CIRCULAR TE_{0n} MODE FILTERS FOR A GUIDED MILLIMETER-WAVE TRANSMISSION

K. Hashimoto, S. Shimada and M. Koyama

Yokosuka Electrical Communication Laboratory, Kanagawa, Japan

Summary: This paper describes theoretical and experimental results of TE_{02} and TE_{03} mode filters for circular waveguides with large diameter. The experimental results show that the TE_{01} insertion loss is less than 0.8 dB for the former and less than 0.4 dB for the latter over the 40 to 80-GHz frequency range. The attenuation loss of the undesired modes is more than 6 dB over the same frequency range for both filters.

In millimeter-wave circular waveguide communication systems, the inner diameter of the circular TE_{01} mode waveguide is chosen to be so much greater than free-space wavelength that a considerable number of undesired modes are generated in the bend or at discontinuities along the transmission path. In particular, circular waveguide corners (the so-called miter elbows[1] capable of bending the wave at sharp angles) and the half-mirror of the Michelson interferometer-type band-splitting filters generate circularly symmetric modes (TE_{02},TE_{03}, etc.) in large quantities. Degradation of the transmission characteristics, therefore, occurs due to the conversion and reconversion between the TE_{01} signal mode and the undesired modes.

Although a helix waveguide is generally very effective as a mode filter, it has no filter-effect on the undesired $TE_{0n}(n \geq 2)$ modes. Therefore, TE_{0n} mode filters capable of absorbing the generated TE_{0n} modes must be specially provided. The required conditions for TE_{0n} mode filters are that the attenuation of undesired modes is high and the insertion loss for the TE_{01} mode is low over a broad frequency range, and that the inner diameter of the filter is nearly equal to that of the TE_{01} transmission line (such as 51 mm or 60 mm).

There have been proposed and tested a wave-coupled type[2], a metal-sector type[3], and a resonant-slot type TE_{02} mode filter, but such filters have not been very effective in the case of the large inner diameter. On the other hand, the TE_{02} and TE_{03} mode filters described in this paper have advantages such as (1) the mode filter length is only a few handred millimeters for 51 mm inner diameters, (2) the construction and the manufacturing are simple, (3) the required fabrication accuracy is not so severe as a wave-coupled type, and (4) broad-band filter effect is expected.

A skech of the overall view and the cross-sectional view of the TE_{02} mode filter are shown together with a photograph in Fig. 1. In the mode filter suggested by us, the filtering is accomplished by converting the TE_{02} mode into unsymmetrical modes (mainly TE_{1n}, TE_{3n}, TM_{1n}, etc. ($n = 1,2,3,\cdots$) modes), which are suppressed by resistive material sheets or helix waveguides.

As can be seen from Fig. 1, a circular waveguide of radius R is divided into two semi-circular waveguides by a metallic slab. One of the two waveguides has the radius R′ and is connected with the taper from R to R′ semi-circular waveguides. At the input and output of the metallic slab the radii of the semi-circular waveguides are made equal and there are resistive sheets in contact with the metallic slab. Furthermore, a semi-circular dielectric with dielectric constant ε_r and thickness t is disposed at the position of 0.546R′ where the electric field of the TE_{02} mode with smaller radius is zero.

By using the design parameters described above in such a manner that the phase difference at the output of the semi-circular waveguide is equal to π for the TE_{0n} ($n \geq 2$) modes, to zero for the TE_{01} mode, we shall obtain the converted unsymmetrical modes only for the undesired mode. The phase difference for two semi-circular TE_{0n} ($n = 1, 2, 3, \cdots$) modes are produced by decrease of the radius and insertion of dielectric in one of the waveguides, and are respectivly determined by the following equation,

$$\Delta\theta_{[on]} \cong \pi \cdot \lambda \frac{X_{[on]}}{2\pi^2} \frac{R - R'}{R \cdot R'^2} \ell_{eq} \quad (1)$$

$$\Delta\varphi_{[on]} \cong 2\pi(\varepsilon_r - 1) \frac{\lambda g_{[on]}}{\lambda^2} \frac{t}{R} \frac{r}{R} \left\{ \frac{J_0(X_{[on]} r/R)}{J_0(X_{[on]})} \right\}^2 \cdot h \quad (2)$$

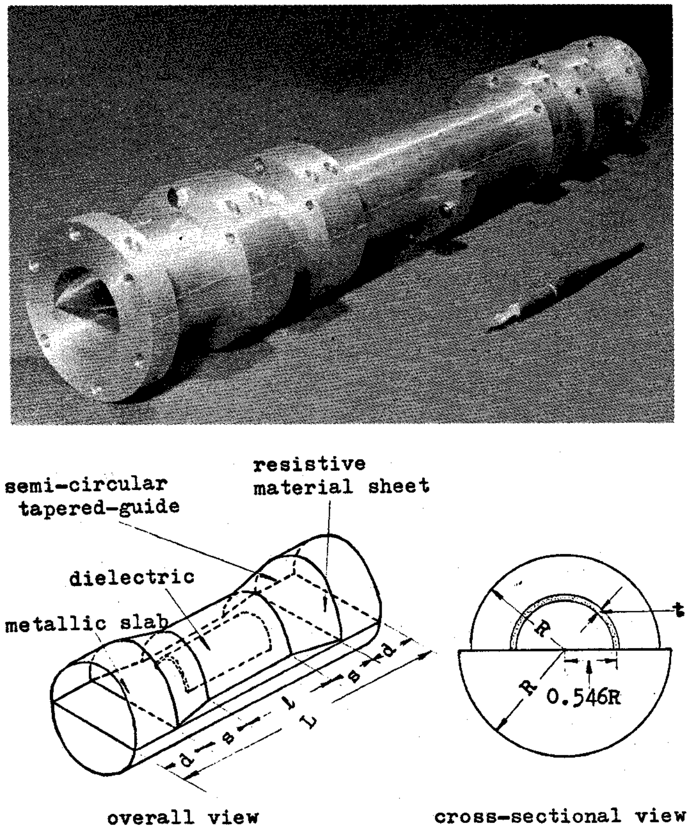


Fig. 1, Circular TE_{02} mode filter

where $X_{[on]}$ and $\lambda_{g[on]}$ are, respectively, an eigen value and a guide-wavelength for the TE_{on} mode, ℓ_{eq} is the equivalent length of the section having the reduced radius R', taking into account the tapered region, and r is the radius of the position where a semi-circular dielectric with length h is disposed.

In the production of a phase difference of the TE_{02} mode, $\Delta\theta_{[02]}$ equal to π only by decrease of the radius, it is obvious that $\Delta\theta_{[01]}$ for the TE_{01} mode does not become zero and that the insertion loss increases.[4] In the case of the TE_{02} mode filter, therefore, $\Delta\theta_{[01]}$ caused by a decrease of radius must be cancelled by a dielectric disposed at the position described above. The TE_{03} mode filter does not require a dielectric because $\Delta\theta_{[01]}$ is very small when designating $\Delta\theta_{[03]}$ equal to π. The manufactured TE_{02} and TE_{03} mode filters are relatively short, having overall lengths, respectively, of 650 mm and 600 mm in spite of the use of a large radius waveguide (51 mm).

Figure 2 shows the frequency characteristics of the phase difference for the TE_{01} and TE_{02} modes which are obtained by changing the radius and disposing a dielectric in the waveguide.

The experimental results for the TE_{02} mode filter are shown in Fig. 3. In Fig. 3-a, which shows the insertion loss characteristics for the TE_{01} mode, it is shown that the experimental values indicated by the solid lines are in good agreement with the theoretical values shown by the broken lines, and that the loss is less than 0.8 dB for 40-80 GHz. The theoretical values take into account the heat loss in the wall, the tan δ loss of the dielectric, the mode conversion loss in the tapered semi-circular waveguides, and the loss due to the phase difference of the TE_{01} mode. Although the phase difference of the TE_{01} mode has been chosen to be zero at 50 GHz in Fig. 2, we can arbitrarily choose the frequency at which the phase difference becomes zero, by changing the dielectric constant or the sizes. Figure 3-b shows the attenuation loss characteristics of the TE_{02} mode. The effect of the dielectric upon the TE_{02} mode is almost negligible, and the attenuation losses are more than 6 dB for 40-80 GHz.

On the other hand, the frequency characteristics of the phase difference of the TE_{01}, TE_{02}, and TE_{03} modes for the TE_{03} mode filter are shown in Fig. 4. As shown in Fig. 4, the phase difference for the TE_{01} modes is so small that the TE_{03} mode filter needs no dielectric and the insertion loss of the TE_{01} mode is very low. Furthermore, this filter has the advantage of absorbing more or less the TE_{02} mode in the low frequency range. The experimental results of the TE_{03} mode filter are shown in Fig.5. As shown in Fig. 5-a, the measured values are in good agreement with theoretical values, and the

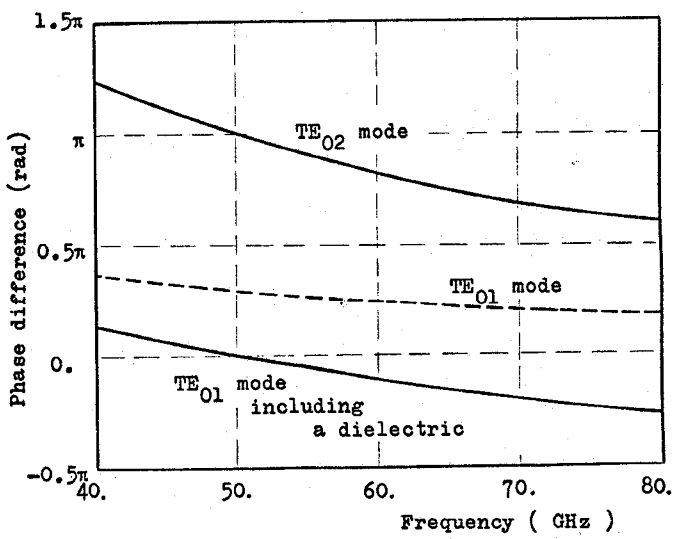


Fig. 2, The frequency characteristics of the phase difference for TE_{02} mode filter.

insertion loss is less than 0.45 dB over the frequency band 40-80 GHz. Figure 5-b and Fig. 5-c show the attenuation losses of the TE_{02} and TE_{03} modes; in particular, the attenuation loss of the TE_{03} mode is more than 6 dB for the same frequency band above.

As demonstrated by these figures, we have been able to obtain good performance of the TE_{02} and TE_{03} mode filters with a large inner diameter of 51 mm. In particular, the construction and the manufacturing of TE_{03} mode filters are simple because of the absence of a dielectric.

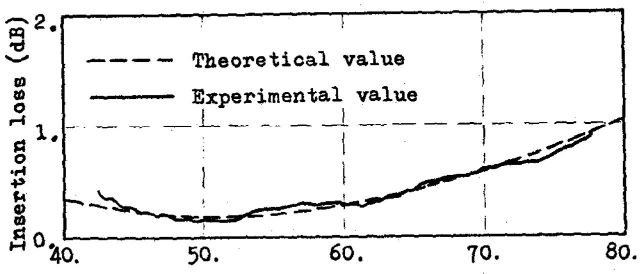
References

(1), E.A.J.Marcatili, Proc. of the Symposium on Quasi-Optics, pp535, Polytecnic Press, 1964.

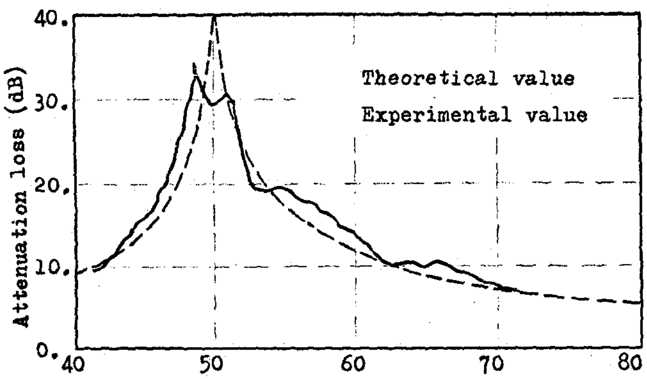
(2), K.Hashimoto, K.Kondoh, and S.Shimada, Rev. of Electr. Commun. Lab., Vol.21, No.12, pp2227, 1972.

(3), Von S Sedlmair, Frequentz, Vol.22, No.4, pp118, 1968.

(4), M.V.Persikov, Radioteknika i Electronika, Vol.6, No.3, pp444, 1961.



(a), Insertion loss characteristics.



(b), Attenuation loss characteristics

Fig. 3, Transmission characteristics of TE_{02} mode filter.

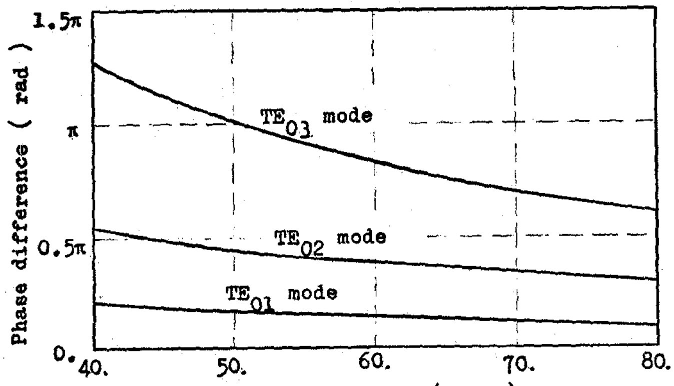
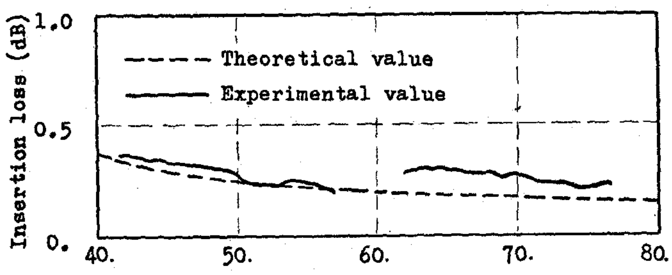
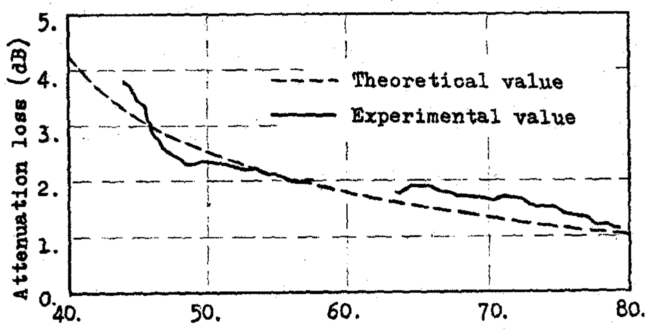


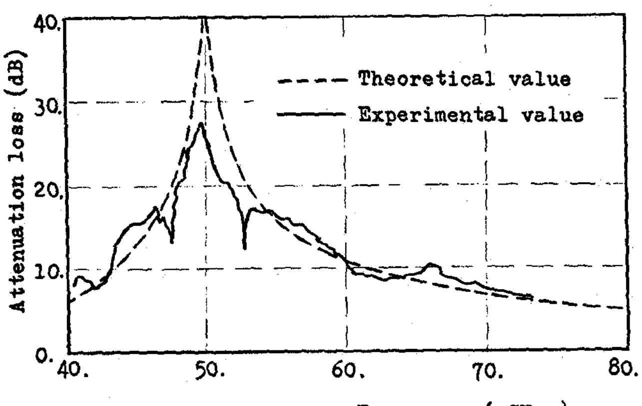
Fig. 4, The frequency characteristics of the phase difference for TE_{03} mode filter.



(a), Insertion loss characteristics.



(b), Attenuation loss characteristics for TE_{02} mode.



(c), Attenuation loss characteristics for TE_{03} mode.

Fig. 5, Transmission characteristics of TE_{03} mode filter.