MEASUREMENT TECHNIQUES FOR THE ATTENUATION CONSTANT OF DIELECTRIC IMAGE LINES IN THE MILLIMETER WAVE RANGE

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ABSTRACT

Measurement techniques for the measurement of the attenuation constant of dielectric image lines in the millimeter wave range are discussed.
A new method using electric field probes and avoiding the drawbacks of the resonator methods is presented.

Introduction

Since the proposal of the dielectric image line as a guiding structure for millimeter waves several authors have described measurements of the field distributions and the guide wavelengths of the lines [1-5], some have published measurements of the attenuation constants of the lines [1,6-8], but only one paper describes measurements of the attenuation constants in the millimeter wave range [8].
In the following the measuring methods for the attenuation constant employed by the experimenters are discussed briefly. A new method is proposed and experiments in the frequency range of 26 to 90 GHz are described.

Discussion

King and Schlesinger [1,2] employ two basic ideas for the measurement of the attenuation constant of semi circular polyethylene dielectric image lines, namely the measurement of the insertion loss of straight image line sections and the measurement of the loaded quality factors of short-circuited dielectric image line resonators of variable length. The latter method has also been used by Wiltse [8] for the determination of the attenuation constants of semi circular foam polystyrene image lines.
Toulios and Knox [7] employ the measurement of the loaded quality factors of lightly coupled short-circuited resonators for the determination of the attenuation constants of rectangular polyethylene and alumina dielectric image lines and they employ the measurement of the loaded quality factors of lightly coupled ring resonators in the case of rectangular titanium dioxide image lines.

The two methods employed by Toulios and Knox cannot be exact, since neither the reflector losses in the short circuited resonators nor the curvature radiation losses in the ring resonators are regarded.
The accuracy of the insertion loss method relies on the length of the employed line sections. As it is not easy to fabricate relatively long sections of e.g. ceramic or semiconductor image lines, this method is not considered to be of general importance for dielectric image lines.

The resonator method of King is an exact method, since it takes into account the losses due to the coupling and the reflector walls. With respect to the simplicity of the technique the method has been modified by the use of electric field probes instead of waveguide coupling holes in the reflector walls.

Experiments

In Fig.1 the measurement setup together with experimental points for the quality factors of a paraffin wax image line resonator are plotted.
Both the reflector walls and the ground plane were polished brass. One of the reflector walls was fixed in position while the second wall could be moved. The coupling of the resonator was through two electric field probes, which were fabricated from short sections of semi rigid coaxial cable and which incorporated coaxial to metal waveguide transitions to couple the RF source or the metal waveguide detector. In Fig.2 the field probe used in the E-band(60-90GHz) is sketched. The dielectric image line was reduced in length(using a cutting tool) in small steps, each time returning the adjustable reflector wall to the open end of the image line and measuring the quality factor of the resultant resonator.

In the experiments the main difficulties resulted from the fact that the adjustable reflector wall did not contain a choke joint along the contact with the ground plane. Thus the losses due to the contacting currents were difficult to control as the reflector wall position was varied.

On the whole the resonator technique proved to be practical for dielectric image lines in the millimeter wave range, though some disadvantages have been experienced:
For the sake of precision in the measurements it has not been possible to use the image guide for the measurement of the attenuation constant at more than one frequency. So, for each frequency point a seperate section of dielectric image line had to be fabricated. On the othe hand, in a correct evaluation of the measured quality factors for the attenuation constant of the lines, the phase velocity as well as the group velocity of the waves on the image lines have to be known.

The VSWR - Method

A new measuring technique has been devised avoiding the disadvantages of the resonator techniques.
In Fig.3 the measuring setup together with typical experimental points is plotted. The dielectric image line is fed by a metal waveguide mode launcher. The incident CW-signal is reflected at the reflector wall and the reflected wave returnes to the mode launcher. The resultant standing wave pattern is probed using an electric field probe(see Fig.2) which is mounted on a three dimensional vernier mechanism.
Using a calibrated variable attenuator in the incident power path, the VSWR, i.e. the ratio of the amplitudes of adjacent maxima and minima of the electric field strength on the image line, is measured. The VSWR is maximum at the reflector wall and decreases with

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increasing distance from the wall.
The analytical expression for the VSWR as a function of the attenuation constant of the line, α, the reflector loss, τ, of the reflector wall and of the distance, z, from the reflector wall readily is calculated as

$$\mathrm{VSWR} = \frac{1 + e^{-\tau} e^{-2\alpha z}}{1 - e^{-\tau} e^{-2\alpha z}} \; .$$

The measured VSWR-values are numerically fitted by this analytical function, yielding the two unknown quantities of the expression τ and α.
The least squares fit algorithm derived for this purpose results in a set of two nonlinear equations which can be solved only iteratively. The algorithm was programmed in BASIC and run on a HP9830A desk top computer.
As can be seen from Fig.3 the approximation line resulting from this procedure practically is a straight line since the losses in the transmission line and in the reflector wall are relatively small ($2\alpha 1 \ll 1, \tau \ll 1$, where 1 is the maximum distance from the reflector wall). In this case the analytical expression for the VSWR can be reduced to a linear dependence

$$1/\mathrm{VSWR} = \frac{\tau}{2} + \alpha z \; ,$$

and the approximation line can be found either graphically or by means of a set of two linear equations, which can be solved directly.
In general this approximation algorithm can be used to find suitable starting values of τ and α for the more delicate exact approximation algorithm.

The method has been applied to the measurement of the attenuation constant of several dielectric image lines made of paraffin wax, Stycast resin[9] and Epsilam-10 substrate.
The measurement results were compared to theoretical results[10] on the basis of an exact solution for the eigenvalue problem of the dielectric image line of rectangular cross section, described in[5].
In Figs.4 and 5 the results of measurements for two paraffin wax lines and one Epsilam-10 line are plotted. The agreement of the measurement points and the theoretical curves is satisfactory. The agreement between the results from the VSWR-method and the result from resonator measurements, also plotted in Fig.4, too is satisfactory.

Two critical parameters of the technique have to be observed:
The height of the field probes above the dielectric line has to be kept as large as possible in order to keep the perturbation of the guided waves on the line as low as possible. The upper limit for the height of the probe is set by the sensitivity of the DC indicator instrument, since the probed electric field strength decays exponentially with the distance from the image guide.
On the other hand it is of importance that the wave, which is returning to the mode launcher from the dielectric image line, is totally absorbed or transmitted by the mode launcher and no interfering second incident wave is launched. Possibly this has to be ensured by loading the mode launcher with absorbing material.

On the whole the VSWR-method was found to be a very simple and reliable method, even if the evaluation of the measurements needed a computer. This basically is a merit of the fact that in this method the field probe is moved instead of the reflector wall in the resonator method.

Like in the resonator method a high degree of confidence in the results can be gained if a high number of measuring values is evaluated.

References

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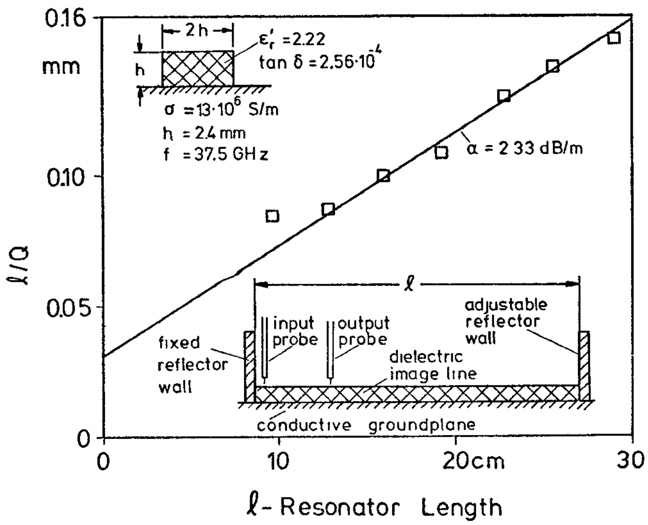

Fig.1 The measurement of the attenuation constants of dielectric image lines using the resonator method of variable length resonators.

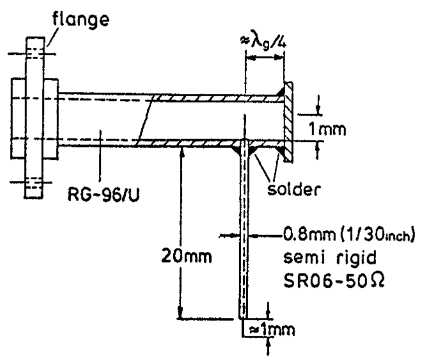

Fig.2 Sketch of the electric field probe used in the E-band experiments.

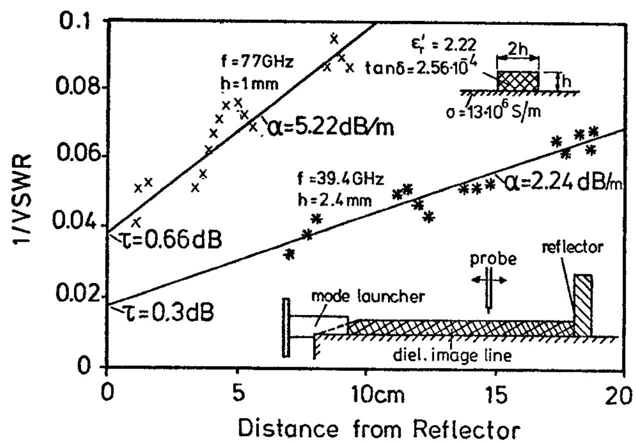

Fig.3 The measurement of the attenuation constants of dielectric image lines using the VSWR-method.

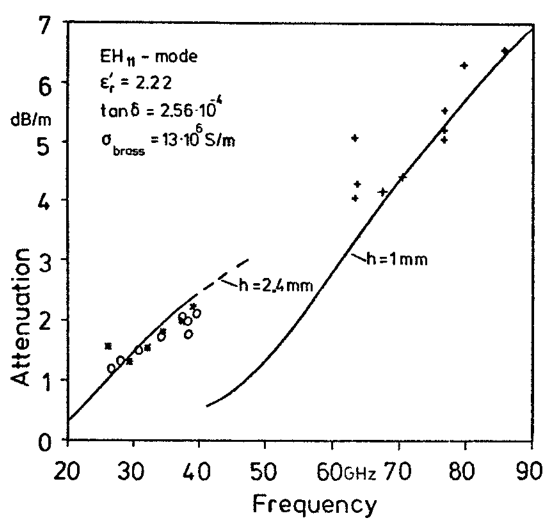

Fig.4 The measured and calculated attenuation constants of two paraffin wax dielectric image lines versus the frequency.
—— Theory, O resonator method of variable length resonators, + and ✱ VSWR-method.

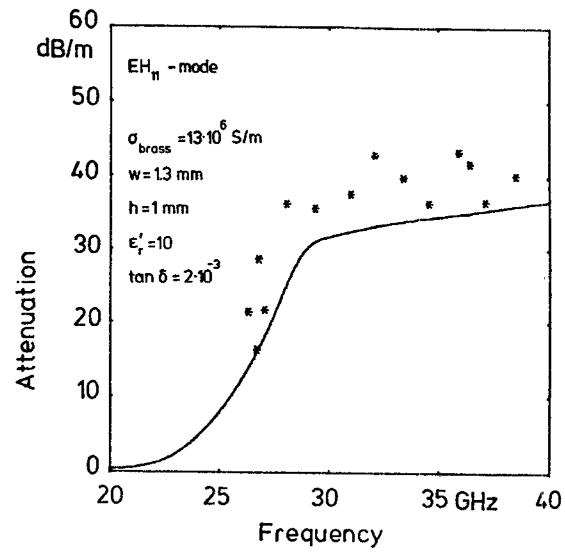

Fig.5 The measured and calculated attenuation constant of an Epsilam-10 dielectric image line versus the frequency.
—— Theory, ✱ VSWR-method.