CHARACTERIZATION OF POWER LOSS FROM DISCONTINUITIES IN GUIDED STRUCTURES

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Abstract

This paper is an extension of the work presented in reference [1]. In [1] it was shown how to utilize the matrix pencil approach to extract S-parameters of N-port microwave structures. In this paper this earlier approach has been extended to analyze radiation/power loss from discontinuities from guided structures. Specifically, computed results are presented for the S-parameters of an open ended rectangular waveguide radiating into free space along with experimental results given by Marcuvitz [2]. In addition power loss from a rectangular and mitered bends are computed for a microstrip line. The present results are more accurate than what is available in the published literature [3].

1. Introduction

Given a guided wave structure, be it a conducting waveguide or an arbitrary shaped microstrip line embedded in multilayered dielectric structures, we utilize the Electric Field Integral Equation (EFIE) [4-8] to solve for the current distribution on the structure. This is accomplished by placing equivalent surface currents on the conductors and the effect of the dielectric slab and the ground planes are taken care of by the Green's function. The equivalent surface current is subdivided into triangular regions and the continuity of the current normal to the edge is maintained. This is accomplished by the method of moments utilizing the conventional delta gap excitation. Then the current along the edges on the structure are approximated by the sum of complex exponentials utilizing the Matrix Pencil Approach [5]. This decomposes the current distribution on the structure into a forward wave, backward wave and higher order modes that may be propagating or evanescent. From the modal amplitudes of the incident and reflected waves the S-parameters of the multiport network is obtained. The new original contribution of this paper is how to use this methodology to evaluate powerloss from discontinuities - like radiation from various types of bends and waveguides radiating into open space.

The accuracy of this methodology is validated by comparing with measured data. Also, this analysis is more accurate than what is currently available [3]. The major advantages of this present approach in estimating the powerloss from a finite region of a discontinuity are that:

(1) The effects of the connecting transmission structures to the discontinuity can easily be deembedded.

(2) One can use a conventional full wave solution/electric field integral equation utilizing a delta gap excitation to carry out a complete electromagnetic analysis of the structure.

(3) There is no need to terminate the lines by their characteristic impedances in order to obtain the S-parameters.

(4) It is not necessary to evaluate the characteristic impedance of the line at the various ports to obtain the S-parameters. This can be a very tricky problem in the high frequency region where the characteristic impedance is not clearly defined!

(5) There is no need to change the planes of reference to isolate the power loss from the discontinuity regions as the S-parameters can be computed directly at the defined planes of reference. This is particularly useful in characterizing radiation or power loss from the discontinuity regions.

Hence in summary, first a complete electromagnetic analysis is carried out of the problem utilizing the appropriate E.M. analysis tools. Then the Matrix Pencil Approach is used to extract the S-parameters. From the

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unitary properties of the S-matrix for a lossless structure, one can evaluate the power loss from the discontinuities. We feel this is the novelty of this approach as the results are more accurate than what is available.

The mathematical details of the various steps are too intricate and detailed to be presented here for completeness. They are described in the references [4-9]. Here we present the examples and compare our results with experimental data and other published results.

Example 1: As a first example consider a conducting rectangular wave guide radiating into free space through a rectangular aperture in a circular screen. Marcuvitz [2] measured the reflection coefficient of the open ended waveguide with dimensions 0.8" × 0.4" at λ = 3.20 cm to be $|\Gamma| = 0.28$. Interestingly whether the waveguide was radiating through rectangular apertures into a space bounded by "infinite" parallel plate extensions of the top and of the bottom sides of the rectangular guides or if the ground screen is a circular disk of 1¾" diameter, the reflection coefficient was measured to be the same [p. 193, 2]. We analyzed the same structure utilizing the EFIE. For this problem, we consider a rectangular waveguide section 2.0λ long. At the end of 2.0λ we put a delta gap excitation along an edge of the triangular patch model used to discretize the surface. The Matrix Pencil was then used to fit the current on the vertical edges along the narrow section of the waveguide. We obtain the reflection coefficient from the ratio of the amplitude of backward travelling current wave over the forward travelling current wave yielding a reflection coefficient 0.26. We think the 7% discrepancy was due to the fact that we did not terminate the waveguide into a disk and the thickness of the conductors were neglected. As the waveguide structure is considered lossless, the power radiated from the open end is given by

$$P_{rad} = 1 - |\Gamma|^2 = 1 - (0.26)^2 = 0.93$$

This result is quite similar to Marcuvitz's experiment. Even though modal analysis can be carried out quite easily to solve the same problem, we utilized this circuitous route to validate our methodology.

Example 2: For the second example we consider a right angled bend situated on a dielectric slab of $\varepsilon_r = 2.33$ and thickness of the dielectric is $h = 0.017\lambda_o$. These are the dimensions of a 50Ω microstripline operating at 10 GHz (λ_o = 3 cm). We consider two segments of a $1.95\lambda_o$ long line attached to the two ends of the right angled bend. The structure is divided into 80 triangular patches. Each of the $1.95\lambda_o$ segments of the transmission line is divided into 39 subsections as shown in Fig. 1. So the rectangular band consist of a region $0.05\lambda_o$ by $0.05\lambda_o$. The structure is excited by a 1V delta gap source at the first nonboundary edge of a triangular patch located away from the bend in one of the arms. First, the method of moments is used to solve for the currents on the structure. The accuracy of the dynamic analysis of electrically small structures can be enhanced by the methodology of [9]. This is accomplished by expanding the current into a divergenceless part and a curlfree part. By splitting the current in this form, the components for the magnetic vector potential A in the formula for the electric field can be evaluated very accurately as different currents contribute to the numerical evaluation of A and V (scalar potential) in

$$\bar{E} = -jw\bar{A} - \bar{\nabla}V$$

The contributions are separate. This results in a very accurate analysis of electrically small structures as illustrated in [9]. It has been assumed that the transverse current distribution is a constant. This is a reasonably good approximation as the width of the line is only $0.05\lambda_o$ [10]. Also since in this case w/h = 3 assuming a constant transverse current distribution (and thereby neglecting the singular behavior at the edges) has practically no effect on the solution.

Earlier analysis [p. 233, 3] has shown that 8% of the incident power is radiated by a right angled bend of dimensions $0.05\lambda_o \times 0.05\lambda_o$ considered in this example. We consider this to be unusually high!

Again as mentioned, we solve for the total current distribution on the structure. The Matrix Pencil Approach is applied to approximate the complex amplitudes on the straight edges parallel to the boundary by a sum of complex exponentials. The origins of the approximations are located at the reference planes as shown in Figure 1. The two reference planes are identified as this bend is characterized by a 2 port network. The incident and reflected current wave amplitudes at the reference planes 1 and 2 are given by this analysis as

$$a_1^i = 2.71\,/\underline{108}^\circ$$

$$b_1^i = 2.69/\underline{76}^\circ$$

$$a_2^i = 2.74/\underline{-85}^\circ$$

$$b_2^i = 2.75/\underline{-91}^\circ$$

The conventional S-parameters are obtained from

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{21} \\ S_{12} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

However, since the line width is symmetric and by the terms of the problem, we have

$$a_1 = a_1^i \qquad b_1 = -b_1^i$$

$$a_2 = -a_2^i \qquad b_2 = b_2^i$$

Therefore

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$$\begin{bmatrix} S_{11} \\ S_{12} \end{bmatrix} = \begin{bmatrix} a_1 & a_2 \\ a_2 & a_1 \end{bmatrix}^{-1} \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} 0.07/\underline{-115}° \\ 0.992/\underline{158} \end{bmatrix}$$

Hence the power radiated by the right angular bend is

$$1 - |S_{11}|^2 - |S_{12}|^2 = 0.011$$

i.e., only 1.1% of the power is radiated. We feel this is more realistic than the results currently available in the published literature.

Example 3: For the final example, we consider a mitered bend as shown in Figure 2. The dimensions of the mitered bend are similar to that of example 2 and it is a 45° miter as shown in Figure 2. As before we attach a 1.95λ long transmission line to both the reference planes as shown in Fig. 2. The entire structure is subdivided into 79 triangular patches. The structure is excited by 1V source located at a nonboundary edge situated at the end furthest from the mitered bend. The current distribution on the structure is computed the same way as before and then a sum of complex exponentials is used to fit the current distribution using the Matrix Pencil Approach. The results of the approximation at the two reference planes are given by

$$a_1^i = 2.8/\underline{107}°$$

$$b_1^i = 2.77/\underline{77}°$$

$$a_2^i = 2.76/\underline{-85}°$$

$$b_2^i = 2.77/\underline{-91}°$$

This yields the s-parameters as

$$\begin{bmatrix} S_{11} \\ S_{12} \end{bmatrix} = \begin{bmatrix} 0.027/\underline{80}° \\ 0.995/\underline{163} \end{bmatrix}$$

Please note that S_{11} of a mitered bend is lower than the S_{11} of a right angled bend as expected, i.e. 0.027 as compared to 0.07 of example 2. From the S-parameters, the radiation from the mitered bend is computed as

$$1 - |S_{11}|^2 - |S_{12}|^2 = 0.0092$$

This means that only 0.92% of the incident power is radiated from the mitered bend as opposed to 0.5% of [3].

2. Conclusion

A novel method is presented for evaluation of power loss from discontinuities. This method is quite accurate as the results obtained by this method compares favorably with experimental data. In addition new results are presented which indicates that this methodology is more stable and accurate compared to earlier analysis.

3. References

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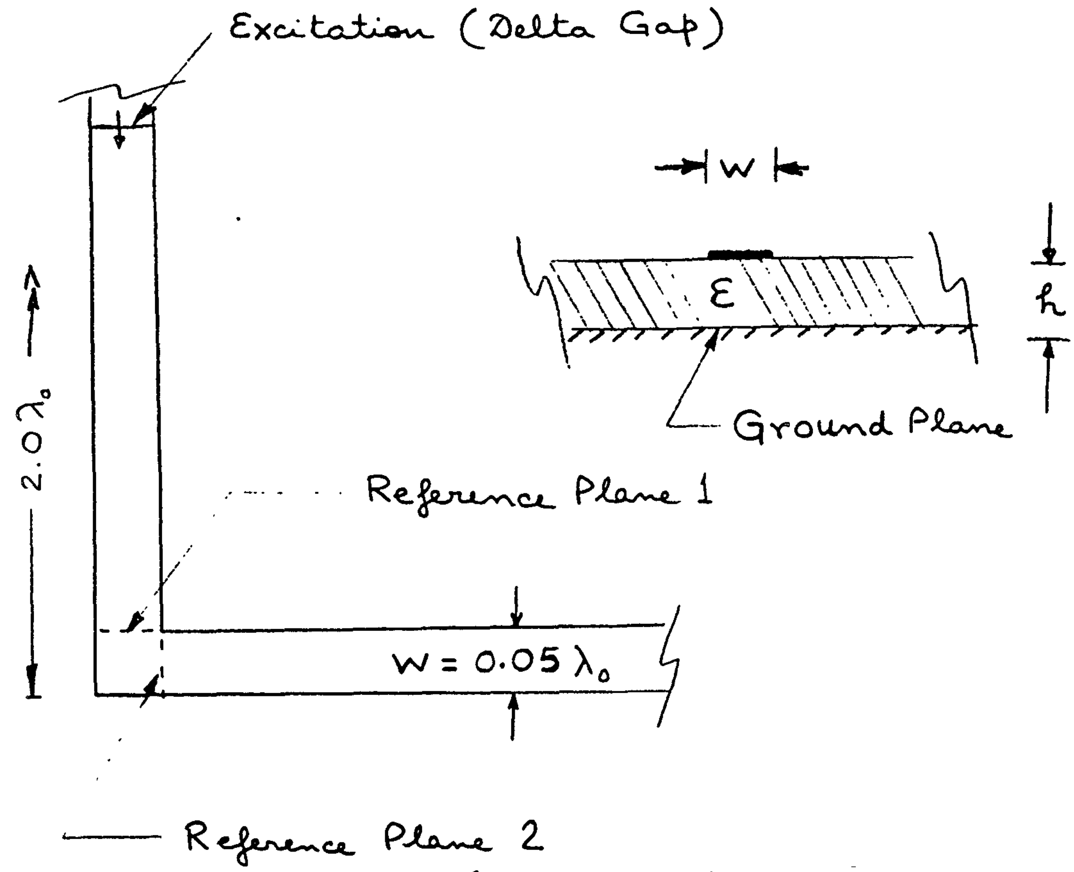
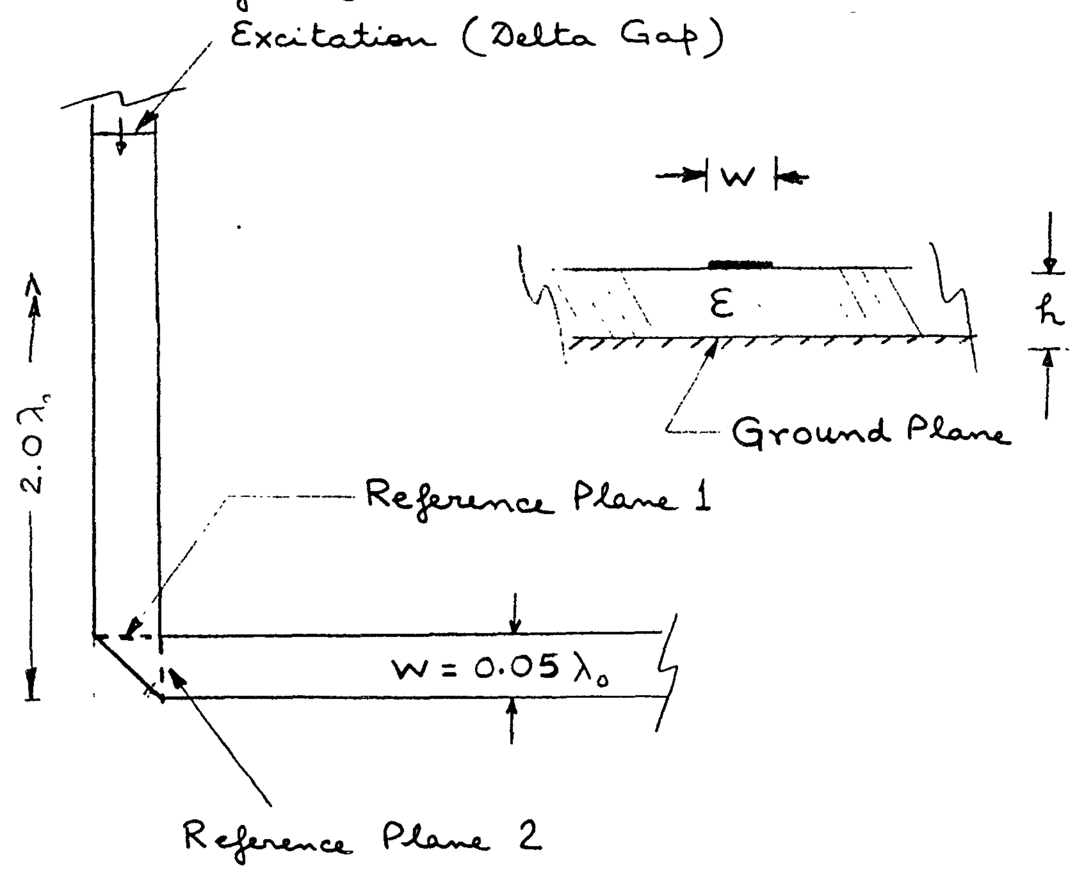


Excitation (Delta Gap)
W
ε
h
Ground Plane
2.0λ₀
Reference Plane 1
W = 0.05 λ₀
Reference Plane 2



Excitation (Delta Gap)
W
ε
h
Ground Plane
2.0λ₀
Reference Plane 1
W = 0.05 λ₀
Reference Plane 2