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# SELECTION OF BEAM SQUINTING DESIGN PARAMETERS FOR OPTIMAL LP-RLSA ANTENNA RADIATION PERFORMANCE

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## ABSTRACT
The linearly polarized radial line slots array antenna exhibits poor return loss. This problem was tackled by imploring the beam squinting and reflection cancelling slots techniques. This paper suggests the use of a numerical solution for selection of the beam squinted slots concentration on the radiation surface by x-raying best design parameters for optimal solutions using MALTAB computations for the objective function. This is aimed at minimizing design and computation time involved in the selection of optimal design parameters hence improving the entire production process. Results obtained from the numerical solutions were used as design parameters on CST MWS for the computation of the antenna radiation characteristics and showed excellent agreement with published literatures on optimal LP-RLSA beam squinted antenna designs in terms of gain and return loss values.

**Keywords:** beam squint, radiation characteristics, radial spacing, azimuthal spacing, return loss, gain, slots, computation time.

## INTRODUCTION
With the evolution of the radial line slots array antenna (RLSA) since its inception in the 50s and further developments by Kelly in the 60s unfolding developments aimed at improving the radiation performance of this remarkable antenna that proffers incredible characteristics as possible replacement to the widely used parabolic reflector antenna for direct broadcast services (DBS) is been ongoing. Researchers have thought of various methods of improving the inherent return loss problems associated with the linearly polarized radial line slots array antenna as well improving the overall radiation efficiency of the (LP-RLSA), as a result; various suggestions has been made as well as attempts imploring numerous techniques to combat this flaws identified. These include improving slots concentrations on the radiating surface as a way of increasing the relative radiation power density by manipulating the products of the radial and azimuthal slots spacing with the view of maximizing the value of the constant obtained from the manipulation. In this submission a careful manipulation of the radial slots spacing is done. The azimuthal slots spacing was carefully chosen as seen in equation (14) to achieve optimal solutions for a LP-RLSA antenna characteristics.

The azimuthal and radial slots spacing are expressed in terms of thetaT ($\theta_T$), phi ($\phi$), and, phiT ($\phi_T$) respectively forming the objective function of this study. Solutions for the differentials of functions of the objective function, thetaT ($\theta_T$), phi ($\phi$), and phiT ($\phi_T$) were obtained, these results were used to obtain the turning points; a logical assumption of $\cos\theta_T \neq 0$ was made for the avoidance of the formation of recursive equations. Numerical solutions using MATLAB computations were realized, results obtained points out optimal parameters for functions of the objective function, thetaT ($\theta_T$), phi ($\phi$), and phiT ($\phi_T$) required for best radiation characteristics. This is aimed at reducing the overall design, computation and production time.

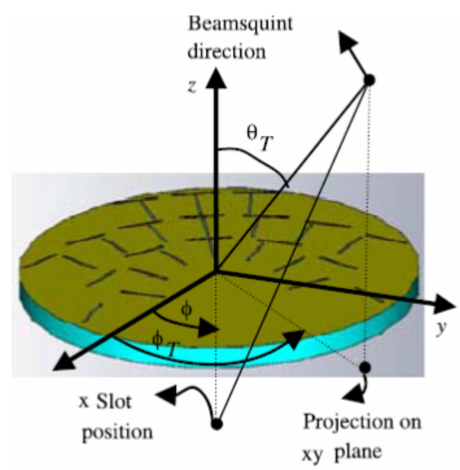


**Figure-1.** CST 3D view of the LP-RLSA Illustration of Antenna parameters [1].

The single layer RLSA is considered to have significant advantages over the double layer cavity; where the radial cavity mode (double layer cavity) compensates power loss from cavity through radiation (inward travelling mode). The single layer cavity utilizes the outward travelling mode of radiation whose power density diminishes by a factor $1/\sqrt{\rho}$ in addition to losses incurred as a result of radiation coupling. To combat this problem it is necessary to utilize a form of coupling control measures to ensure that slots aperture illuminations taper are within tolerable limits. The slots surface densities are kept constant ($S_\rho * S_\phi =$ constant) while controlling

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coupled power proportion from the inner field to the radiated field by manipulating slots length on the radiating surface[2, 3]. Alternatively, it is proposed in this paper that the azimuthal cell separation $S_\phi$ be manipulated to narrow the separation distance between radiating slots as the internal field densities diminishes with increasing antenna radial. This will increase slots surface density $S_\rho * S_\phi$, thereby leading to increment in the relative radiated power density.

## MANIPULATIONS OF RADIATING SLOT LENGTHS AND THE AZIMUTHAL CELL SEPARATION

To achieve a fair constant slots aperture illumination control over the radiating surface, the slot lengths should be varied proportionally with respect to the radial length; and position of slots placed on the radiating surface as seen from the expression [1-8]:

$$L_{rad} = \left(5.8678 + 6.415 \times 10^{-3} * \rho\right) * \frac{12.5 \times 10^{9}}{f_o} \quad (1)$$

Where $\rho$ is the radius of the antenna, with $f_o$ being the desired antenna frequency. Similarly, maintaining constant slots surface density on the radiating surface of an RLSA antenna, the azimuthal slot separation $S_\phi$ should be manipulated to maximize the value for a constant *K*. The constant K shall be used to determine the optimum relative radiated power density required for efficient antenna radiation characteristics. Hence, the product "$S_\rho * S_\phi$" can be maximized for a global best radiation characteristics. Since $S_\rho$ is defined as [1- 8]:

$$s_\rho = \frac{\lambda_g}{1 - \sqrt{\varepsilon_r} * \sin\theta_T \cos(\phi - \phi_T)} \quad (2)$$

$$s_\phi = \frac{2\pi\rho_{min}}{\psi} \quad (3)$$

But $\sqrt{\varepsilon_r} = \sigma$ (4)

$$K = \frac{2\pi\lambda_g\rho_{min}}{\psi} \quad (5)$$

$$s_\rho * s_\phi = \frac{1}{1 - \sigma * \sin\theta_T \cos(\phi - \phi_T)} \quad (6)$$

Where

$\psi$ is the number of slots in the innermost ring, ($\rho_{min}$) is minimum radius, ($\varepsilon_r = 2.33$) is the dielectric constant, and ($\lambda_g$) is the guide wavelength in GHz.

$$\left(s_\rho * s_\phi\right)_{min} = Min \frac{1}{1 - \sigma * \sin\theta_T \cos(\phi - \phi_T)} \quad (7)$$

Solving the objective function; a function of $\theta_T, \phi_T, \phi$ numerically with assumption that $\cos\theta_T \neq 0$ otherwise we will run into series of recursive equations; thus defeating the aim of this study. A range of values for functions of the objective function within; $0 \le \phi \le 180$, $0 \le \theta_T \le 180$ and $0 \le \phi_T \le 180$ respectively is considered in this submission.

$$\frac{\partial f}{\partial\theta_T} = \frac{+\sigma\cos\theta_T\cos(\phi - \phi_T)}{\left[1 - \sigma\sin\theta_T\cos(\phi - \phi_T)\right]^2} \quad (8)$$

$$\frac{\partial f}{\partial\phi} = \frac{-\sigma\sin\theta_T\sin(\phi - \phi_T)}{\left[1 - \sigma\sin\theta_T\cos(\phi - \phi_T)\right]^2} \quad (9)$$

$$\frac{\partial f}{\partial\phi_T} = \frac{\sigma\sin\theta_T\sin(\phi - \phi_T)}{\left[1 - \sigma\sin\theta_T\cos(\phi - \phi_T)\right]^2} \quad (10)$$

$$\theta_T = \tan^{-1}\left\{\frac{1}{2}\left(\frac{\cos\phi\cos\phi_T + \sin\phi\sin\phi_T}{\sin\phi\cos\phi_T - \cos\phi\sin\phi_T}\right)\right\} \quad (11)$$

$$\cos\theta_T[\cos\phi\cos\phi_T + \sin\phi\sin\phi_T] = 0 \quad (12)$$

Assuming $\cos\theta_T \neq 0$, we have

$$\begin{aligned} &\cos\phi\cos\phi_T = -\sin\phi\sin\phi_T \\ &\Rightarrow -\tan\phi\tan\phi_T = 1 \\ &\Rightarrow \tan\phi_T = \frac{-1}{\tan\phi} \Leftrightarrow \phi = \tan^{-1}\left\{\frac{-1}{\tan\phi_T}\right\} \\ &\Rightarrow \phi_T = \tan^{-1}\left\{\frac{-1}{\tan\phi}\right\} \end{aligned} \quad (13)$$

Equation (13) thus gives the required optimal solutions. Substituting equation (13) into equation (11) yields:

$$\theta_T^* = \tan^{-1}\left\{\frac{1}{2}\left(\frac{\cos\phi\cos\left(\tan^{-1}\left\{\frac{-1}{\tan\phi}\right\}\right) + \sin\phi\sin\left(\tan^{-1}\left\{\frac{-1}{\tan\phi}\right\}\right)}{\sin\phi\cos\left(\tan^{-1}\left\{\frac{-1}{\tan\phi}\right\}\right) - \cos\phi\sin\left(\tan^{-1}\left\{\frac{-1}{\tan\phi}\right\}\right)}\right)\right\} \quad (14)$$

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Equation (24) thus gives us the optimal squint angle required for a best radiation characteristic.

$$\phi_T^* = \tan^{-1}\left\{\frac{-1}{\tan\phi^*}\right\}$$

$$\phi^* = \tan^{-1}\left\{\frac{-1}{\tan\phi_T^*}\right\} \qquad (15)$$

Solving for the second derivatives of the objective function gives us

$$\left|\begin{pmatrix} \frac{\partial^2 f}{\partial\theta_T^2} & \frac{\partial^2 f}{\partial\theta_T\partial\phi} & \frac{\partial^2 f}{\partial\theta_T\partial\phi_T} \\ \frac{\partial^2 f}{\partial\phi\partial\theta_T} & \frac{\partial^2 f}{\partial\phi^2} & \frac{\partial^2 f}{\partial\phi\partial\phi_T} \\ \frac{\partial^2 f}{\partial\phi_T\partial\theta_T} & \frac{\partial^2 f}{\partial\phi_T\partial\phi} & \frac{\partial^2 f}{\partial\phi_T^2} \end{pmatrix}\right| < 0$$

;

implies maximum point,

if

$$\left|\begin{pmatrix} \frac{\partial^2 f}{\partial\theta_T^2} & \frac{\partial^2 f}{\partial\theta_T\partial\phi} & \frac{\partial^2 f}{\partial\theta_T\partial\phi_T} \\ \frac{\partial^2 f}{\partial\phi\partial\theta_T} & \frac{\partial^2 f}{\partial\phi^2} & \frac{\partial^2 f}{\partial\phi\partial\phi_T} \\ \frac{\partial^2 f}{\partial\phi_T\partial\theta_T} & \frac{\partial^2 f}{\partial\phi_T\partial\phi} & \frac{\partial^2 f}{\partial\phi_T^2} \end{pmatrix}\right| > 0$$

;

Implies minimum point and

when

$$\left|\begin{pmatrix} \frac{\partial^2 f}{\partial\theta_T^2} & \frac{\partial^2 f}{\partial\theta_T\partial\phi} & \frac{\partial^2 f}{\partial\theta_T\partial\phi_T} \\ \frac{\partial^2 f}{\partial\phi\partial\theta_T} & \frac{\partial^2 f}{\partial\phi^2} & \frac{\partial^2 f}{\partial\phi\partial\phi_T} \\ \frac{\partial^2 f}{\partial\phi_T\partial\theta_T} & \frac{\partial^2 f}{\partial\phi_T\partial\phi} & \frac{\partial^2 f}{\partial\phi_T^2} \end{pmatrix}\right| = 0$$

;

Implies point of inflexion.

Solve for the determinants of the 3 x 3 matrix equation formed from the respective differentials of the second derivatives for the objective function and perform check to arrive at the global best optimal solution. This will enable us to know values of the parameters from the objective function that will give us best radiation power output and as well antenna characteristics, as a result; computation time improved. Solving through the determinants of the matrix formed from the MATLAB computed results of the differentials of the objective function, we have

$$\begin{pmatrix} -16.8851 & -13.6853 & 21.5406 \\ 19.3282 & -21.3841 & -56.8298 \\ -2.0530 & -50.5399 & 19.75 \end{pmatrix} = 37268.035$$

This result indicates that our global best solution is a minimum since the results of the determinant is a positive value from this condition:

$$\left|\begin{pmatrix} \frac{\partial^2 f}{\partial\theta_T^2} & \frac{\partial^2 f}{\partial\theta_T\partial\phi} & \frac{\partial^2 f}{\partial\theta_T\partial\phi_T} \\ \frac{\partial^2 f}{\partial\phi\partial\theta_T} & \frac{\partial^2 f}{\partial\phi^2} & \frac{\partial^2 f}{\partial\phi\partial\phi_T} \\ \frac{\partial^2 f}{\partial\phi_T\partial\theta_T} & \frac{\partial^2 f}{\partial\phi_T\partial\phi} & \frac{\partial^2 f}{\partial\phi_T^2} \end{pmatrix}\right| > 0$$

Which implies a minimum point.

$$\frac{\partial f}{\partial\theta_T} = \frac{+\sigma\cos\theta_T\cos(\phi-\phi_T)}{\left[1-\sigma\sin\theta_T\cos(\phi-\phi_T)\right]^2} \qquad (16)$$

$$\frac{\partial^2 f}{\partial\theta_T^2} = \frac{\begin{pmatrix} 2\sigma^2\cos^2(\phi-\phi_T)[\sin^2\theta_T\cos(\phi-\phi_T)+\cos^2\theta_T-\sigma\cos^2\theta_T\sin\theta_T\cos^2(\phi-\phi_T)]-\ldots\ldots \\ \sigma\sin\theta_T\cos(\phi-\phi_T)[1+\sigma^2\sin^2\theta_T\cos^2(\phi-\phi_T)] \end{pmatrix}}{\left[1-\sigma\sin\theta_T\cos(\phi-\phi_T)\right]^4}$$

$$\frac{\partial^2 f}{\partial\theta_T\partial\phi} == \frac{\left(\sigma\cos(\theta_T)\sin(\phi-\phi_T)[\sigma^2\sin^2\theta_T\cos^2(\phi-\phi_T)-1]\right)}{\left[1-\sigma\sin\theta_T\cos(\phi-\phi_T)\right]^4}\text{`}$$

$$\frac{\partial^2 f}{\partial\theta_T\partial\phi_T} = \frac{\begin{pmatrix} \sigma\sin\theta_T\cos(\phi-\phi_T)[-2\sigma^2\sin^2\theta_T\sin^2(\phi-\phi_T)-\sigma^2\sin^2\theta_T\cos^2(\phi-\phi_T)+\ldots \\ 2\sigma\sin\theta_T\cos(\phi-\phi_T)-2\sin\theta_T-1] \end{pmatrix}}{\left[1-\sigma\sin\theta_T\cos(\phi-\phi_T)\right]^4}$$

$$\frac{\partial f}{\partial\phi} = \frac{-\sigma\sin\theta_T\sin(\phi-\phi_T)}{\left[1-\sigma\sin\theta_T\cos(\phi-\phi_T)\right]^2} \qquad (17)$$

$$\frac{\partial^2 f}{\partial\phi^2} = \frac{\begin{pmatrix} \sigma^2\sin^2\theta_T\sin^2(\phi-\phi_T)[1-2\sigma\sin\theta_T\cos(\phi-\phi_T)]+\sigma\sin\theta_T\cos(\phi-\phi_T)[2\sigma^2\sin\theta_T\cos(\phi-\phi_T)- \\ \sigma^2\sin^2\theta_T\cos^2(\phi-\phi_T)-1] \end{pmatrix}}{\left[1-\sigma\sin\theta_T\cos(\phi-\phi_T)\right]^4}$$

$$\frac{\partial^2 f}{\partial\phi\partial\theta_T} = \frac{\begin{pmatrix} \sigma\cos(\phi-\phi_T)[2\sigma^2\cos^2\theta_T\cos(\phi-\phi_T)+2\sigma\sin^2\theta_T\cos(\phi-\phi_T)-\ldots \\ 2\sigma^2\cos^2\theta_T\sin\theta_T\cos^2(\phi-\phi_T)-\sigma^2\sin^2\theta_T\sin\theta_T\cos^2(\phi-\phi_T)-\sin\theta_T] \end{pmatrix}}{\left[1-\sigma\sin\theta_T\cos(\phi-\phi_T)\right]^4}$$

$$\frac{\partial^2 f}{\partial\phi\partial\phi_T} = \frac{\begin{pmatrix} \sigma^2\sin^2\theta_T\sin(\phi-\phi_T)\cos(\phi-\phi_T)[3\sigma\sin\theta_T\sin(\phi-\phi_T)-2\sigma]\ldots \\ -\sigma\sin\theta_T\cos(\phi-\phi_T)[2\sigma^2\sin\theta_T\sin(\phi-\phi_T)+1] \end{pmatrix}}{\left[1-\sigma\sin\theta_T\cos(\phi-\phi_T)\right]^4}$$

$$\frac{\partial f}{\partial\phi_T} = \frac{\sigma\sin\theta_T\sin(\phi-\phi_T)}{\left[1-\sigma\sin\theta_T\cos(\phi-\phi_T)\right]^2} \qquad (18)$$

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$$\frac{\partial^2 f}{\partial \phi_T^2} = \frac{\begin{pmatrix} -\sigma \sin\theta_T \cos(\phi-\phi_T)[1+\sigma^2 \sin^2\theta_T \cos^2(\phi-\phi_T) - 2\sigma \sin\theta_T \cos(\phi-\phi_T)] \\ +2\sigma^2 \sin^2\theta_T \cos^2(\phi-\phi_T)[1-\sigma \sin\theta_T \cos(\phi-\phi_T)] \end{pmatrix}}{[1-\sigma \sin\theta_T \cos(\phi-\phi_T)]^4}$$

$$\frac{\partial^2 f}{\partial \phi_T \partial \theta_T} = \frac{(\sigma \cos(\theta_T) \sin(\phi-\phi_T)[1-\sigma^2 \sin\theta_T \cos^2(\phi-\phi_T)])}{[1-\sigma \sin\theta_T \cos(\phi-\phi_T)]^4}$$

$$\frac{\partial^2 f}{\partial \phi_T \partial \phi} = \frac{\begin{pmatrix} \sigma \sin\theta_T \cos(\phi-\phi_T)[2\sigma \sin\theta_T + 2\sigma \sin\theta_T \sin^2(\phi-\phi_T) + 2\sigma \sin^2\theta_T \sin^2(\phi-\phi_T) \ldots \\ -\sigma^2 \sin^2\theta_T \cos^2(\phi-\phi_T) - 1] \end{pmatrix}}{[1-\sigma \sin\theta_T \cos(\phi-\phi_T)]^4}$$

MATLAB computations for functions of the objective function; $\theta_T, \phi_T, \phi$ for the confirmation of some of the respective optimal points as seen in Table-1.

**Table-1.** Optimal values for functions of the objective function in this study.

| Numerical solutions | | | |
|---|---|---|---|
| Optimal solutions | $\theta_T^*$ | $\phi^*$ | $\phi_T^*$ |
| Max solution | 0.46350 | 1.50000 | 1.50000 |
| Min solution | - 0.07760 | -1.57078 | -1.57080 |

Table-2 shows some radiation characteristics computed by CST-Microwave Studio from optimal solutions of $\theta_T^*$ and $\phi$ obtained by the numerical computation of the objective function using MATLAB.

**Table-2.** Radiation characteristics of some selected parameters of thetaT and phi.

| Optimal solution $\theta_T^*$ ***Deg*** | $\phi$ ***Deg*** | **Directivity** *(dBi)* | **Gain** *(dB)* | **Rad Eff** *(dB)* | **Total Eff** *(dB)* | $S_{11}$ *(dB)* |
|---|---|---|---|---|---|---|
| 3 | 0.45560 | 27.80 | 27.26 | -0.5297 | -2.708 | -20 |
| 20 | 0.45460 | 32.20 | 32.00 | -0.2307 | -0.5086 | -20 |
| 27 | 0.20630 | 20.03 | 19.80 | -0.2359 | -0.4653 | -20 |
| 42 | -0.57220 | 23.50 | 23.30 | -0.2267 | -0.2756 | -25 |
| 45 | 0.46350 | 30.50 | 30.30 | -0.2321 | -0.2875 | -25 |
| 48 | 0.45750 | 28.50 | 28.20 | -0.2507 | -0.2741 | -25 |
| 133 | 0.46250 | 26.09 | 26.00 | -0.2602 | -0.2941 | -30 |
| 169 | -0.07760 | 29.35 | 29.09 | -0.2515 | -0.3696 | -30 |

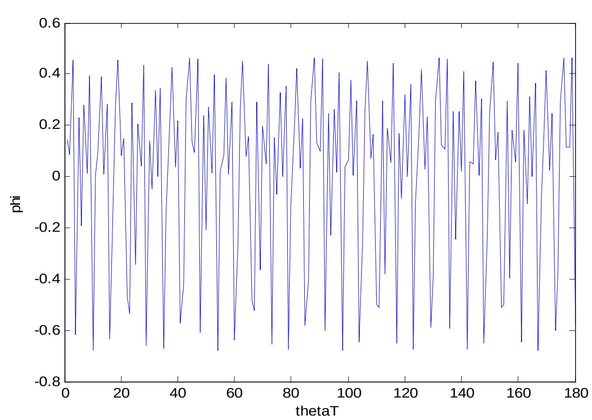


**Figure-2.** Graph of current flow line and optimal squint angles.

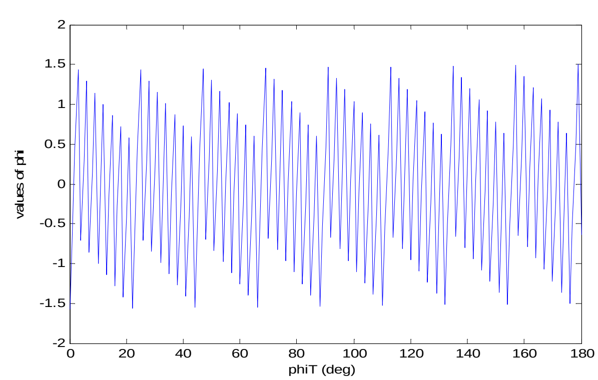


**Figure-3.** Graph of current flow lines and the angle between directions of E-field propagation to the projection plane.

Table-3, shows MATLAB numerical computation for relationship between optimal squint angle thetaT ($\theta_T^*$) and the angle between the current flow line phi ($\phi$) with the x-axis. This validates equation (14) and (15), respectively.

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**Table-3.** Optimal squint angles and current flow lines between 0 and 180 degrees.

| | | $(\theta_T)$ ***Deg*** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **0** | **1** | **2** | **3** | **4** | **5** |
| $(\phi)$ ***Deg*** | 0 | NaN | 0.1449 | 0.0864 | 0.4556 | -0.6163 | 0.2278 |
| | | 7 | 8 | 9 | 10 | 11 | 12 |
| | 1 | -0.1903 | 0.2769 | 0.0106 | 0.3934 | -0.6799 | 0.0044 |
| | | 13 | 14 | 15 | 16 | 17 | 18 |
| | 2 | 0.0964 | 0.3906 | 0.0093 | 0.2809 | -0.6334 | -0.2937 |
| | | 19 | 20 | 21 | 22 | 23 | 24 |
| | 3 | 0.2710 | 0.4546 | 0.0831 | 0.1489 | -0.4707 | -0.5351 |
| | | 25 | 26 | 27 | 28 | 29 | 30 |
| | 4 | 0.2861 | -0.3456 | 0.2063 | 0.0426 | 0.4339 | -0.6601 |
| | | 31 | 32 | 33 | 34 | 35 | 36 |
| | 5 | 0.3196 | -0.0487 | 0.3349 | 0.0001 | 0.3456 | -0.6719 |
| | | 37 | 38 | 39 | 40 | 41 | 42 |
| | 6 | -0.1343 | 0.1971 | 0.4279 | 0.0355 | 0.2188 | -0.5722 |
| | | 43 | 44 | 45 | 46 | 47 | 48 |
| | 7 | -0.4200 | 0.2985 | 0.4635 | 0.1371 | 0.0931 | 0.4575 |
| | | 49 | 50 | 51 | 52 | 53 | 54 |
| | 8 | -0.6085 | 0.2370 | -0.2093 | 0.2687 | 0.0133 | 0.3990 |
| | | 55 | 56 | 57 | 58 | 59 | 60 |
| | 9 | -0.6792 | 0.0219 | 0.0808 | 0.3847 | 0.0071 | 0.2890 |
| | | 61 | 62 | 63 | 64 | 65 | 66 |
| | 10 | -0.6396 | -0.2755 | 0.2647 | 0.4524 | 0.0766 | 0.1569 |
| | | 67 | 68 | 69 | 70 | 71 | 72 |
| | 11 | -0.4844 | -0.5233 | 0.2899 | -0.3626 | 0.1979 | 0.0477 |
| | | 73 | 74 | 75 | 76 | 77 | 78 |
| | 12 | 0.4375 | -0.6557 | 0.1532 | -0.0673 | 0.3275 | 0.0005 |
| | | 79 | 80 | 81 | 82 | 83 | 84 |
| | 13 | 0.3525 | -0.6743 | -0.1153 | 0.1854 | 0.4236 | 0.0311 |
| | | 85 | 86 | 87 | 88 | 89 | 90 |
| | 14 | 0.2272 | -0.5819 | -0.4044 | 0.2969 | 0.4631 | 0.1294 |
| | | 91 | 92 | 93 | 94 | 95 | 96 |
| | 15 | 0.1000 | 0.4591 | -0.6003 | 0.2456 | -0.2281 | 0.2605 |
| | | 97 | 98 | 99 | 100 | 101 | 102 |

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| $(\phi)$ | $(\theta_T)$ | | | | | | |
|---|---|---|---|---|---|---|---|
| | 16 | 0.0163 | 0.4044 | -0.6780 | 0.0390 | 0.0648 | 0.3786 |
| | | 103 | 104 | 105 | 106 | 107 | 108 |
| | 17 | 0.0052 | 0.2969 | -0.6453 | -0.2571 | 0.2577 | 0.4499 |
| | | 109 | 110 | 111 | 112 | 113 | 114 |
| | 18 | 0.0704 | 0.1650 | -0.4976 | -0.5111 | 0.2932 | -0.3793 |
| | | 115 | 116 | 117 | 118 | 119 | 120 |
| | 19 | 0.1896 | 0.0530 | 0.4410 | -0.6509 | 0.1663 | -0.0860 |
| | | 121 | 122 | 123 | 124 | 125 | 126 |
| | 20 | 0.3201 | 0.0012 | 0.3593 | -0.6763 | -0.0964 | 0.1733 |
| | | 127 | 128 | 129 | 130 | 131 | 132 |
| | 21 | 0.4191 | 0.0270 | 0.2356 | -0.5911 | -0.3883 | 0.2947 |
| | | 133 | 134 | 135 | 136 | 137 | 138 |
| | 22 | 0.4625 | 0.1218 | 0.1072 | 0.4605 | -0.5915 | 0.2535 |
| | | 139 | 140 | 141 | 142 | 143 | 144 |
| | 23 | -0.2468 | 0.2522 | 0.0196 | 0.4095 | -0.6764 | 0.0557 |
| | | 145 | 146 | 147 | 148 | 149 | 150 |
| | 24 | 0.0483 | 0.3724 | 0.0035 | 0.3047 | -0.6506 | -0.2385 |
| | | 151 | 152 | 153 | 154 | 155 | 156 |
| | 25 | 0.2501 | 0.4472 | 0.0644 | 0.1731 | -0.5104 | -0.4983 |
| | | 157 | 158 | 159 | 160 | 161 | 162 |
| | 26 | 0.2957 | -0.3955 | 0.1813 | 0.0586 | 0.4442 | -0.6456 |
| | | 163 | 164 | 165 | 166 | 167 | 168 |
| | 27 | 0.1788 | -0.1048 | 0.3124 | 0.0022 | 0.3660 | -0.6779 |
| | | 169 | 170 | 171 | 172 | 173 | 174 |
| | 28 | -0.0776 | 0.1605 | 0.4144 | 0.0231 | 0.2439 | -0.5998 |
| | | 175 | 176 | 177 | 178 | 179 | 180 |
| | 29 | -0.3719 | 0.2918 | 0.4616 | 0.1144 | 0.1144 | 0.4616 |
| | | 181 | | | | | |
| | 30 | -0.5824 | | | | | |

From Table-3 it is easy to notice that, the maximum positive values obtained from these computations are more likely to give best antenna performance in terms of return loss and directivity, it is also worth noting that the most minimum values indicates larger squint angles and are also more likely to give optimum return loss performance as well as good gain margin. Further solutions for the second derivatives confirm if the solution is a minimum, maximum or a point of inflexion as the case might be.

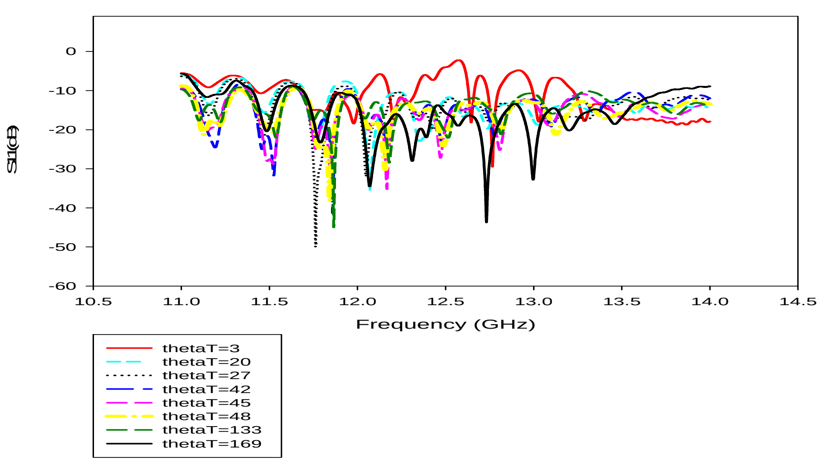


**Figure-4.** Return loss graph for the numerical computation of optimal squint angle thetaT ( $\theta_T^*$ @ 12.5 GHz.

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**Table-4.** Parameters for the simulated LP-RLSA design using Matlab computed optimal results.

| Parameter specifications | Symbols | Values |
|---|---|---|
| Center frequency | $f$ | 12.5GHz |
| Cavity wavelength | $\lambda_g$ | 15.72mm |
| Squint angles | $\theta_T$ | 20, 45, 169, 48, 03 Degrees |
| Slots length | $l$ | $0.5\lambda_g$ |
| Slots width | $w$ | 1mm |
| Antenna radius | $r$ | 300mm |
| Number of slots pair in first ring | $n$ | 16 |
| Cavity thickness | $d_1$ | 6mm |
| Radiating element thickness and background | $d$ | 0.15mm |
| Cavity permittivity | $\varepsilon_r$ | 2.33 |
| Cavity material | - | Polypropylene |
| Radiating element material and background | - | Copper |

It is can easily be seen from Figure-5 that at center frequency of 12.5GHz which is the design frequency considered in this study, the optimal performance is obtained when thetaT = 20, 45, 48, 169 and 133 degrees, respectively with return loss values below -25dB. Best peak gain of 32dB was achieved at 20degree squint angle; this experienced a shift in center frequency to 12GHz with a return loss performance below -25dB. As a result, we may consider our best performance at 45deg squint angle since this conforms to the design frequency of 12.5GHz considered in this submission this gives us a gain value of 30.5dB. However it is worth noting that higher degrees squint angles gave incredible return loss performance across the entire frequency. This is in conformity with the solutions of the determinant for the second derivatives of the objective function matrix which indicates that the global best result is a minimum point.

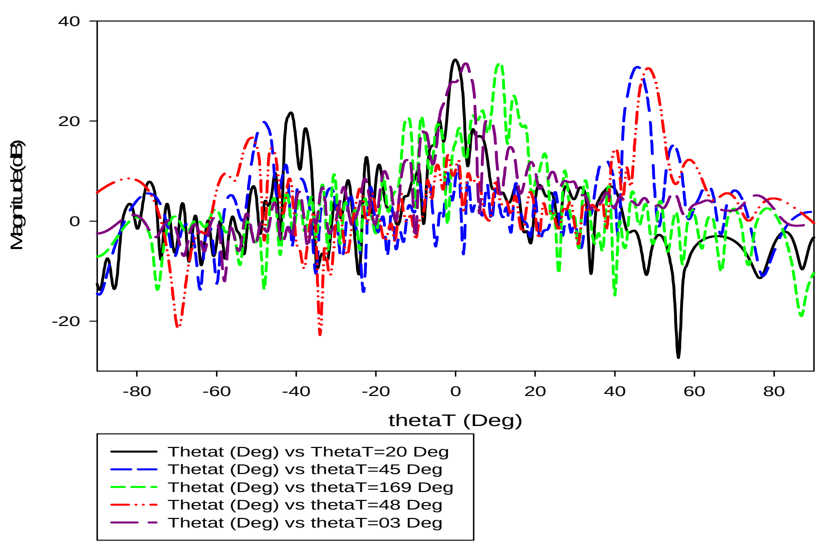


**Figure-5.** Graph of antenna gain versus the squint angles.

## CONCLUSIONS

The numerical solutions presented in this submission has been able to clearly point out solutions of the objective function phi, phiT, and thetaT required to give the LP-RLSA antenna designer optimum antenna characteristics in terms of return loss, directivity and gain.

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This will however reduce design and production time associated with "trial by error" in the selection of optimal parameters respectively. It will also act as guide for the RLSA antenna designer in the choice of optimal design parameters for maximum performance depending on the choice of the radiation characteristics the designer is looking at. Validation of this was carried out using CST Microwave Studio, robust electromagnetic computing software and the results showed excellent agreement with those obtained via MATLAB computation of the optimal solutions for the objective function formed in this submission.

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