Modulation techniques and signal processing: time of flight speed measurement

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1 Hypothesis

With a good pulse generator and oscilloscope, we can measure the propagation delay of signals in cables.

2 Introduction and procedure

The idea is simple: if we send a very short electrical pulse through a long wire, we should be able to measure its propagation delay. Knowing the cable length, we can measure the signal speed. It will differ from the speed of light by a factor of the relative dielectric constant of the insulation used in the cable, which practically speaking means around 0.6-0.7c.

You will do this by connecting the T0 output of the SRS pulse delay generator to both the oscilloscope (CH1) and a very long cable. Use a BNC “T” on the output of the generator, run a short-as-possible cable to the scope, and connect one end of the long cable to the remaining connector on the “T.”

If the end of the cable is shorted, the pulse should reflect off of the end of the cable and return inverted. Just like a string with a fixed end, the reflected pulse is inverted. The scope should then see two pulses: the direct one through the short cable, and the reflected one that first went to the end of the long cable and back.

One should keep the delay time smaller than the delay between pulses, which should be the case for the hardware you have. Verify this by connecting the pulse directly to the scope with a single cable and measure the pulse delay (pulse-to-pulse time) and pulse width.

If the direct pulse (from the short cable) and the inverted return pulse (from the long cable) arrive at the oscilloscope with a delay time smaller than the width of the pulse, you’ll see an interesting interference effect, where you see a signal only at the start and end of the pulse (see figure below).

What about an open cable? This is like a string with a free end, the reflected pulse is not inverted and you just get a second pulse. If the propagation delay is smaller than the pulse width, you’ll just see a slightly longer pulse, but with steps at the start and end. In the middle the signal will be twice as high because the pulses add in phase, and on the ends you’ll see the intensity of just one pulse. On the other hand, if you terminate the cable with a $50\,\Omega$ load, there is no reflection at all and you’ll just see the single direct pulse. Look at the figure below and see if you can figure out why each trace looks like it does (this is raw data from the oscilloscope, by the way).

Handy things: the speed of light in vacuum is about 1 ft/ns, and the floor tiles are exactly 1 ft wide. The speed of light *in your cable* is about 2/3 of what it is in vacuum.

3 Task

Measure the pulse delay for at least 3 lengths of cable (one of which should be at least 5 m), ideally more, and plot the delay vs cable length to estimate the speed of the signal in your cable. Don't forget that it has to make a round trip ...

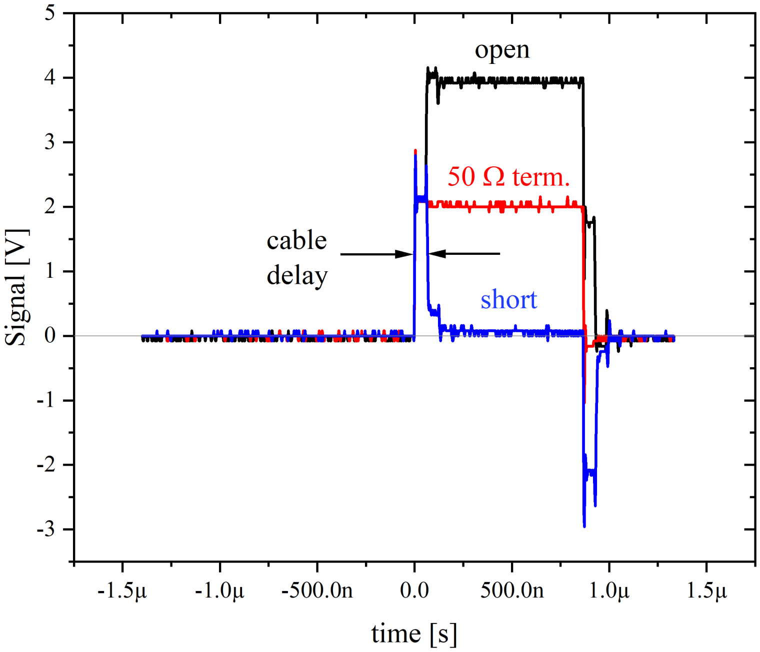

Figure 1: *Test measurements with open, shorted, and 50 Ω-terminated cables of about 5.8 m.*

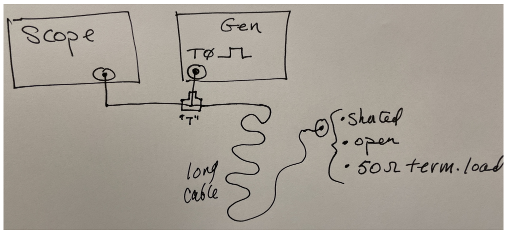

Figure 2: *The cocktail-napkin-equivalent version of the final schematic.*