Multilayer Radome Design and Experimental Characterization of Scattering and Propagation Properties for Atmospheric Radar Applications

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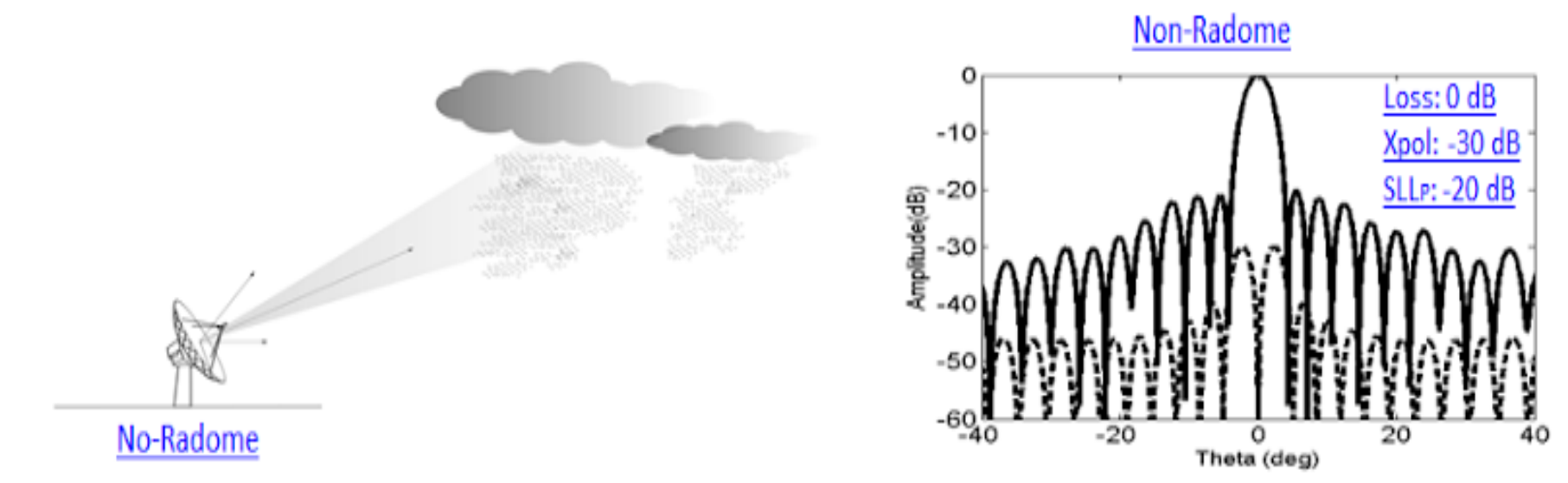
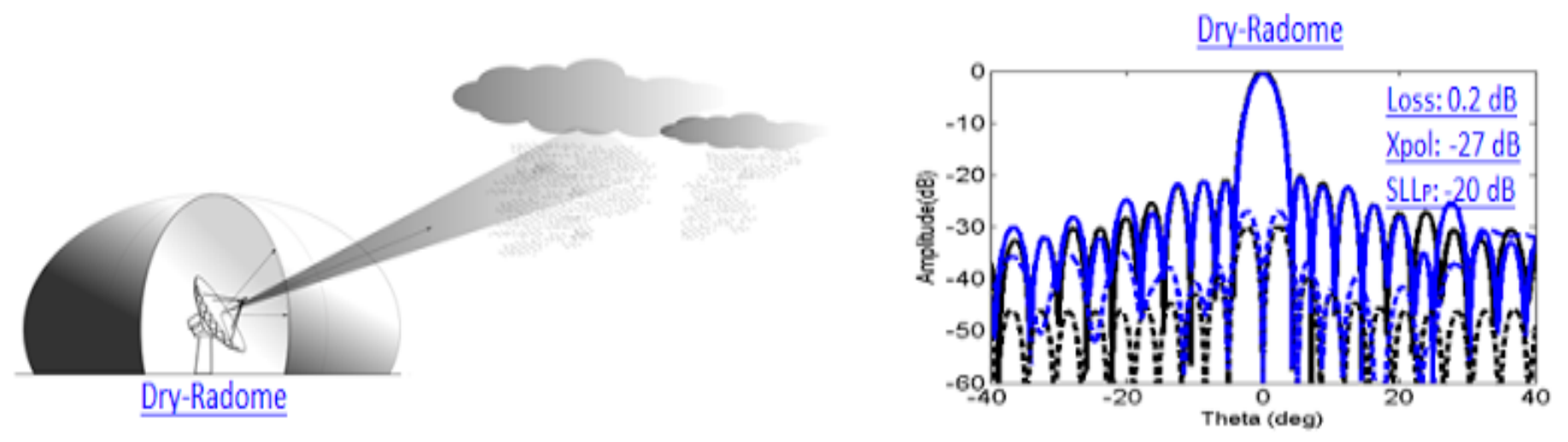
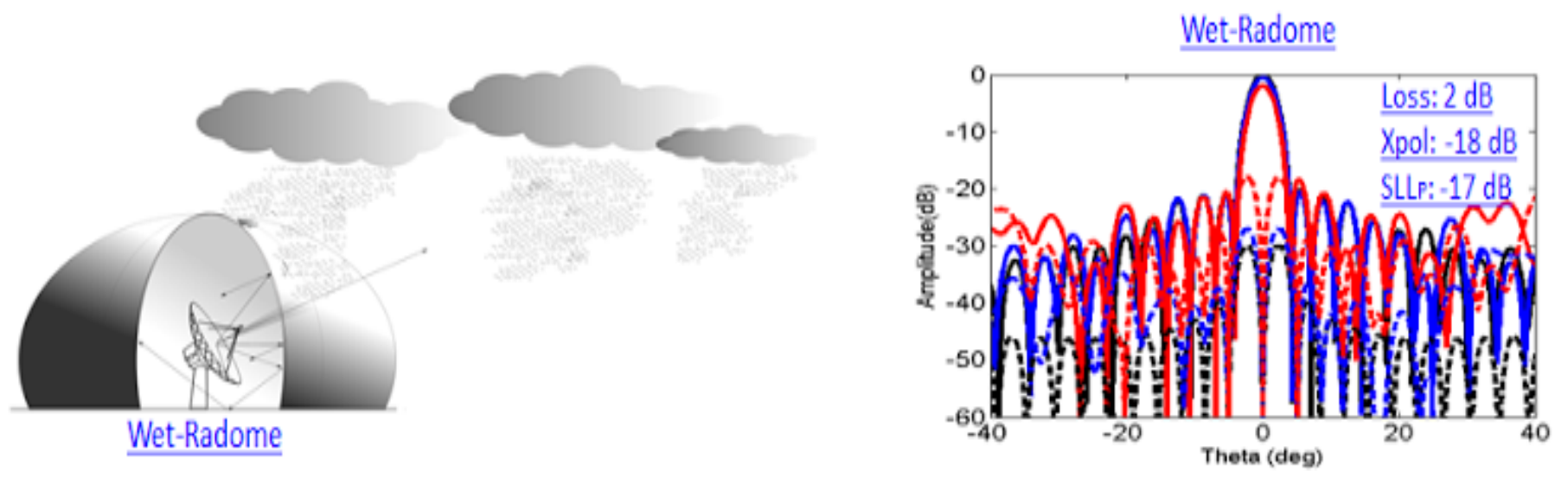
Abstract

For operational systems, the radome is a essential component since it minimizes the high wind load, reduces the need for a heavy and expensive pedestal, and provides consistent nominal temperatures that facilitate the operation and maintenance and improves the life cycle cost of the system. One adverse effect of the radome is the performance degradation of radio signals when they operate in the presence of water or ice. Water accumulated on the radome surface can significantly affect the radar signal. Depending on the frequency of operation, rain and wind conditions, shape, and material, a radome can significantly attenuate, reflect, and depolarize the radar or communication signals.







For frequencies below S-band the impact of wet radomes is relatively small and cannot be considered critical for radar operation. However, for higher frequencies water formation on the radome surface can significantly deteriorate the transmit and receive signals. The attenuation of radio signals on satellite systems that operate between 17 GHz and 22 GHz has been extensively analyzed in the past regarding the large attenuation in the radio signals caused by water accumulation on the radome surface (Gibble 1964; Blevis 1965; Cohen 1966; Anderson 1975; 51 Hendrix et al. 1989; Chang 1985; Fenn 1997, and Crane 2002).

$$t_g = \sqrt[3]{\frac{3\mu G a}{2\rho g}}$$

$$L = -0.34 + 1.61\sqrt[3]{aG}$$

$$0.05 < G < 25mm\ h^{-1}$$

G *represents volumetric flow rate or rain rate (m.s^{-1})*
u *is the kinematic viscosity of water (kg.m^{-1}.s^{-1})*
ρ *is the density of water (kg.m^3)*
g *is the gravitational acceleration (m.s^{-2})*

Supposed Constraints	Requirements in alternate mode	Requirements in hybrid mode
$\lvert\Delta\rho_{hv}\rvert < 10\%$	-	*CPL* < -30 dB
$\lvert\Delta Z_h\rvert < 0.8$ dB	-	*CPL* < -27 dB
$\lvert\Delta Z_{dr}\rvert < 0.2$ dB	*CPL* < -20 dB	*CPL* < -40 dB
$\lvert\Delta K_{dp}\rvert < 10\%$	-	*CPL* < -28 dB

Yanting Wang , V Chandrasekar and David McLaughlin, "Polarization isolation requirements for linear dual-polarization weather Radar in simultaneous transmission mode of operation", IEEE Trans. On Geoscience and Remote Sensing, Volume 44, Issue 8, pp. 2019 – 2028, Aug. 2006.

Previous models assumed that the water formation on top of the radome is composed of a thin water film. However, for hydrophobic materials the assumption fails. Considering that the droplets are small compared to the wavelength (in the case of S-, C-, and X-band), the Maxwell-Garnet mixing formulation can be used. Expression estimates the effective dielectric constant based on a fraction volume (f) of the droplets and air in the specified volume,

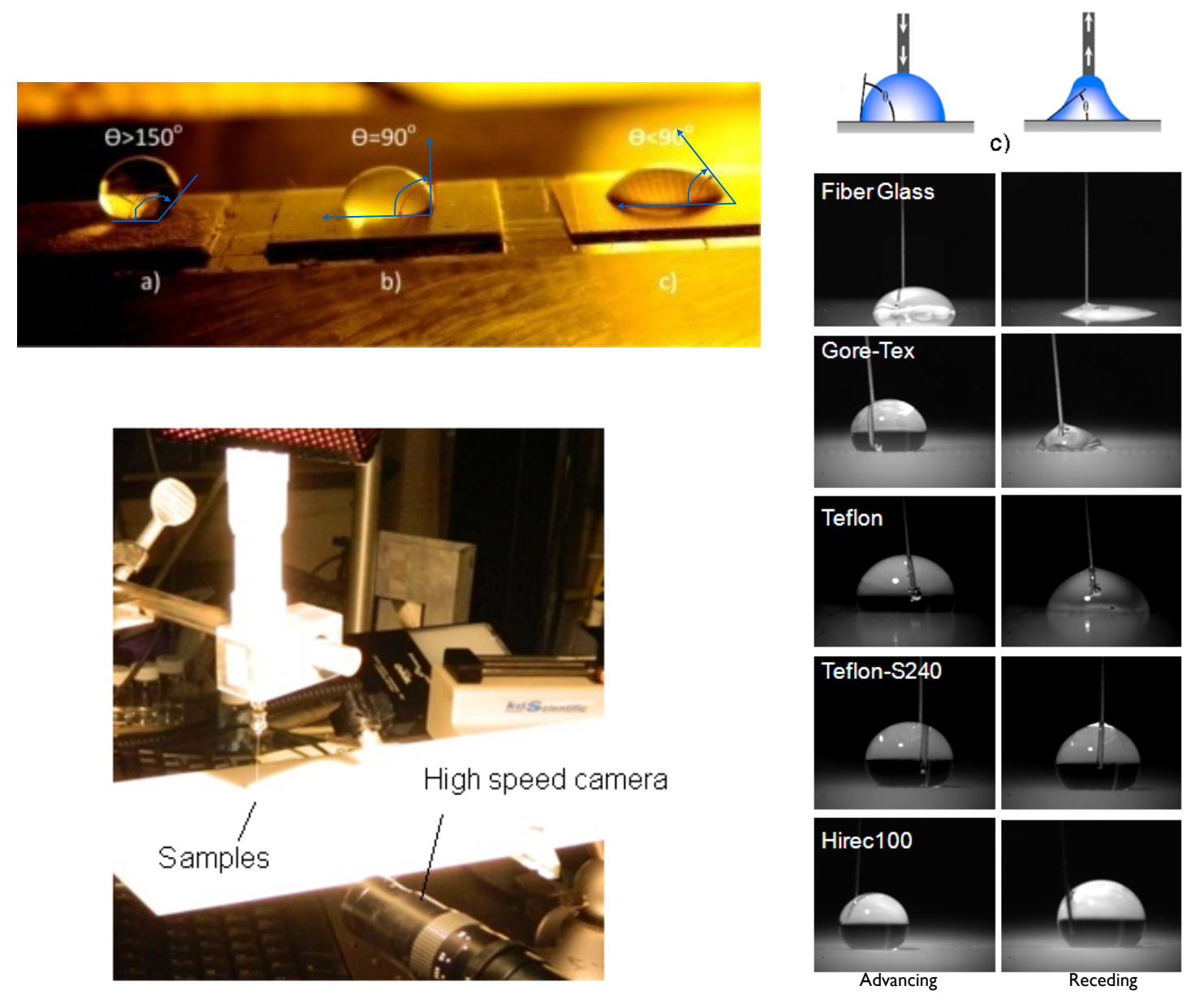
$$\varepsilon_{eff} = \varepsilon_2 + \frac{3f\varepsilon_2(\varepsilon_1 - \varepsilon_2)}{\varepsilon_1 + 2\varepsilon_2 - f(\varepsilon_1 - \varepsilon_2)}$$

where f is the fractional volume of formed water droplets with dielectric constant (e1) over the radome surface with dielectric constant (e2).

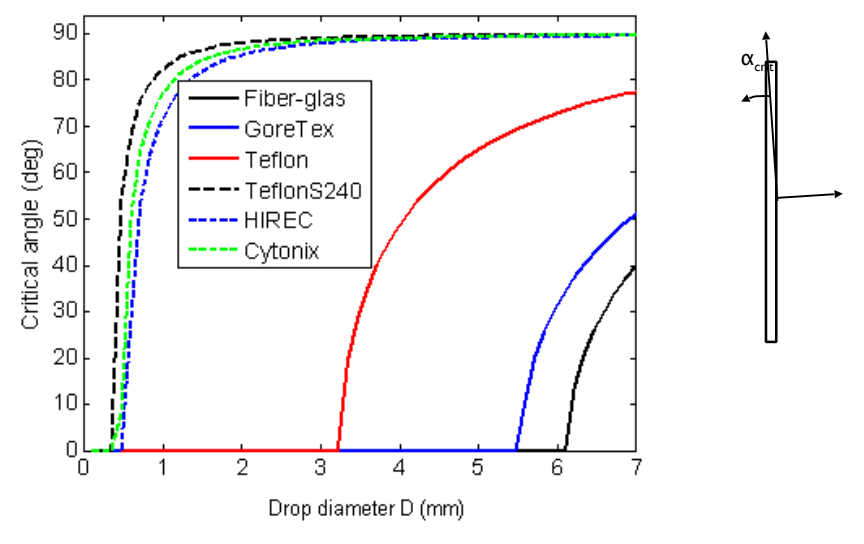
Previos Results

Drop Expansion and Contraction Method

The model proposed consists of estimating the attenuation, reflection, and depolarization of the radar signals that pass through to a wet radome as a function of the radome shape, frequency, incident angle, radome skin material, and rain conditions. The input parameters are raindrop-size distribution, frequency of operation, radome geometry, stack-up, and materials.



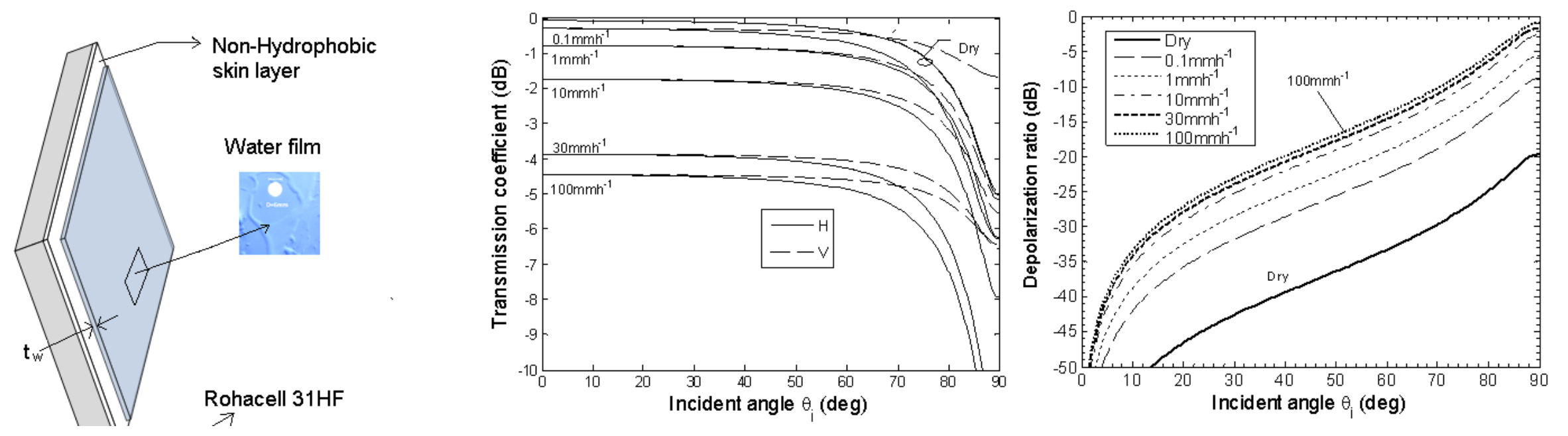
$$\alpha_{crit} = \sin^{-1}\left(\frac{6k^{-2}\sin\left(\pi - \frac{1}{2}\sin\theta_H\right)(\cos\theta_R - \cos\theta_A)}{D^2}\right)$$



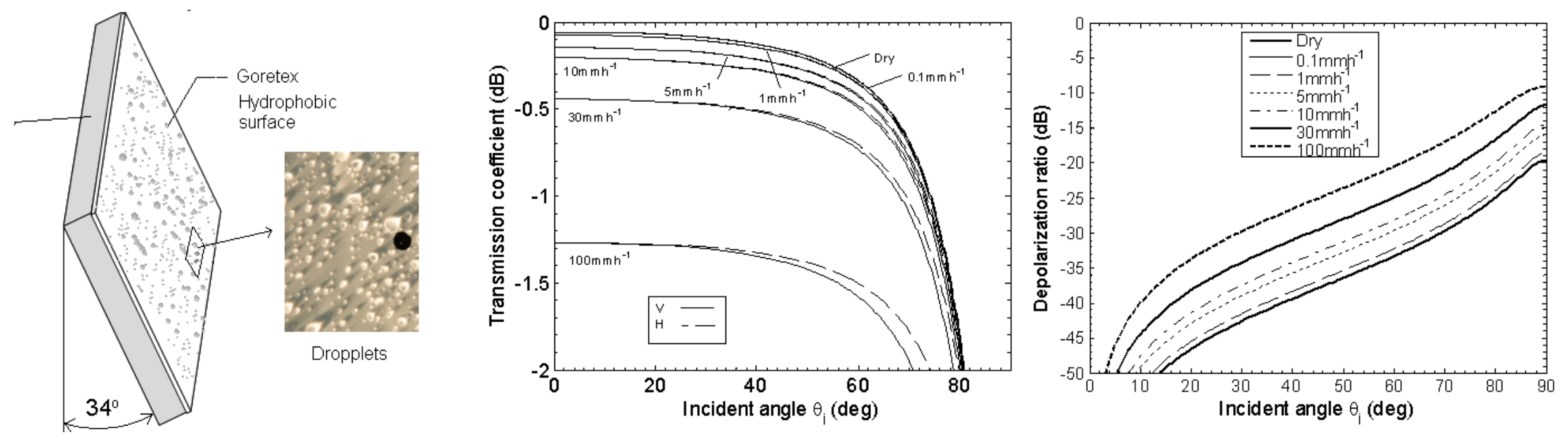
Material	Category	θ_A	θ_R	θ_H
Fiber Glass	None	105°	15°	82°
GoreTex	Hydrophobic	120°	47°	73°
Teflon	Hydrophobic	120°	79°	41°
Teflon S240	Super Hydrop.	150°	144°	6°
Hirec100	Super Hydrop.	151°	144°	7°
Cytonix WX2100	Super Hydrop.	160	151	9

Jorge L. Salazar, V. Chandrasekar, Jorge M. Trabal, Paul Siquiera, Rafael Medina and D. McLaughlin. "A drop size distribution (DSD) based model for evaluation of the performance of wet radomes for dual polarized radars." Manuscript accepted J. Atmos. Oceanic Technol. (Jan. 28. 2014).

The model is subdivided into four parts, or sub-models. The first part consists of projecting the rain on a flat tilted surface called a unit cell and estimating the drop-size distribution on the unit cell surface. The second part introduces the characteristics of the skin radome surface and re-estimates the drop-size distribution as a function of the tilted angle and hydrophobic characteristics of the radome surface. The third section estimates the equivalent effective dielectric constant of a volume that confines the droplets and air. The fourth and last sub-model includes the wet layer in a multilayer radome structure and estimates the attenuation, reflection, and depolarization as a function of the incident angle (in elevation and azimuth), rainfall rate, and frequency.



The figure above shows one-way attenuation for a non-hydrophobic skin layer (center), which indicates that a significant attenuation (1.6 dB to 4.5 dB) can be produced for moderate and high rain intensities (10 mmh-1 to 100 mmh-1). A small variation (less than 0.01 dB) between H and V is observed in the near to broadside; however, it increases up to 0.5 dB at a 45 degree incident angle. At broadside, negligible depolarization is produced (right). However, when the antenna is scanned, the wet radome significantly affects the polarization of the radar signal. At 45 degree scanning in the azimuth plane, it is observed that the radome can degrade cross-polarization by about 20 dB.

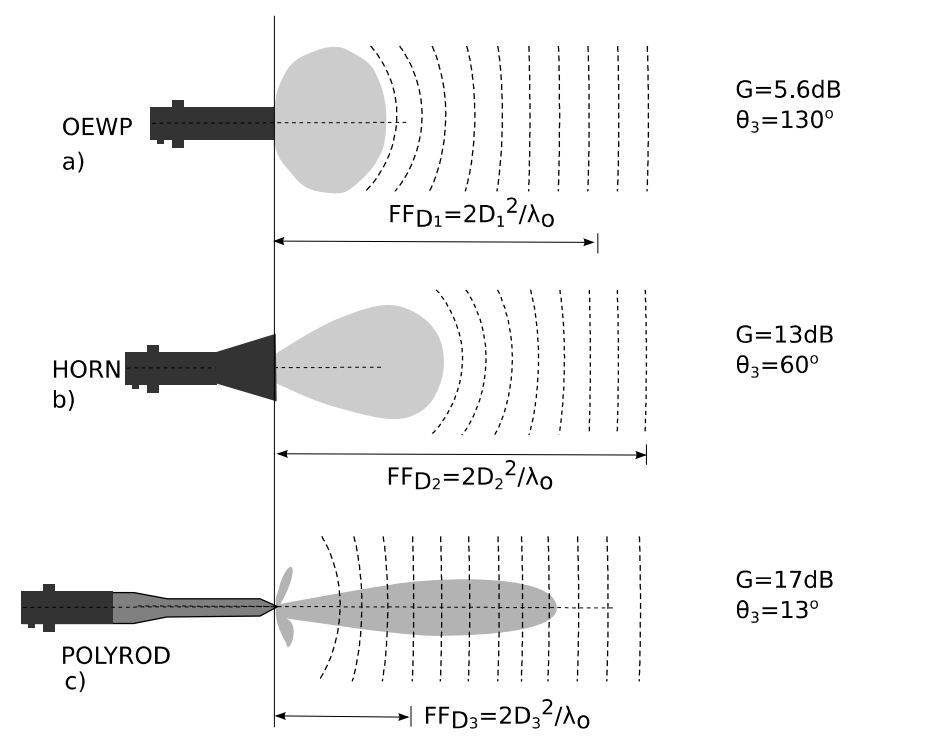


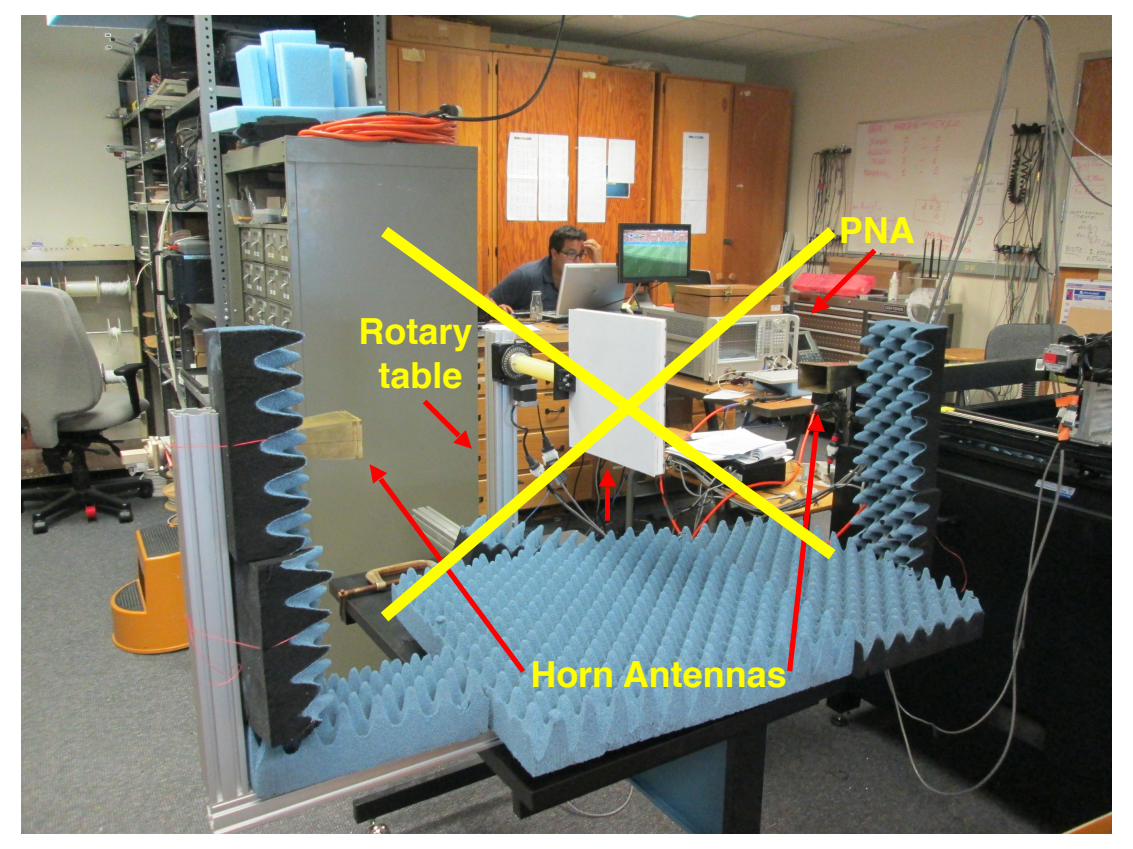
In this case hydrophobic material was used (Gore-Tex) since the material (Teflon-based) is commonly used for weather radome radars. The results indicate that the attenuation is drastically reduced compared to the previous case (non-hydrophobic surface) by about 2.9 dB exposed to 100 mmh-1. As with the previous case, small differences in attenuation existed between H and V with respect to beam position. For 45 degrees, the cross-polarization induced by the radome is about 14 dB (~16 dB better than in the previous case).

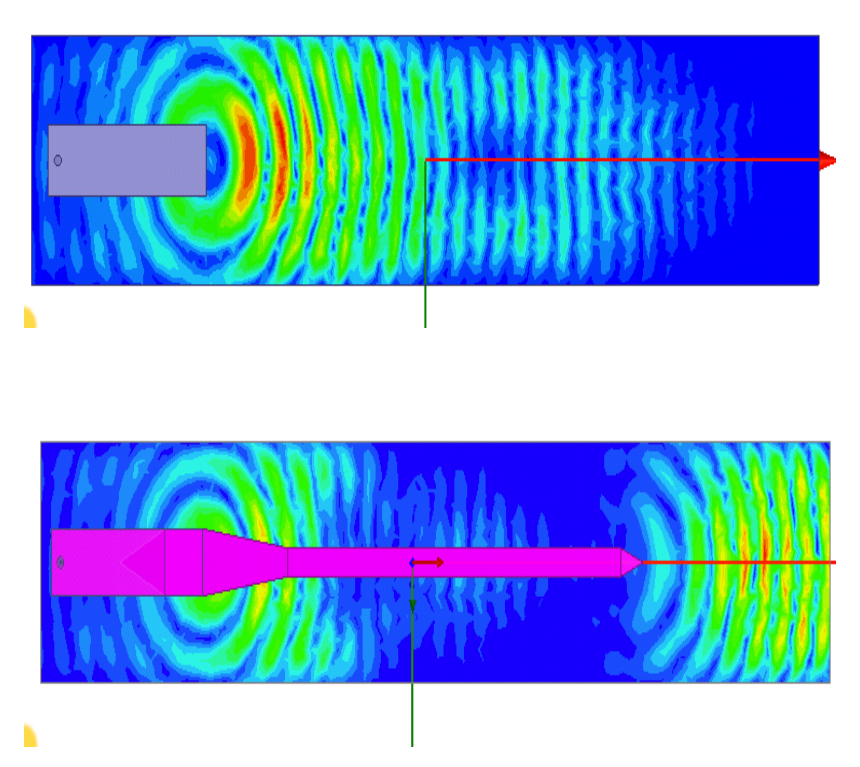
Testing Bed

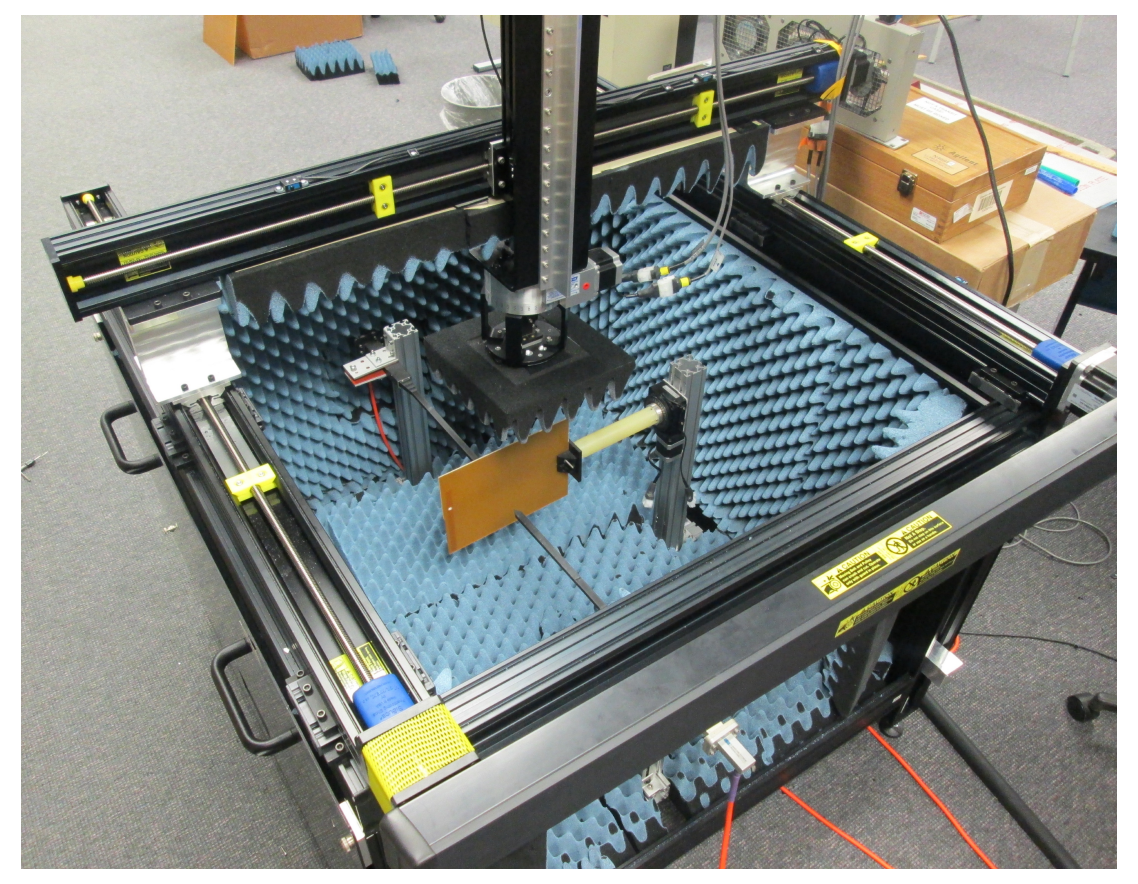
The testing bed was built using a Power Network Analyzer, a motor for the turning table, a computer to succesfully turn the radome while gathering measurements using using LabView and MATLAB as interfaces.

The Far-Field (FF) distances of each antenna were: 29 inches – Probe, 79 inches – Horn, and 2 inches - Polyrod.



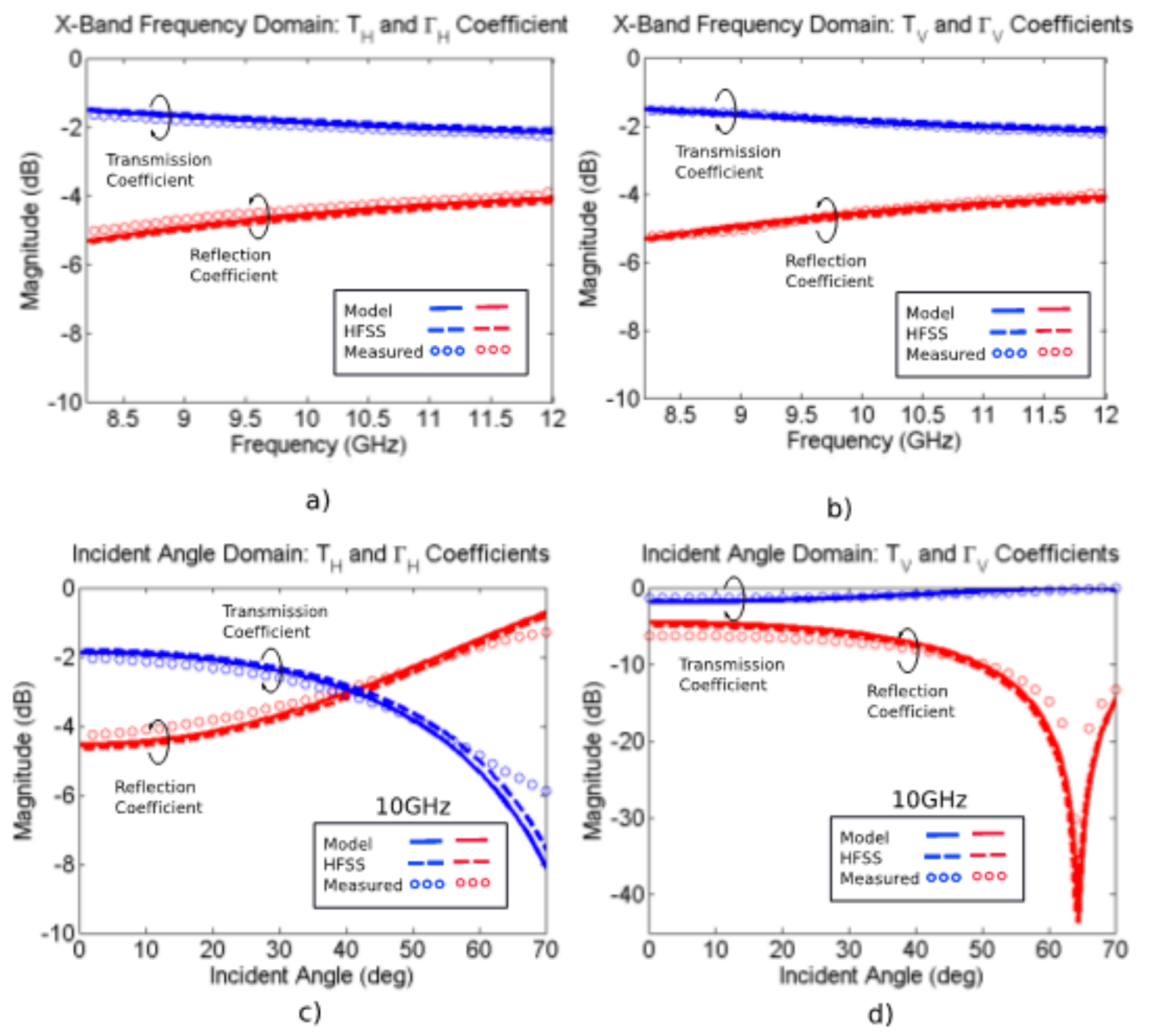






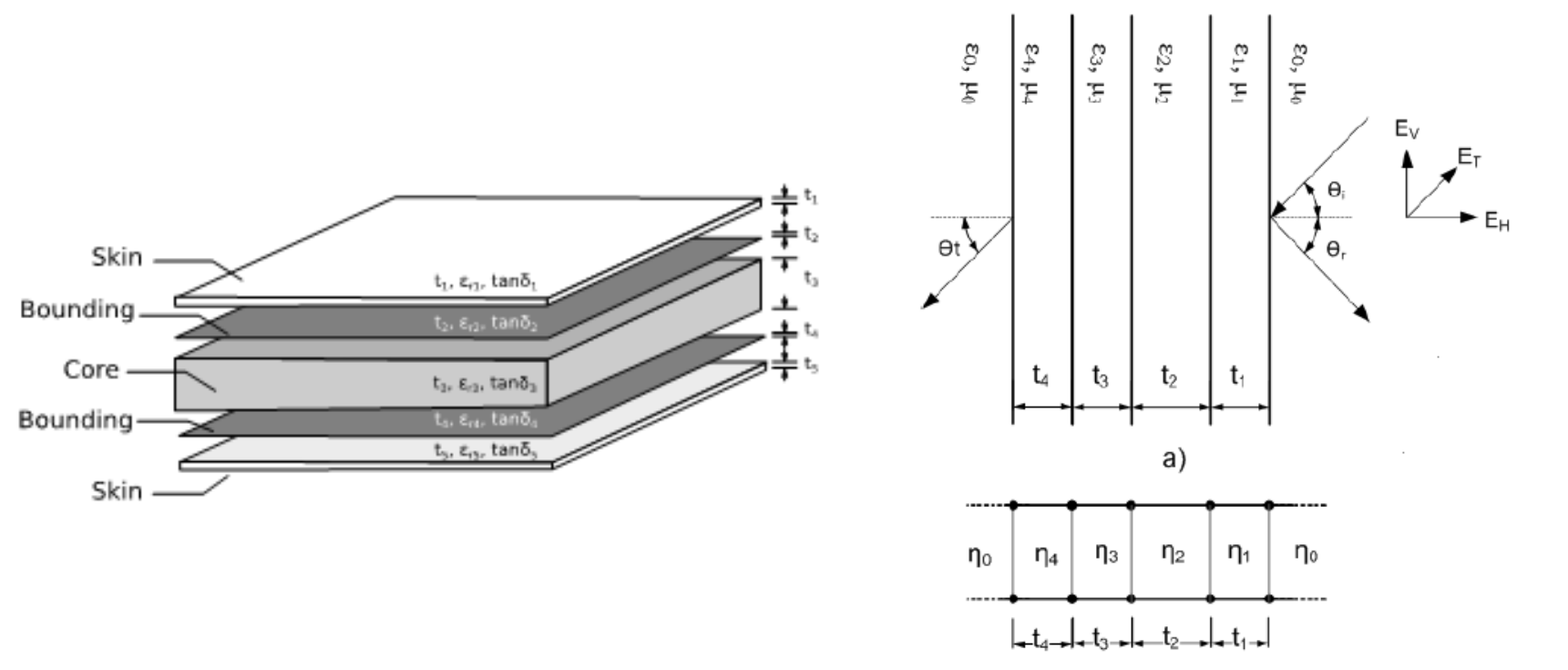
Layer FR4 - Thickness of 20.2184 mm

Results for FR4 showed that there is an agreement in the mesurements when compared to the HFSS and the mathematical model for both frequency and angle domain. After 55 degrees there is a mismatch that can be attributed to irregular incident plane of the antennas on the radome given the tilted angle.



7 Layer Radome Model

The 7 layer radome was composed of three major materials: 2 layers of Teflon, 2 layers of Rohacell, and 3 layer of Epoxy glue. Multilayer radome propagation characteristics were derived using transmission line theory as shown below.



$$\theta_{t(n+1)} = \cos^{-1}\left(\sqrt{1 - \frac{\varepsilon_r(n)}{\varepsilon_r(n+1)}\sin(\theta_{in})^2}\right)$$

$$\eta_{t(n)} = \eta_{(n+1)}\left[\frac{\eta_{(n)} + j\eta_{(n+1)}\tan(\beta_{(n+1)}t_n)}{\eta_{(n+1)} + j\eta_{(n)}\tan(\beta_{(n+1)}t_n)}\right]$$

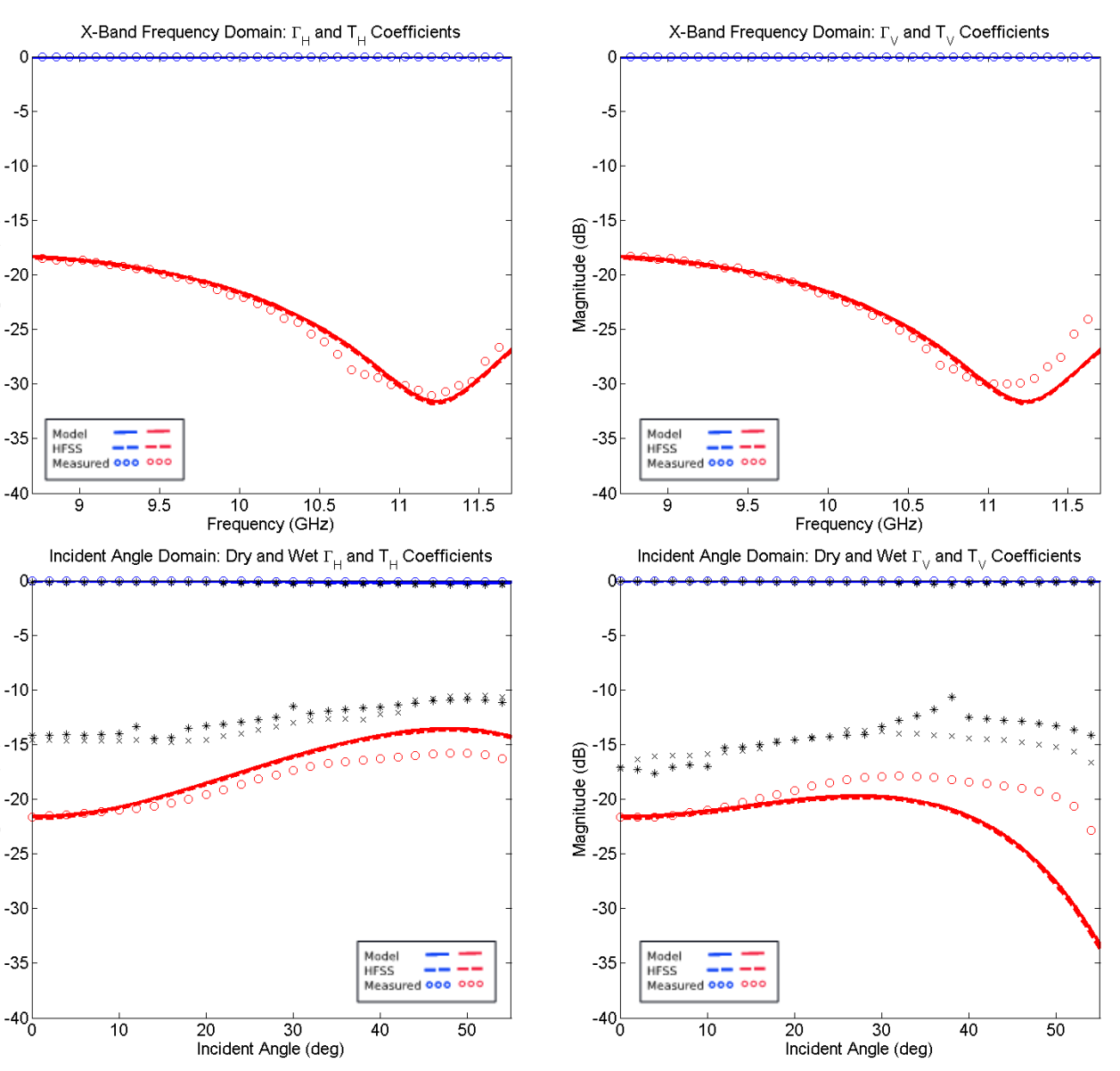
$$\Gamma_H(t_n) = \frac{\eta_{(n+1)}\cos(\theta_{t(n+1)}) - \eta_{t(n)}\cos(\theta_{in})}{\eta_{(n+1)}\cos(\theta_{t(n+1)}) + \eta_{t(n)}\cos(\theta_{in})}$$

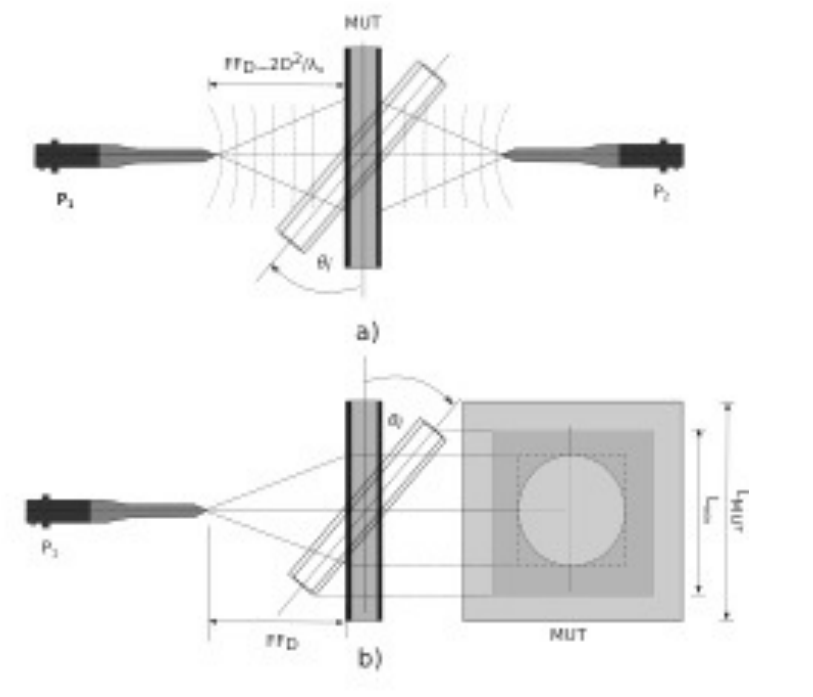
$$T_V(t_n) = \frac{2\eta_{(n+1)}\cos(\theta_{in})}{\eta_{(n+1)}\cos(\theta_{in}) + \eta_{t(n)}\cos(\theta_{t(n+1)})}$$

$$T_H(t_n) = \frac{2\eta_{(n+1)}\cos(\theta_{in})}{\eta_{(n+1)}\cos(\theta_{t(n+1)}) + \eta_{t(n)}\cos(\theta_{in})}$$

Results

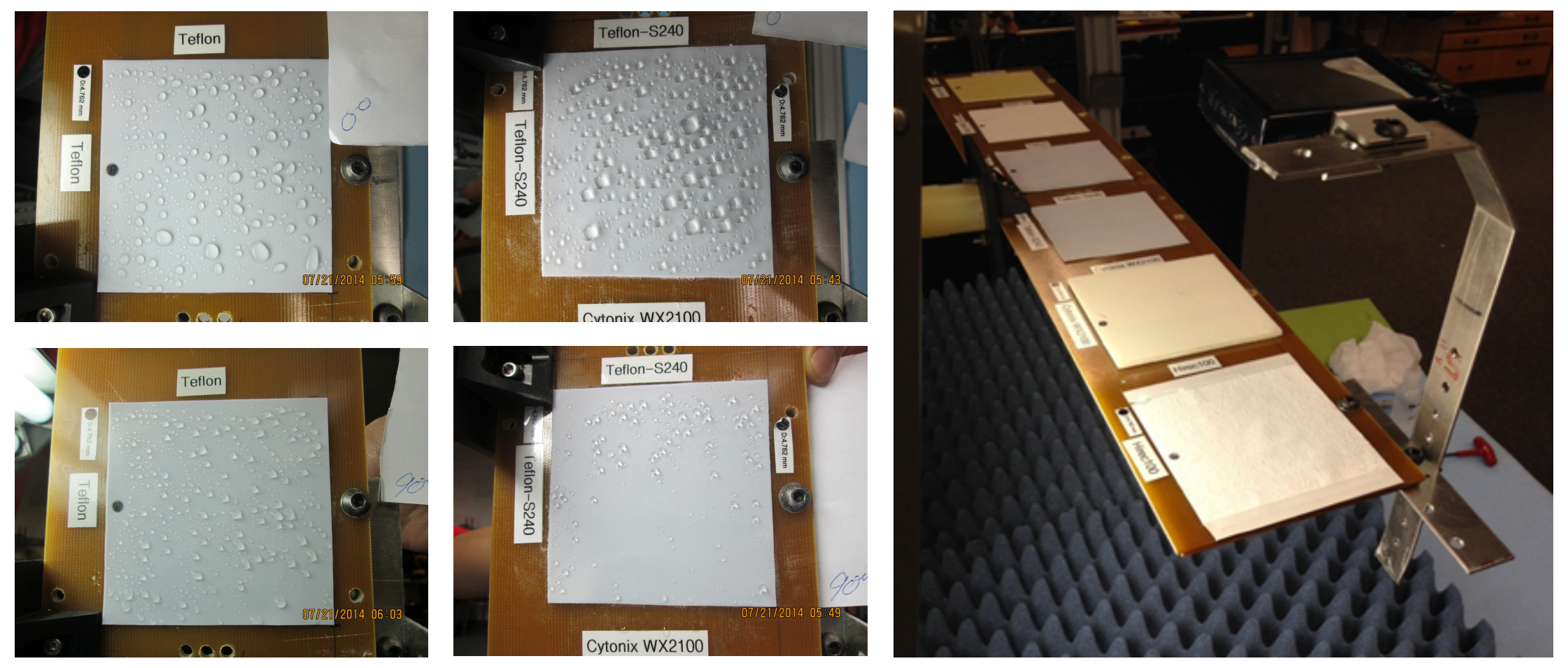
7 Layer Radome





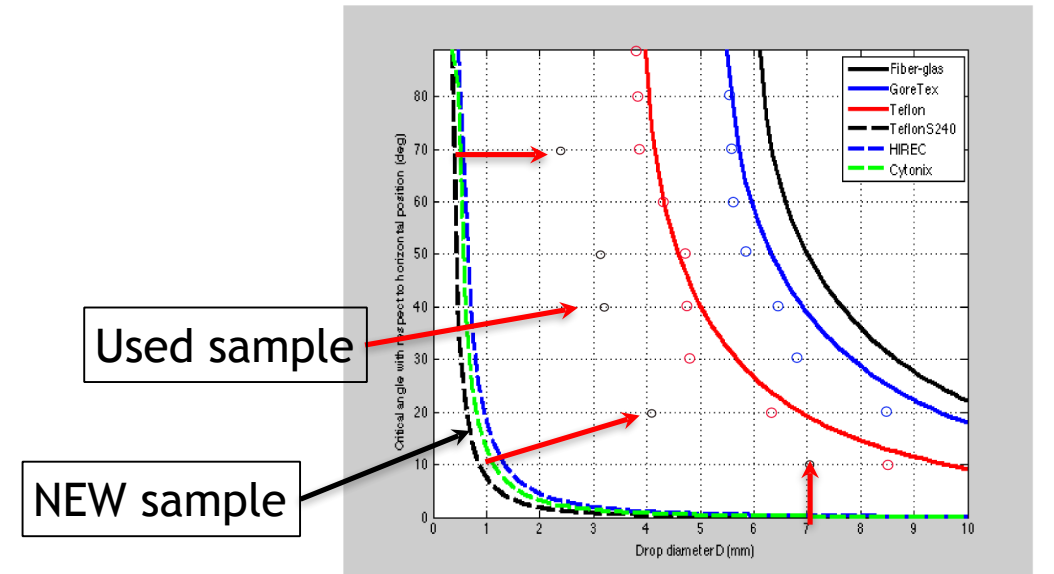
Conclusions

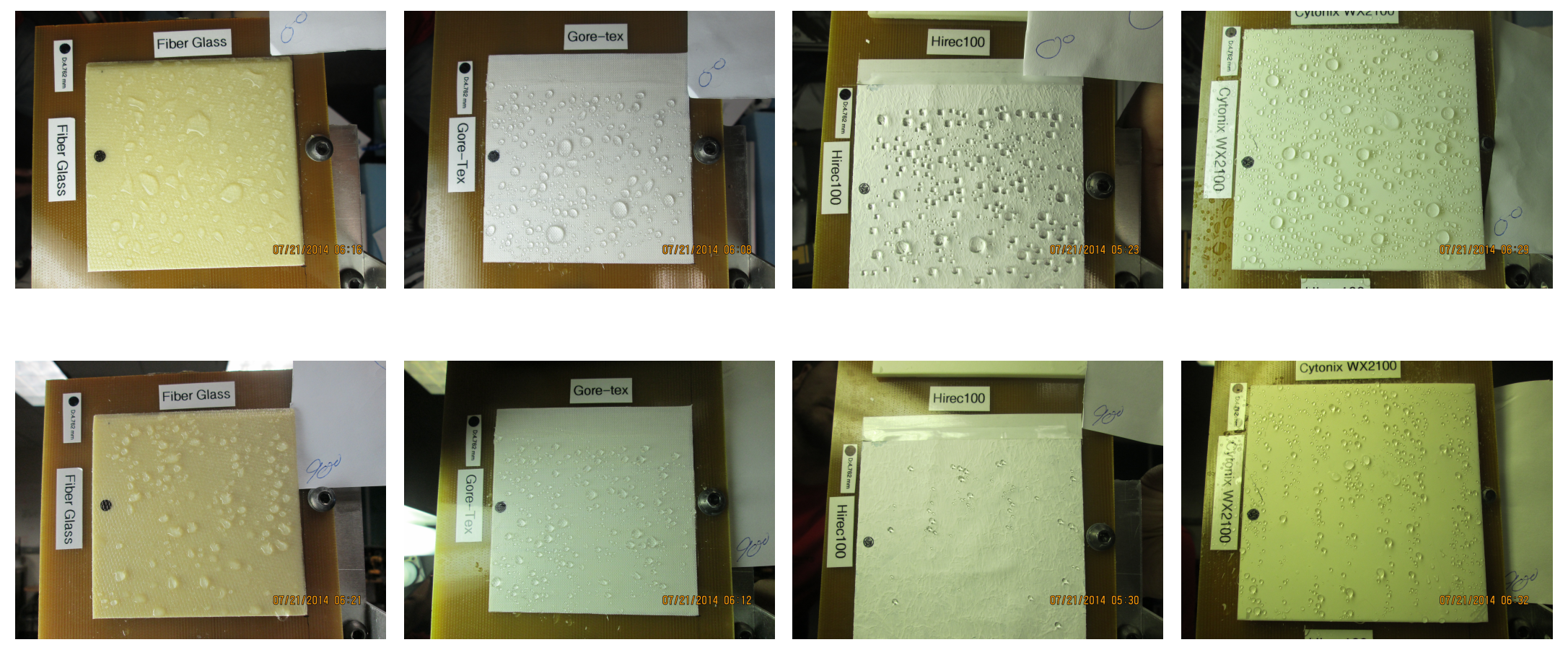
- Wet radomes affect significantly the polarimetric performance of radar signals.
- A new approach to estimate more realistic scattering properties of a radome surface as a function of rain rate, radome material, and geometry was presented.
- Results and validation procedure indicates the proposed model works and can be used for a new radar calibration process.



Future Work

1. Better characterization of rivulet formation on the radome.
2. Characterize polarimetric products suchs as differential reflective as function of the wet radome performance.
3. Use radar data to validate the effect of the wet radome performance in the polarimetric products.





References

[I] Jorge L. Salazar-Cerreño, V. Chandrasekar, Jorge M. Trabal, Paul Siquiera, Rafael Medina, Eric Knapp, and David J. McLaughlin, 2014: A drop size distribution (dsd)-based model for evaluating the performance of wet radomes for dual-polarized radars. J. Atmos. Oceanic Technol., 31, 2409–2430.

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