A NOVEL APPROACH TO THE DESIGN OF A HIGH POWER AUTOMATIC IMPEDANCE MEASURING SCHEME

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Summary

This paper reports a novel design of a swept-frequency, swept-power, microwave automatic impedance measuring scheme using multiple probes and low-frequency signal processors. It can be used, for example, in FM radar or microwave-communication-system monitoring and nonlinear, swept-frequency, real-time $\bar{z}$-measurements.

System Design

The design of this novel system was originated from a modified phasor analysis as discussed below. If a lossless wave guide is connected between an unknown impedance $\bar{z}$ and a generator G with a fixed frequency, and if two fixed probes 1 and 2 are used to sample the E fields in the wave guide as shown in Figure 1, then in principle, one can calculate both the magnitude and the phase of $\bar{z}$ from the sampled field strengths E_1, E_2 (or E_1^2, E_2^2 if square law diodes are used), as shown in the following.

First, we need to calibrate the probes such that the probe output voltages can be read directly as E in the guide. We can then put a matched load (or a reflectionless load) at the loading point L and adjust the probe sensitivities such that the outputs at 1 and 2 are the same and read E_f. Then with the probe gain unchanged and the matched load replaced by the unknown impedance $\bar{z}$, the probe-detected output E_1,E_2 will allow us to determine the value of the unknown $\bar{z}$ as explained in the phasor diagram shown in Figure 2.

In this figure, we draw a circle with radius equal to E_f and use the horizontal phasor $\overline{LO}$ to represent the forward wave at the loading point L. If the reflected wave at L is represented by $\overline{OR}$, we can keep $\overline{OR}$ fixed (in contrast to the conventional phasor analysis that one usually keeps the forward wave $\overline{LO}$ fixed), and rotate $\overline{LO}$ clockwise to $\overline{1O}$ with arc $\overline{L1}$ equal to $2\beta\ell_1$ where $\beta\ell_1$ is the one-way phase difference between points 1 and L in Figure 1. Then the magnitude of phasor $\overline{1R} \doteq \overline{1O} + \overline{OR}$ $\equiv$ (forward wave + reflected wave)$_{\text{at probe 1}}$ will be equal to E_1 as detected by probe 1. Similarly, the magnitude of $\overline{2R}$ will be equal to E_2 as detected by probe 2. Now since points L, 1, 2 are fixed on the circle and E_1, E_2, E_f are measured, point R can be determined geometrically or algebraically and $\overline{OR}$ will be equal to the reflection coefficient $\bar{k}$ at the loading point if the length LO is taken as unity. Consequently, if this phasor diagram is superimposed on a Smith chart with the circumference of the circle in Figure 2 coinciding with that of the Smith chart, and L coinciding with the extreme-left point on the chart, then the impedance on the chart at point R is equal to the impedance of the unknown load $\bar{z}$ because the Smith chart is just a transformation from $\bar{k}$ to $\bar{z}$. While this scheme for measuring $\bar{z}$ appears to be simple enough, there exist several problems. First the frequency cannot be swept during the z measurement because it will change the value of β or the geometry in Figure 2. Second, if the power of the generator fluctuates, the lengths of phasors E_1, E_2 will change with respect to the precalibrated forward-wave phasor E_f, thus the measurement accuracy will fluctuate. Third, there exists a uniqueness problem in the measurements when $|E_1|$, $|E_2|$ take special values. All of these problems, however, can be solved by adding more fixed probes to the design.

Suppose we divide the power from the generator into two channels by means of a magic T as shown in Figure 3. Then, we can use V_6 (in Figure 3), the detected voltage corresponding to the forward wave in the main guide, to normalize all the probe-detected voltages in the main guide and eliminate the power fluctuation problem. Now, if all other fixed probes in the main guide are of equal distance from each other as shown, then the modified phasor diagram of the first four probe outputs with $V_1 \sim e_1^2$, etc., is shown in Figure 4. Analyzing the geometry of Figure 4, one can obtain the two components k_x, k_y of the loading point reflection coefficient $\bar{k}$ (or $\overline{OR}$) as functions of normalized probe outputs e_1^2, e_2^2, e_3^2, e_4^2 as shown in the following.

$$k_x = -k_{2//}\,(2\cos^2\theta - 1) - \frac{e_3^2 - e_1^2}{4}\cos\theta \qquad (1)$$

$$k_y = 2\,k_{2//}\sin\theta\cos\theta - \frac{e_3^2 - e_4^2}{4\sin\theta}(2\cos^2\theta - 1) \qquad (2)$$

where

$$k_{2//} = \frac{2e_2^2 - e_1^2 - e_3^2}{4(1 - \cos\theta)} \qquad (3)$$

$$\cos\theta = \frac{e_1^2 + e_3^2 - e_2^2 - e_4^2}{2(e_2^2 - e_3^2)} \qquad (4)$$

$$\sin\theta = \sqrt{1 - \cos^2\theta} \qquad (5)$$

Notice that in these equations, k_x,k_y are not functions of $\theta \equiv 2\beta\ell$, or of frequency $f \equiv \beta V_g/2\pi$ after (3), (4), (5) are substituted into (1) and (2). Therefore we can design a swept-frequency, swept-power, z-measuring scheme using analog signal processors to implement these five equations such that the outputs of the processors can be fed directly to a polar-display oscilloscope shown in Figure 5. While this system looks very promising, there still exists an ambiguous point. If we look at equation (4), we see that when $e_2 = e_3$, the denominator is zero. We can also prove analytically from Figure 4 that when $e_2 = e_3$ is true, $e_1 = e_4$ will also be true. Therefore $\cos\theta$ in equation (4) becomes an indeterminate form of 0/0 which is unable to handle by any signal processor. But this problem can be taken care of by adding probe 5 to the main guide (Figure 3) and a comparator circuit to the signal processors (Figure 5). Now, when $e_2 \approx e_2$ occurs, $\cos\theta$ will be calculated by the outputs of probes 2 to 5 instead of probes 1 to 4, as shown by the analog switches in Figure 5. Thus, the indeterminacy can be completely removed.

It is seen from this brief description that the novel design is derived from a modified look at the phasor analysis which allows us to use low frequency or d.c. signal processors to display the unknown impedance $\bar{z}$ on a Smith chart automatically when the frequency or when the power is swept. This system may be used in automatic, high-power, nonlinear impedance measurements, high-power, FM radar monitoring, high-power impedance-frequency spectra measurement, etc. A paper reporting some preliminary experimental results using this concept was published in the IEEE Transactions on Microwave Theory and Techniques, January 1979, pp. 38-43, and a long paper with detailed calculation on this scheme is currently submitted to the Proceedings of the IEEE for publication.

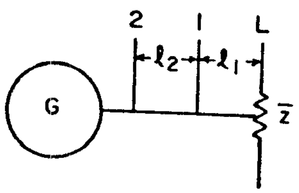

Fig. 1

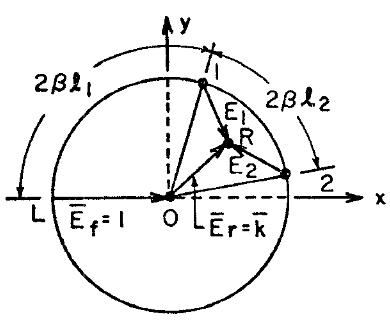

Fig. 2

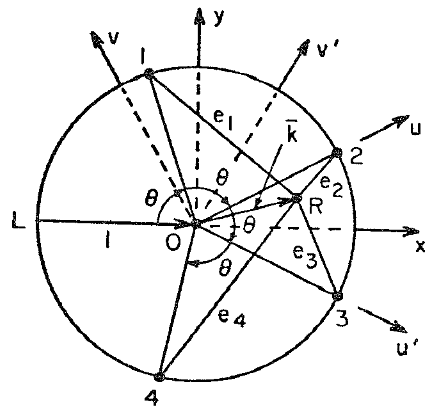

Fig. 4

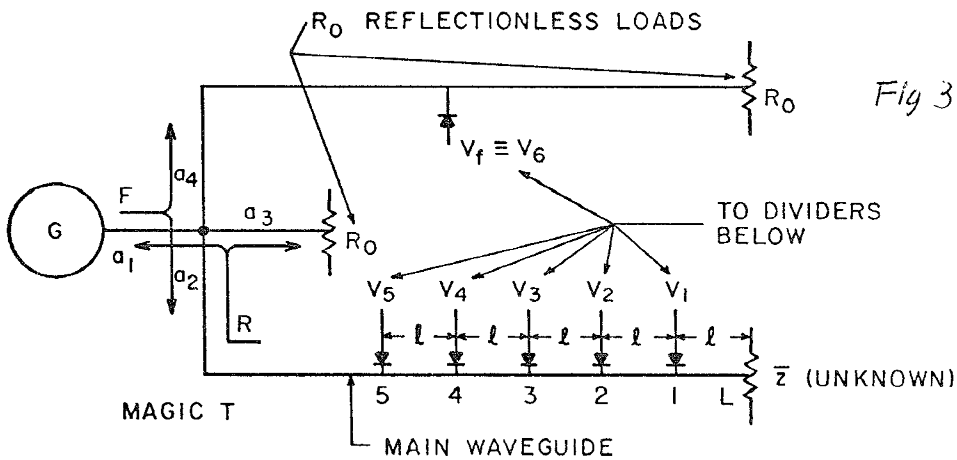

Fig 3

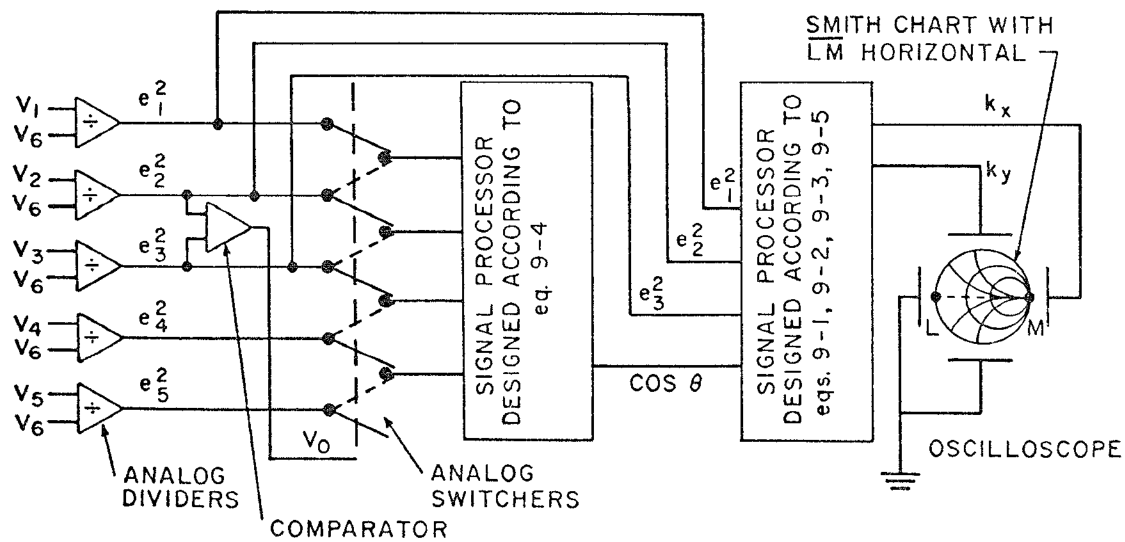

Fig. 5