Rensselaer Polytechnic Institute

Computer Hardware Design – ECSE 4770

"Mini" Lab Assignment 1: Observing Transmission Line Effects With the Agilent 81110A Pulse / Data Generator

Ver. 1.0, Rev. B

Objectives

- To familiarize the student with the Agilent 81110A Pulse / Data Generator.
- To exhibit the problems associated with driving computer busses by examining the near-ideal reflections in a 50 Ω coaxial transmission line.

Introduction

This lab is to both help you see some more important effects of transmission lines and to become familiarized with the Agilent 81110A Pulse / Data Generator. Specifically, the 81110A provides the generation of clean pulses which will allow us to generate more ideal results of the desirable (and undesirable) effects of transmission line termination. Many of you noticed that the circuits you breadboarded for Laboratory 1 produced the line effects we were seeking, but the observed signals were pervaded with noise. Unfortunately, noise introduced in one part of your circuit will inevitably be propagated to others.

Noise is the downfall of any electronic system, especially in digital systems where a few tens of millivolts of noise could cause unstable logic levels. Knowing how to properly deal with noise is an important part of being a designer. It sets apart the good engineers from the bad. The slow, unreliable systems from the fast and dependable. We need to identify noise sources and eliminate them. Consequently, in order to identify noise in a system it is usually desirable to isolate circuit components and use ideal digital signals for testing. This is where the 81110A will help us out: it can generate digital waveforms that are ideal enough for our liking.

In addition, the 81110A is a useful piece of equipment for injecting arbitrary digital waveforms into your circuits. Why couldn't we just use our function generator and create a continuous pulse train for testing? Well, you could…but how useful would that be? First, you could not model *inter-symbol interference* (ISI). Second, most of the time our circuits will be looking for a unique data word like 11011000010 not 1010101... Perhaps you have a *finite state machine* (FSM) running a serial UART controller that activates based upon receipt of a specific binary word 1101001, which can be generated with the 81110A. These are excellent reasons to use the 81110A.

Theory

This laboratory assumes that you have a basic understanding about transmission line effects and why it is important to have properly terminated lines. We witnessed this in Laboratory 1 for a single pulse; imagine what type of havoc an improperly terminated transmission line could wreak on an actual data stream! While the effects we witnessed in the laboratory were interesting, they are in no way fundamental. Transmission line theory is a rather verbose and well-investigated topic that has many different areas than just line termination.[1] Interested students are encouraged to take ECSE-2100, Fields and Waves I.

Transmission line theory is often associated with RF Engineering and waves being emitted from radio antennas. However, it applies just as equally to computer hardware design. Traces on circuit boards or microchips are also transmission lines and have characteristic impedances as well. The signals you witnessed in Laboratory 1 and will witness in this mini-lab exhibit reflections coming back to the source. Why do we care what reflections come back to the source if the signal (sometimes) looks just fine at the load? There are several reasons: reflected energy is wasted and must be subsequently dissipated by the source, limits will be reached where the output signal will begin to be affected, etc.

Most laboratory generation equipment which you will come in contact with is meant to drive a 50 Ω load. Conversely, measurement equipment typically has an input impedance of 50 Ω as well.[2] This may not always be the case, however. Also, some devices—such as the digital storage oscilloscope (DSO) in the lab—may have selectable impedances.

Generally speaking, when you want to "probe" (i.e., look at it without affecting it too much) a signal at a point you should use a high impedance probe. If you connect a 1 MΩ resistor to a point, for instance, very little current flows through it. It's almost as though that resistor is not even there. The same holds true for oscilloscope probes. Hence, if you want to see what the output of a circuit that is designed to drive, and is driving, a 50 Ω load you *should not connect a 50 Ω probe*. If you do, you have just connected another 50 Ω load in parallel with the 50 Ω load under test and effectively halved the resistance of the load being driven.

Consequently, if you simply attach a coaxial line (or a probe that is does not recognize) to the oscilloscope you can manually adjust the input impedance that the line sees. As a result, your displayed signal will also change.

To expedite the completion of this lab, you will be changing the termination impedance by changing the input (sources channel no.). A step-by-step explanation will be provided for you.

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[1] For a brief overview on some of the most important transmission line theory, check out:

http://www.ibiblio.org/obp/electricCircuits/AC/AC_14.html

[2] For a brief review of input impedance and matching, see:

http://zone.ni.com/devzone/conceptd.nsf/webmain/EAF49A89CF5014C186256F2700114FC9

Besides offering us a fast way to change the source termination impedance, we will also be able to capture the plot of the signal "as it would be seen" at the load.

Equipment

The Agilent 81110A Pulse / Data Generator in the lab is configured with the Agilent 81112A output module referenced in the datasheets.[3] The front of the 81110A looks like this:
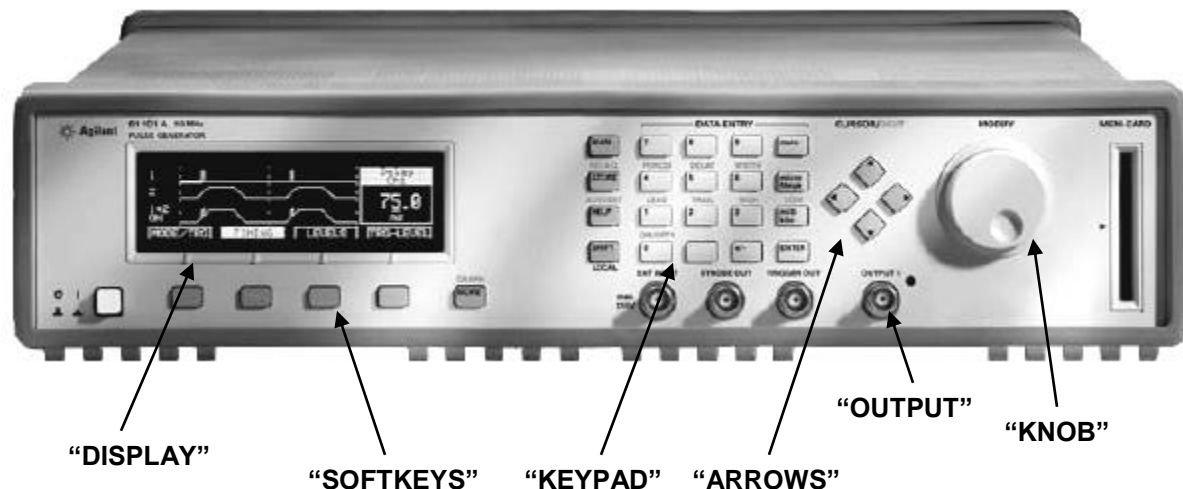
DISPLAY: This is where all of your menus are located and user interaction is performed.

SOFTKEYS: You will see that these buttons fall directly under menu options on the display. These select them.

KEYPAD: This is just like the keypad on the function generator. Here you can manually enter values (e.g., pulse period) when requested to do so. Almost all of the numeric values that you enter here will be followed by pressing the buttons to the right (i.e., *nano*, *micro*, *ENTER*, etc.).

ARROWS: Use these arrows to navigate to the options on the display.

KNOB: Rotate this knob to select sub-menus, change values, etc.

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[3] Screenshots and information contained herein are from the Agilent 81110A Pulse / Data Generator *Reference Guide* and *Quick Start Guide* available on Agilent's website at:

http://cp.literature.agilent.com/litweb/pdf/81110-91021.pdf and
http://cp.literature.agilent.com/litweb/pdf/81110-91020.pdf, respectively.

OUTPUT: This is where the connection is made for the waveform output. The 81110A in the lab has four output BNC connectors. You should only be concerned with OUPUT1 in this lab. $\overline{OUTPUT1}$, for instance, is the complemented version of OUTPUT1.

A typical menu that you will see on the <u>DISPLAY</u> can be seen below. In this case, the user selected the <u>SOFTKEY</u> for the "OUTPUT" menu on the display. They then navigated to the "Freq" entry focus using the <u>ARROWS</u> and selected "ENTER" on the <u>KEYPAD</u>. They then used the <u>KNOB</u> to select "Frequency" on the "MODIFY" submenu instead of "Period."
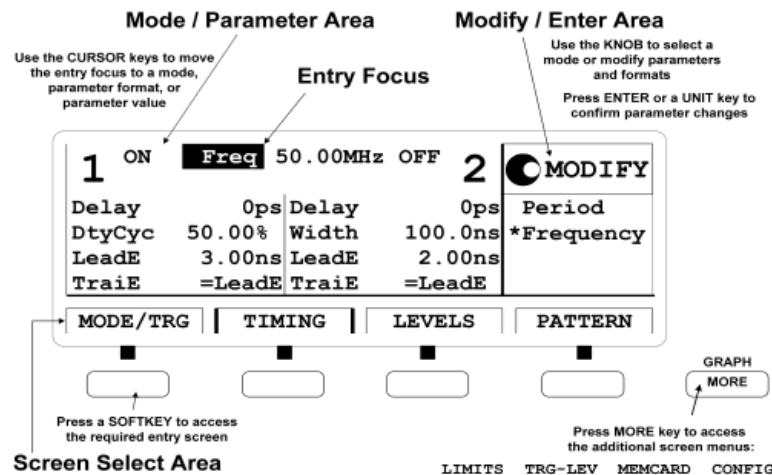
Tips:

1. Sometimes there is a second display associated with a menu which can be accessed by hitting the <u>SOFTKEY</u> a second time.
2. More menus may be available than what you see on the display. Select the "MORE" <u>SOFT KEY</u> to show them.
3. The blue "SHIFT" button on the <u>KEYPAD</u> will allow you to access the options associated with the blue titles above the other keys on the <u>KEYPAD</u>.

Line Reflections of a Single Pulse

In this portion of the lab you will see results similar to, but slightly different than, Laboratory 1. We will again be investigating reflections of a single pulse on a transmission line. Follow the following steps. Make sure you answer all questions and provide all screenshots in your post-lab report!

1. Turn on the oscilloscope and the 81110A.

2. Attach a 50 Ω RG-58 coax cable from OUTPUT1 of the 81110A to Channel #1 of the oscilloscope.

3. Make sure the Input of Channel #1 is set to 1 MΩ.

4. Press the button for the Mode / Trigger ("MODE/TRG") <u>SOFTKEY</u>. Make sure it is set to "CONTINUOUS PULSES." To change this, for example, try:

    a. Navigate to the "PULSES" option.
    b. Ensure that an asterisk (*) is next to the Pulse Stream ("PulseStrm") option under the "MODIFY" menu. If it is not, rotate the <u>KNOB</u> until it is.
    c. Also, make sure "Single-Pulses at Out1" and "Pulse-Period: internal Osc" are displayed. If they are not, fix these parameters.

5. Press the "OUTPUT" <u>SOFTKEY</u>.

6. We need the output options menu. If you see what looks like a waveform on the <u>DISPLAY</u>, this is what your output will look like. This is not a problem…just push the "OUTPUT" <u>SOFTKEY</u> again and the option menu should appear.

7. Navigate to the Period ("Per") option at the upper-left of the <u>DISPLAY</u>. If this instead shows "Freq," you will need to rotate the <u>KNOB</u> to select "Period."

8. Once you see "Per," navigate just to the right of it on the <u>DISPLAY</u> to highlight the time parameter. Enter **1.0 ms** (to select milliseconds, just hit the "milli/kilo" button on the <u>KEYPAD</u>.

9. In a similar fashion, set the following parameters:

 | | | | |
    |---|---|---|---|
    | **Delay:** | **0 ps** | **High:** | **+2.50 V** |
    | **Width:** | **1.515 ns** | **Low:** | **+0.0 V** |
    | **LeadE:** | **0.80 ns** | | |

    Also, make sure that "Normal" appears and not "Complmnt" on the top center of the <u>DISPLAY</u>.

10. Now turn on OUTPUT1. To do so, remember that you need to hit the blue SHIFT button and then the 0 button on the <u>KEYPAD</u>. This selects "ON/OFF 1."

11. You should see the pulse appear on the oscilloscope. Adjust the parameters for the channel on the scope such that the time scale is 2.00 ns/div and the voltage scale is 2.00 V/div. Also, adjust the horizontal positioning such that the pulse starts at time t = 0 on the oscilloscope display.

<u>*Question 1:*</u>   *What do you see? Is this consistent with your settings?*

CAPTURE YOUR RESULT! MAKE SURE WE CAN SEE ALL OF THE SIGNALS!

12. Now connect the cable running from the 81110A to the oscilloscope through a BNC T-connector to Channel #1. Change the time scale on the oscilloscope so that it is 10.0 ns/div.
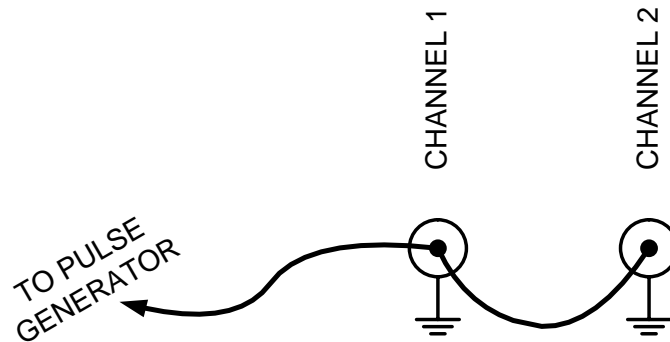
13. Attach another 50 Ω RG-58 cable to the other side of the T-connector on Channel #1. Attach the free end of this other cable to Channel #2 on the oscilloscope. Your connections should look like the figure above. Make sure that the Channel #2 input is set for 50 Ω and then turn on the channel. Set the vertical parameters for each channel to be 1.00 V/div and display Channel #1 above Channel #2.

Question 2:   *What do you see? What is happening? Why is it happening?*

CAPTURE YOUR RESULT! MAKE SURE WE CAN SEE ALL OF THE SIGNALS!

14. Now change the setting for Channel #2 to be 1 MΩ. Keep the same settings as in number 13 above.

Question 3:   *What do you see? What is happening? Why is it happening?*

CAPTURE YOUR RESULT! MAKE SURE WE CAN SEE ALL OF THE SIGNALS!

15. Keep the setting for Channel #2 on the oscilloscope as 1 MΩ. Now change the "Width" setting on the 81110A to 10.00 ns.

Question 4:   *What do you see? What is happening? Why is it happening?*

CAPTURE YOUR RESULT! MAKE SURE WE CAN SEE ALL OF THE SIGNALS!

16. Now change the oscilloscope settings such that the display is 2.00 V/div on the voltage scale and 10.0 ns/div on the time scale. Next, change the "Width" setting on the 81110A to 30.00 ns.

Question 5: **What do you see? What is happening? Why is it happening?**

   CAPTURE YOUR RESULT! MAKE SURE WE CAN SEE ALL OF THE SIGNALS!

   17. Change the setting for Channel #2 on the oscilloscope back to 50 Ω. You should notice a drastic change in the signal.

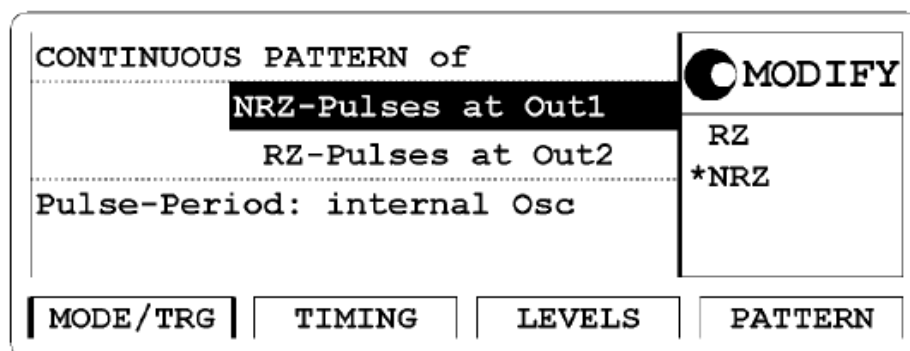*Question 6:* **What do you see? What is happening? Why is it happening?**

   CAPTURE YOUR RESULT! MAKE SURE WE CAN SEE ALL OF THE SIGNALS!

Question 7: **Given what you just saw, why are we so concerned with proper termination?**

Line Reflections of a Serial Stream

Next, we are going to investigate what happens with improperly terminated transmission lines that carry actual data streams. We will be using the arbitrary serial data function of the 81110A. We will assume you learned the basics of navigating through the menus hereon in. Follow these instructions:

   1. Leave your cable attachments to the oscilloscope as they are.

   2. Reset all parameters and modes by pressing SHIFT + STORE (RECALL) + 0.

   3. Press the "MODE/TRG" <u>SOFTKEY</u> to enter the "Mode/Trigger" menu.

   4. Adjust the options such that the top of the <u>DISPLAY</u> reads "CONTINUOUS PATTERN of" at the top.

   5. If it reads "RZ-Pulses at Out1," change it so it says "NRZ-Pulses at Out1" (NRZ = No-Return-to-Zero).   Your <u>DISPLAY</u> should look something like this (note that the 81110A's in the lab have slightly different <u>SOFTKEY</u> menu options):

```
┌─────────────────────────────────────────────────┐
│ CONTINUOUS PATTERN of          ┌──────────────┐  │
│ ......................         │ ⬤MODIFY      │  │
│        NRZ-Pulses at Out1      │              │  │
│                                │   RZ         │  │
│        RZ-Pulses at Out2       │  *NRZ        │  │
│ .....................          │              │  │
│ Pulse-Period: internal Osc     │              │  │
│                                │              │  │
│                                └──────────────┘  │
│                                                  │
│ ┌─────────┐ ┌─────────┐ ┌─────────┐ ┌─────────┐ │
│ │ MODE/TRG│ │ TIMING  │ │ LEVELS  │ │ PATTERN │ │
│ └─────────┘ └─────────┘ └─────────┘ └─────────┘ │
└─────────────────────────────────────────────────┘
```

6. Press the "OUTPUT" <u>SOFTKEY</u> (this is equivalent to the "TIMING" menu above in the figure).

7. We now need to set the timing parameters. Turn on OUTPUT1.

8. Change the timing option such that you can enter a frequency instead of a width. Set the frequency to 80 MHz.

9. Press the "PATTERN" <u>SOFTKEY</u>.

10. Navigate to "Last" and enter a value of 24.

11. Navigate to the bit-editing window for "CH1" and enter the pattern:

    $$111001110011001001010010$$

    by pressing the 0 or 1 key as necessary. When entering the pattern the bit-editing window automatically moves one location to the right after each key stroke. By turning the knob counterclockwise you can move the bit-editing window back.

12. You should notice that the oscilloscope is having a tough time triggering on the signal you are giving it. We are not providing a continuous square wave like we normally would. It does not know where the beginning of the serial stream is. Therefore, we need to give the scope a strobe signal to know when this is. Make sure the first bit of the 24 that you set is 1 for the "STRB" pattern, i.e.:
    $$100000000000000000000000$$

    You then need to connect a cable from the STROBE output on the pulse generator to the trigger input on the oscilloscope. Make sure you change the source on the oscilloscope's trigger settings to use the trigger input instead of the Channels as it normally would. The "Autoscale" button may not work so you will have to set this manually.

13. The input impedance on Channel #1 should still be 1 MΩ. Alternate the input impedance on Channel #2 between 50 Ω and 1 MΩ.

<u>*Question 8:*</u>   *What do you see? What is happening? Why is it happening?*

CAPTURE YOUR RESULT! MAKE SURE WE CAN SEE ALL OF THE SIGNALS!

14. Try changing the frequency of the serial data to something low (≤ 1.0 MHz) and observe what happens.

<u>*Question 9:*</u>   *What do you see? What is happening? Why is it happening? What is the difference between this and the results in <u>Question 8</u>?*

CAPTURE YOUR RESULT! MAKE SURE WE CAN SEE ALL OF THE SIGNALS!