MEASUREMENT OF THE EQUIVALENT CIRCUIT PARAMETERS OF DISCONTINUITIES IN A RESONANT MICROSTRIP RING

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Abstract

This paper presents an analysis of a resonant microstrip ring containing a small reciprocal discontinuity. The equivalent circuit parameters of microstrip discontinuities can be measured accurately with this inexpensive arrangement by observing the shift of the ring resonances. Measurements of the inductance of such cylindrical metallic obstacles are compared with theoretical values obtained with a variational method.

Introduction

Measurements of the scattering on small microstrip discontinuities through transitions require cumbersome error correction. The problem of transitions can be reduced significantly by testing the discontinuity in a resonant ring structure. Stephenson and Easter [1] and Douville and James [2] have demonstrated the resonant technique as applied to the characterisation of 90^{o} corners.

The present paper gives a comprehensive, general analysis of a resonant microstrip ring containing a reciprocal, lossless discontinuity of any kind. In the first part, it is shown how the discontinuity parameters are related to the shift of the ring resonances. The second part describes the experimental technique and presents some measurements made on cylindrical metallic posts.

Analysis of the resonant ring

A microstrip ring resonates if its electrical length is an integral multiple of the guided wavelength. When a reactive discontinuity is introduced into the ring, each resonance degenerates into two distinct modes. This splitting is conveniently interpreted in terms of even and odd excitation of the discontinuity. The even case corresponds to the incidence of two waves of equal magnitude and phase upon the discontinuity, while in the odd case, waves of equal magnitude but opposite phase are incident from both sides. Either mode of resonance can be suppressed by an appropriate choice of the point of excitation along the ring.

If the discontinuity is symmetrical, it can be represented by an equivalent T or π section in a single reference plane. A nonsymmetrical, lossless discontinuity can always be transformed into a symmetrical two-port by adding an appropriate length of line ℓ_a to one of the ports. The plane of electrical symmetry, henceforth called the z = o plane, is then situated halfway between the two planes with respect to which the two-port is symmetrical. The impedance in any other plane can be found by simply transforming it along the transmission line represented by the ring.

Consider the equivalent T-circuit of a lossless discontinuity in its plane of electrical symmetry (Figure 1a). For convenience, the circuit is broken down into two identical half sections of zero electrical length. The elements are expressed in terms of Z-parameters and are purely reactive. If this circuit is excited in the even mode, the current flowing through the z = 0 plane is zero. Therefore, the input impedance of each half-section is not altered by opening the connections in this plane (Figure 1b). The normalized even input impedance at either port is thus $Z_{ie} = Z_{11}+Z_{12}$. The normalized odd input impedance, in turn, is $Z_{io} = Z_{11}-Z_{12}$ and represents the impedance of a half-section which is short-circuited in the z = 0 plane (Figure 1c).

The even and odd impedances of the discontinuity cause the shift in the resonance frequencies of the ring. This becomes evident if the (reactive) impedances are thought of as input impedances of fictitious transmission line sections which are open (even case) or short-circuited (odd case) at the other end. (Figures 2a and 2b). The artificial increase of the electrical length of the ring which is reflected by the decrease of its resonance frequencies, is related to the normalized even and odd input impedances by the following expressions:

$$Z_{ie} = Z_{11}+Z_{12} = -j \cot k\ell_e \qquad \text{(even case)} \qquad (1)$$

$$Z_{io} = Z_{11}-Z_{12} = j \tan k\ell_o \qquad \text{(odd case)} \qquad (2)$$

$k = 2\pi/\lambda_t$ is the dispersive propagation constant of the quasi-TEM mode.

Figures 3 a and 3b show the standing wave pattern on the resonant ring when excited in the fundamental mode. For convenient presentation, the ring is cut open at Z = o and straightened out. The fictitious lines representing Z_{ie} and Z_{io} have been added on either side.

Since at resonance, the total electrical length of the resonator (including the discontinuity) is $n \cdot \lambda_t$, where n is the harmonic number, the resonance conditions are

in the even case : $$\ell_{ring} + 2\ell_e = n\lambda_{te} \qquad (3)$$

in the odd case: $\ell_{ring} + 2\ell_o = n\lambda_{to}$ (4)

ℓ_{ring} is the physical length of the ring along the mean circumference, and λ_{te} and λ_{to} are the guided wavelengths corresponding to the even and odd resonance frequency respectively. Since ℓ_{ring} is known and λ_t can be measured, ℓ_e and ℓ_o are determined from equations (3) and (4). When introduced into equations (1) and (2) respectively, they yield

$$Z_{11}+Z_{12} = -j\ \cot \frac{1}{2} k(n\lambda_{te} - \ell_{ring}) = j\ \cot(\pi \frac{\ell_{ring}}{\lambda_{te}}) \quad (5)$$

$$Z_{11}-Z_{12} = j\ \tan \frac{1}{2} k(n\lambda_{to} - \ell_{ring}) = -j\tan(\pi \frac{\ell_{ring}}{\lambda_{to}}) \quad (6)$$

From these expressions, the elements of the equivalent circuit of the discontinuity can easily be deduced.

The experimental technique

The measurement of the parameters of a discontinuity is performed in two steps:

i) The resonant frequencies of the ring are measured before the discontinuity is introduced in order to obtain the dispersive permitivity ε_{eff} of the line.

ii) The discontinuity is then introduced, and the even and odd resonant frequencies of the structure are measured. Since these frequencies are in general different from those measured in i), the values for ε_{eff} must be found by interpolation.

The ring should be as uniform as possible since any irregularity may introduce effects of the same order as the effects to be measured. It is excited by a capacitive launcher which can be moved along the outer contour of the ring for slightly more than one quarter of its circumference. Resonances are determined from return loss measurements. Coupling should be as light as the sensitivity of the equipment permits. Even then, the launcher changes the resonant frequencies slightly, but this effect may be included in the values for ε_{eff}, thus being practically eliminated if all measurements are made at the same coupling strength.

Great care must be taken to measure all resonant frequencies with the best possible accuracy, since the impedance values are very sensitive to frequency deviations. As an example, if a reactance of j 0.01 is to be measured within 10%, the measurement of the resonance frequency must be accurate within 0.1 %. This accuracy is limited by the sharpness of the resonance response rather than the accuracy of available counters for the microwave range.

Return loss measurements are preferable to transmission measurements because only one probe is required, thus minimizing the influence of the peripheral equipment.

Results

Measurements have been made on centered metallic posts of circular cross-section. The ring was a 20.5 Ω line (w/h = 5.05) on 0.125" substrate with a dielectric constant of 6.8. The oversize substrate was chosen in order to minimize errors due to dimensional inaccuracies. The ring had the form of a racetrack so that the discontinuity could be placed into a straight section of line, and the point of excitation could also be moved along a straight line on the opposite leg. The mean circumference of the ring was 55.124 cm.

Cylindrical metallic posts were chosen because they could easily be introduced without modifying the ring after the empty ring resonances had been measured. The obstacles were realized by drilling a hole across the ring and filling it with mercury. This ensured good electrical contact at the strip and the groundplane, and the electrical parameters of the discontinuity could be reproduced within the limits of accuracy of the equipment.

Return loss measurements were performed in the range from 0.1 to 2 GHz using a network analyzer. Frequencies were measured with a digital counter.

The 3 db linewidth of resonance was typically 1 MHz, and the frequency of the peak of absorption could be localized within 30 kHz.

Figure 4 shows the dispersive effective dielectric constant obtained from resonances of the empty ring. Figure 5 shows the normalized even input impedance of posts of diameter 1/16" and 1/8". Below 1 GHz, measurements agree well with theoretical values obtained from a variational expression. At higher frequencies, measured values for the reactance tend to be somewhat smaller then the calculated values. This is attributed to radiation effects which become more pronounced at high frequencies and reduce the stored energy in the vicinity of the posts. The odd impedance is, according to the theory, 100 times smaller than the even impedance for the 1/16" post and 15 times smaller than the even impedance for the 1/8" post. Measurements of these small quantities were scattered over a range of ± 100% of the theoretical values since they fell below the limits of measurement accuracy.

Conclusion

The equivalent circuit parameters of a discontinuity have been expressed in terms of the resonance shift they produce when introduced into a microstrip ring resonator. Such an arrangement provides a simple, inexpensive technique for characterizing lossless reciprocal microstrip discontinuities at discrete frequencies. Measurement accuracy is determined essentially by the precision with which the resonnance peaks can be located. The typical relative error in measuring a normalized reactance of j 0.01 is about 100 times as large as the error in the frequency measurement. It is therefore mandatory that resonnance frequencies be measured with great care, if discontinuity parameters are small.

References

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2. R.J.P. Douville and D.S. James, "Experimental Characterization of Microstrip Bends and Their Frequency Dependent Behaviour", IEEE International Electrical, Electronics Conference and Exposition, Toronto, CANADA 1973.

3. N. Marcuvitz, "Waveguide Handbook" Boston Technical Publishers, Inc., 1964.

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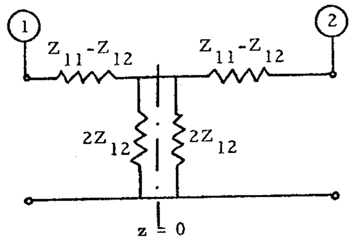

Fig. 1a Equivalent circuit of a symmetrical discontinuity

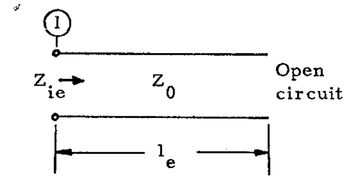

Fig. 2a Representation of the even input impedance Z_{ie} in plane (1) by a fictitious open-circuited line

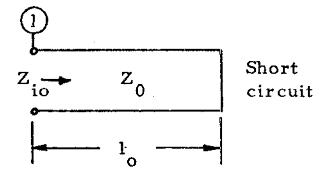

Fig. 2b Representation of the odd input impedance Z_{io} in plane (1) by a fictitious short-circuited line

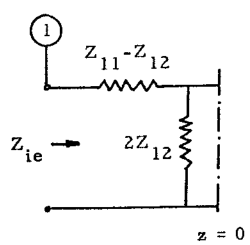

Fig. 1b One half of the equivalent circuit for even excitation $Z_{ie} = Z_{11} + Z_{12}$

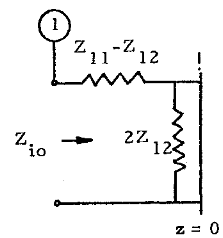

Fig. 1c One half of the equivalent circuit for odd excitation $Z_{io} = Z_{11} - Z_{12}$

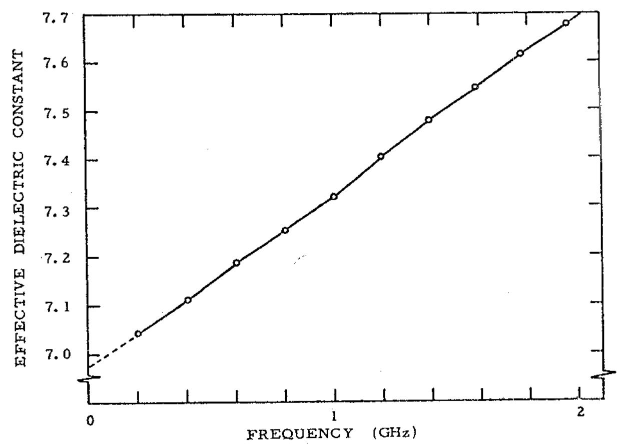

Fig. 4 Variation of effective dielectric constant with frequency for 20.5 Ω line on $\varepsilon_r = 9.6$ Custom High K (h = 0.125", w/h = 5.05)

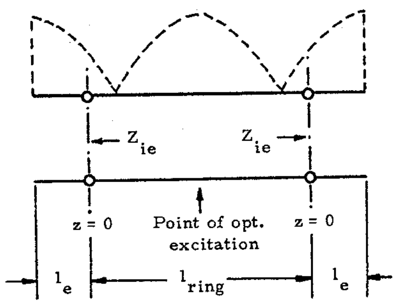

Fig. 3a Standing wave pattern on the ring for even excitation of the discontinuity (n = 1)

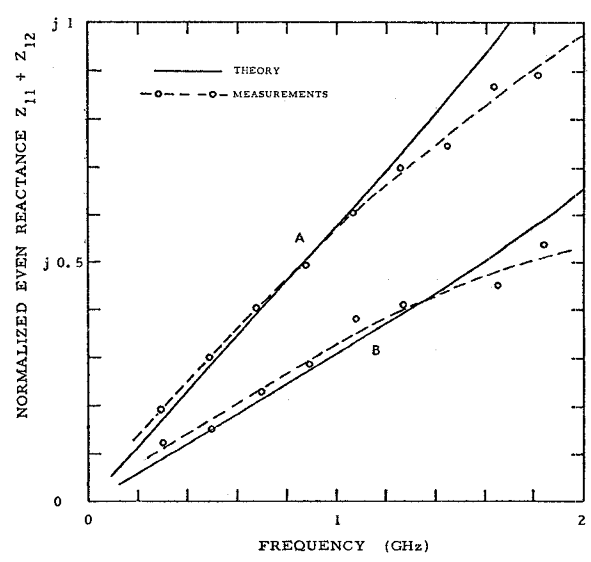

Fig. 5 Normalized even reactance $Z_{11} + Z_{12}$ of centered metallic posts of circular cross-section in a 20.5 Ω line on $\varepsilon_r = 9.6$ Custom High K (h = o.125", w/h = 5.05)

A. Post diameter d = 1/16" B. d = 1/8"

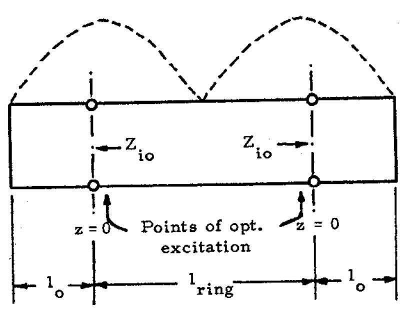

Fig. 3b Standing wave pattern on the ring for odd excitation of the discontinuity (n = 1)