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Signal Transmition

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Abstract

During this experiment, we studied how signal transmission affects the signal. We studied signal reflection and how different resistance termination affects the reflected signal. We also observed how the signal transmission through the long cable affects that signal. Additionally, we determined that the speed of signal propagation is $1.96 \cdot 10^8$ m/s ± 5.8. Finally, we developed the technique to determine the length of the long cable without physically measuring it.

Introduction

When the scientists are working in the laboratory, very often we have to measure the quantities in the form of electrical signal such as voltage or current. Many physically measures quantities are converted into an electrical signal to perform an analysis or simply transmit the signal from point A to point B fast and keep a good quality of a quantity measured. For example, when we record music, the sound waves are converted to an electrical signal and it is transmitted through cables. Different types of noise accomplish all the electrical measurements. In this context, the definition for noise is any signal besides the signal that we want to study. As an example, when we want to measure the luminosity of the light source, there is noise coming from background lightening as well as signal itself if being affected by the electronics around it. In the laboratory, when we perform any kinds of measurements we want to do our best to reduce the sources of noise so we can get a clean signal.

As we perform the measurements and analysis, signal is transmitted along the cables and wires from one equipment to another. It is important to understand what happens to the signal while it is being transmitted. Since the signal is transmitted through the cable, it is also important to know how cables affect the signal. Better understanding of a signal transmission helps a scientist design an experiment where signal is less affected by the noise.

Most common cable type used in the physics laboratory is the coaxial cable. The coaxial cable construction is shown in Figure 1. It consists of circular inner and outer conductor separated by a dielectric insulator. The inner conductor transmits the signal, while the outer conductor acts as a shield that protects the signal along the inner cable from the electromagnetic interference. The outer conductor is like a braid around the dielectric, which makes cable more flexible and durable. In addition, outer conductor carries the return current and it is typically held at ground. The cable is covered with a plastic jacket for a protection [1].

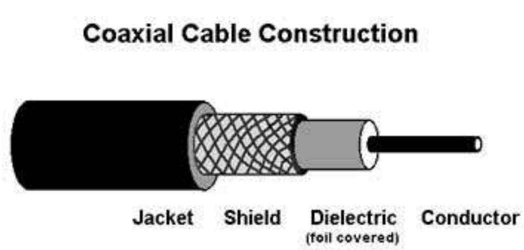

Figure 1: Most common coaxial cable construction example [2].

Each cable has the manufacturer categorization such as RG-6, RG-11 or RG-58. RG stands for “radio guide”. The numbers that follow RG letters show the diameter of the cable. Different types of coaxial cables have different applications, so they have different characteristics. One of the most fundamental properties is the characteristic impedance – Z. Characteristic impedance is the combination of the inductance, resistivity and capacitance that acts as an electrical resistance to the signals [1]. One should not confuse impedance with resistance R that we can measure with an ohmmeter. Characteristic impedance is expressed as a square root of the inductance per unit length L ratio over the capacitance per unit length C as shown in Equation 1 [1].

$$Z = \sqrt{\frac{L}{C}} \tag{1}$$

Typical values for the coaxial cable impedance are in the range from 50 Ω to 200 Ω. The most common cable and the one that I was using for this lab, RG-58, has impedance of 50 Ω [1]. Each piece of an equipment has input and output impedance. When performing the experiments one has to make sure that cable impedance matches the equipment input and output impedance to avoid the reflections in the signal. Most of the equipment have 50 Ω impedance; however, some sensitive devices such as oscilloscope might have a very high input impedance such as 1 MΩ to avoid high input current that might damage the device. To prevent the signal reflection one has to perform the impedance matching by terminating the end of the cable with a terminator that has a resistance that matching the cable impedance.

Another factor that one has to consider when working with the signal transmission is how length of the cable affects the signal. Signal travels fast but not fast enough to reach the speed of light, therefore as the signal is transmitted there might be a small delay that increases with the length of the cable. In addition, when the signal is transmitted it is converted to the frequency space through the Fourier transform. As the signal travels through the cable, higher frequencies are affected more that the smaller frequencies. Higher frequencies make the sharp edges on the pulses [1]. Therefore, the longer the signal travels through the cable the more smeared out pulse signal we get as an output. Such an effect on the frequency results also in the lower amplitude of the output pulse.

In this experiment, we observed what happens to the generated pulse as it travels through the cable. From the data, we derived the signal propagation speed and used it to determine the length of a very long cable. Also, we terminated the end of the cable with different resistor values and observed how it affected the signal. The observations from the experiments help us to understand better what happens to the signal as it travels through the cable.

Procedure

To study the signal transmission through the cable I used HP 8005A Pulse Generator to produce pulses that I observed. The produced pulse had a frequency of 1 kHz, negative amplitude of -1 V and the width of approximately 50 ns. To observe and characterize the generated signal I used the Tektronix TDS 1002B digital oscilloscope. This study had several activities and each activity had a different setup that are shown in the block diagrams in Figures 2 and 3.

Activity 1:

I connected the pulse generator to the oscilloscope Ch1 input with a 1-m BNC cable. I measured the length of the long BNC cable and connected it to the oscilloscope Ch1 input with a BNC tee leaving the other end of the cable free. The block diagram is shown in the Figure 2.

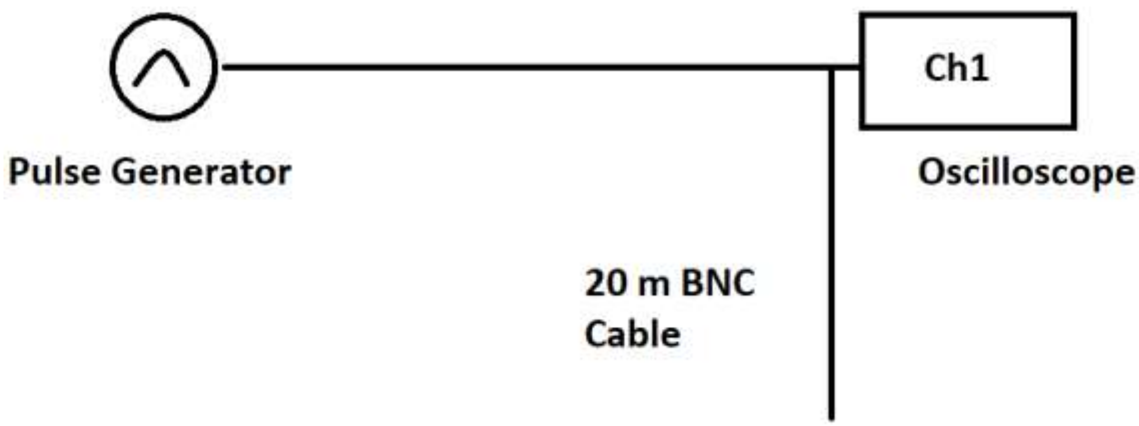

Figure 2: Block diagram for activity 1.

I made observations of what happened to the scope trace as I connected the long BNC cable to the Ch1. From the observation and data collected, I calculated the speed of signal propagation in the cable. I used auto scale on the oscilloscope to scale the signal on the screen as well as I used flash drive and oscilloscope print button to take screen shots of the oscilloscope screen.

Activity 2:

For the second activity, I connected the second end of the long cable to the Ch2 input of the oscilloscope. I made observations of the signal from Ch1 together with the signal from Ch2. The block diagram for the second activity is shown in Figure 3.

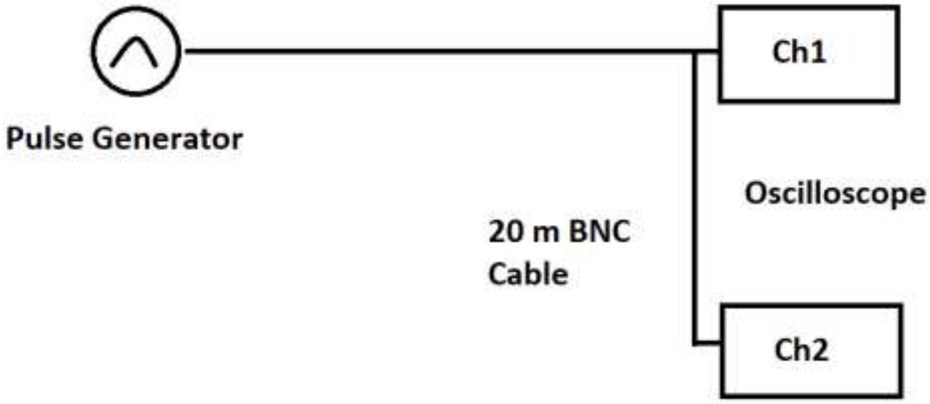

Figure 3: Block diagram for activity 2.

Activity 3:

During this activity, I investigated how termination of the open end of the long BNC cable affects the signal on the Ch1. I upgrade the setup shown in Figure 2 with a BNC-mounted resistor on the open end of the cable. I performed observations with a 500 Ω, 100 Ω, 50 Ω, 25 Ω and 0 Ω resistors as well as 50 Ω terminator.

Activity 4:

This activity is similar to the activity 3. I upgraded the setup shown in Figure 3 with a BNC-mounted resistor connected to Ch2 with a BNC tee. I performed observations on the scope traces for Ch1 and Ch2 with the same set of the resistors and a terminator as in activity 3.

Activity 5:

The last activity was dedicated to determine the length of a very long cable on the spool without physically measuring it. To do so, I connected one end of a very long cable to the Ch1 together with the signal input from the generator as shown in the block diagram in Figure 2, except I use a long cable on the spool instead of 20 m wire. I found the reflection of the signal on the oscilloscope (it was much further than I expected, so it took me some time to find it). I used the data that I got from the oscilloscope and the speed of signal propagation I calculated in the Activity 1 to determine the length of the cable.

Results

The results for this study are mostly observations of the signal scope traces on the oscilloscope; therefore, this result section will be mostly a discussion of my observations. It also includes the calculations for the speed of signal propagation and the length of the cable on the spool.

Activity 1:

During this activity, I measured the length of the BNC cable and I got 64.5±0.5 ft. I converted feet to meters and I got 19.66±0.76 m. The cable was expected to be around 20 m; therefore, I can state that my data is valid. I have a relatively big uncertainty on the measurement because it was hard to make the cable stay perfectly straight while measuring its length.

When I connected the long cable to Ch1, I observed that the amplitude of the initial signal halved. This happens because approximately half of the signal goes to the scope and the other half goes to the cable. In addition, I observed the reflection signal that occurs 200±10 ns after the initial signal. Since the signal, especially the reflected pulse, do not have clean edges, it was hard to say when exactly the pulse starts, which lead to a high uncertainty in my data. The 200 ns separation time between the pulses is the time that it takes for the signal to go one way and back through the cable. To calculate the speed of signal propagation of the cable I divided the time by factor of 2 and used v=d/t formula and calculated that the signal speed was $1.96 \cdot 10^8$ m/s ± 5.8%. It is very close to the speed of light c, which is what I expected for the speed of the electromagnetic signal.

Activity 2:

When I connected the second end of the cable to Ch2 of the oscilloscope, I observed the signal on the Ch1 did not change. However, I made an interesting observation on the Ch2 signal. The pulse that I see on the Ch2 is exactly halfway in between the original signal on Ch1 and its reflection. What happens is that the initial signal is split in two. One half of the signal goes to the oscilloscope and the other half goes to travel through the cable. On Ch2, I observe the pulse when it gets to the end of the cable and then this signal reflects and travels back, so I see the reflection signal on Ch1. In addition, I observed that when I connect cable to the Ch2, the frequency of the signal doubles. When we have cables connected as they are in activity 2, there are a lot of reflections happening and oscilloscope is getting more frequent signals (both initial signal and the reflected signals), which doubles the frequency.

Activity 3:

As I terminate the other end of the long cable with different BNC-mounted resistors, the initial signal does not change. The reflected signal clearly has a dependence on the resistance of the termination. The biggest resistor, 500 Ω, reduces the amplitude of the reflected signal. As I decrease the resistance of the resistor, the amplitude of the reflected signal gets smaller. This happens up to 50 Ω, when the amplitude of the reflected signal is zero. When I terminate the end with the 50 Ω terminator I also see no reflected signal on the oscilloscope. For the resistors with the resistance below 50 Ω I observe a reflected signal with an opposite polarity amplitude. As I decrease the resistance, the amplitude of the reflected signal increases. With 0 Ω resistor I see the reflected signal with approximately same amplitude as an original reflected signal but with an opposite polarity.

From these observations, we can see that terminating the cable with the resistance matching its impedance helps to dispose of the reflection pulses.

Activity 4:

During this activity, I was observing the same signal as I did in Activity 3, but in conjunction with signal from Ch2 that was coming from the second end of the cable. As expected, on Ch2I observe the pulse halfway between the initial and reflected signal. The amplitude of this signal depends on the resistance of the BNC-mounted resistor that I used to terminate the second end of the cable. With 500 Ω resistor the amplitude of the pulse on Ch2 is approximately the same as when I do not have any resistor connected to the cable. As I degrease the resistance, the amplitude of the pulse also decreases. With 0 Ω resistor I observe no pulse on Ch2.

On the signal from Ch2 we observe how much from the incoming signal is going through the resistor and how much goes to the oscilloscope. The lower the resistance on the resister, the more signal goes through the resister instead of going to the oscilloscope. Signal, same as the electron flow, chooses the path with less resistivity.

Activity 5:

When one end of the cable on the spool was connected to the Ch1, I found the reflected pulse on the oscilloscope. It appeared to be 820±20 ns away from the initial pulse. Therefore, it takes 410±10ns for the signal to go one way and back on the cable. Because the pulse traveled a long distance through the cable, we can observe how the reflected pulse is much more smeared out that the initial signal. This happens because in the frequency space, when the signal is traveling through the cable, the higher frequencies are affected more, therefore we observe less sharp signal. Because of that, it was hard to determine the exact time difference between the initial and reflected signal. In addition, the pulses are far apart with respect to their width, so I had to choose a bigger timescale on the oscilloscope to fit both pulses on the screen. The unclear edges of the reflected signal and bigger time scale made me choose a big uncertainty on my data. I used d=vt formula and found that the length of the cable on the spool is 80±7 m.

Conclusion

The observations performed during this study gave us an opportunity to understand better and visually see what happens to the signal, as it is transmitter through the coax cable. I observed that when the signal propagates through the cable, the pulse smears out because highest frequencies are affected more than smaller frequencies. Such a behavior of the signal is a source for the big uncertainty on my data. I also discovered that reflected signal amplitude depends on the resistance of the termination. To avoid the signal reflection we have to match cable impedance and termination resistance. The study of the signal reflection gave me an opportunity to calculate the speed of signal propagation and determine the length of a cable on the spool without actually measuring it. The result for the speed of signal propagation is $1.96 \cdot 10^8$ m/s ± 5.8 and for the length of that cable - 80±7 m. Taking into account the effect of signal propagation, when building an equipment in the laboratory I want to use the shortest cables to connect the devices. In addition, I have to take into consideration the impedance of the cable and the equipment I am using and make sure that they are matching to avoid the signal reflection.

References

[1] W. R. Leo, *Techniques for Nuclear and Particle Physics Experiments, 2e* (Springer-Verlag, Berlin 1994).

[2] Fiber Optic Association, (http://www.thefoa.org/tech/ref/premises/coax.html), retrieved 07 February 2019.