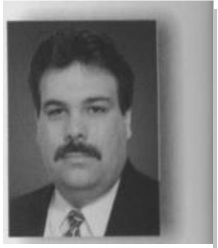
By **Bob** Neves



Permittivity/Dielectric Constant: Do the Math

You can't discuss permittivity and dissipation factor without "doing the math." If this column gets a little deep, bear with me and I will try to make some sense of the mumbo jumbo. Think of permittiviy as a fairy tale with both real and imaginary parts. You might understand the real, but will have to dig deep for the imaginary parts. For those electrical engineers (you know who you are), this column attempts to shed some light on substance, and I won't be telling you anything you don't already know so you can move on now to the "Industry News" section.

Electronics, in general, is headed in one direction: higher speeds and lower operating voltages. It is not uncommon to require a bandwidth 10-20 times that of the clock frequency of the circuit. This translates into greater than 1Ghz analog bandwidth for 50-100Mhz clock frequencies. This is the source of our pain, and drives the practical future of the electronics industry. It is also what demonstrates some of the future's greatest difficulties. Did you know that $E=mc^2$ is really $E=(m_o/(1-v^2/c^2)^{½})c^2$ All that other stuff is only significant at very high speeds (almost warp 1), so $E=mc^2$ is what we mortals use for the theory of relativity. The same thing goes for the frequency dependent properties of dielectric materials. Permittivity and dissipation factor become critical only for high signal speeds, albeit a little lower than the speed of light.

Both permittivity and dissipation factor are dimensionless numbers. No Hertz, Joules, Watts, Farads, Henrys, Volts, Amps or Pascals here! Being a dimensionless value means that the number is a ratio of two like dimensioned number attributes (i.e., volts/volts, farads/farads, etc.). These numbers do not add any influence to an equation other than to add a dimensionless factor to calculations.

To understand dielectric constant and dissipation factor, you first must have a basic understanding of some of the prima? terminology involved. There are many instances where the terms people use are confused and interchanged.

Permittivity

The permittivity of a dielectric material has both real and imaginary mathematical representations. The imaginary part of Permittivity is represented in mathematical equations as epsilon double prime (e") or sometimes kappa double prime (k"). This imaginary part of Permittivity describes the energy loss from an AC signal as it passes through the dielectric. The real part of permittivity, (e'), epsilon prime or (k'), kappa prime, is also called dielectric constant and relative permittivity. The permittivity of a material describes the relationship between an AC signal's transmission speed and the dielectric material's capacitance. When the word "relative" is used in front of permittivity, the implication is that the number is reported relative to the dielectric properties of a vacumm. All measurements that you and I will ever use are relative permittivity numbers. The relative permittivity number can then be used to calculate the impedance of a given circuit, helping the PWB designer optimize a circuit for impedance matching characteristics.

Relative Permittivity (e') = C_p/C_v where C_p = Capacitance of ; dielectric between two parallel plates.

C_v = Capacitance of the same thickness of air (vacuum) between the same two parallel plates.

Dissipation Factor

The simplest way to define dissipation factor (loss tangent) is the ratio of the, energy dissipated to the energy stored in the dielectric material. The more energy that is dissipated into the material. The less is going to make it to the final destination. This dissipated enegy typically turns into heat or is radiated as RF (Radio Frequencies) into the air. The optimal goal is to have 100% of the signal pass through the interconnection network, and not be absorbed in the dielectric. With "high power" signals, a material with a large dissipation factor could result in the development of a tremendous amount of heat, possibly culminating in a fire (advanced dielectric heating). When the signals are very weak a high loss material means that little or no signal is left at the end of the transmission path. In order to retain maximum signal power, a low loss material should be used.

Dissipation factor = e"/e' where: e' is the real portion of permittivity, and e" is the imaginary portion of permittivity.

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What's the Frequency?

So what does it mean when your material supplier says his material has a permittivity of 4.5 and a dissipation factor of 0.030. Well, first off, it has been standard practice in our industry to report permittivity and dissipation factor numbers at a test frequency of 1 Mhz. This may or may not help you with your impedance or signal loss calculations. Both permittivity and dissipation factor values are directly related to dielectric material capacitance, which in turn varies with signal frequency. It is very possible that this same material could have a permittivity of 4.3 and a dissipation factor of 0.070 when measured at 2Ghz.

Another factor affecting permittivity and dissipation factor has to do with the ratio within the dielectric material of resin to reinforcement. Standard di-functional epoxy resin has a 1 Mhz permittivity of approximately 3.7, while E-glass reinforcement has a typical value of approximately 6.5. As you can see, each style of prepreg will have a slightly different dielectric properties due to the mixing of the resin value with the glass value.

The Test Methods

There are several methods for performing dielectric constant and dissipation factor measurement. Parallel plate (ASTM D 150), two fluid cell, sheet resonance, stripline at X-band and clip method. Test procedures for each of these methods can be found in IPC-TM-650 and/or ASTM D 150.

Parallel Plate

Parallel plate methods use the insulating material capacitance and conductance to determine the permittivity and dissipation factor. Capacitance meters hare historically been limited to frequencies less than 30Mhz, which will easily perform the typical 1Mhz test, but cannot get into thk frequency range where much of the high speed electronics are being used (1Ghz Hewlett Packard recently introduced a materials analyzer which performs parallel plate measurements at frequencies up to 1.8Ghz with relative ease. I liked the unit so much I bought one for our lab. This unit bridges the gap between traditional 1Mhz measurements and stripline (see below) measurement techniques with little in the way of sample preparation.

Two Fluid Cell

The two fluid cell method is a variation of the parallel plate method which is currently the most widely used test method in our industry. This method uses a capacitance meter to measure both the capacitance and conductance of the unknown dielectric in two fluids. The two “fluids” typically used are air and silicon oil. Both of these “fluids” have well documented dielectric properties, and the value of both conductance and capacitance of an unknown dielectric material together with the known values for the two fluids allow the calculation of the unknown material’s dielectric properties.

Stripline at X-Band

Stripline at X-band sounds like a description of the seedy bar at the wrong side of town. Well, that mav well he, but in the context of dielectric materials, it is one of the only ways to determine dielectric properties in’ the 8-12 Gigahertz frequency range. A stripline impedance circuit is made by sandwiching the unknown dielectric material between a resonant circuit and a reference plane. This technique typically utilizes a high frequency network analyzer to characterize the signal resonance of the stripline circuit with respect to the reference plane while the unknown dielectric is sandwiched in between. Test sample preparation is tricky, as test patterns and fixtures need to be optimized for the specific dielectric properties of the unknown dielectric. This can prove to be verycostly, and time consuming when the properties of thr unknown dielectric can’t he accurately predicted. The results from this method do not always coincide with other methods of permittivity and dissipation factor determination, but can prove repeatable for process control applications. The results from this method can also vary from actual PWB stripline applications due to variances in circuit geometry and bonding technique.

Full Sheet Resonance

The Full Sheet Resonance test is a quick implementation of the Stripline at X-Band test procedure. The equipment set-up and mathematical calculations are similar, and no special sample circuit preparation is required as in the stripline test. This allows, as the name suggests for full sheets of laminate material to be tested non-destructively. This ease of sample preparation does not come without drawbacks. Assumptions about the dielectric thickness, volumetric area and edge/fringing capacitance must be made, increasing the error in the measurement. This increase in error makes the accurate measurement of loss characteristics almost impossible. As with the stripline test, this is a good tool for process control applications.

What Does It All Mean?

As you can see with more high speed or controlled impedance designs, permittivity and dissipation factor will become a critical parameter to understand. New material types are being developed which aim solely to address these dielectric properties, and these materials and products will shape the way business is done in the future.

I would like to thank Rene' Martinez of Arlon for his insight as he works on his thesis in this field.