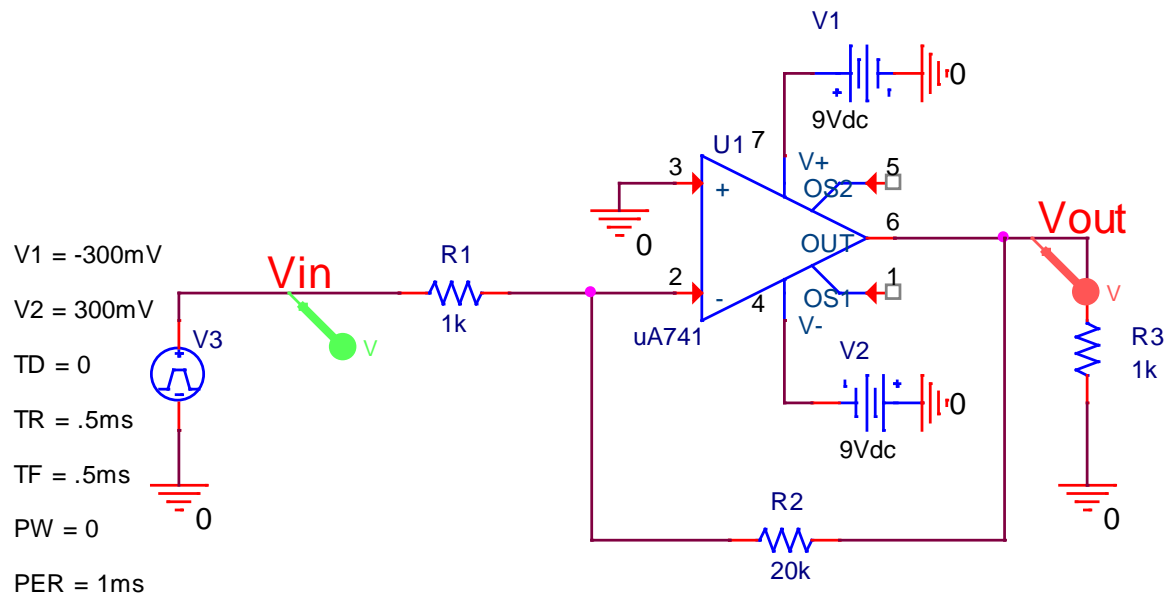


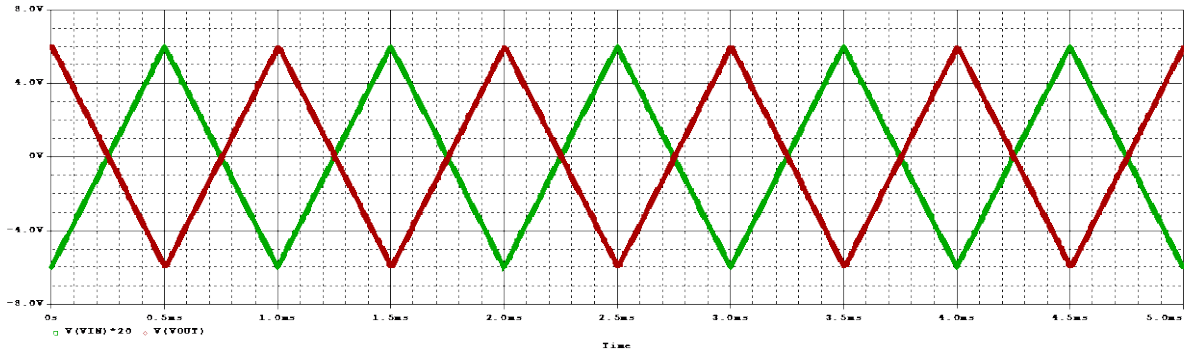
## Validating PSpice

There are at least two major reasons why engineers use simulation tools like PSpice to augment basic theory and experiments. Maybe the most obvious reason is that simulated experiments can be done more cheaply and more rapidly than physical experiments. This allows a designer to run a huge number of test cases rather than building prototypes and putting them through many, many hours of use to see if designs meet specs, safely and reliably under all possible operating conditions. A second reason that is not always obvious to engineering students or new engineers is that simulations can provide information on system parameters that cannot be measured directly. For example, it is possible to determine distributed forces inside a structure when only external forces can be measured. In circuits, we can easily measure voltages, but currents and power can only be done indirectly or by modifying the circuit (Device Under Test).

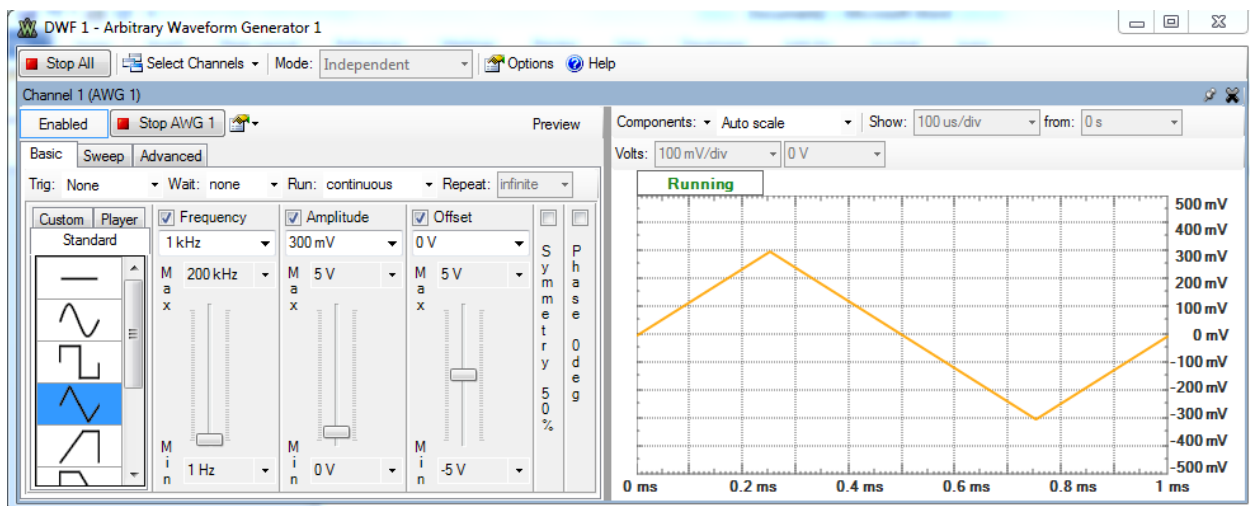
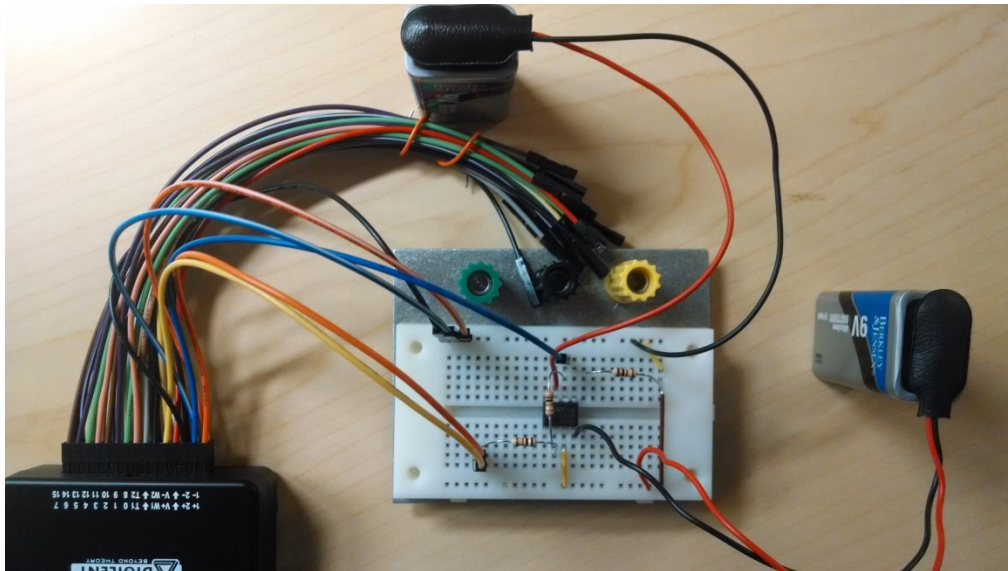
To justify the use of a simulation, one must go through a validation procedure in which the parameters that can be easily measured are compared to experiment. Also, results have to be analyzed to be sure fundamental properties like conservation laws are satisfied. In this document, we look at two examples of simple circuits to see how best to determine the average power consumed when they operate. Our goal is to be able to use the AVG() function in PSpice for this purpose. The first case considered is the inverting amplifier configuration built with a 741 op-amp and powered by two 9V batteries. In PSpice, the circuit is configured as shown below. Note that the gain chosen is -20.

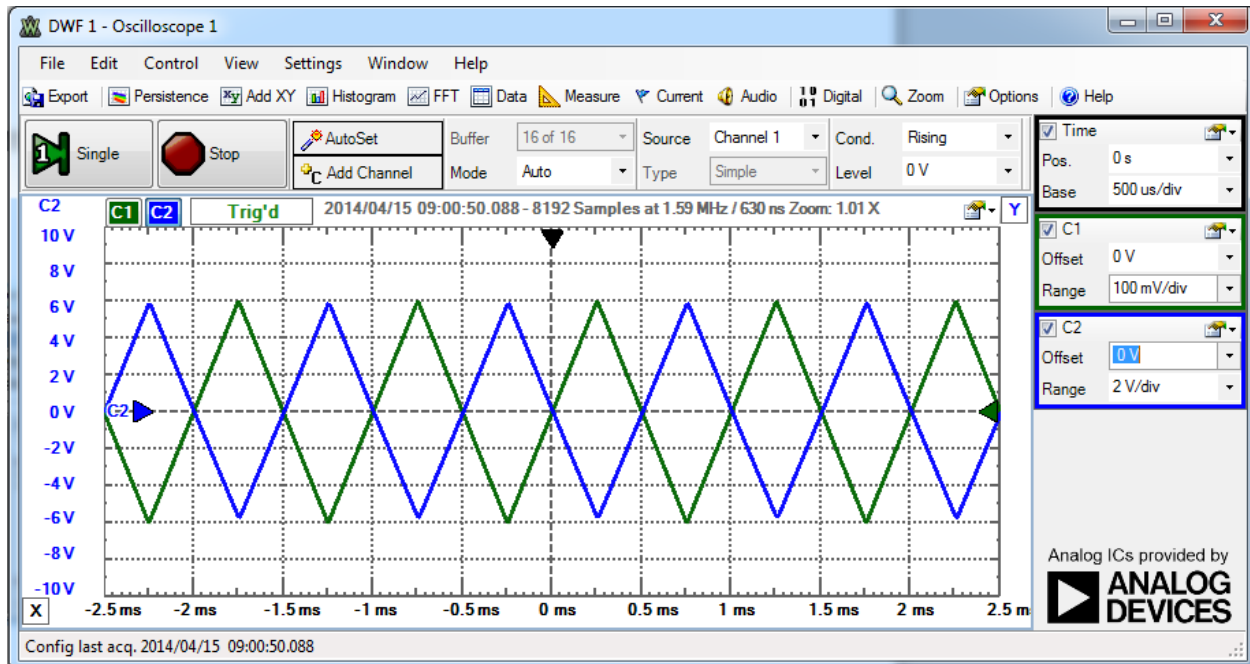


The input voltage is a 300mV amplitude triangular wave, chosen because it is easy to recognize. The input and output voltages are shown in the following figure, where the input has been multiplied by 20 to show that the amplifier is working correctly.



The circuit was then built on a protoboard and then connected to an Analog Discovery board to provide the functionality of the function generator (300mV, 1kHz triangular wave input), and scope measurements of the input and output (pin 6 of 741).

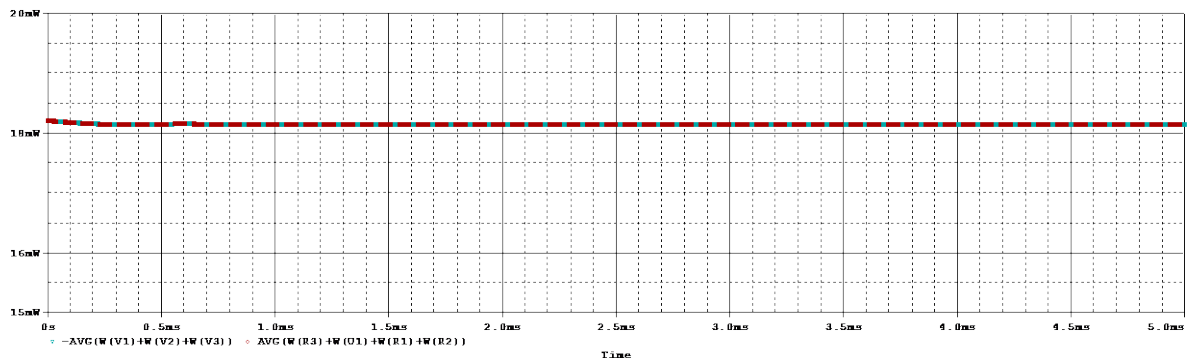




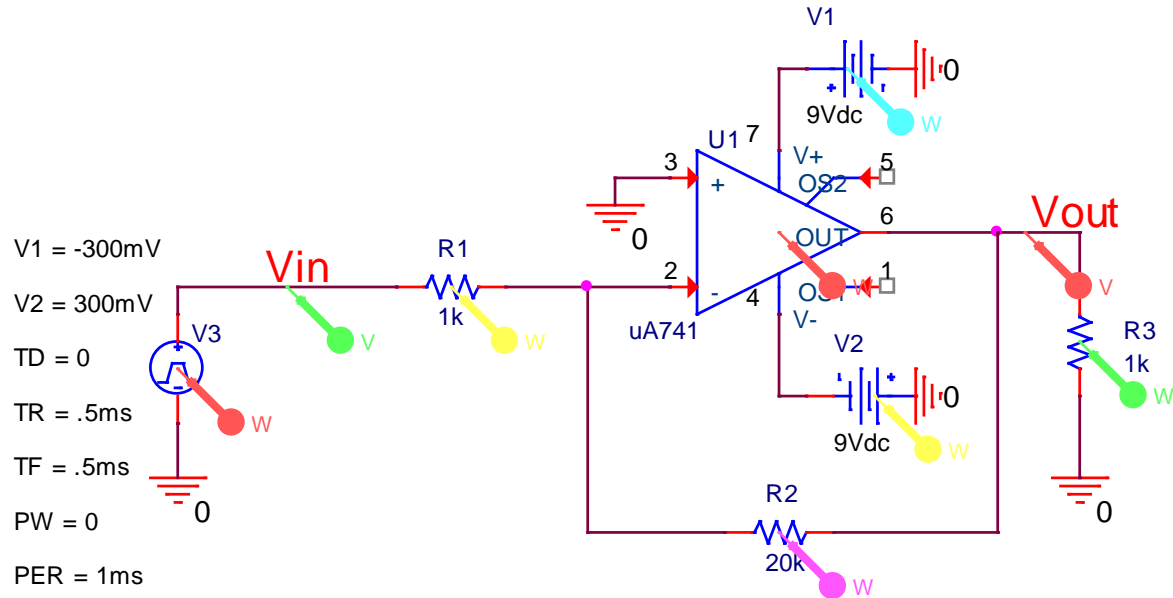
The agreement between the PSpice simulation and the experimentally measured voltages is excellent. The two signals are displayed slightly differently. This could have been fixed by changing either the PSpice voltage source or Analog Discovery triggering, but there is no point when the agreement is so clear.

### Comparing Average Power In to Average Power Out

Next, we want to look at the PSpice results and see if they obey the basic conservation law that the power from the sources should equal the power dissipated in the circuit. Here we used the AVG() function to determine the average of the power sources (the two 9V batteries and the pulsed source) and the average of the sum of the powers from the three resistors and the 741 chip. PSpice has a power probe (see next page) that is placed on each device to determine its power dissipation or generation. Note that the two curves lie precisely on top of one another and thus power is conserved. It is possible for this to be violated if the time step is too large.

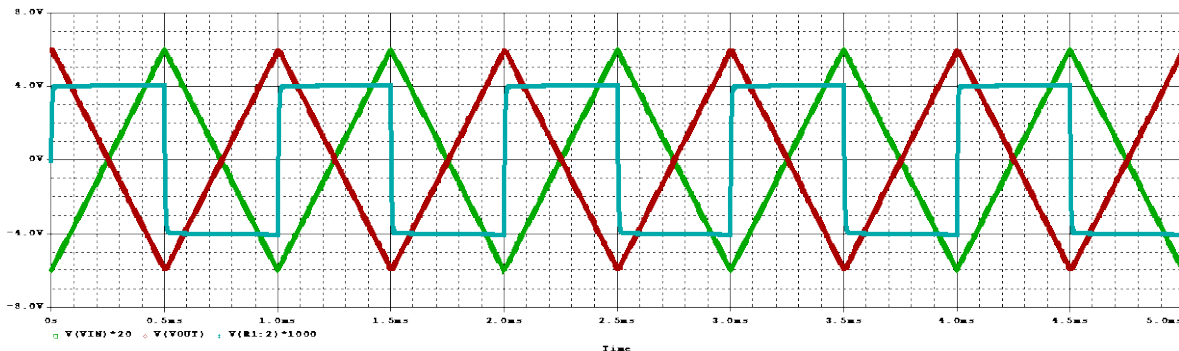


In addition to validating the PSpice results, this comparison of input and output power confirms that either can be used to find the average power dissipated by the circuit. Since there are usually fewer sources than lossy components, it is more convenient to just measure the power from the sources.

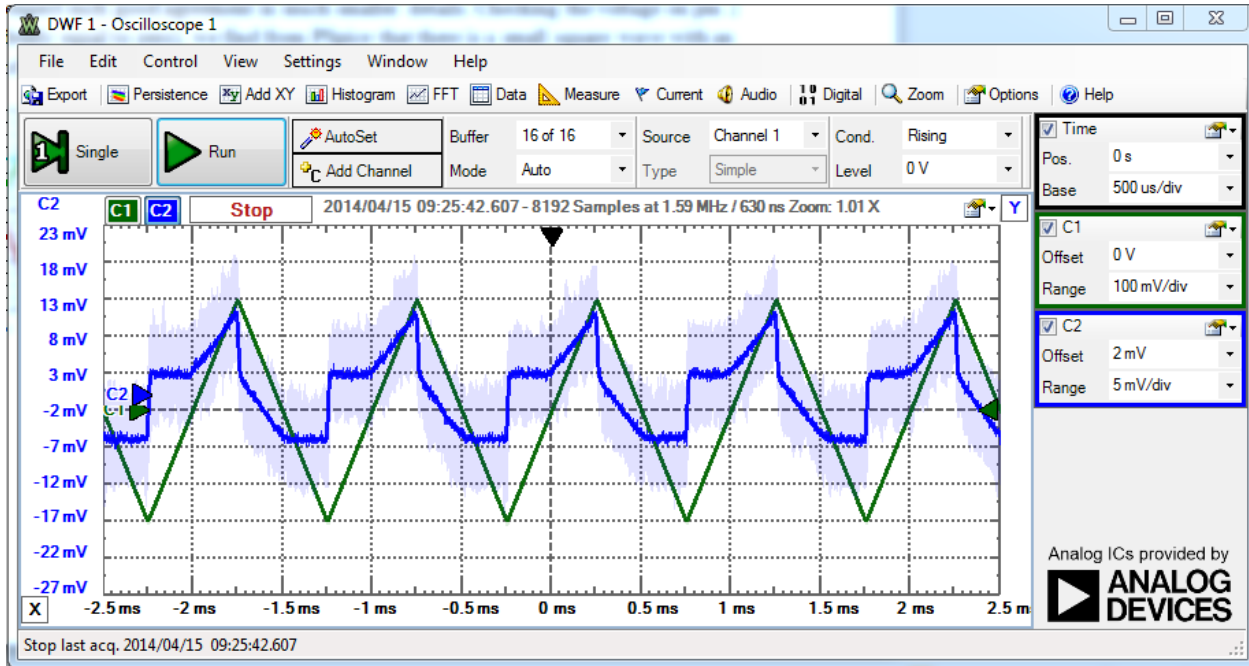


Summarizing, we know that the only direct measurements are for voltage, not current or power. However, since the voltage measurements agree so well (between simulation and experiment), we are free to use the info from PSpice, as long as we check on basic issues like conservation of power.

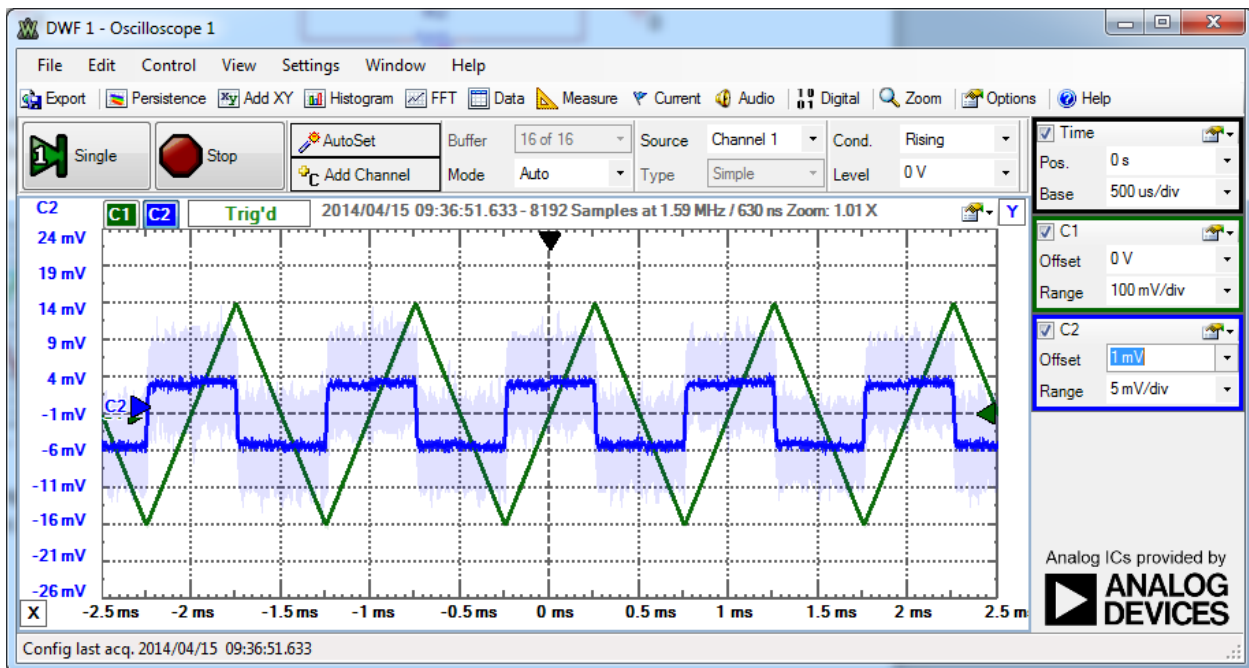
We do not expect such good agreement in much smaller details. Checking the voltage on pin 2 (which is ideally made equal to zero by negative feedback), we find from PSpice that there is a small square wave with an amplitude of about 4mV (the voltage has been multiplied by 1000 to compare it with the output voltage). The intrinsic op-amp gain is not infinity, so it does the best that it can.



From the experiment, we have something similar, but with some significant differences. The small offset is probably instrumental. Here we can only show two voltages simultaneously, because there are only two analog inputs for Analog Discovery. This is usually also the case with any standard scope. Note that about half of the signal agrees roughly with PSpice, but then seems to try to track the input or output voltages for the other half of the period.

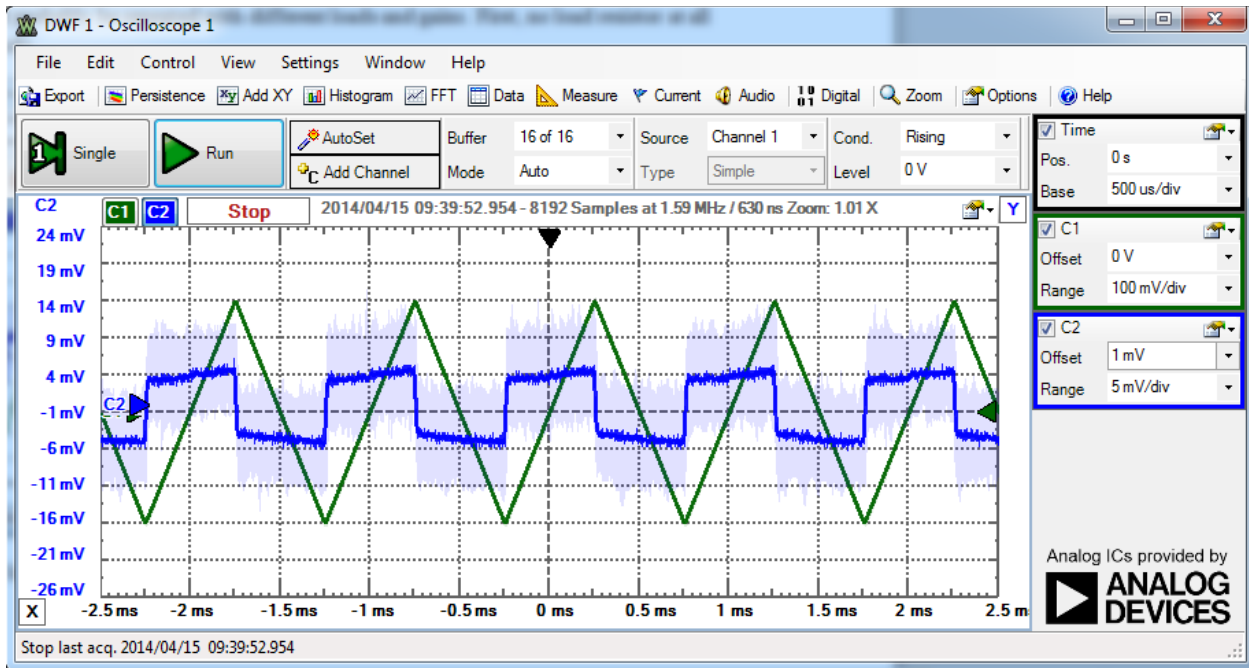


This effect may be due to the load or gain. With no load resistor at all (infinite load):





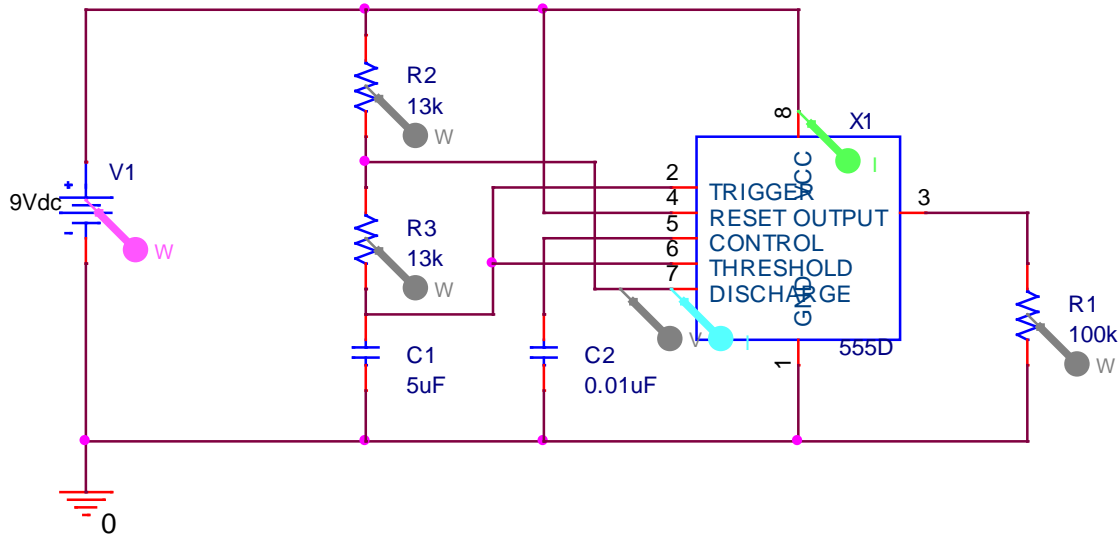
With a 20kΩ load:



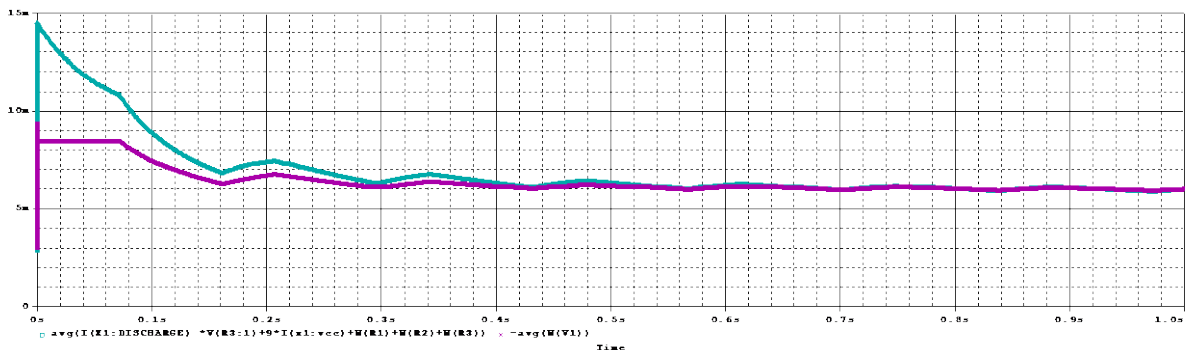
Thus, it does appear that when the 741 has to work harder and drive a load requiring more current, the feedback works a little less well in small details. However, if we are considering only the biggest features of the system, all of the loads considered are fine.

## 555 Astable Power Inventory

Another ubiquitous circuit is the Astable Multivibrator, made with a 555 timer chip. Confirming that the power is conserved is made a bit more difficult because the PSpice power probe does not work with the 555 chip. To address this issue, current probes were placed at all of the pins to identify any significant currents. Most are zero, but finite currents were observed on pins 7 & 8.



The average power in and out were determined and displayed. One curve is all losses, including the significant ones to the 555. Power to the 555 was determined by finding the voltages and currents at the pins where there is significant current and then finding their product. The actual formulas used to display the average input and output powers are shown below the figure.



$$\text{avg}(I(X1:DISCHARGE) * V(R3:1) + 9 * I(x1:vcc) + W(R1) + W(R2) + W(R3))$$

The other curve is the power from the source.  $-\text{avg}(W(V1))$

This demonstrates that the only power it is necessary to monitor is the power from the source.