Current and Power Waveform Measurement Technique

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1 Introduction

In measurement and debugging of power electronics circuits, it is essential to be able to view the waveform of a circuit's current. Furthermore, if a voltage and current waveform are available, they can be multiplied in real time to observe the power waveform.

Oscilloscopes, including the Syscomp DSO-101 Digital Storage Oscilloscope[1] used here, are voltage measuring devices. Consequently, the current must somehow be converted into a voltage signal to view it on an oscilloscope.

Common methods of measuring current are the following:

1. **Shunt** A low value resistance is placed in the circuit and the voltage across it measured. The resistance is known as a *shunt*[2] . Any resistance may be used but for large currents and precise results special shunt resistors are available. Depending on the circuit, the shunt is likely to have some common-mode voltage at its terminals. The measuring circuit must ignore this voltage, that is, the measuring circuit must have a substantial *common-mode rejection ratio*. The voltage across the shunt is a *differential measurement*, that is, the difference in voltage acrosss the shunt resistor. Most oscilloscopes (including the DSO-101) can subtract two input channel voltages, which enables them to make a differential measurement directly. However, this is not possible if one of the channels is needed for a simultaneous measurement of some other variable such as circuit voltage. Furthermore, the measurement is limited to the common-mode voltage of the oscilloscope.

2. **Current Transformer** The current carrying conductor threads through a toroid core, forming the primary of a transformer. A secondary winding on the same core provides an output voltage. This technique has the advantage that the secondary can be grounded – there is no common mode voltage to deal with. However, a current transformer eliminates any DC component in the waveform.

3. **Hall Effect Probe** The *Hall effect* uses a semiconductor sensor to convert the magnetic field accompanying the measurement current, into a signal voltage. The output includes both DC and AC components, which makes it attractive. However, the output signal one I tried was riding on a DC voltage half the supply voltage. It also included a switching waveform, possibly an artifact of an internal chopper-stabilized amplifier.

My first attempt at a current sensor used a Hall Effect device. The circuit and its problems are described in section 6 on page 7.

I then decided to use the shunt measurement technique. The shunt signal is amplified in a differential amplifier, so this measurement technique is known as a *powered shunt*.

The following information is presented not as a *how to build*, but rather as an idea piece, as it will depend on your shunt and the ranges you need most.

[1] Syscomp Electronic Design: www.syscompdesign.com
[2] Wikipedia: Shunt, Electrical http://en.wikipedia.org/wiki/Shunt_(electrical)

2 Measurement Overview

The complete measurement setup is shown in figure 1. From top to bottom:

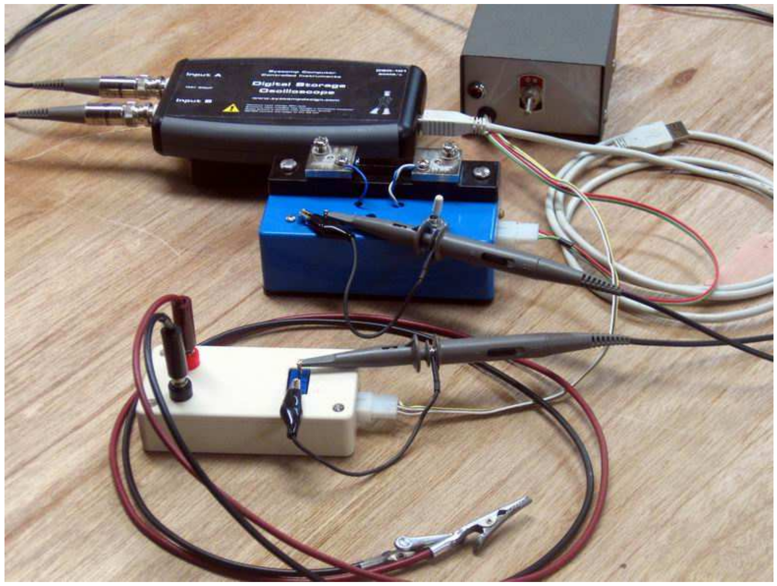


Figure 1: Measurement Setup

- The black box at the top is the $\pm$12V DC power supply for the powered shunt and the differential amplifier.
- Below that is the Syscomp DSO-101 oscilloscope with its USB cable.
- The blue box is the powered shunt, figure 3. The shunt is fastened to the top of the box. The switch is the range switch, the two holes allow adjustment of the multi turn trimmer pots and the output is brought out to the two pins for either a multi meter, data logger or the DSO-101.
- The white box is a differential voltage sensor circuit, figure 5.

Now we will explain each of these units in detail.

3 Powered Shunt

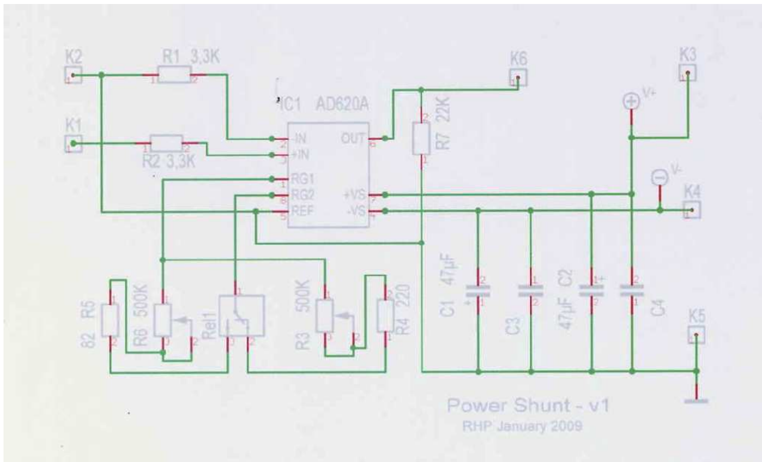


Figure 2: Powered Shunt Schematic

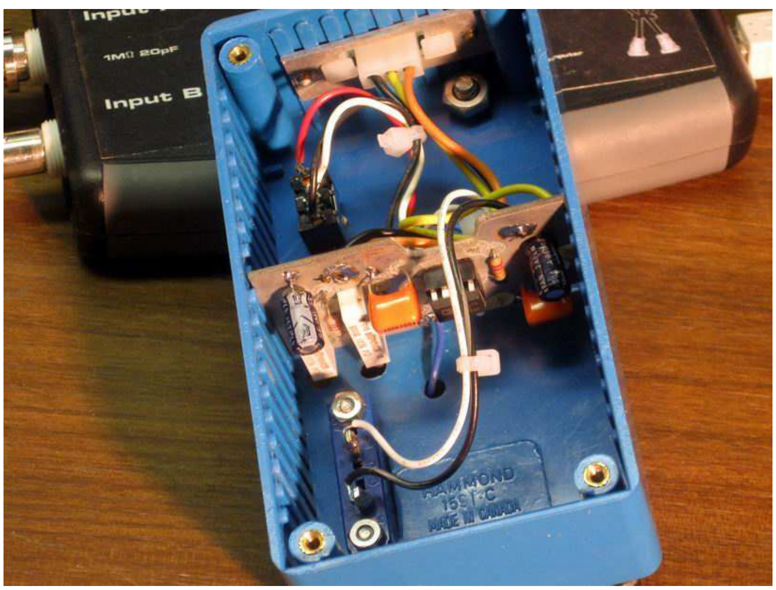


Figure 3: Powered Shunt Assembly

The shunt resistance must be large enough to generate a useful voltage for measurement. However, if the shunt resistance is too high then it can interfere with the proper functioning of the circuit under test. A 25 amp 50 mV shunt has a voltage drop of 50mV at 25A, the maximum allowable continuous current. This was chosen as a reasonable compromise.

The DataQ data logger[3] and other data loggers accept ± 10 volt at the input. With this in mind the scaling for

[3] DataQ: `http://www.dataq.com/data-logger/data-logger.html`

this powered shunt was selected to bring the first range as 1 volt per amp for a 10 amp full scale and .3 volt per amp for a 30 amp scale.

The op-amp chosen was Analog Devices AD620. The schematic, drawn in Target 3001[4], is shown in figure 2.

Driving op-amps from a single rail has always been problematic for me, so this is powered from a +/- 12 supply. The AD620 will safely handle only 8 volts over supply, so I have added R1 and R2 as protection which brings its tolerance level up to closer to 100 volts. The assembly internals of the powered shunt are shown in figure 3.

4 Measuring Voltage

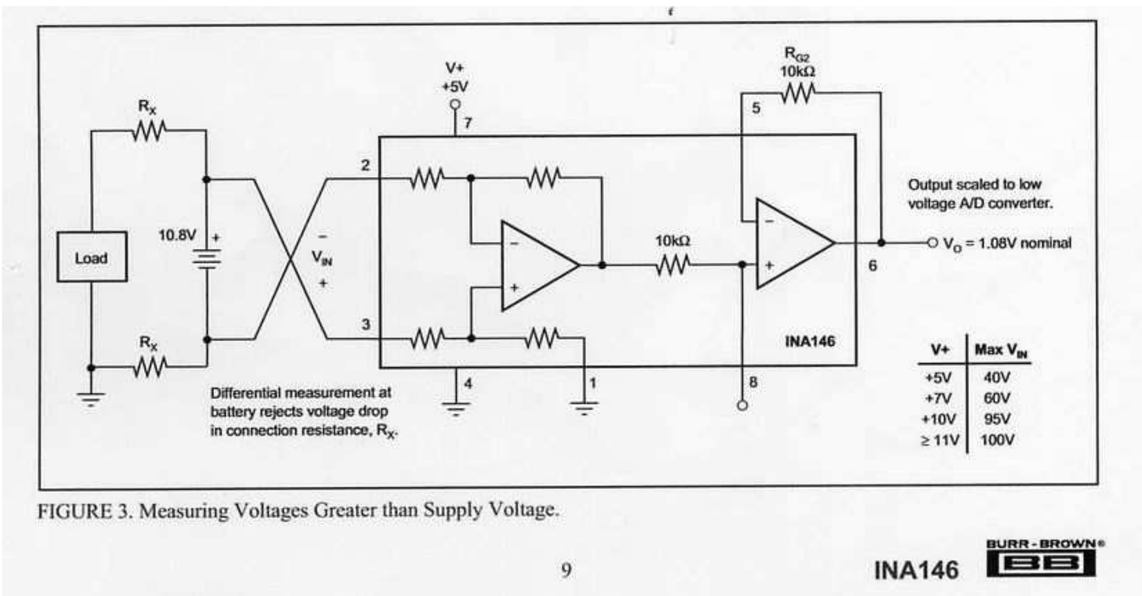


Figure 4: Differential Amplifier Schematic

I described above how I had made a powered shunt to measure the current. How then to measure the voltage across a floating component (a coil, in my case)? Well, this becomes possible with a *High-Voltage, Programmable Gain DIFFERENCE AMPLIFIER* the Burr-Brown/Texas Instruments INA146[5].

The coil voltage is monitored with the op-amps differential inputs and the output of the op-amp is ground referenced. I was using a ± 12 volt regulated supply for the powered shunt and this then powers the new module with no complaint. Note that this supply voltage allows over a hundred common-mode volts to be read. The 1NA146 is a divide by ten in this application so 100 volts differential in is read as 10 volts out. This is then read by one input of the oscilloscope.

Figure 4 is a schematic of the circuit, extracted from the Data Sheet.

Only one resistor is used, everything else is in the chip. An awkward moment comes when you realize the 1NA146 is only available in surface mount.

[4]Wikipedia: TARGET 3001! `http://en.wikipedia.org/wiki/TARGET_3001!`

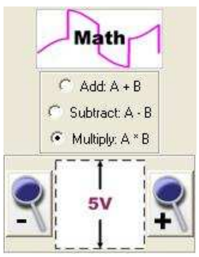
[5]Datasheet: `http://focus.ti.com/lit/ds/symlink/ina146.pdf`

Figure 5 shows the completed board. The diff amp chip is underneath.

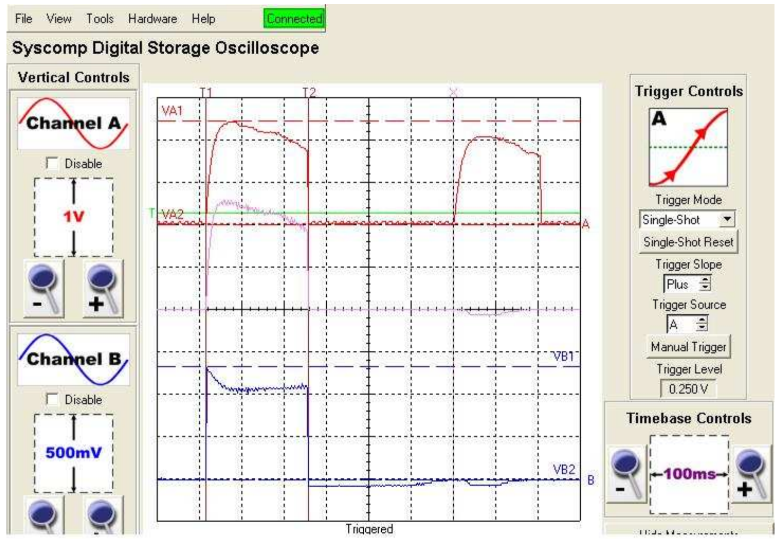
Figure 5: Differential Amplifier Assembly

The circuit in this configuration divides by ten, so no attention was spent on shielding the leads or component box.

5 Measurements



(a) Waveform Math



(b) Current, Power and Voltage Waveforms

Figure 6: Waveforms

Figure 6(a) on page 6 shows the DSO-101 Oscilloscope math function panel with *multiply* waveforms selected and a scale factor of 5V/div for the display of the result.

Figure 6(b) shows a typical measurement. The top (red) trace is the current waveform, scale factor 1 amp/division. The bottom (blue) trace is voltage with an effective scale factor of 5 volts/division. The middle (purple) trace is the power waveform, product of the instantaneous voltage and current.

6 Appendix: Hall Effect Current Sensor

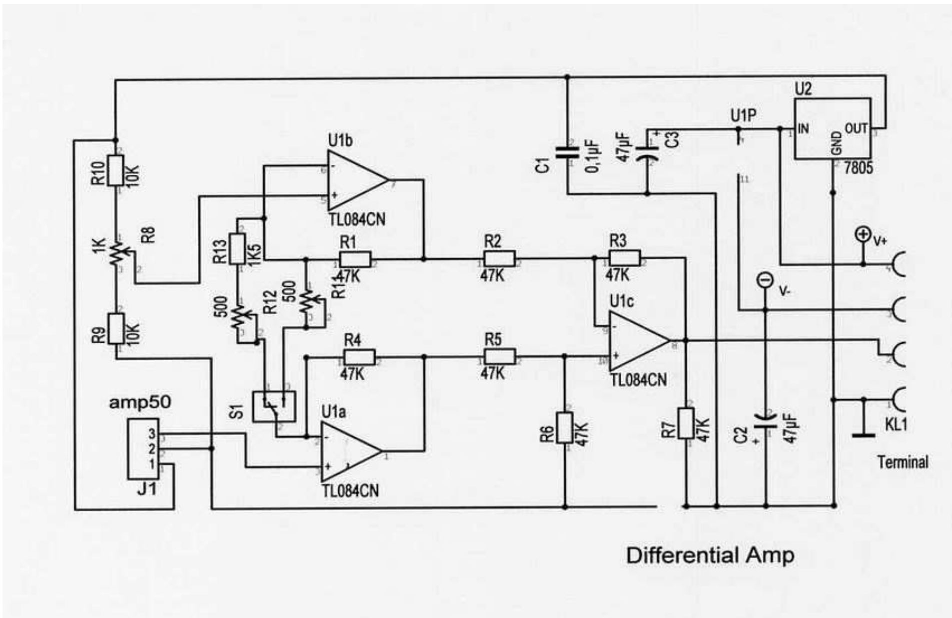


Figure 7: Hall Effect Sensor, Differential Amplifier Schematic

In an attempt to utilize an Amp50 Hall effect sensor I constructed a difference amp. The schematic is shown in figure 7 and the assembly in figure 8. The waveform is shown in figure 9.

This had been bought to work with my Data Q kit, which is a +/- 10 volt input. So in bread boarding this up, the first range worked out nicely at one volt per amp for a +/- 10 amp full scale reading.

I reckoned without noise. To my mind, it makes the trace practically unusable for oscilloscope measurements.

Figure 9 is an actual trace using an ACS756 Hall effect sensor, which is an improvement on the Amp50 Hall sensor called out in figure 7.

I thought at first it was my poor circuit design but have since come to the conclusion that it is inherent in Hall current sensors. Confirmation is evident in that more advanced current probes combine a Hall Effect sensor with a current transformer. *The Hall Effect sensor measures the DC and low frequency components of the signal and the current transformer measures the high frequency components. These signals are combined in the amplifier circuit to yield a wide band signal extending from DC to over 50 MHz.*[6].

[6]Wikipedia: Test probe `http://en.wikipedia.org/wiki/Test_probe`

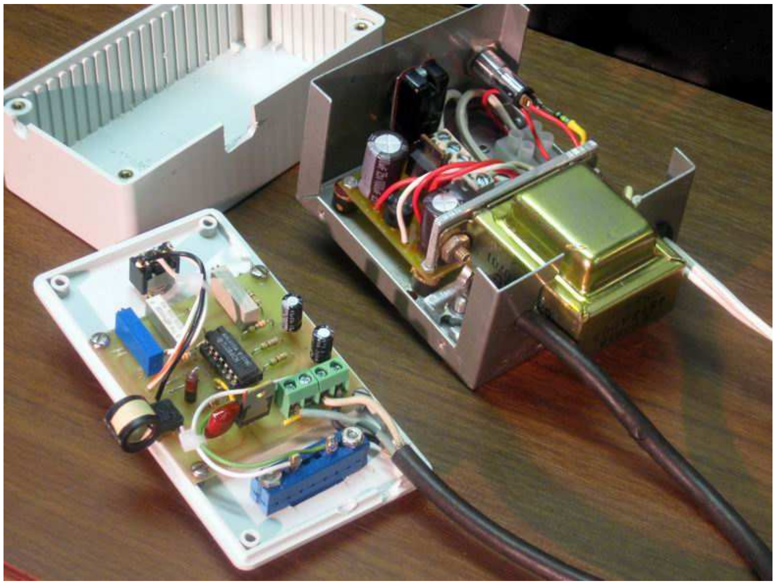


Figure 8: Hall Effect Sensor Assembly and Power Supply. Notice the Hall Effect Sensor on the amplifier circuit board, left side.

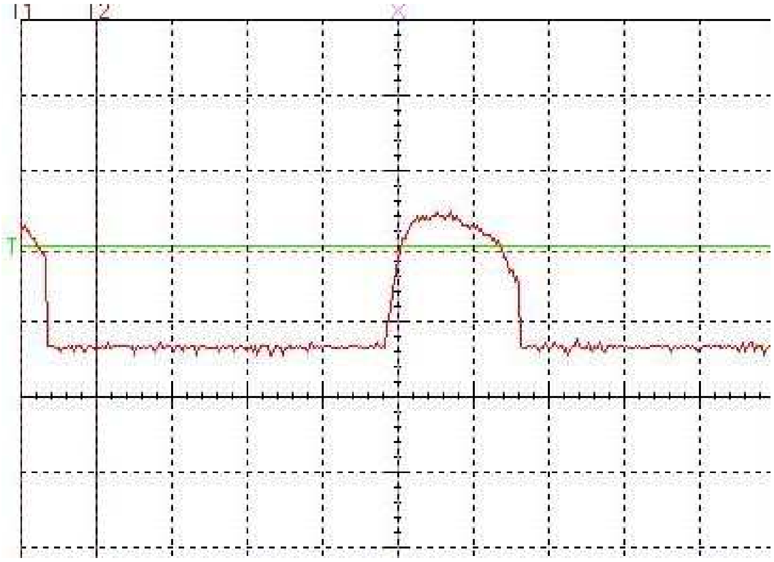


Figure 9: Current Waveform (1 amp per vertical division)