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Laboratory 4: Digital Signal Transmission Line Communication

In exploring the characteristics and behavior of transmission lines, we can begin to understand the effects of transmission line termination on transmission line response, capacitive termination, and impedance matching issues for TTL and CMOS drivers. First, a no load output amplitude from a signal generator can be set to produce a $2V_{pp}$ square wave at 200kHz frequency on the signal generator. As seen in *Figure 1*, the output voltage in this case is 2.06V.

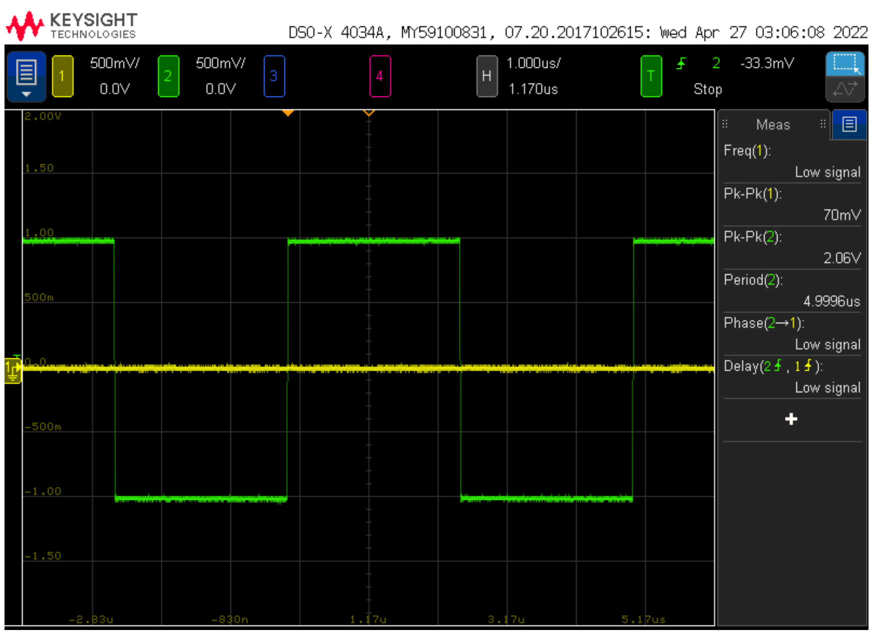

Figure 1: Open circuit output amplitude. Graphed as a function of mV and μs.

After connecting the signal generator to a 50Ω load impedance, we can observe a change in the output voltage—now reading at 2.36V, we can use this to calculate the total output impedance to be 50Ω. This is done by recognizing the case that $V_L = \frac{V_{open}}{2}$ when $z_o = z_L$. This is seen in *Figure 2* where a voltage of 1.31V is observed. Alternatively, we can also calculate this using the following: $z_o = 50\Omega(\frac{2.63V}{1.31V} - 1) = 50\Omega$.

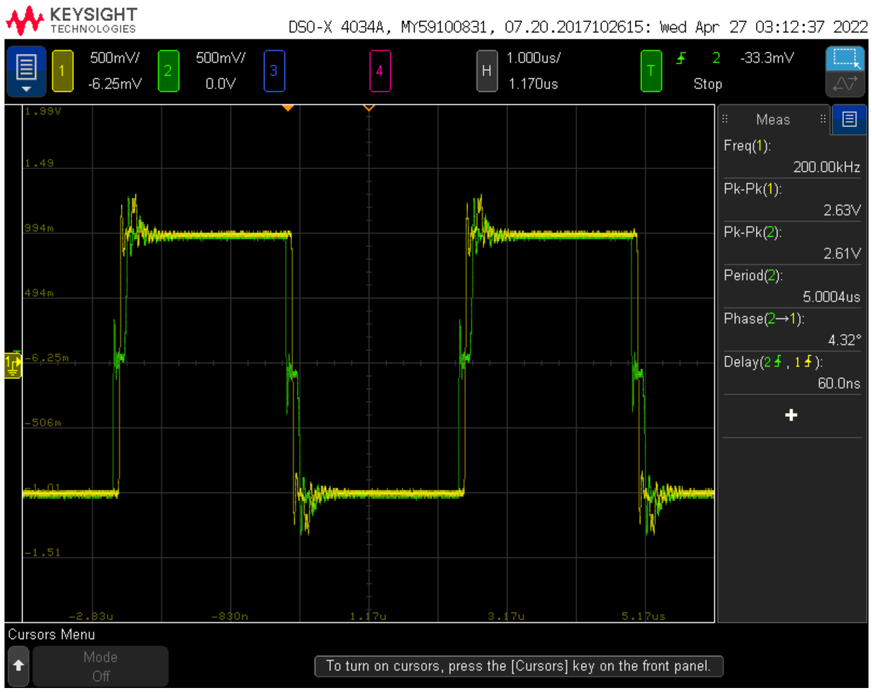

Figure 2: 50Ω load output amplitude. Graphed as a function of mV and μs.

After connecting the signal generator to an open line, the outputs at the near-end and far-end can be observed. This output is seen in *Figure 3*. The characteristics impedance, z_o, can be determined from the following equation: $V_A = V_{source}(z_o R_s + Z_o) = V_2$. After setting this equation for the appropriate values, we find that the characteristic impedance of the line is 50Ω. $1.10 = 2.21(z_o 50\Omega + Z_o)$.

We can then determine the propagation velocity in the coaxial cable, which seems to be realistic, as it is fast, however much beneath the speed of light. This is done by using the observed time delay on the far-end of the coaxial cable.

$$50ft/60.0ns = 2.54\times10\hat{}8\ meters\ per\ second.$$

This setup can be further tested by connecting a 50Ω load resistor to the far-end of the coaxial cable. This output, seen in *Figure 3*, shows that the near-end voltage, V_A, is related to the far end voltage, V_B, through a time delay. This delay is due to propagation times, as well as the voltage drop across V_B due to resistance in the cable and across the 50Ω resistor.

Figure 3: Output amplitude in the 50ft coaxial cable with 50Ω load impedance. Graphed as a function of mV and µs.

Connecting a 220Ω resistor in series between the generator and coaxial cable produces the output seen in *Figure 4* where the green trace is the near-end and the yellow trace is the far-end. We can then calculate the reflection coefficient to be $\Gamma = \frac{\frac{R_L}{z_0}-1}{\frac{R_L}{z_0}+1} = 0.6296$ at the near end. We would expect this to just look like an increased input impedance for the far-end. The expected reflection coefficient, $\Gamma = \frac{v^-}{v^+} = \frac{2.04}{2.08} = 0.981$. This value suggests a 37.7% error, likely due to unwanted capacitance or inductance seen in breadboards, wires, or other components.

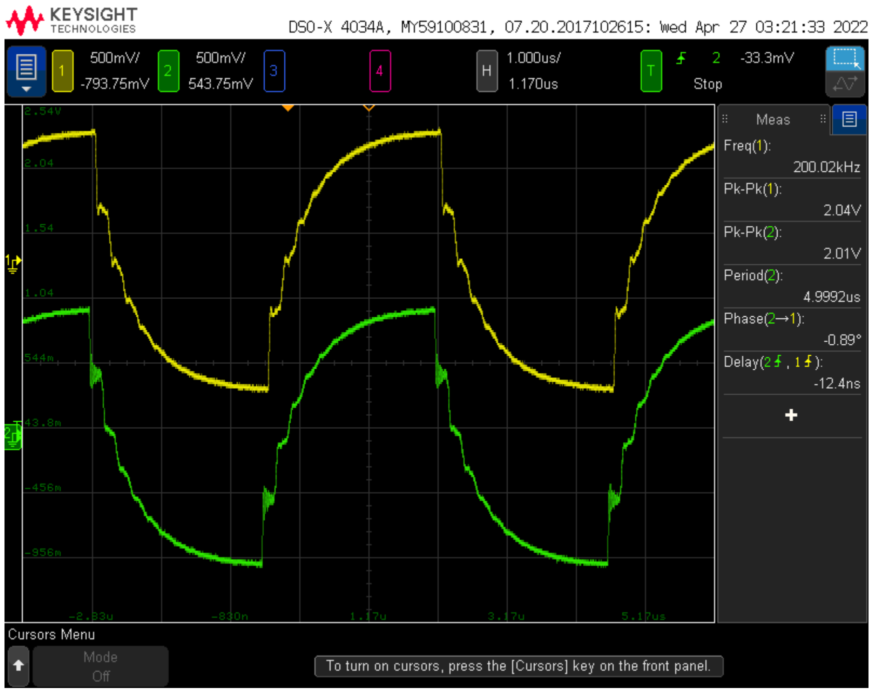

Figure 3: Output amplitude in the 50ft coaxial cable with 220Ω impedance at near-end. Graphed as a function of mV and μs.

The above calculation can be repeated instead with a 22Ω resistor. This results in a reflection coefficient of $\Gamma = \frac{\frac{R_L}{z_0} - 1}{\frac{R_L}{z_0} + 1}$ = -0.38. This negative reflection is expected, and there is a 180º shift between the near-end and far-end of the cable.

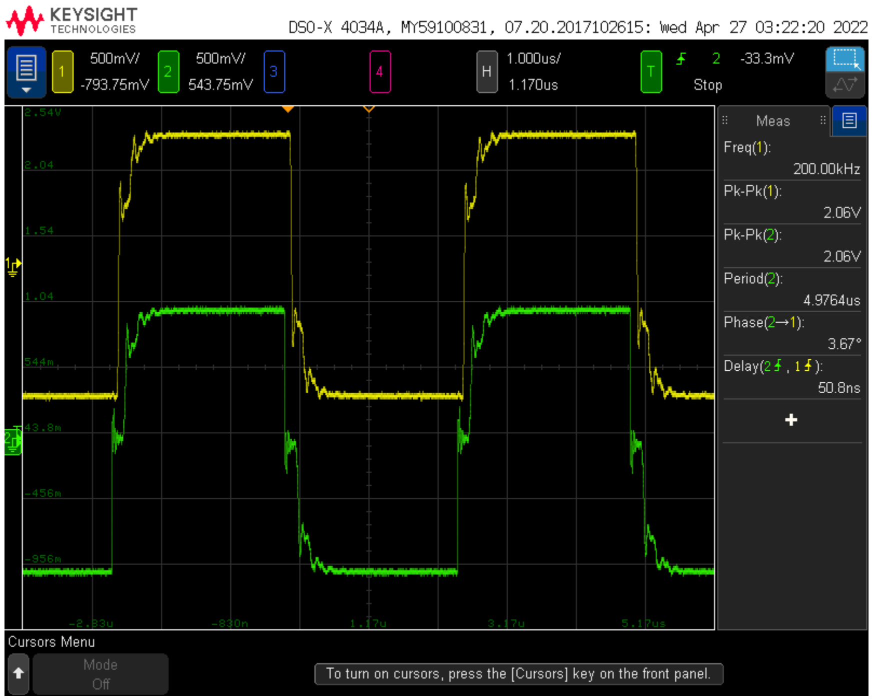

Figure 4: Output amplitude in the 50ft coaxial cable with 22Ω impedance at near-end. Graphed as a function of mV and μs.

Connecting the far-end of the coaxial cable to a 1nF capacitor, we can see the output in *Figure 5*. While this output shows a delay, it is not the value that was expected. The output should show a short, since at high voltages, capacitors act as short circuits. This behavior was verified with a larger 47μF dielectric capacitor, however could not be seen with the 1nF capacitor.

Figure 5: Output amplitude in the 50ft coaxial cable with 1nF impedance at near-end. Graphed as a function of mV and µs.

Using TTL inverters to drive the coaxial cable, we can observe the waveforms seen in *Figure 6* and *Figure 7*. The step-up and step-down voltages can be seen *Figure 7* to be 2V and 1V, respectively. The secondary coaxial cable can be found using the propagation velocity found prior in addition to parameters of the newfound delay.

$2.45 \times 10^{8} meters\ per\ second * 19.6ns = 4.978\ meters$. Error in this measurement was likely due to inefficiencies and parasitic capacitance.

The 74HC04 inverter, whose output is seen in *Figure 8*, has a pull-up(high) and pull-down(low). The driver impedance is the output impedance of the TTL inverter. The effective driver pull-up impedance can be calculated. The pull-up impedance is found to be $z_{pullup} = |50\Omega(\frac{2.63V}{2.30V} - 1)| = 7.17\Omega$. The pull-down impedance is found to be. $z_{pulldown} = |50\Omega(\frac{2.63V}{2.85V} - 1)| = 3.86\Omega$. The differences between these two inverters is based on their device physics—the TTL is composed of BJTs while the other inverter is CMOS.

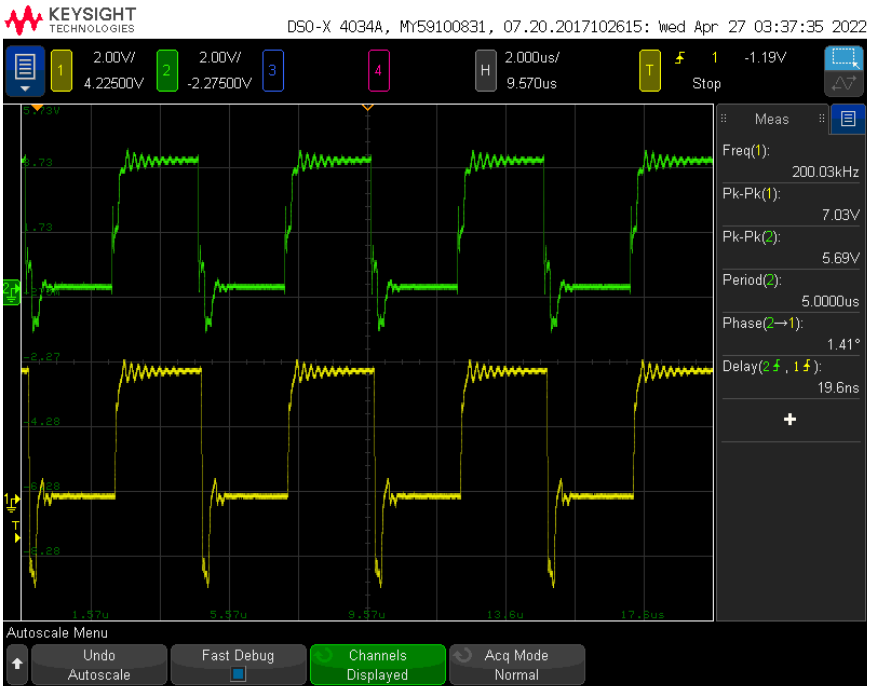

Figure 6: Output amplitude at both the near-end(green) and far-end(yellow). Graphed as a function of V and μs.

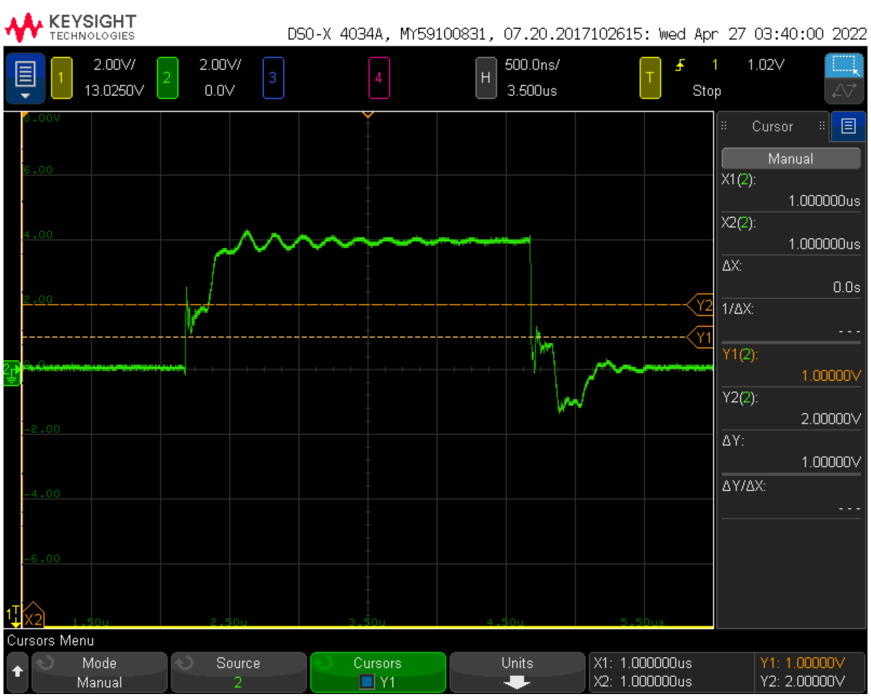

Figure 7: Step-up and step-down voltages for the 74F04. Graphed as a function of V and μs.

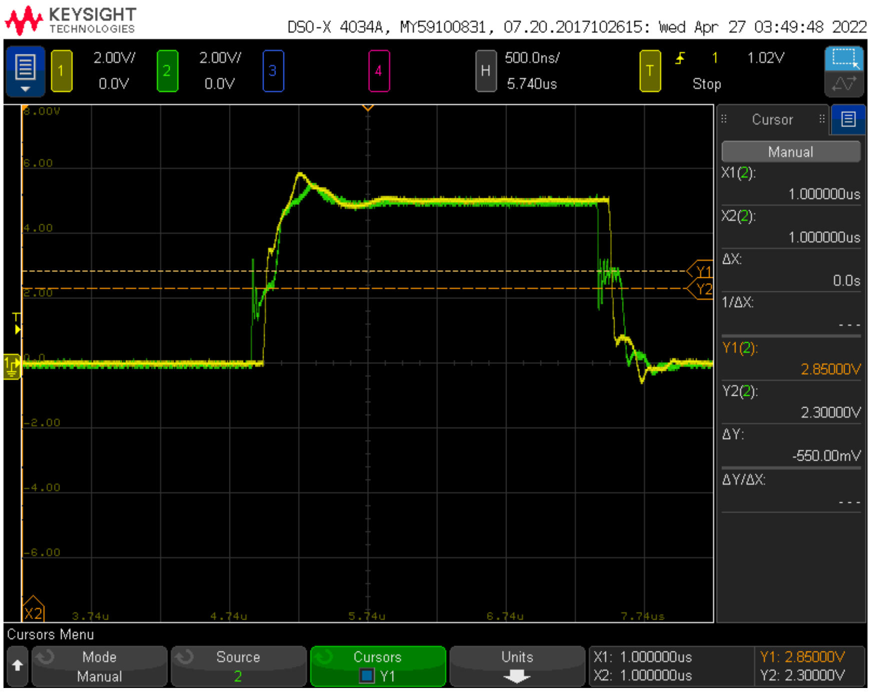

Figure 8: Step-up and step-down voltages for the 74HC04. Graphed as a function of V and μs.