Constructing a precision SWR meter and antenna analyzer.

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Abstract.

I have been asked to put together a detailed article on a SWR meter. In this article I will deal with the theory and the building blocks that one can put in place to construct a precision SWR meter. You can make use of the following building blocks and you can use what you like and you can discard what you like but, if you follow these steps you should be able to put together an effective and highly accurate antenna testing system. Then, let me just state for the record that this article reflects what I have picked up through experience and experimentation and certain aspects may not conform to conventional thinking, but what the heck, this is how I do it.

Load.

The very first thing that one must consider is the load or antenna impedance. One cannot us a SWR meter that is set up for 50 ohm loads to set up a 75 ohm (or any other impedance for that matter.) You will find that most SWR meters do not reflect the most important criteria that one needs to know when using this instrument and that is why no two SWR meters will give the same reading on the same transceiver / antenna / frequency.

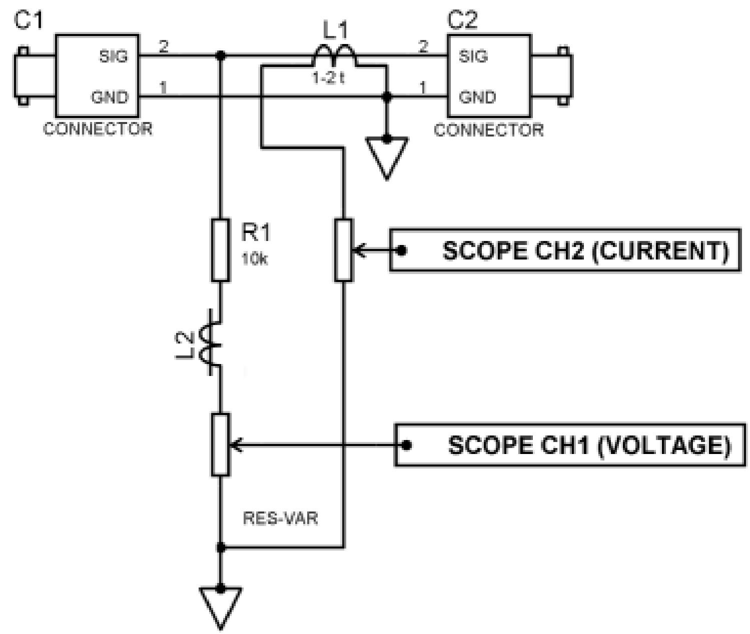
Passive (un-powered) SWR meters are usually set up for a frequency range and specific antenna impedance. Use the instrument on different impedances and towards the ends of the frequency bands and you will just be fooling yourself if you think that the reading is accurate.

Active (powered) SWR meters are generally much more accurate and can operate across a far wider band.

The first step in setting up an antenna system is to have a dummy load that you can use as a reference system. One should ideally calibrate your SWR meter into a dummy load or the appropriate resistance. Ie 50 Ohms.

Voltage and current sensing.

There are various methods that can be used to generate a SWR related signal. I am a fan of the current / voltage sensing method. The disadvantage of this system is that one needs an active (powered) circuit to generate the indication. The advantage is that it is highly accurate and very wide band. In other words, it does not suffer from the loss of accuracy that passive systems are prone to. But hey, every other meter on my desk has a little 9V battery in it so why not the SWR meter. This is the basic circuit:

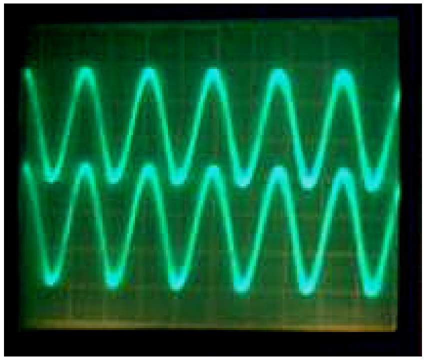


In the above circuit, the voltage is dropped over the resistor R1 and adjusted by the trim-pot. The current passing through the signal line that L1 is looped around will generate a voltage across L1. The current trim-pot adjusts the amplitude of this signal. A low power sensing circuit may need an extra turn or two. The current and voltage sense signals can now be routed to an oscilloscope where one can now view the voltage and current signals. With this system it does not matter which side you connect the antenna or the transceiver, as the signal is AC.

There will be a small phase shift over L1 between the current passing through signal line that L1 is looped around and the voltage generated across L1 and that phase shift will increase as the frequency increases. We therefore put an identical coil in the voltage sensing line that will phase shift the voltage sense signal by the same amount thereby eliminating the inductive phase shift effect of the current sensing coil.

Calibration.

Now we connect a dummy load of the impedance that we wish to calibrate the circuit for. In our case, 50 ohms. We then send an RF signal through the circuit and we calibrate the trim-pots so that the voltage sense signal and the current sense signal are the same amplitude. This is what your trace should look like.



The current and the voltage sense signals are the same size and they are in phase representing a perfect load.

Usage

Right so now you have this thing connected between a transceiver and a dummy load. Now on to the next step. Disconnect the dummy load and connect the antenna and set you transceiver to the lowest output power setting that you can. Select the AM mode (because that usually generates 50% of the power of the CW mode, but, failing that, select the CW mode in the lowest power setting that you can.) Now, key the transmitter and look at the two waveforms.

One of several things is going to happen. You may see that :

1) The relationship between the two signals will be the same as they were when you had the dummy load connected, which means that your antenna is beautiful and you can now go and do something else.
2) The voltage trace is larger that the current trace, which means that your antenna impedance is high.
3) The current trace is larger than the voltage trace, which means that your antenna impedance is low.
4) The voltage trace precedes the current trace which means that your antenna is inductive in nature (too long)
5) The voltage trace follows the current trace which means that your antenna is capacitive in nature (too short)
6) And then, you may find that the current and voltage waveforms are completely different in appearance which means that your antenna system is resonating on an harmonic of the input frequency (which is not good at all)

So now, you go about correcting your antenna system in the manner as indicated by adjusting your feed-line and antenna dimensions.

Feedline correction.

Connect your transmitter to your SWR meter, through your feedline, to your dummy load. (in other words, put an RF plug on the end of your feedline and bring it back to your workbench and plug it into the dummy load.) Measure the amplitude of the voltage signal at the transmitter side. I usually adjust the voltage trace on the scope to reflect 100% of the display (as my scope display has a % setting) .

Is there a phase variation between the voltage and current traces? This will indicate that your feedline is either to long or to short. You will have to make the appropriate correction. Once you have a resistive feedline, that is not reactive (inductive or capacitive) you can then proceed to the next stage of your setup.

Feedline losses.

Now, connect the feedline directly to your transceiver and place the SWR pickup between the end of the feedline and your dummy load. Now key the transmitter and look at the amplitude of the voltage trace. It should be a percentage of the signal amplitude when the pickup was placed between the transmitter and the feedline. To help me to figure things out at a glance, I printed out this calculating disk on my computer.

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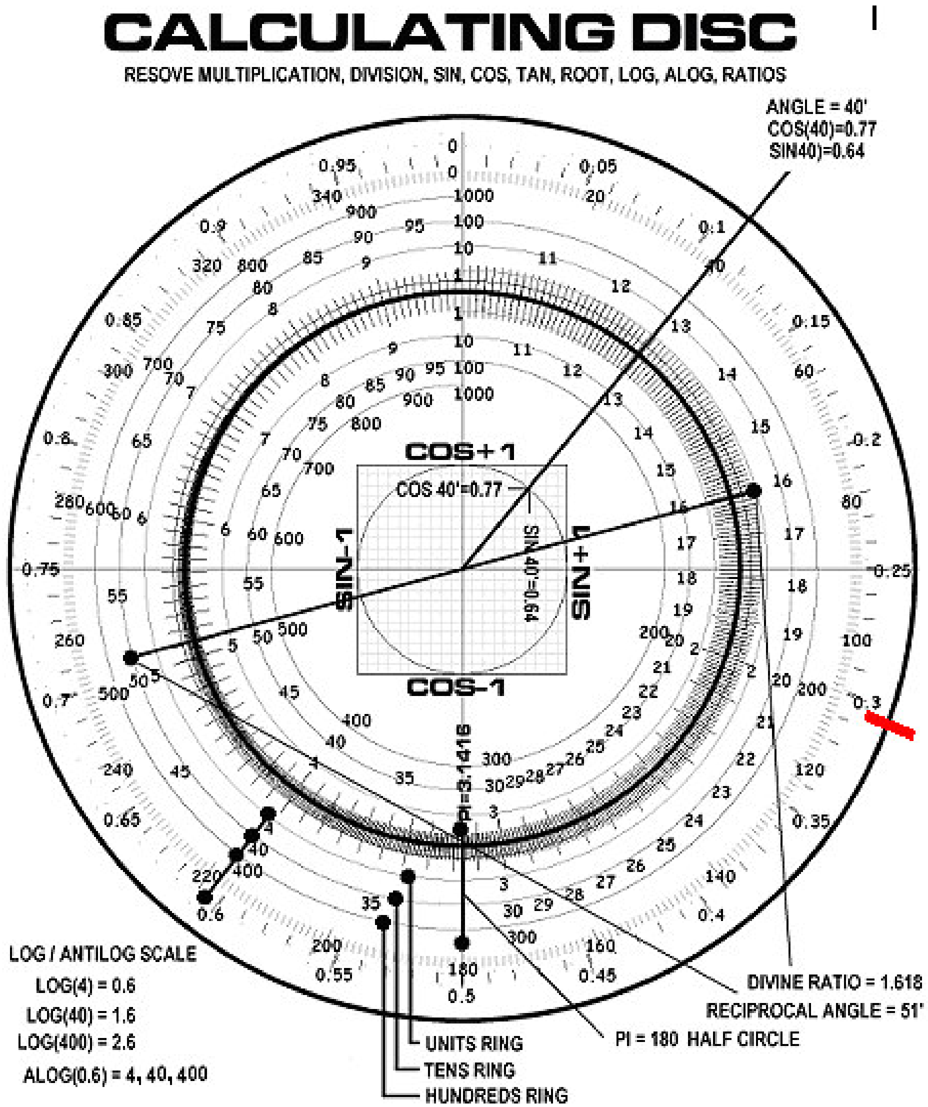


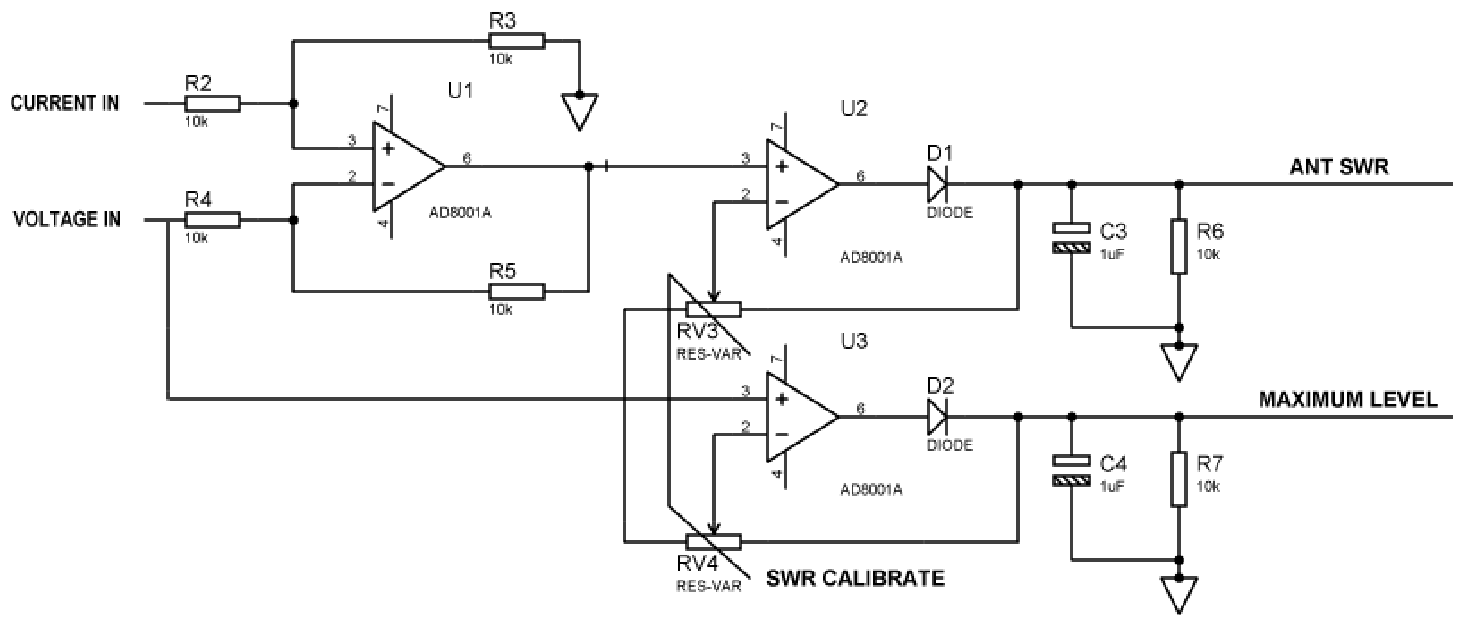
Let us say for example that the voltage amplitude at the dummy load is 50% of the voltage at the transmitter (to make the math easy) . That means that the power at the output point of the transmitter is 2X the power at the input point of the antenna, which is equivalent to a 3dB (0.3B) loss as indicated by the red mark on the calculating disk, (left) . So 400 watts forward is losing 200 watts over your feedline. (not good) . Now, if you were to insert a forward/reflected power meter between the end of the feedline and the input to the antenna and you were to get a reflected power reading of 50 watts, you would get 25 of those watts back at the output of your transmitter (which is the power dissipated by your average soldering iron- which means your output circuit will now try to de-solder itself). 25/400*100 = 6.25% and if u look at the table below, 6.25% ~ a SWR of 1.65:1 which in turn puts your effective output power at 93.75% at your transmitter. But because of your 3dB feedline loss, 47% of your power will be radiated by your feedline as heat and cross channel noise leaving only 47% of your original 400 watts (187 watts) being transmitted as effective RF through you antenna system, and that is it in a nutshell.

* ERP = Percentage of Effective Radiated Power

SWR READING	% OF LOSS	ERP*	WATTS AVAILABLE of 100 out
1.0:1	0.0%	100.0%	100
1.1:1	0.2%	99.8%	99.8
1.2:1	0.8%	99.2%	99.2
1.3:1	1.7%	98.3%	98.3
1.4:1	2.8%	97.2%	97.2
1.5:1	4.0%	96.0%	96.0
1.6:1	5.3%	94.7%	94.7
1.7:1	6.7%	93.3%	93.3
1.8:1	8.2%	91.8%	91.8
2.0:1	11.1%	88.9%	88.9
2.2:1	14.1%	85.9%	85.9
2.4:1	17.0%	83.0%	83.0
2.6:1	19.8%	80.2%	80.2
3.0:1	25.0%	75.0%	75.0
4.0:1	36.0%	64.0%	64.0
5.0:1	44.4%	55.6%	55.6
6.0:1	51.0%	49.0%	49.0
7.0:1	56.3%	43.8%	43.8
8.0:1	60.5%	39.5%	39.5
9.0:1	64.0%	36.0%	36.0
10.0:1	66.9%	33.1%	33.1

A SWR sensing amplifier circuit using precision rectifiers.

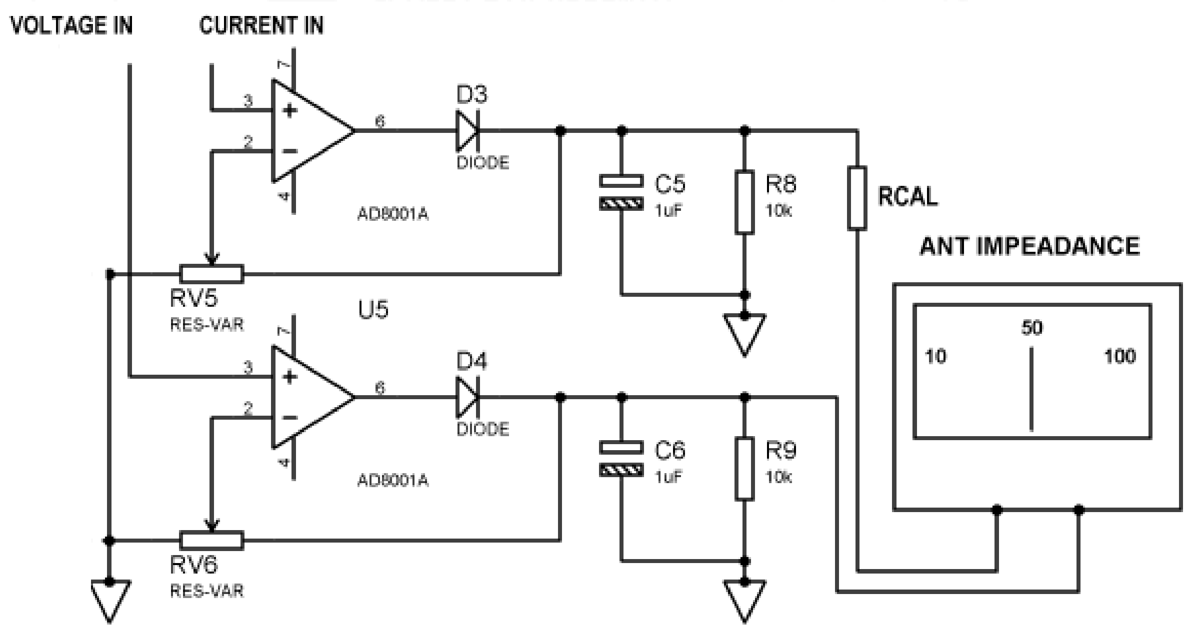
In order to use the SWR pickup in the field, (because it is not always practical to drag a scope around with you, the following circuits can be used to give you the relevant information on a portable field meter.



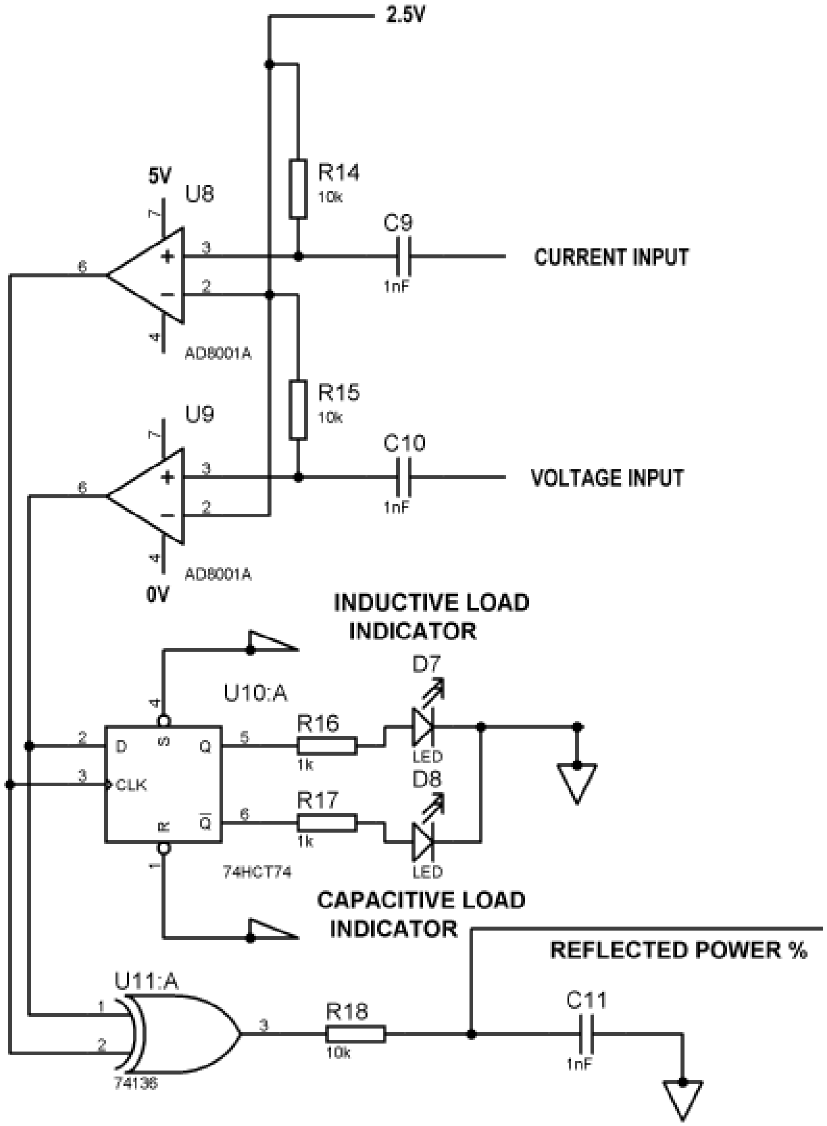
This circuit uses U1 as a differential instrumentation amplifier. The output of U1 is proportional to the difference between the voltage and current sense signals. Ie. If the inputs are identical, then there is no output. U2 and U3 are precision rectifiers reflecting the SWR and Calibrate levels. The output is calibrated using the SWR CALIBRATE adjustment of R3/R4.

An impedance indicator

The following circuit can be used to show the impedance of the antenna system.



The meter is a center zero type. If the voltage and the current sense signals are equal then the output of the voltage and the current precision rectifiers is also equal and there will be no deflection on the meter, which would in turn, indicate a 50-ohm load. If the voltage is higher than the current, that will indicate an impedance higher than 50 ohms. If the current is higher than the voltage, that will indicate an impedance of less than 50 ohms. RCAL should be chosen according to the power level you wish the circuit to operate at.

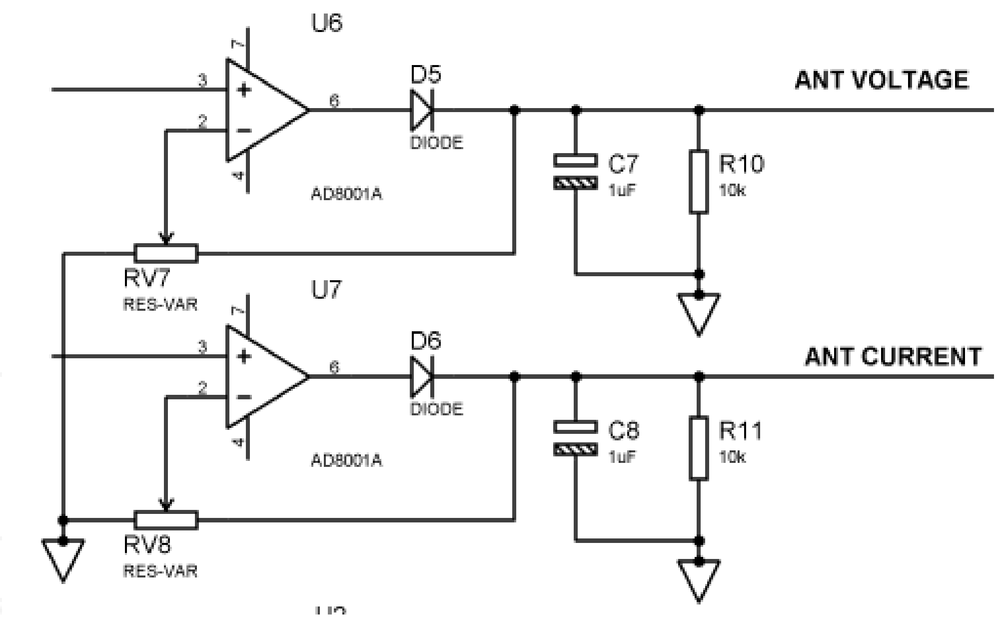


Reactive Load and Phase angle indicator

This circuit can be used to indicate whether a load is inductive or capacitive and the phase angle of the reflected power. U8 and U9 convert the Current and Voltage sine waves into square waves. These signals are fed to the Data and Clock inputs of a Data latch. The current input clocks the state of the voltage signal into the data latch. If the current goes high before the voltage, a 0 is clocked in making Q = 0 and /Q = 1. This turns on the Capacitive load LED. If the voltage goes high before the current, the current input will clock, a 1 is clocked in making Q = 1 and /Q = 0. This turns on the inductive load LED.

The current and voltage square waves are applied to the input of an exclusive or gate which will reflect the difference between the two square waves as a pulse width modulated square wave proportional to the phase angle difference. This PWM square wave is integrated through R18/C11 and the output voltage of 0-5V represents a phase angle of 0-180 degrees, leading or trailing as shown by the capacitive / inductive load indicator.

Antenna voltage and current.



This is a pretty simple circuit consisting of two precision rectifiers that will give a DC output corresponding to the amplitudes of the antenna current and voltage. One can pre-scale them into a multi function meter or one can feed them into a little micro-controller which can then multiply the two signals together and give you an output proportional to the product of the two representing the power. Watts = Volts X Amps. You can of course use the same device to divide the volts by the amps and give you an output reflecting the load impedance.

In fact, by using the above circuits to feed a micro controller, (that is if you are into playing with micro controllers) you can digitize the various signals, send the values to your computer, and have your PC do a full workup on your antenna system. Then, hook up a 74HCT4046 and you can get a full spectrum profile for your antenna system and that piece of kit shouldn't cost you more than about two or three hundred rands.

I hope that this has been of use.

Thanks and best regards.

Mike Brink.
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Please feel free to mail me if you have any questions.

Please visit our club website at www.zs6pot.org for more kit and project stuff

Please visit my personal website at www.zr6bri.co.za for more kit stuff and to check out what I'm busy with.