Verification of Dielectric Constant for Insulators

(Or what to do during an ice storm...)

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Abstract

By using ordinary measurement and test equipment, it is possible to indirectly measure the dielectric constant of insulating materials. The data obtained can be very useful for high frequency design, or verification of material characteristics in production.

Introduction

Microstrip construction on a printed circuit board is a basic requirement for UHF circuitry. In microstrip construction, conductors of precise widths are used as transmission lines to carry signals between circuits on the board. The characteristic impedance of a microstrip is given by the classic equation[1]:

$$(1)\quad Z_0 = \frac{377h}{\sqrt{\varepsilon_r}W[1+1.74\varepsilon_r^{-0.07}(W/h)^{-0.836}]}$$

where ε_r is the relative dielectric constant of the substrate, W is the width of the conductor, and h is the height of the conductor above the conductive backplane.

The characteristic impedance of the line depends on the physical dimensions of the conductors (as a ratio) and the dielectric constant of the insulating material. If the wrong insulating material is used, or the material is out of spec, the resulting characteristic impedance will be a mismatch for the intended application. Table 1 gives the dielectric constants for various PC board materials.

Material	Composition	Dk @ 1 GHz	Dk @ 10 GHz	Loss @ 1 GHz	Loss @ 10 GHz	Tg (*C)
FR4	Resin / Glass	4.50		0.0270		140
FR408	Resin / Glass	3.70		0.0100		180
GETEK	Resin / Glass	3.6-4.1		0.0130		180
N4000-13 SI	Resin / Glass	3.60	3.50	0.0080	0.0060	210
N6000- SI	Resin / Glass	3.40	3.00	0.0030	0.0060	210
RO4003	Plastic / Ceramic / Glass		3.38		0.0022	280
RO4350	Plastic / Ceramic / Glass		3.48		0.0040	280
RO3003	PTFE / Ceramic		3.00		0.0013	NA

Table 1: Dielectric constants for various PC board insulating materials. Source: http://www.dci-us.com/technical/pcb_materials.php

[1] H.A. Wheeler in *Young*, Electronic Communications Techniques 2/e - Merrill

Indirect measurement of the dielectric constant of the material depends upon accurately measuring the physical dimensions and capacitance of a sample of material, as shown in Figure 1.

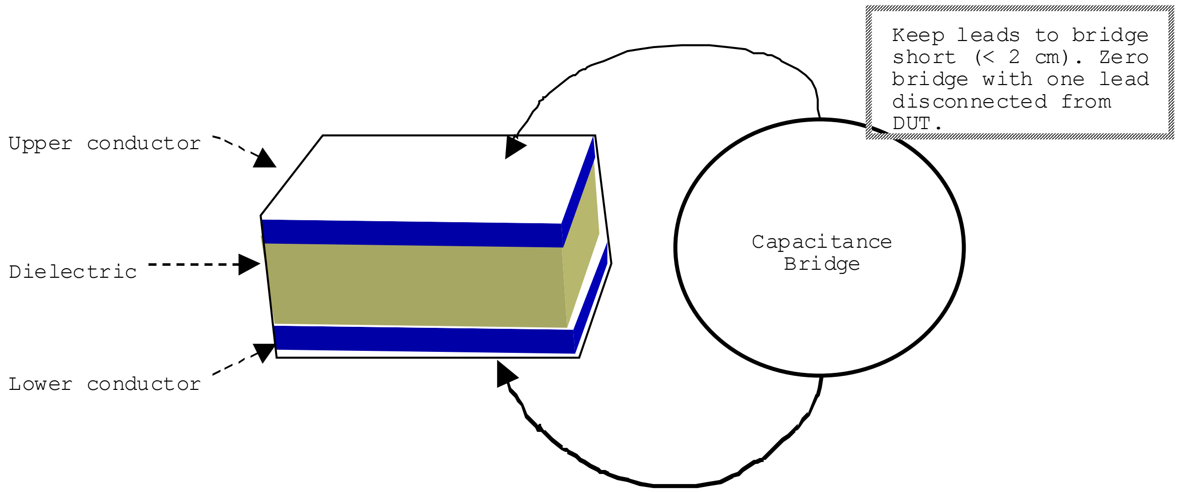

Figure 1: Measurement of the capacitance

When performing this measurement, a digital LCR bridge is preferable; keep the test leads short. For best accuracy, zero the bridge with *one* lead connected to the work, and the other lead adjacent to the work (< 1 cm distance). After zeroing the bridge, connect the second lead and read the capacitance. This measurement should be conducted in an RF-quiet environment.

Equation 2 gives the relationship between capacitance and dielectric constant.

$$(2)\quad C = \frac{\varepsilon A}{d}$$

where ε is the permittivity of the material in Farads/meter, A is the surface area common to the capacitor plates, and d is the distance between the plates. By rearranging Equation 2, we get:

$$(3)\quad \varepsilon = \frac{Cd}{A}$$

where ε is the permittivity of the material in F/m, C is the capacitance of the unit, d is the distance between the plates, and A is the common surface area of the plates. The dielectric constant ε_r can then be calculated by:

$$(4)\quad \varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$$ where ε_0 is the permittivity of free space, 8.854×10^{-12} F/m.

Example Calculation

Two identical samples of FR4 single-sided PC board material were used for testing. The surface area of each piece was 5993.9 mm^2. The two samples were clamped together and the capacitance was measured using a B&K digital LCR bridge as 76.8 pF. The clamping force was important, as the capacitance diminished without it (the capacitance was only 57.8 pF with the boards unclamped). Using double-sided PC board material would have eliminated this issue.

The total thickness of the samples was verified as 3.18 mm using a micrometer. *Etched* samples were used to determine dielectric thickness (the copper was 0.0254 mm thick). According to Equation 3, the permittivity of the material was:

$$\varepsilon = \frac{Cd}{A} = \frac{(76.8pF)(3.18mm)}{5993.9mm^2} = \underline{4.0745425 \times 10^{-11} F/m}$$

The dielectric constant of the material was calculated using Equation 4:

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0} = \frac{4.0745425 \times 10^{-11} F/m}{8.854 \times 10^{-12} F/m} = \underline{\underline{4.6}}$$

Compared to the value for FR4 in Table 1, this result is very close!

Conclusion

The results here certainly aren't groundbreaking; the PC board material dielectric constant value is very close to what the manufacturer promised! However, knowing the dielectric constant is reassuring -- UHF designs relying on this characteristic should work as advertised.

This technique might be useful in areas other than PC board fabrication. Here are some examples where it might come in handy:

- Verify the insulator characteristics for dielectric antennas.
- Calculate total parasitic capacitance for electronic packaging materials (wiring harnesses, enclosures, and so forth.)
- Indirectly estimate common surface area in applications where capacitance and dielectric constant are already known.

Let me know if you find this useful!