

Optimization of the Radial Lines of an LP-RLSA for 40-50 GHz Frequency Band

Md Faiyaz Bin Hassan, Shubhendu Bhardwaj

Department of Electrical and Computer Engineering, University of Nebraska-Lincoln, Lincoln, NE, USA
bhardwaj@unl.edu

Abstract—This study investigates the design of radial lines at four different geometric positions of a slot antenna using in a high frequency range of 40-50 GHz. The slot arrays were positioned in such a way that linear polarization was found with a broadside radiation pattern. The radial line dimensions were optimized to extract the best outcomes from the setup. A peak gain of 11.14 dB was achieved at 47.5 GHz and S_{11} parameter reached as low as -46.06 dB. These radial lines provide an accurate prediction of what to expect when they are implemented to form a linearly polarized RLSA antenna.

Index Terms—directivity, linear polarization, radial line, return loss, slot array.

I. INTRODUCTION

Recently, radial line slot array (RLSA) antennas have gained a lot of attention in RF communication systems. Their applicability in Wi-Fi, 5G technologies, satellite communication, etc. makes them exciting. RLSA antenna allows a low-complexity feeding system to achieve a high gain through a waveguide-based feeding where the wave is fed through a radial line and it propagates in a dielectric region [1]. Both, circularly polarized and linearly polarized RLSAs have been studied before for wireless communication applications [2]. A linearly-polarized (LP) RLSA can have high return loss due to the high reflection from the boundary of the waveguide. Researchers have worked and succeeded in improve this loss at 15-17GHz range using different techniques [3], [4]. The broader aspect of this study is to reduce this return loss with high gain in an LP-RLSA at a higher frequency. To move forward toward this goal, an important first step is to optimize the performance of a sectorial region of the radial line slot array cavity in the intended frequency range.

In this paper, four such sectorial linear arrays of an LP-RLSA were studied in frequency band of 40-50 GHz. One radial line is optimized first and those dimensions are applied to all of them. Section II discusses the theoretical aspects of the design whereas section III provides a detailed idea of the optimization. Section IV demonstrates the final outcome and Section V summarizes everything.

II. GEOMETRY AND SIMULATION MODELING

For this study, four radial sections are chosen to represent the first slot array of each quadrant of a full linearly polarized RLSA antenna. Fig. 1(a) is the LP-RLSA model where only these four radial sections are demonstrated. The rest of the area will be filled with similar radial sections during the full antenna analysis.

The feeding and boundaries are visualized in fig. 1(b). The wave port feeding is applied in the XZ plane. The YZ planes have metal boundaries. As all the radial sections will ultimately form one RLSA, continuity of the electric fields between the radial lines is essential. To ensure this continuity, the design is following a clockwise periodic boundary in the YZ faces of the radial line, and the master-slave faces are displayed in fig. 1(b).

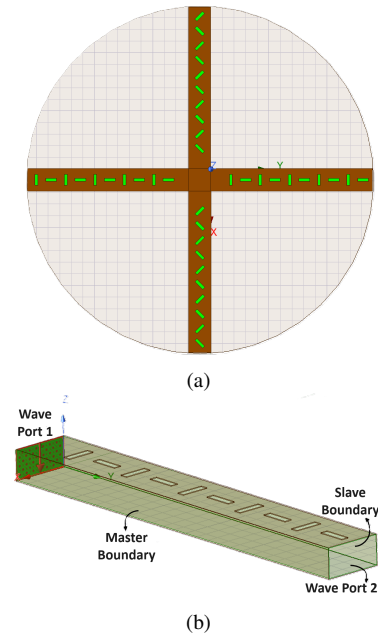


Fig. 1 . Design of (a) the four Radial Lines and (b) ports and boundaries of the LP-RLSA antenna.

The frequency band is chosen to be 40-50GHz for its wide applicability. Due to the slow wave effect, the guided wavelength in the cavity built with Roger RT/duroid 5880 TM ($\epsilon_r = 2.2$) substrate becomes 5.056mm. A general practice is to keep the cavity depth $\lambda_g/4$. The distance between two slots is kept at $\lambda_g/2$ to accommodate the radiation. The distance from the wave port to the first slot is defined as $\lambda_0/2$. Slot lengths and widths will be varied in the optimization section.

III. OPTIMIZATION

As discussed in the previous section, slot length, slot width and number of slot pairs need to be optimized before the study can proceed. The basic process was to optimize one parameter

at a time and with that optimized outcome, we move on to the next parameter. Slot length was varied first. The best gain and S_{11} outcome were found for $0.30\lambda_0$. With this slot length, slot width was varied from $\lambda_g/20$ to $\lambda_g/10$. It is observed that with increasing slot width, all the antenna parameters outcomes are improving. It is also evident that antenna outcomes improve with an increasing number of slot pairs. All of these outcomes are summarized in Table 1.

TABLE I . Antenna Parameter Optimization

Slot Length	Gain	S_{11} Parameter	Efficiency
$0.25\lambda_0$	1.07 dB	-64.0 dB	17.65%
$0.30\lambda_0$	3.09 dB	-34.5 dB	49.60%
Slot Width	Gain	S_{11} Parameter	Efficiency
$\lambda_g/20$	3.09 dB	-34.5 dB	49.60%
$\lambda_g/16$	5.70 dB	-35.1 dB	61.08%
$\lambda_g/12$	6.23 dB	-45.0 dB	68.62%
$\lambda_g/10$	6.61 dB	-45.1 dB	75.95%
No of slots	Gain	S_{11} Parameter	Efficiency
3pair	6.61 dB	-45.1 dB	75.95%
4pair	8.65 dB	-32.0 dB	90.83%
5pair	9.65 dB	-28.9 dB	94.00%

Finally, the optimized parameters (in Table II) and the full geometric attributes are found for one radial line. These are now applied to all of the radial lines as they have uniform dimensions.

TABLE II . Optimized Parameters

Parameters	Value	Parameters	Value
Number of slots	5 pair	Slot Length	1.87 mm
Antenna Length	27.808 mm	Slot Width	0.506 mm
Antenna Width	3.75 mm	Cu Thickness	100 μm
Antenna Height	1.875 mm	Relative permittivity	2.2

IV. RESULT ANALYSIS

In this section, the general performance of each of the radial lines will be discussed. Fig. 3 shows S_{11} and S_{12} parameters for the radial lines. It is observed that the radial lines that have an angle of 2π between them show similar kinds of results. Fig. 3(a) and Fig. 3(c) are 2π degrees apart and show very similar results. The same statement is true for Fig. 3(b) and Fig. 3(d). The lowest S_{11} parameters for the radial lines at 0° , 90° , 180° , and 270° are -28.91 dB, -32.84 dB, -46.06 dB, and -35.93 dB respectively.

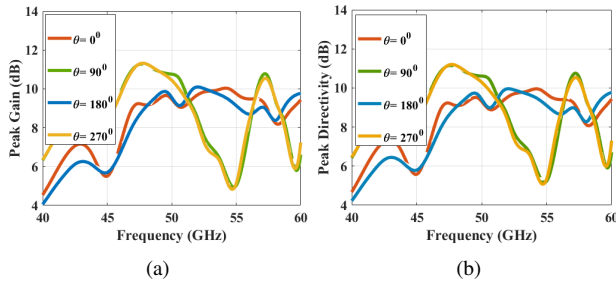


Fig. 2 . (a) Peak Gain and (b) Peak Directivity behavior.

Fig. 2(a) and Fig. 2(b) are showing the peak gain and directivity for all the radial lines. Similar to the S-parameter

outcomes, both gain, and directivity are showing the discussed similarities of radial lines that are 2π degrees apart. The directivity and gain are generally higher for the radial lines that are in 90° and 270° . Both the highest gain (11.14 dB) and directivity (11.26 dB) in this study were found at 47.5 GHz. The small difference between gain and directivity also indicates a great radiation efficiency for the antenna.

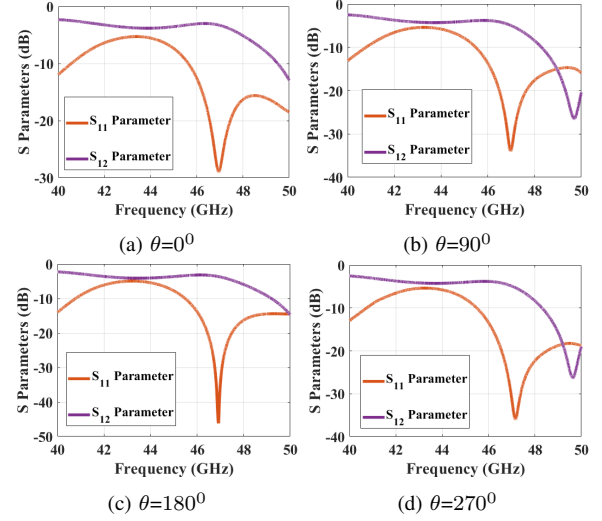


Fig. 3 . S_{11} and S_{12} Parameter Plots.

V. CONCLUSION

In this study, radial lines in four different angles were analyzed with a vision to implement them in an LP-RLSA antenna. The positions of the radial lines were carefully chosen to represent the full RLSA. The maximum individual gain of a radial line was 11.14 dB at 47.5 GHz. The S_{11} and S_{12} parameters showed promising outcomes as the lowest value of S_{11} reached -46.06 dB and S_{12} values were dropping as the frequency was increasing. Although the radial lines will have to be implemented together for a full RLSA, this optimization study is laying down a solid foundation for the overall study. The behavior of the LP-RLSA antenna can be predicted with great accuracy and we can determine what to expect. For future work, an LP-RLSA design is expected to be implemented and fabricated as a continuation of this study.

REFERENCES

- [1] M. J. L. Morales, J. Hirokawa, and M. Sierra-Castañer, "Control of phase in radial line slot antenna for 5g communications at 60ghz," in *2017 11th European Conference on Antennas and Propagation (EUCAP)*, 2017, pp. 3738–3742.
- [2] M. Ando, K. Sakurai, N. Goto, K. Arimura, and Y. Ito, "A radial line slot antenna for 12 ghz satellite tv reception," *IEEE Transactions on Antennas and Propagation*, vol. 33, no. 12, pp. 1347–1353, 1985.
- [3] N. Y. Koli, M. U. Afzal, K. P. Esselle, R. M. Hashmi, and M. Z. Islam, "A beam squinted linearly polarised radial line slot array antenna with improved return loss bandwidth," in *2020 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting*, 2020, pp. 411–412.
- [4] J. I. Herranz, A. Valero-Nogueira, F. Vico, and V. M. Rodrigo, "Optimization of beam-tilted linearly polarized radial-line slot-array antennas," *IEEE Antennas and Wireless Propagation Letters*, vol. 9, pp. 1165–1168, 2010.