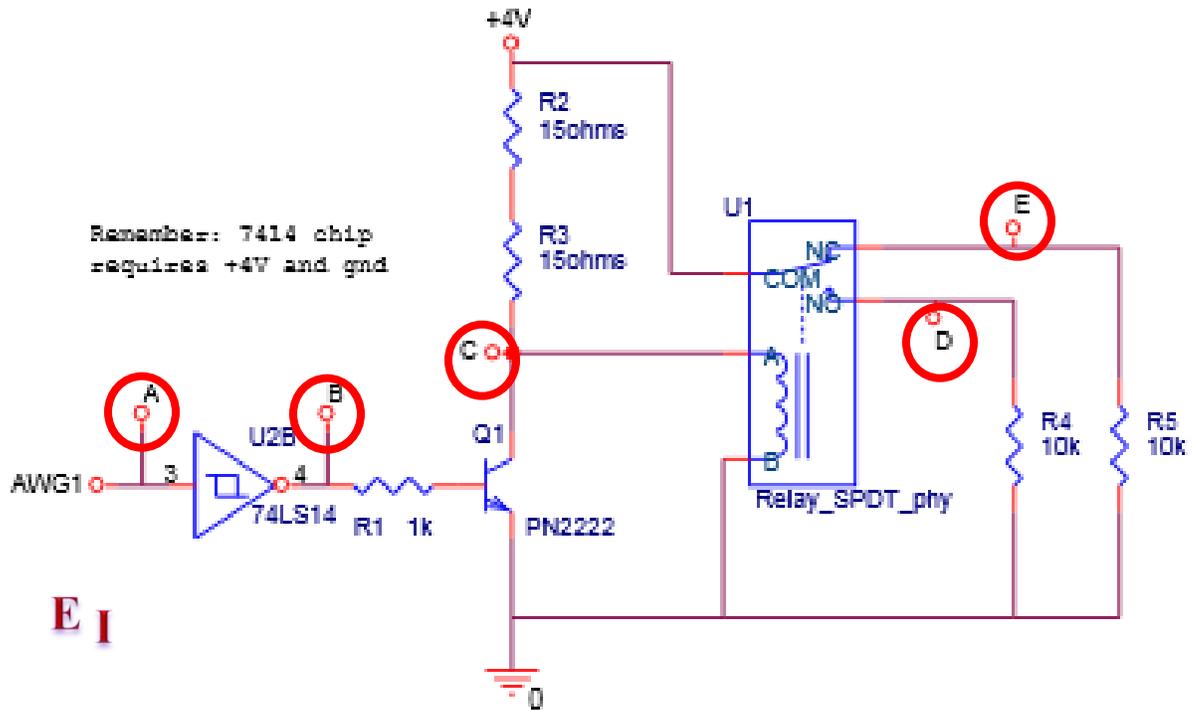


## Electronic Switching – Concept Issue

The following is a discussion of one of the more complex tasks in Experiment 6, where you are asked to find the values of the voltages at five points for the upper and lower switching thresholds. The thresholds are set by the Schmitt Trigger.



This is a good example of the value of predicting before experimenting. Begin with the 7414 Schmitt Trigger. From the table below (copied from the spec sheet), the 7414 should switch at about 1.7V and .9V with 5V power. Since we are using 4V power, the two thresholds could be lower or about 1.4V and .7V. In PSpice, the power supply voltage is not specified (note that there is no connection on the chip for power), so we should assume 5V power.

PARAMETER	TEST CONDITIONS†	SN5414 SN7414			UNIT
		MIN	YP§	MAX	
V <sub>T+</sub>	V <sub>CC</sub> = 5V	1.5	1.7	2	V
V <sub>T-</sub>	V <sub>CC</sub> = 5V	0.6	0.9	1.1	V
Hysteresis (V <sub>T+</sub> - V <sub>T-</sub> )	V <sub>CC</sub> = 5V	0.4	0.8		V

For  $V_A > V_{T+}$  (the upper threshold), the voltage at B should go low. For  $V_A < V_{T-}$  (the lower threshold), the voltage at B should go high. For the 7414 we are using, the high and low output voltages are found from the spec sheet to be about 3.4V & .2V.

V <sub>OH</sub>	V <sub>CC</sub> = MIN,	V <sub>I</sub> = 0.6 V,	I <sub>OH</sub> = -0.8 mA	2.4	3.4		V
V <sub>OL</sub>	V <sub>CC</sub> = MIN,	V <sub>I</sub> = 2 V,	I <sub>OL</sub> = 16 mA		0.2	0.4	V

# ELECTRONIC **E I** INSTRUMENTATION

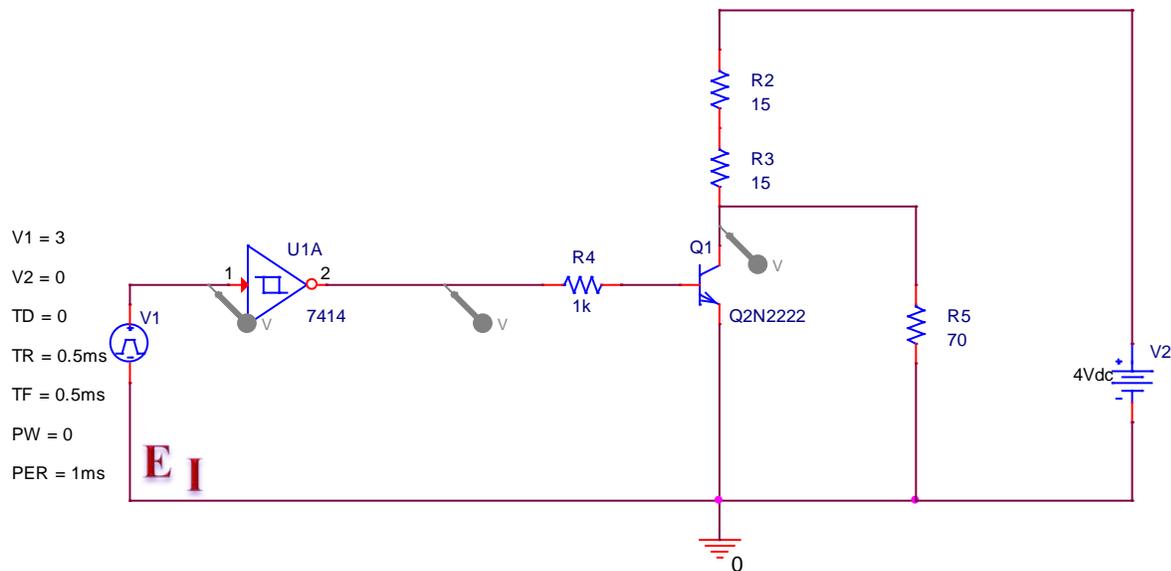
When B is low, the transistor is off, so  $V_C$  is high. The high voltage is determined by the voltage divider created with the coil resistance and the two 15 Ohm resistors. We can look up or measure the coil resistance. Measurement is more reliable, but the spec sheet will give a reasonable value. The spec sheets indicate  $63\Omega$  or  $70\Omega$  for the two types of relays we use. For 4V power, the voltage divider results in 70% of the voltage across the relay coil, or about 2.8V. Note that this is a bit below what the spec sheets say is required to reliably turn on the relays. (You will find the voltage that will definitely turn on the relay called the *must operate voltage*.) When B is high, the transistor is on and C is low. For estimating purposes, we will assume it is near zero. When the switch in the relay is connected to the load, then the voltage across the load is 4V (or whatever the power supply voltage is).

## Predicted Values

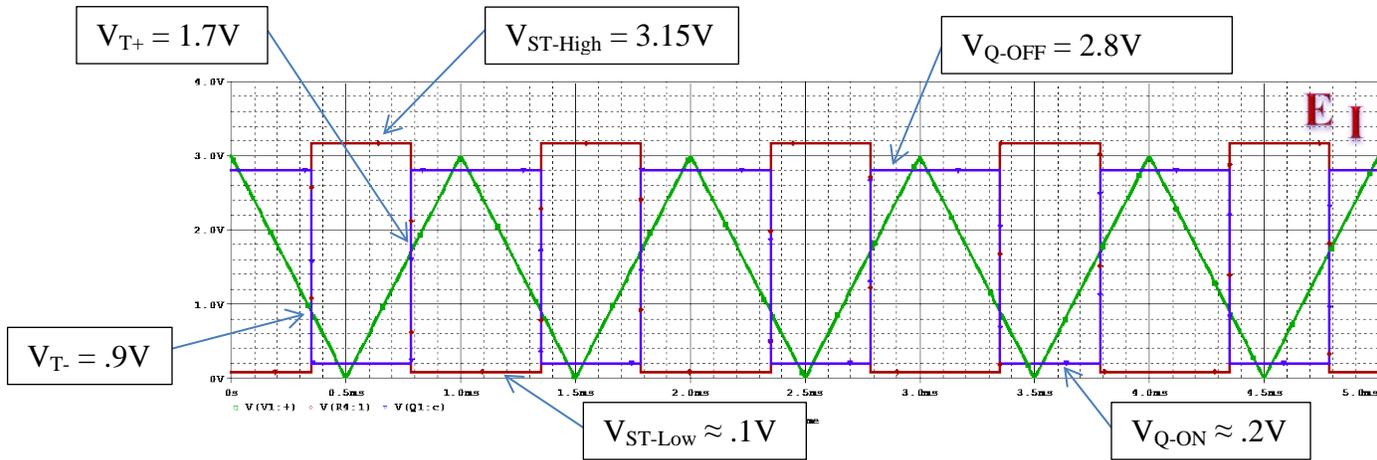
	A	B	C	D	E
Upper $V_{T+}$	1.4 - 1.7V	.2V	2.8	4	0
Lower $V_{T-}$	.7V - .9V	3.4V	$\approx 0$	0	4

## Values from PSpice

A simplified PSpice model can be constructed using a resistor for the relay coil. The relay connections to points D and E are not included in this model, only points A, B & C.



Again, there are no power connections shown for the Schmitt Trigger, so a DC power voltage of 5V is assumed. The switching thresholds and output should then be exactly the spec values.

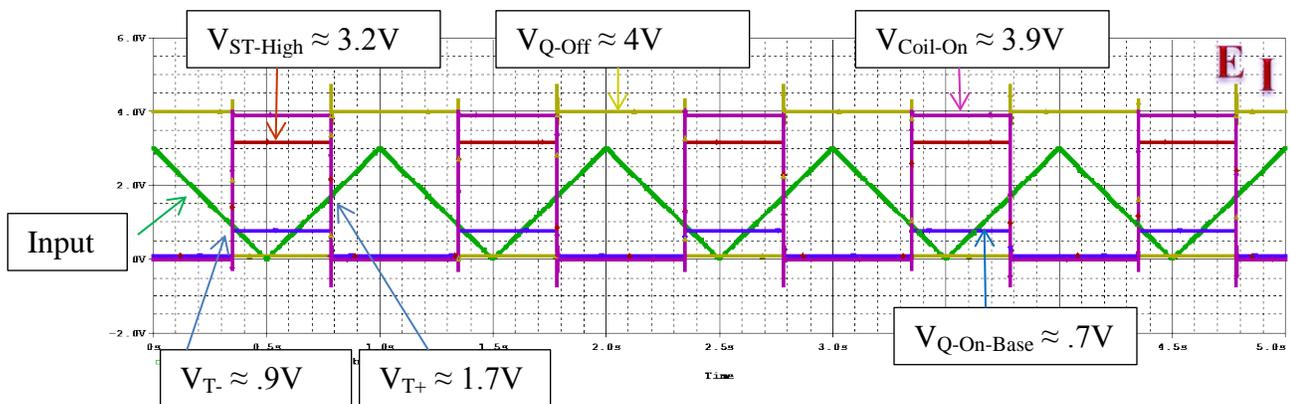
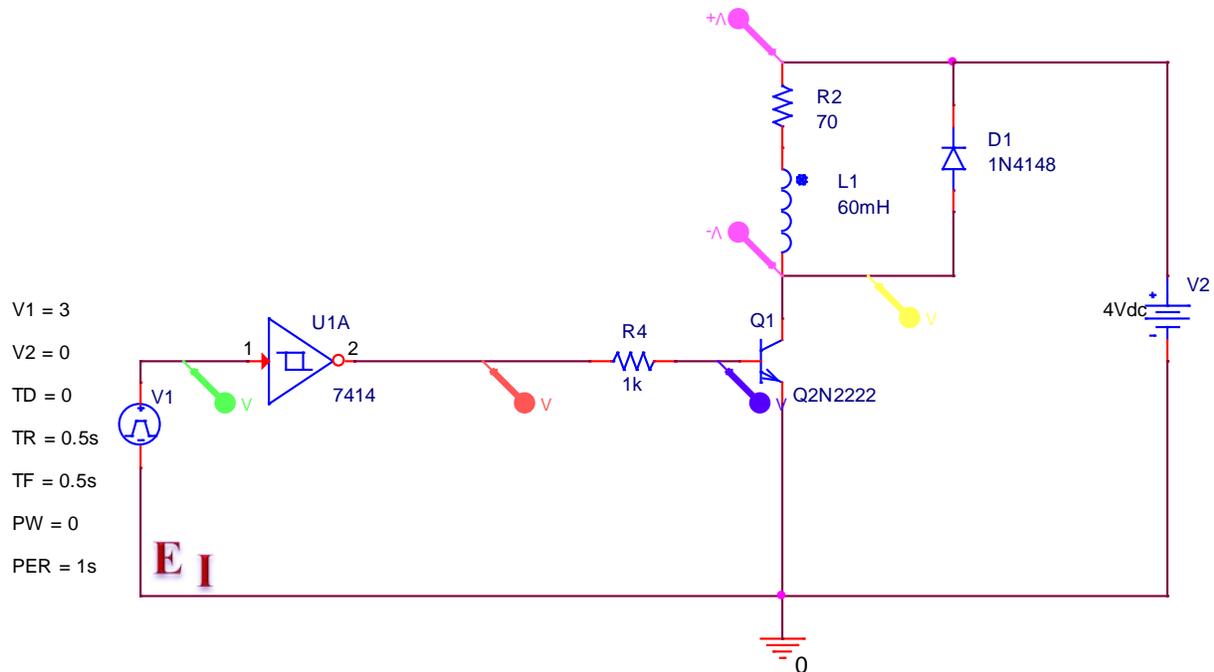


Green is input triangular wave or the voltage at A. Red is the output from the Schmitt Trigger or the voltage at B. Blue is the Transistor Collector Voltage (also the voltage across the relay coil) or the voltage at C. Note that PSpice shows the Schmitt Trigger switches at .9V and 1.7V, as designed, even though the operating voltage is a little low. The outputs are slightly below where predicted. The transistor collector voltages (Q is generally used to indicate a transistor) are as predicted. The PSpice simulation does not show the output values for the switched loads because we don't have a working model for the relay. The relay is represented solely by its coil resistance. Generally, the predictions are quite good.

#### Values from PSpice for Improved Version of Circuit

A simpler and more reliable relay circuit is also discussed in Experiment 6. Because the relay coil has a significant resistance, it can be the bias resistor for the transistor. This has the added advantage of making the full DC voltage available to power the relay. It would be nice if that was all there was to it, but we still have to deal with the inductance of the coil. When the transistor switches, the current through the coil will change very fast; which will result in a large voltage. ( $V = L \frac{dI}{dt}$ ) To provide a path for the current to decay down slowly, it is necessary to add a diode across the coil. We try to make the other relay circuit options work first in Experiment 6 because we have not yet introduced diodes and because it is good to see how to make a circuit like this work if you do not have access to all types of components. Ideally, however, the diode circuit is better because the relay will work better (which means work more reliably).

The PSpice model analyzed above was modified to correspond to an experiment that will follow. In addition to eliminating the bias resistors, moving the relay and adding the diode, the relay model now includes the inductance of the coil (obtained from a measurement with an impedance bridge). The function generator frequency was also lowered to 1Hz.



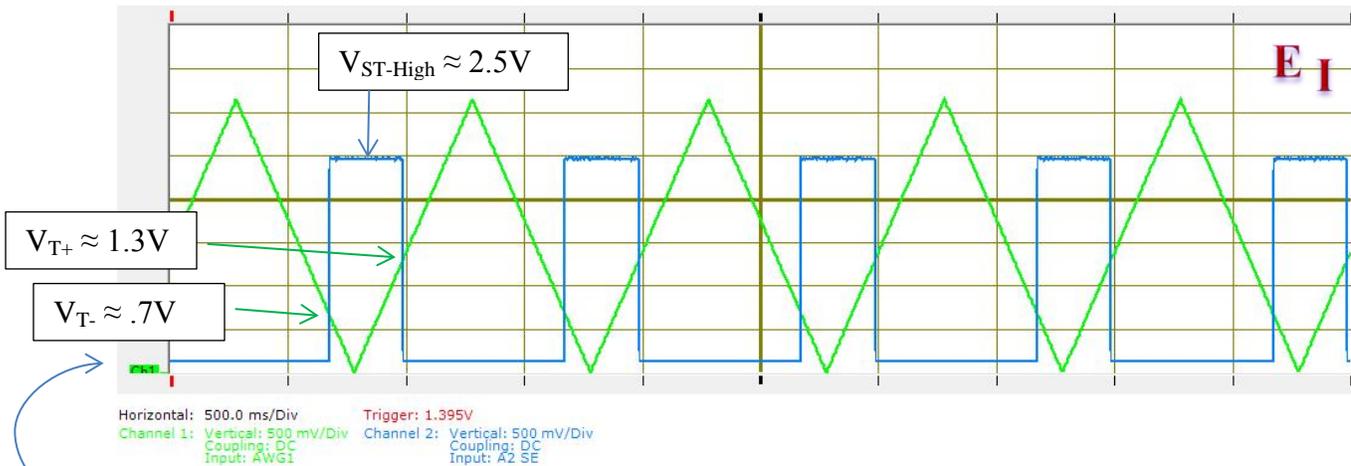
Note that, in this case, the voltage across the relay must be measured using a difference probe and the transistor base voltage is also displayed. For clarity, the low voltages at all points are not labeled and assumed to be essentially zero. Again, because PSpice does not specify the voltage driving logic devices like Schmitt Triggers, the threshold voltages are ideal.

### Values from Experiment

This second version of the relay circuit was built and tested using Mobile Studio. The circuit was built in stages to test each separately. The photo below shows the final configuration. The components on the board were placed neatly but the relay connections are a bit hap-hazard because alligator clips were used. For this experiment, Channel 1 on the scope was configured to display the output from AWG1 (the input voltage) and Channel 2 (the long black wire) was used to display the voltage at other points in the circuit. In the photo, the voltage output from the Normally Closed relay switch was being measured. The neat layout of the onboard components makes it easy to see that the Schmitt Trigger has power (+4V from the red wire connected to the



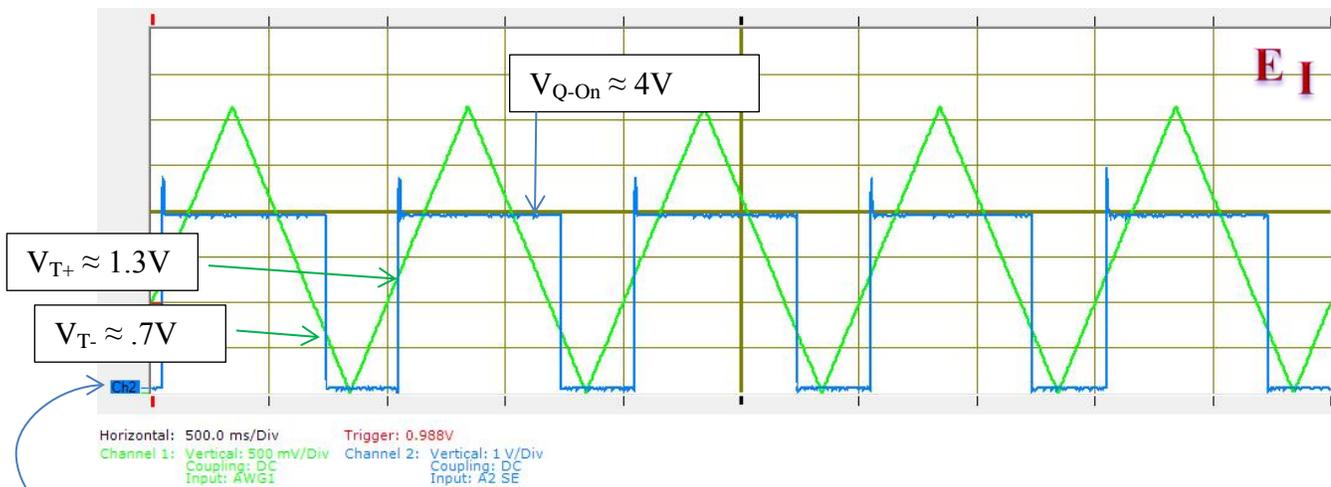
The input voltage from AWG1 (green) and the output voltage (blue) for the Schmitt Trigger:



$V = 0V$  The usual horizontal axis position has been lowered to the bottom of the figure.

The impact of the lower operating voltage (+4V instead of +5V) is obvious in this figure. The threshold voltages and the output voltages are all proportionally lower than under ideal conditions. A little bit of noise is also seen, which shows one of the most common differences between simulation and experiments.

The input voltage (AWG1) and the collector voltage for the transistor:



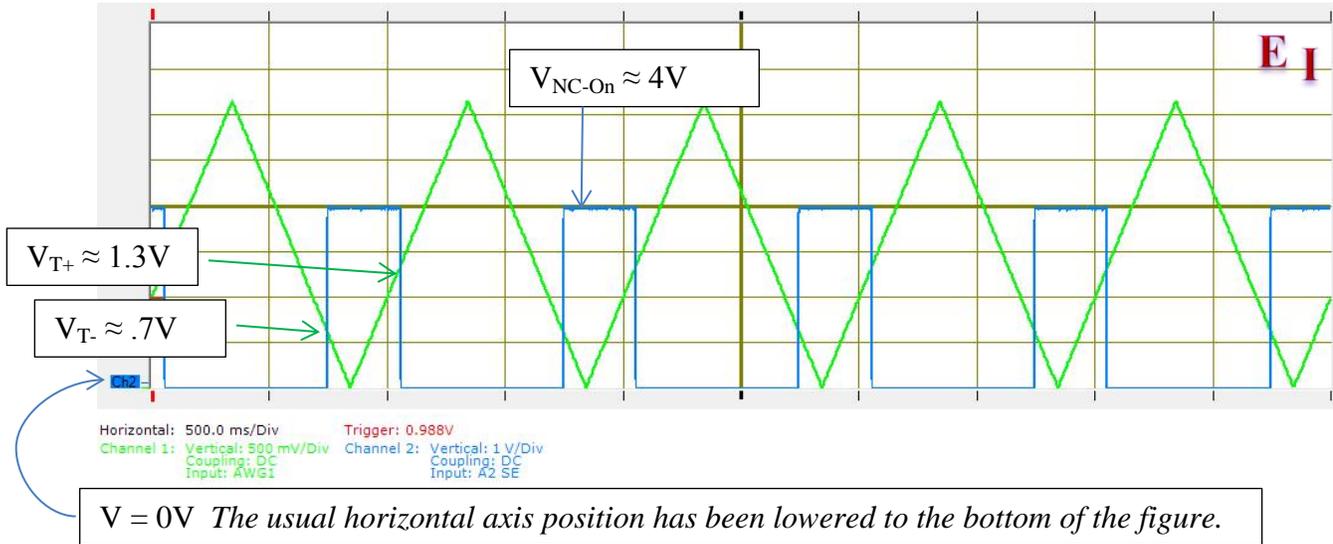
$V = 0V$  The usual horizontal axis position has been lowered to the bottom of the figure.

The output state of the transistor is opposite to the Schmitt Trigger output and, in this configuration, swings from about zero to about 3.8V, which is a little less than predicted. Note that the scale for channel 2 is 1V/Div so that the input impedance of the Mobile Studio is about 6k.

# ELECTRONIC **EI** INSTRUMENTATION

The input voltage (AWG1) and the NC relay output voltage:

The relay voltages look a good deal like the transistor voltages, because one drives the other. The NO output tracks the input and the NC output inverts it. This is different from the original circuit configuration because the relay is on when the transistor is on because it's voltage is low.



The input voltage (AWG1) and the NO relay output voltage:

