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MATERION

TECHNICAL TIDBITS

MATERION PERFORMANCE ALLOYS

At a Loss! – A brief discussion on energy lost as waste heat in materials due to the presence of changing electric fields.

- **Relative Permittivity/ Dielectric Constant (ε_r/D_K or κ)**
- **Dielectric**
- **Relaxation Time**
- **Dissipation Factor (Df)**
- **Loss Tangent [tan (δ)]**
- **Loss Angle**
- **Electric Susceptibility/ Dielectric Susceptibility (χ_e)**
- **Ferroelectric**
- **Dielectric Hysteresis**

The next issue of Technical Tidbits will discuss the effect that dielectric properties have on high frequency signals.

DIELECTRIC LOSS AND **FERROELECTRIC HYSTERESIS**

Last month we made the observation that the permittivity of an ideal capacitor is equal to the **relative permittivity** (**dielectric constant**, abbreviated $\mathbf{D_k}$ or $\boldsymbol{\varepsilon_r}$) multiplied by the **permittivity constant** ($\boldsymbol{\varepsilon_0}$). This is true for direct current (DC) conditions, or for ideal, lossless dielectric materials. However, nature rarely presents us with ideal materials or conditions, so we have to consider real-world cases.

As discussed last month, under the influence of an externally applied electric field, the electric dipoles in a polarizable material will align themselves with the field, if they are free to rotate or move, and if they have enough time to do so. Of course, such movement requires energy (readily available from the electric field) and internal friction results in the generation of a small amount of heat. The transfer of energy from the applied electric field to unrecoverable heat loss is known as **dielectric loss** or **dissipation**. As always, whenever energy is used to do useful work, there is always some lost to waste heat. In other words, entropy increases.

When an applied electric field is reversed, the dipoles will be facing the wrong direction. They will then rotate to align in the opposite direction. The time required for this to happen is called the **relaxation time**. If it is easy for the dipoles to align, then the relaxation time is low. This is a physical property that essentially measures the rate of polarization.

The amount of energy converted to heat during a polarization cycle is known as the **dissipation factor (Df), loss tangent** or **tan (δ),** with **δ** being the **loss angle**. The derivation of the loss angle and the tangent thereof can be a bit esoteric unless you are an electrical engineer. Technical Tidbits always tries to strike a balance between oversimplification (with a risk of inaccuracy) and getting too in depth for introductory material (getting lost in the weeds). However, if you are comfortable with phasors as well as real and imaginary parts of current and capacitance, then feel free to research on.

Under AC conditions, all realistic dielectric materials will have losses. Therefore, permittivity (ε) is represented as a complex number, with the real part relating to capacitance and the imaginary part relating to dielectric losses (ε′-jε″). Per Eric Bogatin, when the complex permittivity is plotted as a vector on the complex plane, the loss angle is the angle between the vector and the real axis. The tangent of the loss angle is thus precisely equal to the imaginary part of the permittivity. So, as the angle increases, so does the loss tangent, and the amount of energy lost (dissipated) as heat. (See the right side of Figure 1.)

Alternatively, per Braithwaite and Weaver, if you imagine a capacitor as a combination of an ideal capacitor and ideal resistor, you can plot a phasor diagram of the current in both elements, and the loss angle will be the angle between the resultant current and the capacitive current. (Left side of Figure 1).

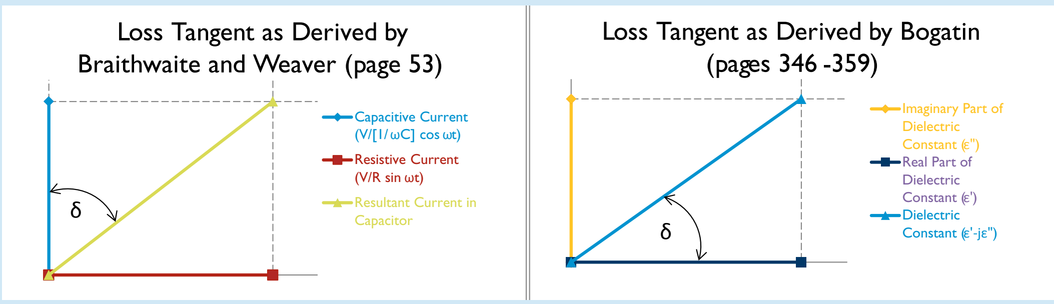

Figure 1. Loss Angle and Loss Tangent.
The diagram on the left is a phasor plot of current, and that on the right is the dielectric constant plotted on the complex plane. In either case, the tangent of the loss angle describes the amount of energy dissipated as heat (dielectric loss).

DIELECTRIC LOSS AND FERROELECTRIC HYSTERESIS (CONTINUED)

Electric susceptibility (χ_e), also known as **dielectric susceptibility**, is the electrical equivalent of magnetic susceptibility. It is related to the relative permittivity by the following equation: $\varepsilon_r = 1+\chi_e$.

To fully describe the losses associated with dielectric materials, we would need both the dielectric constant and the loss tangent. Please note that both of these are likely to be functions of frequency. To put all the concepts together:

$$\varepsilon = \varepsilon_0\varepsilon_r = \epsilon_0\,(1 - \chi_e) = \varepsilon' - j\varepsilon'' = \varepsilon'\,[1 - j \cdot \tan(\delta)]$$

Ferroelectric materials are a class of dielectric materials that can maintain a remnant polarization when the electric field is removed, and behave much like ferromagnetic materials do in magnetic fields. (We will discuss magnetism and magnetic materials in a few months.) These materials show **ferroelectric hysteresis** as shown in Figure 2. The area within the outer curve is a measure of the energy lost per cycle as waste heat. This is another source of loss in some dielectric materials.

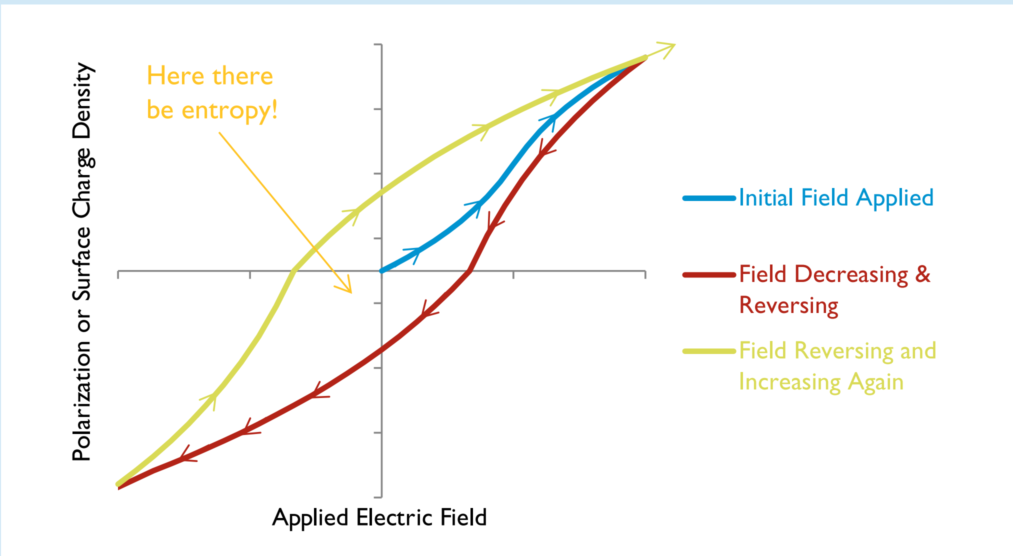

Figure 2. Schematic Drawing of a Ferroelectric Hysteresis Curve.
In hysteresis curves, the area bounded by the curve is a measure of the energy lost per cycle as waste heat.

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