On the Package Design Used for Material Characterization of LTCC in Millimeter-waves

Vasily Kondratyev, Kari Kautio and Markku Lahti
VTT Technical Research Centre of Finland
P.O. Box 1100, FI-90571
OULU, Finland

***Abstract*-Radiation losses being significant in millimeter-waves decrease the accuracy of estimation of low temperature co-fired ceramics (LTCC) properties obtained with the aid of a microstrip resonator. To resolve the problem, it is suggested to use stripline resonator, and important design rules that must be kept in mind while designing test structures for material properties characterization of LTCC in millimeter-waves are formulated and experimentally verified.**

I. Introduction

Material characterization method that employs the measurement of the transmission coefficient of a planar resonator is certainly not new to microwave engineers. Several sources, including Hoffman [1], discuss the theoretical background of this technique in details. However, practical challenges can arise while approaching at necessity to characterize low temperature co-fired ceramics (LTCC) system in broad millimeter-wave band. Information in Hofmann indicates that on the base of a microstrip resonator accurate results can be obtained in rather limited band of 1-18 GHz. The higher frequency the stronger radiation occurs. The fact leads microwave engineers to use stripline resonators for testing in millimeter-waves. As a result, the test structure becomes more complex and the design rules are not that obvious as could be seen at first glance. To anticipate a little, the main tradeoff to be solved is to provide the consequence of resonances as close as possible and, on other hand, to suppress the package modes up to the highest frequency of concern.

The report is to discuss the main ideas of stripline package design for millimeter-wave material characterization of LTCC. Experimental verification is also given and discussed.

II. Design Guidelines

A. General Idea

The total losses of stripline consist of conductor losses and dielectric losses. The former depends on square root of frequency the latter is directly proportional to frequency. If the loss tangent is considered to be frequency independent then it is possible to separately extract the loss values having the total losses at only two frequency points. However, usually the loss tangent depends slightly on frequency. In order to minimize the effect it is better to shift the first resonant frequency of test structure to C-band or even to S-band. Then the resonances appear so close to each other that the loss tangent could be considered as independent on frequency. The drawback of such an approach is quite obvious – the resonator becomes rather lengthy. So does the package.

The main procedure consists of several steps. First, the transmission coefficient of the resonator is measured. The information allows us to determine unloaded Q-factor and the total losses at every resonance frequency (the details of the technique are in Hofmann [1]). Considering first and second resonances, the conductivity of paste and the loss tangent of LTCC can be extracted with ease. Taking into account that the conductivity of paste does not depend on frequency the loss tangent of LTCC can be obtained for millimeter-wave band.

B. Type of resonator

It is customary to use a ring resonator, and certainly it demonstrates its value in practice since there are no open ends, and dielectric permittivity can be determined with high accuracy without numerical calculations. On other hand, the ring resonator occupies rather large area and, being placed between two grounds (stripline structure), plane modes can be excited starting from relatively low frequencies and mask the transmission coefficient of the resonator. No doubt, a half wavelength resonator takes significantly less area but suffers from end effects. However, it was shown in [2] that the open-end effect can be easily removed from consideration by measuring two identical straight resonators of different lengths. But is it possible to produce two identical enough resonators in order to provide the accurate estimation of the dielectric permittivity? It was discussed in [3] that there are several sources that increase the tolerances of high frequency behavior of LTCC structures. The sources are conductor pattern resolution and tolerances, deviation of layer thickness and alignment accuracy between various layers. As a result, it was supposed that the comparison between the two resonators can be unjustified. However, later experimental verification has showed that the test structures are repeatable enough to accurately determine the dielectric permittivity of LTCC by the comparison of two resonators. Also simple estimations show that the two half wavelength resonators occupy less area than the ring resonator. Moreover, sometimes it could be difficult to find one large area to place the ring resonator although smaller places in different parts of substrate are available. It is often the case when the test structures are manufactured together with other microwave devices.

To sum it up, the half wavelength resonator is appropriate structure for testing LTCC losses in millimeter-waves. However, to avoid numerical calculations two half wavelength resonators are required to estimate accurately dielectric permittivity of LTCC substrate. The latter is not the subject of this paper.

C. Excitation type

Generally, there are two possibilities to form coupling between stripline resonator and coplanar contact pads required for measurements. First, there could be an overlap between the stripline resonator and coplanar feed lines. Second, a via connects coplanar feed line to stripline. Then the coupling is just a gap in stripline. The latter is chosen in order to avoid the influence of coplanar discontinuity on the stripline resonator. It is necessary to mention that the via used for connecting coplanar and stripline transmission lines is not grounded at both ends, and, as a result, it operates as a sort of antenna exciting the package electrical modes. They depend on planar size of the package - the larger package the lower dominant electrical mode. That is why special attention must be spent to suppress the generation.

D. Package configuration

Taking into account all above discussed one may come to the configuration of the test structure shown in Fig.1. However, a few lines must be spent to explain the details. First, it is wise to move the dominant electrical mode of the package out of frequency band considered. If the upper frequency is too high then there is a possibility to approach to LTCC technology limits. For example, the critical via pitch is 2.5 times of the via diameter. It means it is hard to manufacture the package with “a” size (see Fig.1) narrower than 500 µm pitch if 100 µm vias are used. Then for A6M LTCC system with dielectric permittivity of 5.7 the dominant frequency can theoretically be shifted to 130 GHz. In practice, the upper frequency of 90-100 GHz is well achieved. Second, not to disturb microwave current flowing under/up signaling line in ground planes, the package must be at least 3 times wider than resonator width. These two sometimes contradictory requirements lead us to form a resonator chamber and an input waveguide. The resonator chamber is more than three times wider than the resonator.

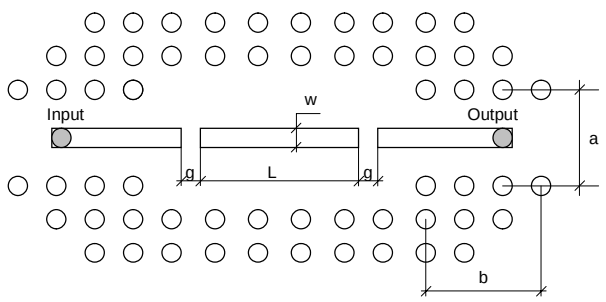

Fig. 1 The view from top of the center conductor layer

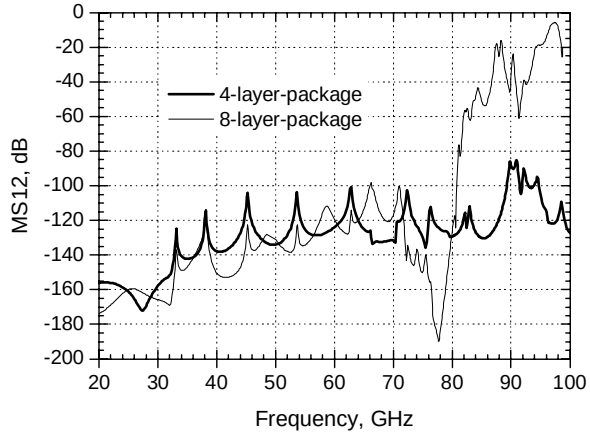

Fig. 2 Simulation characteristics of packages

The input waveguide is so narrow as to place inside only input via to connect coplanar pads to stripline. Note the longer the input waveguide (size “b”) the better damping of the package modes. Also it is necessary to provide multiple connection between top and bottom ground planes, the via pitch being one tenth of the highest frequency considered.

It is worth mentioning that it is always better to avoid symmetry and parallelism while design the package.

E. Number of layers

The choice of the number of LTCC layers depends mainly on three factors. First, the width (usually 50 Ω line) of resonator should not be less than 100 µm in order to obtain reliable/repeatable results. Second, in order to avoid short circuit due to possible conducting paste spreading during lamination the coupling gap should be larger than 100 µm.
Third, one should remember that the thicker substrate the lower dominant magnetic mode occurred between two ground planes. Thus, it limits the upper frequency of the characterization band. So does electrical mode as it was mentioned above. To illustrate phenomena the transmission coefficient of “quasi-open structure” – same package but there is no resonator inside - was calculated for A6M LTCC. The simulation results for 4 and 8 layer packages are shown in Fig.2. It is necessary to point out that the 8-layer-package is better for manufacturing and testing since the 50-Ohm-line is wider comparing to the 4-layer package. As a result, unloaded Q-factor of the resonator is higher. Moreover, the same coupling coefficient is achieved at the larger value of the gap. To put in other way, the repeatability of the 8-layer-package is higher than of 4-layer-package. Nevertheless, in higher frequencies, 4-layer package should be used. As one can see in Fig.2 the noise after 80 GHz will mask the resonator performance if the 8-layer-package is designed. Other interesting observation is that the electrical modes being of rather low level are approximately the same for both packages. It clearly proves that high frequency noise is caused by magnetic modes.

EXPERIMENT AND DISCUSSION

The goal of the experimental investigation is to determine dielectric and conductor losses of commercially available A6M LTCC system [4]. The upper frequency of the band considered is 100 GHz. The 4-layer package was used. Since the 50-Ohm-line is about 0.14 mm the package was designed without chamber. The width of the package is about 0.6 mm. The resonator length is 12.6 mm. The lowest resonance frequency is about 4.78 GHz. It allows us to check our estimations by comparison with data provided by manufacturer. Also, in low frequency there is the best signal-noise-ratio due to lack of the package ringing. Three test resonators were manufactured on the same LTCC substrate. To control the package ringing "quasi-open structure" were also added. The measurements of test structures allow us to determine the total losses at the resonance frequencies up to 90 GHz with the step of 4.78 GHz. Then taking the values of the total losses at first two resonances at 4.78 GHz and 9.56 GHz (see Fig.3) the dielectric losses and the conductivity of gold paste were obtained. The estimation results for first two resonances are given in Table 1. Then taking into account that the conductivity of gold paste is frequency independent the loss tangent of A6M was determined in broad millimetre-wave band. The results are shown in Fig.4. They are in good agreement with data provided by manufacturer [4].

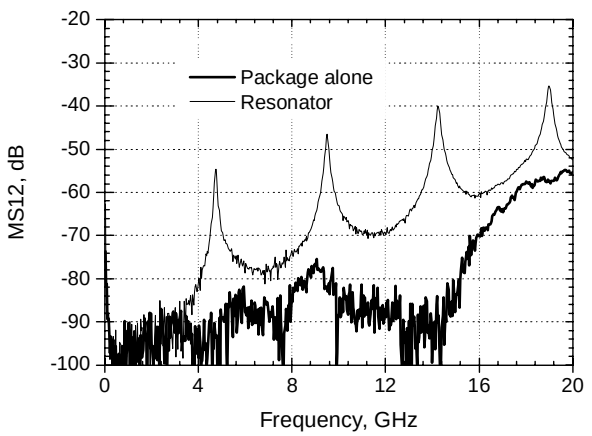

Fig. 3 Transmission coefficient of the package alone and with the resonator

TABLE I
LOW FREQUENCY PARAMETERS

Sample	α_{tot}, Np/m		σ, S/m*10^7	Tanδ 10^{-3}
	f_{01}, GHz	f_{02}, GHz		
1	4.78	9.56	1.81	0.75
2	4.78	9.52	1.87	1.03
3	4.76	9.51	1.81	0.82

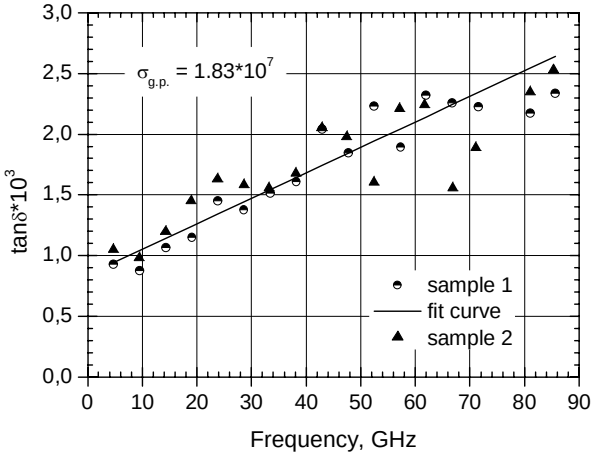

Fig. 4 Loss tangent versus frequency: experimental data and approximation

As one can see there is slight frequency dependence on the frequency of the dielectric losses. Nevertheless, even at 90 GHz the loss tangent is rather small. On other hand, the experiment revealed that the conductivity of the gold paste is rather low. It is less than half of the bulk conductivity of gold. One option to decrease microwave losses is to use silver paste for manufacturing printed conductors.

III. CONCLUSION

The design of the test structure for LTCC material characterization is described. It was shown that the test structure is quite predetermined by certain parameters, the main one being the highest frequency of the characterization band considered. The experimental results are in good coincidence with the data obtained by "split cylinder method".

ACKNOWLEDGMENT

The presented work is done in the frame of MEMSPACK research project. MEMSPACK is a collaboration between IMEC, VTT, FhG-ISiT, Univ. Perugia, FBK institute, IEMN-CNRS and MEMS TC (www.memspack.eu). MEMSPACK receives financial support from the European Commission in the FP7-ICT programme, under the grant agreement nr. 223882.

REFERENCES

[1] R. K. Hoffmann, *Handbook of microwave integrated circuits*, Artech House, 1987, pp. 205-210.

[2] T. C. Edwards and R. P. Owens, "2-18-GHz dispersion measurements on 10-100-Ω microstrip lines on sapphire," *IEEE Trans. Microwave Theory Tech.*, vol. 24, pp. 506–513, Aug. 1976.

[3] V. Kondratyev, M. Lahti, and K. Kautio, "On the LTCC characterization in millimeter-waves, " Microwave Conference (EuMC), 2010 European 2010 , Page(s): 156 - 159

[4] J. Henry, B. Gardner, E. Graddy, E Stadnicar, and A. Shaikh, "Enhanced High-Frequency LTCC for RF and Microwave Packaging," Available: http://www.ferro.com/