Pulse Interval Timing

Update: December 2, 2020

1 Introduction

Electronic pulses, like that shown in Fig. 1 have always played a key role in experimental work. They can signal that some event has occurred, because they either they exist or they do not. Their existence can mean "yes, it occurred," while their absence can mean "nothing has happened." Such pulses can also be generated sequentially, at regular intervals to drive some experimental need, like the flashing of an excitation pulse (of light) for example. The cabling you see among lab equipment is typically the conduit for pulses to travel between devices, that collectively make an experiment work.

Pulses can come in a variety of shapes and sizes. As mentioned, a single "square" pulse is shown in Fig. 1.

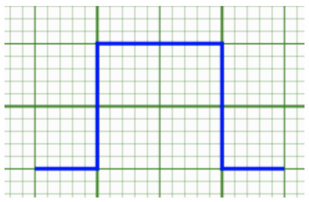
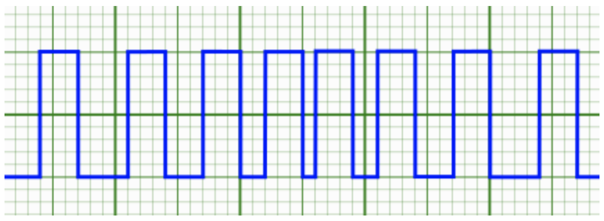


Figure 1: Example of a square pulse.

Such a pulse sits at 0V, rises quickly to +5V for some period of time, then rapidly falls to 0V again. Pulse amplitudes can vary, but formal "logic" pulses typically are either at 3.3 and 5V. Nuclear detection pulses (from a pre-amp) can even go negative in voltage.

A pulse *train* is a sequence of pulses, one arriving after another. They may be equally spaced (as from a function generator), or resemble this with the unequal spacing.



Pulse trains may also be a serial data stream, or a collection of many single pulses arriving at different times, each representing the occurrence of some event.

In this lab, we'll consider the presence of a pulse as a signal that something happened and in particular, we'll focus on examining the timing interval between such pulses for three physical processes:

1. Gamma-ray emission,
2. avalanche breakdown of a Zener diode,
3. and arrival of a Muon from outer space.

The focus here will be to statistically analyze the intervals between pulse arrivals, as generated by these processes.

1.1 Lab Motivation: Random Numbers

Believe it or not, the world is always in need of truly random numbers, or number that are unpredictable. Cryptography and Internet security for example, all critically depend on random numbers. As do gaming (i.e betting and gambling) and forecasting and simulations. Suppose an electronic slot machine in Las Vegas had a winning sequence that was somehow predictable?

As you may agree, there are processes in nature tend to be truly random and inherently unpredictable. This includes small (noise) fluctuations in a variety of scenarios, such as radioactive decay, beam splitting of photons, photoelectric emission, and thermal noise in electronic circuits. These are processes that no one can entirely predict the outcome of.

In this lab, we'll consider the randomness of the emission of a gamma ray from a nucleus and the reverse breakdown of a Zener diode. These events contain true randomness. We'll also address if they could they be used to generate random numbers (think: could you put such inside of a slot machine?).[1]

2 Random Process I: Muon Detection

Muons are created in the earth's upper atmosphere when cosmic particles (mostly protons) from outer space collide with molecules in the atmosphere. Muons then shower down to earth. We can detect them down here at the earth's surface by simply setting up a scintillation detector and leaving it on. When they strike the detector, a Muon will stop in the detector, then decay since Muons are not stable particles. The stop and decay each generate a flash of light in the scintillator. Each flash will cause–you guessed it–a square pulse into the detection electronics. The muon lifetime is shorter than the time itll take them to reach the earths surface, so we shouldnt see them down here save for time dilation in our reference frame, at the near c speeds at which they travel.

[1]A scientist at FermiLab has a gamma-ray detection system connected to the Internet, as seen here: `https://www.fourmilab.ch/hotbits/`. Sequences of random bits are posted.

As you might guess, Muon creation is our first natural and random process to study. No one knows when they will be created or detected. Further, once a Muon hits a detector, when it will decay is also totally random and unpredictable.

This document will not discuss Muon detection further. There is a section on the lab Github page here `https://github.com/tbensky/PhysicsLabs#lab-10-detecting-muons`, and there is also an established lab manual on this experiment you should follow.

3 Random Process II: Zener Diode Breakdown

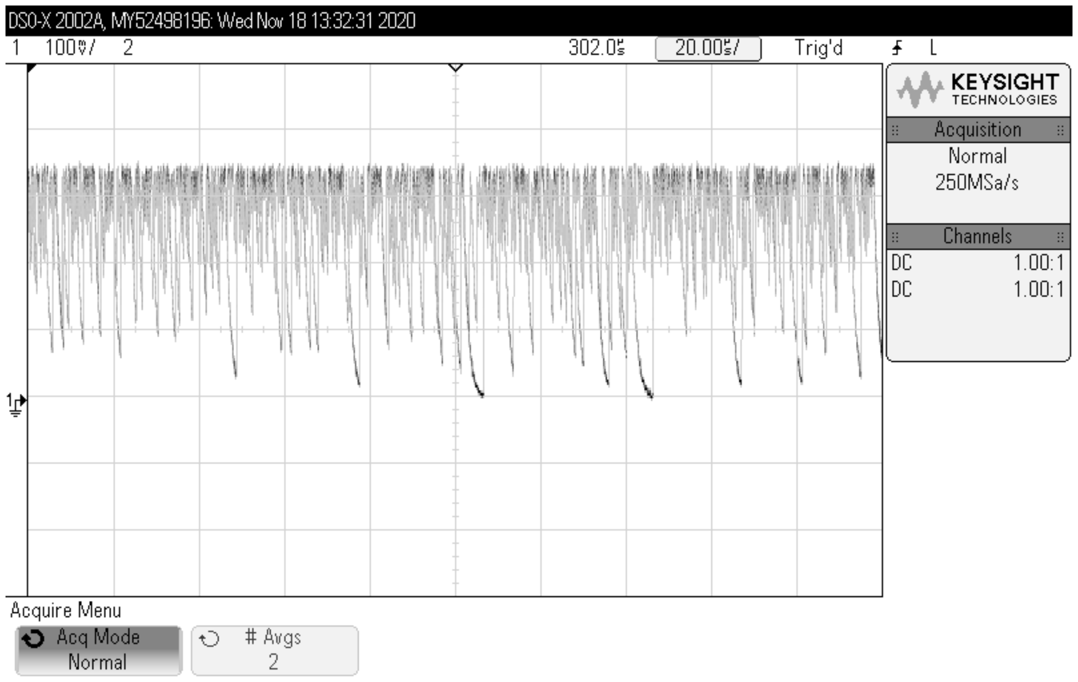
In our second random natural event, we'll look at reverse avalanche breakdown of a Zener diode. Interestingly, you don't need a bunch of sophisticated electronics to study this. It can be done using an Arduino and a small circuit you can build yourself. This idea is based on a paper out of Stanford[2]. This group actually developed a circuitboard that will deliver truly random bits to some downstream computer. What would this be based on?

You may recall a Zener diode does not conduct in the reverse direction until an applied voltage across it exceeds some level. It then begins conducting. As soon as the applied voltage falls below that same level, the diode will cease conducting once again. Suppose we look at at 12.1V Zener diode. The 12.1V is the conduction voltage level. The Zener will not conduct as long as the voltage applied to it is below 12.1V, but will suddenly conduct if the applied voltage exceeds 12.1V. Zeners are often used to protect downstream electronics. Suppose one sits at the input of a sensitive device that can only sustain a 12V input signal. Should the input exceed 12V (or 12.1V), the Zener will conduct, shunting the input signal away from the sensitive input.

Here, we exploit an interesting behavior of Zener diodes. Suppose for the 12.1V Zener, we slowly start increasing the applied voltage across it. As it the voltage reaches around 10V or so, spurious thermal electrons at the PN layer may "jump across" the layer, being accelerated by the applied voltage. As one such electron accelerates, it'll collide with others, causing them to do the same, then others and others; an "avalanche" of electrons will start to jump the junction, causing a spurious and brief conduction event within the Zener. These conduction events are shown here, by the large spikes that grow downward to the CH1 ground level.

This will not be sustained conduction. It'll be brief, only lasting for a few microseconds, but it will be detectable. And note the use of "spurious" twice here, to mean *random*—truly random. No one can predict when a thermal electron will initiate the avalanche process. Thus, a Zener will exhibit truly random fits of temporary conduction. If one builds a circuit to monitor such conduction, the observation of the conduction will be witness to a truly random event in a do-it-yourself circuit.

[2]https://sing.stanford.edu/site/publications/rng-sensys16.pdf



3.1 The Circuit

3.1.1 Parts needed

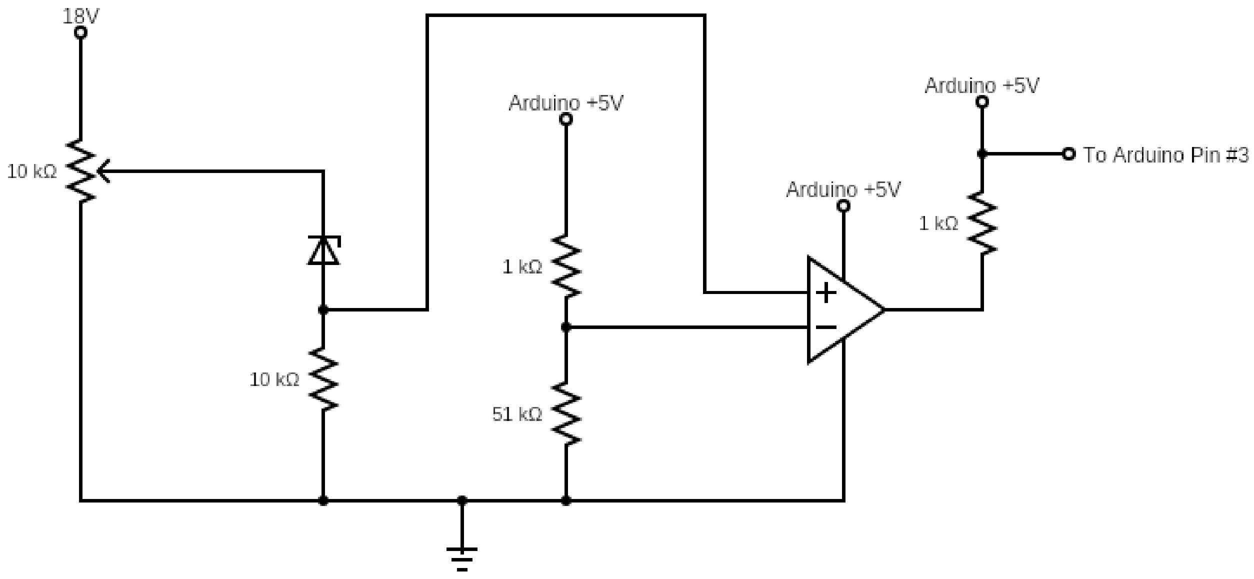
For this, you'll need the following parts.

1. 2 9V batteries
2. 18V battery clip
3. breadboard
4. Arduino Uno
5. Jumper wires
6. LM311
7. 10K resistor
8. Zener Diode
9. (optional) small speaker element
10. 1K resistors (2)
11. 51K resistor
12. Installed Arduino IDE. Free here: `https://www.arduino.cc/en/software`

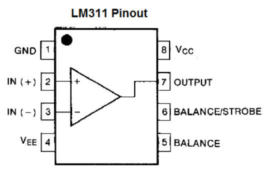
In addition to building this circuit, you'll need an Arduino Uno to perform this experiment. It'll act like lab equipment that will take your data.

3.1.2 Building the circuit

Here is the circuit you'll need to build, along with a pinout of the LM311.



This pin diagram of the LM311 should be useful.



Note when wiring up your LM311:

- Pin 8 is to be at +5
- Pin 4 is to be at ground
- Pin 1 is to be at ground too
- Pins 5 and 6 will be left unconnected
- Pins 2 and 3 are the + and - inputs as shown in the circuit

Circuit assembly hints can be found here: `https://youtu.be/wJv6fEVaaRA`, with a neater version here `https://youtu.be/2udPSj1wQOE`. A tour of the working circuit can be found here `https://youtu.be/XYe5NGDQSmE`.

3.1.3 Running the circuit

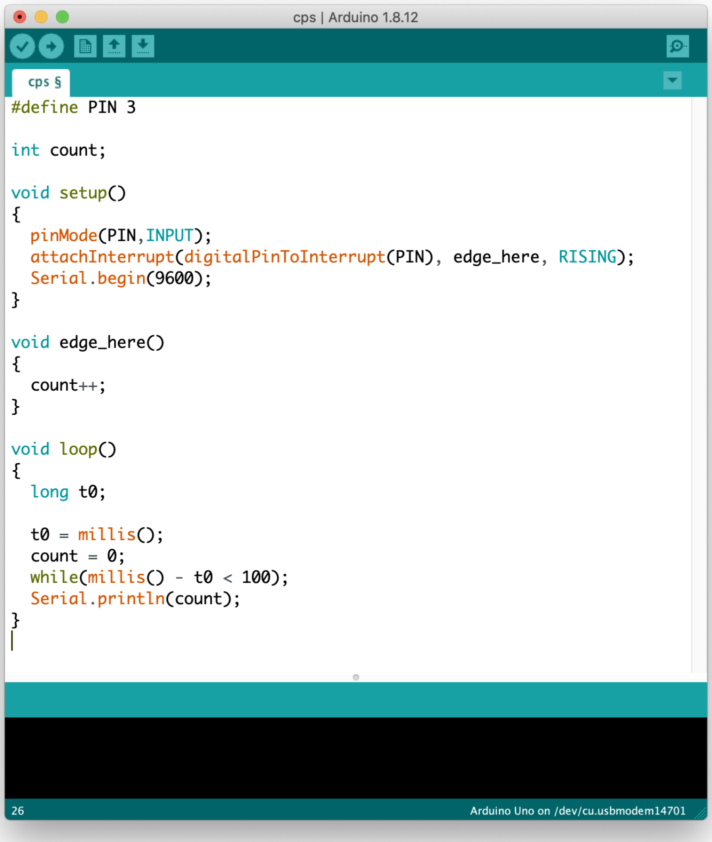
It is hard to know if your circuit is working without an oscilloscope, but here what you may try.

1. Connect the 2 9V batteries to the 18V battery clip (get 2 for $1 at the dollar store).
2. Power up your Arduino by connecting its USB cable to your laptop or a USB plug-in charger.
3. Use your voltmeter to check the voltage on the wiper of the 10K potentiometer. As you turn the knob, this voltage should change. You should be able to vary it from 0 to 18V.
4. Check the voltage at the connection point between the 1K and 51K resistors. It should read about 0.1V.
5. Break the connection between the +5V and the 1K resistor coming out of LM311, connect your small speaker to bridge this break in your circuit.
6. Turn the potentiometer until you hear a whooshing sound. This should happen around 10.3V or so when you turn the potentiometer. If you hear this, it is generated by your Zener going through fits and spurts of random conduction.

3.1.4 Arduino as a scalar

At this point, your circuit is producing pulses. In the lab, counting how many pulses per time interval are produced is a key measurement. This is what the "scalar" did in the gamma-ray labs. Here, you'll program your Arduino to work as a scalar.

The following code will count how many random pulses the Arduino sees coming from your circuit in 100ms (0.1 s). Compile and upload this code into your Arduino. Open the serial monitor. A list of numbers should start scrolling down the screen. Turn the potentiometer until you hear the whooshing sound from your speaker. You should be able to change the number of counts per 100ms you see scrolling by. This is the number of random pulses/100ms your circuit is generating.

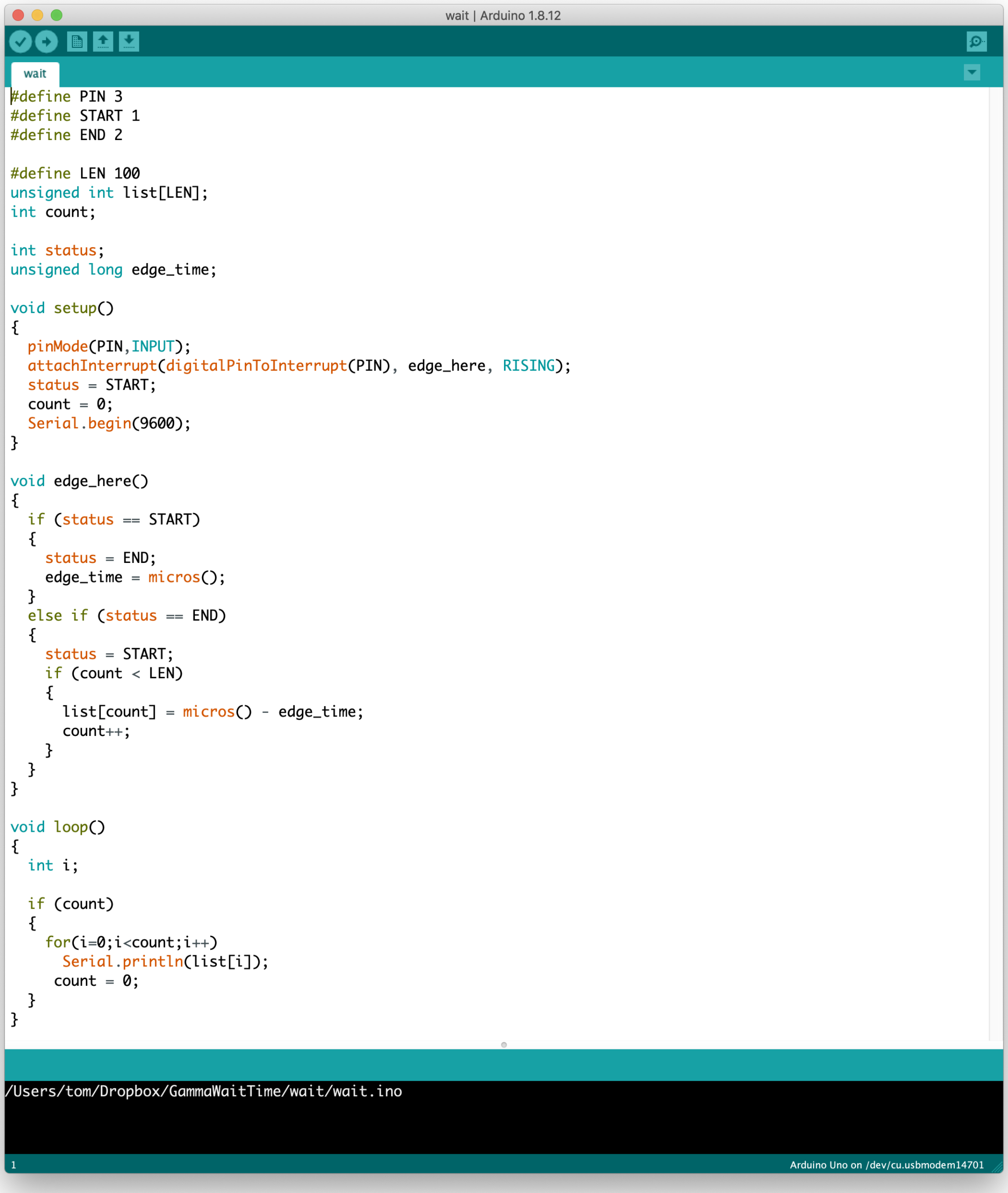


```
#define PIN 3

int count;

void setup()
{
  pinMode(PIN,INPUT);
  attachInterrupt(digitalPinToInterrupt(PIN), edge_here, RISING);
  Serial.begin(9600);
}

void edge_here()
{
  count++;
}

void loop()
{
  long t0;

  t0 = millis();
  count = 0;
  while(millis() - t0 < 100);
  Serial.println(count);
}
```

Figure 2: Code to have the Arduino count how many pulses are seen coming in on digital input pin 3 in 100ms.

3.1.5 Arduino as a pulse interval timer

The following code will log the times *between* pulses coming from your circuit. This is the "pulse interval" timing. Compile and upload this code into your Arduino. Open the serial monitor. A list of numbers should start scrolling down the screen. Turn the potentiometer until you hear the whooshing sound from your speaker. You should be able to change the number of counts per 100ms you see scrolling by. This is the number of random pulses/100ms your circuit is generating.


wait | Arduino 1.8.12

wait

```
#define PIN 3
#define START 1
#define END 2

#define LEN 100
unsigned int list[LEN];
int count;

int status;
unsigned long edge_time;

void setup()
{
  pinMode(PIN,INPUT);
  attachInterrupt(digitalPinToInterrupt(PIN), edge_here, RISING);
  status = START;
  count = 0;
  Serial.begin(9600);
}

void edge_here()
{
  if (status == START)
  {
    status = END;
    edge_time = micros();
  }
  else if (status == END)
  {
    status = START;
    if (count < LEN)
    {
      list[count] = micros() - edge_time;
      count++;
    }
  }
}

void loop()
{
  int i;

  if (count)
  {
    for(i=0;i<count;i++)
      Serial.println(list[i]);
     count = 0;
  }
}
```

```
/Users/tom/Dropbox/GammaWaitTime/wait/wait.ino
```

1 Arduino Uno on /dev/cu.usbmodem14701

Figure 3: Code to have the Arduino behave as a pulse interval timer.