# PHY 651 – LABORATORY 6

## Introduction to the digital scope – Transmission line properties of coaxial cables

### *Introduction*

In this laboratory you will familiarize yourself with the digital scope and learn more features of the BK Precision waveform generator at your laboratory desk. For each measurement, experiment with different vertical sensitivities and horizontal time scale. This waveform generator can produce different signal shapes. You should use the square wave unless instructed otherwise for this laboratory. You can also change the waveform parameters. Note that in this laboratory the square wave should be ideally a step function with negligible rise-time and infinite duration. You can accomplish these goals choosing a square wave with a period bigger than the time span visible in your scope display.

If you have never experimented with transmission lines, you will have a first introduction to some important concepts today:
Characteristic impedance of a coaxial cable;
Reflection coefficient and proper termination of a coaxial cable;
Time that it takes for an electrical signal to move along a coaxial cable.
When the coaxial cable is used to transmit signals of sufficient high frequencies (such as the ones that you will use today), it behaves like a transmission line. Its important characteristics are:
The characteristic impedance
The delay per unit length
The equivalent capacitance and inductance per unit length for ideal transmission line, with additional parameters to characterize the non-ideal characteristics.

### *Glossary*

#### Coaxial cable

A type of wire that consists of a center wire surrounded by insulation and then a grounded shield of braided wire. The shield minimizes electrical and radio frequency interference.

Coaxial cabling is the primary type of cabling used by the cable television industry and is also widely used for computer networks, such as Ethernet. Although more expensive than standard telephone wire, it is much less susceptible to interference and can carry much more data.

## Transmission line

Two wire separated by a dielectric constitute a transmission line. Their properties become interesting when time dependent electrical signals are propagated through them. See your handout for more details.

## *Introduction to the oscilloscope*

In modern experimental physics we use computers to analyze a variety of physics quantities. You have already acquired some experience with modern PC based data acquisition systems through the first four laboratories. One instrument that is present in any lab bench is a digital oscilloscope. This instrument allows visualizing several different waveforms (typically 2 or 4), with a specific synchronization signal (TRIGGER). You have already encountered the concept of trigger in Laboratory 3. In that case you used the rising edge of a digital signal to synchronize the scope VI that you implemented with the NI6023 card. The digital scope that you will be using has a much bigger bandwidth. In addition it features an analog trigger, namely the data acquisition is synchronized with the signal crossing a given threshold either on the rising edge or the falling edge.

Being able to take advantage of the many features of a digital scope will help your experimental work tremendously. The following activities will enable you to experience some of them. If you have used scopes before, concentrate on the quantities that you need to measure. If this is your first introduction to the use of this instrument, be patient and the waveforms will eventually appear on your display. Even if you used oscilloscopes before, chances are that you will have to struggle a bit to find the right knobs on the front panel. However, remember that the time taken in familiarizing yourself with this instrument is very well spent. If you work in a modern laboratory, you will have to use a digital scope sooner or later.

The oscilloscope is a device that has the purpose of displaying the time behavior of one or two waveforms in a specific time window selected depending upon your choice of TRIGGER:
If you choose AUTO, the trigger signal will be generated internally and you will have no control over the synchronization of the signal(s) displayed.
If you choose NORMAL, the trigger signal will be synchronized with one of these 3 events: channel 1 exceeding a value that you select, channel 2 exceeding a value that you select or a signal of your choice plugged in the “external trigger” connection exceeding a value that you select. In general this is the option that you choose more often.
The digital scope that you will find at your lab table can visualize 2 independent signal sources. On each of them you can select independently the vertical sensitivity (volt/div). These scopes have two modes for setting the scale COARSE to select the “order of magnitude” of the signal

height (e.g. the difference between 1 V and 100 mV), and FINE to tune the vertical scale to more precise needs of a specific measurement. Be careful to choose the right attenuation! These scopes have some internal compensation for the attenuation induced by some specific probes. If you are using cables to connect the signal, please be sure to use X1 attenuation!

Finally, you will have to adjust the horizontal scale to the frequency and type of measurement that you are planning to make. For example, if you need to measure a rise time you should choose a horizontal scale that allows you to measure the time it takes for the signal to go from 10% to 90% of its full swing. If you need to measure a period or frequency, you should visualize the full waveform. Note that to make precise time or voltage measurements you can use two vertical and horizontal cursors. There are also some built in utilities that can help you in measuring waveform parameters, you have to be careful not to have noise and to have a proper setting to use those.

Checklist before you do your measurements:

- **Be sure to understand how to trigger a signal in NORMAL mode**
- **Be sure to be able to change the vertical scale**
- **Be sure to be able to change the horizontal scale**

## Note

Throughout these experiments you should use square waveforms from the BK generator. If you do not have it on your test bench please ask for my help. You can vary the frequency on the 1-10 KHz range. Use a horizontal scale that is sensitive enough to observe the details of the time development of the signal (rising edge). You are going to measure rise time, check effects of reflections etc. etc. zooming on the rising edge.

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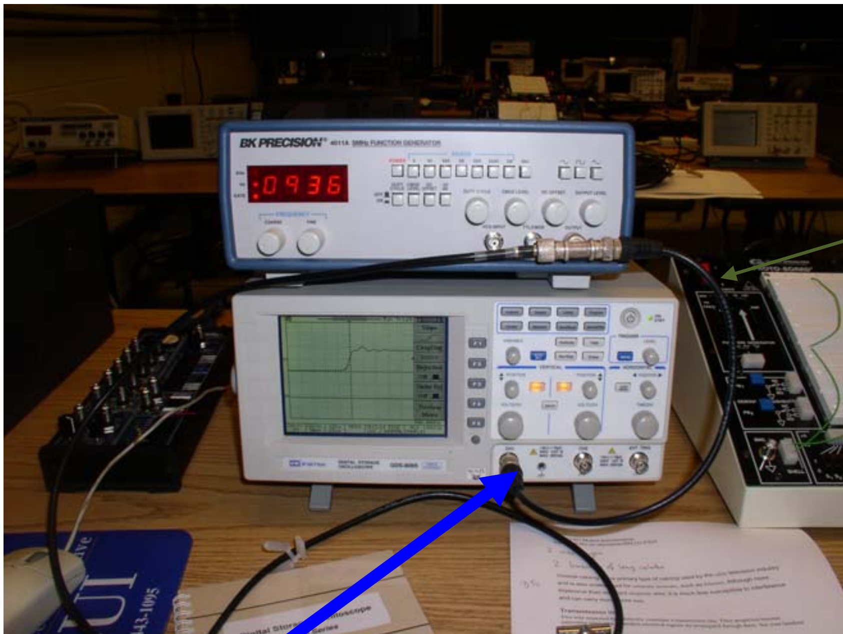
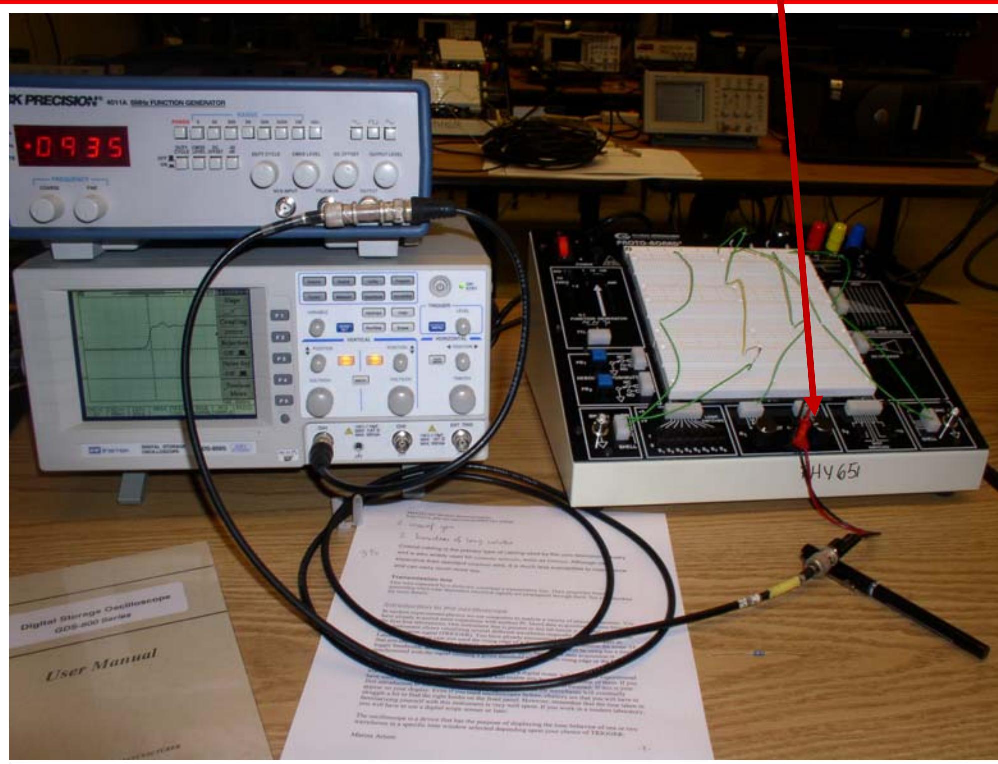



Longer coaxial cable from here to 1KΩ variable resistance on the PB-503

Short cable from waveform generator

Details of the connection of the long cable to the variable resistor



## Experiment 1

Before making measurements with the oscilloscope, grab a small BNC cable and measure the DC resistance of the inner conductor.
Connect the output from your waveform generator to the oscilloscope with a short BNC cable through at T. Observe the signal on the oscilloscope, making sure that you choose DC coupling, high impedance input configuration.
Connect the longer coaxial cable at the junction. What do you observe?
Now connect the inner wire and the shell to the variable resistor on the PB-503 (1KΩ max)
Observe the changes of the waveform as the resistance changes from almost 0 Ω to 1KΩ.
Measure the resistance for which you restore the step function waveform.

### ***Analysis***

Draw the input and output waveform and measure the rise time (time it takes to the first rising edge to go from 10% to 90% of the observed signal). For any " bump" in the direct signal & signal after the long coaxial cable note the distance from the rising edge.

## Experiment 2

Now connect a probe to the end of the long cable connected to the terminating resistor. The probe (set to attenuation /10) must be connected to channel 2 of your digital scope.

Observe the relationship between the signal seen at the source (waveform generator) and at the end of the cable.

## Analysis

Relate the distance between the edges in ch1 and ch2 and the distances between various bumps with different termination resistors. At the end of this laboratory measure the length of the long coaxial cable and determine the signal delay. Also, determine the characteristic impedance of the cable

## Experiment 3

Now repeat the experiment with the very long cable (bundled up) connected as an open circuit. Measure the distance between the incident and reflected wave, and the time separation between the edge of the signal at the source and the one at the end of the long cable. For this experiment you can connect the end of the long cable directly on channel 2 of the digital scope and set the gain equal to 1. Derive the propagation delay in a coaxial cable in ns/ft. At the end of the experiment please recoil the cable using the cable ties provided.