PHYS 5061 Lab 7
Counting and Velocity Measurements

Introduction
Counting is a simple operation for digital systems. Timing is then a simple application of this idea to count regularly repeating clock pulses. As a result of the simplicity of timing, it’s often desirable to convert the physical quantity you want to measure into an interval of time and use counters and a reliable clock to measure that time interval. Hence any quantity easily converted into either a frequency or a period can be measured almost trivially by counting.

Velocity measurements
Perhaps the simplest example of timing to make a physical measurement is measuring velocity, where the connection between time and distance allows simple time measurements to give fairly high resolution measurements of speed. For example, by measuring the time required for an object to travel a fixed distance, the average speed can be extracted easily.

To make timing measurements you have two options: (1) Build a timer circuit based on a single-chip 4 digit counter and quartz crystal oscillator; or (2) Learn how to make use of the USB-6211 timer/counter subsystem and LabVIEW to make a timer. There are notes on the former option later on. The LabVIEW route will require you to dig into the manual for the USB-6211 a little to understand the many possibilities of the counter timer subsystem. There are DAQ Assistant VI’s that allow you to make use of some of the timing features. Essick’s book also provides guidance on delving deeper into using low-level data acquisition routines, the DAQmx VI’s, in chapter 12, although it doesn’t address the use of the timing features directly. These VI’s provide greater flexibility in configuring the DAQ hardware and (eventually) provide a better understanding of what decisions are really being made when you use a DAQ Assistant VI.

Once you have got a functional timing system (chip-built or LabVIEW-based with the USB-6811) you will adapt your timer to a velocity measurement. The balance of this lab will involve making timing measurements on one of two systems. One timing problem consists of timing the duration of the contact between a thin metal rod dropped onto a heavy steel block as the rod bounces back. The duration of contact in the bouncing process can be related to the speed of sound in the rod. The second option is to measure the time-of-flight of a projectile (specifically a BB) shot from a gun over a fixed distance. More information on these options follows. You should keep a good notebook of all your efforts in carrying out the tasks associated with this experiment. You will write a brief technical report on the experiment later. (Details to follow.)

Contact time: If you allow a piece of material to be dropped onto another, the falling piece will usually bounce one or more times. Upon first contact, both it and the piece
underneath are momentarily compressed before the falling piece returns to the air. The situation here is a long thin metal rod dropped onto a heavy steel plate. The objective is to measure how long the rod remains in contact with the plate during the first bounce. You will need to invent an appropriate switch circuit to carry out this measurement. To do the necessary counting make use of as much of your timer system already developed and add and adapt as needed.

Then, after thinking about the physics of the bounce, measure the bounce contact times and determine the speed of sound in the metal rod. In thinking about the bouncing process, you’ll need to be able to explain exactly how it is that the rod is made to move upwards after contact with the plate, and when the bottom end of the rod is made to leave the plate. Since this experiment is supposed to yield a speed of sound, the fact that the rods are stiff but not perfectly rigid must in some way be relevant. You should carry out lots of trials, since the measurements themselves will take very little time.

Investigate at least two different rod materials, and for at least one of those rods or materials look for any systematic dependencies on one other parameters that might influence the contact time: the length of the rod, the diameter of the rod, the initial height the rod is dropped from.

For each rod tested report an average speed of sound deduced from your measurements as well as an uncertainty in that calculated value and report any trends you see in other parameters. Compare your measured value to values reported in handbooks (e.g. CRC Handbook of Chemistry and Physics). If you omit any measurements during your data analysis, suggest reasons or mechanisms why they can be discarded in analyzing your data.

**BB Experiment:** The basic idea is simple: detect when the BB passes a known reference point, start counting clock pulses, and stop when the BB passes a second reference point. Measure the distance between the two locations and use the recorded time values to estimate the velocity. This clearly requires several components, most of which should already be available from your previous work. You should also be sure your existing counting circuit can be started and stopped in a manner compatible with the the rest of your system. You may need to modify your start/stop circuit (clearly the push-button of the preliminary testing is not suitable for this application). The most difficult aspect probably involves designing a suitable mechanism for detecting the arrival of the BB at the start and stop points and ensuring that your measurements will not be significantly affected by switch bounce. The counting, display, and de-bouncing aspects can be taken care of largely without detailed knowledge of the switching mechanism, but rather just a general idea. Attack the problem in a modular fashion. Choosing a switch mechanism is the most troublesome aspect of the problem. A couple of varieties have been used in the past. The simplest method is to rely on the BB to break a thin strip of aluminum foil as it passes each of the two reference points and incorporate the aluminum foil as a switch, initially closed (continuous) and then open (broken) (similar to the scheme described in a problem in chapter 8 of *The Art of Electronics* by Horowitz and Hill). This method can be tedious but is simple to implement. Proper positioning of the aluminum strips can be accomplished
by first placing thin sheets of paper in the path of the BB at the measuring points to locate
the proper foil position based upon holes left by a trial shot.

A more elegant scheme (and more difficult to implement) uses an optically driven tran-
sistor (photo-transistor) and an infrared-emitting LED (c.f. the discussion of optical in-
terrupters in Horowitz and Hill’s *Art of Electronics*). The BB breaks the beam of light to
the photo-transistor (the base is photo-sensitive) and momentarily turns the transistor off.
Once again, one can use the transistor as a switch and detect the change in state. This
method requires careful alignment of the source and detector pair and for truly reliable
operation requires an AC coupled op-amp-based amplifier plus a comparator at the front
end.

Another possibility is to detect the BB passing through a coil of wire inductively. This
might require a bit of tinkering to make it work.

The aluminum foil method, while tedious, is at least straightforward, using a minimum
of additional components. You should carry out at least five complete, reliable measure-
ments, compute the velocity of the BB, and estimate the uncertainties in your results
based upon careful consideration of your measurement methods and the precision of your
measured values.

**Warning!**

Both in the bouncing rod and the BB via aluminum foil, it is important to design “switch”
mechanisms that produce TTL compatible levels and are designed to limit the current that
can plow through your switch mechanism. Allowing a +5 V supply to be shorted directly
to ground is wrong and dangerous to the power supply and perhaps to your grade. Think
carefully about how your mechanism (to detect when the rod is in contact with the block
or whether an aluminum foil strip is broken or not) works: more than just thinking about
voltages, be able to explain what currents are flowing where under the various states of
your switch. Include appropriate pull-up or pull-down resistors that limit currents that can
flow.

**Single IC counter-timer**

Build a timer using a relatively fancy IC counter, the 74C925, which both has a complete
counter built-in and knows how to drive a 7-segment common-cathode LED numerical
display (a 4-digit one, the pinouts are of the K-43 package variety). Your mission is to
build a stopwatch which counts in milliseconds. One push-button switch should start and
stop the timer. A second should reset the timer to zero. As a start, use the SYNC/TRIG
output of the function generator for an input clock. Begin with a 1 kHz clock frequency so
the timer times in milliseconds as a starting point for this part of the lab. Test you timer
thoroughly before upgrading to a faster clock source.

Note that this counter chip is a CMOS chip. These are susceptible to being killed
by static, so please keep the chips either in their black conductive styrofoam or in the
breadboard. Use the 74HCT- family of logic gates with it. These are high speed CMOS
with TTL-compatible logic levels. They often share the same pinouts as the 74LS- family of TTL logic gates. For instance, the 74HCT00 is a quad 2-input CMOS NAND with the same pinout as a TTL NAND 74LS00. There is also a CMOS data book in the lab with all the details on all the chips.

The 74C925 counter has two parts (see the block diagram on the datasheet). The first is a counter, which takes as inputs a clock, a reset and a latch enable. It can count to 9999, and outputs BCD (Binary Coded Decimal). The second part of this chip is the output display driver. It provides 7 output lines (a through g), which light up the seven segments of an LED digit appropriate to form one of the BCD digits present in the counter part of the chip. It outputs one of the four digits of the count at a time, and enables control lines $A_{out}$ through $D_{out}$ so that you know which of the four digits present is currently being sent out over the output bus. This is an example of output multiplexing.

The LED display accepts as input the a through g lines, the $A_{out}$ through $D_{out}$ digit select control lines, and gratuitous controls for making colons and dots appear should you want to make a fancy clock. (can you make your stopwatch output seconds instead of ms with the appropriate decimal place appearing). The seven segment input lines are the actually the LED segment anodes. The chip is common cathode, so the cathodes of all seven segments of a digit are tied together at the appropriate A through D digit select line. To make a segment of a digit light up, the appropriate segment line is enabled powering the LED’s anode, and the digit’s common cathode digit select line is tied to ground so current flows and the LED segment lights up. Use a 2N3904 NPN transistor as a switch to ground, controlled by the counter chip’s digit select line and including a current limiting resistor to control whether or not the cathode is grounded for a given digit (see figure).

Draw a block diagram of your circuit showing how it works. And draw a careful schematic listing pin numbers on the wires. Record your experiences designing, testing, and debugging the thing, and be sure to draw schematics for extra circuit elements you might have to add in order to divide a voltage, debounce a switch, or whatever.

Check your new timer against your wristwatch or the wall clock. If it is running fast or slow, how can you easily adjust the timing? Measure how fast your thumb is by seeing how long it takes for to you start and stop the clock. Take 20 measurements of this and comment on your consistency or lack thereof. What problems with the circuit could lead to very misleading times? Have you already corrected such problems, or how would you go about doing so?

Speed up the counter for faster timing applications: use a 1 MHz quartz crystal oscillator as the clock. These convenient pre-packaged oscillator systems provide a TTL compatible output and are very stable frequency sources. Check the data sheets on wiring them up. Once your circuit is running you will be able to measure the frequency of your particular oscillator precisely with a commercial frequency counter.
Figure 1: Wiring for driving a common cathode 7-segment display from a 74C925 counter chip. Common cathode means that the cathode (-) ends of each of the 7 display segments (LEDS) of one digit are connected together to ground through a shared or common connection, in this case through an external NPN transistor you need to provide. Each of the four digits requires such a transistor. The sketch above includes one current limiting resistor per digit (a lazy approach). The data sheets recommend one resistor per each of the seven segments, placed on the high side of each segment diode.