RADOME ANALYSIS TECHNIQUES

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Abstract

Radar Dome, or usually called Radome, is usually placed over the antenna as an antenna protector from any physical thing that can break it. Ideally, radome does not degrade antenna performance. In fact, it may change antenna performance and cause several effects, such as boresight error, changing antenna side lobe level and depolarization. The antenna engineer must take stringent analysis to estimate the changes of performance due to placing radome.

Methods in the analysis using fast receiving formulation based on Lorentz reciprocity and Geometrical Optics. The radome has been tilted for some angle combinations in azimuth and elevation with respect to the antenna under test in order to get the difference responses.

From the results of measuring and analyzing the radome, it can be concluded that radome can change the antenna performance, including boresight shift, null fill-in and null shifting for difference signals, and changing antenna radiation pattern. In the CATR measurement with two reflectors, the extraneous signal which originates from feed is minimized by adding absorber at the side of the feed. Several things that affect to the accuracy of the simulation program are extraneous signal, loss tangent uncertainty, diffraction, and dielectric uncertainty and inhomogeneity.

Key Words: Radome, CATR, Antenna, Boresight Error

1. INTRODUCTION

The advancement of technologies in antenna's world stimulates increasing new demands to get better antenna performance on the design process for all components, including radome. Radome is dielectric material which is placed over the antenna in order to protect from its physical environment.

Radome ideally does not degrade the antenna performance because radome is radio frequency (RF) transparent. In fact, some effects occurred in antenna performance with radome. Measuring the antenna performance with and without radome and analyzing the effects caused by radome in analysis electrically are intended to ease analyzing boresight, transmitted signal, reflected signal, and transmittance on plane thin-wall radome in this assignment. Methods in the analysis using fast receiving formulation based on Lorentz reciprocity and Geometrical Optics. The radome has been tilted for some angle combinations in azimuth and elevation with respect to the antenna under test in order to get the difference responses.

In the CATR measurement with two reflectors, the extraneous signal which originates from feed is minimized by adding absorber at the side of the feed. Several things that affect to the accuracy of the simulation program are extraneous signal, loss tangent uncertainty, diffraction, and dielectric uncertainty and inhomogeneity.

2. INTRODUCTION OF RADOME

Radome is abbreviation from radar dome. It is placed over the antenna for protection from its physical environment. Radome ideally does not degrade the antenna performance because radome is radio frequency transparent. Radome is made from dielectric materials. In fact, some effects occur in antenna performance when antenna is covered by radome. This chapter explains about materials and constructions of radome and some effects in antenna performance with radome.

2.1 Dielectric Wall

The wave that penetrates from a medium into different medium with the angle θ_i will be partly reflected with reflected angle and transmitted with incidence angle depending on the permittivity of those two materials. That can be noted in Snell's law as:

$$\frac{\sin\theta_t}{\sin\theta_i} = \frac{\sqrt{\varepsilon_i}}{\sqrt{\varepsilon_t}}$$

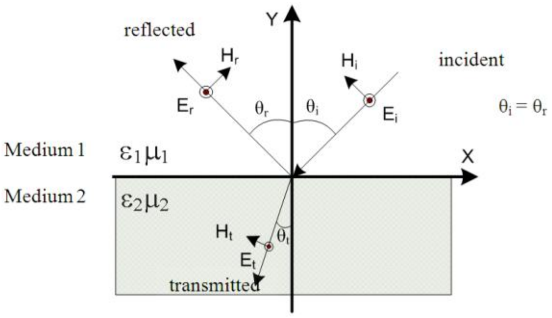

Figure 2.1 The wave penetrating the dielectric material.

When the wave propagates through the dielectric material, it will lose some energy. Power losses in radome are caused by the ability of the radome to store electrical energy and wasting electrical energy as heat. Low dielectric materials are desirable to make radome for communications because these deal with low intensity signals. Any loss signal can be critical for communication systems. A measure of power loss in dielectric material to total power transmitted trough dielectric is called loss tangent.

Two categories for radome wall constructions are:

- Solid (monolithic) design, commonly made of the resin incorporating reinforcements such as chopped glass fibers;
- Sandwich design, combinations of high-density (high relative dielectric constant) and low-density (low relative dielectric constant) materials.

Sandwich radome is more broadband than monolithic radome and has higher strength-to-weight ratio.

Forward and reverse propagating waves on the N-layer dielectric radome wall can be formulated by:

$$\begin{bmatrix} E_0^+ \\ E_0^- \end{bmatrix} = \left[\prod_{i=1}^{N} \frac{1}{T_i} \begin{pmatrix} e^{j\gamma_i t_i} & R_i e^{-j\gamma_i t_i} \\ R_i e^{j\gamma_i t_i} & e^{-j\gamma_i t_i} \end{pmatrix}\right] \times \frac{1}{T_{N+1}} \begin{bmatrix} 1 & R_{N+1} \\ R_{N+1} & 1 \end{bmatrix} \begin{bmatrix} E_{N+1}^+ \\ 0 \end{bmatrix}$$

where

t_i = layer thickness of i_{th} layer

R_i, T_i = Fresnel reflection and transmission coefficient

γ_i = propagation constant within the i_{th} layer

2.2 Boresight Error

Radome is made from dielectric material which distorts electromagnetic wave. The dielectric radome wall was bending the arrival angle relative to the actual arrival angle before electromagnetic wave enters the radome. Difference between the arrival angle relative to the actual arrival angle is called boresight error (BSE). The rate of change of BSE is defined as boresight error slope (BSES).

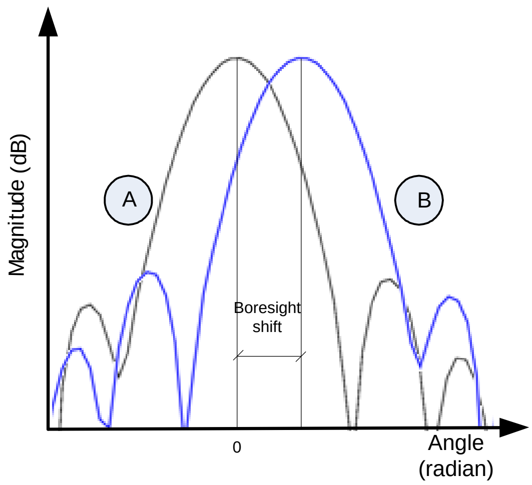

Figure 2.2 Boresight Error

Figure 2.2 illustrates that A is the original received signal without radome and B is the measured received signal of the antenna under test covered with radome. The peak of received signal is shifted. The difference angle between the peak of A and the peak of B is called boresight error/boresight shift. BSE depends on polarization, frequency, and antenna orientation. BSE can cause miss distance of a missile flying guidance trajectory.

2.3 Depolarization

Depolarization occurs when electromagnetic propagates through discontinuous electric and magnetic properties as permittivity ε and permeability μ. When electric field is parallel to the plane of incident it is referred to as Transverse Magnetic (TM) and when electric field is perpendicular to the plane of incident it is referred to as Transverse Electric (TE). Magnitude and phase differences between perpendicular ($\perp$) and parallel (//) of reflection and transmission coefficient will result in depolarization.

We may see depolarization affecting the electric field in terms of transmission coefficient and reflection coefficient at the intercept point on dielectric wall at angle θ of the incident electric field like the figure 2.3 below:

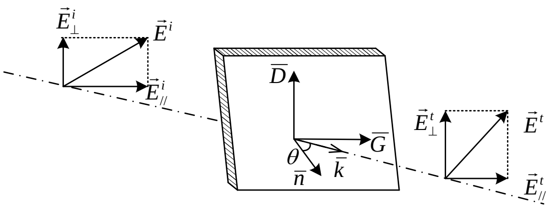

Figure 2.3 Depolarization effect

From the figure above, $\overline{n}$ is surface normal vector and $\overline{k}$ is the direction of propagation vector. The perpendicular vector is:

$$\overline{D} = \overline{n} \times \overline{k}$$

$$\overline{D} = \frac{(n_y k_z - n_z k_y)a_x + (n_z k_x - n_x k_z)a_y + (n_x k_y - n_y k_x)a_z}{\sqrt{(n_y k_z - n_z k_y)^2 + (n_z k_x - n_x k_z)^2 + (n_x k_y - n_y k_x)^2}}$$

$$\overline{D} = d_x a_x + d_y a_y + d_z a_z$$

The parallel vector is:

$$\overline{G} = \overline{D} \times \overline{k}$$

$$\overline{G} = \frac{(d_y k_z - d_z k_y)a_x + (d_z k_x - d_x k_z)a_y + (d_x k_y - d_y k_x)a_z}{\sqrt{(d_y k_z - d_z k_y)^2 + (d_z k_x - d_x k_z)^2 + (d_x k_y - d_y k_x)^2}}$$

$$\overline{G} = g_x a_x + g_y a_y + g_z a_z$$

a_x, a_y, and a_z are unit vectors along the x, y, and z axes. $\overline{E}^i$ is the electric field of the wave incident on the wall and $\overline{E}^t$ is the transmitted wave after propagating wall radome.

2.4 Antenna Aperture

The physical aperture of a monopulse antenna is usually divided into four quadrants.

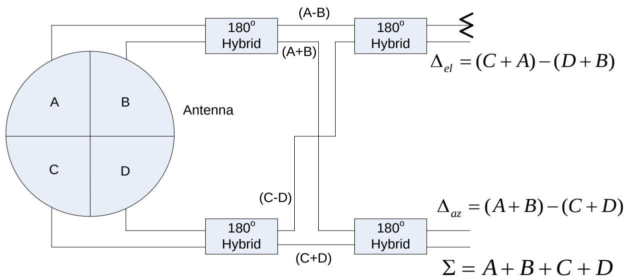

Figure 2.4 Four quadrants of monopulse antenna

It produces sum signal, azimuth difference signal, and elevation difference signal. Referenced to figure 2.4, summing amplitudes and phases of all quadrant apertures results sum signal. The sum of amplitudes and phases of aperture A and B subtracted by the sum of amplitudes and phases of aperture C and D results azimuth difference signal. The sum of amplitudes and phases of aperture A and C subtracted by the sum of amplitudes and phases of aperture B and D results elevation difference signal.

Extraneous signal may cause:

- Boresight error;
- Increasing side lobe level;
- Peak shifting in sum signal;
- Null shifting in difference signal;
- Null fill-in in difference signal;
- Changing the beamwidth of the antenna.

3. MEASUREMENT METHOD

The measurements require that the tested antenna is illuminated by a uniform plane wave. That will be achieved in the far field for range length r > $2D^2/\lambda$ in which many cases needs relatively long distances. Compact Antenna Test Range (CATR) technique can create plane wave fields at distances shorter when compared to the needed distance under the conventional Far Field criteria.

The configuration of CATR in measurements uses dual parabolic cylindrical reflectors. They are vertical and horizontal collimation reflectors. Figure 3.1 shows the CATR configuration for this measurement.

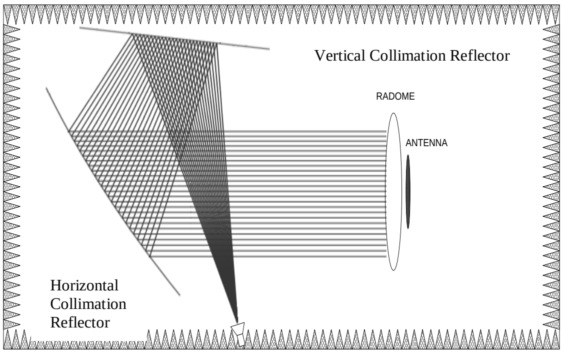

Figure 3.1 CATR configuration

To analyze plane wall radome covered antenna's performance, these measurement analyses use fast receiving formulation based on Geometrical Optics and Lorentz reciprocity. Ray tracing (Geometrical Optics Approaches) assumes transmitted waves to pass directly through the radome wall and reflected rays originate from the point of incidence. The radome is treated as local plane at each intercept point. Other words, GO makes assumption that electrical magnetic wave propagates as a plane wave.

The specifications of the thin-wall plane radome measurement are:

- Material : Polyethylene
- Shape : Plane-wall radome
- Dielectric constant : 2.25
- Loss tangent : 0.0004
- Thickness : 3 mm
- Radome diameter : 122 cm
- Antenna diameter : 60 cm
- Range from antenna : 15 cm
- Frequency : 8.6 – 10.6 GHz
- Polarization : Horizontal

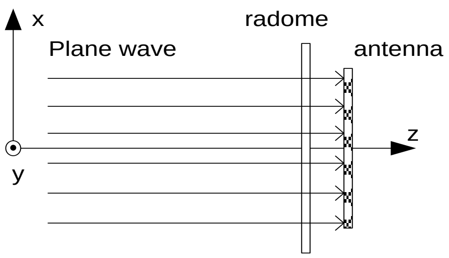

Figure 3.2 Plane wave being incident on the radome

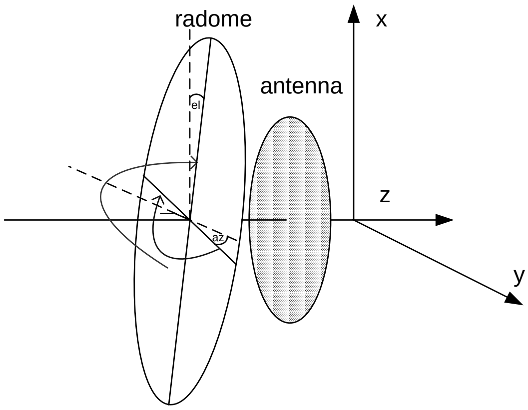

Figure 3.3 Tilting radome in azimuth and elevation

4. RESULTS AND ANALYSES

The analyses were carried out only at 9.6 GHz. The measured signals can be seen at figure 4.1 and the sum simulation signals can be seen at figure 4.2.

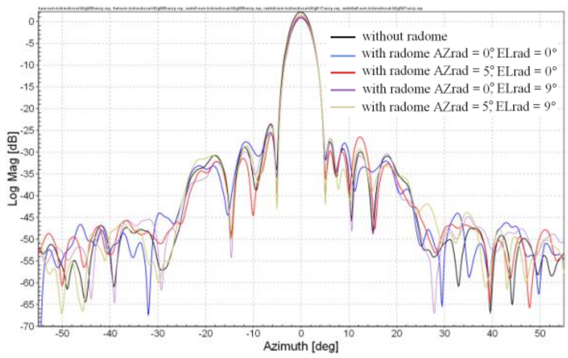

Figure 4.1 Sum signals with and without radome

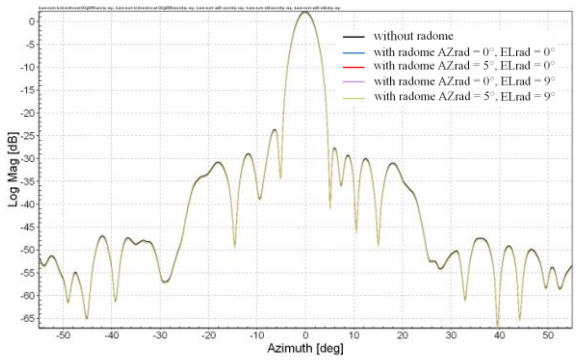

Figure 4.2 Sum simulation signals with and without radome

From figure 4.2, there is slightly difference between signal without radome and with radome. Comparing to measurement results at figure 4.1 and simulation results at figure 4.2, the side lobe level on simulation results do not change significantly like the side lobe level of measured signals because the simulation is ignoring existence of extraneous signals from the environment.

The boresight error also occurs between sum signal of antenna with and without radome.

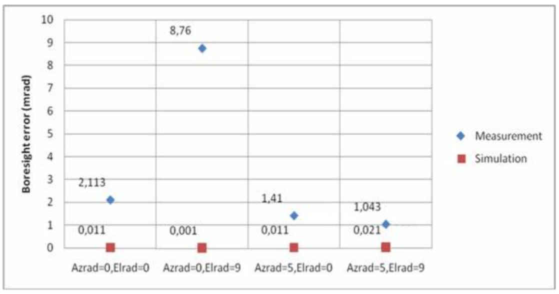

Figure 4.3 Boresight error of sum signal

The changing of transmission coefficient of the radome depending on the angle of incidence, uncertainties of the linearity slope of plane wall radome's surface and extraneous signal which might be incident from its environment or reflected by the frame of the radome positioner cause the changing of boresight axis of the antenna.

The transmittance of the wave with horizontal polarization in azimuth angle is almost same in the range azimuth from -55° to 55°. From software calculation, the transmittance of the radome for parallel polarization can be seen at figure 4.4 below:

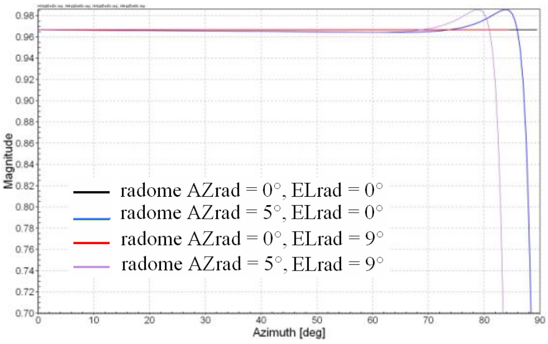

Figure 4.4 Transmittance of parallel polarization

The transmittance of the radome for perpendicular polarization is:

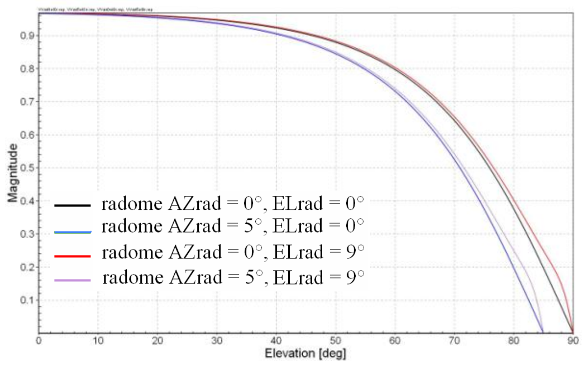

Figure 4.5 Transmittance of perpendicular polarization

Placing radome changes the side lobe level of difference signal of the antenna shown in figure 4.6.

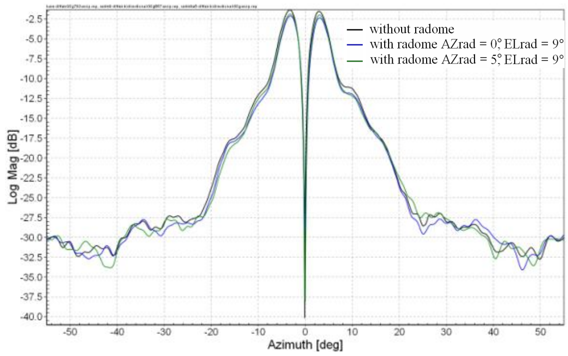

Figure 4.6 Azimuth difference signal with and without radome

The magnitude of local minimum point from both of the difference signals also increase after covering the antenna by radome. This phenomenon is usually called *null fill-in.*

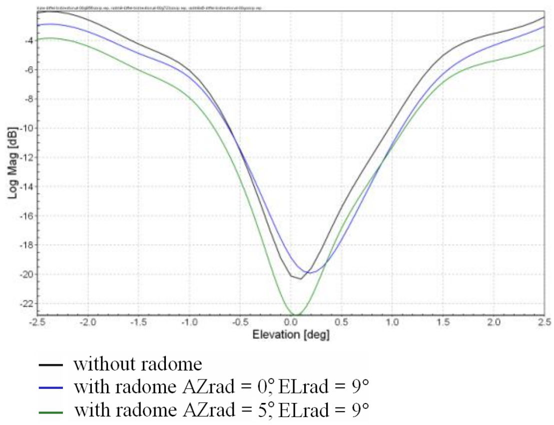

Figure 4.7 Elevation difference signal with and without radome

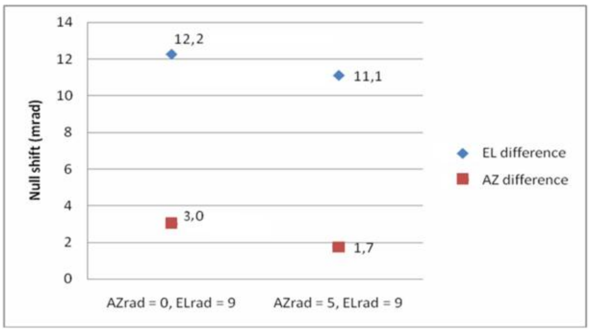

Figure 4.8 Null shift

The angle which is made by radome to antenna will change phase of electromagnetic field for each aperture of the four quadrants of antenna. These phase differences determine how much increase the magnitude at null position is. Another possibility that can make null fill-in is the fact that not all the energy striking the antenna absorbed by the antenna. Some energy will be reflected back to the radome.

The null position shifts depending on the difference phase of incoming wave on each quadrant of the antenna. Radome can change the phase of incoming signal and give phase delay. So, null shifting will occur when covering the antenna with tilted radome.

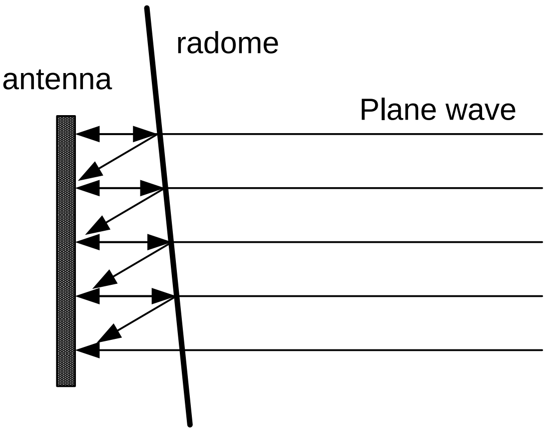

Figure 4.9 Internal reflected wave

In the measurement with CATR technique, there will be two extraneous signals incident to the antenna. Referring to figure 4.10, A is the main signal which is reflected by two reflectors. B and C are extraneous signals to the tested antenna. B is the signal of the feed's side lobe. This signal propagates directly to the tested antenna. C is the signal that originates from triple reflection of the reflectors. The side lobe signal of feed is reflected by vertical reflector and propagates to horizontal reflector. This reflected signal will be reflected again by vertical reflector and propagates to the tested antenna. These extraneous signals affect the result of measurements with the CATR technique.

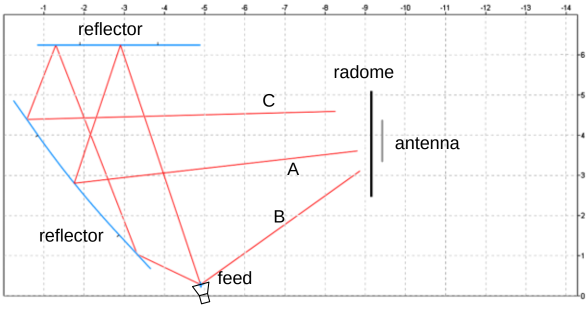

Figure 4.10 Extraneous signals in CATR

When the radome and the antenna are rotating, extraneous signal will come from the incoming wave reflected by frame of radome. Putting the absorber to all frame surfaces can minimize it.

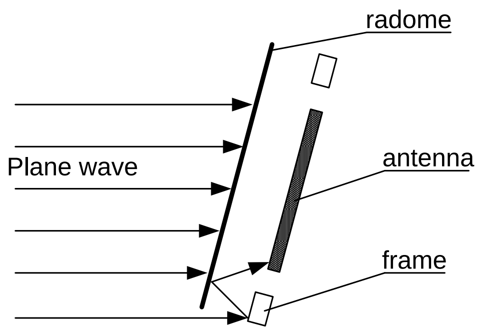

Figure 4.11 Reflected wave from the frame

The radome in this measurement is not produced specially for protecting communication system purposes. The dielectric constant and loss tangent of this material can be different to the material for communication system.

Figure 4.12 shows transmittance simulation of plane wall radome for some dielectric materials at 9.6 GHz with the angle of incidence 0°. Loss tangent of the material for radome is not really affecting the value of transmittance in calculation. The combination of thickness and dielectric constant of the material have big role in affecting the transmittance.

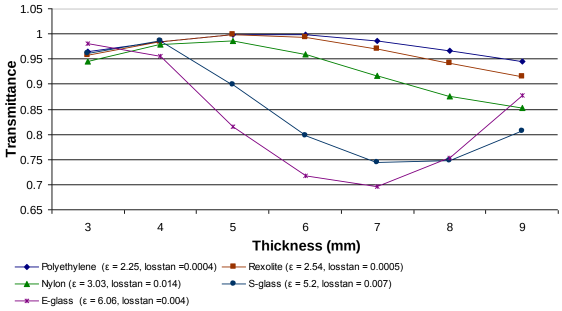

Figure 4.12 Transmittance for some materials

The simulation data in this analysis ignore the presence of extraneous signals from environment.

5. CONCLUSION AND RECOMMENDATION

From the measurements and simulation results, the conclusions are:

1. Loss tangent of dielectric material for radome is not really affecting the value of transmittance.
2. The proper combination of thickness and dielectric constant of radome gives bigger transmission coefficient, so the wave attenuation can be minimized.
3. Tilting the radome with the respect to the antenna changes phase of incident waves and transmission coefficient of the radome at current position of the tested antenna which may arouse null fill-in and null shift for difference signals, and boresight shift for sum signal.
4. Extraneous signal should be minimized in order to get better measurement result because it can change the antenna pattern and degrade the precision of the measurement.
5. Covering the radome frame can reduce extraneous signal from frame reflection.
6. Triple reflection and direct wave in CATR technique with dual reflector can cause boresight shift due to the radome.
7. Reducing side lobe level of the feed can increase measurement accuracy.

After all of the measurements and analyses, some recommendations for next research in the future are:

1. Doing more measurements and changing the distance from the tested antenna to the radome can be interesting in order to see the different response of radome measurement results with respect to the triple reflection signal after gating in time-domain.
2. Solving the problem that makes the first side lobe levels at the positive and the negative angle of antenna have different level from tested antenna or CATR technique with dual reflector can be a good solution for the next radome measurement.
3. The calculations in the program can be improved and applied to other shape of radome, such as tangent ogive and hemispherical radome to get ideal result for comparing with radome measurement data.
4. To get more precision simulation data result, the program needs to get the real measured antenna aperture distribution from Spectrum2D of ARCS 3.5 data result and the incident wave very accurate by scanning field in the full anechoic chamber.
5. To simulate difference signal, the program should work together with AntSim in ARCS 3.5 for modelling the antenna pattern to include antenna aperture distribution, polarization detail, and physical detail and use Physical Optics approaches.

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