A POOR MAN’s ANTENNA ANALYSER

(With sincere thanks to that outstanding engineer/designer, Jim Tregellas VK5JST (1), whose original work inspired me, for his patience, advice, understanding, tolerance and good humour in answering my many e-mails instead of telling me where to go!)  

PART 1

With being a “canny Scot” (not to mention an O.A.P radio amateur), perhaps comes a certain increased motivation to look for cheaper, which in turn generally means simpler, solutions to problems which continue to confront me in this life-long, yet still stimulating hobby of ours.

I am in no doubt that in my early radio amateur days, and as a result of the lack of proper measuring equipment, mostly limited to a home-brew multimeter and a G.D.O. (grid-dip oscillator – blame Lee de Forrest for the “grid”!), I must have spent – sorry, wasted - hundreds of hours and miles of copper wire, in numerous early attempts at making the perfect antenna and any associated loading coils or traps. The G.D.O usually gave me more dips than the “big dipper” and I mostly had little idea what they really indicated.

Many moons later, along came the now almost ubiquitous “antenna analyser”, in particular the MFJ-259. It seemed too good to be true – a possible solution to most of my problems…except one, I couldn’t really justify spending £200 or more on one little black box. Luck was at hand however, on a visit to my old pal Bob Hope (the late LA2UA/5Z4LW) in Stavanger. Bob had won an MFJ-259 in a raffle, could see no need for it and would I like it (for past services rendered!)? I didn’t have to be asked twice.

My world changed. Suddenly, guessing went out of the window, and I could accurately measure a host of previously semi-mysterious variables, and design and analyse the performance of antennas, especially portable and/or mobile. I was truly hooked and some years later, when the opportunity arose to buy the later “259-B” version for £100 new in the U.S.A. arose, how could I resist?!

But, and despite the virtues of these analysers, they remain beyond the pocket of many. I asked myself many times why this was so. Maybe the “canny Scot” in me makes me more curious/inquisitive. What makes them “tick”? Well, a typical analyser consists of an oscillator feeding a Wheatstone-type bridge, a frequency-counter and of course the aerial. The oscillator needs to be sinusoidal, wide-band, constant amplitude, stable and be able to deliver some power to the aerial under test – a tough specification! Various bridge voltages are interpreted to produce readings of aerial input impedance and S.W.R.

Despite the tough spec’. I asked myself if such an instrument could be home-brewed at much less cost. Having, in my teaching days, successfully built many simple frequency counters, that didn’t seem a problem. The oscillator was a different story. Like many RAOTA members, my first transmitter was home-brewed. At the time (in the 60s), I built every conceivable valve oscillator (Colpitts, Hartly, Clapp, Pierce, Franklin, Tesla etc etc) in the search for the elusive one which could be dropped from a foot above the bench, which had zero thermal drift, was unaffected by loading and produced a pure tone…I believe I got as close as was humanly possible on a near-zero budget and with limited East-African resources!
Fortunately, I now have a reasonably well-stocked junk-box. The first step was to design an ultra-simple but accurate 4-digit frequency counter around the now almost obsolete 74C925 counter chip I had saved from my long-gone days as a physics/basic electronics teacher. This worked to perfection. Then the problems began – the oscillator. This had to be stable, both in terms of frequency and amplitude, as well as sinusoidal (i.e. harmonic free), ideally from below 1.8MHz to at least 30MHz, as well as being capable of supplying some power to a low-impedance load. My ‘60s solutions were useless…. At about that time, I had an e-mail from Patrick GW1SXN mentioning that Jim VK5JST had designed an MFJ 259B-type antenna analyser around a very stable, constant amplitude, wide-band “power” oscillator and a multi-function LCD display, the whole lot being controlled by a P.I.C. chip. It was (and still is, I believe) available to Australian amateurs (and indeed anyone anywhere) in kit-form and at the then incredibly low price of less than £40! In true amateur fashion, Jim had also made the circuit and an excellent description, freely available on the internet (2). Despite an intrinsic fear of P.I.C. chips (based wholly on my ignorance thereof), the Scot in me surfaced again, with the reasoning that if an Aussie could do it for £40, maybe (by cutting a few corners!), a Scot could do it for under £20! The target was set. Right away, I decided to omit the PIC chip…my analyser would not be able to compute reactance or impedance. However, I was more concerned with SWR and impedance at resonance.

The oscillator problem would be solved by (reluctantly) “copying” that part of Jim’s circuit. After much staring at the circuit and head scratching, I finally felt I understood roughly how it worked. More problems arose…Jim used a double sided P.C.B (one side acting as a ground-plane) and transistors which I could not find here in the U.K. After much pouring through transistor data, I plumped for what I considered to be a near-equivalent, readily available and costing a few pence each. I could have ordered the P.C.B. from Jim, but this was “cheating” going a bit far! I opted (to Jim’s total amazement and, more especially, horror) for my much-practised, miniaturised Veroboard techniques. After many months of utter frustration (spread over two winters), but driven on by stubbornness and a determination to make it work against all the odds, I finally succeeded…not quite perfectly…I had to add an output FET buffer stage…Jim later reckoned my chosen transistors, despite seeming to be near-identical, were in fact “marginal”…I would now agree!!

I now had the necessary low output-impedance power oscillator with which to feed a fairly traditional Wheatstone bridge circuit. A few diodes and some op-amps completed the set-up. All that was left to do was to produce a new meter scale, to show aerial resistance (at resonance) and S.W.R. A quick check of my miscellaneous aerials showed that my analyser was in indeed not only capable of producing the same basic results as the MFJ-259, but at a fraction of the cost. I had in fact reached my target of “less than £20”. Admittedly, I did have most of the components in my junk box, but I believe the target figure would have been achieved (or very close to it) had I had to buy all or most of the components.

Sad to say, having reached my goal, the instrument (as with many other completed “challenges”) now adorns a shelf in the shack. But, in a way, that’s not the end of the story…rather the beginning of another.

**PART 2**

Forever seeking a challenge, I asked myself just what minimum “feed-back” the average amateur really needs, to ensure his/her aerial, commercial or home-brew, will work with the maximum efficiency theoretically possible for that particular design. I am also constantly aware that aerials are the one field in our hobby where it is still possible to experiment and meet the “raison d’etre” of our licence [as stated in the introduction thereto – Para.1, sub para. 1(1)(a)], and ultimately where considerable savings can indeed be made.
First of all, I observed that the majority of us work with resonant aerials. This means that the input impedance of the aerial, whilst perhaps not the ideal 50 ohms, is purely resistive, i.e. the reactance X is zero, hence the input impedance Z is simply R. Secondly, none of us needs a sophisticated oscillator of the type described earlier – we already have an even better one…in our rigs. Indeed, what are rigs but high quality, stable, wide-band, relatively powerful oscillators?! Furthermore, and for the same reason, we do not need a frequency counter. We do need an SWR-meter as this, together with a knowledge of R, will allow us to properly match the “R” of our aerial to the output impedance of our coax and our rigs (generally 50Ω). The remainder of this article describes a simple instrument which achieves all this, and perhaps best of all requires no power source other than a few watts of RF power from the TX!

Let us first of all look at how a typical “antenna analyser” works? The answer in some ways is “quite simply”…

Referring to Fig.1, the TX (suitably attenuated) produces an r.m.s. voltage V (typically 10V) across one diagonal of a conventional Wheatstone bridge (re-drawn in “rectangular” form for ease of interpretation) with 50Ω resistors in three of its arms, the unknown resistor Rx (the aerial) being placed in the remaining arm. This results in voltages VA and VB appearing at opposite ends of the other diagonal. As R1 = R2 = R3 = 50Ω, VA is V/2. VB will depend on the relative values of R3 and the unknown load RX. VA and VB are then rectified by D1 and D2 respectively, producing d.c. voltages √2 times the r.m.s. values. Diode D3 produces a third d.c. voltage representing the difference between VA and VB. If we represent these three d.c. voltages by v1, v2 and v3 (and, for the time being, neglect diode forward voltage drops), we have:

\[ v_1 = \sqrt{2}V_A \quad v_2 = \sqrt{2}V_B \quad \text{and} \quad v_3 = \sqrt{2}(V_B - V_A) \]

Let us now consider the following three basic bridge conditions:

(i) \( R_x = 0 \) (ii) \( R_x = 50 \text{ ohms} \) (iii) \( R_x = \infty \)

[Note: Errors caused by the diode forward voltage drops are minimised by using Schottky barrier types (\( V_f \approx 200\text{mV} \) or less). A sensitive meter (\( 50\mu\text{A} \) or \( 100\mu\text{A} \)) is also used. The other resistors and capacitors simply provide RF filtering].

<table>
<thead>
<tr>
<th>( R_x )</th>
<th>( V_A )</th>
<th>( V_B )</th>
<th>( V_1 = \sqrt{2}V_A )</th>
<th>( V_2 = \sqrt{2}V_B )</th>
<th>( (\text{the magnitude of...}) \ V_3 = V_2 - V_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>V/2</td>
<td>0</td>
<td>0.707V</td>
<td>0V</td>
<td>± 0.707V</td>
</tr>
<tr>
<td>50</td>
<td>V/2</td>
<td>V/2</td>
<td>0.707V</td>
<td>0.707V</td>
<td>0</td>
</tr>
<tr>
<td>( \infty )</td>
<td>V/2</td>
<td>V</td>
<td>0.707V</td>
<td>1.414V</td>
<td>± 0.707V</td>
</tr>
</tbody>
</table>

Table 1
Studying this table, we see that as it does not change with changing load, \( v_1 \) can therefore be used to represent applied input power or voltage. We also see that the value of \( v_2 \) depends on the value of \( R_x \), ranging from 0V when \( R_x = 0 \) to 2V when \( R_x = \infty \). Voltage \( v_2 \) can therefore be used to represent \( R_x \). Finally, voltage \( v_3 \) is 0V when \( R_x = 50\, \Omega \) (SWR = 1) rising to a maximum of 0.707V when \( R_x \) tends either to zero or to infinity (SWR = \( \infty \) in both cases). \( v_3 \) can thus be used to indicate SWR on a scale calibrated from 1 to infinity (\( \infty \)). It should be noted that the \( R_x \) scale will be incorrect for reactive loads. However, \( v_2 \) is always a minimum at resonance - a useful indicator thereof. The SWR and \( R_x \) scales are clearly non-linear but can be established using a selection of known resistors, or by calculation (see later). Jim VK5JST demonstrates mathematically that, irrespective of whether \( R_x \) is purely resistive or complex (i.e. \( R + jX \)), the resulting SWR scale is in fact correct.

Fig.2 (including minor component value changes as of May 2013)
In the circuit diagram (Fig 2) above, resistors R9 to R20 form a Π-pad 10dB attenuator (2). Two inputs to the bridge are available. When the “HIGH” input (20W max.) is selected (TX connected to “HIGH I/P” and switch closed), the signal passes to the bridge via the 10dB attenuator which reduces the power by a factor of 10. When the “LOW” input is used (2W max.), the signal is fed directly to the bridge. After completing assembly, the analyser is pre-calibrated, WITH NO AERIAL CONNECTED, as follows:

(i) switch S1 to “I/P LEVEL” (position 1), apply 1→2W directly to the bridge (or about 10→20W via the attenuator) and check that the meter reading is in the “INPUT OK” (green) range.
(ii) switch S1 to “F.S.D.” (position 2) and adjust VR3 for full-scale deflection (∞ on SWR scale)
(iii) switch S1 to “SWR” (position 3) and adjust VR1 to give full-scale deflection (∞ on SWR scale)
(iv) switch S1 to “R or Z” (position 4) and adjust VR2 to give full-scale deflection (∞ on “R or Z” scale)
(v) If a good 50Ω dummy load is available, check that S.W.R. is 1 : 1 and Rₓ is 50Ω! (N.B. Always set F.S.D. before taking SWR and Rₓ readings on any aerial).

CONSTRUCTION:

Over many years managing ‘O’ Level Electronics projects in schools, I developed (as mentioned earlier) my own “Veroboard” assembly method which has worked well for both simple and more complex projects. The layout of the main board is shown in Fig.3 below:

![Circuit Diagram](image)

Fig.3 (including minor component value changes as of May 2013)

VR₁ and VR₂ are shown “dotted” as their exact position will depend on their shape, physical size and pin layout. The edges of the board are tapered, as the 4” x 3” x 1.5” ABS plastic boxes used are themselves tapered. The 2.9” (tapering to 2.8”) x 0.8” board slots into the “guides” at each side of the box.
A slight variation of the technique, using double-sided PCB was used for the construction of the 10dB attenuator (Fig.4).

Creating an SWR scale from readings of \( v_x \)

Clearly, the scale will depend on the meter used (I was fortunate to acquire some new high quality, very linear and very good value, Russian military 50\( \mu \)A meters from Bulgaria on eBay!).

Whilst both scales can be created using a selection of known (non-inductive) resistors, I preferred to use some simple maths and do some (repetitive) calculations. For these, I assumed an input power \( P_{\text{IN}} = 2\text{W} \) and \( R_{\text{IN}} = 50\Omega \), so that \( V_{\text{bridge}} = 10\text{V} \) (r.m.s.). (from \( P = V^2/R \)).

So as not to overwhelm everyone with off-putting mathematics, I will only reproduce the final formulae from which you could produce your own scales (I am happy to e-mail or post the missing “details” to anyone requesting them).

For meters with linear movements (not “VU” meters for example), where the meter angular deflection \( \theta \) is proportional to \( v \), and \( v_x \) is the “unknown” voltage, it can be shown that

\[
v_x/v_{\text{fsd}} = (\text{SWR} - 1)/(\text{SWR} + 1)
\]

and

\[
\theta_x/\theta_{\text{fsd}} = v_x/v_{\text{fsd}} \quad \text{or} \quad \theta_x = \theta_{\text{fsd}} (v_x/v_{\text{fsd}}) \quad \text{or} \quad \theta_x = \theta_{\text{fsd}} (\text{SWR} - 1)/(\text{SWR} + 1)
\]

\( \theta_{\text{fsd}} \) is of course the angle for full-scale deflection for the particular meter used (mine was 87°).

A table of angles corresponding to chosen SWR values can thus be constructed, and a new scale produced, for any chosen meter. I found Jim VK5JST’s scale points very convenient and used these. The scale is numbered at SWR 1, 1.5, 2, 3, 5, 10 and \( \infty \), with 4 intermediate graduation marks between SWRs 1 and 1.5, 1.5 and 2 and 2 and 3, as well as single marks at 4, 6, 7, 8 and 9.
N.B.: In the case of SWR, the forward voltage drop \( V_f \) of the diode is not a variable, and, as stated previously, the scale is also correct for reactive loads.

**Creating a resistance scale from readings of \( v_2 \)**

In this instance, diode forward voltage drop IS a variable. In the relevant calculations, I have assumed a typical Schottky value of 0.2V. As a consequence, \( R_x = 0 \Omega \) occurs a shade below actual zero volts, whilst \( R_x = \infty \) occurs a shade above actual f.s.d. As a further consequence, the \( R_x \) scale is in fact only correct for one specific level of input power which in this design is \( P_{IN} = 2\)W (or 20W via the attenuator). The scale IS correct at ½ f.s.d., i.e. \( R_x = 50 \Omega \). However, at other power levels, the error is so small as to be insignificant. For example, if \( P_{IN} \) were only 0.2W (i.e. an unlikely 10 times less), there would be a progressively increasing error above and below 50Ω. For example, for a real \( R_x \) of 15Ω, the needle will be just over 1.5˚ too low, representing an apparent \( R_x \) of 13.5Ω – hardly discernible, and quite insignificant in the matching process.

Similarly, for a real \( R_x \) of 200Ω, the needle will be just under 2˚ too high, representing an apparent \( R_x \) of 228Ω, again hardly discernible and fairly insignificant. A power \( P_{IN} = 2\)W was chosen as the best compromise – this instrument was not designed as a digital ohm-meter – nor was it intended as an accurate scientific measuring instrument. It is a cheap, simple, hand-held, supply voltage-free, informative instrument, which allows the user to set up his/her aerial by indicating, fairly accurately, S.W.R. and input resistance at resonance. If necessary, simple transformer matching can then be used at the aerial input, thus dispensing with the lossy, inappropriate A.T.U. (another costly gadget). Now for some maths...

For an unknown resistance \( R_x \), \( v_2 \) (see Fig.1) = \( v_x = 14.14 \left[ R_x / (R_x + 50) \right] - 0.2 \)

We need to calculate \( v_x \) for each value of \( R_x \) anticipated (I again used VK5JST’s values of 10, 20, 30, 40, 50, 100, 200, 500 and \( \infty \), with intermediate scale points – see photo’)

If we choose “half f.s.d.” to occur at \( R_x = 50\Omega \), \( v_{fsd} \) computes to be 13.74 volts. Each scale point angle \( \theta_x \) can then be calculated by substituting the values for \( v_x \) (calculated above) in the following formula:

\[
\theta_x = v_x \left( \theta_{fsd} / 13.74 \right) \quad (\theta_{fsd} \text{ is of course the meter f.s.d. angle})
\]

FINALLY...High SWR presents NO risk of damage to the rig. If the aerial I/P is open-circuit, the impedance presented to the rig is 1000Ω (an SWR of 2 : 1). Similarly, if it is short-circuit, the impedance is 33.3Ω ( an SWR of 1.5 : 1). Both values are thus well within the safety limits of all transmitters.

I now keep this analyser in my own car for tuning my /M aerials (no risk then of losing/damaging my MFJ259B). The final Mk4 version uses the Russian 50µA meter and forms the basis of the present article. I have enough components to assemble a limited number of complete instruments at a cost of £70 (inc. P&P) – payable in advance. (I have been let down too many times!). For those wishing to “have a go”, but feel that calibrating an existing meter is a bit too involved, I can supply a limited number of re-scaled 50µA meters (identical to mine) for £20 (inc. P&P).

**Acknowledgements:**

1. Jim Tregellas, VK5JST (http://users.send.com.au)(e-mail: endsodds@internode.on.net), who planted the seeds, and in true radio amateur spirit, was free with his help and advice. (N.B. Jim’s “Q-meter” design is also well worth looking at).

2. 10dB Π Attenuator: p151, RSGB Radio Data Reference Book, by George Jessop G6JP

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