ROGERS CORPORATION

Design

General Information of Dielectric Constant for RT/duroid® 6010.2LM and RO3010™ High Frequency Circuit Materials

Abstract

This text is a supplement to a paper titled "General Information of Dielectric Constants for the Circuit Design using Rogers High Frequency Materials". This paper can be found at http://www.rogerscorp.com. It is intended to promote better understanding of the Specification Dk and the Design Dk as shown on the Rogers Corporation datasheets and Product Selector Guide.

Rogers Corporation uses the X-band clamped stripline resonator test method described in IPC-TM-650 2.5.5.5c as the specification method for the dielectric constant of a high frequency material. This test method has a high degree of repeatability as well as excellent performance for internal quality control to ensure the manufacturing of consistent high frequency laminate products. However as mentioned in the previously referenced paper, this test method has some potential issues with anisotropy and compressive modulus of the material under test. Due to these properties being different in the RT/duroid® 6010.2LM and the RO3010™ laminates, there are differences to be accounted for regarding the results of the clamped stripline test as compared to other test methods. Knowing these differences will help the designer understand the electrical performance of these materials with different circuit designs and applications.

Introduction

The X-band clamped stripline test will give results of Dk and Df (dissipation factor) for a material under test. These results may or may not correlate well to the same material used in a microstrip application, as an example, where the electromagnetic environment of the circuit application is very different from the stripline test.

Other test methods that will be discussed are the Full Sheet Resonator (FSR), Split Post Dielectric Resonator (SPDR) and differential phase length method. There is no known good correlation between the clamped stripline test and these other test methods. However in the case of the RT/duroid 6010.2LM and the RO3010 laminate which have a mean Dk value that is very similar in the clamped stripline test, they will generally have a Dk value that is significantly different when tested with these other methods.

Comparisons between Clamped stripline and other test methods

A simple graphic representation of the clamped stripline test method is given in figure 1.

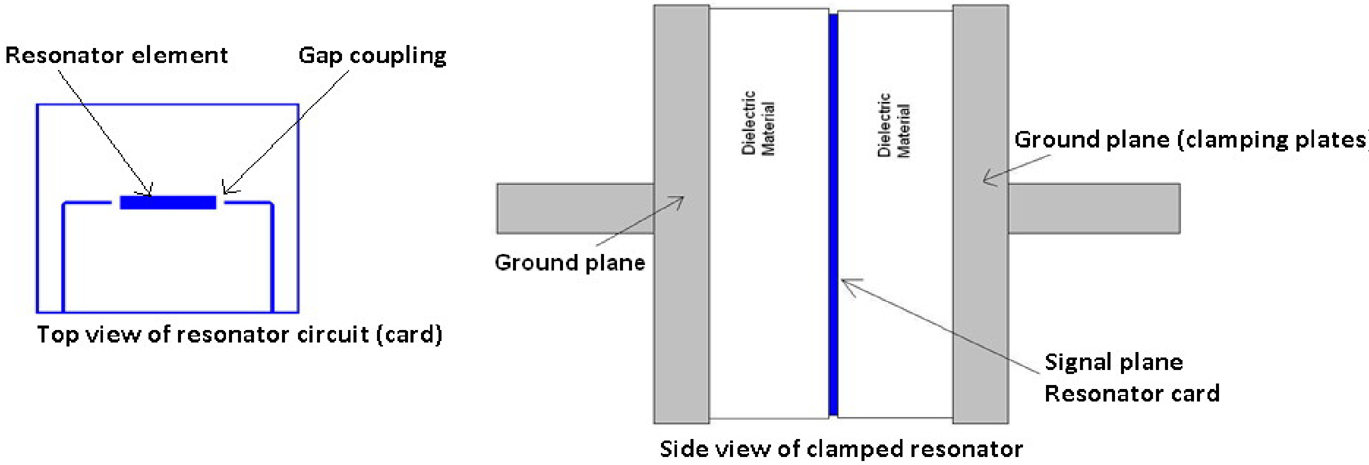

Figure 1. X-band clamped stripline resonator test showing dielectric material under test

The material under test is sandwiched between two clamping plates that are held under pressure. These plates act as the ground planes for the clamped stripline structure. The resonator circuit is relatively thin, designed to be loosely coupled (gap coupled) and the element is 2 wavelengths, in physical length, at 10GHz for a particular material. The electric fringing fields in the gap coupled area are where the concern for X-Y plane anisotropy can be an issue.

Another factor affecting the test is how well the sample under test will conform to the resonator circuit image. The copper circuit image on the resonator circuit has some height above the substrate. If the material under test is very rigid then it will not conform around the resonator circuit features as well and more entrapped air will cause the Dk value to differ. A very soft material (low compressive modulus) conforms quite well to the circuit image with minimal amount of entrapped air. The copper surface roughness also has an effect. The material under test had been laminated as a copper clad laminate and then all of the copper etched off prior to this test. The mirror image of the copper surface roughness is now the substrate surface roughness. When a copper is used which has a rougher surface this will translate to more surface area of the material under test. More surface area has the potential to have more entrapped air which can lower the reported Dk value. However, in the case of the materials discussed in this paper, they are relatively soft and the surface topology can compress when tested under pressure and the effects of the copper roughness are lessened. Also the two materials discussed here use the same copper so any reported Dk differences of these materials are not typically due to the copper effect.

Another test method that is often used is IPC-TM-650 2.5.5.6 Full Sheet Resonance test. This method does not have the issue of entrapped air or sensitivity to anisotropic material properties, as does the stripline test. This method uses the copper clad laminate as a parallel plate waveguide and determines the dielectric constant from resonant peaks established by standing waves corresponding to the physical size of the laminate. These standing waves typically occur at low frequencies due to the size of the panel under test.

Therefore the FSR test is usually considered a low frequency test, which evaluates the Dk properties of the laminate in the Z axis (thickness axis) only. A graphic representation of this test method is shown in figure 2.

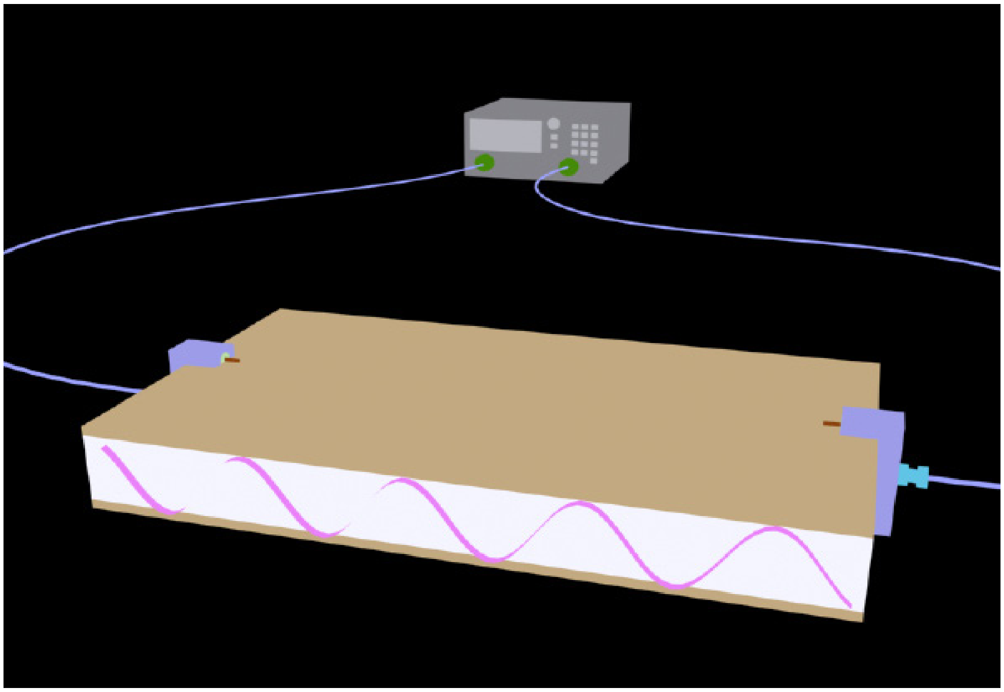

Figure 2. Copper clad laminate under test using the FSR test method

The clamped stripline resonator mostly tests the Z axis of the material as well; however the gap coupling in the stripline test can be sensitive to X-Y plane electrical properties.

Most PTFE materials which have a lower Dk value do not have significantly different electrical properties in the Z axis versus the X-Y plane. Or in other words, they are not significantly anisotropic for Dk properties. By the nature of what is used to raise the Dk in PTFE materials to a higher value, there is a pronounced anisotropic effect with higher Dk PTFE materials.

When comparing test data of the RT/duroid 6010.2LM and the RO3010 laminate, one will find that the mean Dk value of these materials in the stripline test (Specification Dk) is very similar and is around 10.2. However when the same materials are tested in the FSR test, there is a significant difference in the Dk value. There are multiple causes for this phenomenon. One issue is that the Dk value for the X-Y plane of the RT/duroid 6010.2LM is much higher than the X-Y plane Dk of RO3010 laminate. This difference will have no effect on the FSR test results, however it will have an effect on the stripline test to raise the reported Dk value. A balancing effect for the RT/duroid 6010.2LM for the Dk value in the stripline test is the fact that it has a higher compressive modulus and therefore it has more entrapped air. The entrapped air lowers the Dk value which offsets the rise due to the anisotropic effect. The FSR test is not affected by the X-Y plane Dk differences as well as the compressive modulus differences between the two materials, whereas these differences do impact the results of the stripline test.

The Z axis Dk value from the differential phase length difference method for the RT/duroid 6010.2LM is approximately 10.7 and the RO3010 laminate is about 11.2. These numbers are considered the Design Dk for these materials. The DK numbers for these materials may be slightly lower when using the FSR test method however there is relatively good agreement. Both of these methods will test the Z axis of the material; however the differential phase length method is a higher frequency test. These numbers can be seen in figure 3, where the SPDR (split post dielectric resonator) method will test the material in the X-Y plane.

Material	Clamped Stripline Specification Dk	FSR (Z-axis) Average Dk	SPDR (X-Y Plane) Average Dk
RO3010	10.2	11.00	12.10
RT/duroid 6010.2LM	10.2	10.60	13.33

Figure 3. FSR, Differential Phase length and SPDR test results.

The comparison between the FSR and SPDR results are a good generality for anisotropic effects of the material. It can be seen that the RT/duroid 6010.2LM substrate has much more anisotropic behavior than the RO3010 material, as previously mentioned.

There have been several cases where customers report an apparent Dk value for RT/duroid 6010.2LM substrate of approximately 11.4 and the same material will be reported by another customer with a different application as 10.8. This is likely due to one application having electromagnetic fields using the X-Y plane more so than the other application which is using mostly the Z axis properties of the material. Typical applications which will utilize more of the X-Y plane Dk properties of a material would be edge coupled features such as some couplers or filters. The applications which use primarily the Z axis Dk properties are single ended transmission lines, stub tuning structures and some stepped impedance filters. There are applications which will use the Z axis in combination with the X-Y plane properties to a varying degree based on the design. An example of this type of application could be a microstrip ring resonator with gap coupling. The gap coupling is sensitive to the X-Y plane properties and the resonator is more Z axis related.

Conclusion

The X-band clamped stripline test method is an IPC standard used to test raw circuit materials to a specification Dk value. This is an excellent test for repeatability and quality/process control for a laminate supplier. However this test has some sensitivity to entrapped air between the material samples during test. It also has sensitivity to the compressive modulus of the material as well as the anisotropic properties of the material. In the case of the RT/duroid 6010.2LM and the RO3010 laminate, they both have the same target specification Dk per the stripline test, however their compressive modulus and anisotropy effects are very different. Due to these differences, other test methods which are not sensitivity to modulus and anisotropy effects will report dissimilar Dk values between these two materials. Understanding that the X-Y Dk values for these materials are much higher than the Z axis value is important in understanding differing apparent Dk values when considering edge coupled circuit designs. This document is in support of another document which can be found at http://www.rogerscorp.com and is titled "General Information of Dielectric Constants for the Circuit Design using Rogers High Frequency Materials". This paper has tables of Dk information using other test methods regarding RT/duroid and RO3010 laminates, as well as other Rogers High Frequency laminates.

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