Gain Enhancement of Membrane Antenna Utilizing Dielectric Lens for Millimeter Wave Applications

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Abstract

The design, configuration and simulation results of a membrane antenna integrated with homogenous hemispherical dielectric (Teflon) lens is presented. The membrane antenna consists of six layers and a homogenous extended hemispherical dielectric lens, which is placed over the top layer of membrane antenna. The longitudinal rectangular slot etched in the SIW ground plane is utilized to excite the microstrip patch antenna (MPA). The membrane antenna gain is enhanced by integration of a homogenous extended hemispherical dielectric lens. The proposed antenna operates in millimeter wave band and having bandwidth of 6 GHz (90 - 96 GHz). Furthermore, the antenna gain is found to be above 15 dB.

Keywords:

Millimeter Wave, Membrane Antenna, Substrate Integrated Waveguide, Homogenous Extended Hemispherical Dielectric Lens, 94 GHz

I. Introduction

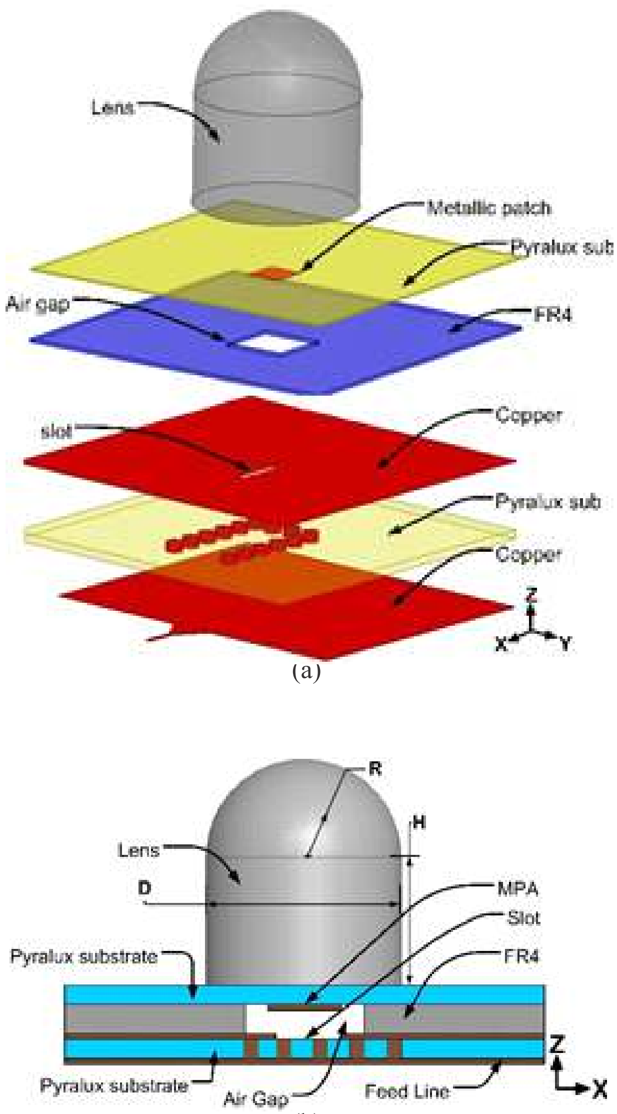
The millimeter wave region especially, the W-band window having center frequency of 94 GHz is in focus due to its elite property of high transmission through atmospheric obstructions like clouds, fog, thin dielectrics and smoke [1],in addition to for the development of ultra broadband wireless communications systems and high resolution imaging applications [2]. Furthermore, due to the small wavelength at millimeter wave (mmW) region, fabrication of compressed structures for various modern communication systems such as radio astronomy, remote sensing, compact sensors [3], automotive collision warning radar [4], cloud radar and point to pointmulti GBPS communications is possible. The basic requirements for mmW antennas includes high antenna gains, wide operating bandwidth, high radiation efficiency, compatibility and easy integration with other communications modules. Furthermore, To convert a non-planar structure to its equivalent planar structure [8], the SIW [5-7] is currently the best possible candidate in the structure of family of Substrate Integrated Circuits (SICs).Utilizing SIW benefits of a rectangular waveguide such aselectrical shielding, high Q-factor and high power handling can be attained. In the SIW geometry metallic viasholes are placed in close proximity through which radiation leakage is minimized and metallic rectangular waveguide like propagation properties are achieved [9]. Due to these advantages the SIW in utilized in proposed antenna design to mitigate high metallic losses in mmW operation. The implementation of SIW based structures can be made by employing conventional PCB process [10, 11], multi-layer PCB process [12], photo-imageable thick film technology [13] and LTCC technique.

In this article the design, configuration and simulation results of a membrane antenna integrated with a homogenous extended hemispherical dielectric lensare presented. As found in literature addition of dielectric lens can be utilized to enhance antenna gain [14]. It will be shown that integration of homogenous extended hemispherical dielectric lens with membrane antenna will result in 7 dB increase in overall gain of antenna. The available flexible pyralux TK copper clad laminate and FR-4 dielectric substrates are exploited in proposed antenna. Furthermore, the ANSYS HFSS is utilized for modelling and optimization of proposed antenna.

In section 2 antenna design and configuration is shown. Where as in section 3 the results of membrane antenna with and without the homogenous extended hemispherical dielectric lens are presented. The conclusion is presented in section 4.

II. Antenna Design and Configuration

The proposed membrane antenna (6 layers) integrated with homogenous hemispherical dielectric lens is shown in Fig. 1. The proposed design comprises of two substrates i.e. FR4 substrates having $\varepsilon_r = 4.4$ and pyralux substrate with $\varepsilon_r = 2.5$. The dielectric losses are included in simulation by keeping loss tangent ($\tan\delta$) = 0.002 and 0.02 for the pyralux and FR4 substrates respectively. In Fig. 1(a) the 3D layered model of proposed antenna geometry is shown. The top layer contains a rectangular microstrip patch antenna. The patch is etched below the top pyralux substrate. The FR4 substrate having a rectangular air gap constitutes the second layer of membrane antenna. This FR4 layer is integrated into design to support the patch antenna above the SIW. The SIW geometry is constructed in bottom three layers. To excite the patch antenna on top layer the rectangular slot is etched on the SIW top ground plane. This slot antenna in SIW excites the patch through the air cavity present in FR4 substrate. The main advantage of the SIW utilization in the design is to reduce inherent high metallic losses present in the millimeter range. The homogenous extended hemispherical dielectric lens is placed over the top layer, through which gain of membrane antenna is enhanced. The proposed membrane antenna structure integrated with homogenous extended hemispherical dielectric lens is shown in Fig. 1(b).The homogenous extended hemispherical dielectric lens consists of Teflonmaterial ($\varepsilon_r = 2.1$). The height of cylinder is H = 3.2 mm whereas the diameter and radius of top sphere is 4.8 mm and 2.4 mm respectively. The copper clad in proposed membrane antenna have thickness of 18 µm, whereas the thickness of dielectric substrates i.e. FR4 and pyralux are taken to be 100 µm and 50 µm respectively. The overall thickness of membrane antenna is 0.218 mm.



(a)

(b)

Fig. 1. Geometry of proposed 6-layered membrane antenna integrated withhomogenous extended hemispherical dielectric lens. (a). 3-D layered model. (b). 2-D side view.

The cut off frequency of SIWis determined by the spacing between two parallel rows of metallic via holes engraved in dielectric medium (substrate). Generally, TM modes are not supported by SIW and dominant mode of SIW is TE_{n0} mode. The broad side dimension of SIW i.e. $a_d$is foundby

$$a_d = \frac{a}{\sqrt{\varepsilon_r}}$$

Where, dielectric constant of substrate is represented by ε_r and dimensions of a i.e. width of SIW is from standard WR-10 waveguide (2.54mm). The following expression is utilized to calculate the distance among the two parallel rows of metallic via holes in SIW geometry i.e. a_s

$$a_s = a_d + \frac{d^2}{0.95p}$$

'd'in above expression is the diameter of metallic via holes joining the lower and upper metallic layers of the substrate (pyralux). The initial dimensions of metallic via diameter is chosen by $d = \lambda_g/5$. Furthermore, the SIW 'pitch' dimension is taken by $p<2d$.

In Fig. 2 the top view of the proposed antenna and placement of rectangular longitudinal slot is emphasized. The recommended distance from the SIW short-circuited end to the center of longitudinal slotd_{off2} is usually multiple of quarter of the guided wavelengths. However, this distance is takento be three quarter of the guided wavelength. The slot offset i.e. d_{off1} is adjusted for coupling of H-field from the longitudinal slot to excite the patch antenna. The initial length for longitudinal slot is calculated from the expression given as below.

$$L_s = \frac{\lambda_o}{\sqrt{2(\varepsilon_r + 1)}}$$

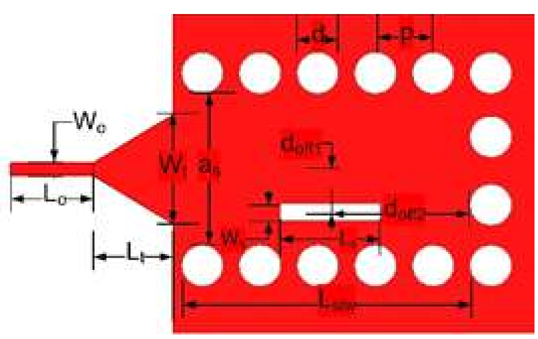


Fig. 2. Microstrip feed SIW slot antenna with rectangular slot and triangular transition.

The FR4 substrate is utilized to support the patch antenna. The air cavity of 1.8 × 1.8 mm in FR4 substrate is utilized to efficiently couple the H-field from the longitudinal slot. The optimum measurements for microstrip patch antenna are found to be 1.115 × 0.985 mm. The homogenous extended hemispherical dielectric lensis placed over the top layer. The center of dielectric lens is aligned with the center of MPA as can be observed in the Fig. 3. The overall antenna size is 10 × 10 × 5.88 mm. The membrane antenna is feed by a50 Ω microstrip line.

To avoid impedance mismatch between the SIW and microstrip feed a tapered microstrip (triangular) transition is utilized. The various important antenna parameters are shown in Fig. 3. Whereas, the optimum dimension after tedious simulations carried out in ANSYS HFSS to achieve required results are as following. $W_t = 1.335$, $W_o = 0.144$, $L_o = 1$, $d = 0.5$, $L_t = 0.91$, $a_s = 1.49$, $p = 0.7$, $L_s = 1.225$, $W_s = 0.201$, $d_{off1} = 0.55$, $L = 3.5$, $d_{off2} = 1.4125$, $L_a = 1.849$, $W_p = 1.05$, $W_a = 1.849$, $L_p = 1.151$, $L = 10$ and $W = 10$, (all dimension in "mm").

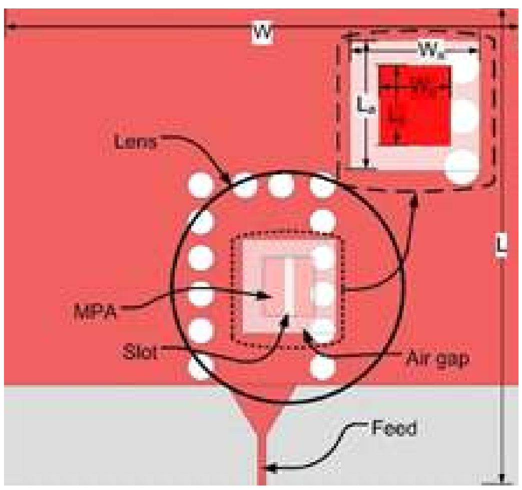


Fig. 3. Membrane antenna integrated with homogenous extended hemispherical dielectric lens (top view).

III. Results and Discussion

The membrane antenna integrated with dielectric lens is simulated and optimized using Ansys High Frequency Structure Simulator (HFSS©).

The reflection coefficient (S_{11}) of two cases i.e. with and without the dielectric lens is shown in Fig. 4. The two resonances are achieved. These are due to existence of patch and slot in antenna geometry. The both resonances are merged together to achieve widerbandwidth. The antenna operating bandwidth is found to be 6 GHz (90-96 GHz). Itcan be easily observed that with integration of homogenous extended hemispherical dielectric lensthe impedance bandwidth is also slightly improved.

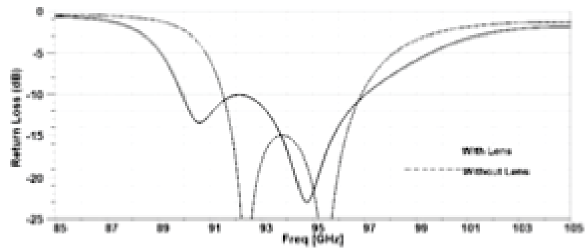
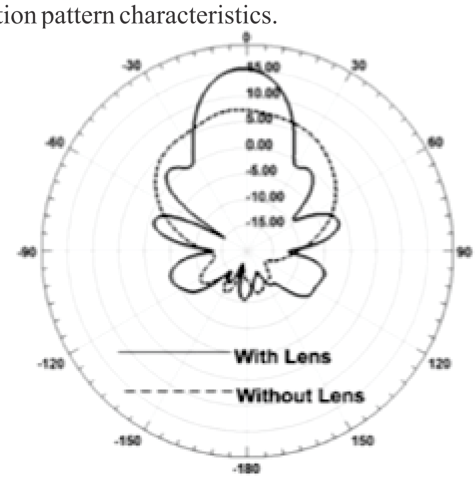


Fig. 4. Simulated return loss of membrane antenna with and without homogenous extended hemispherical dielectric lens.

The 2D radiation pattern in E and H plane is shown in Fig 5a and Fig5b respectively. It can be easily observed that antenna beamwidth is narrowed with integration ofhomogenous extended hemispherical dielectric lens.The gain enhancement of approximately 7 dB by integration of homogenous extended hemispherical dielectric lens can also be observed.The 3D radiation pattern of membrane antenna alone and with integration of homogenous extended hemispherical dielectric lens is shown in Fig 6 for a better understanding of antenna radiation pattern characteristics.



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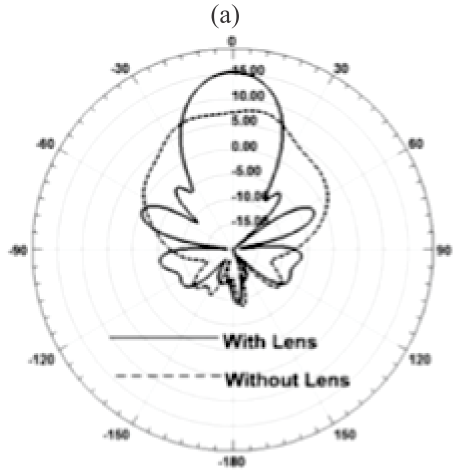
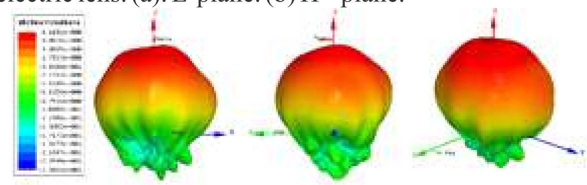
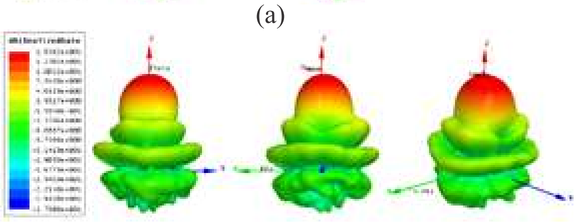


(b)

Fig. 5. Comparison of simulated 2D radiation pattern for membrane antenna alone and membrane antenna integrated withhomogenous extended hemispherical dielectric lens. (a). E-plane. (b) H – plane.



(a)



(b)

Fig. 6. 3D radiation pattern of proposed antenna. (a). Membrane antenna alone. (b). membrane antenna integrated with homogenous extended hemispherical dielectric lens.

The comparison of antenna realized gain for membrane antenna with and without homogenous extended hemispherical dielectric lens is shown in Fig. 7. The gain enhancement of more than 7 dB can be clearly observed. Furthermore, the advantage of utilizing SIW in antenna structure can be seen in Fig. 8, where it is clearly seen that the the E-filed in well confined inside the proximity of SIW.

The performance comparison of membrane antenna alone and membrane antenna integrates with homogenous extended hemispherical dielectric lens is given in table 1 for a better understanding.

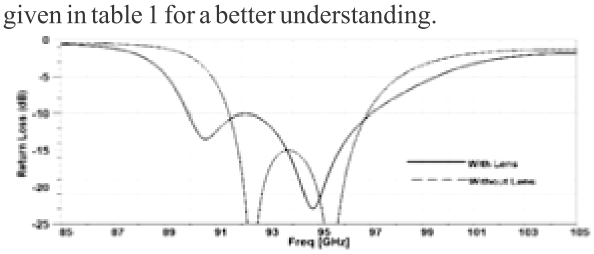
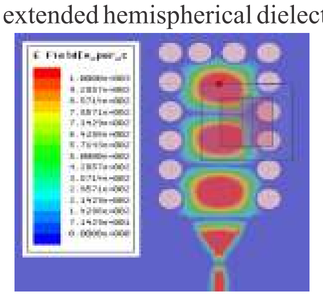
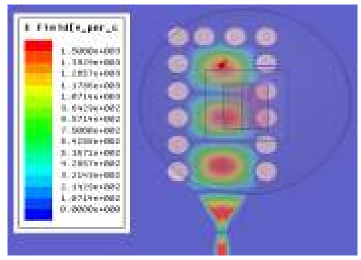


Fig. 7. Comparison of Simulated gain of membrane antenna alone and membrane antenna integrated with homogenous extended hemispherical dielectric lens.



(a)



(b)

Fig. 8. Electric field distribution inside SIW (a). Membrane antenna alone. (b). membrane antenna integrated with homogenous extended hemispherical dielectric lens.

	Membrane Antenna alone	Membrane Antenna with lens
Brandwidth	6.5 GHz	7 GHz
Realized Gain	7.9 dBi	15.33 dBi
Beamwidth E-Plane	60^{o}	28^{o}
Beamwidth H-plane	60^{o}	28^{o}

Table. 1: Performance comparison of membrane antenna alone and membrane antenna integrated with homogenous extended hemispherical dielectric lens.

IV. Conclusion

The design and simulation results of a 6 layer membrane antenna integrated with homogenous extended hemispherical dielectric lens is presented. The antenna is operating at center frequency of 94 GHz and a wide impedance bandwidth of approximately 6 GHz is achieved. The gain enhancement of more that 7 dB is achieved by integration of homogenous extended hemispherical dielectric lens. Furthermore, the SIW is effectively incorporated in theproposed antenna geometry for mitigating inherent metallic losses present in the mmW region.

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