# EFFICIENT ANALYSIS OF A WAVEGUIDE π-JUNCTION WITH AN INDUCTIVE POST

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## ABSTRACT

The waveguide $\pi$-junction with an inductive post is utilized as the element of a multiple-way power divider in a slotted waveguide array. Based on the port reflection coefficient method (PRCM), an efficient fullwave approach is proposed for the accurate characterization of the $\pi$-junction. Scattering behaviors of the four-port junction are provided as a function of the geometric dimensions of the structure, and they are helpful for the design of power dividers using this $\pi$-junction configuration. The results are compared with available data, and good agreement is found.

## INTRODUCTION

Waveguide $T$-junction is one of the most commonly used components in microwave circuits. It is also one of the key building blocks for many other components, such as multiplexers, power dividers, couplers and filters, *etc.* [1]. Studies on waveguide $T$-junctions have been performed extensively in the past decades, and many analysis methods have been proposed, which evolved from the initial approximate electrostatic equivalent circuit model [2], to various numerical approaches developed in recent years [3]-[7].

The continued demand for high performance microwave circuits has resulted in the development of new refined circuit structures. As a consequence, waveguide $T$-junctions with more complicated configurations have been suggested and investigated for meeting a variety of application requirements. In [8], a ridge waveguide $T$-junction was proposed for wide bandwidth usage, and in [9] and [10] a waveguide $T$-junction was loaded with an inductive post for lowering reflection at the input port. The characteristics of a slit-coupled $T$-junction were discussed in [11] and [12] by two different approaches.

In this paper, the scattering characteristics of a complex waveguide four-port junction, illustrated in Fig. 1(a), are investigated. This structure was proposed by [13] as the basic element of a multiple-way power divider in a single-layer slotted waveguide array, shown in Fig. 1(b), and was called waveguide $\pi$-junction.

The waveguide $\pi$-junction can be obviously divided into two parts, a slit-coupled $T$-junction and a waveguide bifurcation, and these two parts are linked by a wider waveguide of dimensions $(a_3+t+a_4)\times h$, in which the higher $TE_{20}$ mode propagates. Because of the higher order mode interactions between the $T$-junction and the waveguide bifurcation, these two parts can not be treated separately in the analysis, but need to be considered as a whole. This means that the sophisticated analysis techniques and numerical results for the three-port $T$-junctions can not be applied to this four-port $\pi$-junction.

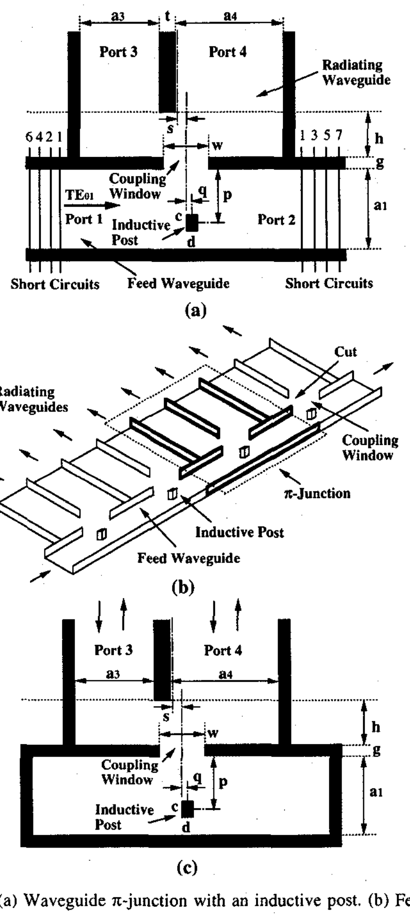


Fig. 1. (a) Waveguide $\pi$-junction with an inductive post. (b) Feed structure of a single-layer slotted waveguide array. (c)The resulting two-port configuration for solving reflections at Ports 3 and 4.

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To accomplish accurate characterization of the waveguide $\pi$-junction, numerical approaches like the finite element method (FEM), the boundary element method (BEM), *etc.*, can be employed. However, a well known shortcoming of these approaches is that they require large computer memories and heavy numerical computations. The Galerkin's method of moments of [13] yielded fairly accurate results. However, it costed considerable efforts in both analytical formulation and numerical computation.

In this contribution, an efficient fullwave approach is developed for characterizing the waveguide $\pi$-junction with an inductive post. This approach is based on the port reflection coefficient method (PRCM), proposed by the authors [14] for the treatment of multi-port microwave network problems, and its main process is described as follows: First we terminate Ports 1 and 2 by short circuits, as shown in Fig. 1(a). Then, looking from Ports 3 and 4, the original four-port structure is turned into a two-port configuration, shown by Fig. 1(c), which consists of cascaded waveguide discontinuities: a waveguide bifurcation, a metal slit of width $w$ and thickness $g$, and an inductive-post-loaded waveguide of length $a_1$. Using the mode-matching method, we solve the scattering matrices of all these discontinuities, and by employing the generalized scattering matrix technique, we find the reflection coefficients looked at Ports 3 and 4. Repeat the above process *seven times*, each time with a move of the short circuit at Port 1 or 2, we get seven different groups of reflection coefficients at the ports. (The numbers above the short circuits in Fig. 1(a) indicate a possible sequence for moving the short circuits.) Substituting the obtained reflection coefficients into formulations given in [14], we have the desired scattering parameters of the $\pi$-junction. Since the original four-port problem is turned into a one-port waveguide cascaded discontinuity problem, the analysis and the solution procedures are extremely simplified.

## NUMERICAL RESULTS AND DISCUSSIONS

The validity and accuracy of this method is first proved by comparing the obtained results with those of [13] using the Galerkin's method of moments. The dimensions of the calculated $\pi$-junction are: $a_1 = a_3 = a_4 = 58.1$ mm, $g = 1.6$ mm, $h = 34.0$ mm, $t = 3.2$ mm, $w = 30.0$ mm, $s = 0.0$ mm, $p = 43.0$ mm and $q = 5.0$ mm. In Fig. 2, the frequency dependence of the divided powers to Ports 3 and 4, $S_{31}$ and $S_{41}$, and the reflection $S_{11}$ at Port 1 are illustrated. It is seen that the calculated results by the two approaches are in good agreement. We note that the inductive post of [13] was a circular one with a diameter $2r = 4$ mm, but the post in our computation is a square one with dimensions determined by the approximate equivalent relation, $c = d \approx 4r/2.365 \approx 3.4$ mm [15]. However, the present approach is applicable to posts of arbitrary cross sections. For a circular post of diameter $2r = 4$ mm, for example, we can approximate it by staircases, and our computations demonstrate that a seven staircases division yields converged results that are coincident with those of [13].

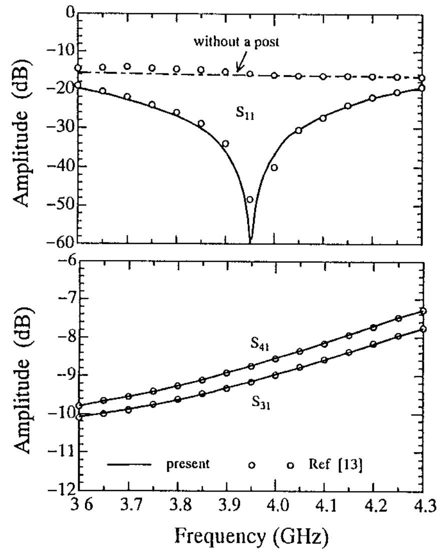

Fig. 2. Frequency dependence of the power reflection and transmission coefficients of a waveguide $\pi$-junction, calculated by two different approaches

The dimensions of the above $\pi$-junction were designed by [13] for realizing equal transmitted powers to Ports 3 and 4 while suppressing reflection at Port 1. This is ended by adjusting the slit width $w$ to control the coupling of power, and changing the location of the inductive post to minimize the reflection $S_{11}$. The working frequency is 3.95 GHz. From Fig. 2 we see clearly that by introducing the inductive post, the reflection at frequencies around 3.95 GHz is lowered down drastically. The difference between the transmitted powers to Ports 3 and 4 is illustrated in Fig. 3, and we see that the average amplitude difference is about 0.3 dB and the phase difference 1.5 degree. Measured results of [13] are also indicated by dots, and they agree favorably with the calculated ones.

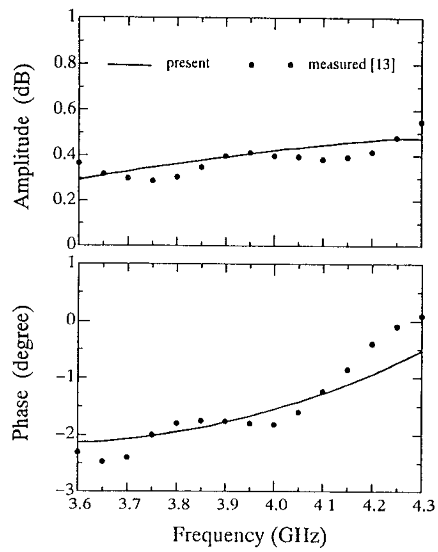

Fig. 3 Comparison between the calculated and measured results of the difference between the transmitted power to Ports 3 and 4 of a waveguide $\pi$-junction.

In Fig. 4, the frequency dependence of the divided power to Ports 3 and 4, and the reflection $S_{11}$ at Port 1 are depicted for square posts with three different widths, c=d=2 mm, 3.4 mm and 6 mm, respectively. It is seen that when c=d=3.4 mm, the reflection coefficient is below −30 dB from 3.84 GHz to 4.05 GHz (5.4% bandwidth), reaching a minimum point of −58 dB at the designed 3.95 GHz. The amplitude and phase differences between the transmitted powers to Ports 3 and 4 are of the same level for all of the three cases, as we can see from Fig. 4.

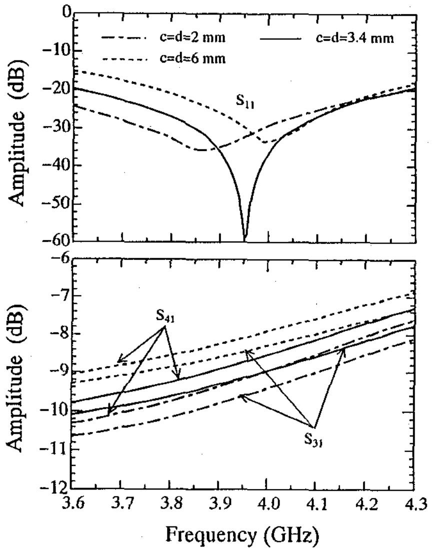


Fig. 4. Frequency dependence of the power reflection and transmission coefficients of the waveguide π-junctions with different dimensions of the post.

Similar behaviors are found in Figs. 5 and 6, where the locations of the post are varied with different values of $p$ or $q$ (refer to Fig. 1). It is seen that the frequency at which the minimum reflection occurs shifts from high to low values when the value of $p$ is increased or the value of $q$ is decreased.

We stated above that the slit width $w$ can be changed for controling the power transmitted to Ports 3 and 4. This is demonstrated by Fig. 7. When the value of $w$ is changed from 25 mm to 35 mm, the power transmitted to Ports 3 and 4 at 3.95 GHZ is increased approximately from -12 dB to -7.2 dB. Also we see that the frequency at which the minimum reflection occurs shifts from high to low values as the value of $w$ is increased.

Finally, the frequency dependence of the divided powers to Ports 3 and 4, and the reflection $S_{11}$ at Port 1 are compared in Fig. 8 for rectangular posts with different aspect ratios. The solid line is for $c = d = 3.4$ mm, the dotted line for $c = 2.0$ mm and $d = 4.8$ mm, and the dashed line for $c = 4.8$ mm and $d = 2.0$ mm. In each case, the perimeter of the post is maintained a constant, *i.e.*, $2(c + d) = 13.6$ mm. The results reveal that while the difference between the transmitted powers to Ports 3 and 4 is kept nearly unvaried, and the reflection at Port 1 is maintained a low level at frequencies around 3.95 GHz, the frequency at which the minimum reflection occurs can be shifted by adjusting the aspect ratio of the post.

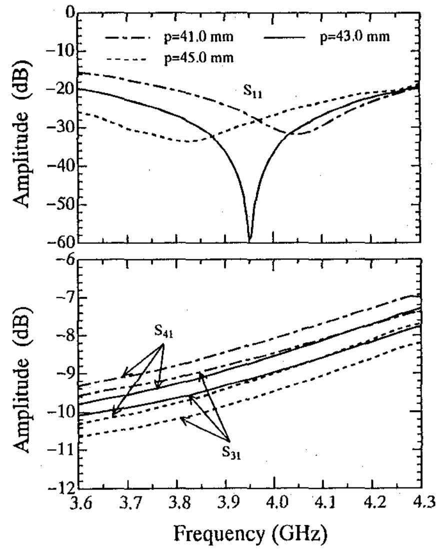


Fig. 5. Frequency dependence of the power reflection and transmission coefficients of the waveguide π-junctions with different values of $p$ of the post location.

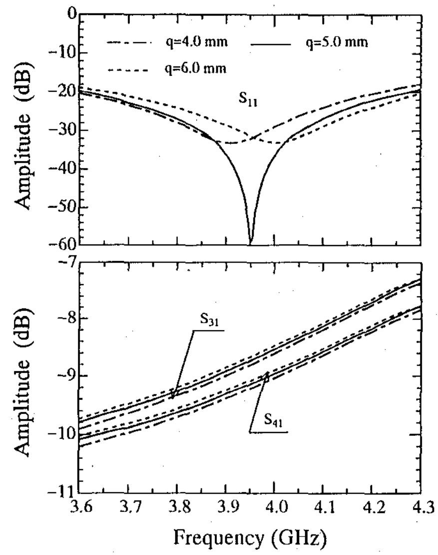


Fig. 6. Frequency dependence of the power reflection and transmission coefficients of the waveguide π-junctions with different values of $q$ of the post location.

## CONCLUSIONS

An efficient fullwave approach is developed for characterizing the waveguide $\pi$-junction with an inductive post. The analysis and the solution are easy to perform because they are simplified to the computations of field reflections at waveguide step-junction type discontinuities. Variation behaviors of the scattering parameters of this $\pi$-junction are demonstrated as a function of the geometric dimensions, and they are verified by available results. A simple equivalent relation between circular and square inductive posts in such a $\pi$-junction is numerically proved valid.

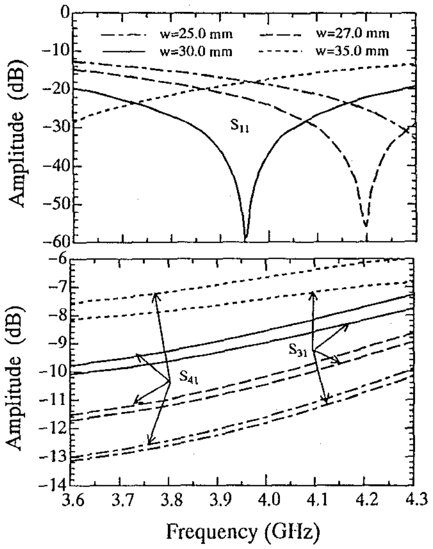


Fig. 7. Frequency dependence of the power reflection and transmission coefficients of the waveguide $\pi$-junctions with different values of $w$ of the slit width.

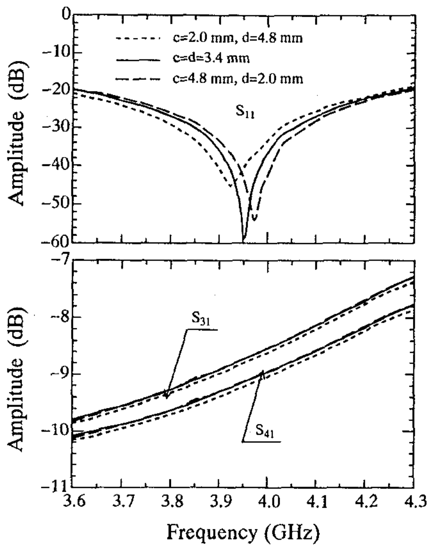


Fig. 8. Frequency dependence of the power reflection and transmission coefficients of the waveguide $\pi$-junctions with different aspect ratios of the post.

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