Progress In Electromagnetics Research, PIER 90, 51–62, 2009

A STABLE DESIGN OF COAXIAL ADAPTOR FOR RADIAL LINE SLOT ANTENNA

O. Beheshti-Zavareh and M. Hakak

Faculty of Engineering
Department of Electrical Engineering
Tarbiat Modares University (TMU)
Tehran, Iran

Abstract—A new design of feed for radial line slot antenna (RLSA) is presented. For better impedance match to the waveguide the effect of the various feed parameters is analyzed and their design sensitivity is studied. This paper emphasizes the advantages of using feed with a funnel below the connector entry and a conical segment over the entering probe.

1. INTRODUCTION

The Radial Line Slot Antenna (RLSA) is a planar antenna having attributes such as high efficiency of about 70% and higher gain of about 33 dBi [1] compared with antennas in similar usage. It can be designed for circular [2, 3] or linear polarization [4]. An interest in using this antenna is growing because of its ease in manufacturing and lower loss [1]. Nowadays, this antenna finds different applications such as satellite TV reception Direct Broadcast System, DBS [2, 5], local multiport distribution system (LMDS) [6] and Wireless LANs [7]. This design presented in this paper has better performance than many equivalent designs [8–11].

One RLSA antenna with linear polarization and its feeding structure is shown in Figure 1. The slots are oriented in order to have linear polarization [12]. There are two types of structures of this antenna, two-layers [2, 4] and one-layer [13]. The two-layer type uses incoming wave and the one-layer type uses outgoing wave for exciting the slots.

Figure 2 shows two types of adaptors that are used in RLSA antennas as feeding structures [14–18]. The conical probe adaptor

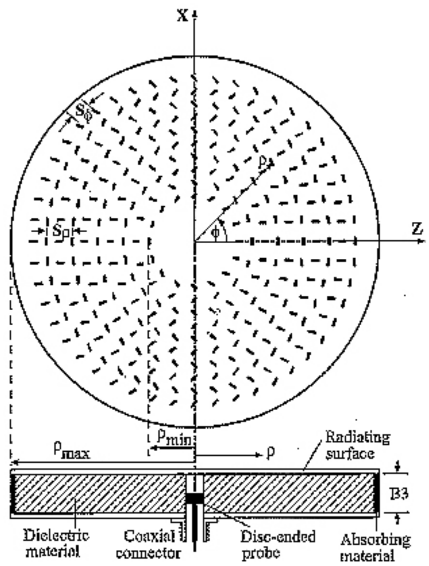
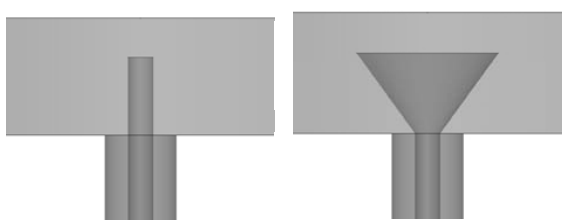


Figure 1. A radial line slot antenna with linear polarization and coax gap to radial line adaptor [1].



(a) (b)

Figure 2. RLSA antenna adapters (a) conventional (b) conical probe.

has wider application than the conventional type because of its wide bandwidth and thickness of RLSA.

In this paper, a modified structure that is less sensitive to manufacturing tolerances is proposed. For this purpose it is necessary to analyze the mutual effects of the various design parameters involved.

2. THEORETICAL ANALYSIS

An elaborate discussion on the probe-fed waveguide is given in [19]. Initially, the probe is modeled with a monopole antenna over infinite lossless ground plane (Figure 3).

The total radiated power over the upper hemisphere of radius r can be written as

$$\mathrm{p}_{rad} = \oiint_S W_{av} \cdot dS = \frac{1}{2\eta} \int_0^{2\pi} \int_0^{\pi/2} |E_\theta|^2 \, r^2 \sin\theta d\theta d\phi \tag{1}$$

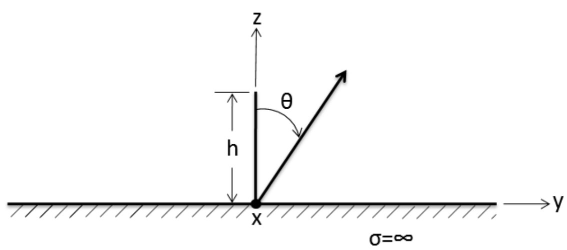


Figure 3. Monopole on infinite electric conductor.

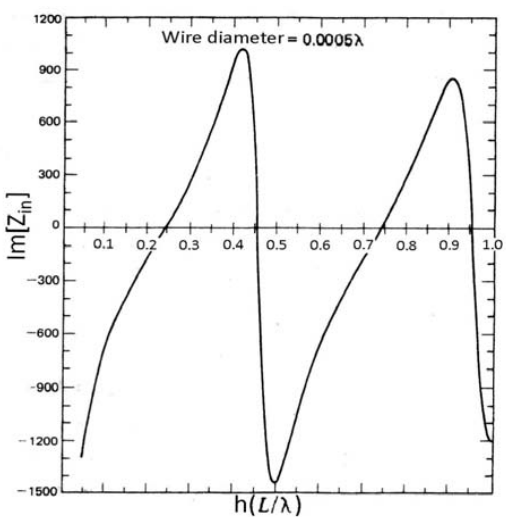


Figure 4. Calculated input reactance for monopole antenna as antenna height, h [21].

where

$$\begin{cases} E_\theta \cong j\eta \frac{kl_0 h e^{-jkr}}{4\pi r} \sin\theta \left[2\cos(kh/2\cos\theta)\right] & z \geq 0 \\ E_\theta = 0 & z < 0 \end{cases} \tag{2}$$

and η and k are the free-space impedance and wave number, respectively.

This equation can be used to plot $\mathrm{Im}(Z_{in})$ as a function of the monopole height, h. As shown in Figure 4, most radiated power from the antenna can be achieved with $h = \lambda/4$ [20]. Therefore, $h = \lambda/4$ is the starting point for designing the conventional probe adaptor.

3. THE FEED ADAPTOR DESIGN

A coaxial to radial guide adaptor, which is useful for arbitrary heights of radial line, is designed here. A return loss (RL) below -30 dB and a bandwidth of 500 MHz at 12.45 GHz frequency are suitable specification for use in DBS antennas. For the input coaxial port, SMA-type connector is considered.

3.1. Conventional Probe Adaptor

Figure 5 shows the conventional type of coaxial to radial line adaptor. The quantity of reflection from waveguide is simulated for a wide variety of height of probe tuck h_1 and the height of waveguide h_2. Figure 6 shows the contour maps of reflection below -15 dB, -20 dB, -25 dB and -30 dB as a function of h_1 and h_2. As shown, to have the RL below a desired value, the variation range of h_2 is higher than h_1. Also, the variation range of h_1 and h_2 is low. For example, to have RL below -30 dB, h_1 is between 5.5 mm and 5.8 mm (the variation is

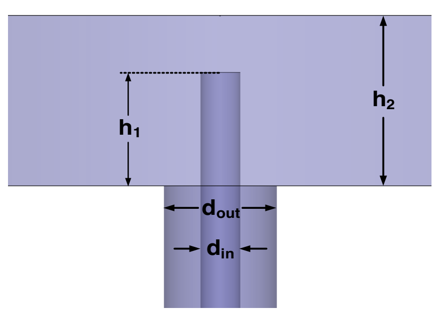


Figure 5. Conventional probe adaptor for $f_0 = 12.45$ GHz, $d_{in} = 1.3$ mm, $d_{out} = 3.3$ mm, $\varepsilon_r = 2.1$.

0.3 mm) and h_2 is between 9.5 mm and 10 mm (the variation is 0.5 mm). But, for practical applications of feed adaptor in the RLSA antenna, h_2 must be about $\lambda/4$ ($\approx$ 6 mm at 12.45 GHz) [1, 4, 5]. In the next sections, the method for increasing these variations is proposed. The reflection takes its minimum at $h_1 = 9.4$ mm and $h_2 = 5.4$ mm (Figure 7). The next sections demonstrate methods for resolving this restriction.

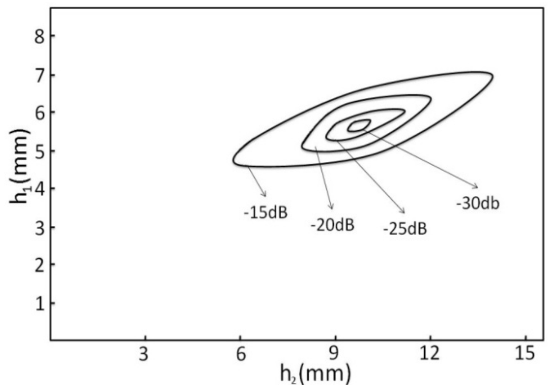


Figure 6. Return loss of the probe as function of h_1 and h_2, $d_{in} = 1.3$ mm, $d_{out} = 3.3$ mm, $\varepsilon_r = 2.1$.

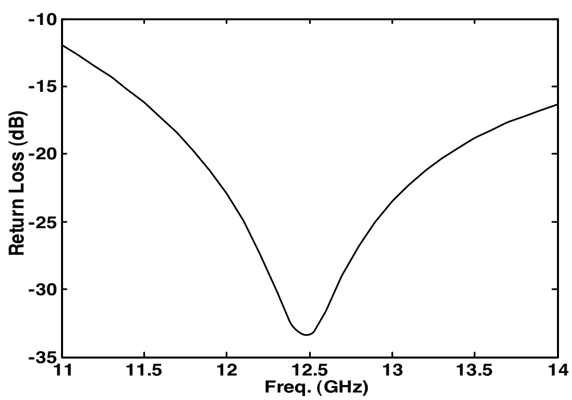


Figure 7. The frequency characteristics of coax gap adaptor with $h_1 = 5.4$ mm and $h_2 = 9.6$ mm.

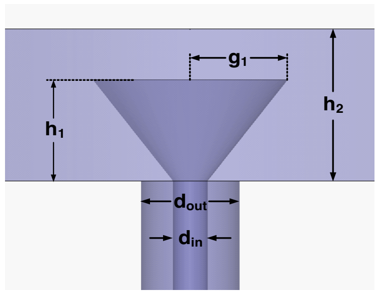


Figure 8. Conical probe adaptor.

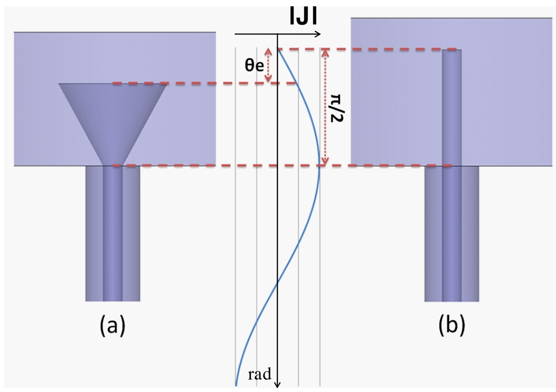


Figure 9. Current distribution on conventional and conical probes.

3.2. Conical Probe Adaptor

Figure 8 shows the conical probe adaptor and its design parameters h_1, h_2 and cone's upper radius g_1.

In the conventional feed adaptor the current amplitude is zero at feed end, but in the conical type it is not zero because of the primary phase created, θe. As shown in Figure 9, since the current phase must be $\pi/2$ at the feed input for having best matching, the conical probe can be associated with a reduced waveguide height, h_2.

Figure 10 shows contours for reflections below -15 dB, -20 dB, -25 dB and -30 dB as design parameters h_1 and h_2 vary. g_1 is optimized for minimum reflection. This figure also shows that there is larger area than conventional probe for reflection below -30 dB where h_1 and h_2 may vary, but for practical values of h_2 (about 6 mm at 12.45 GHz), the reflection is sensitive to the design parameters (h_1 and g_1). In the next section a method is described to overcome this restriction.

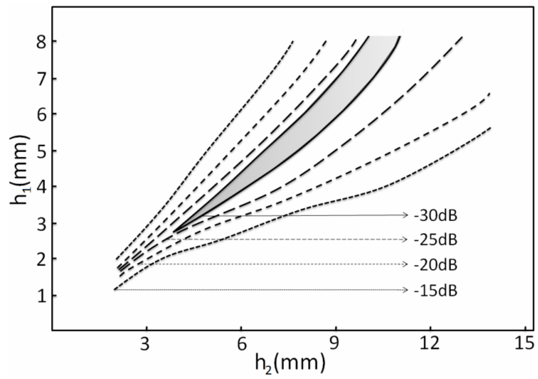


Figure 10. Return loss of conical feed as function of h_1 and h_2 for optimized g_1, $f_0 = 12.4\,5\,\text{GHz}$, $d_{in} = 1.3\,\text{mm}$, $d_{out} = 3.3\,\text{mm}$, $\varepsilon_r = 2.1$.

By comparing Figure 11(a) with Figure 7 it is noticed that for the same value of h_2 there is an increase in the passband width and decrease in return loss at center frequency, 12.45 GHz. Figure 11(b) shows the frequency characteristics of conical adaptor for $h_2 = 6\,\text{mm}$.

3.3. Funnel Probe Adaptor

Figure 12 shows the funnel probe adaptor design and its geometrical parameters h_1, h_2, g_1, g_2 and h_3, for use in the RLSA antenna application. The height h_2 must be about $\lambda/4$ [22], i.e., $\approx 6\,\text{mm}$ at 12.45 GHz. Therefore, the design is performed using $h_2 = \lambda/4$ and also by trial and error $h_3 = \lambda/2$.

Figure 13 shows the return loss as a function of h_3 for various values of h_1. The g_1 parameter is optimized by simulation. By decreasing h_3 for having return loss below $-30\,\text{dB}$, h_1 is decreased, too. For $h_1 = 3.6\,\text{mm}$, return loss is found to assume a minimum value.

Figure 14 shows the contour map for the reflections below $-15\,\text{dB}$, $-20\,\text{dB}$, $-25\,\text{dB}$ and $-30\,\text{dB}$ as functions of g_1 and h_3 which occupied 83%, 52%, 17% and 8% of the area in the diagram, respectively.

The figure above predicts that if g_1 and h_3 are selected to have RL below $-30\,\text{dB}$, it is easy to do it by changing h_1. Figure 15 predicts the reflection by optimized g_1 and h_3. The dashed line shows the accepted tolerance for h_1 when g_1 and h_3 are optimum and fixed. For example, by selecting $h_1 = 3.6\,\text{mm}$ and optimized g_1 and h_3, the maximum acceptable tolerance of h_1 is 1.3 mm, 1.6 mm, 1.9 mm and 2.6 mm for reflections below $-15\,\text{dB}$, $-20\,\text{dB}$, $-25\,\text{dB}$ and $-30\,\text{dB}$, respectively.

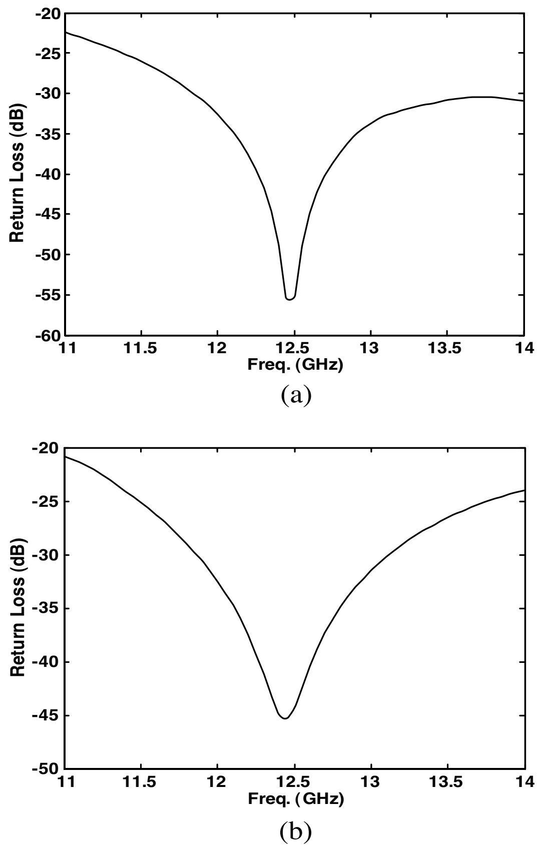


Figure 11. Frequency characteristics of coax gap adaptor with (a) $h_2 = 9.6\,\text{mm}$ and (b) $h_2 = 6\,\text{mm}$, $f_0 = 12.45\,\text{GHz}$, $d_{in} = 1.3\,\text{mm}$, $d_{out} = 3.3\,\text{mm}$, $\varepsilon_r = 2.1$.

This indicates that there is good manufacturing allowable tolerance for this adaptor.

Figure 16 shows the effect of changing the height of feed probe from its optimized value when g_1 and h_3 are fixed. It is clear that it is possible to have RL $< -25\,\text{dB}$ by changing h_1 when the optimized g_1 and h_3 for a given h_1 is selected.

Finally, Figure 17 shows the simulation result for the funnel probe adaptor. The frequency band is 12.2–12.7 GHz for use in DBS TV reception. In this band the reflection is below $-30\,\text{dB}$ and the accepted tolerance for h_1 is 1.6 mm.

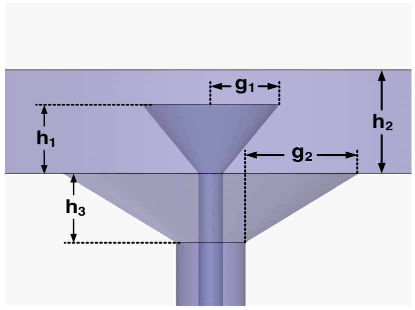


Figure 12. Funnel probe adaptor.

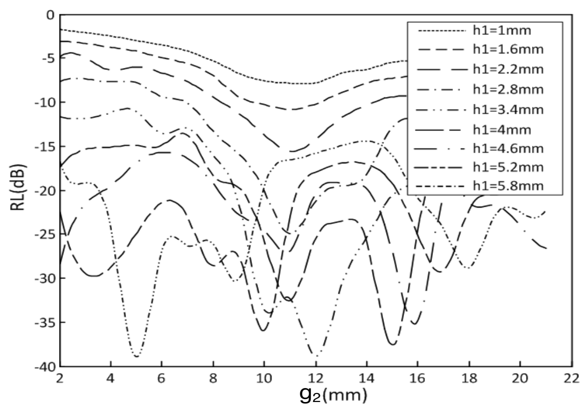


Figure 13. Reflection from funnel probe adaptor as a function of g_2 for various h_1.

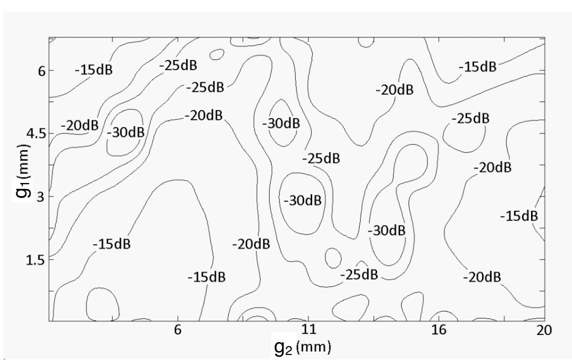


Figure 14. Reflection from funnel probe adaptor as functions of g_2 and g_1.

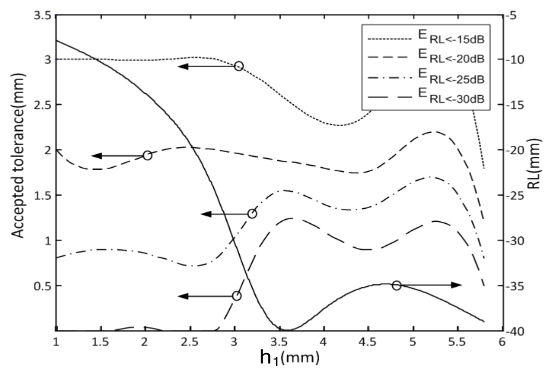


Figure 15. Acceptable tolerance for reflections below $-15\,\text{dB}$, $-20\,\text{dB}$, $-25\,\text{dB}$ and $-30\,\text{dB}$ and optimized reflection as a function of h_1.

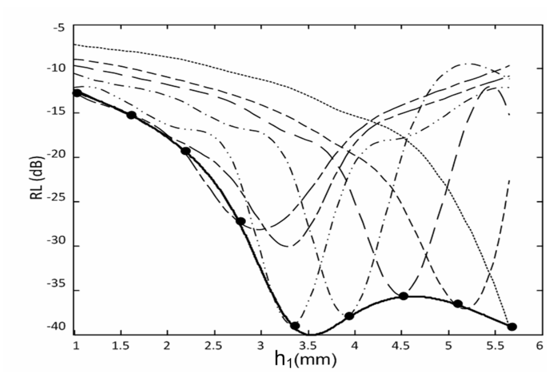


Figure 16. Effect of changing h_1 when other parameters are fixed, on RL.

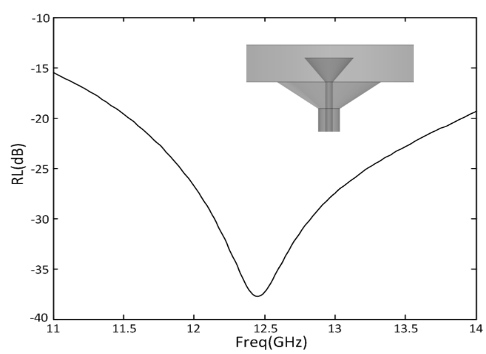


Figure 17. Reflection characteristics of a funnel probe adaptor. $f_0 = 12.45\,\text{GHz}$, $h_1 = 3.6\,\text{mm}$, $h_2 = \lambda/4$, $g_2 = \lambda/2$, $h_3 = 12.2\,\text{mm}$, $g_1 = 2.9\,\text{mm}$.

4. CONCLUSION

A new design of coaxial to radial guide adaptor for RLSA antenna is presented. Simulation results show that the funnel probe may provide RL below −25 dB throughout desired frequency band, and also exhibit much improved tolerance in manufacturing it.

ACKNOWLEDGMENT

The authors acknowledge the financial support for this work from the Iran Telecommunication Research Center (ITRC) under the contract ITRC 10314.

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