where

$$\beta=\sqrt{\epsilon_r k_0^2-q^2-(\pi/a)^2} \tag{4a}$$

$$r_s=\sqrt{\frac{\omega\mu_0}{2\sigma}}\Bigg/\sqrt{\frac{\mu_0}{\epsilon_0}}=\sqrt{\frac{\omega\epsilon_0}{2\sigma}}. \tag{4b}$$

In the above equations, ϵ_r and $\tan\delta$ are the relative dielectric constant and loss factor of the dielectric strip, ϵ_0 and k_0 are the free space permittivity and wavenumber, β is the propagation constant of the dominant mode in the NRD-guide, σ and r_s are the conductivity and normalized surface resistance of the metal plates, a and b are the height and width of the dielectric strip, and the parameters p and q are the lowest eigenvalues of the following characteristic equations for TM surface waves supported by a dielectric slab with a thickness of b:

$$\epsilon_r p=q\tan\left(\frac{qb}{2}\right) \tag{5a}$$

$$p^2+q^2=(\epsilon_r-1)k_0^2. \tag{5b}$$

Assuming the top and bottom plates to be silver-plated ($\sigma=6.17\times10^7$ S/m), the attenuation constant is calculated for polystyrene ($\epsilon_r=2.56$, $\tan\delta=9\times10^{-4}$) and Teflon ($\epsilon_r=2.04$, $\tan\delta=1.5\times10^{-4}$) and compared with measured data in Fig. 5. Agreement between theory and measurements is quite satisfactory.

IV. Conclusions

A technique for measuring the attenuation constant of the NRD-guide was developed and applied to polystyrene and Teflon NRD-guides at 50 GHz. Measured attenuation constants are about 13 dB/m for a polystyrene NRD-guide and 4 dB/m for a Teflon NRD-guide. These results clearly show that the NRD-guide can be of practical use as a transmission line for millimeter-wave integrated circuits because of its low-loss nature, as well as its radiation suppression capability. The calculated attenuation constant is also found to be in a good agreement with measurements.

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Comments on "The Microstrip Open-Ring Resonator"

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Abstract —**Attention is drawn to the analogy existing between the electromagnetic fields of the open-ring resonator and the ring-sector waveguide [1], [2]. Except for the eigenvalues of γ and k, the spatial variations of their fields in the cross-sectional plane are solutions of the same differential equation [3].**

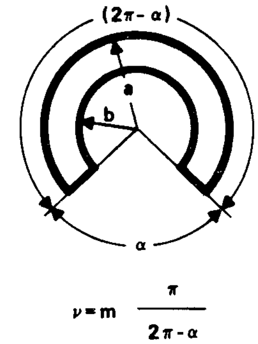

Fig. 1. Cross-sectional geometry of ring-sector waveguide and open-ring resonator.

In a recent paper[1], the open-ring microstrip resonator was analyzed by means of the two-dimensional magnetic wall model. When taking a look at the expressions, the authors derived for the components of the electromagnetic fields, one detects a striking analogy to those of the ring sector or coaxial sector waveguide which were published in 1961 [2]. The differences impacting the solutions for the field components of the coaxial sector waveguide and the open-ring resonator are the conducting walls versus the magnetic walls and the three-dimensional versus the two-dimensional geometry. As a result of the first (conducting versus magnetic walls), the magnetic-field components of the ring-sector waveguide as functions of the transverse coordinates r and ϕ are similar to the electric-field components fo the open-ring resonator. The same similarity exists between the electric-field components of the ring-sector waveguide and the magnetic-field components of the open-ring resonator. However, the second deviation (three-dimensional versus two-dimensional geometry) causes the transverse electric fields of the open-ring resonator not to be excited. The analogy between the fields of the two structures having the cross-sectional geometry of Fig. 1 is easily discernible from the proportionalities of the corresponding fields summarized in Table I. Here, the wavenumber k is related to the eigenvalue γ in accordance with $\gamma^2=k^2-\beta^2$, where $j\beta$ is the propagation constant of the waveguide.

As early as 1955, P. R. Clement and W. C. Johnson pointed out the analogy that exists between the uniform waveguide and its two-dimensional model [3]. As to the solutions of the differential equations which are found to be common to both structures, one could interpret the two-dimensional problem as a special case of the uniform waveguide problem, distinguished from each other only by a different set of boundary conditions. Since field patterns of uniform waveguides have been reported for many cross-sectional shapes, a familiarization with the work reported in [3] may be highly beneficial for the understanding of microstrip structures with corresponding geometries. A rigorous analysis of the coaxial sector waveguide, including field distributions and cutoff frequencies of the TE_{mn}- and TM_{mn}-modes, as well as an approximation for the characteristic impedance of the TE_{11} mode, is contained in [2]. As open-ring resonators have been proposed for filters and planar antennas, coaxial waveguides have been employed as coupling elements for traveling-wave amplifiers [4],

Manuscript received February 17, 1984.

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[1] I. Wolff and V K. Tripathi, *IEEE Trans Microwave Theory Tech.*, vol. MTT-32, pp. 102–107, Jan 1984

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TABLE I
PROPORTIONALITY OF FIELD COMPONENTS IN THE RING-SECTOR WAVEGUIDE AND THE OPEN-RING RESONATOR

COAXIAL SECTOR WAVEGUIDE (TE_{mn} MODES)	OPEN RING RESONATOR TM_{mn0} MODES
$E_r \propto \frac{\nu}{r}\left[J_\nu(\gamma r) - \frac{J'_\nu(\gamma a)}{Y'_\nu(\gamma a)} Y_\nu(\gamma a)\right] \sin(\nu\phi)$	$H_r \propto \frac{\nu}{r}\left[J_\nu(kr) - \frac{J'_\nu(ka)}{Y'_\nu(ka)} Y_\nu(kr)\right] \sin(\nu\phi)$
$E_\phi \propto \left[J'_\nu(\gamma r) - \frac{J'_\nu(\gamma a)}{Y'_\nu(\gamma a)} Y'_\nu(\gamma a)\right] \cos(\nu\phi)$	$H_\phi \propto \left[J'_\nu(kr) - \frac{J'_\nu(ka)}{Y'_\nu(ka)} Y'_\nu(kr)\right] \cos(\nu\phi)$
$E_z = 0$	$H_z = 0$
$H_r \propto \left[J'_\nu(\gamma r) - \frac{J'_\nu(\gamma a)}{Y'_\nu(\gamma a)} Y'_\nu(\gamma a)\right] \cos(\nu\phi)$	$E_r = 0$
$H_\phi \propto \frac{\nu}{r}\left[J_\nu(\gamma r) - \frac{J'_\nu(\gamma a)}{Y'_\nu(\gamma a)} Y_\nu(\gamma a)\right] \sin(\nu\phi)$	$E_\phi = 0$
$H_z \propto \left[J_\nu(\gamma r) - \frac{J'_\nu(\gamma a)}{Y'_\nu(\gamma a)} Y_\nu(\gamma r)\right] \cos(\nu\phi)$	$E_z \propto \left[J_\nu(kr) - \frac{J'_\nu(ka)}{Y'_\nu(ka)} Y_\nu(kr)\right] \cos(\nu\phi)$
$\gamma^2 = k^2 - \beta^2$	$k = \omega\sqrt{\epsilon\mu}$

[5] and, more recently, for gyrotron traveling-wave amplifiers [6], [7].

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Reply[2] *by I. Wolff and V. K. Tripathi*[3]

It is surely a mistake that we did not know, and therefore did not reference, the interesting paper of K. B. Niclas[1] on ring-sector waveguides, despite the fact that it already was published in 1961. Niclas is right to draw attention to the similarities between the field distributions in metallic waveguides and magnetic wall models for microstrip components. They have been used intensively in the past for modeling microstrip circuits. The comment is highly appreciated.

[2]Manuscript received March 7, 1984.

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