RMS Experiments

We recently had an enquiry from a teacher regarding a higher physics RMS experiment which was suggested on SPUTNIK.

The SQA Higher Physics course specification contains the following:

Electricity
Monitoring and measuring AC

Knowledge that AC is a current which changes direction and instantaneous value with time.
Use of appropriate relationships to solve problems involving root mean square (rms) and peak values.

$$Vrms = \frac{Vpeak}{\sqrt{2}}$$

There is no mention of the wave form. However as $\sqrt{2}$ is used in the denominator and AC is the heading, a sinusoidal wave is perhaps implied (although other waveforms could also result in a factor of $\sqrt{2}\ see\ later$).

Experiment

A simple light detector was constructed consisting of a BPW34 Si photodiode in parallel with a 43 Ω resistor (See figure 2). A digital multimeter is connected across this parallel combination. The photodiode is inserted into a short length of 15 mm plastic pipe, lined with matt black card.

A DPDT (double pole double throw) switch box was also constructed but this is not strictly needed it, just makes life easier!

With the DPDT switch set to the DC position adjust the DC output voltage until a convenient value is noted on the voltmeter attached to the light sensor. This will be in the order of a few millivolts. Note this value along with the value on the voltmeter attached to the DC supply. Now switch the DPDT switch to the AC power supply and adjust its output voltage until the reading on the voltmeter attached to the light sensor is as close as possible to the value previously recorded. Note down the peak voltage from the CRO (or better still the peak – peak voltage, then half it). Repeat this procedure for other values and voltages. Plot the DC value voltage on the x-axis against the AC peak voltage on the y-axis the gradient of the graph will be the V_{peak}/V_{DC} ratio.

For best results choose both your DC and AC power supplies carefully. Some power supplies with both DC and AC outputs may have a great looking sinusoidal AC output but only a full wave rectified, unsmoothed DC (See fig 1). Conversely the DC may be flat and smooth but the AC only vaguely resembles a Sine wave! We used two different power supplies to get the results for the Sine wave rms value. It is also good practice to measure the output voltages and not simply rely on the dial setting!

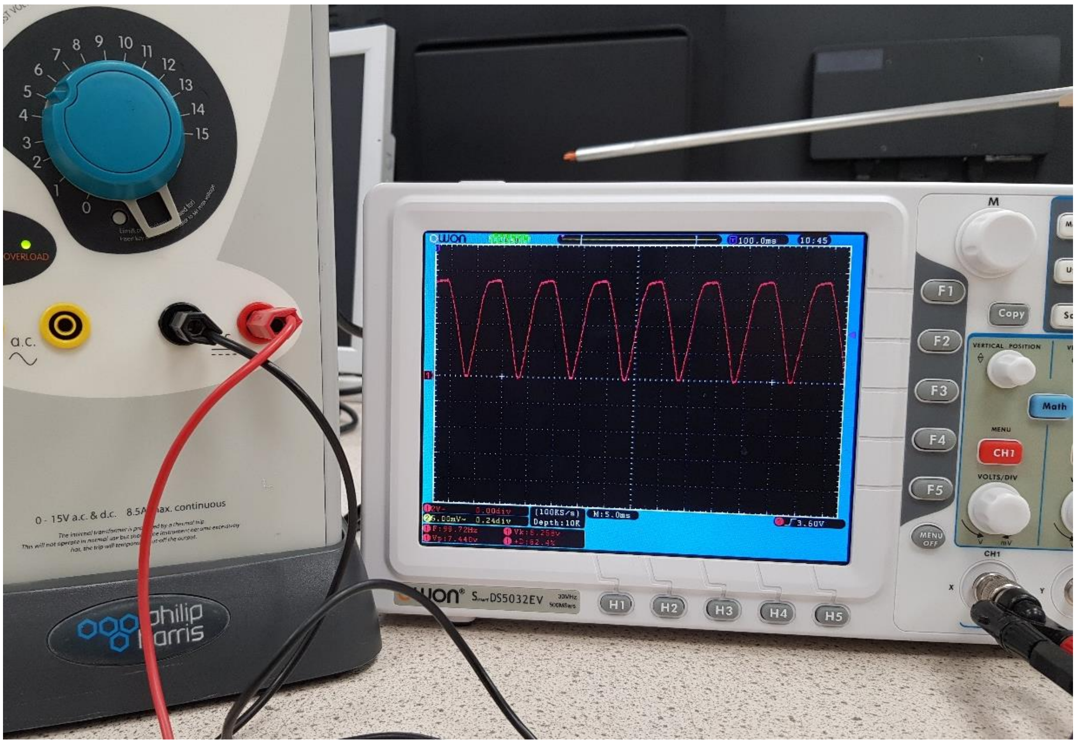

Fig 1. Unsmoothed (full wave rectified) DC

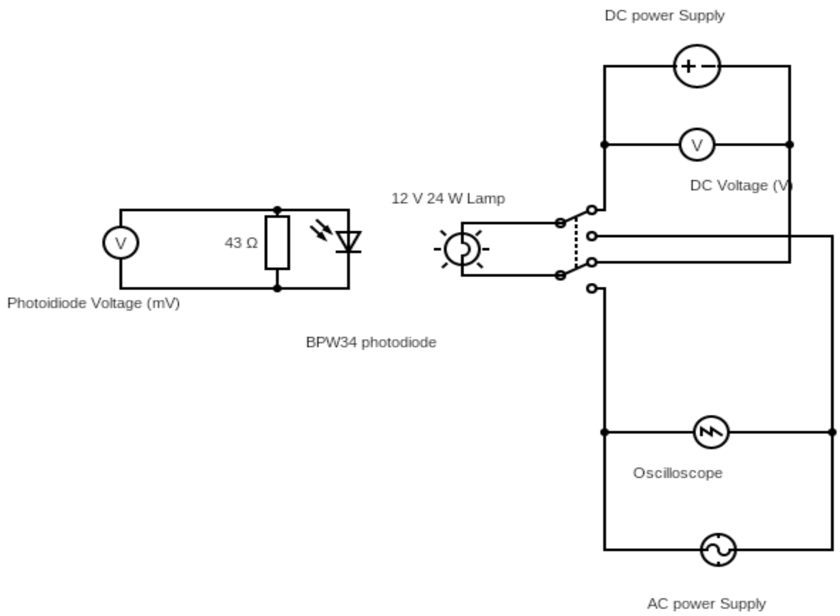

Fig 2. Circuit diagram of set up.

Results

Sine wave

SIN RMS V expt			
Photodiode Voltage (mV)	V (dc) (V)	V (pk-pk) (V)	V (pk) (V)
0.1	2.39	6.6	3.3
1.0	3.76	10.0	5.0
5.0	5.50	15.4	7.7
10.1	6.79	19.0	9.5
20.6	8.70	24.0	12.0
30.2	9.93	27.6	13.8
40.1	10.98	30.8	15.4
50.1	12.10	34.0	17.0
	LINEST	1.41344605	-0.16485
		0.011793668	0.096668
		0.999582449	0.10887
		14363.51258	6
		170.2476333	0.071117

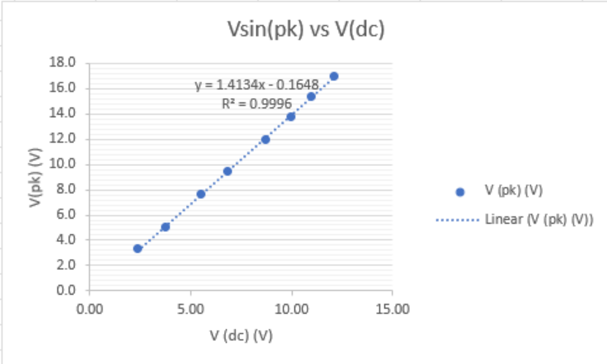

Fig 3. Sin wave result showing a gradient of 1.41

Extra

As an extra, repeat the whole process but replace the sinusoidal AC power supply with a bipolar triangular power signal generator or with a bipolar square wave power signal generator if you have one.

Triangular Wave

Tri RMS V expt			
Photodiode Voltage (mV)	V (dc) (V)	V (pk-pk) (V)	V (pk) (V)
0.1	2.33	7.0	3.5
1.0	3.48	11.2	5.6
1.5	3.81	12.4	6.2
2.0	4.11	13.2	6.6
2.5	4.33	14.0	7.0
3.0	4.54	14.4	7.2
3.5	4.74		
	LINEST	1.70127829	-0.39148
		0.056378649	0.216291
		0.995626441	0.100559
		910.5868747	4
		9.207885198	0.040448

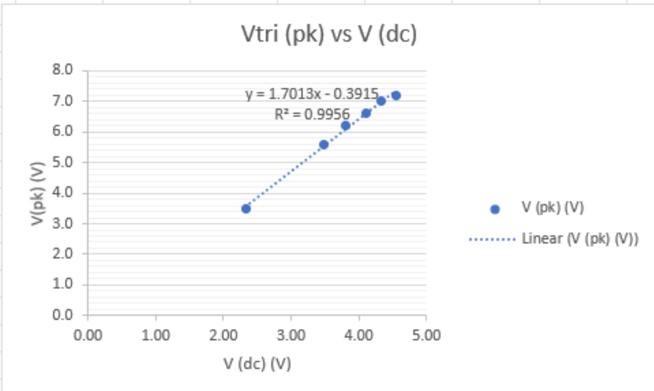

Fig 4. Triangular wave result showing a gradient of 1.70

Square Wave

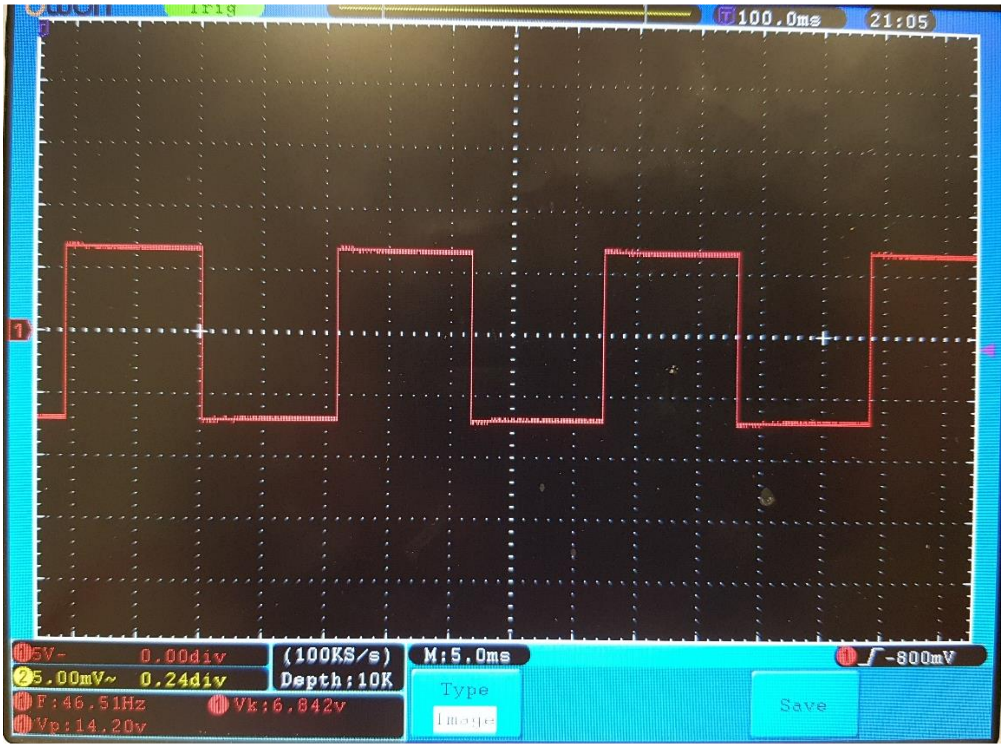

Fig 5. CRO screen showing square wave

Keep a careful eye on the shape of the waveform on the CRO as the waveform may distort at higher outputs.

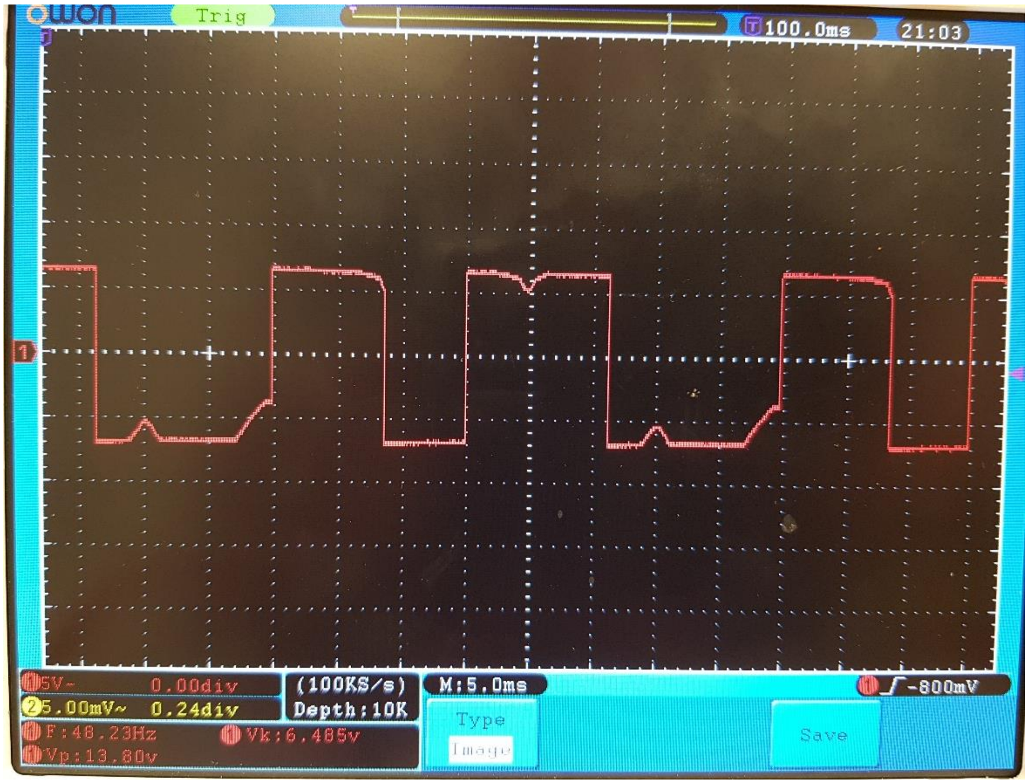

Fig 6. showing waveform distortion.

SQU RMS V expt			
Photodiode Voltage (mV)	V (dc) (V)	V (pk-pk) (V)	V (pk) (V)
0.1	2.20	4.6	2.3
1.0	3.48	7.4	3.7
1.5	3.85	7.8	3.9
2.0	4.10	8.6	4.3
2.5	4.37	9.4	4.7
3.0	4.55	9.8	4.9
3.5	4.73	10.2	5.1
4.0	4.93	10.6	5.3
4.5	5.08	11.0	5.5
5.0	5.24	11.4	5.7
	LINEST	1.126919496	-0.25279
		0.029119738	0.126369
		0.994686687	0.079449
		1497.651867	8
		9.453502271	0.050498

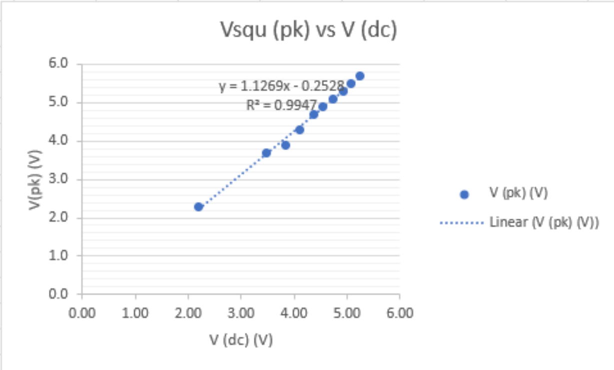

Fig 7. Square wave results showing a gradient of 1.13

<u>Pulse Wave</u>

It is also possible to find the RMS value of a pulsed DC waveform. We had one signal generator at SSERC that was able to provide a TTL waveform with a fixed 50% duty cycle and a fixed, no load, voltage of 5 V.

We took two readings and found that to get the equivalent brightness produced by a 4.8 V, 50% duty cycle, pulsed wave we measured that we needed an average DC voltage of 3.39 V.

This gave a value of 4.8 / 3.39 = 1.42 i.e for a 50% duty cycle pulsed wave i.e. $Vrms = \frac{Vpeak}{\sqrt{2}}$.

Fig 8. Pulsed (TTL) waveform. Fixed 5 V 50% duty cycle.

Experimental results comparison with theoretical values

Waveform	Experimental result	Theoretical value
Sinusoidal	1.41	1.414
Triangular	1.70	1.732
Square	1.13	1.000
Pulsed 50% duty cycle	1.42	1.414