# Letters

## Comments on "Attenuation Measurement of Very Low Loss Dielectric Waveguides by the Cavity Resonator Method Applicable in the Millimeter/Submillimeter Wavelength Range"

D. G. JABLONSKI AND A. D. KRALL

Shimabukuro and Yeh[1] describe the use of a cavity to measure the attenuation factors for circular dielectric waveguides propagating the $HE_{11}$ mode [1]. We would like to comment on three issues.

First, the authors fail to cite the work by Elsasser [1] to derive the attenuation factor for a circular dielectric waveguide. This is surprising, given that earlier work by Yeh [2] does acknowledge Elsasser's derivation.

Second, Shimabukuro and Yeh show that commonly used formulas for the $Q$ of a resonator are not correct for a system propagating a hybrid mode. They use this result to support the argument that a hybrid wave cannot be modeled accurately as a "single equivalent transmission line." We question this interpretation. The authors' use of a single propagation constant implies the existence of a single equivalent transmission line model. The problem of defining a wave impedance is secondary.

This is a semantic point, however. The more important issue, to us, is that commonly used expressions for $Q$ can be inaccurate. This helps resolve some ambiguous data we obtained in an attempt to use the cavity technique at 70 GHz [3].

This leads to the final point. The title of the article suggests that the cavity technique is applicable in the millimeter and submillimeter range. When we used the cavity technique at 70 GHz, we encountered numerous difficulties associated with the small rod diameter. In particular, it was not practical to decrease the rod diameter at the walls of the cavity. As a result, the loaded $Q$ of the cavity was small, and the corresponding bandwidth measurements were unsatisfactory. Rather than correct this deficiency, we chose to eliminate the cavity and measure the attenuation directly with a moving probe [4].

To summarize, mechanical difficulties associated with the cavity technique will grow dramatically as frequency is increased. For example, use of a fused quartz rod in a high-$Q$ cavity at 100 GHz will not be a trivial extension of the work at *Ka*-band.

*Reply[2] by F. I. Shimabukuro and C. Yeh[3]*

The most important comment that we can gather from the comments by Jablonski and Krall is their statement: "...commonly used expressions for $Q$ can be inaccurate. This helps resolve some ambiguous data we obtained in an attempt to use the cavity technique at 70 GHz." This recognition of the importance of our general formula relating $Q$ and $\alpha$ is appreciated.

As far as the concept of wave impedance is concerned, we believe the existence of an equivalent simple transmission line for any wave guidance structure depends critically on our ability to define a characteristic impedance for the transmission line which is not a function of the transverse coordinates of the guiding structure. For a hybrid wave on a dielectric waveguide, the usual definition for the characteristic impedance [5], which is the ratio of the transverse electric field to the transverse magnetic field of the mode, yields an impedance which is a function of the transverse coordinates of the guiding structure. Consequently, we concluded that a *simple* "single equivalent transmission line" may not be an adequate representation for the hybrid wave. A simple "single equivalent transmission line" exists only for a TE, TM, or TEM wave [6]. It is *not* adequate to simply say that the existence of a single propagation constant implies the existence of a *simple* single equivalent transmission line model given in most textbooks; one must be able to define a single characteristic impedance (that is not a function of the transverse coordinates of the guide) for the transmission line model which is inherently a one-dimensional structure.

Let us now address the question whether we can extend our techniques to the millimeter and submillimeter range. We have found that it was not difficult to make the $Q$ measurements at *Ka*-band. In fact, we have deliberately coupled to the waveguides off center, to see if other modes were excited. It is not possible for us to comment on why Jablonski has difficulty in making $Q$ measurements at 70 GHz using the resonator technique, since we are not familiar with his experiments. However, we can make a few general remarks about the technique we have used. To make the measurements at higher frequencies, all dimensions have to be scaled accordingly. This means that the waveguide has a smaller diameter, but it is shorter. The coupling aperture is smaller, and the reflector plates have a smaller diameter. It is true that one has to be more careful in aligning the waveguide within the cavity, but the tolerances needed can be readily attained with presently available components, accessory instruments, and gauges ordinarily used for optical measurements (e.g., laser alignment, use of optical rails, three-axis lens holders for the reflecting plates, $xyz$ micrometer stages), as we have done. Of course one has to be careful with the waveguide supports, ensuring that the supports do not affect the cavity $Q$. Using very fine dielectric strings to support the waveguides solved this problem.

Finally, we wish to comment that no intentional attempt was made to exclude citing the work by Elsasser [1]; it was merely an editorial decision on our part. After all, his work, as well as important work by others [7], was quoted in an earlier work by Yeh [2]. The significance of Elsasser's work is well recognized.

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[2] Manuscript received September 23, 1988
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