AN EXPANSION JOINT FOR A MILLIMETER WAVEGUIDE TRANSMISSION SYSTEM

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Abstract

An expansion joint for a circular (TE_{01}) waveguide millimeter wave transmission system was fabricated for a 51 mm. diameter guide. The spurious mode level was measured from 50-70 GHz and found to be at least -40dB lower than the incident TE_{01} level. The measured results compared favorably with an analytic prediction of a -50dB or lower spurious mode level from 40-110 GHz.

Introduction

In recent years, interest has grown in the use of millimeter waves for a long haul, high capacity communication system. One type of system calls for a transmission medium consisting of oversized circular waveguide (radius >> wavelength) in which the information is carried by the low loss circular electric TE_{01} mode. Such a system may require the use of expansion joints at the interface between the main waveguide run and terminal diplexer assembly, and in the waveguide run itself when certain difficult installation problems are encountered requiring the use of a non-constrained waveguide support structure.

Text

One type of expansion joint under consideration is shown in Fig. 1. The unit consists of two metallic sleeves so designed that one can slide over the other; both sleeves are maintained in axial alignment by a pair of bearings. A provision for keying these sleeves to prevent rotation about the longitudinal axis is also provided. The ingress of foreign matter into the sleeve bearing area is prevented by a complaint boot. The bellows, which provides the electrical continuity for the assembly, was made by conventional electroforming techniques.

The bellows must present a good "electrical" match to the incoming guide in order to keep mode conversion to the higher order TE_{0n} modes at a minimum. This is achieved by shaping the individual convolutions of the bellows so that they dimple or "oilcan" on contraction or expansion, thus maintaining approximately constant inner and outer diameters.

An idealized model of the bellows assembly is analyzed below; this model assumes the waveguide radius is S and the convolutes are sinusoidal in shape with amplitude δS and period ℓ, as shown in Fig. 2a. For the values of S, δS and ℓ given in Fig. 2, a reasonable choice for the best "electrical" match is to set the average bellows diameter equal to the guide diameter as shown in Fig. 2a, and thus this type of model was analyzed and built.

As a first approximation for the spurious mode levels, a waveguide with an equivalent step in radius of δS, as shown in Fig. 2b, was examined. The relative power P_{0n}^{step} scattered to any TE_{0n} mode for an incident TE_{01} mode is given in Karbowiak.[1]

$$P_{0n}^{step} = \left(\frac{2\, \chi_{01}\, \chi_{0n}}{\chi_{01}^2-\chi_{0n}^2}\right)^2 \left(\frac{\delta s}{S}\right)^2 \qquad (1)$$

where χ_{0n} is the eigenvalue. The total power scattered to all spurious TE_{0n} modes (P_{Σ}^{step}) is:

$$P_{\Sigma}^{step} \approx 3.6\left(\frac{\delta s}{S}\right)^2 \qquad (2)$$

We expect that the predictions from (1) and (2) of P_{02}^{step} = -34dB and P_{Σ}^{step} = -32.5dB for the bellows in Fig. 2 are conservative since we really do not have a simple step, but instead we have a bellows waveguide section having an average diameter which is the same as the incoming waveguide diameter.

To reinforce this statement, we will make use of a result obtained by Rice[2] which relates the plane wave scattering from rough surfaces to the spectral density of the surface roughness. Since the waveguide is oversized, the scattering is similar to that one obtains for a perpendicular polarized plane wave incident at an angle Ø on a planar surface equivalent to that shown in Fig. 2a. Here Ø is given by

$$\emptyset \approx \Pi/_2 - \frac{\lambda}{S}\left(\frac{\chi_{01}}{2\Pi}\right)$$

and λ is the wavelength.

From Rice's equation (3.30) it can be shown that the total diffuse scattered power for a plane wave incident at angle Ø on a stepped planar surface corresponding to that shown in Fig. 2b is given by

$$P_{\Sigma}^{step} \cong 3.6\left(\frac{\delta s}{S}\right)^2 \quad \text{(planar equivalent)} \qquad (3)$$

The fact that the cylindrical and planar models of a step discontinuity yield the same result suggests that we can use Rice's twodimensional planar analysis of rough surface to derive the actual scattering from cylindrical bellows. To proceed with this analysis we note that the diffuse scattered power is strongly dependent on the low frequency content of the spectral density of the reflecting surface; it can be readily shown by comparing the spectral densities for the two bellows models under consideration that the diffuse scattered power for the planar bellows ($P_\Sigma^{Bellows}$) is related to that of the step by

$$P_\Sigma^{Bellows} < \left[\left(\frac{2\ell}{\lambda}\right)\right]^4 P_\Sigma^{step} \qquad (4)$$

Thus for the bellows structure in Fig. 2, (2) and (4) predict that for 2S = 51 mm and ℓ = 0.254 mm, the spurious mode level is -60 dB down from the incident TE_{01} level for the frequency band of 40 - 110 GHz. This level (-60 dB) is for a semi-infinite bellows. The level for a finite length bellows would be -54 dB for the worst case. This occurs when the mode conversion at each end adds in a constructive fashion which leads to the highest possible spurious mode level.

This low spurious mode level prediction has been confirmed by performing electrical measurements on a 51 mm bellows structure designed as shown in Fig. 1. The results of these measurements are shown in Fig. 3. The results were obtained on a computerized Klinger cavity test set from 50-75 GHz.[3] The average TE_{02} mode conversion level was measured with the test set alone and then with test set plus bellows. It is difficult to estimate, from the results in Fig. 3, the actual TE_{02} level due to the bellows alone, since the residual TE_{02} level in the test set is high (-35 to -45 dB) due primarily to the taper used. However, it is clear that the mode conversion levels are quite low (-40 dB or more) thus confirming, in an approximate sense, the prediction derived from Eq. (4). The measured spurious mode levels were changed only slightly (< ±1 dB) as the length of the bellows was varied from 125-150 mm. An increase in the bellows diameter from 51 to 60 mm., as is planned for future applications, will lead to a further reduction in the individual spurious mode levels.

Conclusion

In summary, an experimental model of an expansion joint has been analyzed, built and tested. The measured and predicted results indicate the spurious mode level is down at least (-40 dB) from the incident TE_{01} level from 50-75 GHz.

References

1) Karbowiak, A. E. "Trunk Waveguide Communication", Chapman and Hall LTD, 1965, p.78.

2) Rice, S. O. "Reflection on Electromagnetic Waves from Slightly Rough Surfaces", Theory of Electromagnetic Waves, Dover Pub., 1965, pp. 351-378.

3) Hinderks, L. W. and Seip, B. S. "A New Computer-Controlled Klinger Cavity Mode Conversion Test Set", G-MTT Int. Microwave Symp., Boulder, Colorado, June, 1973.

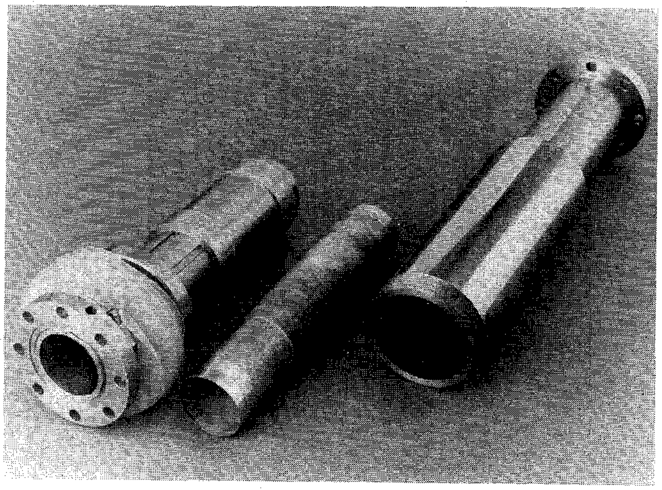

Fig. 1. Expansion joint - major component parts.

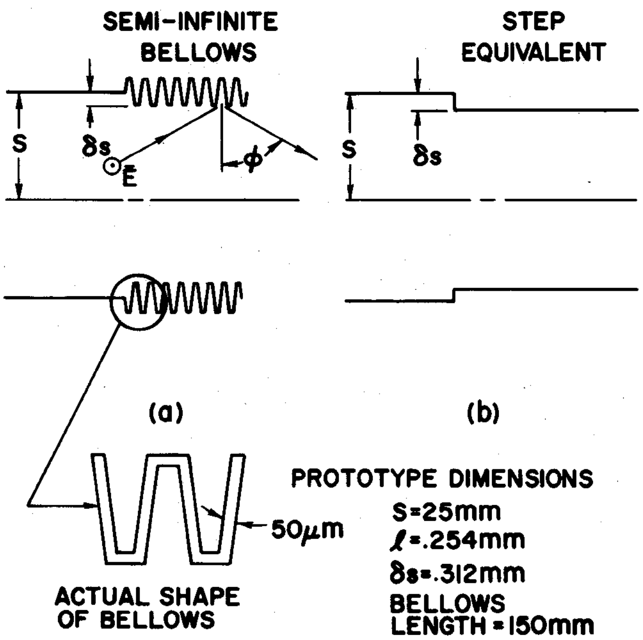

Fig. 2. Idealized model of bellows.

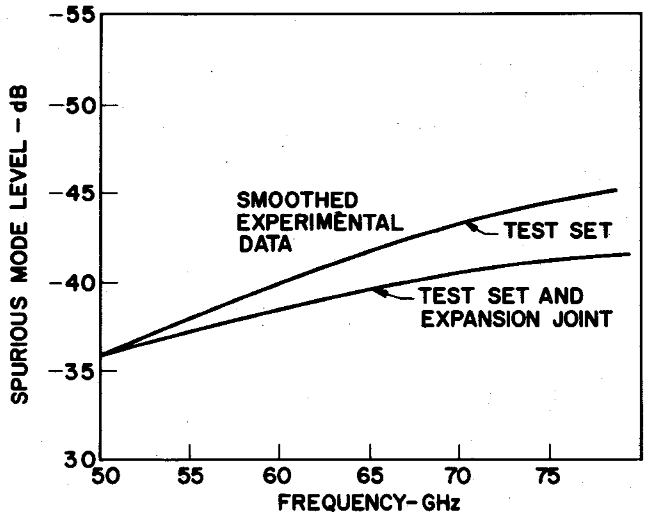

Fig. 3. Average TE_{02} levels for expansion joint.