URSI GASS 2021, Rome, Italy, 28 August - 4 September 2021

Analysis of Radome Structures Placed in the Near-Field of Antennas

Varsha Mishra[(1), (2)], Filippo Costa[(1), (2)], Shengjun Zhang[(3)], Jiaqi Liu[(3)], Yichun Cui[(3)], Agostino Monorchio*[(1),(2)]
(1) Department of Information Engineering, University of Pisa, Pisa, 56122, Italy
(2) Consorzio Nazionale Interuniversitario per le Telecomunicazioni (C.N.I.T.), Pisa, 56124, Italy
(3) Beijing Institute of Space Long March Vehicle, Beijing, China
email: varsha.mishra@ing.unipi.it, {filippo.costa, agostino.monorchio}@unipi.it

Abstract

In this paper, we present a preliminary analysis of radomes structures operating in the near field of moderate or high gain antennas. The analysis of radome structures is carried out in the frequency range from 2 to 18 GHz. The analysis is based on the transmission line method and the transverse resonance method. Once computed the transmission properties of radome, surface wave modes are studied in the radome structures since they are placed in the near field of radar-antenna. The analysis is carried out by using typical examples of radomes, where effect of electrical (e.g. permittivity) and physical (e.g. thickness) parameter on the surface wave propagation and transmission properties are studied. The presented analysis is helpful in the development of radomes specifically designed to operate in the near-field of antennas.

1 Introduction

Radome structures have been used to cover the outdoor antennas in order to protect them adverse environmental conditions. The radome should be transparent to the electromagnetic (EM) signal and it should have good transmission properties with respect to operating frequency and incident angle [1-3]. In literature, various kinds of single- or multi-layer radomes have been designed, e.g. monolithic, A-structure, B-structure, and C-structure [3-4]. Transmission properties and mechanical strength have been the main focused characteristics of radome structures. However, the problem of surface wave propagation in radome, excited due to near-field of the antenna has very limited discussion [5-6]. The surface wave propagation in radome may hamper the performance of the device, such as antenna. Therefore, it is very important to compute the surface wave modes in radomes and analyze the suitability of their usage.
In this paper, an analysis of radome structures is carried out for transmission and surface wave modes. Consequently, the effect of radome parameters, i.e. dielectric and thickness over frequency dependent transmission properties and surface wave propagation is studied. Moreover, theoretical background of transmission line and transverse resonance method are presented in Section II. In Section III, the analysis is carried out using two typical radome configurations. Conclusion is reported in the Section IV.

2 Theoretical Background

In this section, theoretical model for the computation of transmission properties and surface wave propagation of N-layer homogeneous medium is discussed. The transmission coefficient (S_{21}) of multilayering of lossy/lossless mediums with air on both sides has been presented in detail in [3]. Using matching and propagation matrices, the electric field (E-field) can be defined at the boundary and through the length of the medium, respectively. Consequently, transmission coefficient (S_{21}) can be computed as the ratio of transmitted E-field ($E'_{M+1,+}$) to incident E-field (E_{i+}) (Eq. 6.1.2 in ref. [3]). In this paper, similar formulae are used in our paper to compute the transmission properties of the radome structure. Due to limited space formulae are not presented here.

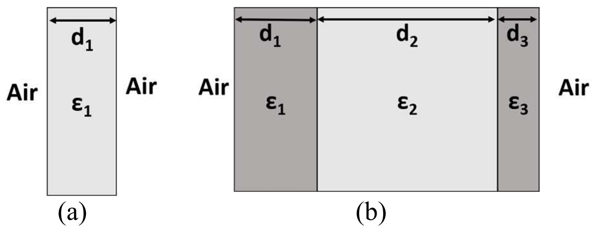


Figure 1. Schematic of (a) monolithic (ε_1=9, μ_1=1, d_1=5.44 mm) and (b) A-structure (ε_1=ε_3=3.5, ε_3=1.2, μ_1=μ_2=μ_3=1, d_1=1.37 mm, d_2=3 mm, d_3=0.7 mm) radomes.

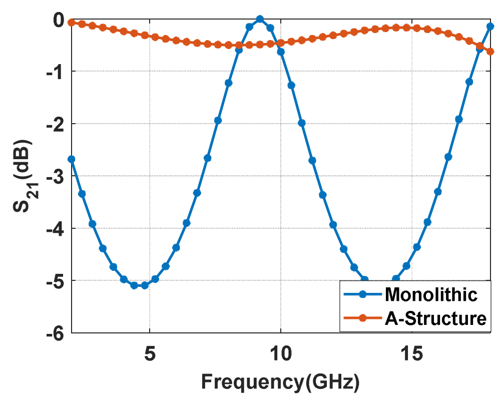
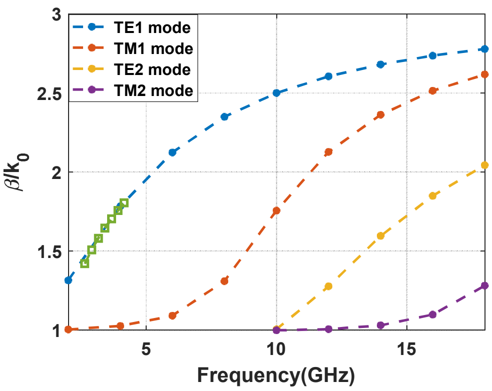


Figure 2. Transmission (S_{21} in dB) properties of both monolithic and A-structure radomes in the frequency range from 2 to 18 GHz at the normal incidence angle.

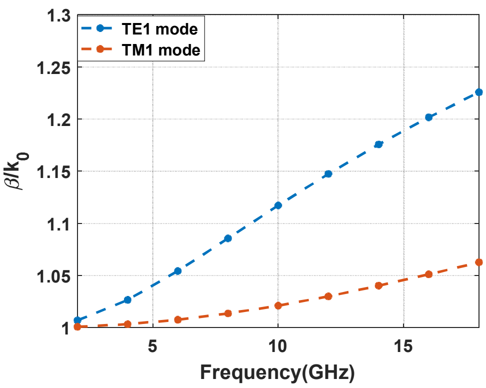
Moreover, surface wave analysis is carried out by using mathematical model of transverse resonance method (TRM) $Z_{in}^{r} + Z_{in}^{l} = 0$ [4] (Eq. 3.206 in [4]) where, Z_{in}^{r} and Z_{in}^{l} are the impedance looking toward right and left, respectively.

3 Preliminary Analysis

In this section, typical example of monolithic and A-structure radomes are considered for our analysis as they are situated in the near-field of antenna [2]. The geometry along with the permittivity, permeability, and thickness of both structures are specified in Fig. 1 (a, b). In order to reduce the computation, dielectric losses of the material are ignored at first stage. The monolithic radome is a single dielectric layer [See, Fig. 1(a)], whereas A-structure radome consist of lower dielectric slab (also known as core) sandwiched with higher dielectric slabs (also known as skin) [See, Fig. 1 (b)]. Dielectric permittivity of the core is lower than skins whereas, thickness of core is kept greater than both skin layers. This type of construction of the A-structure radome improves the mechanical strength, while keeping the effective dielectric constant minimum.



(a)



(b)

Figure 3. Normalized propagation constant (β_z/k_0) of (a) monolithic (plot in green square box line is validation with full wave simulation), and (b) A-structure radome wall in TE and TM mode.

The transmission properties of both radomes are computed at the normal incidence angle. It is overserved that -0.5 dB transmission bandwidth of monolithic and A-structure radome are 1.64 GHz (8.4-10.04 GHz), and 15.6 GHz (2-17.6 GHz), respectively [See, Fig. 2]. The angular behavior is not discussed here, but the e.m. response to wide incidence angle is a desired feature that will be considered at a further stage of the study.

Moreover, the surface waves may be excited into the radome wall due to the presence of the antenna. In order to assess the modes supported by the radome structure, the surface wave propagation is computed by using the TRM. Moreover, results are validated with the full wave simulation for TE_1 mode of monolithic radome [See, Fig. 3(a)]. The results shows that monolithic radome supports overall four modes, and A-structure radome supports two modes of both TE/TM types. The amplitude of the propagation constant is increasing linearly and then saturates at higher frequency up to maximum value of $\sqrt{\varepsilon_{max}}$, where ε_{max} is the maximum dielectric constant out of the multilayer dielectric slab. Hence, the surface wave propagation mainly depends on the dielectric, thickness, and frequency.

6 Conclusion

The analysis of the transmission properties and surface wave propagation of multilayered structures employed as radomes with respect to dielectric and thickness is carried out. The analysis has been carried out by referring to two kind of commonly employed configuration, i.e. monolithic and A-structure. It is observed that A-structure radome has good transmission bandwidth and a smaller number of surface wave modes as compared to the monolithic radome for the analyzed frequency range of 2-18 GHz.

Additional results will be presented at the conference, aimed at showing the effect of oblique incidence, losses of materials and interaction with antenna near field.

7 References

1. C. A. Balanis, Advanced Engineering Electromagnetics. New York: Wiley, 1989.
2. S. M. Herzog, “Radiation pattern calculation for missile radomes in the near field from of an antenna,” in United States Navy B.S.A.A.E., The Ohio State University, 1988.
3. S. J. Orfanidis, Electromagnetic Waves and Antennas. in Rutgers University Rutgers, 2008.
4. D. M. Pozar, Microwave engineering; 3rd ed. Hoboken, NJ: Wiley, 2005.
5. W. M. Cady, M. B. Karelitz, and L. A. Turner, Radar Scanners and Radomes. New York, NY, USA: McGraw-Hill, 1948.
6. V. Mishra, F. Costa, and A. Monorchio, “Study of surface wave and transmission properties in radome surface,” in 2020 XXXIIIrd General Assembly and Scientific Symposium of the International Union of Radio Science, 2020, pp. 1–2.