MULTIPORT BRANCH-WAVEGUIDE COUPLERS WITH ARBITRARY POWER SPLITTING

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ABSTRACT

An optimised synthesis method to design multiport branch-waveguide couplers with arbitrary output power distributions is presented. This component offers the potential to reduce complexity, mass and size of beam forming networks of multiple or contoured satellite antennas.

Besides, the power distributions obtained, feeding separately any input port, are orthogonal and that gives this device suitable for "multimode" antenna applications.

The design of a six-port coupler in WR75 waveguide is outlined in detail. Comparing the experimental results with the computed performance shows that the synthesis procedure is verified very satisfactorily.

Moreover, the theoretical and measured results obtained on an eight-port coupler prototype will be available at the time of the symposium.

1. INTRODUCTION

Modern multiple or contoured beam satellite antennas require beam forming networks(BFN) more and more complicated. The key component in BFN are the power splitters. However in order to minimise the number of these devices for a given number of feed horns, it would be desirable to use directional couplers with more than two output ports.

The only power splitter with more than two output ports dealt with in literature is the six-port branch-waveguide coupler proposed in [1]. Because of its symmetry two of the three output power levels, in which the input power is split, are equal and that restricts its use.

In this paper a design method that allows the output power levels of the coupler to be different from each other is presented. For obtaining this result the exact knowledge of the scattering matrix of the double asymmetrical E-plane T-junction (Fig.2) is necessary. Because no study was available in literature for this junction the S matrix of it has been calculated with a mode-matching technique [2].

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Moreover this power splitter can be used as multiport power divider with three input and three output ports. That because the output power distributions, obtained feeding from the ports 1,2 and 3 the device respectively, are orthogonal. For this reason this coupler is very suitable to synthetise orthogonal power distributions for "multimode" antennas.

Besides the design method here presented can be easily extended to the general case of N-port directional coupler. An eight-port prototype will be available at the time of the symposium.

2. ANALYSIS

To make easy the description of the analysis method the six-port coupler example is presented. But it is not difficult to extend the method to the general case of the N-port device.

The six-port power divider is shown in Fig.1a. The three rectangular waveguides are connected to each other by two arrays of branch guides. The device is symmetrical with respect to the plane B-B. The choice of the number of branches (five in the example of the Fig. 1a) is related to the coupler frequency bandwidth.

The analysis algorithm of this device,the first building block of the design method,is done on the model shown in Fig.1b utilizing the S-matrix representation. The calculations are carried out by dividing the coupler in sections as shown in Fig.1b. The field-theoretical treatment of each section is accomplished by investigating separately the E-plane T-junctions and the double asymmetrical E-plane T-junction inside of the section and subsequently connecting them as shown in Fig.1b.

In order to accurately determine the S matrix of the T-junctions and the double T-junctions we have to take into account the effect of higher order modes.The E-plane T-junction constitutes a well-known microwave-engineering problem for which many different analysis methods [3], [4], [5] and [6] have been suggested during the past 45 years. The method proposed in [5] has been used.

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On the other hand no study was available in literature for the double asymmetrical E-plane T-junction. Then a rigorous and accurate characterization of this junction type has been developed by means of a mode-matching technique [2]. In this approach the waveguide junction in Fig.2 is subdivided into the regions I,II,III,IV and V for which complete representations for the electromagnetic field can be found. In region V the principle of expansion of the field in cavities [5], [7] is utilized. This allows the multiaperture problem to be reduced to a mere superposition of simpler cavity problems by subsequently shorting all apertures but one.

The boundary conditions require continuous tangential fields across the common boundary planes. They lead to a system of linear equations for the expansion coefficients from which the scattering matrix of the junction can be determined.

Finally, connecting all sections of the coupler model of Fig.1b the S matrix of the six-port power divider is obtained.

This analysis method allows to reduce calculation time because the coupler symmetry decreases the number of sections that must be calculated (in the example of the Fig.1b only three of the five sections must be calculated).

3. SYNTHESIS AND OPTIMISATION

The synthesis of the six-port coupler shown in Fig.1a, with input power at the port 2 of the device, is here presented. But the design method can be applied feeding anyone of the three input ports. The first step of the design method, known the two coupling values desired (C24 and C26), is the synthesis of two four-port couplers with C24 and C26 as nominal coupling respectively. This is done by the algorithm proposed in [8]. In this way the first approximation geometrical dimensions of the six-port coupler (SPC) (bi,Si,t,bi',Si',t') are obtained.

Then, with the previous analysis algorithm, the coupler S parameters are calculated (see Fig.3, dashed line). These parameters are not coincident with the desired values and then an optimisation algorithm must be utilized.

The core of this algorithm makes use of a multivariable pattern search [9] in which the geometrical dimensions of the SPC (bi,Si,t,bi',Si' and t') are the variables. However it must be born in mind that the device symmetry reduces the number of variables by two as shown in Fig.1a.

The objective function is done so as to allow:

a) minimisation of input reflection and isolation;

b) adjustment of the coupling values;

c) adjustment of the mid-frequency.

The objective function, that is to be minimized, turns out to be the following

$$F = \sum_{n=1}^{N} \{(|Iro| + S22n)^2 + (Iso + S21n)^2 + (Iso + S23n)^2 + [W1(C24 + S24n)]^2 + [W2(C26 + S26n)]^2\}$$

where

Iro,Iso,C24,C26
: are the required values (in dB) for: input reflection, isolation and couplings;

S22n,S21n,S23n,S24n,S26n
: are the scattering parameters (in dB) calculated at the n-frequency point;

N is the number of frequency points in which the device response is calculated;

W1,W2 are weight constants which values depend on the parameters to be optimised.

N can be chosen between 5-10 depending of the coupler bandwidth. The first three terms of F are not taken into account if:
$|Iro| + S22n<0$, $Iso + S21n<0$, $Iso + 23n<0$.
Because a loss-free structure is assumed the forward transmission (S25) is related to the above scattering coefficients via the unitary condition and can therefore be disregarded in defining F.

The convergence of the optimisation algorithm is rapid.

4. DESIGN EXAMPLE AND EXPERIMENTAL RESULTS

The design technique described above has been successfully employed to design and manufacture a six-port five-branch coupler in WR75 waveguide with 10.95-12.75 GHz bandwidth. The nominal coupling values were: C24=5 dB and C26=7.4 dB and then the forward transmission was: C25=3 dB.

The geometrical dimensions of the prototype are summarized in Table 1. Fig.3 shows the calculated frequency response of the coupler before and after the optimisation process and the experimental performance. The input reflection (S22) and the isolations (S21 and S23) are 40 dB minimum on a design frequency bandwidth. The measured couplings (S24 and S26) and the forward transmission (S25) values well agree with the computed frequency performance. The shift, of about 0.1 dB, between measured and theoretical results for the S24 parameter can be imputed to the electromagnetic model used that does not take the losses into account.

The phase shift between direct and coupled ports, not reported for brevity's sake, is 90° with error lower than 1°on the design frequency bandwidth.

A remarkable thing is that the experimental results are obtained without the necessity of any experimental trimming. That demonstrated the validity of the proposed design method.

5. CONCLUSIONS

An optimised design method for multiport branch-waveguide couplers with arbitrary output power distributions has been presented.

The validity of the design method has been proved by the realization of a six-port device.

The measured results well agree with the computed frequency response. The performance of this device seems very suitable not only for beam forming networks but even for "multimode" antenna applications.

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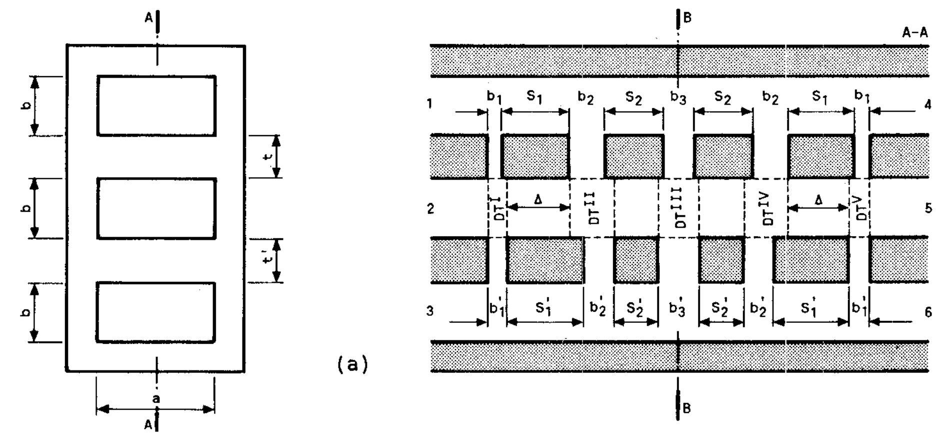
b_1	1.05
b_2	3.14
b_3	4.19
S_1	5.78
S_2	4.21
t	6.74
b_1'	0.89
b_2'	2.32
b_3'	2.91
S_1'	6.85
S_2'	6.16
t'	6.96

Table 1 - Geometrical dimensions(mm) of the six-port coupler prototype in WR75 waveguide (see Fig.1).



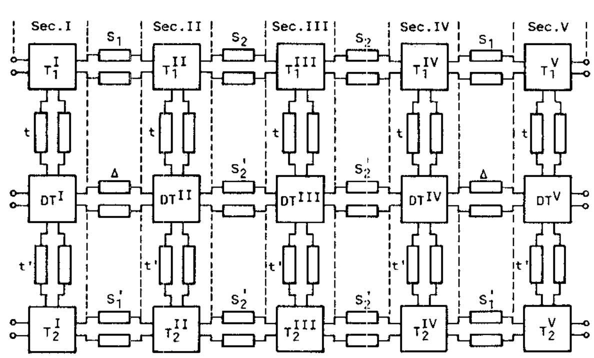


Fig.1 - (a) Six-port branch-waveguide coupler.
(b) Model of the coupler for S matrix computation:
T = E-plane T-junction - DT = double E-plane T-junction
equivalent line of a rectangular waveguide with length L, excited only by TE10 mode.

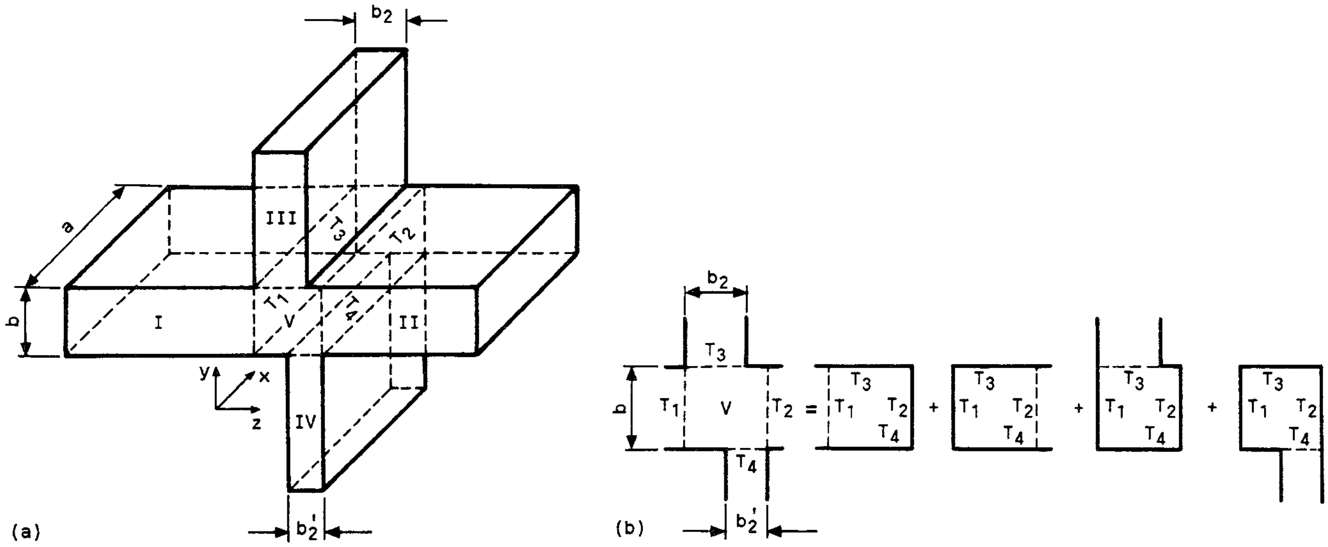


Fig.2 - (a) Double asymmetrical E-plane T-junction; (b) Field representation in region V.

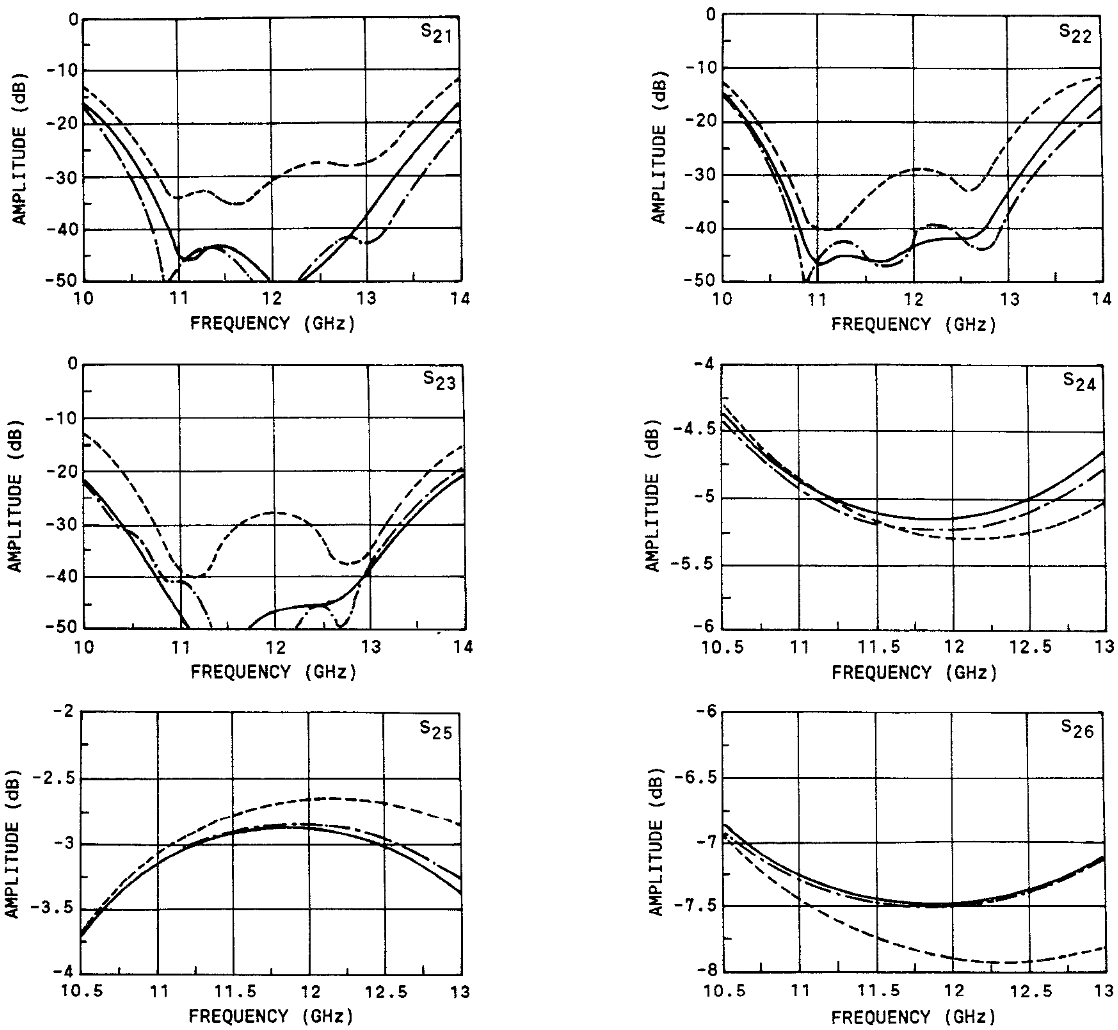


Fig.3 - Scattering parameters of the six-port branch-waveguide coupler.
Theory: ---- before optim., ——— after. Exper.: — - —