Digital Electronics Lab 4 Report

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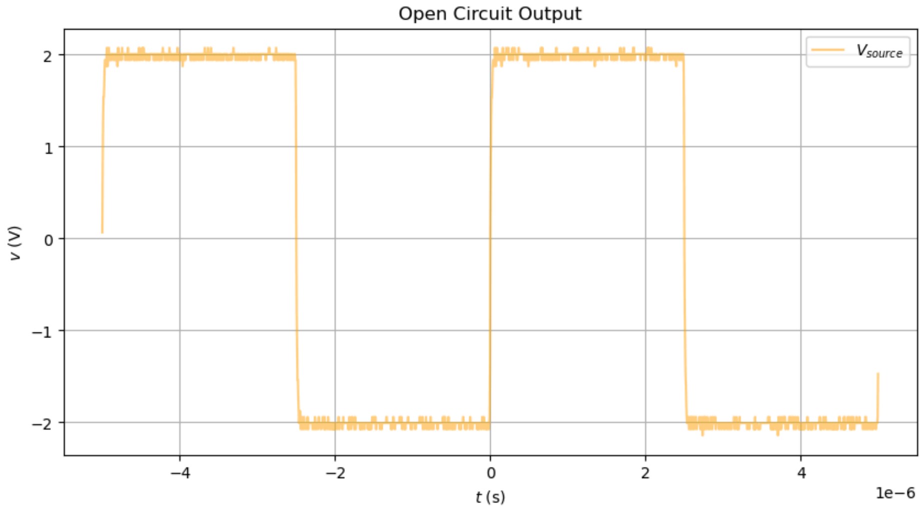
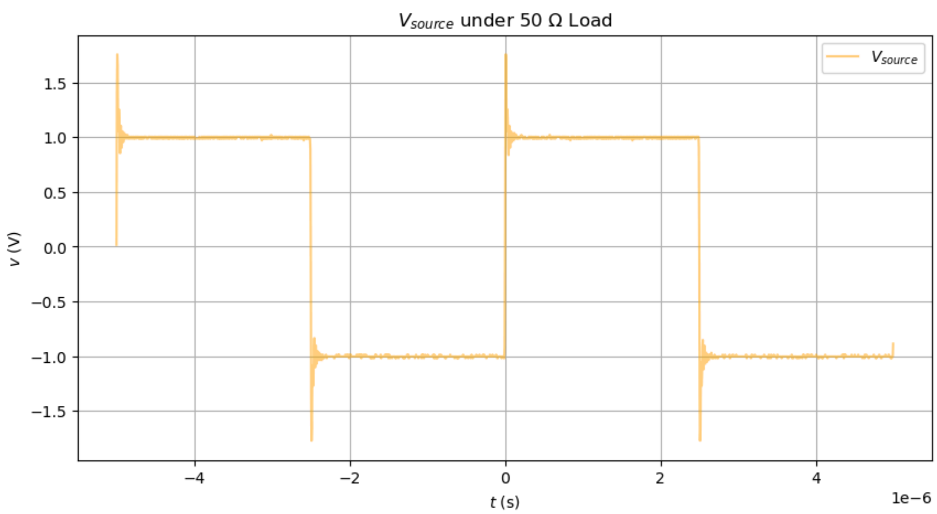
P Open-circuit Termination

Source Amplitude = 2V.



Q1 Output Impedance

Output voltage with 50Ω load:



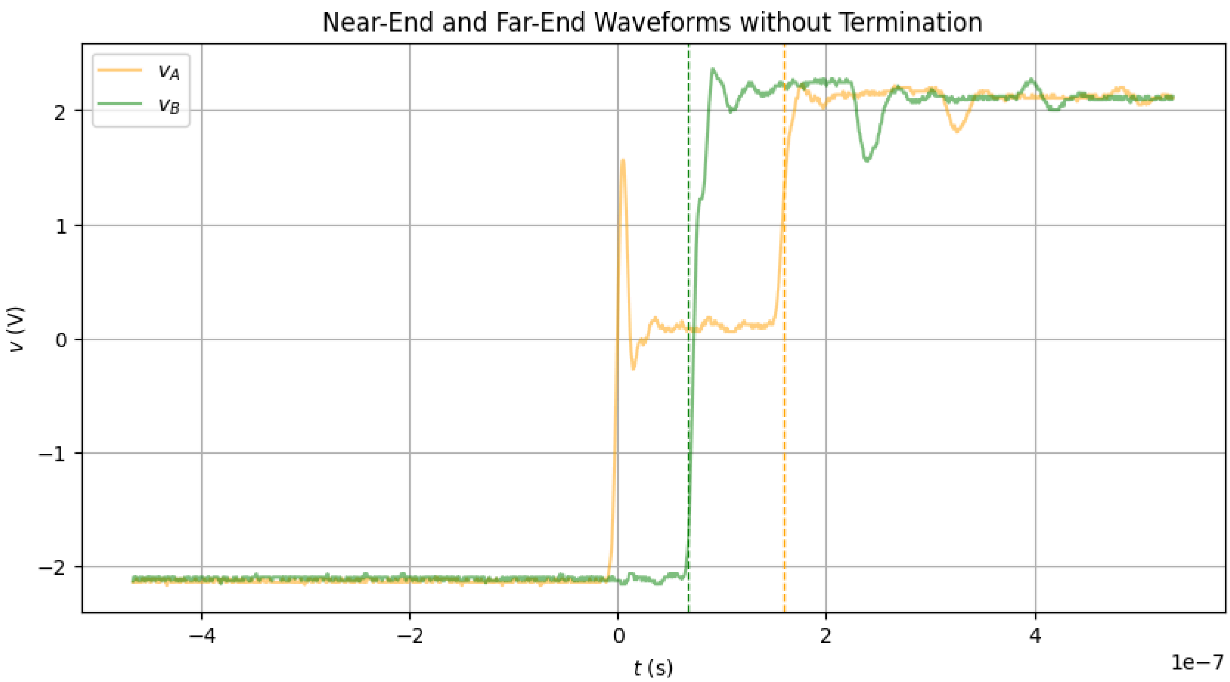
Steady-state V_{source} measured is about 1V. The simple circuit is a voltage divider, which suggests a matched source resistance to split half source voltage amplitude $\frac{1V}{2V} = \frac{R_C}{50\Omega + R_C}$.

Thus, the output impedance of the function generator R_C is 50Ω.

Coaxial Cable

Q2 Open line termination

Here are the recorded near-end (v_A) and far-end (v_B) waveforms. With an open circuit at the load end, the reflection coefficient is 1, which suggests that the circuit takes time to decay out transients and reach a steady state. Coaxial cable's characteristic impedance usually lies in the range of 50Ω to 100Ω.



When the input square wave switches phase from -2V to +2V, the pulse has magnitude of +4V However, v_A initially only experiences a 2 pulse, suggesting that the rest are divided by the line's characteristic impedance.

$\Delta v_A = \Delta v_{in}\frac{Z_0}{R_c+Z_0}, \frac{Z_0}{50\Omega+Z_0} = \frac{2V}{4V} = 0.5$, so $Z_0 = 50\Omega$ as well.

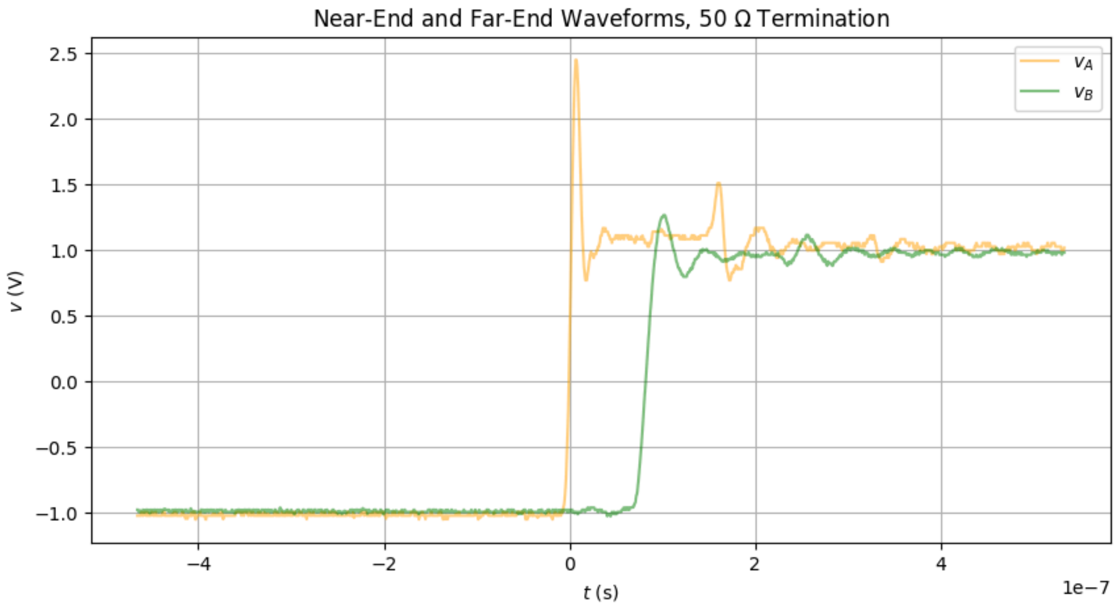
where Δv_{in} is the change of voltage at v_A when the function generator outputs a 4V unit step.

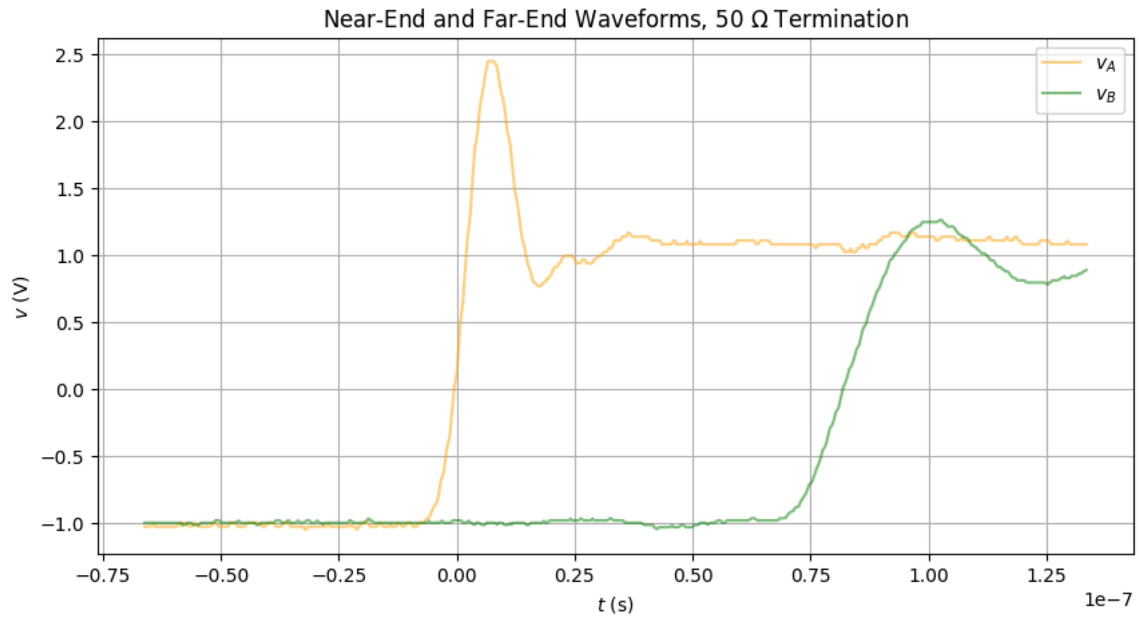
The first unexpected peak is probably due to TL effects of the cable wire connecting the coax cable and the function generator. The incident wave v_A is fully reflected at the far end, resulting in a single step of magnitude 4V in v_B.

The propagation velocity $u_p = \frac{l}{T_p} = \frac{30.48\ m}{(1.7e-7s-6.8e-8s)} \approx 2.988 \times 10^8 m/s$ where T_p is approximated by the time at which v_A changes after the pulse of v_B. This is very close to the speed of light as expected.

Q3 50 Ω Termination

Next, we use a 50 Ω resistor at the load instead. Since the termination resistor is the same as the characteristic impedance of the cable, we would expect a reflection coefficient of exactly 1. That is, v_A will be a 2V step due to voltage division, and nothing will be reflected from the far-end. v_B will also be a single 2V step after propagation. Because there's reflection, v_A and v_B will both stay stable.





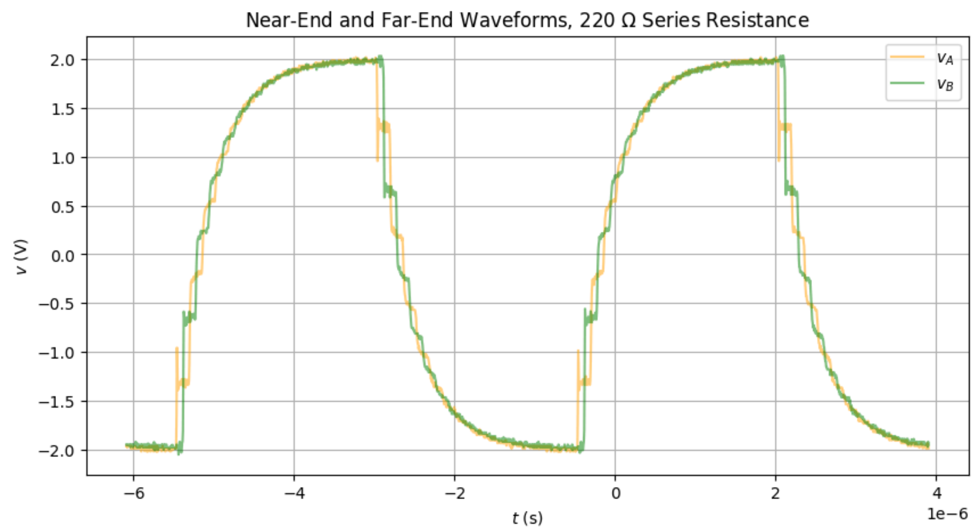
Compared to Q2, although the initial near-end pulse remains the same, the incident wave does reflect back at the far end, halfing the overall change. The result is also consistent with the voltage division at the termination, that the termination resistor divides half the voltage with the source impedance.

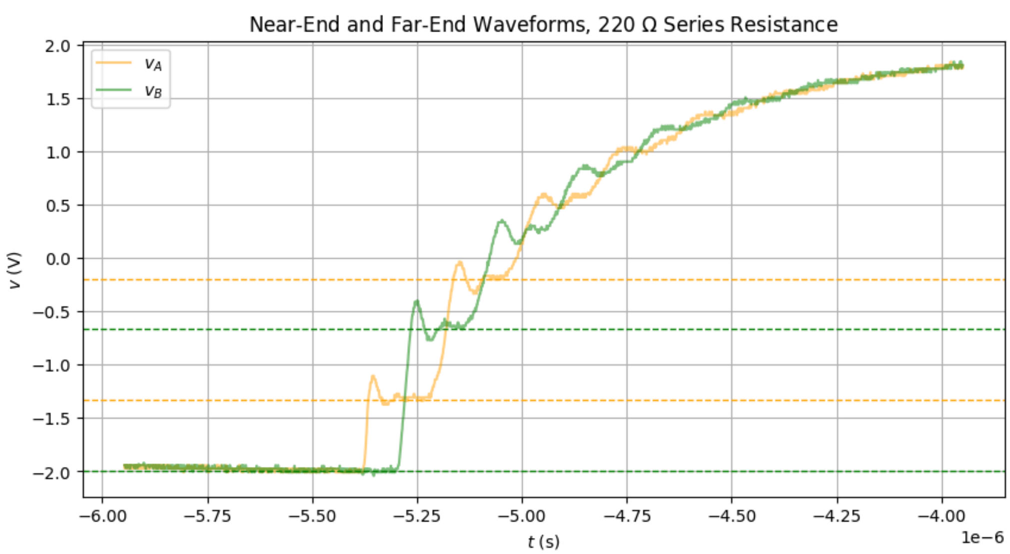
Series Input Resistance

Q4 R_C = 270 Ω

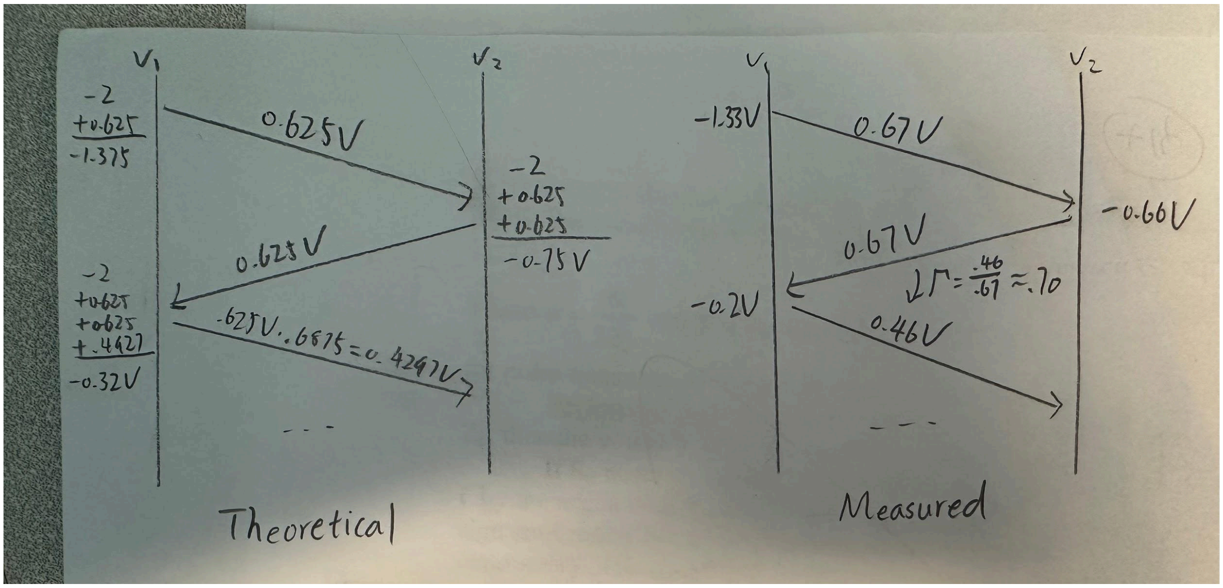
With an additional 220 Ω resistor in series with the function generator, the source resistance becomes 50 Ω+220 Ω=270 Ω, resulting in a near-end reflection coefficient of about $\frac{270/50-1}{270/50+1} = 0.6875$. The reflection coefficient at the termination is 1, since R_2 is infinity.

The **initial** v_1^+ **will be small** ($2 * 2V\frac{50}{50+220+50} = 0.625V$) because source resistance divides more voltage, but the positive reflection coefficient will eventually increase the voltages. Thus, we expect the **transients take a very long time to die out** and TL takes a very long time to reach a steady state.





Below are the theoretical calculations are actual measurements taken from the plot above:

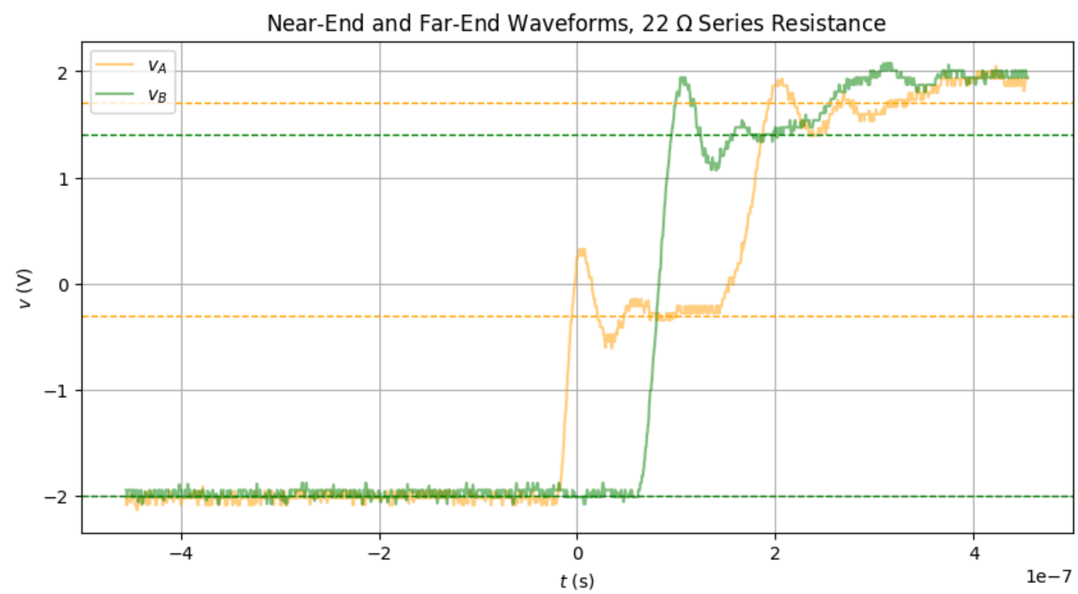


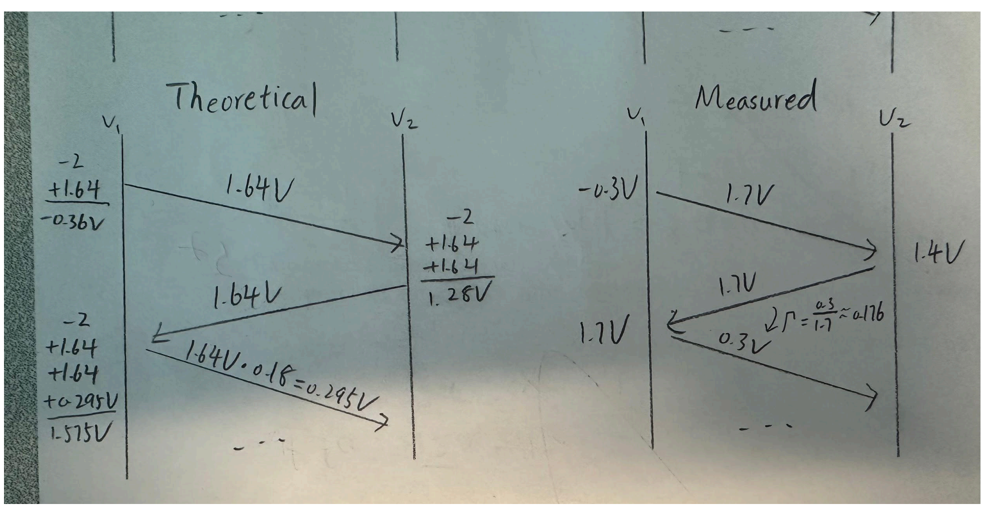
Theoretically, the initial v_1^+ step should have $2 * 2V\frac{50}{50+220+50} = 0.625V$, which is fully reflected at the far end, and then reflected at the near-end at a coefficient of 0.6875, propagating back and forth until equilibrium.

Our measured values are slightly different, due to the resistor variations. The measured initial amplitude was -1.33 - (-2) = 0.67 V, which is fully reflected from the back end, resulting in v_2 = -0.66 - (-2) = 1.34 V, the same as expected.
Then, the near-end reelected component v_1^- = -0.2 - (-2) - 1.34 = 0.46 V. The near-end incident component v_1^+ is 0.67 V. Therefore, the measured reflection coefficient $\Gamma = \frac{0.46V}{0.67V} \approx 0.70$, close to the theoretical value of 0.6875.
From the far-end's perspective, the addition of the 220Ω resistor divides more voltage from the cable, resulting in smaller incidental pulses in each propagation cycle. However, compared to a perfect 50Ω near-end impedance matching in Q2, the 220Ω resistor reflects a portion of the wave back to the far-end. Eventually, the far-end reaches the desired voltage.

Q5 R_C = 72 Ω

Now we change the 220Ω resistor to a **22Ω** resistor. Now the source resistance becomes 22 + 52 = 72Ω, corresponding to a reflection coefficient at the source of abou t$\frac{72/50-1}{72/50+1} = 0.18$. The **initial V_1^+ will be larger** compared to the 220Ω case because source resistance splits less voltage: $4V\frac{50\Omega}{50\Omega+22\Omega+50\Omega} = 1.64V$. Smaller reflection coefficient indicates that the **transients converge quicker** and TL reaches steady state in a short time. Here is the trace:





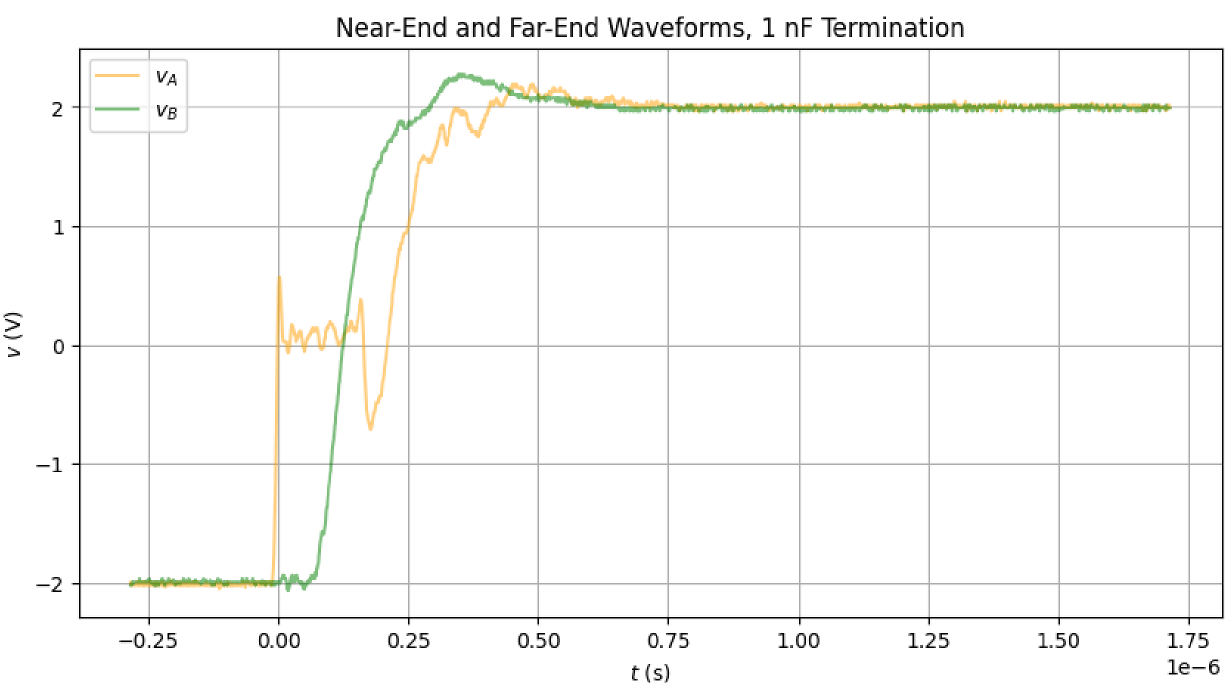
Same analysis here. The measured $\Gamma = \frac{0.3V}{1.7V} \approx 0.176$, pretty close to the calculated values.

Compared to the 220Ω case, the smaller R_C divides more voltage to the line, but also reflects less. Therefore, the effect is between Q2 and Q4.

Q6 Capacitive Termination

Now a 1 nF capacitor is insured at the load and the TL is connected directly to the source. We should expect the following: the initial V_1^+ should be similar to V_1^+ observed in Open/Resistor load Termination. The initial pulse is divided by half by the source and cable's impedance.

Originally, as the source sends out the pulse, the signal is of very large frequency. Thus, we can view the capacitor as short, corresponding to the reflection coefficient at the load of -1. Hence, at Tp, the initial voltage seen at the load would be zero.
Nonetheless, at Tp, the pulse voltage arrives at the load and starts to charge up the capacitor. This generates an exponential RC charging pattern after Tp, until the TL reaches steady state where now the capacitor acts like an open circuit. Hence the steady state voltage should be identical to the Open load Termination case.
In addition, the far-end exponential wave propagates from load to source and thus the voltage at the near-end would have the exponential pattern as well.



The trace is consistent with our expectations: RC charging pattern at far-end, which is propagated back to the near end. The near-end waveform didn't fully drop to 0 due to the opposite reflected wave from far-end. This is because the capacitor wasn't an ideal short when charged by a pulse with a finite slew reate.

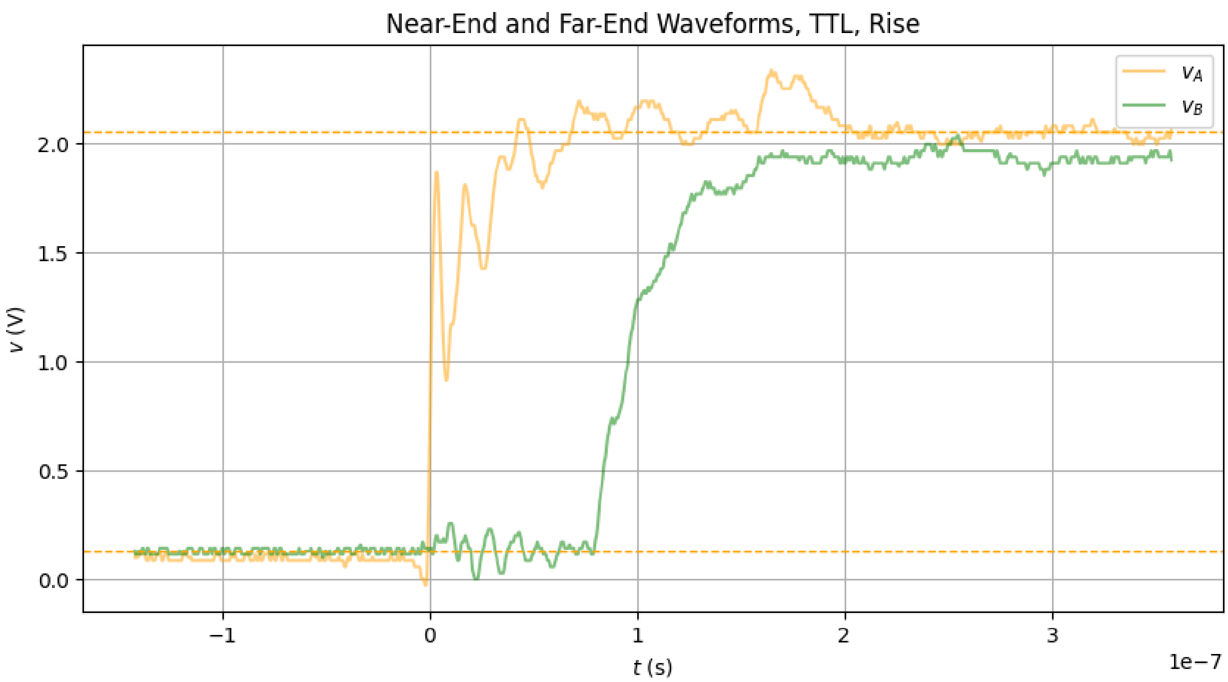
Impedance matching of SSI Logic Gates

Q7 TTL

To calculate the effective driver impedance, we characterized the TTL as an ideal voltage source driving a linear resistor. The initial V_1^+ is a result of a voltage divider between the cable's characteristic impedance and the output impedance of the logic gate. Therefore, $v_A = v_{out}\frac{50\Omega}{R_{out}+50\Omega}$, where R_{out} will be the PUN and PDN impedances.

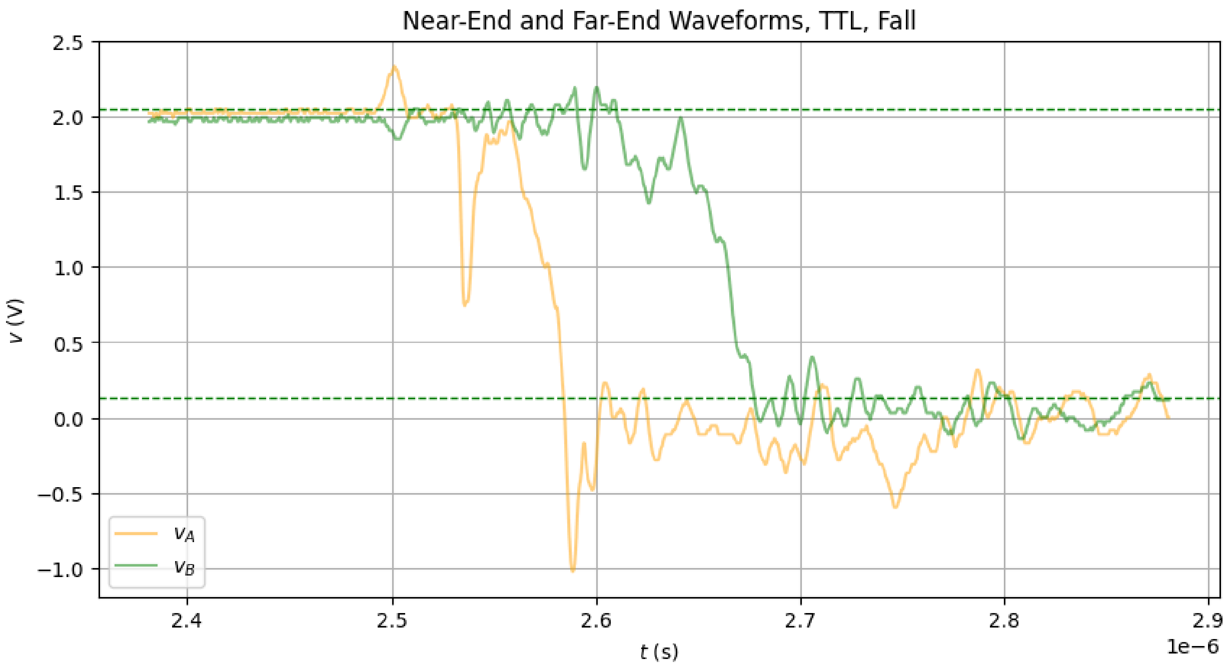
The far end is impedance matched with the cable's characteristic impedance (as in Q3), so nothing will be reflected back. v_B will have the same waveform as v_A, just delayed.

For Q7, to simulate logic, we simply added a 2V DC offset to the $2V_p$ square wave, so the resulting square wave has a range of [0, 4].



From the 74F04 datasheet, V_{high} goes to 0.9 V_{CC} = 3.6 V.

$$Z_{PUN} = \frac{50\Omega\, v_{out}}{v_A} - 50\Omega = \frac{50\Omega\, 3.6V}{2.05V} - 50\Omega = 38\Omega$$

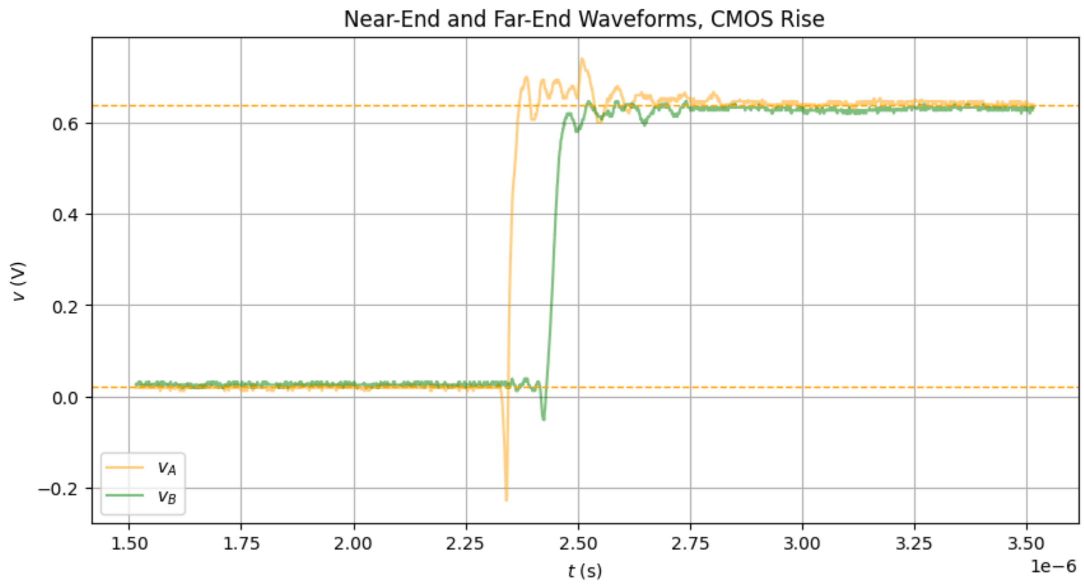


From the datasheet, V_{low} = 0.25 V

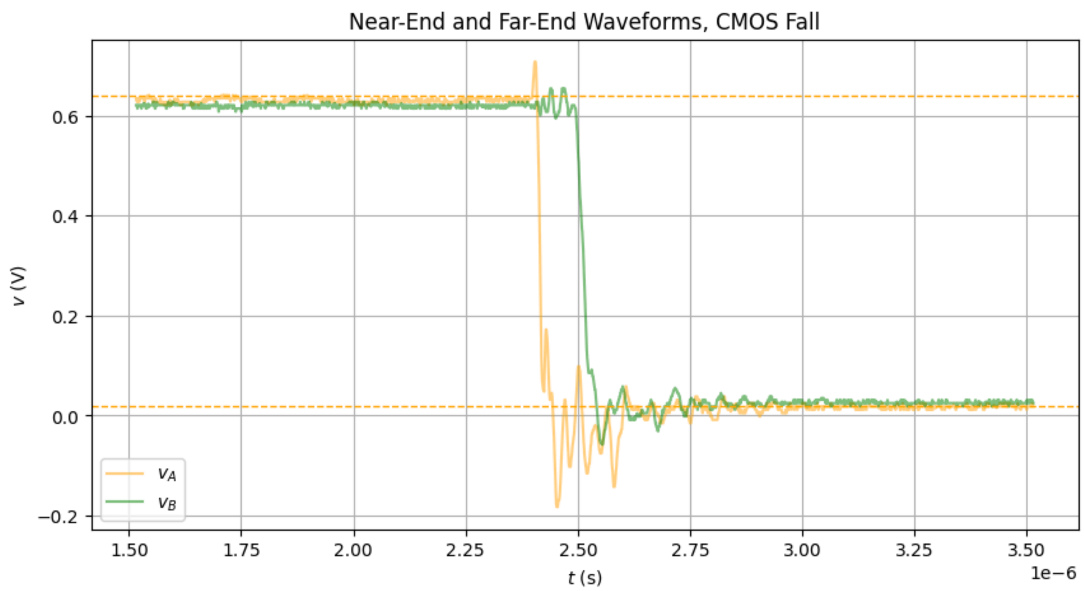
$$Z_{PDN} = \frac{50\Omega\, v_{out}}{v_A} - 50\Omega = \frac{50\Omega\, 0.25V}{0.13V} - 50\Omega = 46\Omega$$

Q8 CMOS

We follow the same procedure and equations as in Q7. We used 74VHC00 NAND gates. We drove it with a square wave from 0V to 2V. From the datasheet, V_{high} = 1.8 V, V_{low} = 0.05 V.



$$Z_{PUN} = \frac{50\Omega\, v_{out}}{v_A} - 50\Omega = \frac{50\Omega\ 1.8V}{0.64V} - 50\Omega = 91\Omega$$



$$Z_{PDN} = \frac{50\Omega\, v_{out}}{v_A} - 50\Omega = \frac{50\Omega\ 0.05V}{0.02V} - 50\Omega = 75\Omega$$

Comparison: **CMOS's driver impedance is much larger than that of TTL**. This is as expected due to the **gate oxide** of CMOS. On the other hand, due to CMOS's limited output level, the **final steady-state voltage is much lower** than that of TTL. This is as expected since CMOS is designed for the energy-saving setting (low voltage) while TTL can provide more voltages (not preferred for the energy-saving perspective).