Coaxial Probe Modeling in Waveguides and Cavities

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Abstract

Extraction of 2-port scattering matrix of a probe-excited semi-infinite waveguide based on moment method solutions of three short circuited guides is presented. Results show that this solution: (i) provides an easy way to determine the 2-port scattering matrix of probe-excited waveguide problems; and (ii) enable the accurate determination of the loading effects of the probe on the resonant frequencies of unperturbed cavities. Both of these are keys in the design of input/output cavities of waveguide filters. Agreement with experimental data is excellent for loose-coupled probe-excited semi-infinite waveguide problems.

I. Introduction

The input and output ports of microwave cavity filters are usually realized by coaxial probe-excited cavities[1],[2] in order to avoid using extra coaxial waveguide transitions. There are no accurate theoretical models in the literature for predicting the 2-port scattering matrix of coaxial probe excited cavities or the loading effects of the probe on the resonant frequencies. The traditional method of probe-excited input/output cavities design is experimental and requires additional tunning screws to fine-tune the resonance frequency [1]. The probe-excited waveguide problem has been treated for three decades [3],[4],[5], but the efforts were only focused on solving for the input impedance problem as a function of waveguide and probe dimensions to design good adaptor by optimizing the dimensions. For microwave cavity filter design, the available procedures are not adequate for exact design.

In this paper, the 2-port scattering matrix of probe-excited semi-infinite waveguide is extracted from the input impedances moment method's solutions of three probe-excited cavities. Result of the numerical calculations show excellent agreement with experimental data. Several aspects of numerical computation are also presented.

II. Experimental and Theoretical Determination of 2-port Scattering Matrix

Consider the problem of determining (by measurement or by numerical calculations) the two port scattering matrix of the probe-excited waveguide shown in Fig.1(a), with equivalent circuit shown in Fig.1(b). If port 2 is terminated by three different known lengths ($L_i, i = 1,2,3$) of short circuit waveguides, and the corresponding input reflection coefficients at port 1 $\rho_i (i = 1,2,3)$ are measured (or computed), then it can be shown that all the 2-port scattering matrix elements can be calculated, by solving three equations [6]. The measurement configuration is shown in Fig.1(c). For accuracy, the phases of the terminating short circuited waveguide sections should not have 360^o differences at the frequencies of interest. The best condition is that these phases differ by 120^o and 240^o only.

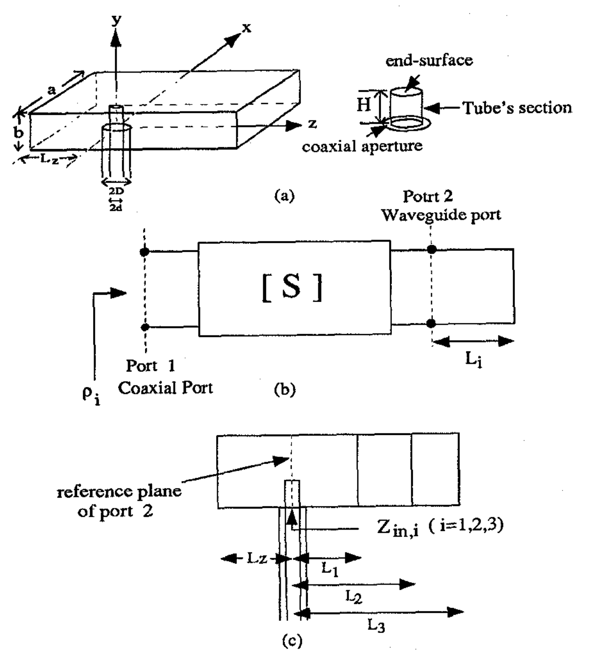

Figure 1. (a) Probe-excited semi-infinite retangular waveguide
(b) Two port equivalent circuit
(c) Three probed-excited cavity

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To compute the reflection coefficients ρ_i, the moment method is used to compute the input impedances of probe-excited cavities of Fig.1(c). The formulation is similar to semi-infinite waveguide problem [5] and is summarized as following. Assume the aperture field is a coaxial TEM mode, then the field at the aperture is a function of coaxial terminal voltage at the junction. According to the equivalence principle, this aperture field can be replaced by equivalent magnetic current source backed by perfect electrical conductor. The Green's function of y-directed electrical current on the probe, x- and z-directed magnetic currents on the aperture should be derived and must be transformed to fast-convergent series [5],[7]. Total fields in the cavity is the summation of radiation fields due to electrical currents on the probe and magnetic currents at the aperture. Forcing the tangential electrical field on outside of probe to be zero ,the electrical current on probe can be determined. The input impedance is computed by the input terminal voltage at the coaxial aperture divided by the electrical current on probe at the coaxial-waveguide junction.

III. Numerical and Experimental Results

Figures 2 and 3 show the computed and experimental measurements results of the magnitude and phase of input reflection coefficients of probe-excited semi-infinite waveguide (S11 parameter of the scattering matrix). The moment method solutions are obtained and shown for following cases:

1. solutions for 3 shorted lengths of waveguides (cavities) with 1 filament axially-concentrated probe current, as shown in Fig.4.(a)
2. solutions for 3 shorted lengths of waveguides (cavities) with multifilament probe current, as shown in Fig.4.(b)
3. solution directly for semi-infinite waveguide with 1 filament axially-concentrated probe current
4. solution directly for semi-infinite waveguide with multifilament probe current

A single expansion function is used for the probe current in the case of cavity, i.e., $\sin k_o(y-h)$, where k_o is the free space wave number. For the moment method in semi-infinite waveguide cases, two expansion functions are used, as in [5]. The additional term is $\sin k_o(y-h)+\alpha(1-cos(h-y))$, where α is constant to make this function orthogonal to $\sin k_o(y-h)$.

Figures 5 and 6 show the experimental and 3-cavity moment method results of the 2-port scattering matrix of typical loss-coupled probe-excited semi-infinite waveguide prob-

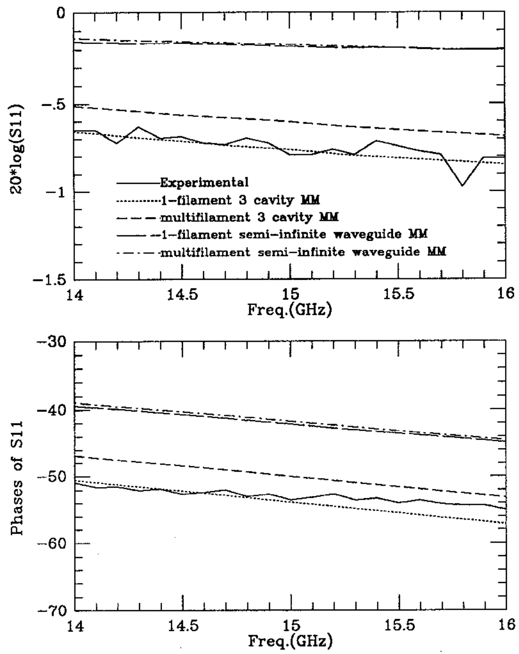

Fig.2 Numerical and theoretical S_{11} for a probe excited semi-infinite waveguide. The dimensions are: a=0.622", b=0.311", Lz=0.219" ,H=0.051", d=0.025", D=0.083".

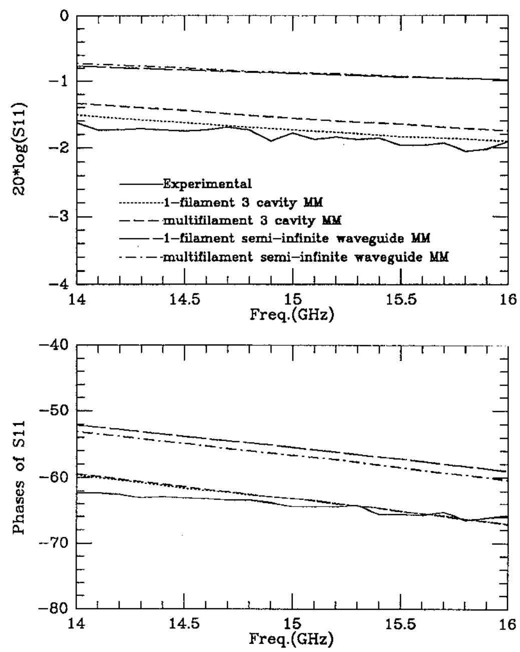

Fig.3 Numerical and theoretical S_{11} for a probe excited semi-infinite waveguide. The dimensions are: a=0.622", b=0.311", Lz=0.219" ,H=0.078", d=0.025", D=0.083".

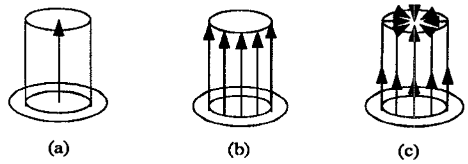

Figure 4 (a) One-filament axially-concentrated current approximation
(b) Multifilament current approximation
(c) Real current flow on probe

lem (The magnitude of S22 is not shown here because it equal to magnitude of S11).

From the shown results and many computer simulations using each of the above described moment method computations, the following observations are worth noticing:

1. The solution with center-filament current approximation yields closer result to experiment than multifilament current modeling for the probe current

2. The input impedance solution of the semi-infinite waveguide problem by the three-cavity moment method yields better results than the solution obtained directly for the semi-infinite waveguide.

3. The computed phase of S_{22} is much closer to the experimental data than that of S_{11}.

4. Further analysis showed that for long probes, the numerical results are less accurate than for longer probes.

The formulation of the cavity problem is very similar to Pocklington's equation for dipole antenna. If the wire is long, i.e., h $\gg$ 2d, the effect of probe's end surface is not significant and can be neglected. The consequencies of this approximation (thin-wire approximation) lead to two results: there is no current flow on the outside end surface of the probe and the boundary condition on that is not forced. In practice, the electrical currents do exit on the end surface [8]. The thin-wire approximation for the probe in the waveguide is less accurate than for dipole antennas, because the probe's radius could be comparable to its length. The current's models of 1-filament axially-concentrated and multifilament are shown in Fig.4(a),(b). However the actual current flows on probe is shown as in Fig.4(c). The boundary conditions on the end surface are not enforced in Fig.4(a) and (b). Even though the multi-filament current is a better model for the electrical current of probe's tubular surface section, the current at the edge is forced to be zero while in reality this is not the case. Thus axially-concentrated 1-filament current current model yields more accurate result than multifilament current probe's model.

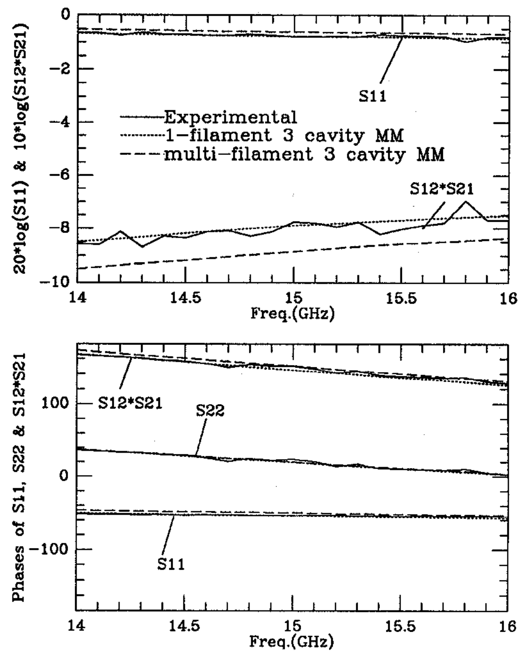

Fig.5 Numerical and theoretical scattering matrix a probe excited semi-infinite waveguide. The dimensions are: a=0.622", b=0.311", Lz=0.219", H=0.051", d=0.025", D=0.083".

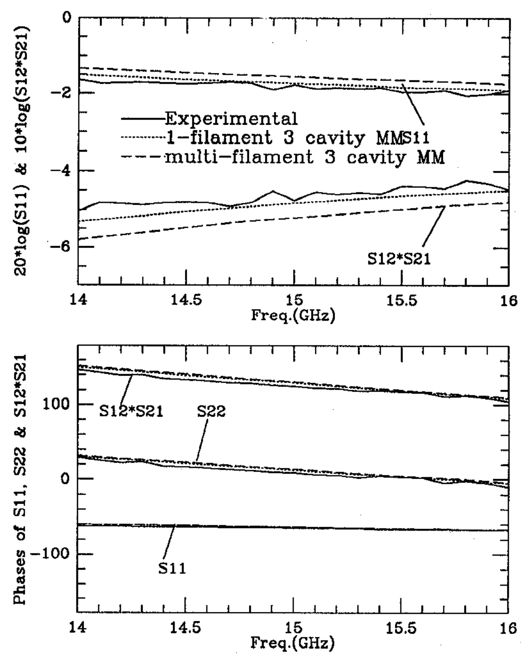

Fig.6 Numerical and theoretical scattering matrix a probe excited semi-infinite waveguide. The dimensions are: a=0.622", b=0.311", Lz=0.219", H=0.078", d=0.025", D=0.083".

Thin wire approximation also plays an important role in choosing expansion function for probe current. Neglecting the effect of probe's end surface could cause non-physical current oscillations near the probe's ends if probe's current is expanded using sub-domain functions [9]. This is due to the fact that the Green's function of a unit electrical current is a second derivative of a delta-type function. For long wire case one can increase the segment length of sub-domain expansion function to mask this oscillation. For short probes in waveguide problem, the non-physical current oscillation could dominate the numerical process. Full-domain functions can be chosen to expand the probe's current to avoid this problem. The current distributions on probe in the cavity and in the semi-infinite waveguide are different due to different boundary conditions. In this paper, the wave-dependent function $\sin k_o(y-h)$ is used. This function provides a better approximation for short probe in the cavity than in the semi-infinite waveguide, because there are radiation losses in the semi-infinite waveguide. Comparing with experimental data, we find that direct moment method input impedance solution in semi-infinite waveguide is less accurate than that extracted from 3-cavity solution, even though two current expansion functions are used to improve the current approximations for semi-infinite waveguide.

The resonant frequency of a probe-excited cavity resonator is lower than that of an unperturbed cavity with the same dimension [10]. The element of scattering matrix S_{22} can be used to determine the real location of the shorted plane in the $z \geq 0$ waveguide side in Fig.1 for a given resonant frequency. As shown in Fig.1(a), if L_z is known, then S_{22} are computed by the moment method. By adding a section of transmission line, the phase of S_{22} can be shifted to 180^o in the Smith chart for a given frequency.

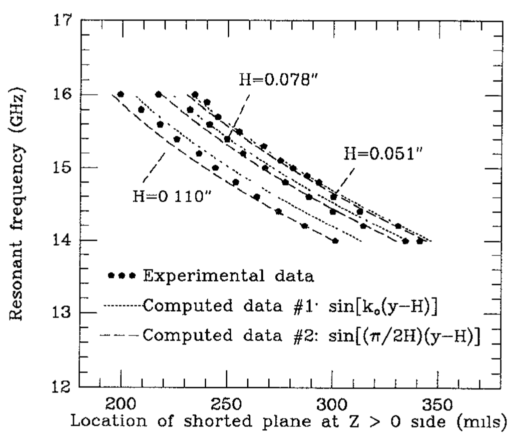

Fig.7 Loading effects of probe on cavity's resonant frequency(waveguide is the same as in Fig 2).

This length of the transmission line is the required length of waveguide that make the cavity resonate at that frequency. Fig.7 shows the measured and computed results of the locations of the shorted plane at the corresponding resonant frequencies for different trial functions, i.e., $\sin k_o(y-h)$ and $\sin(\pi/2H)(y-h)$. The experimental data is found to fall between the results of these two current approximations.

Conclusions

The procedure of theoretical and experimental characterization of probe-excited semi-infinite waveguide has been presented. Our results show very good agreement between theoretical and experimental measurements. Several aspects of numerical computations on probe in waveguide and cavity problem are discussed. This work paves the way to the precise design of input/output probe-excited rectangular cavities.

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