EM Implosion Memos

Memo 24

May 2008

Testing a Sample Slab to Be Used as a Focusing Lens Layer

Serhat Altunc, Carl E. Baum, C. Jerald Buchenauer, Christos G. Christodoulou and Edl Schamiloglu

University of New Mexico
Department of Electrical and Computer Engineering
Albuquerque New Mexico 87131

Abstract

This paper basically discusses the determination of the dielectric constant, dispersion and loss of a sample slab that can be used as a layer of a focusing lens.

1. Introduction

A log-periodic lens design procedure can be used to obtain better focusing at the second focal point of a prolate-spheroidal IRA[1,2,3]. Figure 1. presents the lens and target.

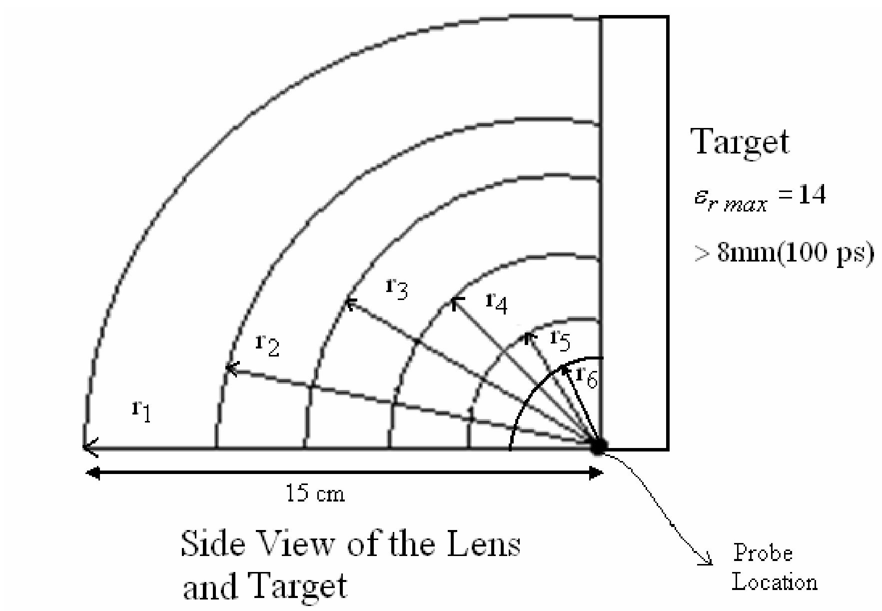

Figure 1. Lens and Target Geometry

In the final design, we will have a log-periodic dielectric lens which has 10 subsequent layers and the ratio of the dielectric constant between two layers is $81^{1/10} = 1.55$. However, for our initial design, we go up to 5 or 6 layers with a maximum relative-dielectric constant of $\varepsilon_{r\,max} = 9$ or 14 because of possible loss and dispersion at higher ε_r [4].

2. Experimental Setup

A slab sample, which has a $\varepsilon_r = 9$ (estimate) and $7.62\,\text{cm} \times 15.24\,\text{cm} \times 1.27\,\text{cm}$ dimensions, is used to determine the dielectric constant, dispersion and loss of sample material provided by TPL (Technologies to Products on the Leading Edge) company.

A curved parallel plate was used to obtain uniform field distribution at the desired points. In [2], the circular geometry is studied in details and it is found that maximum field uniformity occurs (with 3 derivatives zero at the origin) when each plate sustains an angle of 90^o $(\alpha = 45^o)$ at the center of the circle with a radius of r_o. The impedances and field distributions of two curved parallel-plates are presented in figure 2. We used an experimental setup presented in figure 3 to explore the dielectric constant and dispersion of the sample slab. The wave launcher has a radius of $r_o = 30\,\text{cm}$ and characteristic impedance of $Z_c = Z_o / 4 \approx 100\,\Omega$.

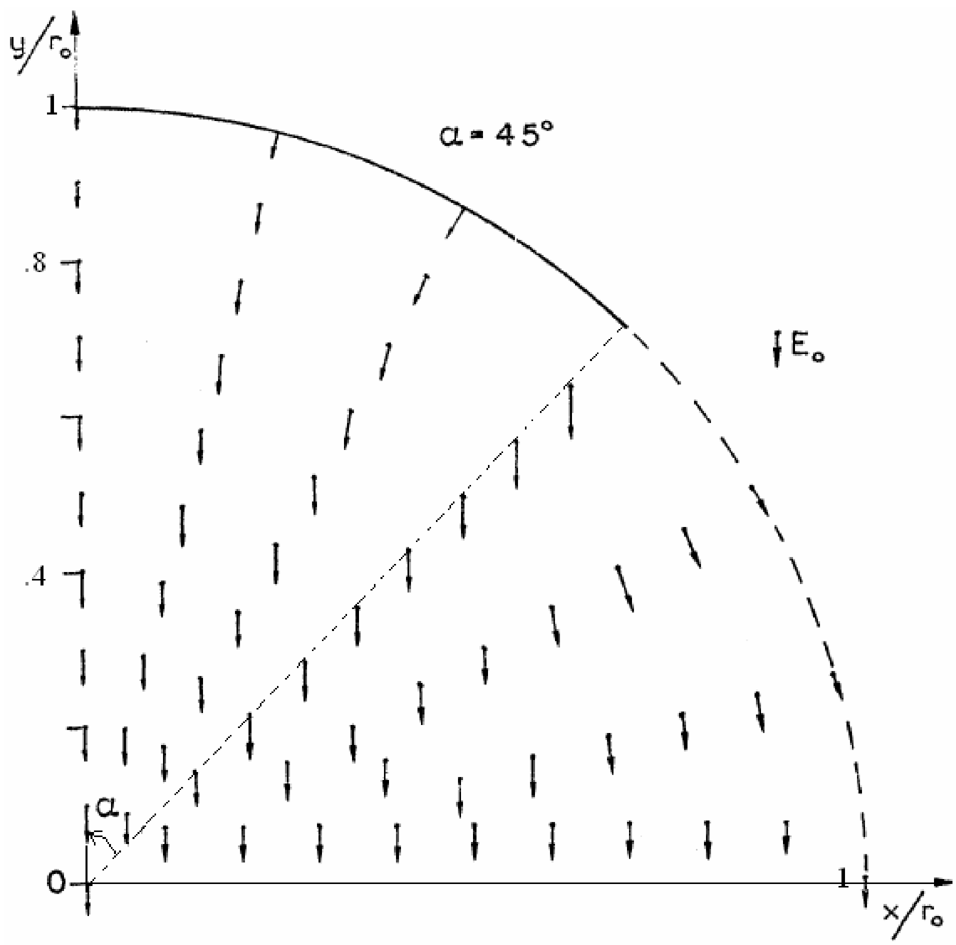

Figure 2. The electric field distributions inside the circular region. The lengths of the vectors are proportional to the magnitude of the electric field [5].

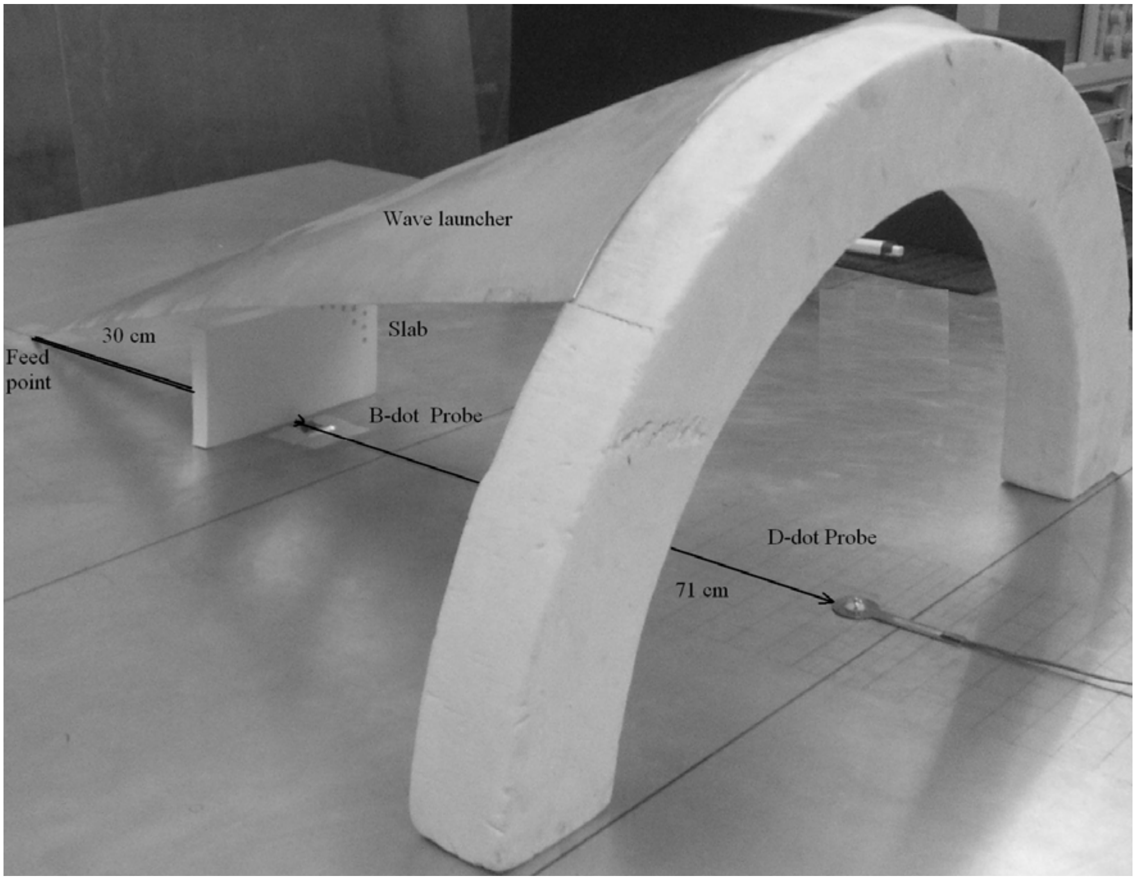

Figure 3. Experimental setup for determination of ε_r and dispersion.

3. Clear Time

Since we are dealing with time-domain measurements, we should consider the clear time while we are measuring the reflection and transmission.

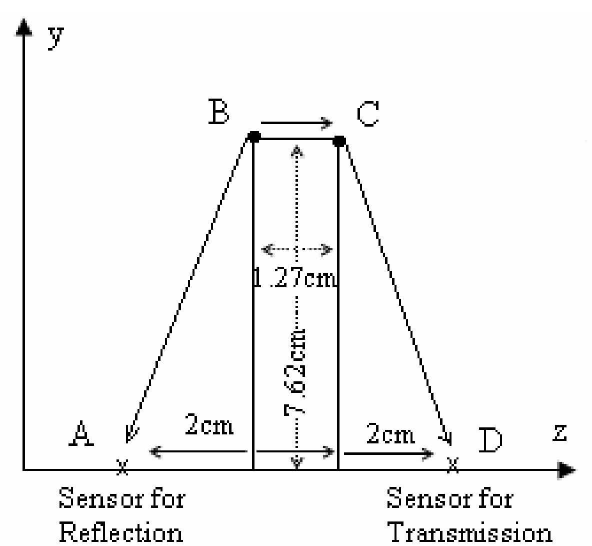

Figure 4. Test sample for clear time calculations

One can easily calculate the clear time for reflection (t_{cr}) by subtracting the propagation time of the reflected wave from the left wall (incident wall) of the test slab as the scattered wave propagates from point B to A.

$$t_{cr} = \left(\sqrt{7.62^2 + 2^2} - 2 \right) / c = 196\,\mathrm{ps} \tag{3.1}$$

Subtracting the propagation time of the wave propagating through the slab and right wall to the point D from the wave propagates BC and CD distances gives us the clear time for transmission (t_{ct}) is

$$t_{ct} = \frac{\left(\sqrt{7.62^2 + 2^2} + 1.27 \right)}{c} - \left(\frac{1.27}{c/\sqrt{\varepsilon_r}} + \frac{2}{c} \right) = 113\,\mathrm{ps} \tag{3.2}$$

Note that, because of the higher ε_r of the slab the fastest scattered wave propagates through BCD way. One should also consider that, we picked up the dimensions of our slab such a way that the scattered wave from the sides and top propagate at the same time to the sensor.

4. Determination of Relative Dielectric Constant ε_r, Dispersion and Loss

One can determine the dielectric constant of the sample slab by measuring time delay, transmission coefficient and reflection coefficient. Comparing the shapes and amplitudes of the normalized waveforms for the wave without and with slab may give us information about the dispersion and loss, respectively.

4.1 Time-delay measurements

The easiest and more accurate ε_r determination can be done by time-delay measurement. Subtracting the wave propagation time through the thickness of the slab ($\ell = 1.27\,\mathrm{cm}$) in case of with and without slab gives us the time delay as

$$\Delta t = \frac{\ell\sqrt{\varepsilon_r}}{c} - \frac{\ell}{c}. \tag{4.1}$$

From (4.1), ε_r can be found as

$$\varepsilon_r = \left(\frac{\ell + c\Delta t}{\ell} \right)^2. \tag{4.2}$$

Figures 5 and 6 show the time delay that is measured by fast D-dot (71 cm away from the feed point) and B-dot probes (30 cm away from the feed point), respectively.

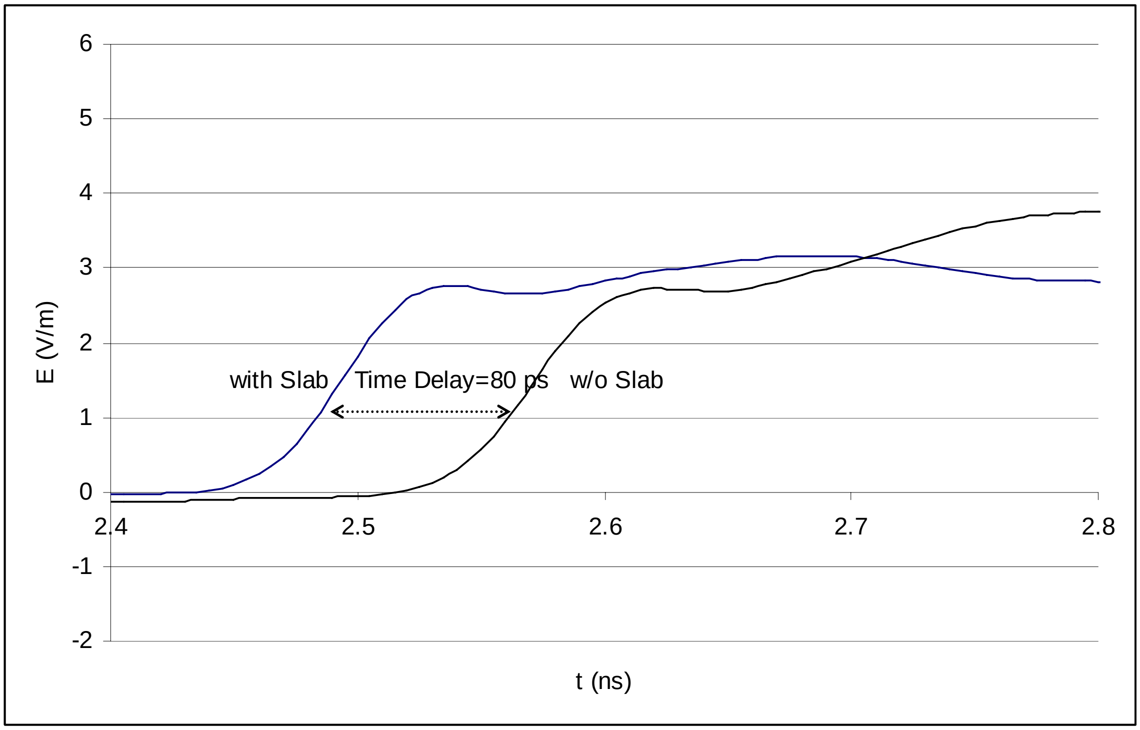

Figure 5. Measured time delay measured by the fast D-dot located 71 cm away from the feed point

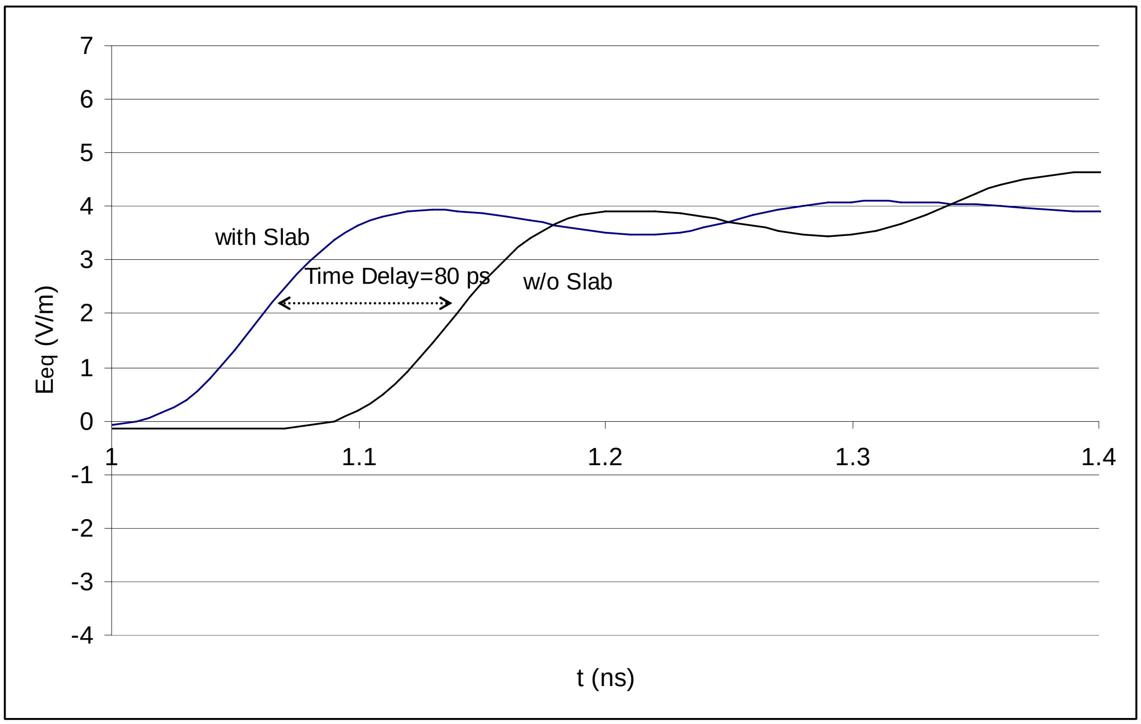

Figure 6. Measured time delay measured by the fast B-dot located 30 cm away from the feed point

By substituting the measured time delay from Figures 5 and 6 the measured ε_r can be found from (4.1)

$$\varepsilon_r = \left(\frac{1.27x10^{-2} + 3x10^{8} X80x10^{-12}}{1.27x10^{-2}} \right)^2 = 8.2 , \tag{4.3}$$

which is close to 9 the target ε_r as provided from TPL. However, there is some error since the rise time of the pulse (about 60 ps) is not short compared to the time delay.

4.2 Transmission measurements

We can find the ε_r from transmission measurements. Transmission measurements may also give us information about loss and dispersion. The total transmission coefficient can be found as multiplication of the transmission coefficient between air and left wall of the slab and right wall of the slab and air.

$$T = T_1 T_2 = \frac{2Z_L}{Z_L + Z_0} \frac{2Z_0}{Z_L + Z_0} = \frac{4\sqrt{\varepsilon_r}}{\left(\sqrt{\varepsilon_r} + 1\right)^2} \tag{4.4}$$

$$Z_L = \varepsilon_r^{-1/2} Z_0 = \text{wave impedance of slab}$$

$$Z_0 \cong 377\,\Omega = \text{wave impedance of air}$$

From (4.4), one can find the ε_r in terms of the transmission coefficient as

$$\varepsilon_r = \left(\frac{2 - T + \sqrt{4 - 4T}}{T} \right)^2 \tag{4.5}$$

Figures 7 and 8 are devoted to transmission measurement results for fast B-dot and D-dot probes, respectively. One can see what may be the capacitance effect due to the reflected field between the D-dot sensor and the slab reaching the sensor in figure 8. This is associated with the D-dot sensor (as expected due to electric field coupling from the slab), but not the B-dot sensor. The field was measured by B-dot and D-dot sensors, the measured field with slab was normalized by multiplying it with 1/T. Table 1 presents the measured transmission coefficients and analytically calculated ε_r values from (4.5). Figures 7 and 8 show this slab does not have dispersion that affects our experiments because the field without slab and normalized field with slab are almost identical.

Table 1. Measured transmission coefficients and calculated ε_r values from them

	T	ε_r
B-Dot	0.798	6.93
D-Dot	0.8	6.85

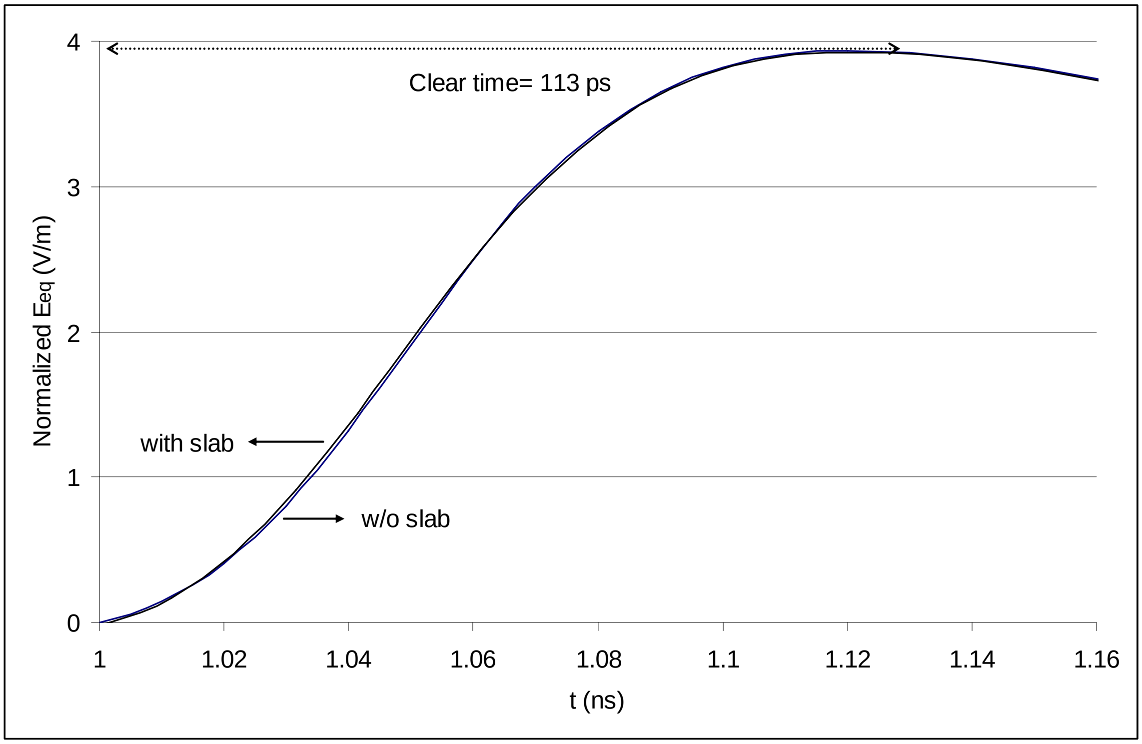

Figure 7. Transmission measurement for fast B-dot probe

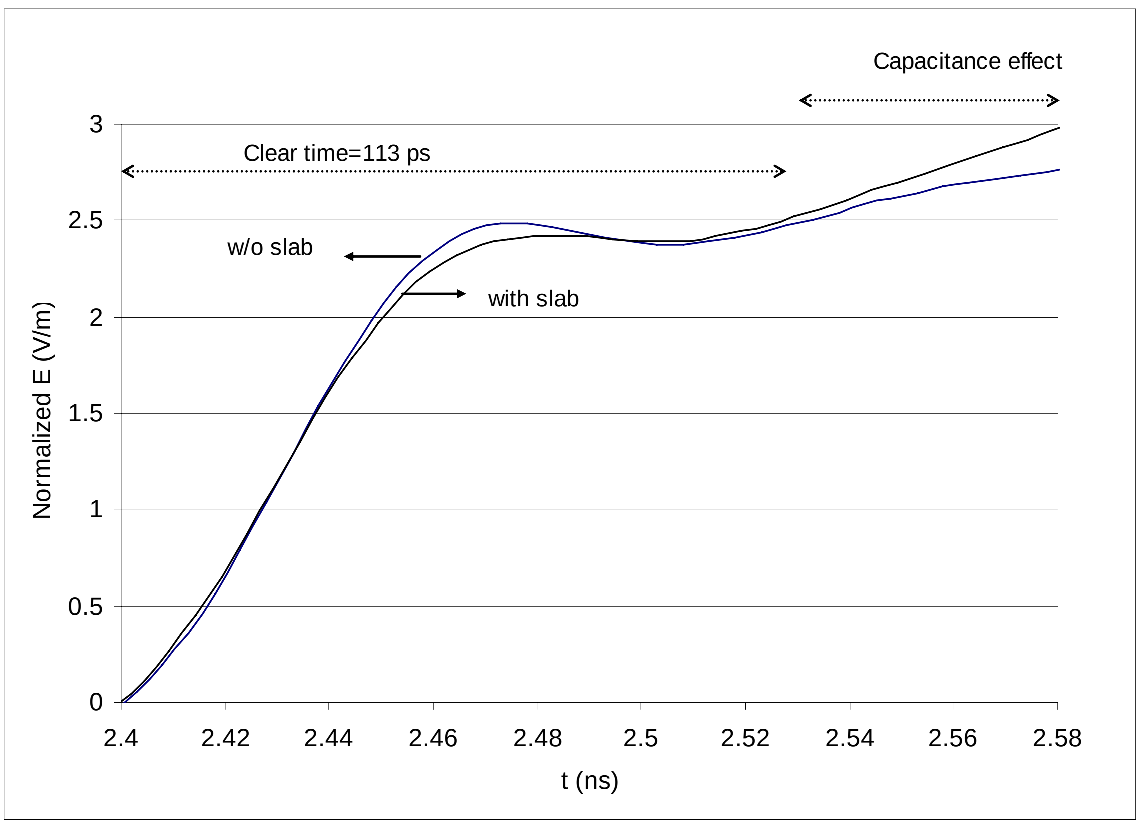

Figure 8 Transmission measurement for fast D-dot probe

4.3 Reflection measurements

The relative dielectric constant can be written as a function of reflection coefficient as

$$\varepsilon_r = \left(\frac{1-\Gamma}{1+\Gamma}\right)^2, \tag{4.6}$$

where Γ is the reflection coefficient.

In the conical transmission line, the field amplitude decreases proportional to 1/R. For this reason, one should consider the field correction factor for reflection measurements. Figure 9 shows these distances used for these corrections.

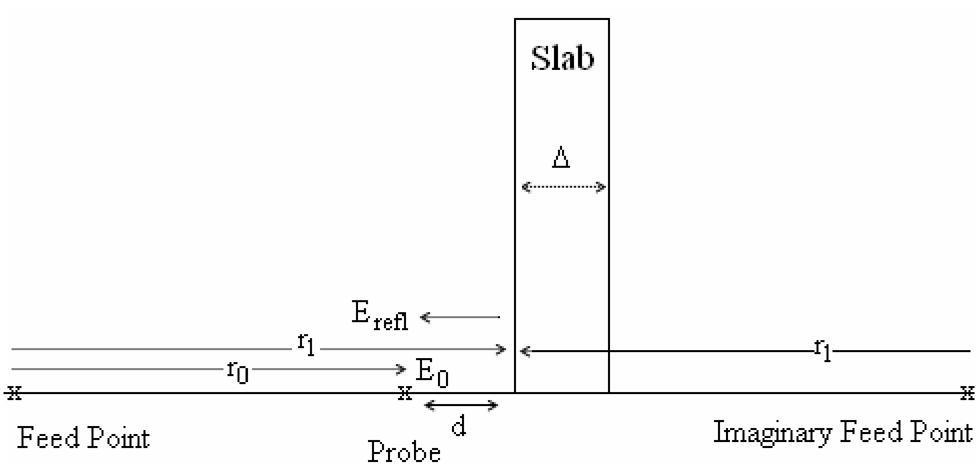

Figure 9 Distances used for field correction.

We can write the ratio of the reflected field to the incident field as

$$\frac{E_{refl}}{E_0} = \Gamma \frac{r_0}{r_1} \frac{r_1}{r_1+d} = \Gamma \frac{r_1-d}{r_1+d}. \tag{4.7}$$

The reflected filed can not be measured directly. Therefore, first we measure the incident field without slab then we measure the sum of the reflected and incident field. Subtracting the incident field from the total field gives us the reflected field.
One can define a field correction factor from (4.7) as

$$\text{Correction factor} = \frac{r_1-d}{r_1+d} \tag{4.8}$$

Table 2 is devoted to

Note that, in our experiments we have used B-dot and D-dot sensor located at 30 cm and 71 cm away from the feed point, respectively. One can see r_0, r_1, Δ and correction factor values for B-dot and D-dot probes measurements in table 2.

Table 2. r_0, r_1, Δ and correction factors for B-dot and D-dot probes measurements

	B-Dot	D-Dot
r_0	30 cm	71 cm
r_1	32 cm	73 cm
Δ	1.27 cm	1.27 cm
Correction Factor	0.88	0.95

Figure 10 and 11 are devoted to Reflection coefficient for B-dot and D-dot probe after field correction.

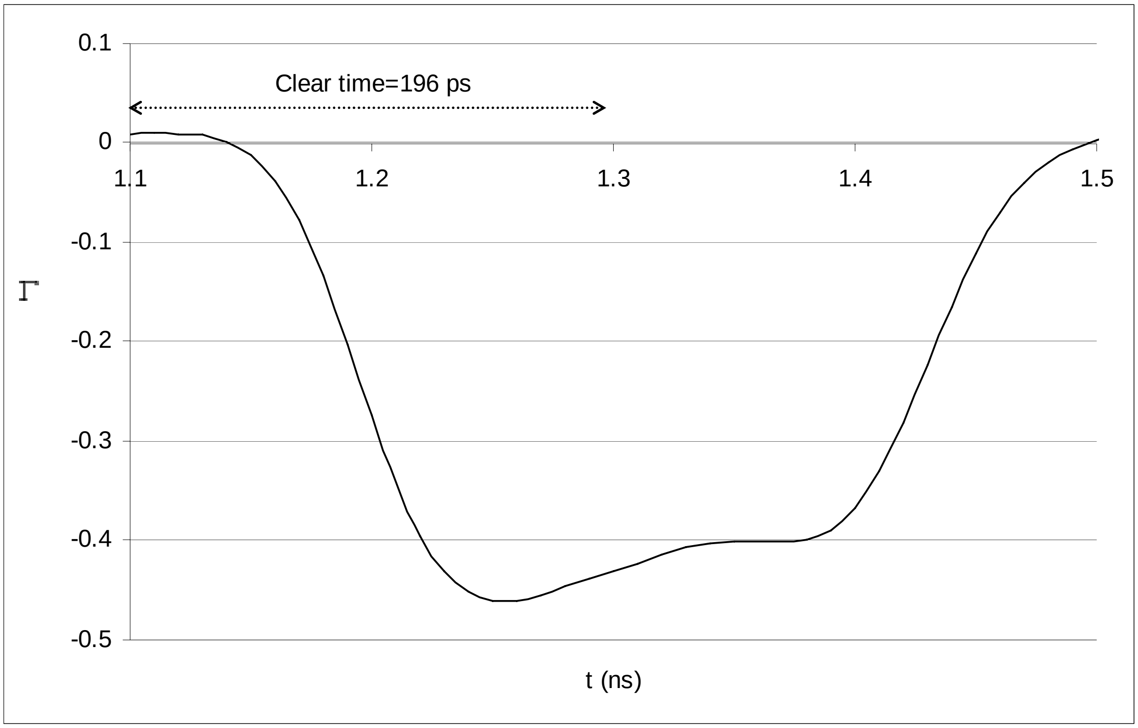

Figure 10. Reflection coefficient for B-dot Probe after field correction

As seen from table 3, one can calculate the ε_r values for measured Γ values by (4.6)

Table 3. Measured Γ and ε_r values.

	Γ	ε_r
B-Dot	-0.45	7
D-Dot	-0.42	6

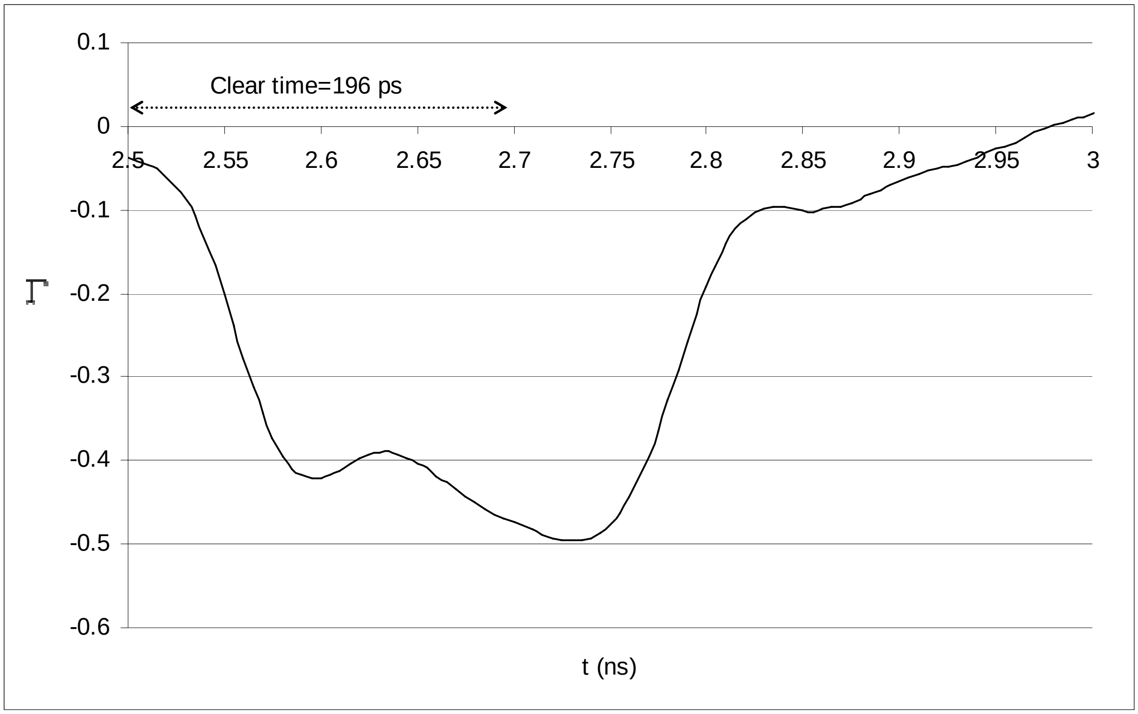

Figure 11. Reflection coefficient for D-dot Probe after field correction

From Table 3, we can easily conclude that we have not observed any loss. However, our measurements are not yet sufficiently accurate.

Conclusion

We have determined dielectric constant and dispersion characteristics of a sample slab that can be used as a layer of a focusing lens. We have used three different techniques which are time-delay, transmission and reflection measurements.

Time-delay measurement is easiest and more accurate way to determine ε_r. The dielectric constant of the slab is measured as $\varepsilon_r = 8.2$, which is close to the target $\varepsilon_r = 9$.

Transmission and reflection measurement experiments were performed to find ε_r, dispersion and loss. We did not observe any dispersion or loss that affect our final experimental setup. However, the measured ε_r values are lower than the target $\varepsilon_r = 9$. The differences between ε_r values may be caused by experimental error and most probably the interference between clear time and pulser rise time which is around 60 ps.

References

1. S. Altunc, C. E. Baum, C.G. Christodoulou, E. Shamiloglu, and C.J. Buchenaur, "Focal waveforms for various source waveforms driving a prolate-spheroidal impulse radiating antenna," Radio Sci., Feb. 2008, RS003775.
2. S. Altunc and C. E. Baum, "Lens Design for a Prolate Spheroidal IRA", Sensor and Simulation Note 525, Oct 2007.
3. S. Altunc, C. E. Baum, Christos G. Christodoulou and Edl Schamiloglu, "Lens Design with Constant Wavelength to Cross Section Ratio as ε_r varies : A Log-Periodic Lens", EM Implosion Memos, Memo 19, February 2008.
4. S. Altunc, C. E. Baum, Christos G. Christodoulou, Edl Schamiloglu, C. Jerald Buchenauer "Experimental Lens Design Parameters for a Prolate-Spheroidal IRA", EM Implosion Memos, Memo 23, May 2008.
5. Tom K. Liu, "Impedances and Field Distributions of Curved Parallel-Plate Transmission-Line Simulators," Sensor and Simulation Note 170, Feb 1973.