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An Optimized design for Luneburg Lens Scanning Antenna using PIN diodes for Beam-Switching

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Abstract —*The Luneburg lens scanning antenna is optimized and is evaluated with two backing ground planes. The beam of the antenna is scanned as in a full or hemispherical lens antenna. The antenna weight is halved relative to the hemispherical lens as quarter of the lens is used. Simulations are conducted indicating a negligible scanning loss in both the antenna principle planes. Lens design with electronic beam-switching using PIN diodes as switching element has been proposed reducing the cost and complexity. Each switching state can be obtained by forward biasing one half of the diodes when the other half is reverse biased.*

Keywords*- Luneburg lens, Beam-switching, lens weight, antenna scanning, PIN diodes.*

I. INTRODUCTION

A Luneburg lens is used in applications requiring high gain and wide scanning. A hemispherical lens backed by ground plane is used for vehicular applications [1]. To reduce the complexity of the lens a quarter-sphere lens backed with two ground planes is proposed. The advantage is the reduction in the lens weight. It is important as the lens weight increases with the cube of its radius. Quarter-sphere lens designed with solid dielectric materials significantly reduces the cost and time [2]. The general virtual source Luneburg lenses are discussed in [3] but the results are available only for hemispherical lens backed by ground plane. Our work aims in evaluating scanning characteristics of quarter-sphere lens with beam switching using PIN diodes. Lens antennas produce a focused, shaped and contoured beam by introducing sufficient phase shift for the field. They present low cost and high efficiency while providing the possibility of implementing electronic beam reconfiguration at a low cost. The proposed work is effective for implementing the electronic control in Luneburg lenses without the necessity of any bulky mechanism and keeping the antenna structure static [4]-[13]. Varactor diodes were used in [5] and [6] and the concepts were demonstrated at element level. The phase response change with a change in bias voltage. Beam switching with multiple elements was demonstrated in [7] using varactor diodes. Ring slot resonators [8] and tilted patches [9] have also been used to control the phase of the reflected field. For the case of electronically reconfigurable antennas the proposed method allows a complete isolation between the radiating section and the control devices reducing the cost and complexity.

II. QUARTER-SPHERE LENS SCANNING ANTENNA

The proposed model of quarter-sphere lens with ground plane is presented in Figure 1. The scanning properties are evaluated for the two-layer quarter sphere lens. The feed considered is a short section of circular waveguide. The side view of the proposed lens antenna with the feed rotated in the y-z plane with respect to z-axis is shown in Figure 2. In this plane if the feed is rotated by an angle the main beam is pointed in the same direction. Hence, this property is utilized for scanning the beam for a certain range.

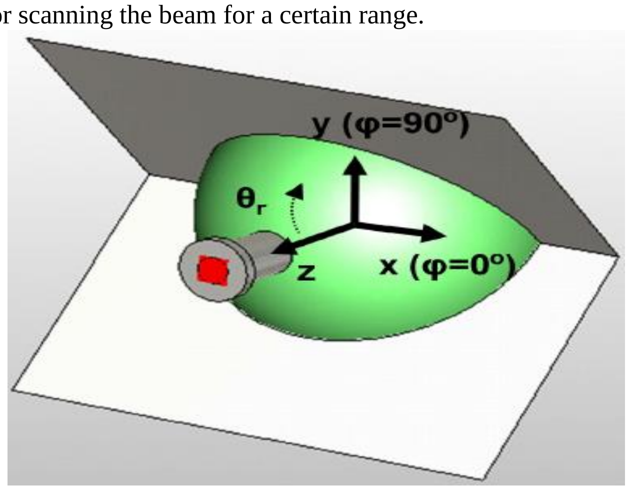


Figure 1: A quarter-sphere lens with ground planes and co-ordinate axis

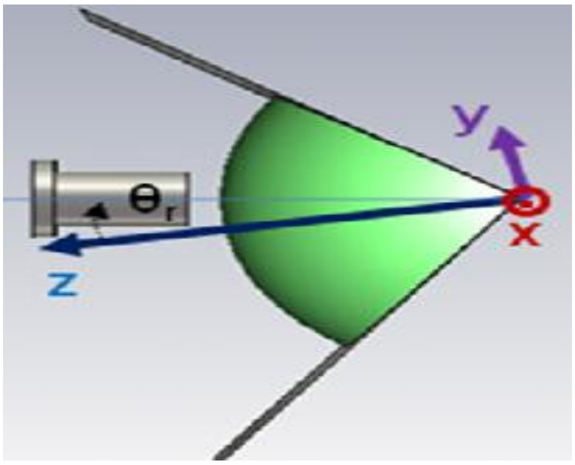


Figure 2: 3-D Radiation pattern of the antenna with feed rotated in y-z plane

For all angles θ_r there shall be some blockage due to the feed antenna. Further, for lager θ_r increases due to the finite size of ground plane. Figure 3 shows the side view and radiation pattern of the antenna with the feed rotation in x-z plane. The gain reduces by feed blockage only if the feed is placed close to the y-z plane.

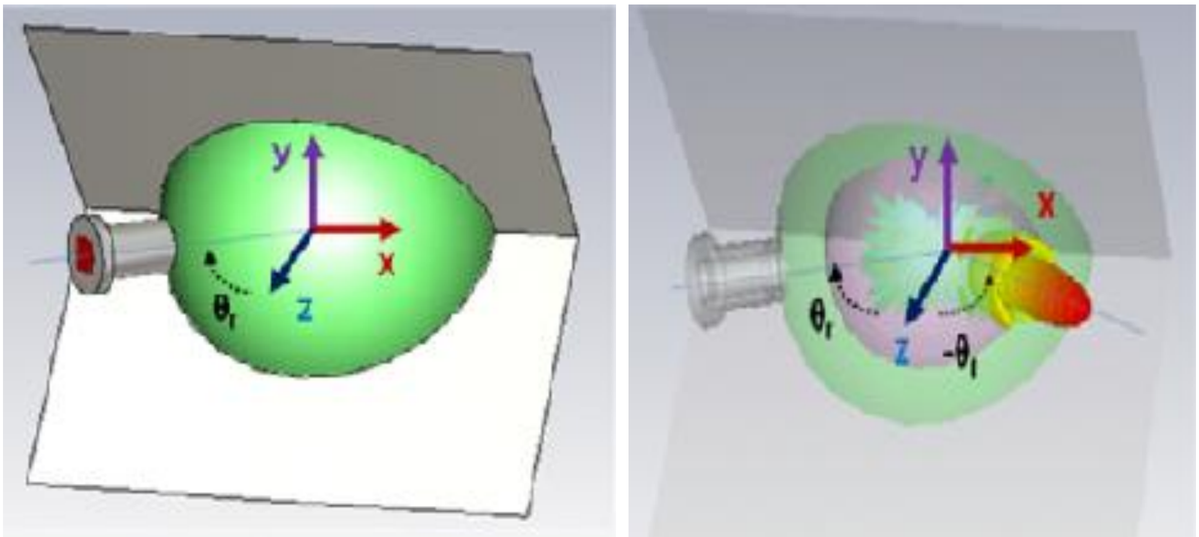


Figure 3: 3-D pattern of the lens with feed rotated in x-z plane

III. PIN DIODE FOR BEAM-SWITCHING

For the electronic control of the phase a PIN diode (MACOM–GaAs [14]) is considered for the implementation. The electric characteristics for this device are shown in Table I. The design is carried out considering the diode device (Diode and packaging) as two line sections connected to resistance or a capacitor depending on the biasing.

Table I : Diode Electrical Specifications

Parameter	**Value**
Capacitance	0.025 pF
Series Resistance	4.2 ohm
Forward Voltage	1.33 V
Reverse Voltage Current	10 micro amp

This paper describes the design process of switching the beam in band from 10.10 GHz to 10.70 GHz. This band is considered as the design can be easily tuned to other neighboring bands. This method of implementation is novel with an important saving in number of control devices and the associated biasing lines. The phase of each element is controlled with the help of PIN diodes.

The radiation pattern is switched between -5 degrees, 0 degrees, +5 degrees in a plane measured with respect to y-z plane. The lateral beams along with a central beam contained in the switching plane measured with respect to the y-z plane. The radiation beams are arbitrary fixed with the aim of radiating out from the main planes without any blockage.

The switching angles (-5,0,+5) are selected considering the geostationary orbit with 9 degrees such that the whole earth can be covered with 9 degrees. Larger switching angle can be obtained with the required phase distribution.

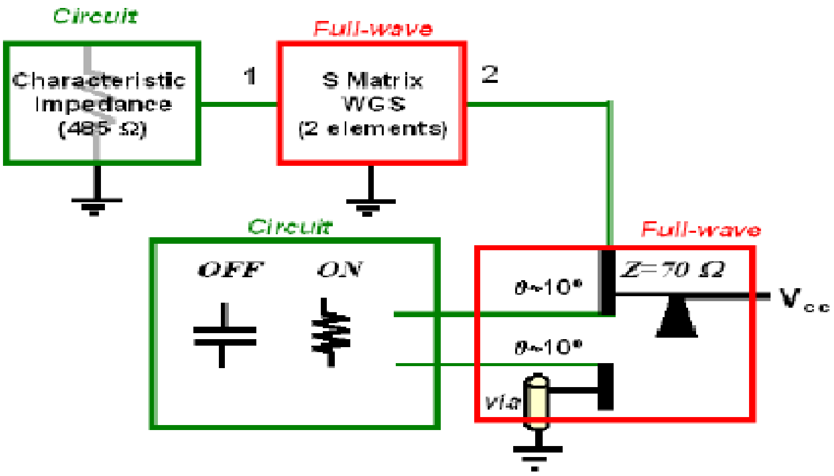


Figure 4: Equivalent circuit of PIN diode characterization for simulation

The first in the design is the choice of geometry. The reflection coefficient in free space is obtained using Frequency domain solver [15] taking into account the coupling between the elements. The reflection coefficient in free space without phase control at 10.40 GHz have losses around 0.5 dB which further can be reduced with low loss materials. The element without phase control has been considered for reference for electronically controllable element which changes the electric length by introducing a PIN diode. The scattering matrix under consideration is connected to a line section through the diode.

The equivalent circuit for the electronic control is shown in Figure 4. From this circuit an equivalent delay line that represents the diode and its packaging will be extracted. This equivalent delay line is used to design whole antenna in a simple manner. The full wave simulation using the time domain solver has been performed.

The port 1 which is referenced to the plane of the element surface is loaded with the characteristic impedance of the fundamental mode of the chosen waveguide at 10.40 GHz. The port 2 which is set from the T-junction at the delay line is loaded with an S-matrix which models the biasing network.

The diode which is placed between the two segments is modeled as a capacitance in OFF state (Reverse biasing) or as a resistance in an ON state (Forward biasing). With this approach the losses and extra phase-shift introduced by the diode and its packaging can be replaced in the design by an equivalent transmission line segment with a phase delay of 20 degrees for the diode in the OFF state (0.20 dB of loss) and 40 degrees for the diode in the ON state (0.5 dB of loss).

The undesired radiation can be drastically reduced or eliminated [16] with an irregular lattice. The feed position has been defined as a tradeoff between reducing the incidence angle from the phase centre of a feed to the centre equal to the radiating angle of the beam with the aim of reducing the squint in the radiation [17] whenever frequency changes. Once the elements are considered the next step is determining the phase delay which must be introduced by each element for radiating in the desired direction which is simulated taking into account the antenna geometry.

IV. SIMULATION RESULTS

Two different phase distributions are simulated; one to produce a beam scanned +5 degrees with respect to z-x plane and the other to scan the beam -5 degrees. Because of the symmetry of the 5 degree beam with respect z-x plane, the central row does not require any phase shift when the beam is switched between any of the beam states and as a consequence there is no necessary to implement any diode in that row. 104 diodes are required; 52 direct biased in each lateral beam. A third beam pointing towards 0 deg can be obtained if all the diodes are inverse biased at the same time. The phase distribution corresponding to this case is shown in Fig 5(a).

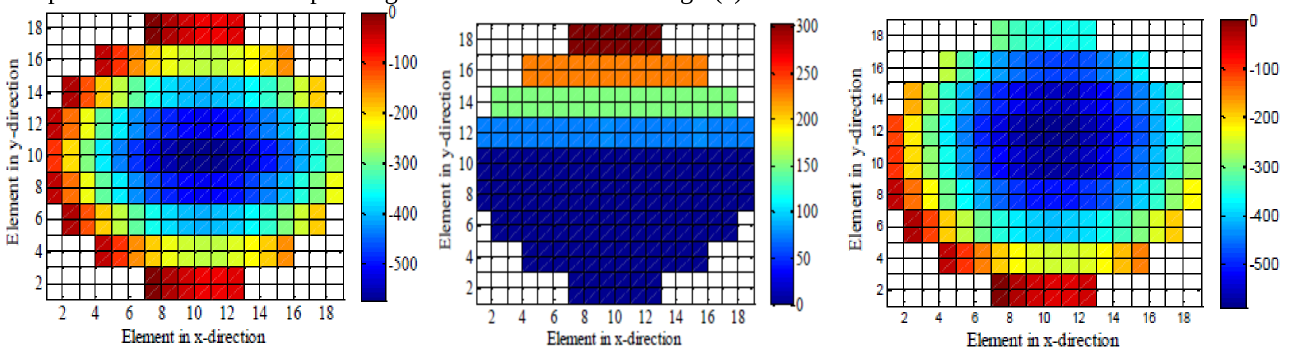


Figure 5: Simulated phase distributions for generating beam switching (a) all diodes in OFF state phase provided by first segment of delay lines (b) phase to be introduced by second segment of delay lines to produce beam towards 5 degrees (c) Resulting phase distribution for pointing towards 5 degrees.

This phase distribution has been obtained by combining one half of the corresponding phase distributions to produce each beam pointing towards ±5 deg. The central beam will not be properly focused, because the phase distributions are defined to focus only the lateral switched beams, while the phase distributions used to radiate the central beam will result when combining one half for +5 deg and the other half for -5 deg. To properly focus the central beam two diodes are required. Fig 5(b) shows the phase which is subtracted to the first one in order to point the beam towards +5 deg. Only 52 elements require a phase delay which is obtained by connecting segments through the diode in ON state. Fig 5(c) shows the resulting phase distribution to radiate towards +5 deg. The symmetric beam towards -5 deg is obtained in the same way with reverse biasing the complementary diodes. Fig 6 shows the tridimensional simulated far field pattern in gain at 10.40 GHz corresponding to the 5 deg and 0 deg beams respectively.

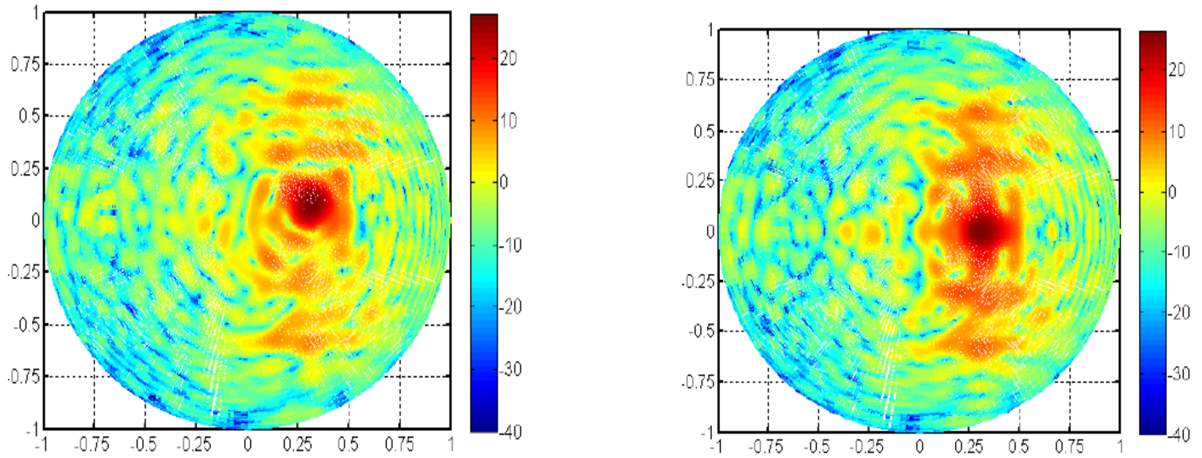
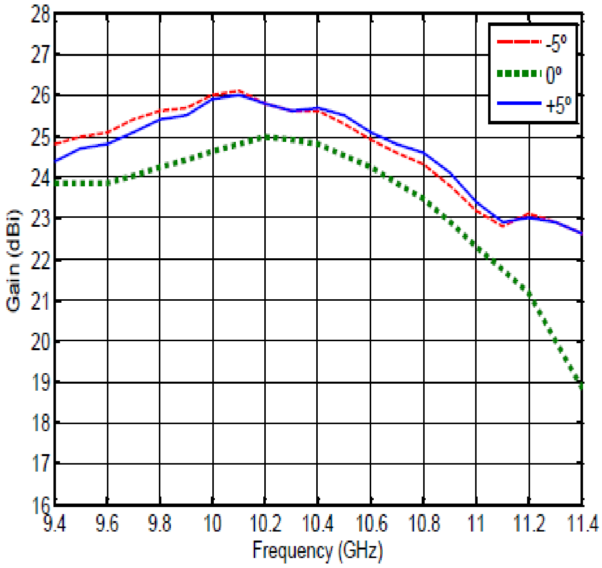


FIGURE 6: THREE DIMENSIONAL RADIATION PATTERNS AT 10.40 GHZ FOR BEAM DIRECTED TOWARDS 5 DEG AND 0 DEG

The simulated maximum gain for each one of the three switching states is shown in Fig 7 in the frequency range from 9.4 GHz to 11.4 GHz with a 1-db bandwidth of 10 percent. The radiation pattern corresponding to 5 deg beam have also been simulated for the main plane in the band from 10.10 GHz to 10.70 GHz as shown in Fig 8.



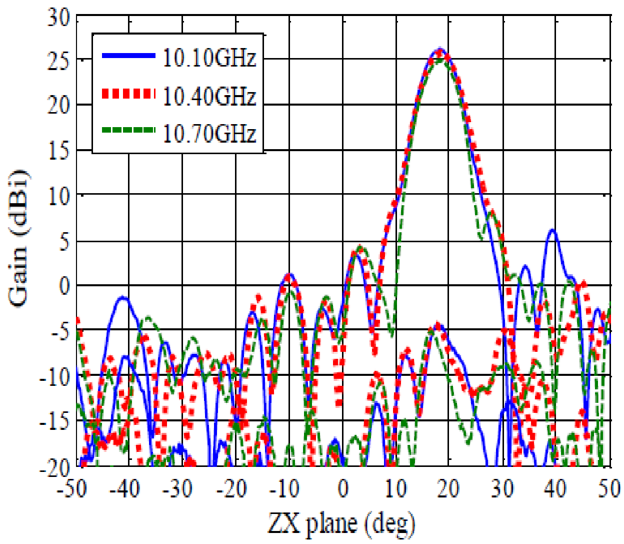


Figure 7: Gain for the three switching states for the whole band

Figure 8: Radiation pattern for 5 deg beam in 10.10 GHz to 10.70 GHz in ZX plane

Fig 9 shows the peak gain for a quarter sphere lens as a function of the ground plane. For comparison we include the results for the gain of a spherical and hemispherical lens. Both lenses are two layers with the same radii and dielectric values as the quarter sphere lens.

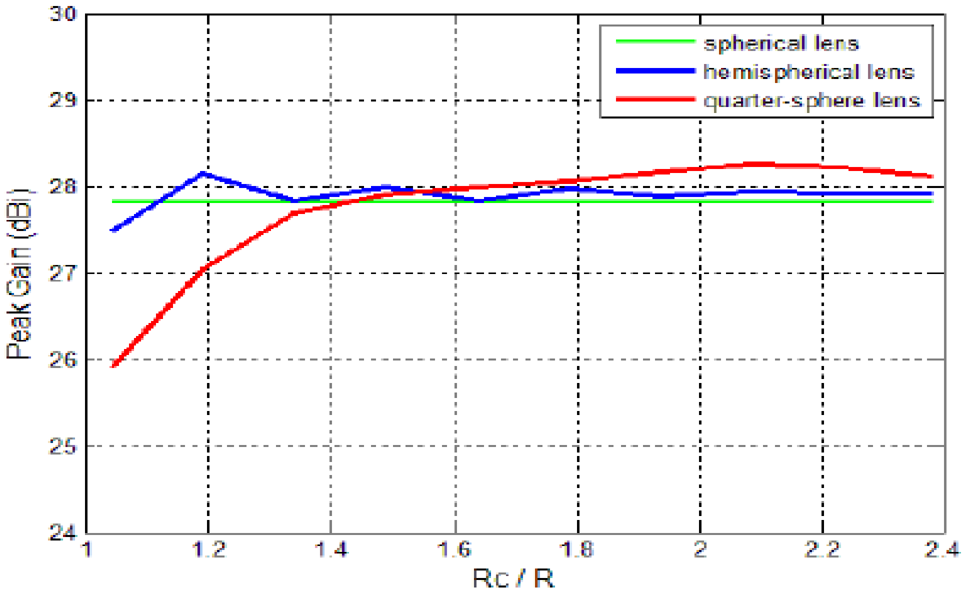


Figure 9: Peak gain calculated as a function of the ground plane size

To exclude the effect of the feed blockage, the feed antenna is replaced by its equivalent near field source. The results presented in Fig 9 show that by a small extension of the ground plane ($R_c > 1.4$ R, where R is lens radius) it is possible to achieve the peak gain close to the gain obtained using a hemispherical or spherical lens antenna.

V. CONCLUSION

A switchable Lens antenna design using PIN diodes as control elements has been proposed and simulated demonstrating the validity of controlling the phase allowing a significant reduction of the number of control devices and the associated biasing lines reducing both the manufacturing complexity and the cost of the antenna without reduction in the performance of the antenna. The properties of a small quarter-sphere lens antenna are presented. Compared to designs using a hemispherical lens, the main advantage of the quarter sphere lens antenna is its reduced weight.

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