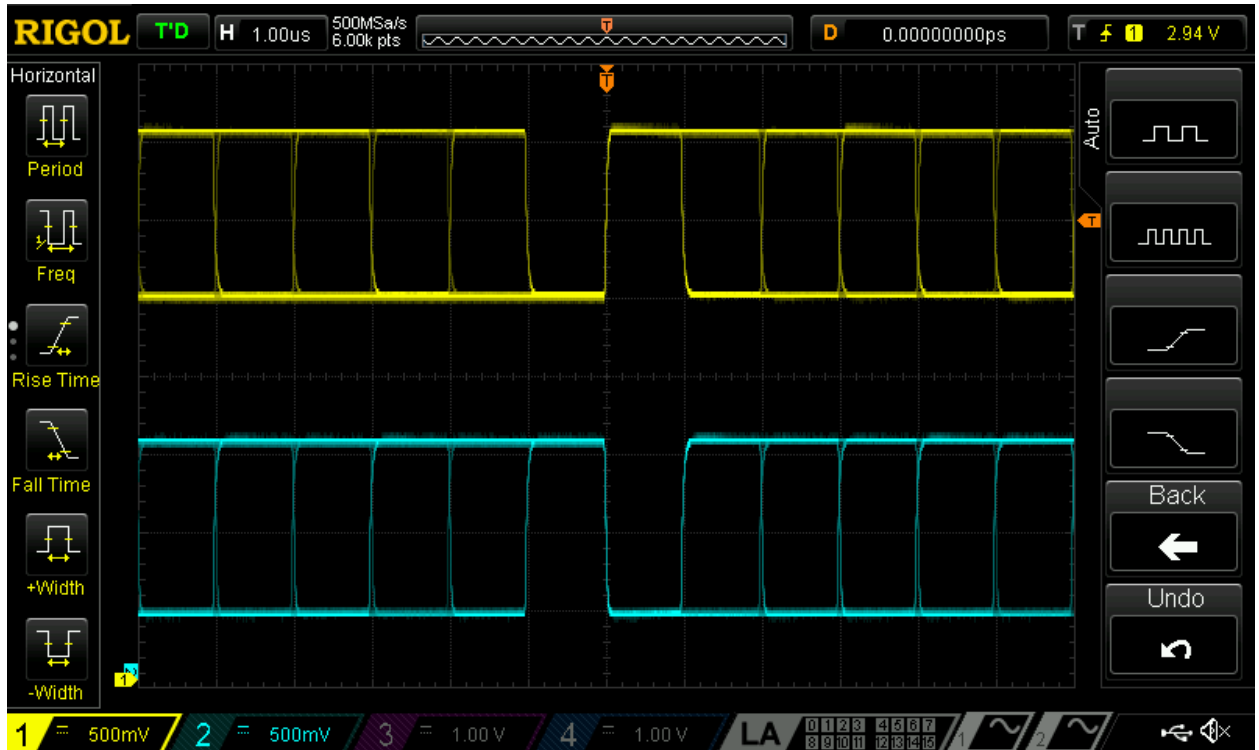13. Screen shot your results / summarize them here:

Differential Signalling

In a *differential voltage* system, there are two wires to carry a signal, usually identified as wire_P, and wire_N (the positive and negative wire). Examples of systems that use differential signalling include: USB, Ethernet, CAN, and SATA busses. The differential aspect of the wiring pairs means that a differential op-amp can take the differential ended wires as input and re-create a singled-ended output. In this scenario, it isn't the absolute voltage that determines logic high or low, but the difference between them. So, when one of them is high, and the other is low, there is a larger value (logic high), and when they are at the same level, then there is little value difference (logic low).

The reasons why these high-speed systems use this model is beyond the scope of this lab. However, we can use it to exercise other features of the Rigol scope.

Differential Signalling Lab
1. Connect the DS6K demo-board's USB cable to a power source (e.g. PC)
2. Insert a USB disk into the oscilloscope, turn the device on.
3. Connect the BNC end of two RP2200 probes on channels 1 and 2
4. Connect the two ground clips to any GROUND loop on the DS6K
5. Connect the spring-clip of the CH1 probe onto the CAN_H loop on the DS6K
6. Connect the spring-clip of the CH2 probe onto the CAN_L loop on the DS6K
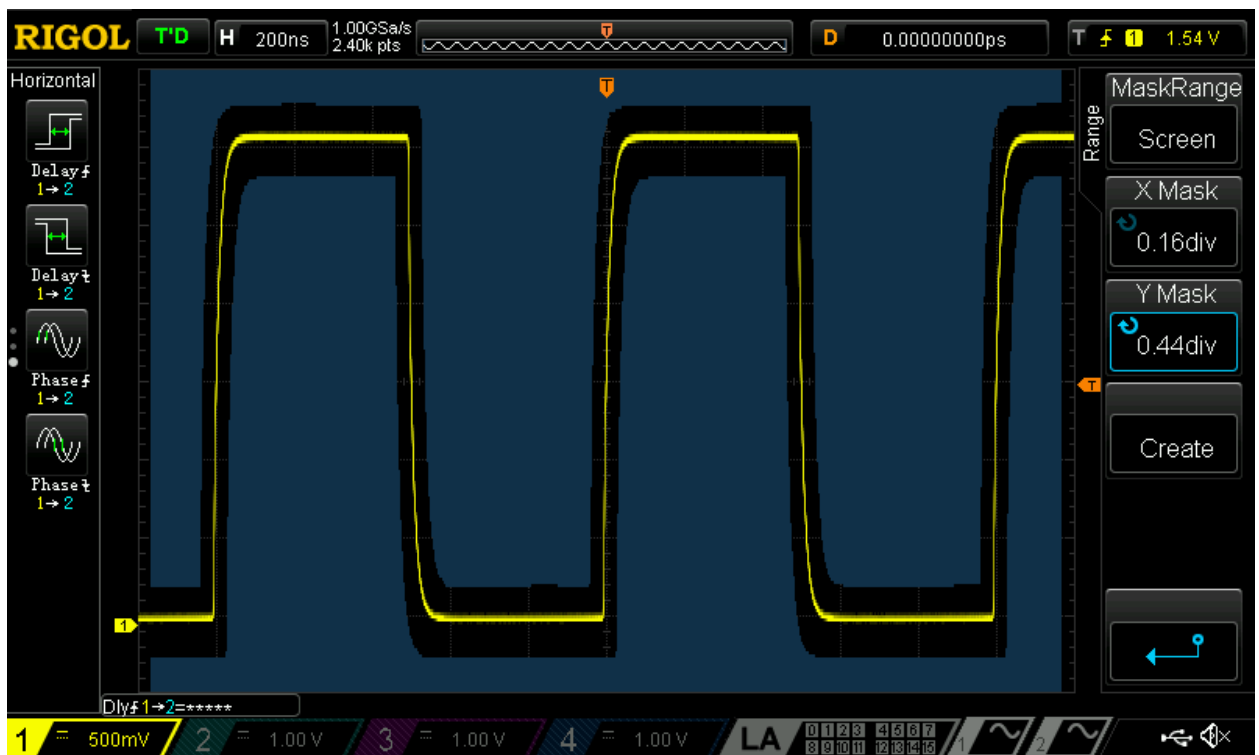7. Press the "Auto" button to auto-set the scope. The result should look like the following:

8. Press the "MATH" button
9. Use the soft-keys:
    a. Operator: A-B
    b. SourceA: CH1
    c. SourceB: CH2
    d. Operation: On
    e. Offset / Scale: adjust to your satisfaction
10. Observe how the math function is now showing the individually transmitted bits of a message from the difference of the captured signals!. Capture your data to the USB drive.

Pass / Fail Mode

The Rigol scope has a powerful feature that enables quick validation and error detection of a signal. We start with the shape of a well-formed signal and define an acceptable margin of error. Then, we probe another signal, and the scope will detect when the signal fails our test.

Pass / Fail Lab

14. Connect the DS6K demo-board's USB cable to a power source (e.g. PC)
15. Insert a USB disk into the oscilloscope, turn the device on.
16. Connect the BNC end of one RP2200 probes on channel 1.
17. Connect the ground clip to any GROUND loop on the DS6K
18. Connect the spring-clip of the CH1 probe onto the SQUARE loop on the DS6K
19. Press the "Auto" button to auto-set the scope. The result should look like the following:
20. Select the "Utility" function key.
21. Select "Pass/Fail" soft key.
22. Select Source: CH1
23. Select Range soft key
24. Select "Mask Range" Screen
25. Select XMask, use the knob to select the tolerance - the larger the number, the more tolerant of errors.
26. Select YMask, and use the knob in the same way.
27. Press Create.   The result should look like the following:

28. Use the softkey to go back up a menu
29. Use the Stat Reset softkey
30. Press the Stat Disp: ON softkey
31. Press the "Operate" button, verify that there are no failure, and the pass/total lines are increasing.
32. Press the "Operate" button to stop processing.
33. Move the CH1 probe to the RARE_AN loop.
34. Repeat the "Mask Range" steps to adjust the envelopes.
35. Press the "Operate" button and record at least 10,000 wfs, and determine the number of success / failure. Press the "Operate" button again to stop it.
    a. Fail:
    b. Pass:
    c. Total:
36. Reset the statistics.
37. Move the CH1 probe to FREQ_AN loop
38. Press the "Operate" button and record at least 10,000 wfs, and determine the number of success / failure. Press the "Operate" button again to stop it.
    a. Fail:
    b. Pass:
    c. Total:

39. Summarize the differences between the frequent and rare anomalies.

Reference Waveforms

The Rigol scope can capture a triggered waveform and store it in its internal memory. That waveform can then be displayed while other values are captured. This allows the operator to quickly detect differences in the waveforms.
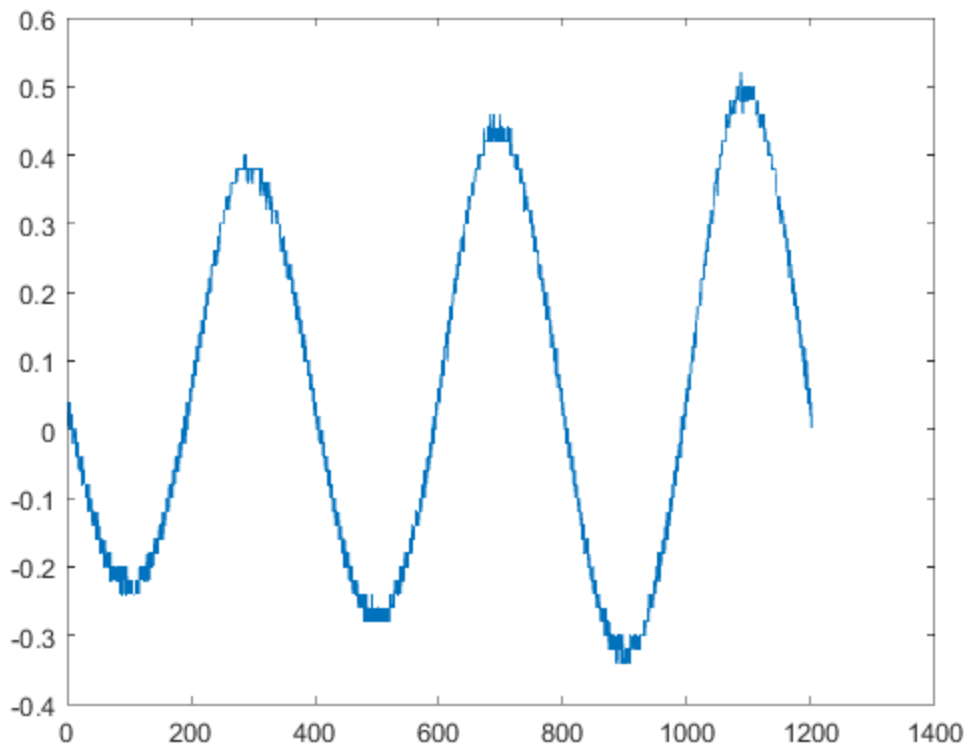
Reference Waveform Lab

1. Connect the DS6K demo-board's USB cable to a power source (e.g. PC)
2. Insert a USB disk into the oscilloscope, turn the device on.
3. Connect the BNC end of one RP2200 probes on channel 1.
4. Connect the ground clip to any GROUND loop on the DS6K
5. Connect the spring-clip of the CH1 probe onto the MANU_AN loop on the DS6K
6. Press the "Auto" button to auto-set the scope.
7. Press the REF button

8. Press Save
9. Remove the CH1 probe from the MANU_AN loop, and note that the reference signal is still displayed.
10. Reconnect the probe, and note that very little of the reference signal is visible - the new CH1 signal is essentially identical to the reference.
11. Move the CH1 probe to the RARE_AN loop and note that the signals look very different.

Save Waveform Data

1. Connect the DS6K demo-board's USB cable to a power source (e.g. PC)
2. Insert a USB disk into the oscilloscope, turn the device on.
3. Connect the BNC end of one RP2200 probes on channel 1.
4. Connect the ground clip to any GROUND loop on the DS6K
5. Connect the spring-clip of the CH1 probe onto the AM_MOD loop on the DS6K
6. Press the "Auto" button to auto-set the scope.
7. Press Storage
8. Use soft-keys:
    a. Storage: CSV
    b. DataSrc: Screen
    c. Param: ON
9. Press Save soft-key
10. Choose your Disk D (your thumb-drive)
11. Choose New File
12. Use keyboard to enter a name (e.g. data.csv)
13. Save the file.
14. Move the thumbdrive to a lab PC
15. The save created two files:
    a. a .txt file that has the capture parameters
    b. a .csv file that has the data

The captured waveform can be opened and analyzed by utilities such as Excel or MATLAB for even more advanced (but offline) analysis.

Exercises

1. Measure the rising delay between the CAN_H and CAN_P wires. Compute the maximum and average observed delay between them.