

# Materials and Transmission Line Measurements Comparing HTCC and Thick Film Alumina

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**Abstract:** HTCC and thick film based packages continue to be used extensively in commercial, industrial and military products. However, detailed and comparative measurements of their material properties are difficult to find. Moreover, transmission line measurements showing and comparing their insertion loss is even scarcer. Therefore, this work remedies this deficiency by showing detailed measurements of HTCC ceramic and alumina thick film with extracted materials data from 1-30GHz and transmission line insertion loss for microstrip. The resulting data will be useful for designers and technology managers who must make critical decisions about which materials to select for their product development.

## I. Introduction

Design of most any product at microwave and millimeter-wave frequencies requires detailed knowledge of the dielectrics materials used. This is especially true if the dielectric materials are used to support transmission lines or other structures with high frequency signals. The parameters of most interest for design of high speed circuits are the dielectric constant and loss tangent. The reason is those parameters affect the line impedance and line loss of transmission lines.

As a result, detailed methods have been developed to characterize dielectrics. One method, that was developed by Gordon Kentk, J. Baker-Jarvis, and M.D. Janezic, uses a split cavity resonator that accepts a dielectric sample [1, 2, 3]. An image of such a dielectric resonator developed and used in the RLS Design, Inc laboratory is shown in Figure 1. In this technique, the cavity generates a high Q resonance which is changed by a dielectric sample placed between the two cavity halves. The dielectric constant is determined by the change in resonant frequency. At least one industry specification has been developed by the IPC

standards group that is useful and contains a detailed description of this method [4].

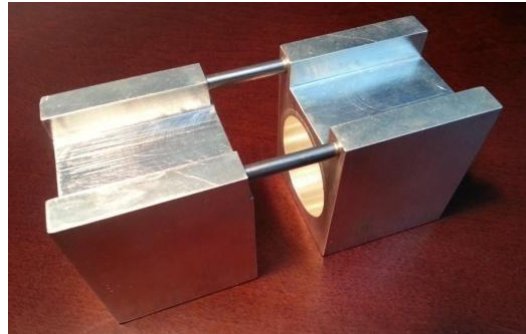


Figure 1. Image of the cavity test fixture used to characterize dielectric materials.

Other methods have been developed to measure dielectric materials such as the ring resonator technique [5]. It uses a circular transmission line that is lightly coupled to input and output transmission lines. Figure 2 shows an image of a ring resonator printed on an alumina thick film substrate that is prepared for probe testing at high frequencies.

Many other methods have been developed to measure dielectric materials such as techniques that use waveguide filled with dielectric samples [6, 7]. A useful overview of a few of the methods is contained in [2] and [5]. For our investigation we will focus on the ring resonator method and on transmission line measurements.

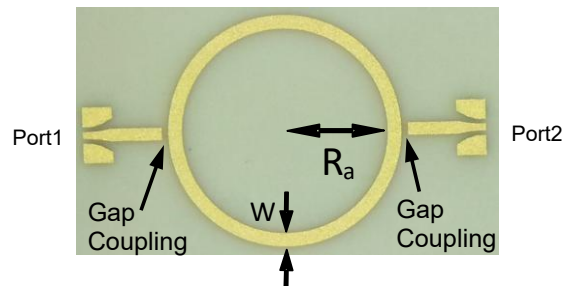


Figure 2. Image of a ring resonator.

## II. Ring Resonator Electrical Model

An important step in using ring resonator tests for dielectric material characterization is to choose the modeling or analysis method. For the ring resonator approach, a simple but accurate electrical model can be developed. In the model, the circuit is represented electrically as a set of transmission lines with input and output coupling capacitors. Figure 3 shows the model. The transmission lines of length  $L$  simulate the ring itself while the capacitors  $C_1$  and  $C_2$  represent the coupling at the input and output of the ring.

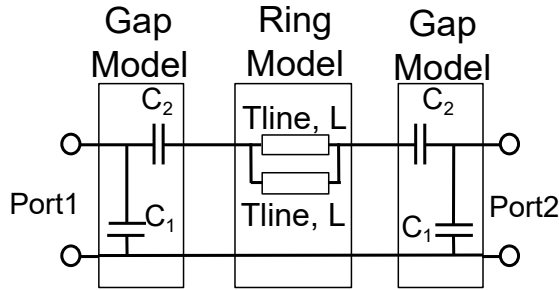


Figure 3. Electrical model of the ring resonator.

The resonances that occur in the ring can be predicted by realizing that the resonance occurs when each of the line sections satisfy  $L = \pi R_m$  where  $R_m = R_a + W/2 =$  the approximate mean radius of the ring. Since the resonant lines,  $L$ , are symmetrically terminated they will resonate at half wave frequencies so that,

$$\frac{n\lambda}{2} = \pi R_m \quad (1)$$

Where:

$\lambda$  = the wavelength of the microstrip line mode  
 $R_m$  = mean radius of the line =  $R_a + W/2$   
 $n$  = the resonance number of the  $n$ th resonance  
 However, if we recall that

$$\lambda = \frac{c}{f\sqrt{\epsilon_{\text{reff}}}} \quad (2)$$

Where:

$\epsilon_{\text{reff}}$  = transmission line effective dielectric constant  
 $= 3 \times 10^8$  m/s = speed of light in free space

It is possible to re-arrange (1) and (2) to yield the equation for the resonant frequency

$$f_n = \frac{nc}{2\pi(R_a + \frac{W}{2})\sqrt{\epsilon_{\text{reff}}(f)}} \quad (3)$$

and

$$\epsilon_{\text{reff}}(f, n) = \frac{nc}{2\pi(R_a + \frac{W}{2})f_n} \quad (4)$$

Using (4) and any standard transmission line calculator, it is possible to obtain the dielectric constant of the substrate material.

## III. Ring Resonator Fabricated Substrates

Substrates were fabricated in HTCC Alumina Ceramic (Courtesy of AMATEK General Ceramics) and in thick film ceramic (Courtesy of CMS Circuit Solutions, Inc.). The circuits are shown in Figure 4. The substrates are

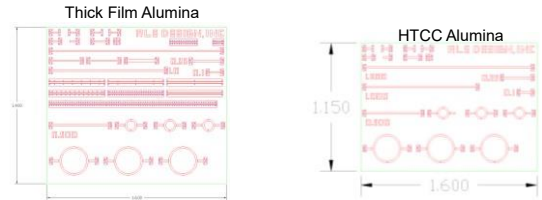


Figure 4. Thick film alumina and HTCC Alumina circuits used in the electrical testing.

15mil thick ceramic and contain both microstrip and coplanar waveguide transmission lines. The substrates use standard processing for the metals and dielectrics. The thick film boards use 96% alumina.

## IV. Measurements and Determination of Dielectric Constant and Loss Tangent

Instead of using (3) and (4) for determining the dielectric constant, a more efficient method is to use the model shown in Figure 5 and vary the dielectric constant and loss tangent of the substrate used in the transmission line model for transmission lines,  $L$ . This method was used and the full model is shown in Figure 5. Note how

C1=0.0173  
 C2=0.005  
 L1=376.9  
 MSUB

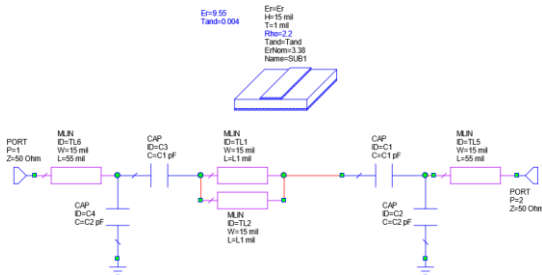


Figure 5. Full electrical model for the ring resonator.

the model includes the section of transmission line at the input and output ports to represent the length of transmission line at the input and output.

The ring resonators were subjected to electrical testing at the University of California at Davis. The testing was conducted using a probe station with high quality ground-signal ground probes with an electrical bandwidth to 50GHz. The system was calibrated using a thru reflect-line (TRL) calibration method [8]. Figure 6 shows an image of one of the ceramic substrate and probes used for testing.

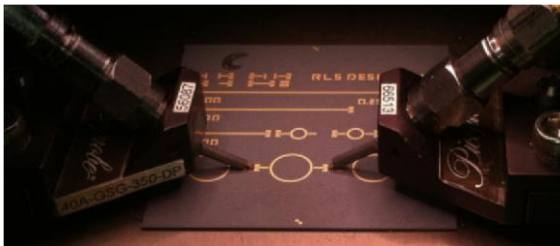


Figure 6. Image of the material under electrical testing at a probe station and vector network analyzer.

Measurements were first conducted on the alumina thick film circuits. The results are shown in Figure 7. The measured data are in the thin black dashed lines and the darker black line is the model. Note how the measured and modeled results have good agreement to 20GHz. The result of this test is that the dielectric constant is approximately 9.55 and the loss tangent is predicted to be approximately 0.004. The dielectric constant value is very close to the published data for dielectric constant varies from approximately 9.55 to 9.6 so that this result shows excellent agreement. The predicted loss

tangent is higher than the published of 0.0004. However, that published value is for a frequency of 1MHz. Also, at these low levels of loss tangent, the ring resonator method is not a high fidelity method due to the conductor loss.

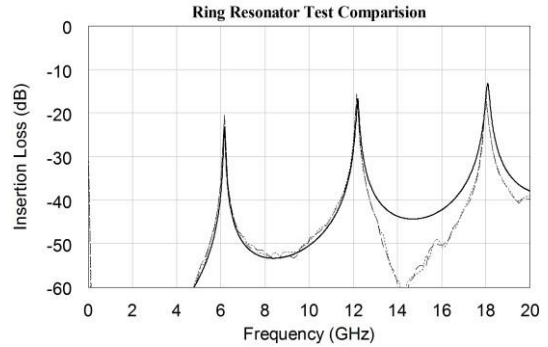


Figure 7. Comparison of measured and model data for the Alumina Thick Film Ring Resonator.

The HTCC alumina substrates were also subjected to electrical testing and modeling. The results are shown in Figure 8. The figure shows model data in the solid black line and the

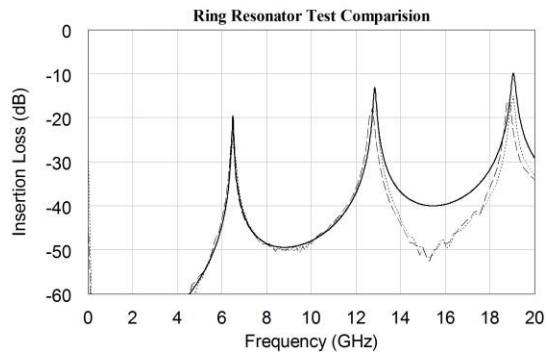


Figure 8. Ring resonator measured and model data for the HTCC alumina substrates.

measured data are the thin black dashed lines. The agreement is excellent. The result from the model is that the dielectric constant is approximately 8.517 and the loss tangent is approximately 0.004. It is also interesting to note that the measured data shows that the HTCC ceramic has high Q resonances that are similar to the HTCC alumina. The high Q resonances are an indication of the low loss of the material.

## V. Transmission Line Measurements

In addition to the ring resonator measurements, transmission line measurements were conducted. Transmission line measurements are important because transmission lines are what are used by designers in their work of developing product. Therefore, they often judge the ability of a material set or dielectric material by its transmission line loss and comparing to familiar materials. Also, transmission line data is a useful tool for designers who must budget such things and gain and noise figure in their products. The insertion loss per unit length can be used directly by the designers in their product development.

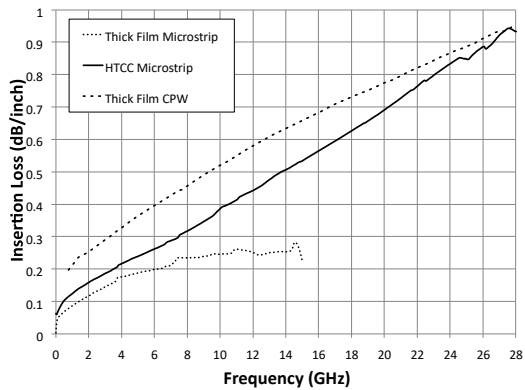


Figure 9. Measured transmission line loss for HTCC in microstrip and thick film in microstrip and thick film.

The measured results of the transmission line testing are shown in Figure 9. What is interesting to note is that the HTCC and thick film microstrip lines have insertion that is comparable and that the HTCC microstrip line loss is lower than the thick film insertion loss for coplanar waveguide lines.

## VI. Conclusions

The results of this testing show that HTCC Alumina material has comparable insertion loss characteristics to thick film alumina. This means that designers can use HTCC alumina for product designs in microwave and millimeter-wave frequencies.

## References

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