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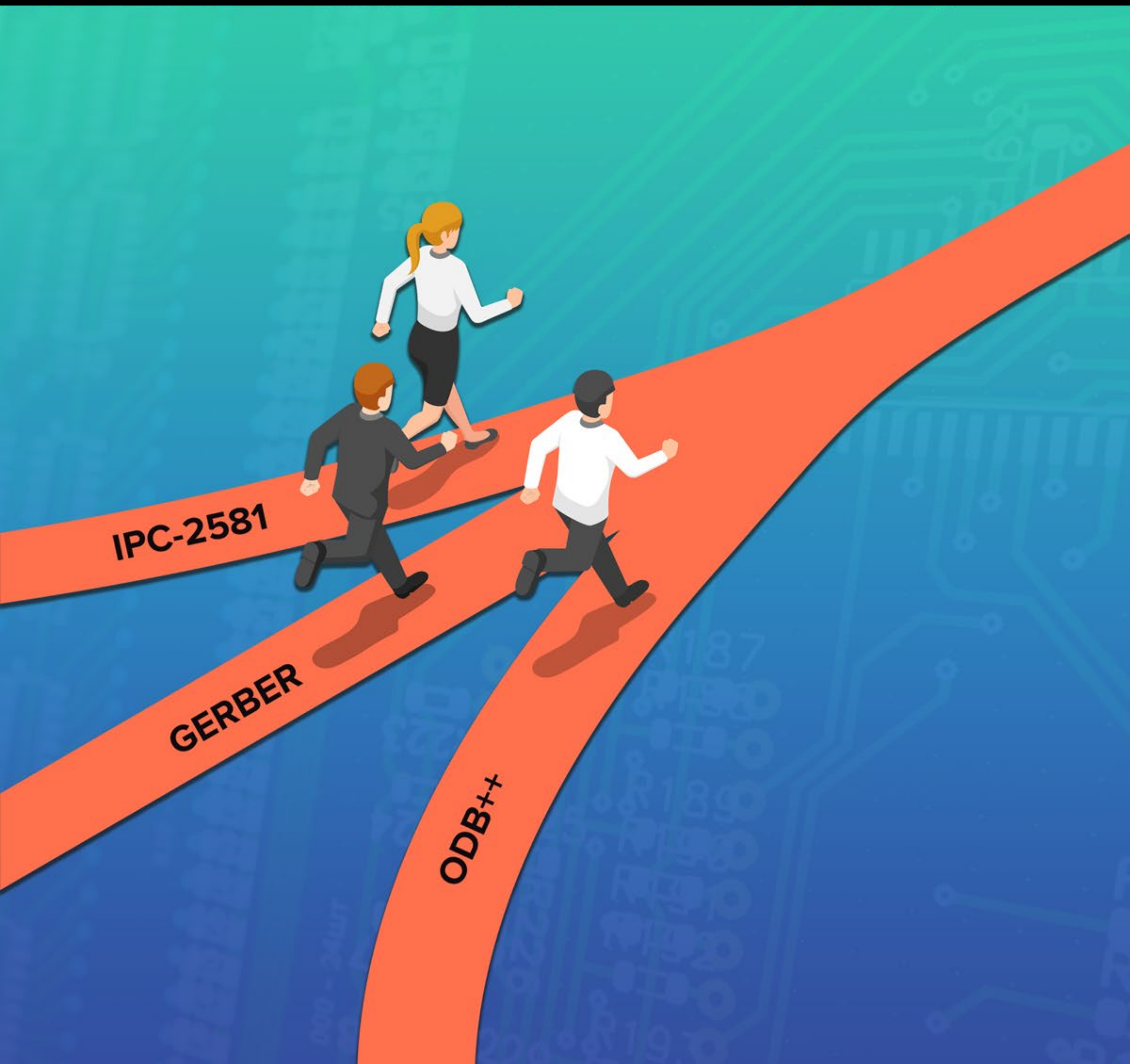


Overview of Test Methods to Determine Material Dk and Df

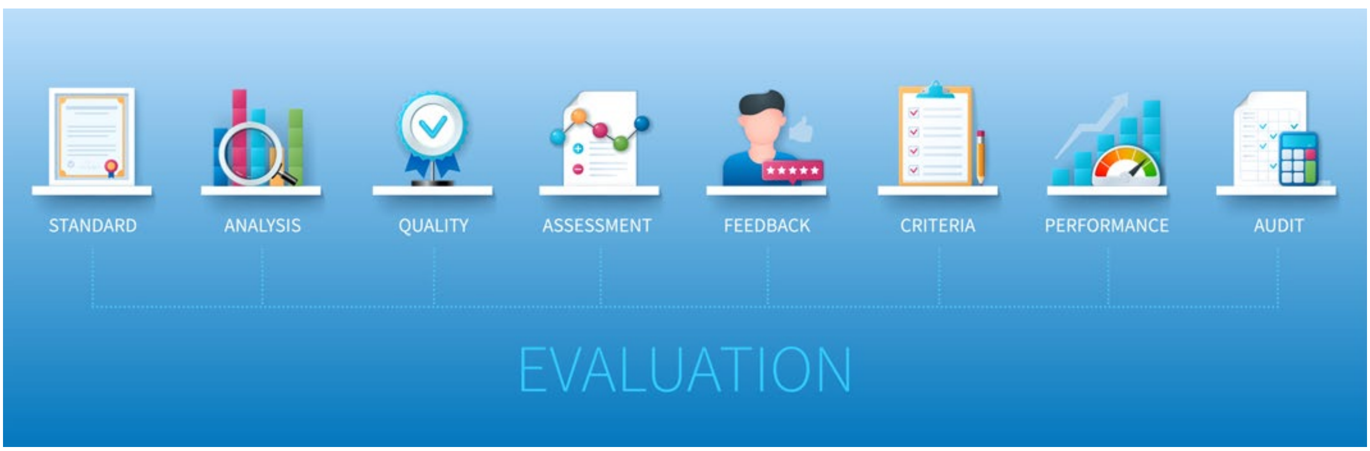
Lightning Speed Laminates

by John Coonrod, ROGERS CORPORATION

There are many different test methods which can be used to determine the Dk (dielectric constant or ε_r) and Df (dissipation factor, Tan Delta, loss tangent) for circuit materials. IPC has 12 different test methods to determine Dk for materials. Additionally, there are material Dk test methods defined by other industry organizations, universities, and many companies. I have a book on microwave material characterization which has over 80 different test methods to evaluate circuit materials for Dk and Df. The bottom line is, there is no perfect test method, and an engineer should use the test method that most closely emulates their end-use product. In this column, I'll give an overview of test method concepts and discuss common test methods which are used to determine Dk and Df.

Test Methods Concepts

There are two general categories for test methods used for high frequency circuit materials: material test methods and circuit test methods. The material test methods typically use fixtures to evaluate the raw dielectric material. This type of testing is evaluating the raw material only and without circuit fabrication variables. The other category is using circuit test vehicles to extract the Dk (and sometimes Df) based on circuit performance. Since the accuracy of the material test methods are dependent on fixture variations and the circuit test methods are dependent on circuit fabrication variations, the Dk/Df values extracted from these two different types of test methods should not be expected to be the same.



Another issue is test methods will extract the Dk/Df values based on the orientation of the electric fields, in relation to the material being evaluated. Generally, some test methods will test the Z-axis (thickness axis) and other test methods will evaluate the X-Y plane of the material. Since most circuit materials used in the PCB industry are anisotropic, Dk is different on each axis of the material. It is possible to test the same piece of material with two different test methods and achieve two different Dk values, and both values are correct. If the material is anisotropic, one test method is evaluating the Z-axis of the material and the other test method is evaluating the X-Y plane; we should achieve different Dk values when testing the same material.

A few other considerations for test method concepts are material dispersion, copper surface roughness, and the use of resonant or transmission/reflection techniques. All materials have dispersion and that means the Dk will vary with a change in frequency. So, if the same material is tested twice using the same test method, but tested at different frequencies, there should be a difference reported in the Dk value. Basically, as frequency increases, the Dk value will slightly decrease.

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Copper surface roughness can slow the propagating wave and a slower wave will be perceived as a higher Dk value, regardless of the material Dk value. Some test methods are sensitive to the copper surface roughness and other test methods are not.

Lastly, it is well accepted that a test method which uses resonance is typically more accurate than a test method which uses transmission/reflection. The resonator test methods are usually more accurate, but they typically give Dk results at a discrete frequency or multiples of a discrete frequency. Many of the transmission/reflection techniques will give Dk results vs. frequency over a wide band of frequencies.

Following is an overview of several common test methods used in the PCB industry.

X-band Clamped Stripline Resonator Test per IPC-TM-650 2.5.5.5C

After the laminate is made, all copper is etched off and samples of the raw material are put inside a clamping fixture. The fixture has a very thin resonator circuit image in the middle, a ground plane on both sides of the resonator, and the material under test (MUT) is put between the resonator and the ground planes. When clamped together, the fixture has the RF structure of a stripline which is ground-signal-ground; more specific to this test method is the clamped structure, ground-MUT-signal-MUT-ground. This test method evaluates the Z-axis of the material for Dk and Df. It can be used at increments of 2.5 GHz and up to about 12.5 GHz. Typically, this test method is used at 10 GHz and is a relatively accurate test method.

One drawback to this test method is the reported Dk value will sometimes be lower than the Dk of the material, due to the natural issue of a clamped fixture having entrapped air (air has a Dk of about 1). Another potential issue for this test method is that when testing material with high anisotropy (Dk is very different on all three axes), the resonant peak can be altered in such a way to be less accurate for the Dk extraction. This is typically not a concern, except for some materials with high nominal Dk values, such as having a Dk of 6 or more. Overall, this is an excellent test method for a high-volume circuit material manufacturer to use for ensuring consistent Dk/Df properties of their material.

Split Cylinder Resonator Test per IPC-TM-650 2.5.5.13

This test method is a cylinder resonator and as the name implies, it is split and can be opened and closed. After the laminate is made and all copper is etched off, the material to be tested (MUT) is put between the split cylinder and it is closed. The resonator will have several different resonant peaks for the user to choose to evaluate the Dk and Df. These different resonant peaks are at different frequencies. This test method will evaluate the X-Y plane of the material and not the Z-axis. Due to this difference and the fact this test method can also operate at the same frequency as the clamped stripline test method (Z-axis method), a comparison of data when evaluating the same material in these two tests will give information regarding the Dk anisotropy of the MUT. Additionally, if the material is anisotropic, it should be expected to obtain a different Dk value in the split cylinder test when evaluating the same material with the clamped stripline test.

Microstrip Ring Resonator Test Method

This method is a circuit test method, and the ring resonator circuit pattern is the test vehicle which is built on the material to be evaluated. The ring resonator typically has open-ended 50-ohm transmission lines (feedlines), which bring the RF energy to both sides of a ring circuit pattern (ring pattern looks like a very thin donut). The gaps between the two feedlines and the ring structure are critical and variations in the gap areas can cause the Dk extraction to be inaccurate. Also, if the ring circuit structure is plated with thicker copper in the PCB process, as compared to another ring resonator built on the exact same material but having thinner copper plating, the gap area will have more fields in air for the thick copper-plated circuit and the resonant peak will shift to be different than the ring resonator with the thinner copper plating thickness. Because of the difference in copper plating, the extracted Dk value will be different and is not correct when trying to evaluate the Dk of the material only. The gap and the copper plating thickness variation is a normal circuit variable; a circuit test will include this, but most material tests do not. Copper plating thickness has a natural variation in the PCB fabrication process and that thickness difference can cause inaccurate Dk results when using a ring resonator. Assuming the engineer is aware of the copper thickness issue and accounts for it in the extraction process, the correct Dk can be found. Additionally, this test method is affected by copper surface roughness, whereas the previous two test methods are not impacted by roughness effects. The ring resonator evaluates the Z-axis of the material.

Understanding the differences between test methods can be very important for a design engineer and especially when the engineer is comparing Dk and Df values on data sheets. If a comparison of data sheet Dk values is being done, the test method which generated the Dk values needs to be understood. Ideally, it would be best to compare Dk data using the same test method and at the same frequencies, but that is not feasible sometimes. However, if different test methods are used for Dk values on data sheets being compared, and both data sheets are reporting the Z-axis Dk at approximately the same frequency, it should be a good comparison.

When comparing datasheets or investigating material properties for a new design, it is important to consult the material manufacturer to understand how the critical data on the datasheet was obtained. DESIGN007

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