A Complex Impedance Meter

Simple Instrument Measures Both R and X

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The voltage-current relationships along a transmission line are well known. The author has taken these principles and developed a very simple means of indicating the complex nature of an RF load, with an X-Y oscilloscope display that approximates a Smith chart. One of the entries in the First Annual RF Design Contest, the enthusiasm of the author for his idea comes through clearly as he describes the instrument!

The idea of this instrument was conceived through the better understanding of the Smith chart that I was able to receive in the late '70s. It took a few years, until around 1980, to get around to building one, verifying the concept. I remember that it was an antenna that defied tuning, and a 2-meter (145 MHz) version of the instrument was built.

As is apparent in the Smith chart, all mismatches reflect power. At an open end of a transmission line a voltage maximum will occur. This corresponds to a point at the right edge of a Smith chart. At a shorted end there will be a voltage minimum (the left edge), and in the case of a perfect match, there will be equal voltage along the line (chart center). Correspondingly, loads with some imaginary part, inductors and capacitors combined with the load, will move vertically from the center, inductors up and capacitors down. They will not move on a straight line, like their resistive counterparts, but along some resistive circle, the unity circle if the resistive part is a match. In the vicinity of the center, this vertical movement is approximately a straight line. How do we detect and indicate these deviations, then?

A wise man, Magnus Koch at the Chal-

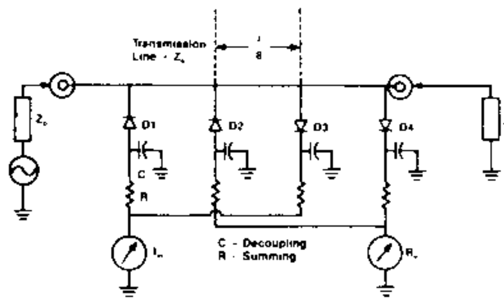

Figure 1(a). Basic schematic of impedance meter.

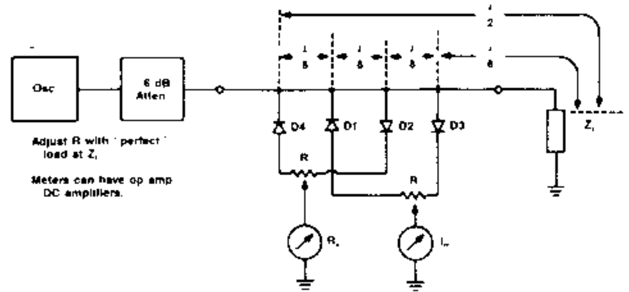

Figure 1(b). Circuit with measurement plane outside "unknown" connector. Note diode numbering change.

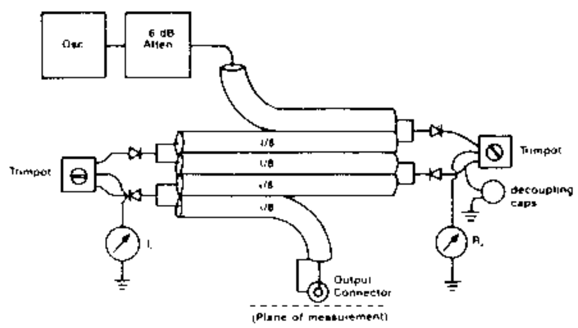

Figure 1(c). Practical construction method.

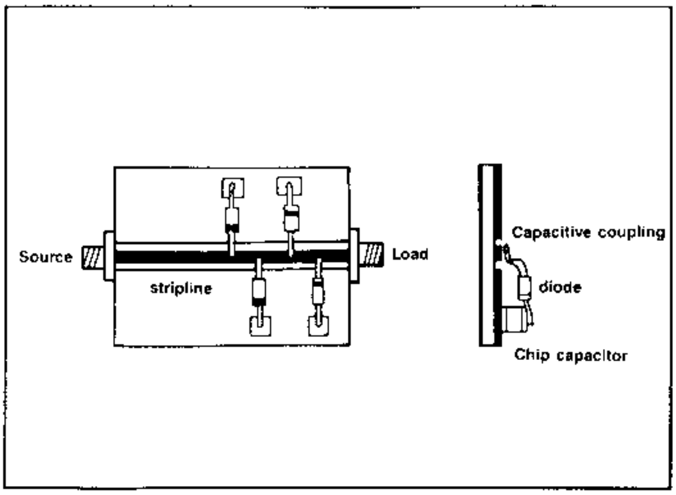

Figure 2. Possible microwave construction method.

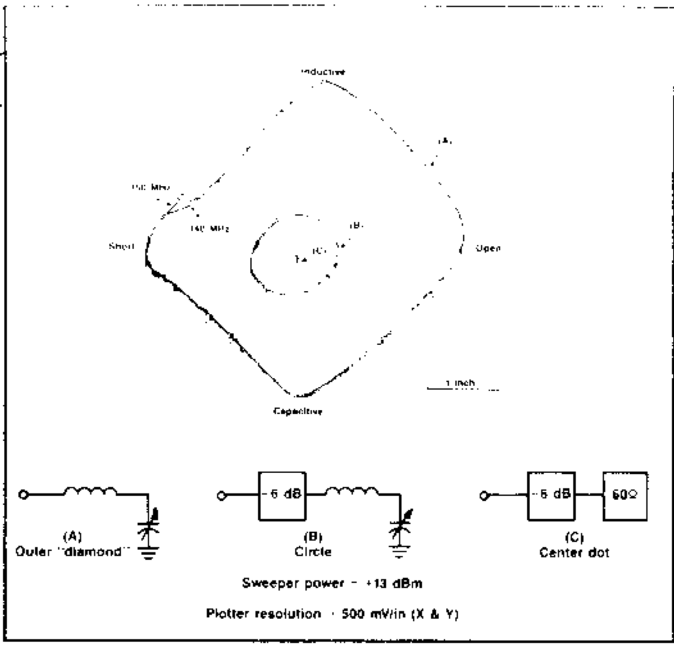

Figure 3. Display of "reference" measurements.

mers U. of Technology, Göteborg, Sweden, once told me, "If you can measure something with a bridge, do it!" As the years have gone by, I have found them to be words of wisdom, and they certainly apply here. A bridge, how to make a bridge that can detect in what direction something takes off on a Smith chart?

One does not have to! As you go along a transmission line away from, say a shorted end, you start at the leftmost end, and we all know that after $\lambda/8$, looking back, we will see an inductance with $j\omega L = Z_0$. After another $\lambda/8$, making $\lambda/4$ total, it looks like an open circuit, and so on. After one turn around the chart we have traveled $\lambda/2$ along the line. Let us now put four little detector diodes, monitoring the voltage on the line, spaced $\lambda/8$ apart, one in each "compass direction" around the chart. Well, you say, you can not do that! It introduces a mismatch! True, but all four diodes do the same. Since they are mutually cancelling, *at that frequency*, plus a little line loss, it does not matter.

Let us excite the line and try various loads at the other end. The last diode is to be positioned where the loads will be applied, or an integer multiple of $\lambda/8$, in which case the indicators will change sign and label.

Referring to the basic schematic (Figure 1), let us look at a short circuit. D4 will obviously get no voltage at all to detect, but D2 will get twice the normal. D3 and D1 will not see any change. Due to the way D2 and D4 are turned, a negative voltage will appear at their summing point. An open circuit will produce the opposite effect, with a positive voltage from D4 and no voltage from D2. In both cases, D1 and D3 will detect equally strong signals, but of opposite signs, so their sum is zero. In a similar way it works for imaginary deviations. Just imagine the chart rotated 90 degrees!

The beauty of the Smith chart, or at least one of them, is preserved is this apparatus. It is the fact that near perfect loads will be treated especially carefully and accurately. Also, the concept is clearly not limited to 50 ohm lines. One can imagine the use of perhaps a 5 ohm line in a test fixture for measuring transistor input impedances.

A limitation is the bandwidth. I would say that the function is very satisfying within a 10 percent band centered around the design frequency. That is certainly more than enough for most "band" operations, be it ham radio, cellular mobile, radar, microwave link or CB. An exception from the bandwidth limitation is, of course, the well-matched load, which will appear as such no matter what the frequency.

The maximum possible frequency of operation that can be achieved remains to be determined. The diodes have to be operating, of course, and can always be spread by multiples of $\lambda/8$ if physically necessary, but the bandwidth will suffer. Hewlett-Packard has been kind enough to supply me with some zero bias diodes good to 10 GHz, but in spite of a lot of care, they got damaged by static electricity. Using regular "hot carrier" diodes will work to at least 1 GHz, but a signal level of at least −15 dBm is necessary for good signals. A possible method of building the instrument for microwave frequencies is shown in Figure 2.

Practical Aspects

It may be more desirable to have the test plane outside the connector, as opposed to just behind it. This is possible by just adding some line after the last diode. This may actually be the preferred method, since all the diodes then will be mounted in an identical manner on the line, thereby balancing each other better. They will then have to be permutated, changing the order from 1-2-3-4 to 4-1-2-3.

It is also possible to measure remote (100λ) objects. By leaving the end of the line open, one can determine to what extent the chart is rotated, and either change the frequency slightly to get the open located on the right, or add some cable, or just remember the position. The insertion loss of the cable limits the sensitivity, of course, but I have derived useful information about a load with a 20 dB attenuator in line and +10 dBm excitation. This corresponds to a VSWR of 1.02:1 or 40 dB return loss. With the same level of excitation I can detect the difference between a "perfect" load and one of 70 dB reflection. To observe that mismatch on a Smith chart, you would have to use a microscope, since it corresponds to a distance from the center of half the thickness of a human hair.

Displaying the voltages on an X-Y oscilloscope (or a plotter for swept signals) is very convenient. It then becomes apparent that the outline of the displayed field, corresponding to the circular border of the Smith chart, is not really circular, but somewhat diamond shaped. Should this be disturbing, a 6 dB attenuator can be left on the measurement port. It is "transparent" enough to make good measurements through. It also provides the necessary DC return path for the diode currents, which may not be present in the load or source.

The matching impedance of the source is not critical at all. A mismatch there reflects part of the power back to the source, but what travels down the line is what counts. With zero bias diodes it

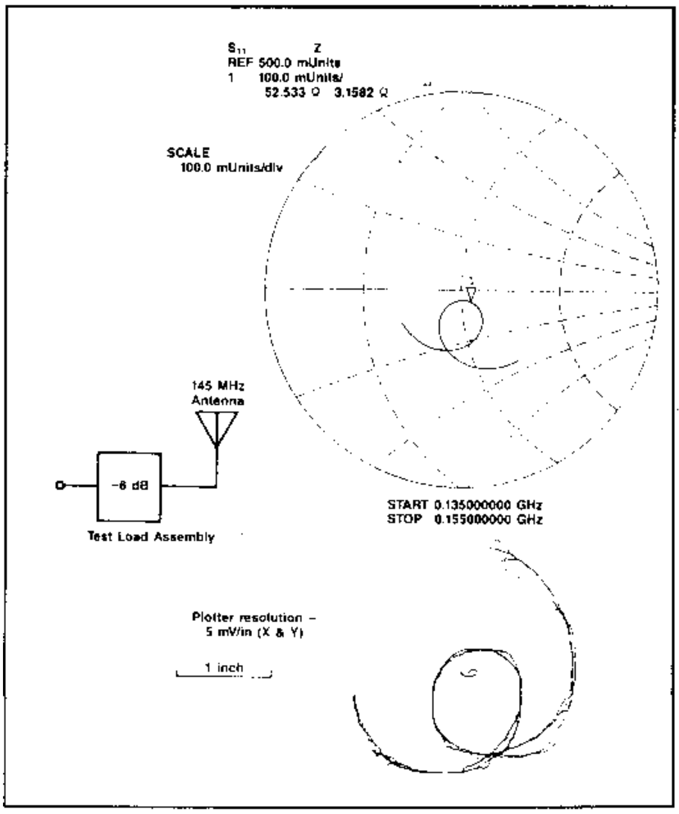

Figure 4. Top plot from HP8510 Network Analyzer. Bottom plot of same load by impedance meter. Note similarity of shape.

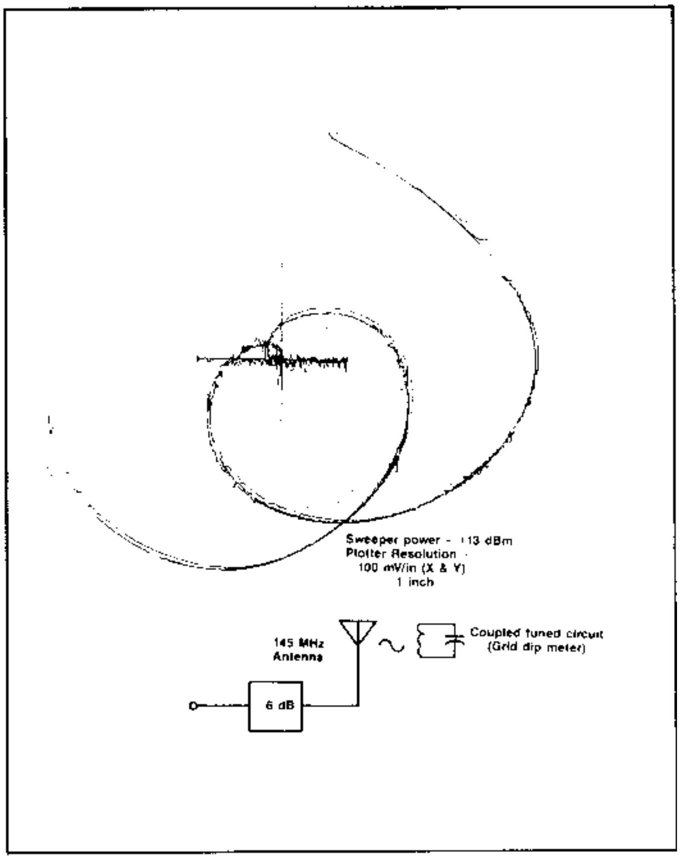

Figure 5. Effects of an additional tuned circuit, coupled to the antenna.

should be possible to use a regular signal generator for the source, with levels of 1 mV (−47 dBm), and measure receiver inputs without driving them into non-linear regions.

Substituting the "perfect" load with a resonant circuit opens up a few interesting applications. The output from the jX detector becomes very sensitive to changes in frequency, being zero at resonance. This can be used to measure deviation, modulation, PLL step response and maybe even phase noise. The higher the Q of the attached resonant circuit, the more sensitivity. A VCO can be locked to a cavity or a stub, by feeding back the DC signal.

Another application could be a distance meter, connecting both outputs to an UP/DOWN counter, with an antenna for a load. The sine/cosine information in the reflected signal will run the counter up or down, and one count for every half wavelength will be gathered. This may be a good detector for doppler radar burglar alarms, eliminating false alarms from objects that are just swinging back and forth in the wind.

To conclude, a detector has been described that in sensitivity far exceeds the common VSWR meter and furthermore provides information about the complex nature of the load, while still being of the same simplicity as a VSWR meter. The tradeoff is bandwidth. Also, it has other potential uses, as outlined, that a VSWR meter has not.

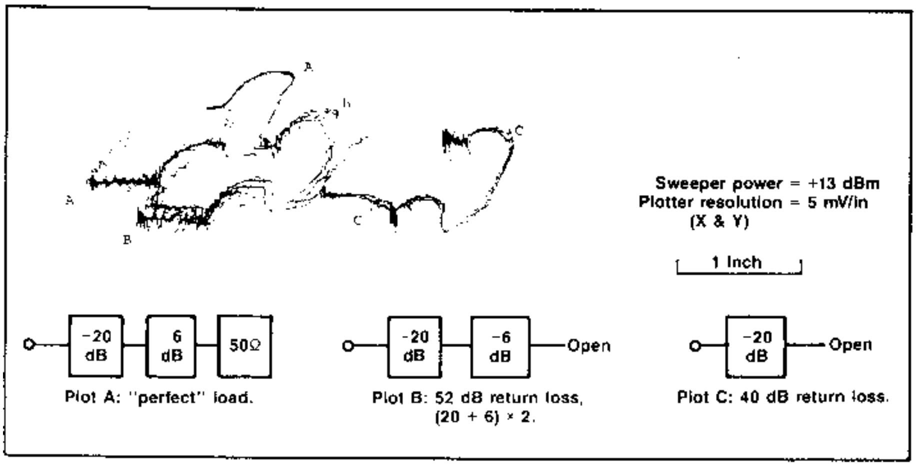

Figure 6. Sensitivity demonstration — High sensitivity display can discern difference between "perfect," 52 dB return loss and 40 dB return loss loads.

Acknowledgements

To Magnus Koch, as mentioned above, and to Ingvar Svensson, my teacher at TGG, Goteborg, who had the ability of explaining the Smith chart so vividly that this concept surfaced in one of his more absent-minded students' mind! If all teachers were like him, this world would be a much better place. rf

About the Author

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