Lab #13a: Distance to the Moon (Time Delay)

PROCEDURE AND LAB REPORT

Date:_______ Your name: ___________Partner's name: ___________ Section: ___/___

Maximum two students may work together as partners!

Read:

In the laboratory exercise, we'll use a method based on the delay of radio signals to determine the distance to the Moon.

Radio waves and light are essentially the same thing, differing only in wavelength (you might say that radio waves are light of very-very red color). They all propagate with the same "speed of light". You will measure the time delay in a conversation between the Flight Center in Houston, TX and the astronauts orbiting the Moon. The conversation is carried from and to the Moon in the form of radio waves. You will also measure the speed of light in a cable. The two results put together will tell you how far the Moon is. In fact, the most accurate measurement of the distance to the Moon has been a variation of this lab: the Apollo 11 astronauts left a mirror on the lunar surface, and astronomers use it to reflect a laser beam back to their telescopes. They measure the time the laser beam takes to go two ways just like you'll measure the time radio waves take to carry the sound of the people in the conversation, to and back from the Moon.

As Apollo 13 was getting ready for landing, an on-board oxygen tank suddenly exploded. The astronauts had been taught to remain calm in emergencies and use code instead of panicking. They said, "Houston, we have a problem here!" Then, "Say that again!" and "Houston, we have a problem!" The conversation is about an explosion, and the astronauts take a long break before answering? The delay is due to the time the signal takes to propagate from Earth to Moon and back.

Procedure:

Listen to the audio clip named *TroubleSequence.mp3*, an excerpt from NASA's Apollo archive, and located in the *AstroLab/AstroDocuments* folder. Note the delay between question and answer, even in a situation when you would think the astronauts would certainly give an immediate answer. Using a stopwatch, measure the time delay. Notice that there are many exchanges of conversation, and you need to guess in which one(s) is the wait due to the travel time of the signal, and in which case the other party just did not answer immediately. Obviously, whenever the person does not answer immediately, the delay is *longer* than the delay due purely to the travel time of the signal. Use common sense! Your result is: ____ *sec*.
This is the delay between question and answer; during this time, radio waves must travel the distance between Earth and Moon *twice*.

You conclude that the distance to the Moon is _____ *light seconds*.

Read:

Your measurement of the distance to the Moon in light seconds needs to be converted into *km'*s, and that can be done only if we can measure the speed of light (which is, again, the same as the speed of radio waves) in a laboratory on Earth. For this measurement we send a radio pulse through a coaxial cable and measure how long it takes to go from one end to the other. Measuring also the length of the cable, we can figure out the speed of light.

Obviously, the speed of light is very large, so we will expect a very short time delay between the pulse entering one end of the cable and coming out at the other end. Because of this, the experiment is quite sensitive and takes a long time to correctly set up. Your instructor will demonstrate the measurement and explain how the devices work, and your job will be to take the readings and use them to calculate the speed of light.

Here is how the experiment works. An electric circuit that we call "pulser", placed in a small black box, creates very short pulses of radio signals that are led into a green coaxial cable. The coaxial cable is a flexible thin metal tube with another metal wire inside it. Between the tube and the wire there is a layer of polypropylene (plastic), which slows the radio waves by 33%, and you'll have to correct for this at the end of your calculation.

Fig. 1: Direct signal

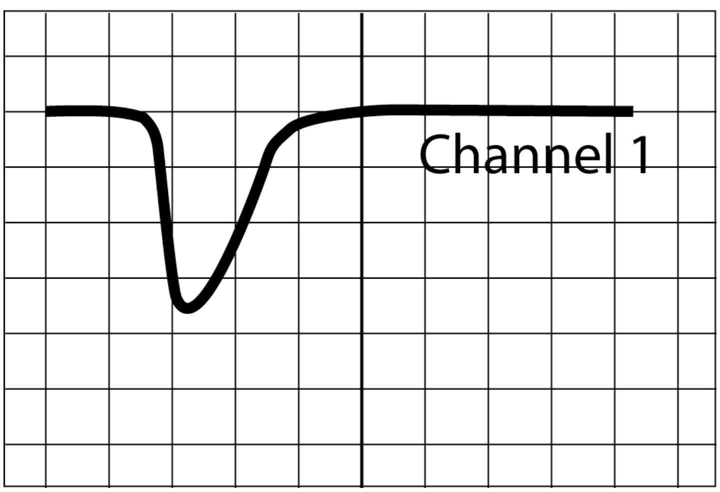
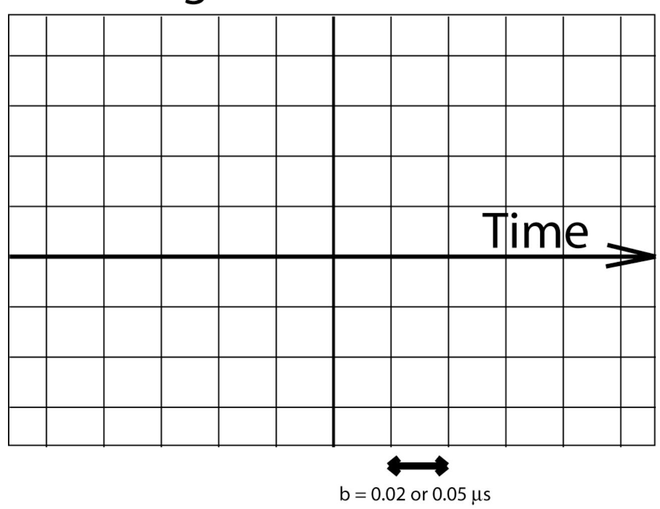


Fig. 2: The time unit

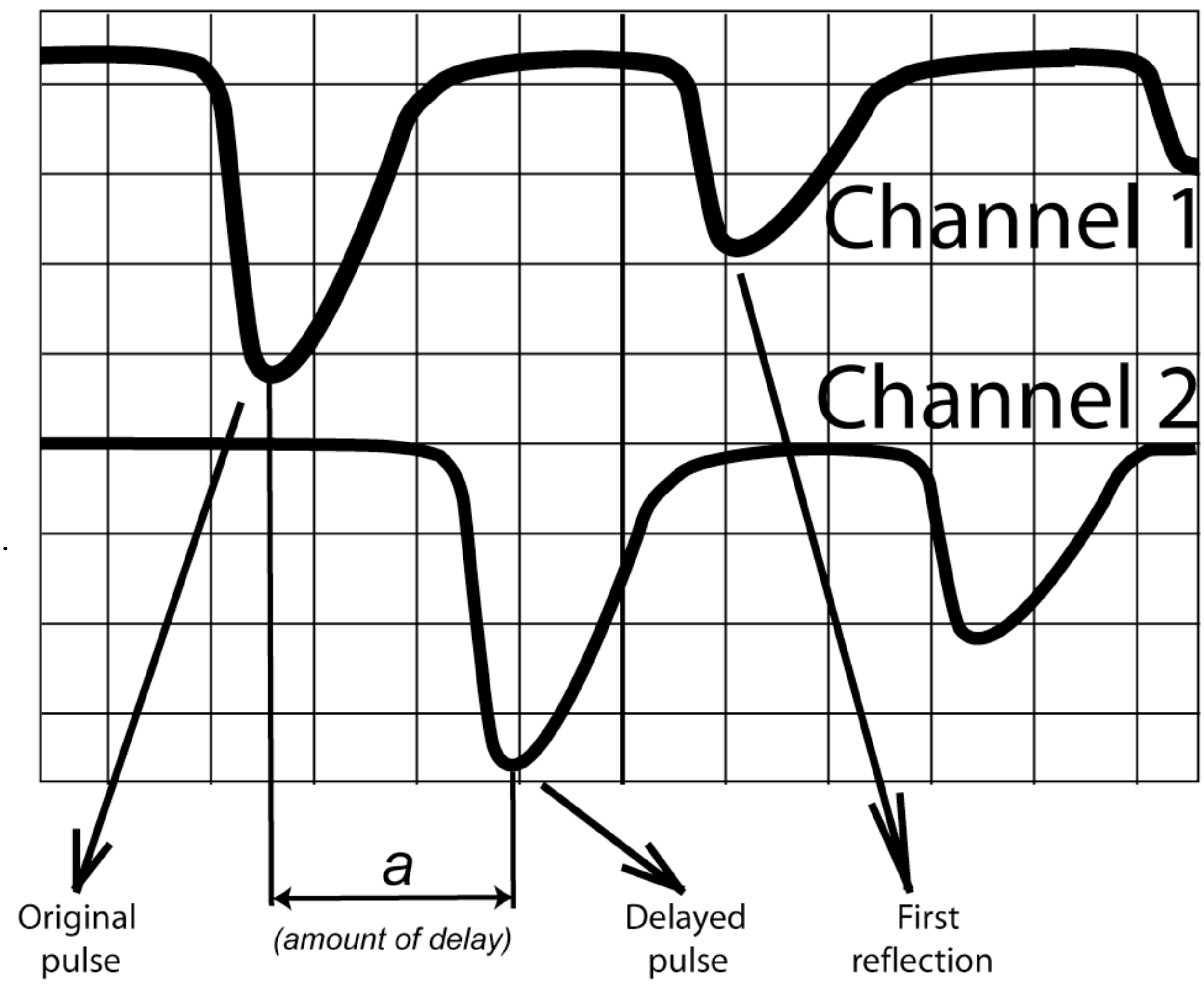


The pulses are led to the oscilloscope's Channel 1 and show up as a dip on the otherwise straight line on the screen (Fig. 1). You will see this curve when the outgoing end of the cable is "terminated", so that the pulse neither leaks out nor bounces back.

The radio pulse is then led to Channel 2 through a long coil of coaxial cable. The oscilloscope plots both channels simultaneously. The horizontal axis is time, and one large box, called "division", corresponds to $b = 0.02\ \mu s = 20\ ns$ or $b = 0.05\ \mu s = 50\ ns$, or some similar value. (See Fig. 2; the actual value is in the bottom of the screen, e.g. "M 25.0ns".) Note that one *ns*, read nanosecond, is a very short time, one-billionth of a second. You will see (Fig. 3) that the signal arrives at Channel 2 later than at Channel 1, the difference indicated by letter *a* on Fig. 3. This is the delay due to the fact that it takes time for the signal to run along the cable.

In addition to the first pulse on each channel, additional pulses are detected on both. These are due to the fact that some of the pulse, upon entering the oscilloscope, bounces back, travels again along the wire and shows up on the other channel. Then some of that bounces back again, so we end up a long series of pulses bouncing to and fro. This explains the rest of the spikes. In order to measure the delay time, we may ignore these, and look only at the first pulse on each of the channels.

Fig. 3: Both channels



We may vary the length of the cable. We can attach two cables to make it twice as long (attached in 'series'), and predictably, the delay time *a* on Fig. 3 will become twice as large. It is a good cross-check to see this really happen, because it can convince us that what we are seeing is really the delay caused by the wire.

At each station we have set up the same experiment, only the length of the cables is varied. The setups have 0, 1, 2, 3 or 4 cables in series.

Procedure:

(1) Measure the length of one green cable: _____ *m*.
(2) Read off the delay time from the oscilloscope in each setup, with all different length of cable between the channels. Fill in the table. (If a particular setup is unavailable, skip it.) In the first column you need a number with one decimal digit, such as *2.2* or *0.7* or *1.9*.

Delay time [boxes]	Delay time [*ns*]	Number of cables in series	Total cable length [*m*]	Speed of radio signal [*m/ns*]
		0	n/a	n/a
		1		
		2		
		3		
		4		
			Average:	

(3) Convert your result for the speed of the signal to *km/s*:

________ *m/ ns* = __________ *km/s*.

(4) The speed of light in vacuum (meaning empty space, even without air) is 1.5 times as much as this, due the fact that the plastic in the cable slows down the radio waves. Correcting for that, your measurement of the speed of light is ____________ *km/s*.
(5) How does this result compare with the accepted value of the speed of light, c = *300,000 km/s*? ______________________________
(6) Now, you know the speed of light and you know the time delay in the conversation to the astronauts. What do you find then for the distance to the Moon? ______________ *km*.
(7) Given that distance, and the fact that the Moon looks 0.5 degrees in size, what is the diameter of the Moon? ______________ *km*.

Read:

Measurements of time delays in reflected signals have been used with great success to determine the distance to the Moon, the Sun, and a few planets. Both laser and radio signals were used to bounce back from these objects. In fact, due to this measurement, we know the distance to the Moon with a precision of an inch, more precisely than we know the distance between, say, New York and Los Angeles!

Of course, such methods cannot be used to measure the distance to stars, because they are too far for that. The signal would be way too weak upon return, and it would take years to travel both ways.