Investigation of Using the Harmonics of a Microstrip Ring Resonator Structure on Determination of Dielectric Properties

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Abstract — **Microstrip ring resonator structures are used in many conjunctions for determination of dielectric constant and dissipation factor of materials. In this paper, an experimental research of characteristics of a microstrip ring resonator was carried out. The aim of the research was to find out, if the harmonics of the resonance frequency could be used to accurate determination of dielectric properties. The research was carried out with five measurement structures, which included several two-port microstrip ring resonators. Results of the research offer essential information about determination of the dielectric properties by using microstrip ring resonator structures.**

Index Terms — **Dielectric constant, dissipation factor, harmonics, quality factor, ring resonator.**

I. INTRODUCTION

A microstrip ring resonator structure is often applied in many microwave circuits. Troughton [1] presented the first ring resonator application for determination of phase velocity and dispersive characteristics of a microstrip line in 1969. Since then, the microstrip ring resonator structures have been used to determine dielectric properties in function of frequency. E.g. [2] – [3].

Dielectric constant and dissipation factor of dielectric material can be measured at wide frequency range with single microstrip ring resonator structure instead of multiple measurement structures. The wide frequency range is obtained by using harmonics of the main resonance frequency. Using the harmonics may have effects to the determination accuracy. In this paper effects of the harmonics to the determination accuracy of a two-port microstrip ring resonator are investigated.

The two-port ring resonator structure includes feed lines, closed transmission line loop and coupling gaps. Resonance frequencies of a two-port microstrip ring resonator can be calculated with the equation:

$$2\pi r = n\lambda_g \,, \qquad (1)$$

where r is the mean radius of the ring, n is the number of harmonic and λ_g is the guided wavelength. (For more information, refer [1], [4])

The basic idea behind the determination values of dielectric constant, is to design the microstrip ring resonator structure to the certain main resonance frequency. The design is based on the estimated value of the dielectric constant. If the measured resonance frequency deviates from the theoretical value, the actual value of the material dielectric constant deviates from the estimated value. The actual material dielectric values can be calculated basing on the measured resonance frequency and the dimensions of the ring resonator structure. The dissipation factor tanδ can be calculated from the measured values of the -3dB bandwidth of the resonance frequencies. More information about determination and calculation method of dielectric properties using a microstrip ring resonator structure is presented in [5].

II. ANALYSIS

The function of the microstrip ring resonator structure cannot be completely explained by the equation (1). Effects of curvature, coupling gaps and fringing fields require use of more sophisticate solution. Those effects may also have a significance effect to determination of dielectric properties. In addition, an accurate mean radius of the ring resonator structure is difficult to determine and can cause error to the results.

An experimental research of characteristics of the microstrip ring resonator was carried out. The aim of the research was to find out, if the harmonics of the resonance frequency could be used to accurate determination of dielectric properties. The research was carried out with five measurement structures that included several two-port microstrip ring resonators. The main resonance frequencies of the resonators were 1,2, 3, 4, 5 and 6 GHz. The laminate material of the measurement structure was selected to be one FR-4 type printed circuit board material, which has relatively high dielectric losses compared to typical microwave materials. Connector interfaces of the resonators were implemented with SMAconnectors and specific holding blocks. The measurement structure is presented in fig. 1.

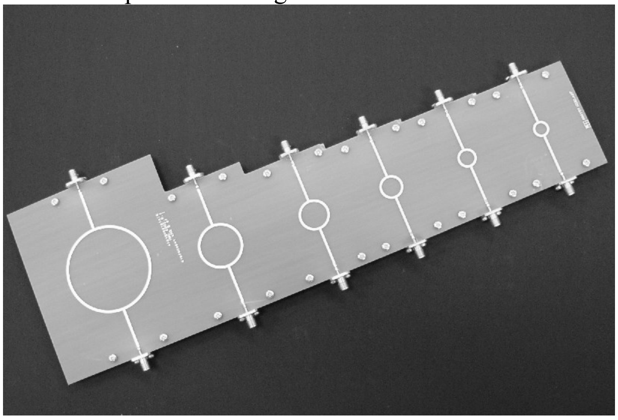

Fig. 1. The Measurement structure, which includes 1, 2, 3, 4, 5 and 6 GHz microstrip ring resonator.

A. The coupling gaps

Length of the coupling gap affects to the resonance frequencies of the microstrip ring resonator. With a small coupling gap, the fields of the ring resonator are noticeably disturbed. With larger coupling gap the fields of the resonator are less disturbed but losses will be higher in the coupling gap region. [4] The length of coupling gap has to be optimized. If the coupling is carried out as a loose coupling, the coupling gaps have negligible effects to resonance frequencies of the ring resonator.[6] The length of the coupling gaps can be chosen based on simulation results or based on earlier experiences.

B. The curvature effect and higher order modes

The curvature effect could affect noticeably to function of the microstrip ring resonator if substrate material with small relative permittivity and lines with small impedances are used. [2] With small impedance and permittivity, the width of the microstrip line becomes large and the mean radius of the ring is difficult to define. The curvature effect will be increased also if the mean radius of the ring is small.

The determination method of the dielectric properties used in FR-4 Epsilon-R modeling project does not take the curvature effect into account. Thus, possible effects of curvature were wanted to be eliminated in the experimental research and in the research project.

The TM_{110} is a dominant mode of the ring resonator of any width. The higher order modes TM_{nm0} can be supported with wider line widths [7]. The higher order modes will be excited when the line width reaches half the guided wavelength. The higher order modes of the microstrip ring resonator can be avoided if normalized ring width/ring radius $w/R< 0.2$ [4]. Normalized width/ring radius rations of the used ring resonators are presented in table I.

TABLE I. NORMALIZED WIDTH/RING RADIUS RATION

The main resonance frequency	The mean radius of the ring	w/r
1.0 GHz	26.309 mm	0.05
2.0 GHz	13.155 mm	0.10
3.0 GHz	8.769 mm	0.16
4.0 GHz	6.577 mm	0.21
5.0 GHz	5.262 mm	0.26
6.0 GHz	4.385 mm	0.30

C. The fringing fields

Effects of the fringing fields are increased if the mean radius of the microstrip ring resonator is small. The effects of the fringing fields cannot be taken into account in equation (1) or in magnetic wall model. The effects of the fringing fields can be avoided by using large mean radius of the ring resonator [4]. In the experimental research, the fringing fields might cause error at least with 4.0, 5.0 and 6.0 GHz ring resonators.

III. RESULTS

The frequency responses of the microstrip ring resonators were measured using the HP8720D network analyzer. The calibration of the network analyzer was carried out with a specific TRL-calibration kit. Thus, unwanted effects of the connector interfaces and feed lines were eliminated. The resonance frequencies of the all measurement structures were almost identical. The resonance frequency of the 6.0 GHz ring resonator deviated slightly more from the harmonics of the 1.0 GHz ring resonator than other resonators.

From the experimental measurements of the microstrip ring resonators, an increased difference can be noticed between the unloaded and the loaded quality factor of the microstrip ring resonators. If the size of the coupling gap region increased relation to the ring resonator, the difference between unloaded quality factor Q_0 and loaded quality factor Q_L will be increased. This phenomenon can be explained by increasing loading of the ring resonator caused by the coupling gap region. Differences of the loaded and the unloaded quality factors at 6.0 GHz are presented in table II.

TABLE II.

The main resonance frequency	Q_L at 6 GHz	Q_0 at 6 GHz
1.0 GHz	57.93233	60.89909
2.0 GHz	54.71071	60.79259
3.0 GHz	49.54292	58.30245
6.0 GHz	36.14265	47.84061

The dielectric constant and dissipation factor were calculated from the frequency response data based on method presented in [5]. Average values of calculated dielectric constant from different ring resonators are presented in fig. 3 and average values of dissipation factor in fig. 4.

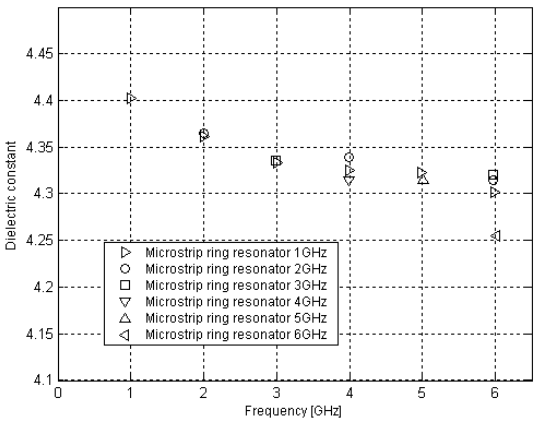

Fig. 3. The average values of the dielectric constant. (FR-4, RC ~40,3%)

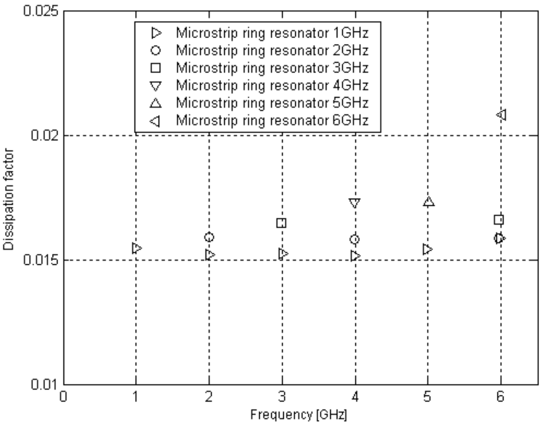

Fig. 4. The average values of the dissipation factor. (FR-4 RC ~40,3%)

From the figure 3. can be noticed that results of dielectric constant are quite similar expect value calculated from the 6.0 GHz microstrip ring resonator. Also at 4 GHz can be slightly deviation noticed. The deviation at 4 GHz is inside limits of the determination accuracy. Also values of dissipation factor are inside the limits of the determination accuracy and only noticeable error is at 6 GHz frequency. The increased deviation of dissipation factor in function of frequency can be probably explained by effects of the fringing fields, the curvature and the coupling gap region.

Despite the fact that effects of curvature, coupling gaps and fringing fields are not taken into account in the determination method used, the results measured with different size rings are very similar. At higher frequencies, differences will probably increase because of very small values of the mean radiuses of the ring. Basing on the experimental research, a conclusion can be made that use of harmonics makes possible to get accurate results at wide frequency range with single microstrip ring resonator structure.

V. CONCLUSIONS

The harmonics of the main resonance frequency of the microstrip ring resonator structure can be used to accurate determination of dielectric constant and dissipation factor of printed circuit board materials. The experimental research with one FR-4 type material shows the use of the harmonics to be a recommend way to measure dielectric properties in function of frequency using the microstrip ring resonator. Important notes are:

1) Using harmonics of the main resonance frequency, the mean radius of the ring resonator structure can be designed large enough to minimize problems caused by curvature effect, coupling gaps, determination of the mean radius and fringing fields.

2) If the size of the coupling gap region is increased relation to the size of the microstrip ring resonator, the difference between unloaded and loaded quality factor will be increased.

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