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The Effect of Flange Loss on the Reflection Coefficient of Reduced-Height Waveguide Reflection Standards

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Abstract—**It is shown that when reflection-coefficient standards are constructed from reduced-height waveguide having the plane of the change in height coincident with that of the flange, the flange loss will reduce the calculated reflection coefficient, and for small reflection-coefficient standards ($|\rho_S|<0.1$) and practical flange losses, the effect is more significant than step capacitance which is usually taken into account.**

I. Introduction

FOR AN international intercomparison of waveguide reflection-coefficient magnitude at 10 GHz between a number of standards laboratories[1], National Bureau of Standards (NBS), United States, and Royal Signals and Radar Establishment (RSRE), United Kingdom, have submitted travelling standards to be measured by all participants. During the course of this intercomparison the extent to which these reflection-coefficient standards are "absolute", i.e., calculable from dimensions, was examined. It has been found that the ever-present flange loss significantly affects the calculated performance of the reduced-height travelling standards.

II. Discussion

The most frequently used fixed waveguide reflection-coefficient standard takes the form of a nominal width, but reduced height waveguide, terminated in a sliding matched load. Sliding the (imperfect) matched load results in a circular movement of the input reflection coefficient on the Smith chart, and the center of this circle represents the reflection that would be obtained with a perfect termination. The factors usually taken into consideration in predicting the reflection from such a device are as follows.

1) The change in characteristic impedance resulting from the reduced height of the guide, where $z_0 \propto b'/b$, and b' and b are the reduced and nominal heights of the guides on the two sides of the flange connection.

2) The step capacitance resulting from the setting up of evanescent modes by the abrupt change of guide height.

3) The radii of curvature of the corners of the nominally rectangular waveguide aperture.

However, flange loss also will affect the reflection coefficient, but hitherto this effect usually has been neglected.

As evidenced below, flange loss may be modeled as a series, lumped resistance, and its normalized value is given by

$$R=2(10^{A/20}-1) \tag{1}$$

where A is the attenuation in decibels caused by the series insertion of R between a source and load, both having normalized resistances of unity. The reflection coefficient of a normalized series resistance of R is

$$\rho_R=\frac{R}{2+R} \tag{2}$$

and it may be shown that if a standard having a reflection

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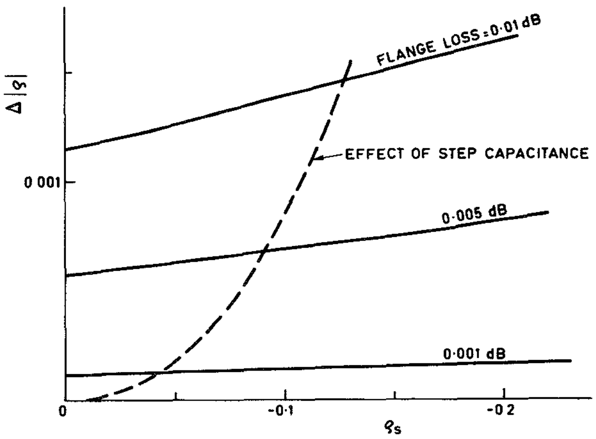

Fig. 1. The amount by which the magnitude of ρ_S, the reflection coefficient of reduced-height waveguide reflection standards, will be reduced due to flange loss versus ρ_S. The dashed curve is the increase of ρ_S caused by the step capacitance in WG 16. It is seen that for $|\rho_S|<0.1$, a flange loss of 0.006 dB will have a greater effect on $|\rho_{in}|$ than the step capacitance.

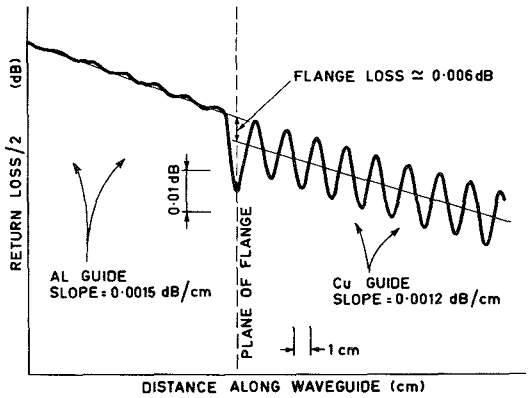

Fig. 2. Variation of return loss as a function of the position of a sliding, noncontacting short circuit. The short circuit is moved over a flange connection, and the offset between the average slopes is a direct measure of flange loss. The increased ripples are caused by the reflection set up by flange loss alone.

coefficient of ρ_S has a series loss component in the plane of the change of Z_0, the resultant reflection coefficient of the combination will be

$$\rho_{in}=\rho_R+\frac{(1-\rho_R)^2\rho_S}{1-\rho_R\rho_S}=1-10^{-A/20}+\frac{\rho_S\cdot 10^{-2A/20}}{1-\rho_S(1-10^{-A/20})}. \tag{3}$$

For reduced-height guides ρ_S is very closely real and negative, whereas ρ_R is real positive, therefore, the effective reflection-coefficient magnitude will be *reduced* by the flange loss. The difference between the theoretical (loss free) and actual values of reflection-coefficient magnitude measured will be very closely $\Delta\rho\simeq\rho_S-\rho_{in}$, which is plotted in Fig. 1 as a function of ρ_S, calculated from change of height only, with the flange loss as the parameter. Superimposed on Fig. 1 is the effect of the step capacitance [1] on the magnitude of the reflection coefficient, which is in quadrature with the real change of Z_0. It is seen from Fig. 1 that whereas the effect of step capacitance diminishes to zero as the height of the reduced-height guide approaches nominal, the effect of flange loss approaches a nonzero value. Thus from flange loss alone, we must expect a (real) reflection coefficient set up in the plane of connected waveguide flanges.

III. The Measurement of Flange Loss

Connector/adaptor loss measurement methods have been reported by Engen [2] and Almassy [3], using tuned reflectometers, by Skilton [4] using a resonance technique, and by scattering parameter measurements [5]. Because reflection-coefficient standards are one-port devices, neither of the above methods could be used directly. However by restricting the measurement to flanges connecting waveguides of equal dimensions, a tuned reflectometer could be used in conjunction with a microwave attenuation calibration setup [6], which displayed flange and guide loss directly, without the need for computation. A tuned reflectometer (tuned to meet simultaneously the conditions of source match and low leakage) was connected to the attenuator calibrator so as to display the return loss from a sliding, noncontacting short circuit, as the short circuit is moved along the guide and through the flange connection. Fig. 2 shows the result of a typical measurement when connecting (not recently) lapped brass and aluminum flanges. The average slopes of the curves on both sides of the flange represent waveguide loss, and the offset between the average slopes represents the flange loss. The "overshoot" of the first ripple is caused by evanescent modes associated with the sliding short circuit when in proximity to the flange connection causing excess attenuation by the flange loss. The increased ripple in the second guide results from the reflection caused by flange loss, and this is further evidenced by the peaks being equal to the offset, i.e., the flange appears to be loss free when a current node is positioned over it, indicating that the flange loss is indeed lumped. The nature of the flange loss was examined also using the Locating Reflectometer, when a typical result of locating flange reflections, like fig. 7 of [7], was examined for phase, and the phase of the reflection coefficient of flange couplings was found to be 0°, indicating that the cause of the flange reflection is a series loss, not flange misalignment, which would result in a reflection-coefficient angle of + or −90°.

IV. Conclusion

It was shown that when reduced-height guides are used as calculable standards of reflection coefficient, the loss of the coupling flange will affect the reflection coefficient in antiphase and the effect is significant when high precision is required. Therefore, it is suggested that if flange misalignment is well controlled (with extra locating pins, for instance), a more suitable reflection-coefficient standard may be constructed by stepping the waveguide height a quarter-guide wavelength, or odd multiples of this, away from the flange, causing the flange loss to be in quadrature with the theoretically calculable reflection coefficient, and so having a reduced effect on the magnitude of ρ_S.

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Dielectric Hemisphere-Loaded Scalar Horn as a Gaussian-Beam Launcher for Microwave Exposure Studies

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Abstract—A new type of Gaussian-beam launcher for producing a focused-microwave exposure field in biological experiments for selective partial-body irradiation is studied. The proposed launcher consists of a scalar horn (corrugated cylindrical open-ended waveguide) excited with a balanced hybrid (HE_{11}) mode and the aperture of the horn is loaded with a dielectric hemisphere. This launcher is similar to the structure described by one of the authors elsewhere [1], except that a dielectric hemisphere instead of a full sphere is used, with the result that the spherical aberration is considerably reduced, as well as that the weight and the size are, to a certain extent, reduced. It is shown that the present structure also produces in the image space of hemispherical lens, a near-circular Gaussian beam with a high-focusing factor. Design details, theoretical calculations, and experimental results concerning a practical *X*-band launcher are presented.

I. Introduction

In the recent past, Neelakantaswamy *et al.* [1]–[4] developed a class of microwave radiators termed as "Gaussian-beam launchers", to produce a focused exposure field in biological experiments for partial-body irradiations. These compact and simple structures with their ability to focus the microwave energy in a very small region indicate their practical utility, in the areas of biological researches and medical applications of microwaves, such as for selective heating of diseased/cancerous tissues. These launchers can also be used in noninvasive beam-wave reflectometric and spectrometric instrumentations for measuring complex permittivity of biological material at microwave frequencies, as indicated by Neelakantaswamy elsewhere [5]–[7].

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When compared to the microwave beam-launching system described in [8], which consists of a plane-wave irradiated dielectric sphere (lens), the launcher formed by combining a scalar horn and a dielectric sphere [1] is a more practical source of microwave Gaussian beam. However, the use of a dielectric sphere as the focusing lens results in significant amount of spherical aberrations in the focal field, as indicated by Neelakantaswamy *et al.* in [9]. The aberration effects are mainly due to the path lengths of rays traversing the sphere (lens) and can be quantified in terms the spherical aberration function $K_0V(\sigma)$, defined in [10], [11].

In the present work, a Gaussian-beam launcher is formed by placing a dielectric hemisphere (instead of a full sphere) at the aperture end of corrugated circular waveguide (scalar horn). This enables a reduction in the path length of the ray in the lens-medium, and hence the spherical aberration effects are relatively minimized. Further, by using a hemisphere in the place of a full sphere, the launcher structure becomes less massive and smaller.

II. Description of the Proposed Structure

Fig. 1 illustrates the launcher structure presently proposed. It consists of an open-ended corrugated circular

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