Instrumentation Report Two

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1 Introduction

The design of the complex impedance meter will be based on the Auto-Balancing Bridge method. This will allow the voltage and current vectors in the device under test to be measured, and thus the impedance determined. The phase difference will be found using timers and a zero crossing detector.

2 Schematic

2.1 DUT Excitation Signal Generator

The signal source used to generate the test signal applied to the unknown device will consist of a digital direct synthesizer. This is implemented using an AD9833 Programmable Waveform Generator, this allows a frequency of up to 12.5MHz to be generated, fully encompassing the range of measurement needed. This signal goes into a programmable gain amplifier used to vary the test signal level, allowing lower currents to be used when measuring low impedance devices. A trim potentiometer is used before to get to range of operation out of single ended PGA. The output of the PGA is then high pass filtered using an RC first order filter centring it around 0V, and passed to an AD817 which is used to drive the DUT.

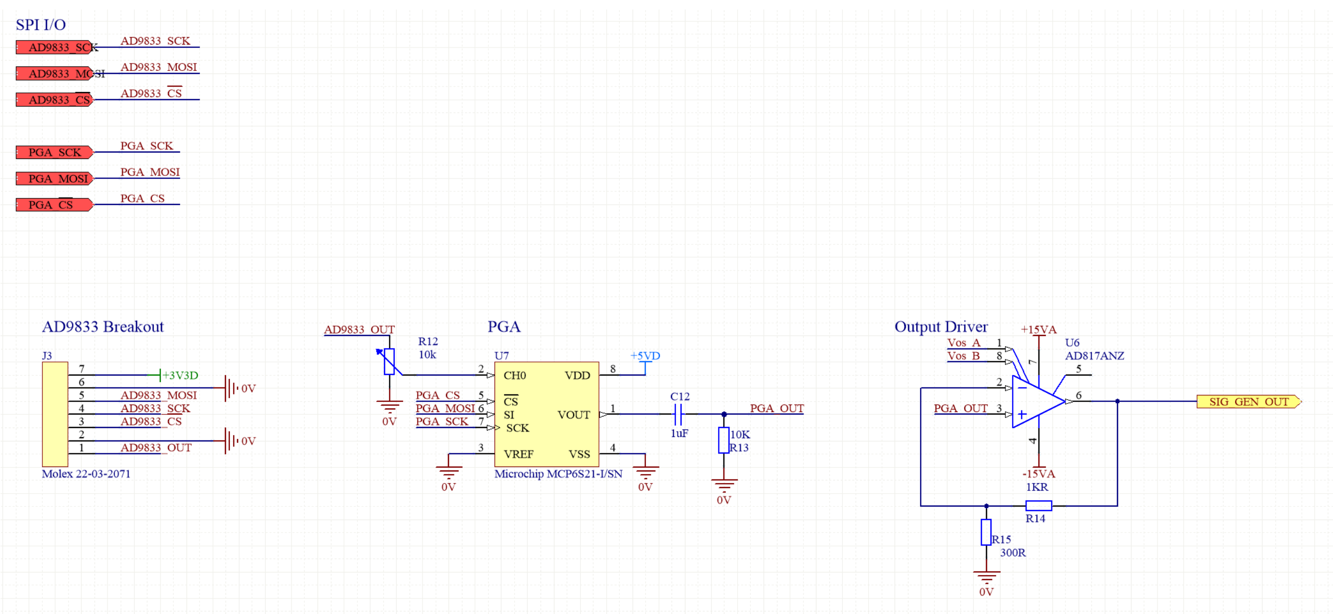

Figure 1: Z Meter Signal Source

2.2 Auto Balancing Bridge

An auto balancing bridge is used to perform the impedance measurement. This allows the low terminal of the DUT to be held at virtual ground when the impedance measurement is performed, and the bridge op amp and range resistor act as a current to voltage converter allowing accurate current measurement through the DUT. The voltage across the DUT is also measured using an instrumentation amplifier, as this will enable a kelvin connection to the DUT, and thus a more accurate measurement at lower impedances.

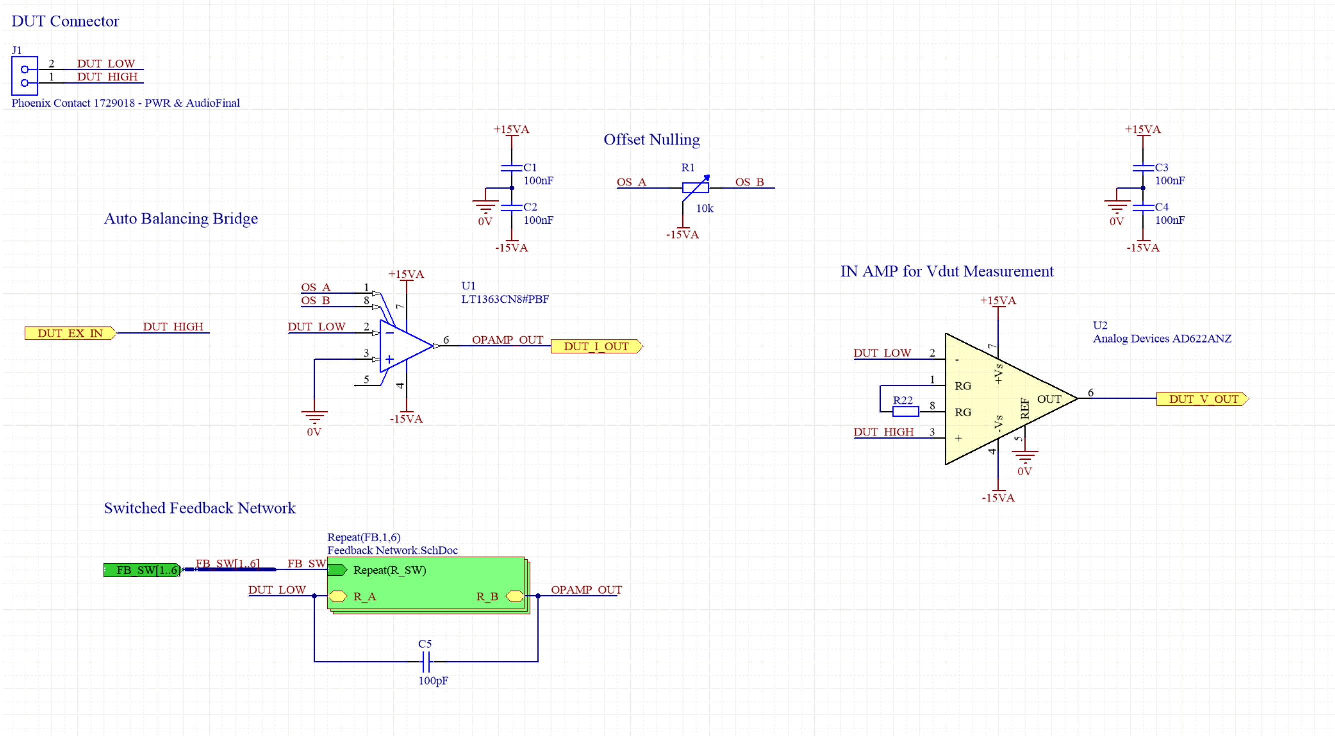

Figure 2: Auto Balancing Bridge

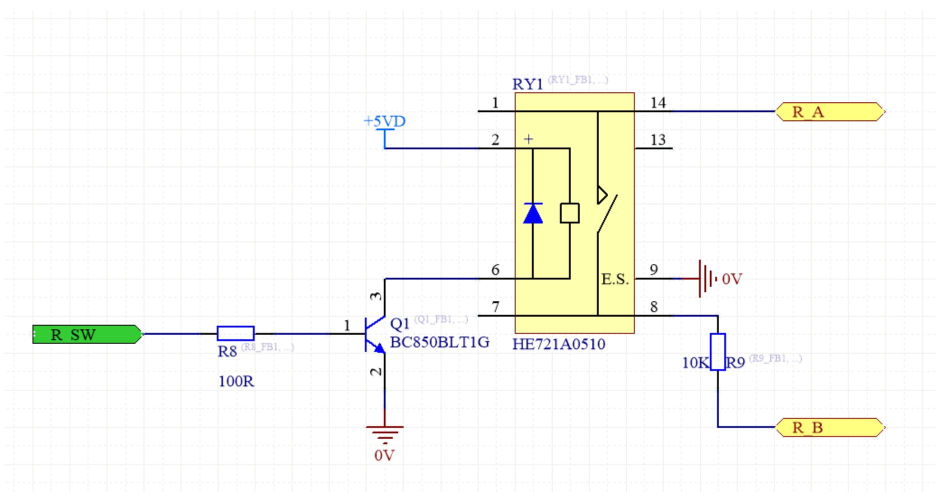

Figure 3: Feedback Network for Auto Balancing Bridge

The transimpedance amplifier used in the auto balancing bridge requires switched gain resistors close to the value of the DUT. This switching action is performed by using reed relays, which enable very low parasitic on resistance in series with the reference resistor. This presents a significant advantage to using an analogue switch which would suffer from this issue, as well as charge injection and other similar issues. The relays however will take longer to switch and suffer from switch bounce, however since the DUT impedance does not change quickly, some time is allowable for the measurement to settle. The relays will be used to switch fixed resistors of decade values between $10\Omega, 1M\Omega$. The capacitor in the feedback network of the transimpedence amplifier will be used to compensate the instability due to parasitic input capacitances, and set the bandwidth of the amplifier.

2.3 Vector Voltmeter

The vector voltmeter used to measure both the device under test voltage and the output of the transimpedance amplifier and compromises both a magnitude and phase measurement.

For magnitude measurement a precision full wave rectifier followed by a buffered low pass filter. This gives the average rectified value of the waveform which can then be measured by the ADC. In software this can then be converted to either an RMS or magnitude of the waveform via the form factor.

The output of this stage also incorporates a resistor divider which allows the signal level to be scaled to a level suitable for the MCU ADC inputs.

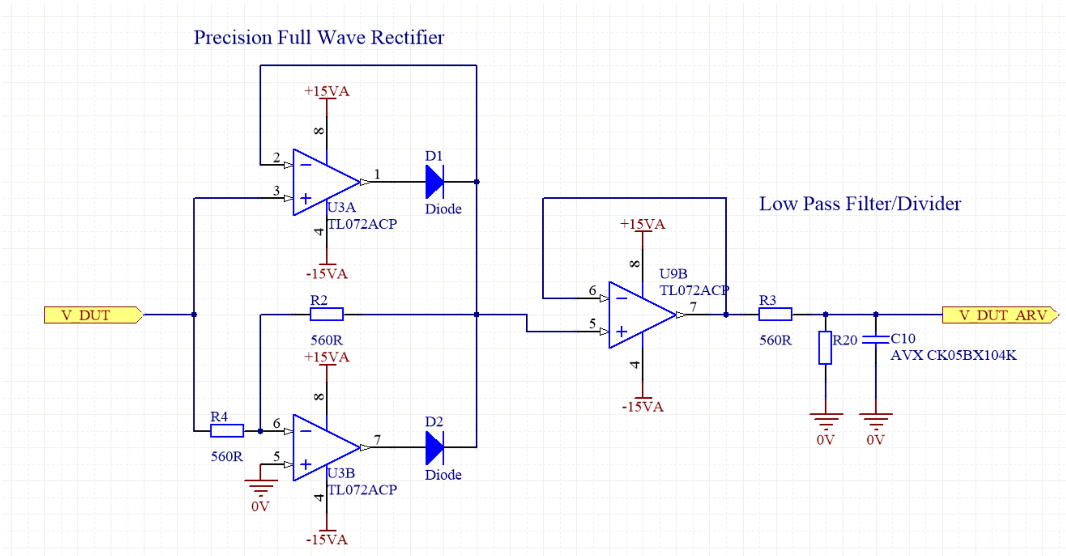

Figure 4: Full wave rectifier and averaging circuit (LPF)

The phase measurement is performed by timing the zero crossings of the voltage and current waveforms. In order to perform this measurement the waveforms should be processed such that each zero crossing can cause an MCU interrupt.

By using a comparator to 'square up' the waveform, and a resistor on the open collector output to the 3V3 supply the output can be sent directly the the MCU input. A small amount of hysteresis is used in the comparator circuit in order to prevent false switching.

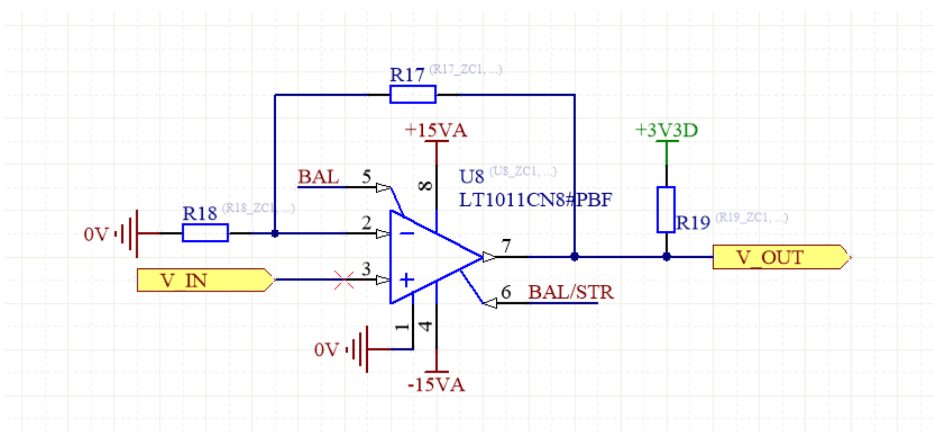

Figure 5: Zero Crossing Detection for Phase Measurement

The connections to the microcontroller can be seen below:

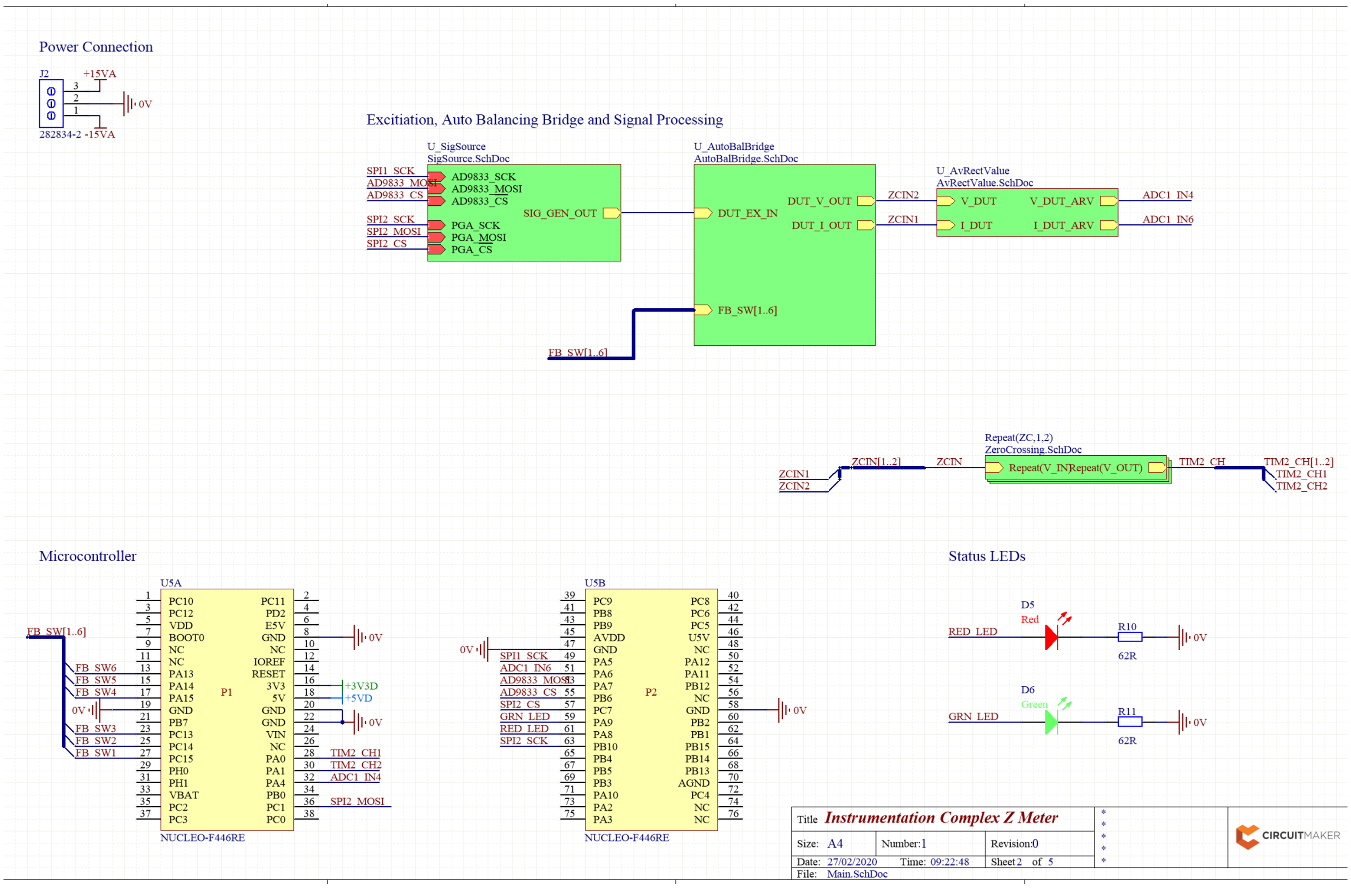

Figure 6: MCU Connections

3 PCB

The two sides of the PCB can be seen below, along with a 3 dimensional view of the PCB.

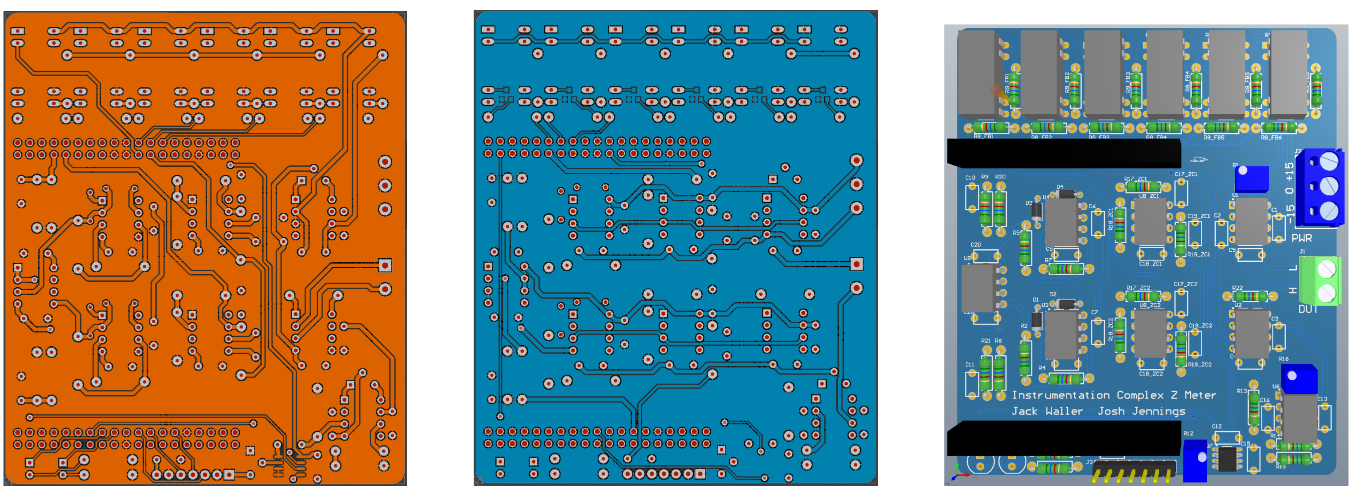

Figure 7: PCB Top and Bottom Copper, and 3D View.

The PCB has been designed in order to prevent problems encountered while prototyping with breadboard. Decoupling capacitors have been placed as close as possible to all IC power pins, and the voltage and current measurements have been separated into two channels running down the centre of the board, the SPI interfaces between the MCU and AD9833/PGA have also been kept as short as possible and away from analogue signals in order to prevent interference through capacitive coupling.

Where available, the relevant offset nulling circuitry has been incorporated to the PCB, particularly on the output driver of the signal source and the transimpedence amplifier. This will enable a reduction in error as any offset at these op amps will be able to be calibrated out.

The board also incorporates kelvin sensing to the DUT terminals, this prevents the current from the signal generator output causing a non-negligible voltage drop across the PCB trace when driving low impedance DUTs. Ground planes have also been used on both sides of the board in order to minimise the length of any current return path.

The PCB has also been designed using a majority of through hole components for ease and speed of assembly, and only using surface mount components in areas of the design where space is a premium or a through hole alternative was not available (e.g. the PGA). An example of this is the transistors used to switch the relays for the auto balancing bridge, using a standard through hole package would have been difficult to fit onto the PCB, but by using a through hole variant they were relocated to the bottom of the PCB.

4 High Level Overview of Code

4.1 MCU Code overview

The main process of the microcontroller is a task based loop executing tasks depending on flags set asynchronously. Different flags are set when serial messages are received from the desktop application. If the update frequency flag is true, the microcontroller communicates with the AD9833 to set the desired frequency to measure at via SPI. A similar task is performed for the PGA gain setting.

The measurement of the magnitude and phase of the voltage and current are performed asynchronously to the main microcontroller task loop, the phase measurement being performed using callbacks when zero crossings occur as outlined below, and the magnitude measured using DMA in order to maintain a constant sampling rate, and enable easy implementation of FIR filtering if needed.

- The **phase difference** is measured by timing the difference between the zero crossings of voltage and current waveforms. This is implemented using a single timer module with the voltage and current waveforms on separate channels. On the rising edge of the first waveform, the timer is started, and on the rising edge of the second, the timer ticks value is read. A callback is then triggered which saves this value.

  The value of the first timer is found using a function call back that is called when the channel one pin receives a rising edge. When this happens, a boolean flag is set to tell the MCU that counting has started. If this bool is true, then channel two of the timer can be read in the same way using the channel two pin, and the difference between the two times is saved. The flag is then set too zero.

- The **magnitude** of the signal is measured directly using the in built ADC on the microcontroller. It uses direct memory analysis to load the values directly from the ADC to a memory buffer. Callbacks occur when the buffer is half full and completely full. This allows the CPU to apply a finite input response filter if needed to the signal, which will remove any remaining AC signal components which have remained after the analogue filtering. The output of the filter is then used as the magnitude and stored in a variable which is sent to the user in the main loop.

The messages that are used to set the previously mentioned values are sent over UART. These messages are a 12 byte packet consisting of a header containing a message delimiter, length information and a message ID, followed by 8 data bytes and finally a single byte checksum used for error checking. This message structure is also used to transmit data in the form of magnitude and phase values back to the desktop application.

4.2 Desktop Application Overview

A companion desktop application that is used to configure the desired parameters while making the measurement. It is written in C# and has been designed to take the information from the user and sends the relevant commands over UART to the microcontroller. It also receives messages over UART from the microcontroller and presents the measurements to the user.

5 Operating Modes and Accuracy Estimates

5.1 Modes of Operation

The device will operate in the apply V, measure I mode. The software will incorporate the means to resolve the measured complex impedance into a series or parallel RC circuit, controllable by the user.

5.2 Accuracy Estimates

5.2.1 Magnitude Accuracy

ADC Resolution The ADC resolution will cause a reduction in the magnitude accuracy due to its quantization noise, however this should not be the limiting factor for accuracy in this circuit.

Op-Amp offsets/bias The op amps used in the signal conditioning prior to the signal conditioning will introduce errors, due to their input bias/offsets. The TL072 and LT1363 have 6mV and 1.5mV input offset voltage respectively. This error however can be compensated using offset nulling where available to remove the offset. Therefore the op-amp errors can in theory be reduced to errors due to finite gain bandwidth and error due to $\frac{1}{f}$ noise.

Rectifier/LPF offset To prevent offsets due to diode voltage drops, a precision rectifier circuit is used to prevent the offset by using negative feedback to make the output of the diode the same as the input. This reduces the offset of the rectifier to the the diode's turn on voltage divided by the open loop gain of the op amp. Making use of a TL072, this means the diode offset voltage is reduced to 3.5mV. The use of op amps will also introduce errors due to input offset/biasing which are around 6mV.

In-Amp offsets The AD662 has a 125uV input voltage offset and a 1.5mV output offset. These can also be calibrated out.

5.2.2 Phase Accuracy

The accuracy of the phase measurement will be dependant on the resolution of the timers used. Since the timers in the MCU are 32 bit, they need to be able to time the signal to +180 degrees. If the timer is used without a prescaler the timer tick value corresponds to 5.56ns. This means the maximum value of the timer before a rollover is approximately 23s. Therefore for all test frequencies the timer can be operated without a prescaler. The value of one timer tick in degrees for each test frequency is the approximate error. This is shown in Table 1. This shows using the timer the full spec can be achieved at frequencies lower than 1MHz. The signal conditioning circuitry used on the current and voltage waveforms will also introduce errors, however if the signal conditioning for both is suitably matched, then this will effectively cancel out. The LT1011 used for timing has a maximum 250ns response time, and 150ns typical response time, this discrepency corresponds to a 36 degree uncertainty at 1MHz and a 3.6 degree uncertainty at 100kHz, however this is a worst case scenario.

Test Frequency	degrees per timer tick
1kHz	0.002
10kHz	0.02
100kHz	0.2
1MHz	2

Table 1: Phase error at different test frequencies.