VSRT MEMO #035

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To: VSRT Group
From: Alan E.E. Rogers
Subject: Near field geometry and dielectric constant measurements.

1] Near Field geometry

In memo 34 we approximate the time difference of arrival, τ , with the simple relation

$\tau = (D/c)\sin(\theta)$

where D = baseline length in m

c = velocity of light in m/s

θ = angle between the wavefront and the baseline

If the source is not at infinity the wavefront is spherical and when this curvature has an appreciable effect (i.e. an appreciable fraction of a wavelength) we say the source is in the "near field" of the interferometer. In this case, we need to calculate the distance of the source to each LNBF and take the difference in this case

$$\begin{aligned} c\tau &= \left((x_b - x_\ell)^2 (y_b - y_\ell)^2 + (z_b - z_\ell)^2 \right)^{1/2} \\ &- \left((x_a - x_\ell)^2 + (y_a - x_\ell)^2 + (z_a - z_\ell)^2 \right)^{1/2} \end{aligned} \qquad (1)$$

where (x_a, y_a, z_a) and (x_b, y_b, z_b) are the coordinates of the LNBFs and (x_ℓ, y_ℓ, z_ℓ) are the coordinates of the lamp. In practice it is useful to have an approximation. If we define θ as the angle between the CFL source and a perpendicular at the middle of the baseline and R as the distance to the CFL then

$$\begin{aligned} c\tau &= \left((R + D/2\sin\theta)^2 + (D/2\cos\theta)^2 \right)^{1/2} \\ &- \left((R - D/2\sin\theta)^2 + (D/2\cos\theta)^2 \right)^{1/2} \end{aligned} \qquad (2)$$

This can be approximated by

$$\approx D\left(1 - (D/R)^2 (1 - \sin^2\theta)/8\right)\sin\theta \text{ for } (D/R) >> 1 \qquad (3)$$

2] Refractometer

It is possible to use the single baseline interferometer to measure the refractive index of material transparent to radio waves. Figure 1 shows the set-up. The set-up is a variation of the single baseline set-up described in memos (25 and 28). In memo (25) we show the condition that leads to a minimum when the fringe phase from one CFL is 180˚ degrees from the fringe phase of the other CFL. This condition is

$$w\left(\tau_x - \tau_{ref}\right) = \left(2n+1\right)\pi \tag{4}$$

where τ_{ref} is the time difference of arrival of the microwaves from the "reference" CFL and τ_x is the time difference of arrival of the microwaves from the other CFL. We arrange the reference CFL off to one site as illustrated in Figure 1. We will hold this CFL fixed so that τ_{ref} will remain constant. The reference CFL is moved off at an angle to make it possible to place the dielectric so that it only effects the path from the "test" CFL to the "A" LNBF. The reference CFL is moved closer to compensate from the signal loss which results from it being 50˚ off the axis of feed. Next we adjust the position of the test CFL to obtain a deep minimum in the fringe amplitude. To achieve a deep null, turn on lamp one at a time and adjust the distance of the test to obtain equal fringe amplitudes. Now we insert the dielectric and move the test CFL to follow the null as the dielectric is inserted.

The change in path is

$$D\cos\theta\left(d/R\right) = \ell\left(\sqrt{\varepsilon} - 1\right) \tag{5}$$

where d = change in lateral distance
R = distance from test CFL
ℓ = thickness of dielectric
D = interferometer baseline
ε = dielectric constant

The index of refraction is $\sqrt{\varepsilon}$ and the velocity of propagation in the dielectric medium is $c/\sqrt{\varepsilon}$

Experimental results:

If D = 3.5", R = 32", ℓ = 0.5", d = 2.0", ε = 2.07"

Questions/Comments

1] How large does the dielectric slab need to be too avoid errors due to the diffraction?
2] How would you measure the loss through a lossy material like moist wood?
3] What's the major sources of error in this setup? How could it be improved?
4] How much would your result change using the near field geometry.
5] Solid Teflon is expensive. Other less expensive materials are wood, PVC, Plexiglas, styrofoam and glass. What about the propagation through corn oil, water, snow, ice?
6] What is the effect of reflections from the dielectric?
7] What happens to the microwave path if the dielectric is tilted?

The setup is also shown in the photograph in Figure 2.

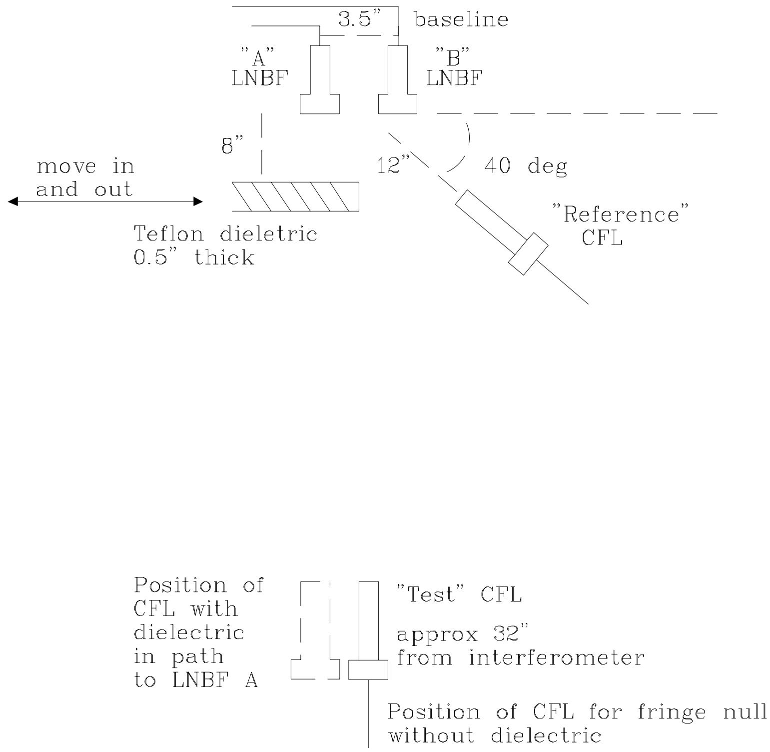

Figure 1. Interferometer setup as a refractometer

Figure 2. Single baseline interferometer show with dielectric slab in path to one LNBF.