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Analysis of radome materials, electric field enhancement and disturbances of plasma density in satellite and radar technology

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ABSTRACT

As we know engineering is the practical application of scientific facts in an economical way. In this modern age of science and technology role of satellite technology has become multifold. Every satellite and Radar has a lot of antennas. Radom's are most important parts of antennas. They use to act as protector and shielding of these systems. Average life span of transport radome is approximately three years. Radoms are susceptible to bird strikes, erosion, lightning strikes, thunderstorms, electric fields, static precipitation, water ingression, delimitation etc. Most frequent damage to radome is holes in structures cause by static discharges. Air, acrylic, foam and Teflon are the eminently used dielectric in radomes. In this paper effect of electric field of earth on Air, Acrylic and Teflon type of radome have been discussed. It has been proved that high dielectric will produce high dissipation energy but they provide high mechanical strength with the additional property of aerodynamically stability. Teflon type of radome is most eminently used. Finally, it has been proved that the performance of radome is dependent on operating frequency, thickness of walls; presence of earth's surrounding electric field, loss tangent of dielectric constant, and dielectric constant using MATLAB software. Effect of DC electric field and plasma disturbances in the upper ionosphere (at 950 kilometers) on COSMOS-1809 satellite over the zones of strong tropical storms and typhoons have been discussed also.

KEYWORDS

Radome;
Hydrophobicity;
Dielectric heating;
Light combat crafts;
Microwave landing system;
Plasma density.

INTRODUCTION

As EM wave hits the dielectric interface, a part of wave is transmitted through the dielectric material, and rest is reflected (as shown in figure 1) and its characteristic impedance is given by

$$Z_D = \frac{377\Omega}{\sqrt{\varepsilon_r}}$$

Let us consider there exists a dielectric of having real part ξr × and imaginary part ξr" in between the radome walls. The present electric field around the wall is E, the

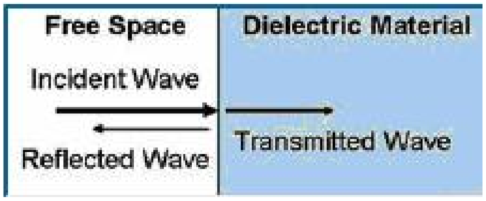

Figure 1

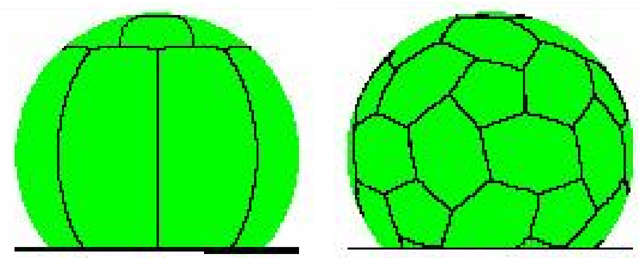

Figure 2 : Practical radomes

loss tangent is Tanδ; the thickness of radome wall is b. When an electric field on the dielectric material, there is dislocation in the equilibrium position of atoms or molecules of the dielectric material. The term required to restore equilibrium is called relaxation time = T. When T = 1/f, where f = frequency of ac field, then resonance occurs and the currents lead the voltage by (90-δ) degree. The dielectric loss power lossdue to heating is maximum when the relaxation time of polarization process matches the period of the ac fields. The loss occurrence can be explained in terms of complex relative permittivity $\varepsilon^* = \varepsilon_{v'} - j\varepsilon_{v}''$

As, the flux density = charge density

D (t) = Q (t)

Henze J(t) = dQ/dt

Since $E(t) = Re[E_0 \exp jwt]$ & $D = \varepsilon_r\varepsilon_o E$

Thus, $D(t) = \varepsilon_o E_o Re(\varepsilon^*_r \exp jwt)$

$= \varepsilon_o E_o Re\{\varepsilon_{v'} - j\varepsilon_{v''}\}\exp\{jwt\}$

$= \varepsilon_o E_o Re\{\varepsilon_{v'} - j\varepsilon_{v''}\}\{coswt+jsinwt\}$

$J(t) = dD(t)/dt = \varepsilon_o E_o w\{\varepsilon_{v''} coswt - \varepsilon_{v'} sinwt\}$

$J(t) = 0 + \varepsilon_o E_o w\, \varepsilon_{v'} cos(wt+90)$

Then $\tan\delta$ = power factor = $\varepsilon_v''/\varepsilon_{v'}$

Now every radome can be considered as loss condenser. Current through the capacitor I(t) = Cdv/dt

Let us consider $V = V_o coswt$

$= Vo\, Re\{e^{jwt}\}$

Let, d = thickness = 1m & Area = 1sq.m

I (t) = c dV/dot

$I(t) = \{\varepsilon_o(\varepsilon_{v'} - j\varepsilon_v'')\} x Vo\, d\{Re \exp jwt\}/dt$

$= \varepsilon_o Vo\, Re\{\varepsilon_{v'} - j\varepsilon_v''\}(jw)\, e^{jwt}$

$= \varepsilon_o Vo\, w\, \{\varepsilon_{v''} coswt - eV'sinwt\} = \varepsilon_o\, \varepsilon_v''wVo\, coswt - (\varepsilon_o\, \varepsilon_{v'} Vow)sinwt$

In an electrically thin dielectric layer, reflections at the air/dielectric boundary are cancelled by the reflectionsof the laminate at the dielectric/air boundary, resulting in low loss transmission of the incident waves

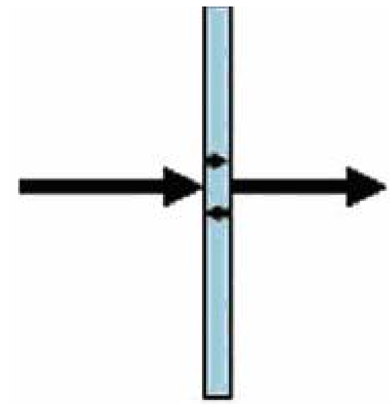

Figure 3 : Electrically thin dielectric layer

Dielectric heating

All the electrical insulating materials(dielectrics) are imperfect in their structure due to minute (milli,micro) ohmic resistance. Hence these materials are heated by dielectric. Power loss that occurs when they are placed between plates of a capacitor carrying high frequency (microwaves)current at high a.c voltages.Heating in mica is very small. But if it is high in plastic/high dielectric type of material. This heating is called dielectric heating given by[3] The electrical power loss can be expressed as follows

$H = P/V = 0.555 * 10^{-10} f(E/b)^2 \varepsilon_r \tan\delta$ P = Electrical power

V = Volume of dielectric material

$\tan\delta = \varepsilon_v''/\varepsilon_{v''}$ = Power loss factor

Because of phase lag of current w.r.t voltage, the actual capacitor can be replaced by the equivalent ckt. Shown below in figure 4.

$P = EI\cos\theta = EI_c \cot\delta = EI_c \tan\delta$, Where the power factor angle δ(the loss angle δ) & the current I_c are indicated in the ckt. E = r.m.s voltage applied to the capacitor

$I_c = E/X_c = 2\pi fcE = 2\pi f\{\varepsilon_o\varepsilon_r A/b\}E$

Thus $I_c = (2\pi f)(\varepsilon_o)\,\varepsilon_r A/b * E$

Power Loss = $0.555 * 10^{-10} AfE^2\, \varepsilon_r \tan\delta / b$ Now, Volume = V = Ab

Power / unit volume = $0.555 * 10^{-10}\, (f)(E/b)^2 * \varepsilon_r \tan\delta$

Power / unit volume = $0.555 * 10^{-10}$ [frequency] [dielectric constant] [loss tangent]*[E / thickness of radome] Or, $P = 6.6 * f * \varepsilon_{r*} \tan\delta [\text{Electric field}]^2$,

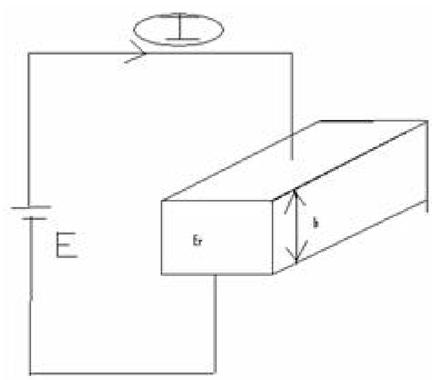

Figure 4 : Equivalent ckt of capacitance

Where E is 120V/m practicaly[8]

There can be thermal breakdown due to the attainment of an excessive temperature in the dielectric. The energy loss, as discussed earlier, has to be dissipated as heat. If the heat dissipated is less than heat generated, there is a progressive increase in the temperature of dielectric, which may melt the radome eventually.

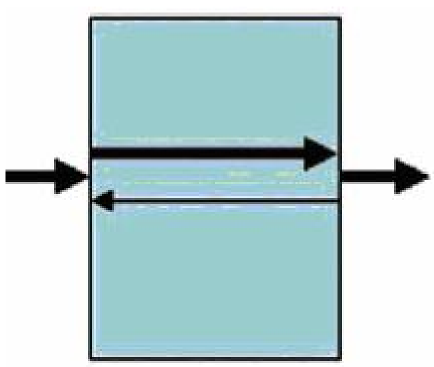

Figure 5 : Half wave length thick radome

In a half wave length thick radome, the round trip of signals through and reflected by laminate introduces a 360 degree phase shift. The reflections of each interface cancels because they are out of phase, which results in high net transmission of the incident signals.

TYPES OF RADOME CONFIGURATIONS

The following are some wall construction that has been used in radomes.

Thin wall

A Radome that is electrically thin (less than $.1\lambda$) gives good RF performance as signal reflections at the space /dielectric boundary are cancelled out by out of phase reflections from the space boundary on the other side of the dielectric material.But the drawback of better thermal insulation can't be overcome for this radome.It is characterized by $d < 0.005$ (operated wavelength)/ $\varepsilon r^{0.5}$Where d is wall physical thickness

Half wavelength

This is solid dielectric surface whose electrical thickness is approximately half of the wavelength. Theoretically, as we know that half wave thick surface is non reflecting and has more loss than ohmic losses of the other materials.It is having limited bandwidth as well as limited in the range of incidence angles over which the electromagnetic energy can be transmitted with minimal reflection. There can be multiple half wave surfaces.

A-Sandwich

A three layer wall consisting of two thin relatively high dielectric constant skins separated by a low dielectric constant core whose thickness is approximately ¼ of wavelength. The skins are glass reinforced plastic laminated and are thin compared to a wavelength. The core might be a honeycomb or foam.

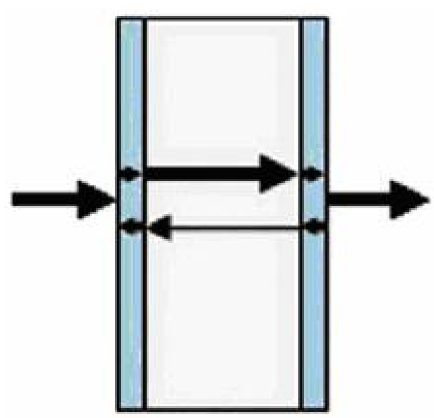

Figure 6 : A-sandwich radome construction

B-Sandwich

It is the inverse of A Sandwich with quarter wavelength skins having a dielectric constant lower than that of core.

C-Sandwich

This is nothing but two back to back sandwiches. It is used when a sandwich does not provide sufficient strength

Multilayer

A general form of more layers than compare to C-sandwich form.

EARTHS VERTICAL ELECTRICAL FIELD

In the ionosphere region of atmosphere the radiation from the sun is energetic .So, continuous ionization use to take place which yields to creation of electrons.

Now, electrons are free to move around in the region core, which conduct electrically, like one of a pair of parallel plates. The other parallel plate is the earth itself, which is also capable of conducting electrically. Although the earth is spherical, the atmosphere is quite thin. So the atmosphere and the earth form the pair of parallel plates, with some slight curve in them.

Charging of plates

The most obvious electrical phenomenon in our atmosphere is thunderstorm and there exists change on our parallel plate example. Thunderstorms are very violent phenomena .There is large positive charge on the top of the cloud and large negative charge on .Now, earth's electric field is created by the transfer of the charges from the thundercloud to the ionosphere .

Effect of fields on satellites[9]

Cosmos 1809 satellite was operated in the near circular orbit with the altitude of 950Kms . When this satellite crosses magnetic field aligned plasma density irregularities, then there exists electrical field disturbances. This is due to enhancement of plasma density up to 20%with regard to background values and appearances of small scale fluctuations of plasma density with relative magnitude of 8%.The satellite data shows that tropical storms, at different stages of there evolution (from depression to typhoon), are accomplished by localized disturbances in the quasi stationary electric field reaching tens of mV/mat an altitude of 950Kmsin the ionosphere. The detection of large scale electric field at such altitudes, observed in sufficiently large number of events, allows us to conclude that a typhoon represents global phenomenon.

RADOME PERFORMANCE VARIABLES

There are various radome performance variables viz.Antenna polarization, water, high ξr, nontangent,as at microwave frequency the signals are absorbed by OH-ions.Antenna noise temperature plays important part in it.

This is dependent on –

1. Noise temperature due to absorption in the radome walls say, NT1, which is equal to 300Pa where, Pa is the amount of energy absorbed in the radome wall.
2. Noise temperature due to reflection in the radome walls say, NT2, which is equal to 300Pa/2 as it is assumed that half of this energy is reflected in case of the reflection contribution to the cold sky and half to the warm earth 300K
3. Noise temperature due to scattering in the radome walls says, NT3 which is equal to 300Pa/4

Hence,

Total noise contribution due radome walls = 300Pa + 150Pa + 75Pa

PRACTICAL OTHER RADOME MATERIALS SYNTACTIC FOAM PRODUCTS[12]

1. **EX1515**

   It is developed by NASA, this is second generation, low temperature curing, toughened cynate ester matrix, ultra high conversion, extremely low moisture absorption, low outgoing,high radiation resistance, fully adhesive and is approved for man rated spacecraft application by NASA.
2. **EX 1541**

   It offers an unparalleled density of 160-192 kg/m^3Low CTE, & high temperature resistance to 290 °C it also offers outstanding electrical performance.EX 1541-1has lower price epoxy formula.
3. **BC 550**

   It has properties of

   i High performance film format

   ii Syntactic foam with €r = 2

   iii Low moisture absorption, with stand up-to 177 °C & flexible cure. It is used in Radom's, antenna, spacecraft structure, aircraft structure& submersible (not in missiles).Connate ester matrix has ultra high conversion, extremely low moisture absorption, low outgoing, high radiation resistance is fully adhesive & is approved for man rated spacecraft application by NASA.

4. **EX 1522**

   it has low moisture absorption, Low out gassing & excellent microcredit resistance compared to other epoxy system.

5. **BTC4-1**

   it can operate at 204°C, excellent structural properties of toughness, Low out gassing &excellent electrical properties.

6. **TEFLON**

   Tetra flour ethylene is well known for its non stick and non wet ability properties. It has good hydrophobicity. The contact angle of approx. 90° It also has good expectancy with very little deterioration of the radome material. It is also a boon to microwave landing system, as in MLS, Radome must be of suspended type rather than conformal.It should be hydrophobic

RESULT AND DISCUSSION

In accordance with attached graphs it is has been analyzed that Teflon type of Radome is best suited radiomen for radar. It is having the excellency of hydrophobicity. It has been found that at higher frequencies there exists generation of thermal power in the radome.A high dielectric constant use to provide mechanical stability. Although dissipation in Air type of radome is less but it is not aerodynamically stable

FUTURE ASPECTS

Radomes are used in satellites, spacecrafts and aircrafts. In India Department of Defence is developling a light combat craft (lcc)since 1980. Till now Dep't. Has developed three high combat crafts. The main issue is of lesser weight of crafts and satellites. There exists developments of RS422 interface which use to convert the parameters of outer environment in to different voltage level (like temperature, humidity etc.)The different levels are voltage, resistance temperature detector, thermocouple, temperature pressure scanner, voice, synchronous angle, fine events etc. There exist a technology by which resistance of a cut can be decreased. As we know the Universal truth of resistance, that it use to to take maximum area in IC fabrication technology which is the main motto of LCC viz. TEJAS. Hence for LCC the selected random should be such that, it has lesser weight & highly strong, so that It can become aerodynamically stable.

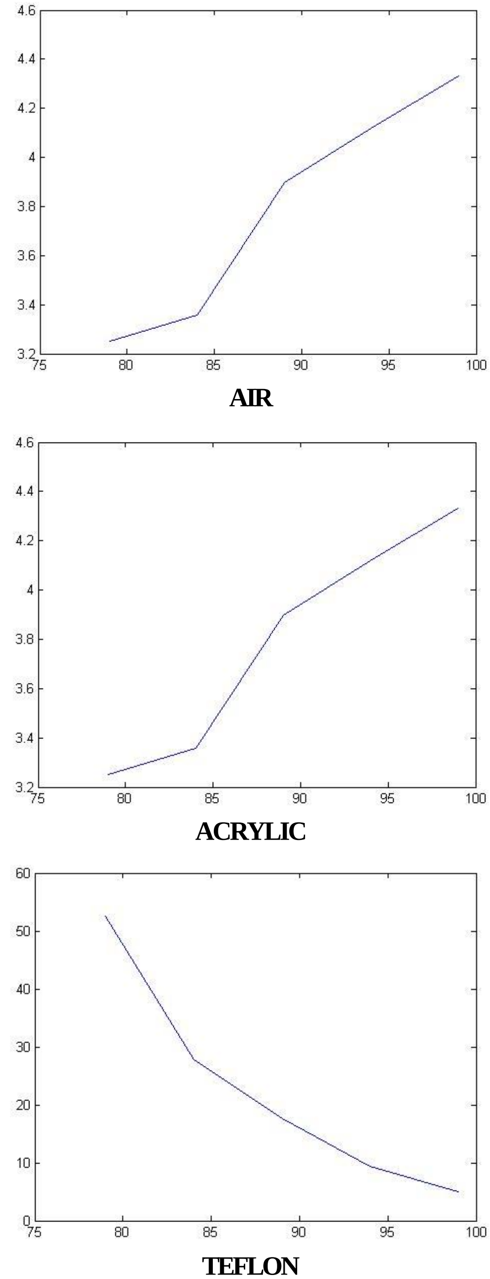

Figure 7 : Frequency vs dielectric heating
X axis = frequency in GHz and Y Axis = per unit volume heating in radomes microwatts

CONCLUSION

To, summarize, the performance of Air. Acrylic and

Teflon type of radome have been analyzed by MATLAB software. It is shown that radomes are highly dependent on operating frequency and dielectric constant. Mother Nature creates problem in radomes as the present electric field (120 V/m) surrounding the earth creates dielectric heating problem which yields to provide high noise temperature. So, air and foam type of radome are aerodynamically unstable. Teflon type of Radome is best suited radome for radar. It is having the excellency of hydrophobicity, which is boon to MLS.

REFERENCES

[1] V.Raghavan; 'Material Science and Engg.' 3rd Edition, PHI ND **(1993)**.

[2] Skolnic I.Merrill; 'Introduction to Radar System' 3rd Edition, TMH.

[3] J.Decker; 'Engineering Materials', TMH.

[4] S.Reuven; 'Scattering Effect of Seams on Sandwich Radome Performance'.

[5] Chassell Rick; 'The Effect of Rain on Microwave Landing System Antenna Radomes' IEEE Symposium on Antenna Technology & Applied Electromagnetic Winnipeg Canada, Aug 15-17, **(1990)**.

[6] Boumens Morcel, Wagner Ulrike; 'Spherical near Field Radome Test Facility for Nose Mounted Radomes of Commercial Traffic Aircraft' Orbit /Fr-Europe Gmblt Johann –Seb Astion – Batch, Str 11,85591 Vaters Stetten, Germany.

[7] Griffith Lances; 'A Fundamental and Technical Review of Radome', May **(2008)**.

[8] 'Electric Field on Earth', The Physics Fact Book Edited by Glenn Elert and Atmospheric Electricity by ELAT. Institute National de Pesqesus Spacious June **(2005)**.

[9] N.V.Isaev, V.M.Sorokin, O.N.Serebryakova, G.A.Stanev, A.K.Yaschenko, E.P.Trushkina; 'Electric Field Enhancement and Disturbances of Plasma Density in the Ionosphere', SENS, Varna, Bulgaria, 14-16 June, **(2006)**.

[10] K.K.Chan, P.R.Chang, F.Hsu; 'Radome Design by Simulated Annealing Technique' IEEE Trans 07803-07305/92, **(1992)**.

[11] X.-C.Nie, N.Yuan, W.L.Li, T.S.Yeo, Y.B.Gan; PIER, **54**, 37-59 **(2005)**.

[12] Radome Materials TENCADE, Advanced Composite Material, USA, Morgan Hill, CA, www.tencate.com.