Penerbit Akademia Baru

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage: www.akademiabaru.com/araset.html

ISSN: 2462-1943

Advanced Research in Applied Sciences and Engineering Technology

Radial line slot array antenna at 28 GHz with modified coaxial to waveguide feed probe adaptor

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ARTICLE INFO

Article history:
Received 10 March 2017
Received in revised form 7 May 2017
Accepted 22 May 2017
Available online 23 May 2017

Keywords:
28 GHz, coaxial to waveguide connector, loaded feed probe, radial line slot array antenna

ABSTRACT

Coaxial to waveguide transition adaptor with disk shaped terminated feed probe was found to be an effective feed network for single layer radial line slot array antenna. However, further studies with the feed probe terminated in none disk shaped elements is required. Thus; termination with conical and frustum shaped elements are studied for a single layer radial line slot array antenna at 28 GHz in this paper. The sensitivity of the modified termination on impedance bandwidth, radiation characteristics and efficiency were examined. It was found that termination with the disk shaped element showed reduced reflection coefficient and efficiency at the centre frequency in comparison to the conical and frustum shaped terminations. But it has an overall better performance over the simulation frequency range.

1. Introduction

Radial line slot array antenna (RLSA) is a low loss planar antenna which has ease of manufacture and possess attributes like high efficiency and gain [1]. It can be designed for linear [2] or circular [3], [4] polarization. It attracted attention in applications such as wireless LANs [5], local multiport distribution system (LMDS) [6], satellite TV reception [7] and point to point microwave links [8], [9]. Similarly, it will be a perfect antenna for small cell millimeter wave wireless backhauling in wireless systems like the fifth generation (5G), where high gain and atheistically pleasing antennas will be required.

Single layer RLSA consists of four major parts as shown in Figure 1. The slotted waveguide cavity is formed by using two parallel plates - the radiating surface which bears the radiating elements and the background or ground. The cavity which is the space between the parallel plates in most cases is

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filled with dielectric material(s) of appropriate permittivity. The feeding is accomplished centrally using a coaxial to waveguide connector that is customized to ensure proper matching between the waveguide and the coaxial transmission line. The radiating surface which has circular dimension can be made of metal such as brass, copper or aluminum. Likewise the background, which in addition do not carry any slot. The radiating slots are created in an array form to produce radiation of desired polarization. The size and orientation of the arrayed slots influence the type of polarization and the radiation pattern produced. The dielectric material in the cavity is in the form of a tube. These components when brought together makes up the desired RLSA.

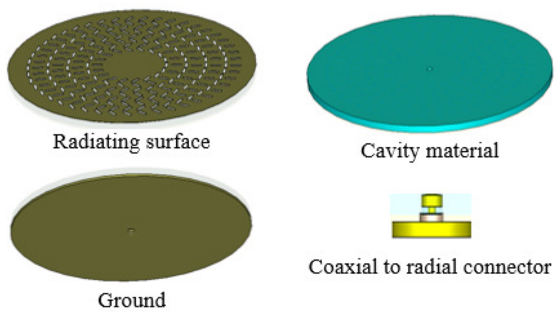


Fig. 1. Components of RLSA

Apart from proper placement of the radiating slots and the choice of dielectric material for the cavity, the most important aspect of RLSA design is matching the transmission line and the waveguide cavity. Coaxial to waveguide transition is popular for single layer RLSAs at frequencies below 60 GHz. Therefore this paper studied RLSA where a 50 Ω SSMA connector with straight solid probe coated with dielectric material is used. The connector can operate up to 40 GHz.

Accurate modelling and analysis of coaxial to waveguide adaptor for practical application has been presented in [10], [11], [12], [13]. However, since the demonstration of the analysis of coaxial to waveguide adaptor using 3D electromagnetic simulator by Ansoft and Hewlett-Packard [14], the practice has now become a standard. Hence, using a simulator, variety of coaxial to waveguide adaptors can easily be implemented and analyzed.

In this paper, computer simulation technology microwave studio 2014 (CST MWS 2014) software is used for the study of the proposed feeding configurations. Firstly, a base antenna is designed at 28 GHz with disk ended feed probe. Then, the disk end was replaced with a conical and frustum shaped ends. The obtained results are analyzed for possible performance improvements.

2. Methodology

In the structure of single layer RLSA where single material fill the cavity, has the feed probe extending into the cavity. And it pierce through the center of the dielectric material. It is customized accordingly for proper matching. Coaxial to waveguide adaptor with feed probe loaded with disk shaped element was studied for single layer RLSA in [15]. Results from the study shows that the arrangement is effective in receiving and transmitting the radial cavity TEM mode wave into transmission line mode and vice versa. Its initial design and analysis were based on Field Matching Method where Bialkowski [16], [17] provided a set of programmable algebraic equations that readily simplify the analysis. For the Field Matching Method, the structure of the transition is divided into a number of regions which are cylindrical in shape as shown in Figure 2. These are: region I (region under the disk element), region II (region above the disk element) and region III (the surrounding cavity). The regions in most cases are filled with materials of dielectric constants εrI, εrII and εrIII respectively. However for this paper, region I and II are filled with air. Whereas region III is filled with polypropylene polymer.

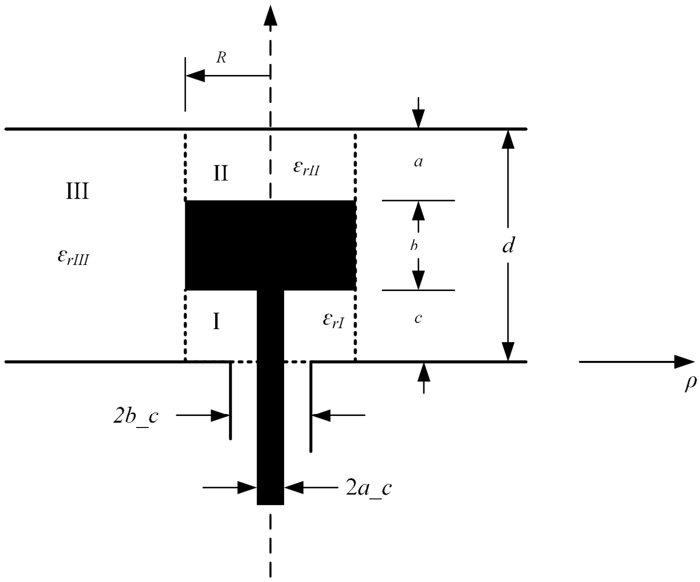


Fig. 2. Coaxial to waveguide transition with disk ended feed post

The field in the coaxial aperture is the standard coaxial line field given by

$$\vec{E}_o = \vec{E}_\rho \hat{\rho} = -\frac{V}{\rho In\left(b\_c / a\_c\right)}\hat{\rho} \tag{1}$$

where V is the voltage applied between the conductors of dimensions a_c and b_c.   is the radius of the radiating surface and   is the unit vector in the radius direction. By applying the boundary conditions and evaluating the fields , and for regions I, II and III respectively, the coaxial line input admittance and the required matching can be accomplished. Detailed mathematical formulation required for the matching can be found in [15]. Consequently, parameters a, b, c and R need be optimized for optimum performance.

However, using a simulator, which has now become a standard in antenna design, the difficulty in solving the complex mathematical relationships for the fields in the regions is avoided. Whence the probe loading is modified to conical and frustum shapes. This result in new shape for region I which the electromagnetic phenomenon can be studied easily using the simulator. For the case of CST, the electromagnetic phenomenon in the regions is solved by breaking the region into thousands of smaller regions and applying the appropriate boundary conditions. Afterwards, using one of the solvers, the design is simulated and the required performance metrics can be tracked and optimised.

Figure 3 shows the modified feed probe for this paper. RLSA at 28 GHz utilising these arrangement is implemented and optimized using the CST. Set of parameters necessary for achieving the desired matching between the transition line and the waveguide were navigated through for better results. Polypropylene polymer of thickness 3.0 mm [18], dielectric permittivity 2.33 is used as the cavity material. The center frequency is 28 GHz. The radiating surface is copper with radius 50 mm. Likewise the background is copper but of thickness 1.0 mm so as to rigidly support the feed connector in the prototype. Linear polarization is realized by placing the radiating element on the surface in accordance with the procedure outlined in [19]. The feeding is facilitated using a dielectric coated straight 50 Ω SSMA connector. The connector is centrally mounted so that radially travelling wave will be sent into the cavity upon excitation.

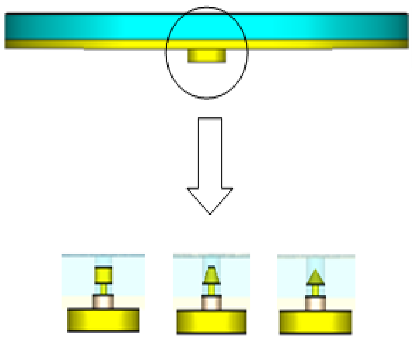
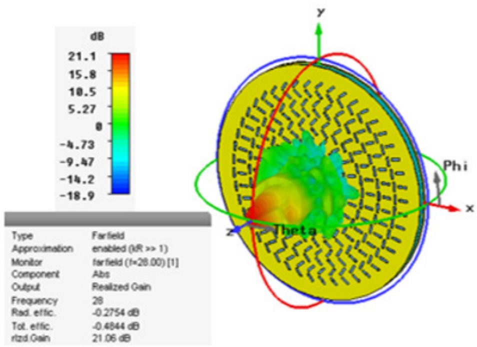


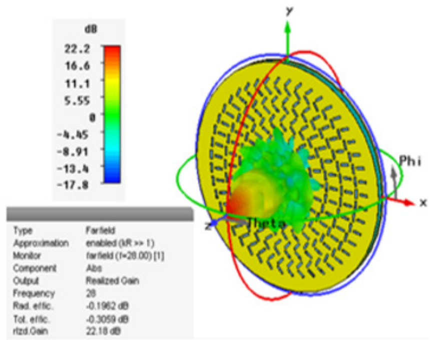
Fig. 3. Modified feed probe studied

3. Results and Discussion

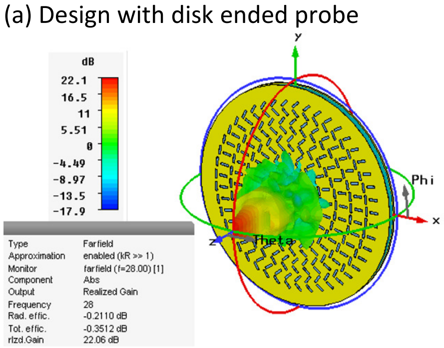
The antenna with the proposed modifications are realized and studied using the software. In each case, after setting the initial parameter values for the design, the radiating slots geometry and the feed dimensions are systematically optimized until the best settings are achieved. Figure 4 depicts the 3D radiation pattern. It can be seen that a directed beam in the broadside direction is produced. The realized gain stand at 22.1 dB, 22.2 dB and 22.1 dB for the disk, conical and frustum ended cases respectively.



(a) Design with disk ended probe



(b) Design with conical ended probe



(c) Design with frustum ended probe

Fig. 4. 3D simulated radiation pattern

The reflection coefficient curve is shown in Figure 5. An impedance bandwidth of 0.7 GHz (27.6-28.3 GHz) and S11 value of -14.4 dB at 28 GHz were achieved for the design with the disk ended head. The conical ended head has S11 value of -14.7 dB at 28 GHz with an impedance bandwidth of 0.7 GHz (27.8-28.5 GHz). Whereas, an impedance bandwidth of 0.8 GHz (27.7-24.5 GHz) and S11 of -16.4 dB at 28 GHz were achieved for the frustum ended. In all, the frustum ended gave better bandwitth and S11 at 28 GHz.

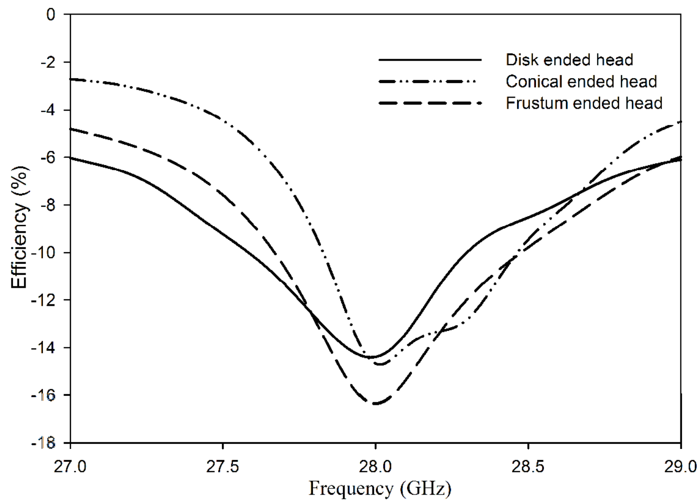


Fig. 5. Simulated reflection coefficient performance

Similarly, the efficiencies for the designs are compared in Figure 6. A value between 70%-89%, 41%-93%, 61%-92 % with 89%, 93%, 92% at 28 GHz were achieved for the disk, conical and frustum ended respectively. Though the disk ended has only 89% at 28 GHz, on the average, it has a more stable value over the frequency band.

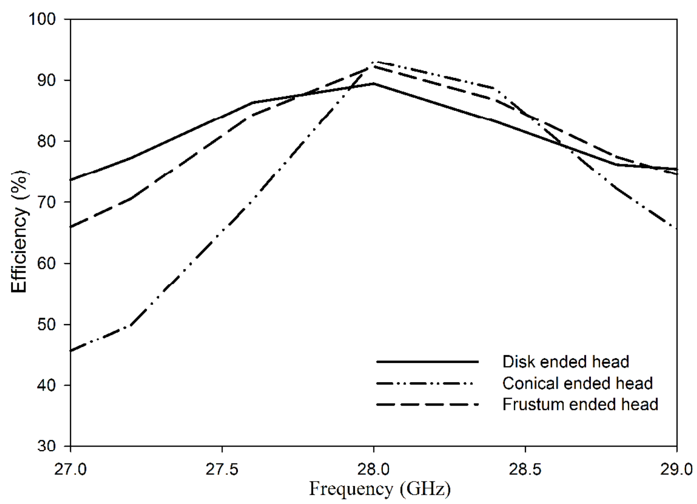


Fig. 6. Simulated total efficiency

Summary of the obtained results are given in Table 1. It can be seen that the S11 improved from the disk ended to the frustum ended designs. The bandwidth increased slightly in the frustum ended case with the conical ended having higher gain. The conical and frustum ended gave a little higher efficiency than in the disk ended case.

Table 1
Summary of results

Design	S_{11} (dB)	Impedance Bandwidth (GHz)	Gain (dB)	Efficiency (%)
Disk ended	-14.4	0.7	21.1	89
Conical ended	-14.7	0.7	22.2	93
Frustum ended	-16.4	0.8	22.1	92

4. Conclusion

Standard form liearly polarised RLSA at 28 GHz fed by coaxial to waveguide feed probe modified with disk, conical and frustum ends were studied. The antenna having reduced size is simulated and analysed in terms of return loss performance, radiation pattern, gain and efficiency. Generally the results obtained in the various cases are close with the disk ended yielding a more stable result over the frequency of simulation.

Acknowledgement

The authors would like to acknowledge for the financial supports given from RIGS (RIGS15-1490149) grant from IIUM.

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