ANALYSIS OF A WAVEGUIDE-DISK LOAD

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ABSTRACT

A theoretical analysis of a waveguide-disk load commonly used in radar duplexers is carried out. An expression for the input reflection coefficient of the load is derived and verified exerimentally. Based on computational results the operation of the load is explained.

INTRODUCTION

A waveguide-disk load is frequently used as a medium power termination in radar duplexer systems where efficient use of the available space is of primary importance. The load is formed by a section of circular waveguide which is filled with absorbing material and sealed at its end by a short circuit. The load diameter is slightly greater than the rectangular waveguide width and between the rectangular guide and the absorber a small gap is created. By chosing suitable parameters of the load good match between the guide and the load over a moderately wide frequency band can be achieved. Although a waveguide-disk load in the form described here has been frequently used its operation is not clearly understood. Until now the design of this device has been purely empirical and based on the "cut-and-try" method.

In this paper an approximate theoretical analysis of the waveguide-disk load is given making the design of the device predictable.

ANALYSIS

A waveguide disk load considered here is shown in Fig.1. From the designers point of view the parameter of interest is the reflection coefficient presented by the load at the junction with the rectangular waveguide. To obtain a predictable design this parameter should be known for an arbitrary diameter and length of the terminating waveguide as well as for arbitrary electrical parameters of the absorbing material. From the theoretical point of view the problem of the waveguide disk load can be regarded as an aperture problem in which a rectangular waveguide excites a cylindrical cavity which is partially filled with an absorbing material.

The problem stated in this form can be regarded as a three-dimensional electromagnetic field problem and is very difficult to solve unless some approximations are introduced.

In the approach presented here the following approximations are made:

(i) The circular shape of the terminating waveguide is replaced by a square or in general a rectangular end (as is shown in Fig.2).

(ii) The electric field in the aperture is approximated by the dominant rectangular waveguide mode (1):

$$E_x(z=0) = \begin{cases} \sin\left[\frac{\pi}{b}(y-y_o)\right] & \text{in the aperture} \\ 0 & \text{elsewhere} \end{cases} \qquad (1)$$

It can be expected that approximation (i) will produce reasonably accurate results if a proper equivalence between circular and square cross-sectioned waveguides is established. The equivalence may be based on equal cross-sectional areas or equal average radii (calculated as the average distance from the waveguide centre to its perimeter).

Approximation (ii) will be quite good throughout the frequency band of the single mode operation of the launching waveguide.

For a given electric field in the aperture the reflection coefficient can be determined once the magnetic field is known. The steps to determine the magnetic field are described below.

The terminating waveguide can be divided into two regions: region I which is empty and described by the relative dielectric and magnetic constants $\epsilon_r^{(1)} = 1$, $\mu_r^{(1)} = 1$ and region II filled with a lossy material described by the complex relative dielectric and magnetic constants $\epsilon_r^{(2)}$ $\mu_r^{(2)}$. It can be shown that for the present form of excitation the y-component of the magnetic field and the x-component of the electric field for regions I and II can be represented by an infinite series given by (2):

$$Hy^{(i)} = \sum_{m=0}^{\infty} \sum_{n=1}^{\infty} C_{mn}^{(i)} \frac{2\epsilon_{om}}{AB} \cos(k_{xm}x) \sin(k_{yn}y) \cdot \left[e^{-\Gamma_{mn}^{(i)}(z-l_i)} + \delta_{mn}^{(i)} e^{-\Gamma_{mn}^{(i)}(z-l_i)} \right] \quad (2)$$

$$Ex^{(i)} = \sum_{m=0}^{\infty} \sum_{n=1}^{\infty} C_{mn}^{(i)} \frac{2\epsilon om}{AB} \frac{jk_iZ_i}{k_{yn}^2 - k_i^2} \Gamma_{mn}^{(i)} \cos(k_{xm}x) \sin(k_{yn}y) \cdot \left[e^{-\Gamma_{mn}^{(i)}(z-l_i)} - \delta_{mn}^{(i)} e^{-\Gamma_{mn}^{(i)}(z-l_i)} \right]$$

where i = 1,2 correspond to regions I and II respectively.

k_i, Z_i - are wave numbers and wave impedances

$$k_{xm} = \frac{m\pi}{A}, \quad k_{yn} = \frac{n\pi}{B}$$

$$\Gamma_{mn}^{(i)} = k_{xm}^2 + k_{yn}^2 - k_i^2$$

$j = \sqrt{-1}$, ϵ_{om}- Neumann factor $Cmn^{(i)}$ and $\delta mn^{(i)}$ are unknown coefficients.

The unknown coefficients Cmn, δmn can be determined by using continuity conditions for the x and y components of the electromagnetic field at the boundary z=L1,L2 and by performing Fourier analysis for the x-component of the electric field in the aperture (z=0).

Having determined coefficients δmn and Cmn the y-component of the magnetic field can be found by using expression (2).

The normalized input admittance of the load at the junction between the two waveguides can be calculated by using expression (3):

$$Yin = \frac{Z_1}{\sqrt{1-(\pi/bk_1)^2}} \frac{2}{ab} \int_{x_o}^{x_o+a} \int_{y_o}^{y_o+b} Hy^{(1)}(z=0) \sin\left[\frac{\pi}{b}(y-y_o) \right] d_x d_y \quad (3)$$

The reflection coefficient at the junction can be calculated from (4):

$$R = \frac{1 - Yin}{1 + Yin} \quad (4)$$

Expressions (2),(3) and (4) lead to the closed form expression for the reflection coefficient.

MODEL VERIFICATION

A short Fortran program for an IBM PC/AT was written to investigate the validity of the expression for the reflection coefficient at the junction between the rectangular waveguide and the disk load.

First, it was noticed that the approach presented could be applied to the problem of E- and H-plane steps in a rectangular waveguide for which theoretical solutions have already been given [3]. In these solutions the steps are modelled by lumped reactive elements whose values are given from the static analysis.

Comparison between values calculated by using the algorithm developed here with those in [3] showed worst case conditions differences of 5% (corresponding to the upper band of frequencies for which the static solutions were expected to produce least accurate results). The overall good agreement indicated that the expression derived here could confidently be used to determine the input reflection coefficient for arbitrary parameters of the waveguide- disk load.

Investigations were performed for the case of a typical X-band waveguide-disk load with the parameters as follows:

Rectangular waveguide: a=22.86mm, b=10.16mm cylindrical waveguide diameter D=31.75mm, load length L_2=29.74mm, gap height L_1=2.54mm, absorbing material: Emerson & Cuming Eccosorb

MF-117, with ϵ_r= 21-j0.5, μ_r=1.1-j1.7 at 10GHz (in calculations these constants were used throughout the whole X-band).

The equivalent square-shaped load dimensions were assumed to be close to the following values: A = B = 31.75/1.129 = 28.13mm, based on equal cross-sectional area, or A = B = 31.75/1.1478 = 27.66mm, based on equal average radii. The rectangular waveguide was assumed to be centrally positioned with respect to the load. Fig.3 shows the comparison between theoretical and experimental values of the VSWR for the disk load. The numerical results are for the square-shaped load for which A=B was assumed to be equal to 27.5mm and for the gap height equal to 2.62mm.

Good agreement between theoretical and experimental values can be observed.

WAVEGUIDE DISK-LOAD OPERATION

Having a relatively good agreement between experiment and theory it was decided to further use the theoretical analysis to investigate how parameters such as the load diameter, length and gap height and a change in electrical parameters of the absorbing material affect matching conditions.

The investigation was performed on Emerson & Cuming Eccosorb family of absorbers: MF112, MF114, MF116, MF117 and MF124.

The following data for these absorbers was used:

	ϵ_r	μ_r
MF-112:	4.8 -j0.19	1.1 -j0.26,
MF-114:	9.7 -j0.49	1.11-j0.44,
MF-116:	16.0-j0.96	1.50-j0.68,
MF-124:	23.6-j0.71	1.5 -j2.10,

and for MF-117 as above.

First, the dimensions of the load were assumed the same as for the absorber MF- 117 which was investigated earlier.

The calculated results are shown in Fig.4. It can be seen that the change in the absorbing material mainly affected the matching frequency. In the next experiment the length of the load was varied. The results of these experiments showed that this parameter had only a small effect on the matching conditions. For example reducing the load length from 27.94mm by 10 mm to 17.94mm for the absorber MF-117 did not show any visible change in the results presented earlier in Fig.3.

Experiments in which the load diameter was varied showed that this parameter was of importance. Fig.5 shows VSWR for a few values of diameter of the load with the MF-117 absorber.

It can be seen that the matching frequency is strongly dependent on the load diameter value. Fig.6 shows the variation of VSWR with the gap height. It can be noticed that the gap height is responsible for fine changes in the match. Summarizing the above results the following observations about the operation of the waveguide disk load were made. The transverse region between the junction and the absorber can be regarded as a lossy transmission line which is short-circuited at its end (the short is created by a side metal wall of the disk load).

The line is characterized by a complex valued characteristic impedance and complex propagation constant. At the matching frequency the short is transformed into a resistance. The value of this resistance is controlled by the height of the gap. In the approach presented here no attempt was made to determine equivalent parameters of the transverse transmission line. Instead an explicit expression for the input reflection coefficient at the junction was given.

CONCLUSIONS

A simple expression for the input reflection coefficient of a waveguide disk load has been derived. The validity of this expression has been tested through comparison with the other theories and experiments. Based on theoretical analysis it has been shown that for typical absorbers the most important parameters responsible for matching are the diameter of the load and the height of the gap between the absorber and the junction.

The presented analysis and results should be of major interest to the designers of the waveguide-disk load.

REFERENCES

[1] Emerson & Cuming Eccosorb MF, Technical Buletin.

[2] Onning Shahan, "Calling All Waveguide Disc-Load Experts", Letter to the Editor, MSN & CT , June 1988.

[3] N.Marcuvitz: "Waveguide Handbook", McGraw - Hill, 1951, Chapter 4: Two-terminal Structures".

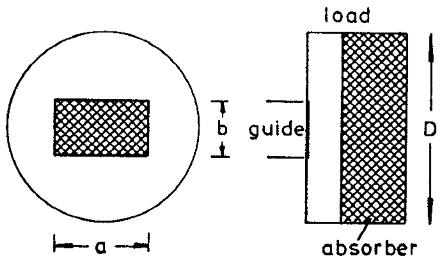

Fig.1 Waveguide-disk load.

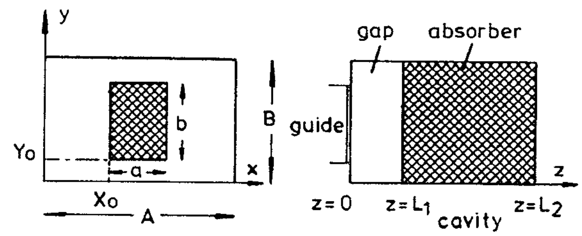

Fig. 2 Junction between a rectangular guide and a rectangular end.

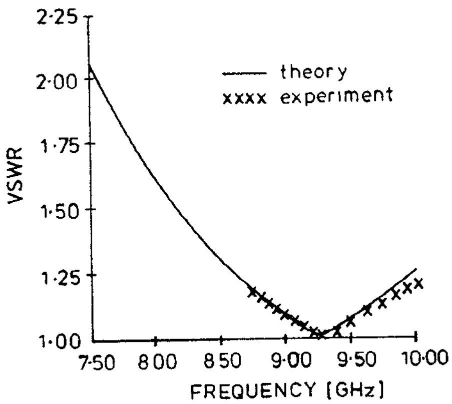

Fig.3 VSWR for a typical X-band waveguide-disk load-comparison between theory and experiment (dimensions in text).

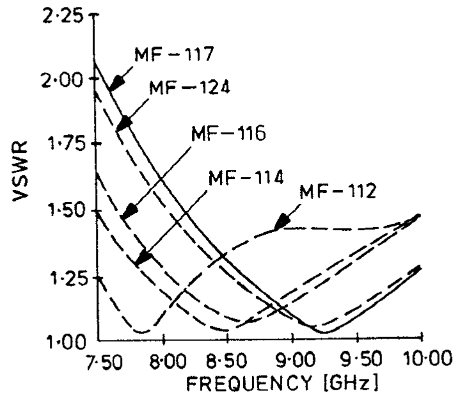

Fig. 4 Theoretical values of VSWR for a waveguide-disk load for different absorbers. Dimension as for Fig. 3.

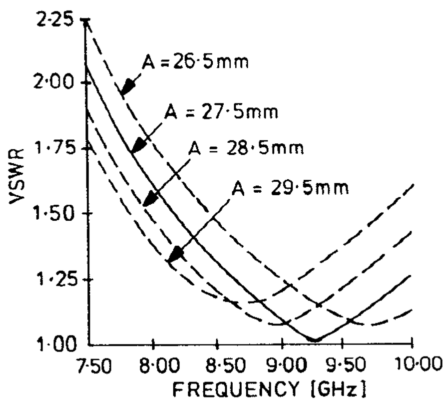

Fig.5 VSWR for a disk load with MF-117 absorber for different values of load diameter.

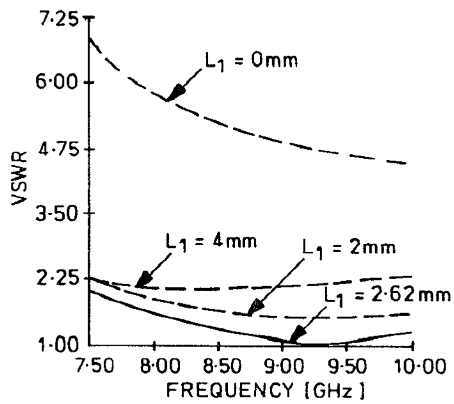

Fig. 6 VSWR for a disk load with MF-117 absorber for different values of the gap height. Other dimensions as for Fig. 3.