HYBRID HEM_{11p} -MODE DIELECTRIC RESONATORS FOR FILTER APPLICATIONS AT SHORT MILLIMETER WAVELENGTHS

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ABSTRACT

This paper describes the measurement of permittivity and dielectric losses of recently available ceramic materials in the frequency range of 80 to 100 GHz. Design criteria for cylindrical dielectric resonators are given and, subsequently to measuring their characteristic absorption curves, unloaded Q factors are calculated for resonators of different materials and aspect ratios. A short description of a 96 GHz bandpass filter gives an example for a typical application.

INTRODUCTION

Since a couple of years, dielectric materials have become available with properties making them useful even for frequency ranges beyond the classical microwave bands (1, 2). An upper frequency limitation for resonators made of these ceramics does not basically exist. They can be applied to waveguide or microstrip devices operating at frequencies up to 100 GHz rather. It is predominantly for the manufacturers of the materials to provide low loss ceramics as to allow resonators to be made being a real alternative to waveguide cavities or half-wavelength planar microstrip resonators.

CHARACTERISTICS OF CERAMIC MATERIALS

Ceramic materials for use as dielectric resonators are characterized by their dielectric constant ε_r and losses $\tan\delta$. Typical values of these parameters range from ε_r equaling 10 to around 100, $\tan\delta$ should be in the order of $1\cdot10^{-3}$ or less. Manufacturers' specifications are seldom made for frequencies exceeding X-band. However, a severe frequency dependence exists for these values, and so the task arises to find suitable measuring procedures for permittivity and dielectric losses at millimetric wavelengths, i.e. for W-band in our case.

A frequency domain method has been chosen for this purpose being based on cuboid probes of the materials of interest which fill the entire cross-section of a WR-10 waveguide. If the frequency of the TE_{10}-wave propagating in the waveguide is swept over a certain range, the probes show characteristic resonances of the TE_{10p}-mode with p = n, n+1, n+2, ... The measurement of frequency and minimum transmission loss of at least two successive resonances allows the calculation of ε_r and $\tan\delta$.

A variety of commercially available materials have been investigated in this manner. Of particular interest were two barium titanates ATD-38 and -50 as well as a titania compound ATD-100, all provided by Ampex Corp., USA. With respect to possible waveguiding media, also low permittivity materials, i.e. PTFE and Polystyrene, have been tested. Table 1 shows the results for the frequency range of 80 to 100 GHz.

Material	ε_r	$\tan\delta$ $(\cdot10^{-3})$
ATD- 38	37.6	1.9
ATD- 50	48.1	1.7
ATD-100	98.2	1.0
PTFE	1.9	1.7
Polystyrene	2.5	1.2

Table 1: Dielectric properties of materials for resonators and waveguides measured in W-band

A comparison with low frequency values shows that the permittivity of dielectric materials varies only slightly with frequency, whereas losses suffer from a characteristic increase at higher frequencies. As an example, Figure 1 shows $\tan\delta$ of PTFE over a frequency range of more than 10 decades.

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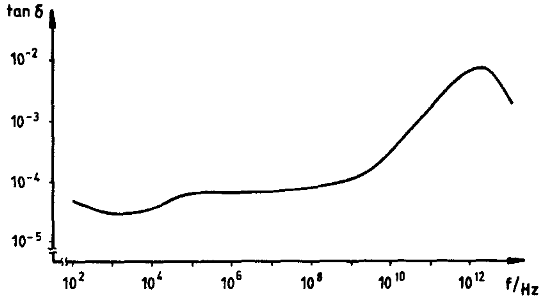

Figure 1: Frequency dependence of tan δ for PTFE

The reason for increasing losses at millimeter and submillimeter wavelengths are lattice vibration absorptions which rise to a maximum at about $1.4 \cdot 10^{12}$ Hz. These absorptions are caused by a plurality of resonances occurring in wavelengths with a certain relationship to the lattice dimensions of the material.

DESIGN OF HEM_{11p}-MODE RESONATORS

The starting-point of the design of dielectric resonators for the frequency range of 90 to 100 GHz was a theoretical investigation of a dielectric rod waveguide. All resonance modes which can exist in such a rod and consequently in a cylindrical resonator can be described by the eigenvalue equation (3). A numerical computation of this equation yields a mode chart giving the correlation of geometry and resonance frequency of a cylindrically shaped dielectric resonator in a graphic form. With this resource, resonators of different aspect ratio were designed and manufactured out of the aforementioned materials ATD-38, -50, and -100. Of particular interest for the measurement of Q factors and for later applications are the fundamental hybrid modes HEM_{11p}. A mode chart for HEM_{11p}-resonators of the materials used is shown in Figure 2.

The ordinate is marked by the eigenvalues u responding to

$$u = \pi D \sqrt{\frac{\varepsilon_r}{\lambda_0^2} - \left(\frac{p}{2H}\right)^2}$$

with D and H being diameter and height of the resonator and λ_0 being the free space resonance wavelength. The abscissa shows the normalized resonator diameter $\pi D / \lambda_0$.

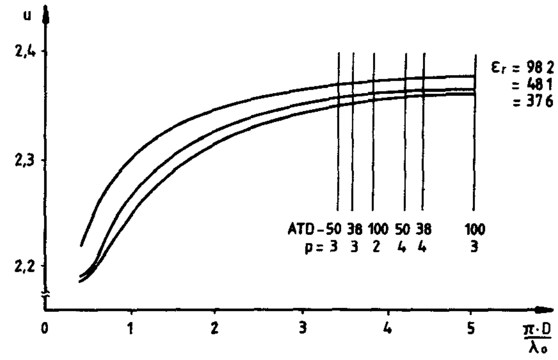

Figure 2: Mode chart for cylindrical HEM_{11p}-resonators

RESONATOR ABSORPTION CURVES

For the measurement of absorption curves of resonators with different aspect ratio a test fixture was built as shown in Figure 3. It consists of a dielectric image line made of PTFE on a gold-plated conducting surface. Plates of a hard and very low permittivity foam are placed at both sides of a section of the line. By varying the height of the plates, different air gaps t and therewith different coupling factors between line and resonators can be realized.

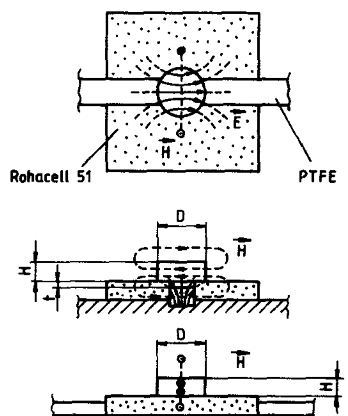

Figure 3: Test fixture for measurement of absorption curves

The cross-section of the image line is dimensioned in a way as to allow only the dipole-mode E^y_{11} being launched by the TE_{10}-mode propagating in an attached metallic waveguide WR-10 (4). With this precondition, in a cylindrical ATD-100 resonator with H = 0.32 mm and D = 3.85 mm positioned as shown in Figure 3, the excitation of three hybrid modes can be observed in the frequency range of 90 to 100 GHz: HEM_{112}, HEM_{132}, and HEM_{152}. The absorption curve is shown in Figure 4.

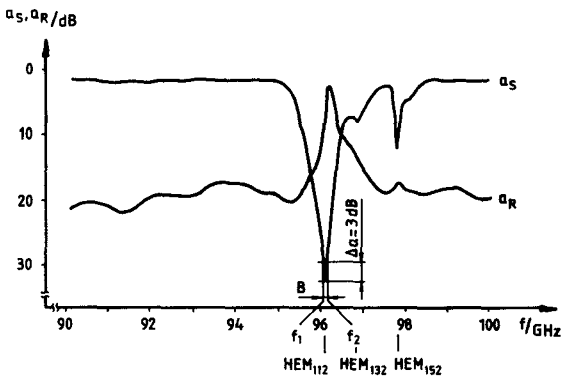

Figure 4: Absorption curve of an ATD-100 resonator

By a preceding calculation of the resonance frequencies using the mode chart, and by considering symmetry conditions and field configuration of the image line, these modes can be undoubtedly identified within the variety of theoretically existing modes. A difference between calculated and measured resonance frequency was observed, i.e. 1.3 per cent for the resonators of ε_r = 37.6 and 48.1, and 0.8 per cent for ε_r = 98.2. This effect is due to the fringing field of the resonators which effectively shortens the resonator's height H and thus leads to a higher resonance frequency.

EXAMINATION OF Q-FACTORS

The quality factor of dielectric resonators is mainly determined by two influences: dielectric losses, characterized by the material's tan δ, and radiation losses, predominantly depending on the shape and permittivity of the resonator. Therefore the "unloaded Q" of a dielectric resonator can be defined as

$$\frac{1}{Q_U} = \frac{1}{Q_M} + \frac{1}{Q_R}$$

where Q_M is the "material Q" and Q_R the "radiation Q". The unloaded Q holds for a resonator in free space. With the resonator being part of a waveguide or microstrip assembly, the value is reduced to the "loaded Q" depending on the coupling factor between resonator and surroundings.

With the described test fixture and the resulting absorption curves, individual unloaded Q factors have been calculated for a number of resonators. In order to simulate free space conditions to a sufficient approach, the air gap t was adjusted to yield maximum stopband attenuation a_S and minimum return loss a_R. Then the 3 dB-bandwidth $B = f_2 - f_1$ and resonance frequency f_R were measured. Table 2 gives the results of the calculation of Q_U according to

$$Q_U = \frac{f_R}{B}$$

Material	D/H	Q_U	mode
ATD- 38	4.6 4.3	475 497	HEM_{113} HEM_{114}
ATD- 50	5.0 4.6	531 563	HEM_{113} HEM_{114}
ATD-100	12.0 10.4	961 988	HEM_{112} HEM_{113}

Table 2: Unloaded Q of dielectric resonators of different D/H-ratio in the frequency range of 95 to 100 GHz

The measured unloaded Q values differ only slightly from the "material Q" defined as $Q_M = \tan\delta^{-1}$. This fact obviously indicates very small radiation losses for high permittivity resonators at millimetric wavelengths. Metallic shielding, which is necessary for dielectric resonators at lower microwave frequencies in order to prevent losses due to radiation, loses importance for the millimeterwave range.

APPLICATION

Still before exact examinations of Q-factors were carried out, a 96 GHz bandpass filter had been built as a first application (5). It consists of three cylindrical resonators of ATD-100 operating in the HEM_{119}-mode. They are spaced by polystyrene discs to realize the desired coupling factors. The filter element is fed by an E^y_{11}-mode image line of low-loss PTFE being attached to a fundamental-mode WR-10 waveguide. Figure 5 gives an impression of the assembled bandpass filter.

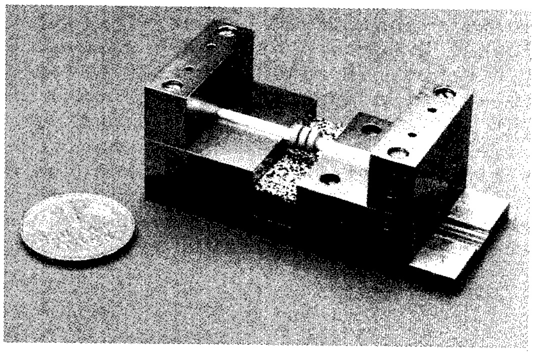

Figure 5: 96 GHz dielectric resonator bandpass filter

An insertion loss of around 2 dB was measured for the complete setup, i.e. waveguide transitions included, over a bandwidth of 1.5 GHz. Stopband attenuation is better than 30 dB for 96 ± 2.5 GHz. Generally, all data are within the expected scope of the theoretical calculation. Figure 6 shows the frequency response of the filter.

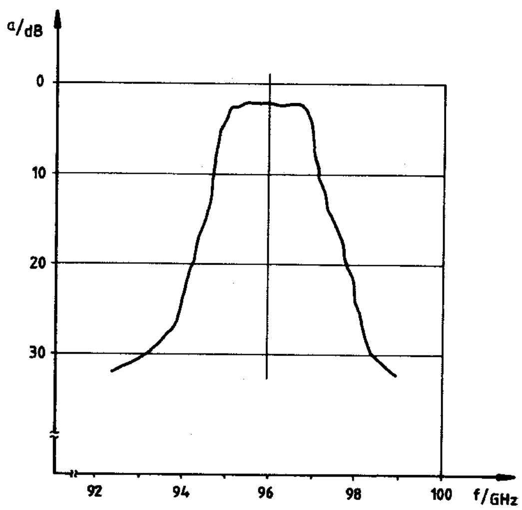

Figure 6: Frequency response of the bandpass filter

CONCLUSION

The availability and detailed study of low-loss, high permittivity dielectric materials and resonators have been important preconditions for their use in the millimeterwave range. Very promising applications in W-band have already been reported (5, 6). The influence of dielectric resonators on design and performance of millimetric components in waveguide as well as in planar and hybrid technology will doubtlessly increase in the years to come.

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