Free Space Measurement Method for define Dielectric constant by Microwave

Permittivity

Permittivity, also called electric permittivity, is a constant of proportionality that exists between electric displacement and electric field intensity. This constant is equal to approximately 8.85 x 10^{-12} farad per meter (F/m) in free space (a vacuum). In other materials it can be much different, often substantially greater than the free-space value, which is symbolized ε_0.

Permittivity is often expressed in relative, rather than in absolute, terms. If e_o represents the permittivity of free space (that is, 8.85 x 10^{-12} F/m) and e represents the permittivity of the substance in question (also specified in farads per meter), then the relative permittivity, also called the dielectric constant ε_r, is given by: $\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$.

Dielectric Materials

Insulating materials are also termed as dielectrics. The difference in the name between dielectric and insulator lies in the application to which these materials are put. • When these materials are used to prevent flow of electricity through them on the application of potential difference, then they are called insulators or passive dielectrics. • On the other hand, if they are used for charge storage then they are called dielectrics or active dielectrics.

Examples of Dielectric Material

Most dielectric materials are solid. Examples include porcelain (ceramic), mica, glass, plastics, and the oxides of various metals. • Some liquids and gases can serve as good dielectric materials. • Dry air is an excellent dielectric, and is used in variable capacitors. Distilled water is a fair dielectric.

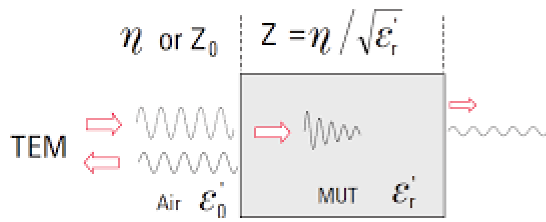
Application of dielectric Materials

Based on various properties like insulation, temperature dependency, permittivity, dielectric strength, dielectric materials are used as various industrial materials for manufacturing of electrical devices. Most common uses of these materials are in. Capacitor, power Transformer, Cables, Spark generators, transducers.

Electromagnetic Wave Propagation

In the time-varying case, electric fields and magnetic fields appear together. This electromagnetic wave can propagate through free space (at the speed of light, c = 3 x 108 m/s) or through materials at slower speed. Electromagnetic waves of various wavelengths exist. The wavelength l of a signal is inversely proportional to its frequency f (λ = c/f), such that as the frequency increases, the wavelength decreases.

For example, in free space a 10 MHz signal has a wavelength of 30 m, while at 10 GHz it is just 3 cm. Many aspects of wave propagation are dependent on the permittivity and permeability of a material. Consider a flat slab of material (MUT), material under test in space, with a TEM wave incident on its surface.



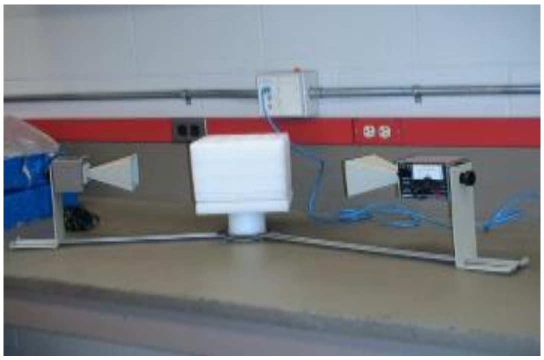
There will be incident, reflected and transmitted waves. Since the impedance of the wave in the material Z is different (lower) from the free space impedance η (or Z0) there will be impedance mismatch and this will create the reflected wave. Part of the energy will penetrate the sample. Once in the slab, the wave velocity v, is slower than the speed of light c. The wavelength λd is shorter than the wavelength λ0 in free space according to the equations below. Since the material will always have some loss, there will be attenuation or insertion loss. For simplicity the mismatch on the second border is not considered.

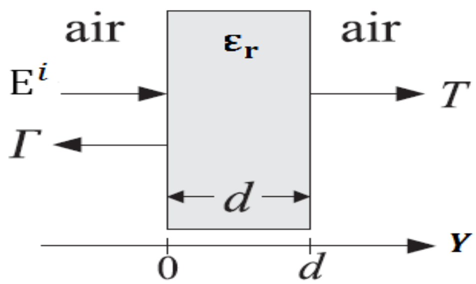
Summary of EM Plane Wave in Media

	Any Medium	Lossless Medium ($\sigma = 0$)	Low-loss Medium ($\varepsilon''/\varepsilon' \ll 1$)	Good Conductor ($\varepsilon''/\varepsilon' \gg 1$)	Units
$\alpha =$	$\omega\left[\frac{\mu\varepsilon'}{2}\left[\sqrt{1+\left(\frac{\varepsilon''}{\varepsilon'}\right)^2}-1\right]\right]^{1/2}$	0	$\frac{\sigma}{2}\sqrt{\frac{\mu}{\varepsilon}}$	$\sqrt{\pi f \mu \sigma}$	(Np/m)
$\beta =$	$\omega\left[\frac{\mu\varepsilon'}{2}\left[\sqrt{1+\left(\frac{\varepsilon''}{\varepsilon'}\right)^2}+1\right]\right]^{1/2}$	$\omega\sqrt{\mu\varepsilon}$	$\omega\sqrt{\mu\varepsilon}$	$\sqrt{\pi f \mu \sigma}$	(rad/m)
$\eta_c =$	$\sqrt{\frac{\mu}{\varepsilon'}}\left(1-j\frac{\varepsilon''}{\varepsilon'}\right)^{-1/2}$	$\sqrt{\frac{\mu}{\varepsilon}}$	$\sqrt{\frac{\mu}{\varepsilon}}$	$(1+j)\frac{\alpha}{\sigma}$	(Ω)
$u_p =$	ω/β	$1/\sqrt{\mu\varepsilon}$	$1/\sqrt{\mu\varepsilon}$	$\sqrt{4\pi f/\mu\sigma}$	(m/s)
$\lambda =$	$2\pi/\beta = u_p/f$	u_p/f	u_p/f	u_p/f	(m)

Notes: $\varepsilon' = \varepsilon$; $\varepsilon'' = \sigma/\omega$; in free space, $\varepsilon = \varepsilon_0$, $\mu = \mu_0$; in practice, a material is considered a low-loss medium if $\varepsilon''/\varepsilon' = \sigma/\omega\varepsilon < 0.01$ and a good conducting medium if $\varepsilon''/\varepsilon' > 100$.

How we can measurement the dielectric constant and attenuation constant.





Any wave can transmit, reflected or absorption, to determine ε_r and α for any materials provided that it is not metal using the formula of total transmission coefficient, T:

$$T = \frac{1}{\frac{1}{2}\left(\frac{1}{\sqrt{\varepsilon_r}} + \sqrt{\varepsilon_r}\right)\left(sinh(\alpha d + j\beta d) + cosh(\alpha d + j\beta d)\right)}$$

Where: $\beta = 2\pi\ \lambda\ \sqrt{}$, Phase constant (rad/m).

α Attenuation constant (Np/m).

d Thickness of material (m).

When the program run, it ask as to input values of Lambda, λ(wavelength of the microwave), the Tm, Total transmission coefficient measured, and d the width of sample.

The samples don't have magnetic characteristics.

Then, the program try to find the value of Tc (which we calculated by program) by all values which we input it.
When the values achieves the condition ,if<=0.0001, that men Tm ≈ Tc , this is what we want to reach and that is mean the values of ε_r and Alpha makes the Tc ≈ Tm, which are for material that we measurement.

Four programs are included

```
alpha_Er_surf2.m
microwave_0.C
microwave_2d.C
microwave_solution.C
```

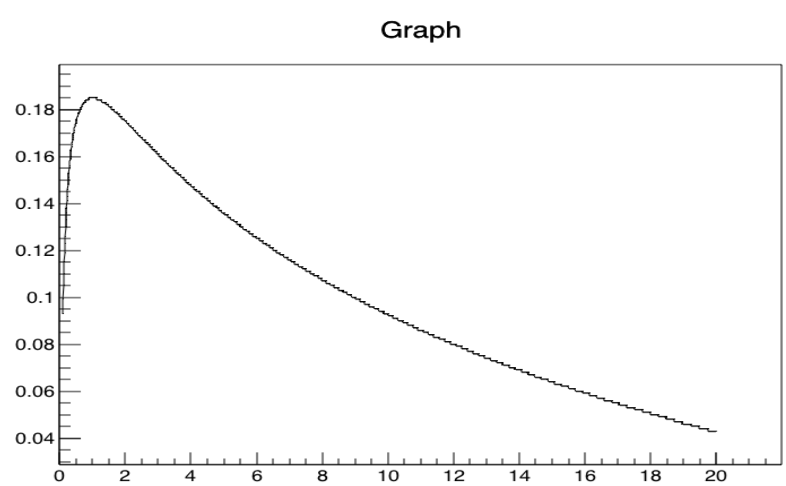
1. `alpha_Er_surf2.m` in Matlab
This is included only for completeness. Does not need to be tested, I used this to develop the concept.
I used Matlab because I know it to some degree, then I used root scripts and C++, to use the concept.

2. Program number one `microwave_0.C`.

I include this for completeness. This program tested the translation from Matlab to C++.
It can be run root

```
microwave_0.C
```

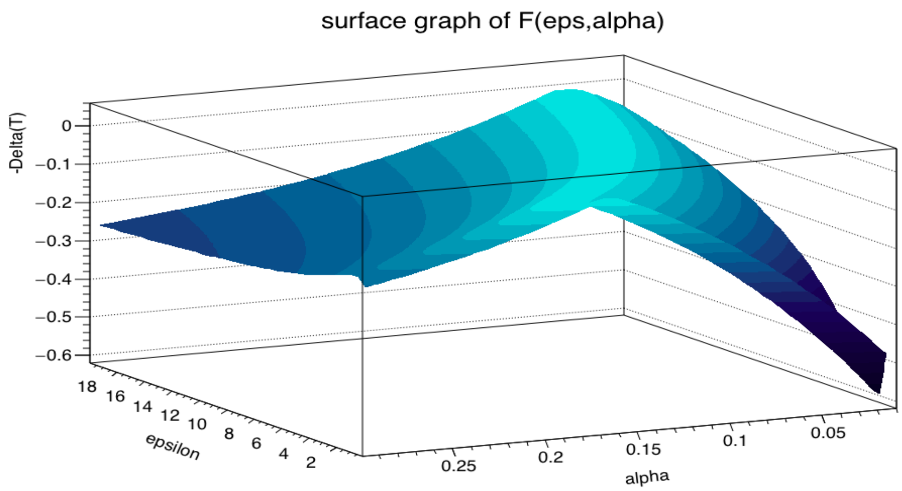
The user answers 'd' for demonstration or any other character - then program would ask for the values.



3. First program submitted is `microwave_2d.C`.

This program shows how one measurement can be handled the Transmission coefficient T is evaluated on a 2-dim mesh of points and plotted is - abs (T - Tm) .

The negative is chosen because it shows the curve of possible solution in the plane z=0 - as a "roof" on the plotted surface.



To run this simply type root

`microwave_2d.C`

The user answers ’d’ for demonstration or any other character - then program would ask for the values.

4. The final program `microwave_solution.C`
finding the solution pair Alpha, ε_r as the intersection of the two curves.

To run this, simply type root
`microwave_solution.C`.
The user answers 'd' for demonstration or any other character - then program would ask for the values.

Here is the output of the demonstration run: