An Improved Mathematical Modelling of Directivity for Radial Line Slot Array Antenna

Ayodeji Matthew Monebi and Solomon Zakwoi Iliya

February 4, 2020

An Improved Mathematical Modelling of Directivity for Radial Line Slot Array Antenna

Monebi Ayodeji Matthew [1], Iliya Solomon Zakwoi [2]

[1] Department of Telecommunication Engineering, Federal University of Technology Minna, Nigeria, School of Engineering and Engineering Technology, Federal University of Technology, Minna

[2] AACELAB-NASRDA, Obasanjo Space Centre, Airport Road, Abuja, FCT, Nigeria

Institute of Space Science and Engineering National Space Research and Development Agency, Abuja, Nigeria.

Authors: aydjmonebitee@gmail.com, iliya.solomon@aacelab.nasrda.gov.ng,

---

An Improved Mathematical Modelling of Directivity for Radial Line Slot Array Antenna

Abstract

This submission formulates a more realistic mathematical model for directivity evaluations of RLSA antennas. It addresses both the effects of aperture and slots concentrations on the aperture in formulating a precise directivity evaluation relationship looking at the 3dB half power beamwidth (3dB-HPBW) and slot surface area. CST MWS suite's simulations results of varying aperture and slots sizes were recorded. MATLAB regression tool was used for the computations to obtain a best fit polynomial evaluation equation for the 3dB HPBW in *E* and *H* planes respectively. The best fit polynomial was expressed as a function of slots surface area *f*(A). Results computed were compared with those obtained from previous study and showed 5% directivity evaluations improvement. This affirms that the combine contributions from slots concentrations and the aperture of an RLSA antenna gives a more realistic directivity evaluation than the consideration of only the RLSA aperture.

Keywords: Mathematical modelling, directivity, RLSA antenna, regression

1. Introduction

Mathematical models are used to express explicitly the performance of antenna. Over the years efforts have been made to obtain more realistic mathematical equations that define the directivity of antenna. Balanis (2005) formulated directivity formula for aperture antenna considering *3dB HPBW* for *E* and *H* planes respectively. This was achieved by the way of formulating equation for aperture antennas that made the products of *E* and *H* planes to be inversely proportional to the directivity as seen in equation 1.1. This directivity formula works well for apertures antennas. However, *3d BHPBW* at *E* and *H* planes respectively, and antenna aperture do not describe well enough the radiation behaviour of RLSA antenna that has radiating slots (Solomon, 2015).

$$D_o = \frac{32{,}400}{\Theta_{Ed} * \Theta_{Hd}} \quad (1.1)$$

D_o Represents the directivity, Θ_{Ed} represents the *3d BHPBW* Electric field plane, and Θ_{Hd} represents the *3d BHPBW* magnetic field plane.

Further directivity studies of the RLSA antenna looking at the slot width variations, and the radiation contribution of each slot was looked into by Solomon *et al.* (2014). The authors used regression model to model the directivity formula for RLSA antenna as a function of slot width and *3dB HPBW*. This technique describes better the directivity of a typical RLSA antenna that has considered, beyond just aperture, and *3dB HPBW*, the slot widths and its radiation effect which when summed up, describes better, the directivity of a typical RLSA antenna. However, the slot of an RLSA antenna is rectangular and the surface area has not been considered. Graphical representation of a typical RLSA antenna, and its slot is seen in figure 1.1 and 1.2 below:

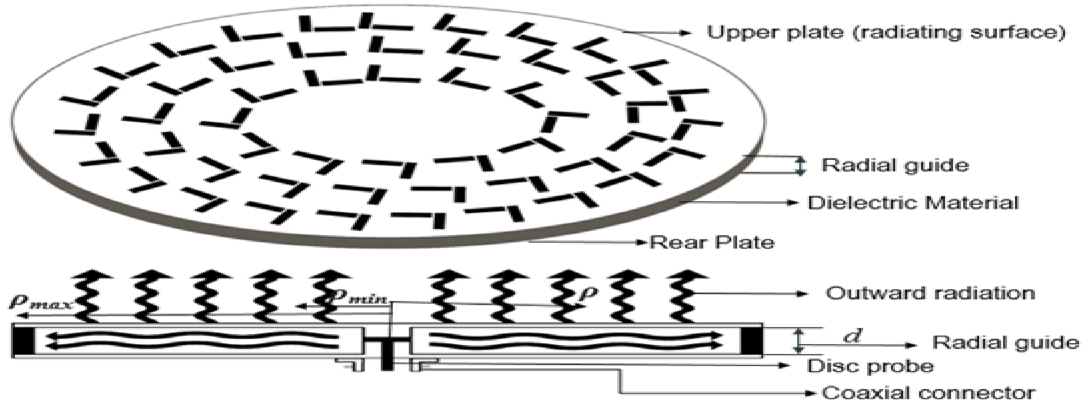

Figure 2.1 The Single layer of the RLSA Antenna Feeder and Radial guide (Islam, 2007)

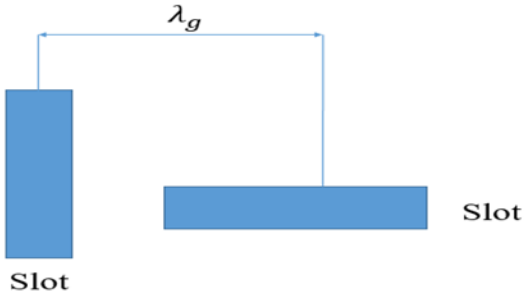

Figure 2.2: Slots Pair (Solomon, 2015)

2. Directivity Formula for RLSA Antenna

The relationship that exists between dependent and independent variables can be obtained using regression statistical model coupled with the fact that MATLAB regression offers simplicity, accuracy, for regression analysis, hence, it has so been chosen to simulate this work.

The steps that achieve this research are itemized as follows;

1. Conventional directivity formula is used and improved upon in this study.
2. Data set of previous study is used in the formulation of improved directivity formula of RLSA antenna based on slot area consideration. This work takes cognisance of the slot surface area on the radiation surface (copper plate) for a better directivity description of a typical RLSA antenna as a follow up to conventional directivity formula used for aperture antennas.
3. Slot length of this variation (Length = (1.25:1.25:23.75) is considered and used for the computation of the slots area used for this study.
4. MATLAB Regression simulation tool is used for the evaluations of the *3 dB PHBW* function at *E* and *H* planes respectively to generate a new function that considers slots area on the aperture of the RLSA antenna. Lines of best fits is chosen to obtain the possible best function that is used in formulating the products of the *3 dB PHBW* in *E* and *H* planes.
5. The product of these new functions is then used in the denominator of the conventional directivity formula to formulate the improved mathematical model for RLSA antenna.
6. Comparison is made between the newly computed directivity function and the previous studies with a view to showing the improvement achieved by this study.

The Table 1 shows the data obtained from previous study IIiya *et al*. (2014).

This Table 1 shows the slots width variation, the *3 dB PHBW* at *E* and *H* planes respectively generated using CST simulation, and their directivity values with 12 slots number considered.

Table 1 Computations from CST MWS in the Previous Work

SLOT WIDTH(MM)	**DIR (dBi):N=12**	**Θ_{Hd} (deg)**	**Θ_{Ed} (deg)**
0.25	8.25	1.2	1.3
0.5	25.6	1.2	2.5
0.75	29	1.3	2.7
1	32.9	2.5	2.4
1.25	31.3	4	2.5
1.5	32.2	3.6	2.5
1.75	32.1	3.2	2.4
2	31.8	2.9	2.4
2.25	31.5	2.3	2.5
2.5	31.3	2.1	2.6
2.75	31.1	2.5	2.6
3	30.7	3.0	2.9
3.25	31.7	2.4	2.9
3.5	30.6	3.5	2.9
3.75	30.6	2.7	3.1
4	29.9	2.3	3.2
4.25	29.3	2.2	3.4
4.5	28.9	2.2	3.5
4.75	27.2	5.5	3.2

2.1 Development of the Improved Model

Numerical expression for directivity (D_o) has been formulated in the literature by Balani (2005), Davis (2000) and Zagghoul *et al.* (2001), it expresses directivity for aperture antenna to be as inversely proportional to product of *3dB HPBW in the electromagnetic plane* as seen in equation 2.1: Balanis (2005)

$$D_o = \frac{32{,}400}{\Theta_{Ed} * \Theta_{Hd}} \qquad (2.1)$$

D_o represents the directivity, Θ_{Ed} represents the *3d BHPBW* Electric field plane, and Θ_{Hd} represents the *3d BHPBW* Magnetic field plane.

The directivity formula in equation 2.1 is the conventional directivity formula, and it is well suited for aperture antenna, nevertheless, for RLSA antenna, it has not considered at all the impact and the presence of the slots that produce the radiation. IIiya *et al.* (2014) considered the width of the slot that produced the radiation, measured its implications on the *3dB HPBW* in the electromagnetic plane, and formulated a function to describe how *E* and *H* planes varies with the slot width. 12 slots in the first ring were used to carry out this work. The product of the functions generated for the *3dB HPBW E* and *H* planes upon computations based on sloth width, was then taken into the conventional directivity formula to formulate the directivity for RLSA antenna based on slot width variations.

The mathematical analysis of what was done by IIiya *et al.* (2014) is expressed in equation 2.2 and equation 2.3

$$D_o = \frac{32{,}400}{f(w)} \qquad (2.2)$$

$$(\Theta_{Ed}) * (\Theta_{Hd}) = f(w) \qquad (2.3)$$

Where:

$\Theta_{Hd} = 3dB\ HPBW$ Magnetic plane

$\Theta_{Ed} = 3dB\ HPBW$ Electric plane

$w = (0.25{:}\,0.25{:}\,4.75);$

This research has considered the fact the typical slot of RLSA antenna is rectangular, which implies that it has length and width, slot area has been computed and related to the *3dB HPBW* in the electromagnetic plane, and has been used within microwave frequency for any possible slot number. Slot area is then used to generate the new function that describes better, the directivity of a typical RLSA antenna.

In the equation 2.5, the surface area of the slot of RLSA antenna is a function of the *3dB HPBW* for Electric Field and Magnetic Field planes respectively.

$$D_o = \frac{32{,}400}{f(A)} \qquad (2.4)$$

$$(\Theta_{Ed}) * (\Theta_{Hd}) = f(A) \qquad (2.5)$$

Where: $\Theta_{Hd}\ is\ 3dB\ HPBW,$ magnetic plane

$\Theta_{Ed}\ is\ 3dB\ HPBW$ electric plane, A is Slot Area(mm^2)

MATLAB regression tool is used to generate the requisite function, which is a polynomial function of 6^{th} order for the *3dB HPBW* for E (Electric Field) and H (Magnetic Field) planes respectively, the 6^{th} order represents the best fittings for the data as in table 2 and is used to eventually compute the improved directivity formula for the RLSA antenna. The requisite function as seen in figure 4.3 and 4.4 best describe the relationship between the *3dB HPBW* in the electromagnetic plane and the slot area.

2.2The Improved Directivity Function

Physical length of the slot ranging from L= (1.25:1.25:23.75) has been considered for this research. This range of length variation has been carefully chosen based on the various designs done on RLSA antenna. For example Jiro (1989) utilized (slot length 10mm, and slot width 1mm), in his RLSA antenna design. Purnamirza (2012) used (slot length $0.5\lambda_g$, and slot width 1mm) for the RLSA antenna he fabricated, Illiya (2015) adopted (slot length $0.5\lambda_g$, and slot width 1mm) in his RLSA antenna design, Kamaruddin (2015) utilized (sloth length 5mm, and slot width 1mm). The table 2 shows the formulation of the slot area for the study.

Width = (0.25:0.25:4.75) and Length = (1.25:1.25:23.75)

Table.2: Slot Area Computation

SLOT WIDTH(MM)	**SLOT LENGTH (MM)**	**SLOT AREA WIDTH*LENGTH) (MM^2)**	**Θ_{Hd} (DEGREES)**	**Θ_{Ed} (DEGREES)**
0.25	1.250	0.3125	1.2	1.3
0.50	2.500	1.25	1.2	2.5
0.75	3.750	2.8125	1.3	2.7
1.00	5.000	5.0	2.5	2.4
1.25	6.250	7.8125	4	2.5
1.50	7.500	11.25	3.6	2.5
1.75	8.750	15.3125	3.2	2.4
2.00	10.00	20	2.9	2.4
2.25	11.25	25.3125	2.3	2.5
2.50	12.50	31.25	2.1	2.6
2.75	13.75	37.8125	2.5	2.6
3.00	15.00	45	3.0	2.9
3.25	16.25	52.8125	2.4	2.9
3.50	17.50	61.25	3.5	2.9
3.75	18.75	70.3125	2.7	3.1
4.00	20.00	80	2.3	3.2
4.25	21.25	90.3125	2.2	3.4
4.50	22.50	101.25	2.2	3.5
4.75	23.75	112.8125	5.5	3.2

2.3 Regression Analysis

MATLAB regression tool is used to fit the computed data (slot area and the 3dB HPBW in the electromagnetic plane) as seen in table 2 to a curve that best describe the relationship between the 3dB *HPBW* in the E and H planes and the slot area. Essentially, this analytical tool generates new functions by minimizing the sum of squared difference between the original data set, and the fit function to obtain the improved polynomial function. This work considers 6th order polynomial function in the formulation of the new directivity function because, 6th order delivers the best fits for the curve that describes the relationship between the 3dB HPBW in the electromagnetic plane, and the slots area.
Figures 3.3 and 3.4 present the improved 3dB HPBW function of the study.

3. Results

The results of this research are displayed in Figures 3.1, 3.2 and 3.3, 3.4.

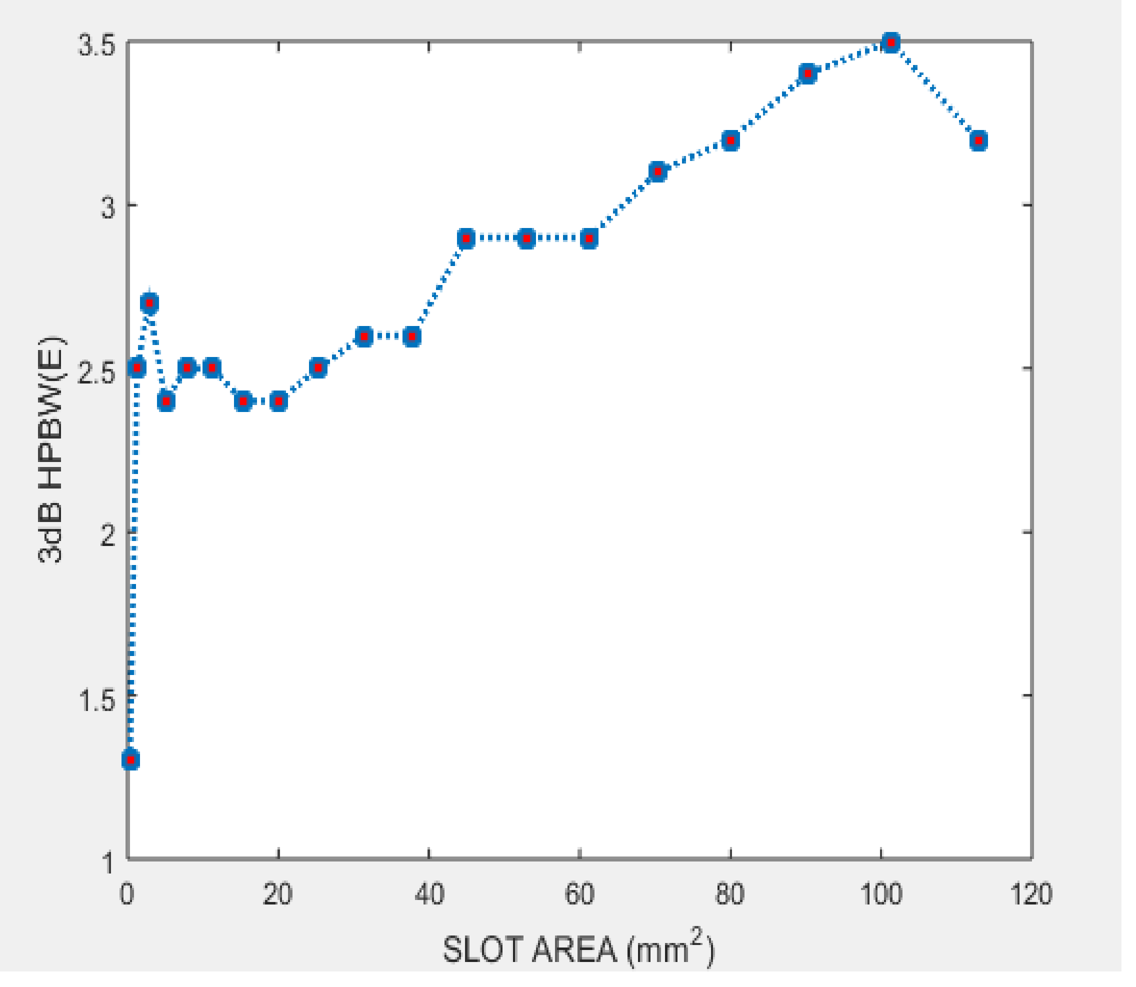

Figure 3.1 Slots Area and 3dB HPBW (degrees) E-planes

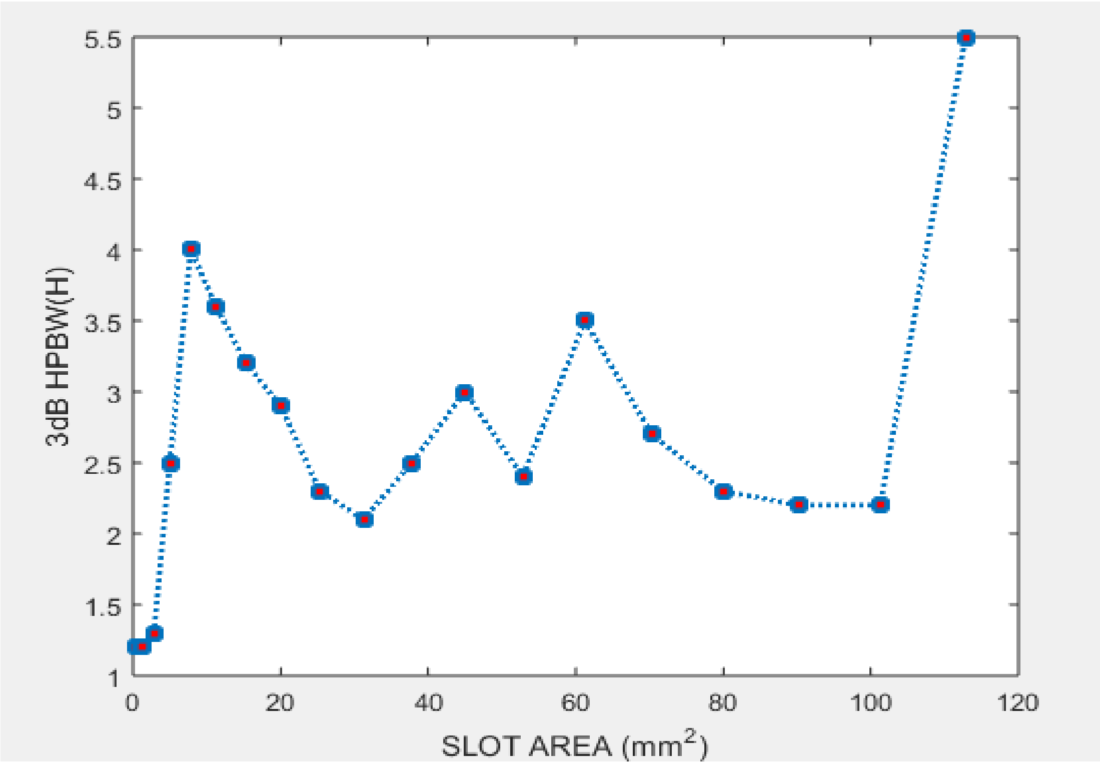

Figure 3.2 Slots Area and 3dB HPBW (degrees) H-planes

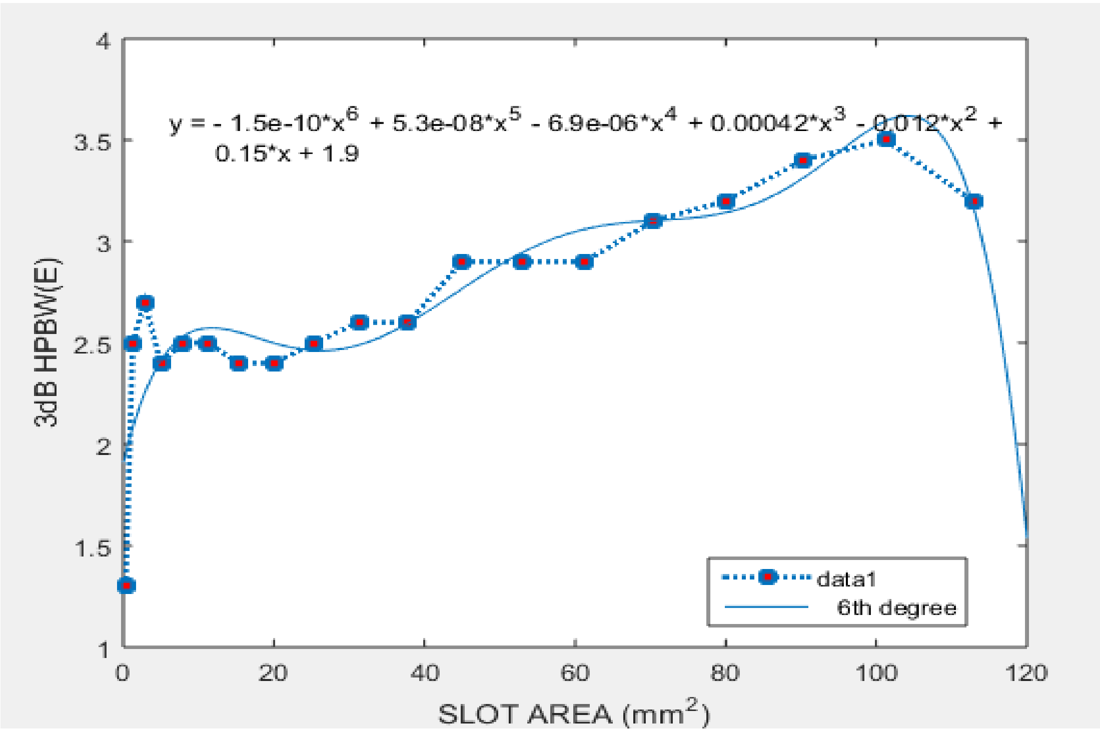

Figure 3.3 Generated function for Slots Area and 3dB HPBW (deg) E-planes

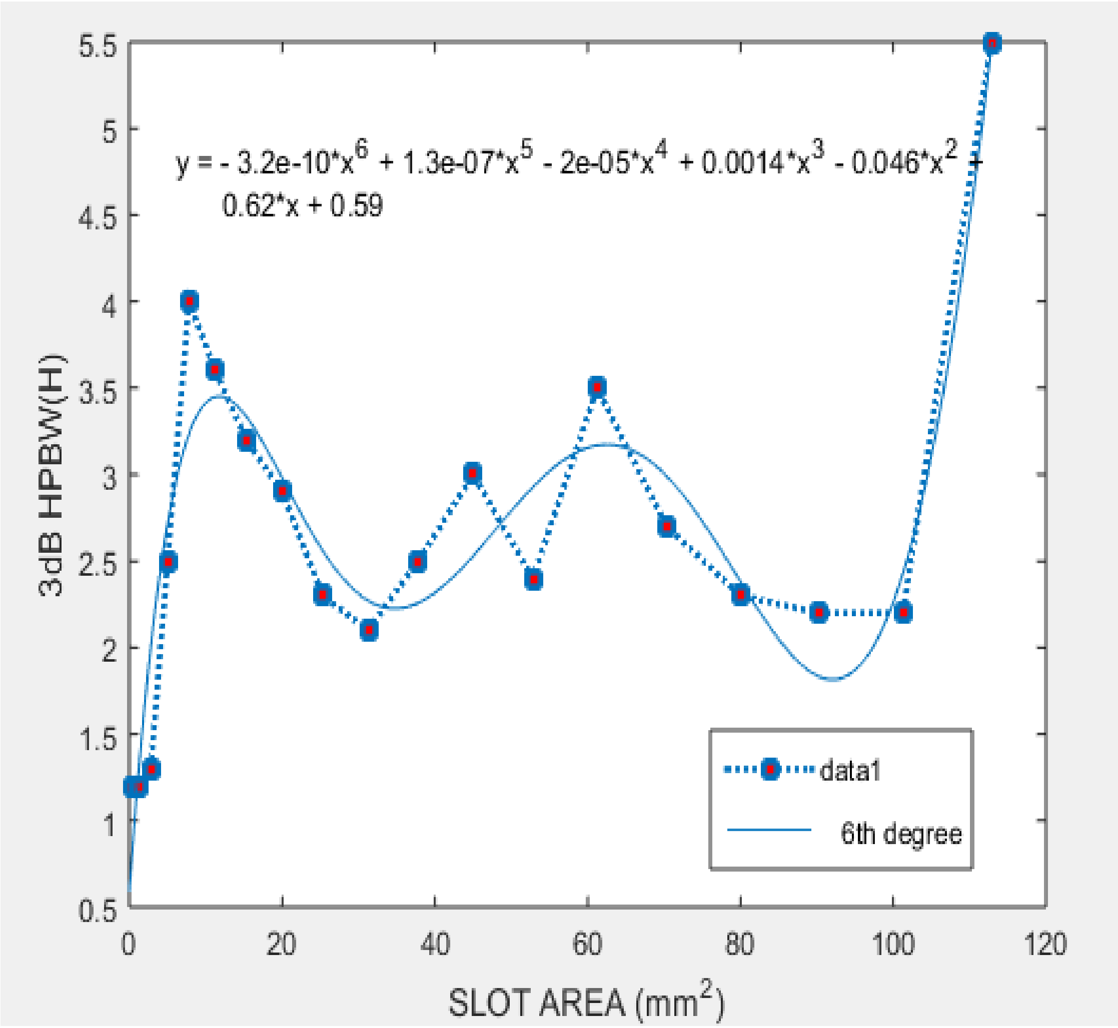

Figure 3.4 Generated function for Slots Area and 3dB HPBW (deg) H-planes

3.1 Results Interpretation

Figures 3.1 and 3.2, show the implication of the slots area variations on the *3dB HPBW* in the electromagnetic plane for RLSA antennas. Essentially, *3dB HPBW* in the electromagnetic plane is used to measure the directivity of antenna. The graphs strengthen the known fact that it will not be enough, to measure the directivity of RLSA antennas, without considering the area of the slots that actually produce the radiation. Figures 3.1 and 3.2 shows that the variations in the slots area on the aperture of a typical RLSA antenna, create variation in the *3dB HPBW*, which ultimately affect the directivity of the antenna. Figures 3.1 and 3.2 also show the orthogonality that characterizes electromagnetic wave.

Figures 3.3 and 3.4 show the results of the MATLAB regression analytical tool. These figures display the line of best fits, the curve fittings, and the new function that has factored in slots area on the aperture of RLSA antenna. The slot area is the result of the product of the introduced slot length and the slot width obtained from the literature. Essentially as discussed earlier, the regression tool performs the task of minimizing the sum of the squared difference between the original data points, and the fit function to generate the new function for the *3dB HPBW* in the electromagnetic plane with due consideration of the slots area in the formulation of the function.

The improved functions from the Figure 3.3 and 3.4 are presented in equation 3.1 and equation 3.2 respectively.

$$\Theta_{Hd} = -0.00000000032A^6 + 0.00000013A^5 - 0.00002A^4 + 0.0014A^3 - 0.046A^2 + 0.62A + 0.59 \quad (3.1)$$

$$\Theta_{Ed} = -0.00000000015A^6 + 0.000000053A^5 - 0.0000069A^4 + 0.00042A^3 - 0.0126A^2 + 0.15A + 1.9 \quad (3.2)$$

Also, as stated in chapter one, given that;

$$D_o = \frac{32{,}400}{\Theta_{Ed} * \Theta_{Hd}} \quad (3.3)$$

Where:

$$\Theta_{Hd} = H_{-plane} 3dB\ HPBW$$

$\Theta_{Ed} = E_{-plane} 3dB\ HPBW$

Substituting equation 3.1 and equation 3.2 into equation 3.4, using the values of slots Area (*A*), we have the improved directivity function for RLSA antenna.

$$D_o = \frac{32{,}400}{f(A)} \quad (3.4)$$

Equation 3.4 is the improved directivity formula for RLSA antenna. This formula has most importantly factored in the surface area of the slots on the radiating surface that actually produces the radiation

Numerical computations are seen below:

$$\Theta_{Hd} = -0.0000000032(0.3125)^6 + 0.00000013(1.25)^5 - 0.00002(2.8125)^4 + 0.0014(5)^3 - 0.046(7.8125)^2 + 0.62(11.25) + 0.59$$

= 4.931131798 deg.

$$\Theta_{Ed} = -0.00000000015(0.3125)^6 + 0.000000053(1.25)^5 - 0.0000069(2.8125)^4 + 0.00042(5)^3 - 0.0126(7.8125)^2 + 0.15(11.25) + 1.9$$

= 2.90714655 deg.

$$(\Theta_{Ed}) * (\Theta_{Hd}) = f(A)$$

$$f(A) = 2.90714655 * 4.931131798 = 14.33552279 \quad (3.5)$$

Substituting equation 3.5 into equation 3.4 we have;

$$D_o = \frac{32{,}400}{f(A)} \quad (3.6)$$

$$D_o = \frac{32{,}400}{14.33552279} = 2260.119876 = 10\ log(2260.119876)$$

$$D_o = 33.54131475 dBi$$

Table.3 Results Comparison

CST SIMULATED DIRECTIVITY (dBi) IIiya *et al.* (2014)	REGRESSION ANALYSIS SIMULATED DIRECTIVITY (dBi). IIiya *et al.* (2014)	DIRECTIVITY (dBi) FROM STUDY.	DIRECTIVITY FROM CONVENTIONAL FORMULA (dBi) *Solomon I. Z. (2015)*
32.9	31.94	33.54	37.32

3.2 Discussions

Following the mathematical computations using slots area, the improved modeled formula for RLSA antenna achieved directivity $D_o = 33.54\ dBi$. This shows a good agreement with the CST simulated directivity whose directivity is D_o = $32.9\ dBi$. The difference of 0.64*dBi*, is attributed to the fact that CST simulated directivity resulted from a directivity model that considered slots width variations, and has not taken into cognizance the effects of slots area on the radiation surface.

The directivity ($D_o = 33.54\ dBi$) obtained from the improved formula for this study also shows good agreement with the directivity (dBi) from previous study IIiya *et al.* (2014, 2015), where slot width was considered. The previous study achieved directivity D_o = 31.94dBi . The 1.6 dBi difference seen when juxtaposed with result of this study is due to the fact that previous study IIiya *et al.* (2014, 2015), only considered the width of the slots as against slot area considered by this research.

Conventional directivity formula achieved directivity D_o = 37.2dBi. There is a wide difference of 3.66 dBi when compared with the directivity ($D_o = 33.54\ dBi$) obtained from this study. This difference, as established, by previous studies, is due to the fact that conventional formula has only considered the aperture and the $3dB\ HPBW$ in the electromagnetic plane, the conventional formula has factored-in neither the sloths width, nor slots length, nor slots area on the aperture. Hence this research has achieved an improved mathematical model for directivity of RLSA antenna with convincing results.

4. Conclusion

This work has therefore achieved an improved directivity formula suitable for the RLSA antennas. Formulation of the improved directivity formula for RLSA antenna was realized considering the aperture, 3dB

HPBW in the electromagnetic plane, and slot surface area. This work viewed that the slot of a typical RLSA antenna is rectangular, and hence has length and width which when computed produced the surface area of the slot. Essentially slot area was used to produce improved functions for the 3dB HPBW half power beamwidth in the electromagnetic plane, which was eventually used to produce the improved mathematical model of directivity for RLSA antenna.

The directivity result of 33.54 (dBi) obtained for this study using MATLAB regression showed that slots area have great effect on the directivity of RLSA antenna and overall radiation performance as compared with the directivity result of previous study that has considered the width variation of the slot of RLSA antenna that has 31.94 (dBi) as its directivity. This further establishes that considering the slots area of RLSA antenna in modeling its directivity, describes better its directivity.

4.1 Further Work

Sharp variation was noticed in the radiation behaviour of RLSA antenna in the electromagnetic plane as revealed by the result of this research at slot length 22.50mm & slot width 4.50mm which produced slot area 101.25mm^2, this strange phenomenon can be investigated by researchers. Also, poor return loss in linearly polarized RLSA especially in the areas of DBS applications is open to investigation.

References

Ando, M., K. Sakurai, N. Goto, K. Arimura and Y. Ito (1985). A Radial Line Slot Antenna for 12 GHz satellite TV Reception. Antennas and Propagation, IEEE Transactions on, 33(12): 1347-1353.

Ando, M. (1993). New DBS receiver antennas in Microwave Conference, 23rd European. IEEE 1993.

Ando, M., T. Numata, J. I. Takada and N. Goto, (1988). A Linearly Polarized Radial Line Slot Antenna. Antennas and Propagation, IEEE Transactions on, 36(12): 1675-1680.

Arai H. (2015). Radial Line Slot Antennas, in Handbook of Antenna Technologies, Yokohama, Kanagawa, Japan, Springer Science Business Media Singapore, 1-11.

Bialkowski M. E. and P.W. Davis, (2000). Design and development of a radial line slot array antenna of arbitrary polarisation. In: Microwave Conference, 2000 IEEE. Asia-Pacific.

Bialkowski, M. E. and P.W. Davis, (2002). Analysis of Circular Patch Antenna Radiating in a Parallel-Plate Radial Guide. Antennas and Propagation, IEEE Transactions on, 50(2): 180-187.

Bialkowski, M. E. and P.W. Davis, (2000). Radial line slot antenna, Google Patents.

Bialkowski, M. E. (1995). Analysis of a Coaxial-To-Waveguide Adaptor Including a Descended Probe and a Tuning Post. Microwave Theory and Techniques, IEEE Transactions on, 43(2): 344-349.

Bialkowski, M. E. and P.W. Davis, (1999). Predicting the Radiation Pattern of a Radial Line Slot Array Antenna. In Microwave Conference, 1999 Asia Pacific. IEEE.

Bialkowski, M. E. and P.W. Davis, (2000). Unified Design Of A Single-Layer Radial Line Slot Array Antenna. In Microwave Conference, 30th European. IEEE 2000, 53.

Bialkowski, M. E. and P.W. Davis, (2000). Radial Line Slot Antenna, Google Patents.

Balanis C. A. (2005). Antenna Theory Third Edition, New Jersey: John Wiley & Sons, Inc., Hoboken,

Cheng, D.K. (1993). Fundamentals of Engineering Electromagnetics.

Dallal, G. E. (1992). The Computer Analysis of Factorial Experiments With Nested Factors The American Statistician, 46, 240.

Davis, P. and M. Bialkowski, (1997). Comparing beam squinting and reflection cancelling slot methods for reflection coefficient improvement in RLSA antennas. In Antennas and Propagation Society International Symposium, IEEE, 1997 Digest.

Davis, P.W. and M.E. Bialkowski, (1999). Linearly Polarized Radial-Line Slot-Array Antennas With Improved Return-Loss Performance. Antennas and Propagation Magazine, IEEE, 41(1): 52-61.

Davis, P.W. and M.E. Bialkowski, (1997). Experimental Investigations into a Linearly Polarized Radial Slot Antenna for DBS TV in Australia. Antennas and Propagation, IEEE Transactions on, 45(7): 1123-1129.

Davis, P. (2000a). A Linearly Polarised Radial Line Slot Array Antenna for Direct Broadcast Satellite Services. PhD Thesis Submitted To The Department Of Computer Science And Electrical Engineering, University Of Queensland, Australia.

Davis, P. and M. Bialkowski, (1997). Comparing Beam Squinting And Reflection Cancelling Slot Methods For Reflection Coefficient Improvement In RLSA Antennas. In Antennas and Propagation Society International Symposium, 1997. IEEE, 1997 Digest.

Davis, P.W. and M.E. Bialkowski, (1999). Linearly Polarized Radial-Line Slot-Array Antennas with Improved Return-Loss Performance. Antennas and Propagation Magazine, IEEE, 1999. 41(1): p. 52-61.

Davis, P. and M. Bialkowski, (2000). Beam Synthesis in Linearly Polarized Radial Line Slot Array Antennas. In Antennas and Propagation Society International Symposium, IEEE.

Davis, P.W. and M.E. Bialkowski, (1997). The Performance of A Linearly Polarised RLSA Antenna for Different Beam Squint Angles. In Microwave Conference Proceedings, 1997. APMC'97, 1997 Asia-Pacific. IEEE.

Davis, P.W. (2000b). A Linearly Polarized Radial Line Slot Antenna for Direct Broadcast Satellite Services." University Of Queensland, Australia, Ph.D. Thesis.

Garfagnini, G., M. Cerretelli, R. Serenelli and G. B. Gentili (2004). Dual Circularly Polarized Radial Line Slot Antenna. Attidella XV RiNEm, - elettromagnetismo.

Goto, N. (1990). Slotted waveguide antenna, Google Patents.

Goebels Jr, F. and K. Kelly (1961). Arbitrary Polarization from Annular Slot Planner Antennas. Antennas and Propagation, IRE Transactions On, 9(4): 342-349.

Herranz, J.I., A. Valero-Nogueira, E. Alfonso and V. Rodrigo (2010). Optimized Design Of Beam-Tilted Linearly-Polarized Radial-Line Slot-Array Antennas. In Antennas and Propagation Society International Symposium (APSURSI), IEEE.

Herranz, J. I., A. Valero-Nogueira, E. Alfonso and V. Rodrigo, (2010). Optimization of Beam-Tilted Linearly Polarized Radial-Line Slot-Array Antennas. Antennas and Wireless Propagation Letters, IEEE, 9: 1165-1168.

Iliya, S. Z., Rahman, T. A., & Abdulrahman, Y. A. (2014). Regression Analysis, *9*(7), 1107–1110.

Iliya, S. Z., Rahman T. A., and Abdulrahman, Y. A. (2014). Relationship For Slots Width, Antenna Directivity, And The 3db HPBW Of An RLSA Antenna At 12.4ghz Using

Iliya *et al*., (2013). Radial Line Slots Array Antenna (RLSA) Performance, WAP Journal. Vol (3), no. Issue (6), 205-211.

Iliya *et al.*, (2015). Optimization of Radial Line Slot Array Antenna Design for Satellite Communications, Wireless Communication Centre Universiti Teknologi Malaysia (UTM), 1-5

Islam, M. R. U. (2007). Radial Line Slot Array (RLSA) Antenna Design for Point to Point Communication at 5.8GHz. Thesis Submitted to the Faculty of Electrical Engineering, Universiti Teknologi Malaysia.

Jinhang Hu., (2013). "A New Improvement of Radial Line Slot Antenna," Applied Mechanics and Materials, Vols. Vols 385-386, 1244-1248.

Jiro Hirokawa', ljlakoto Ando and Naohisa Goto, (1989). An Analysis of Slot Radiation on a Parallel Plate Waveguide for a Radial Line Slot Antenna, Faculty of Engineering Tokyo Institute of Technology, Tokyo, Japan, 1452-1455.

Jose I. Herranz, Alejandro Valero-Nogueira, Felipe Vico, and Vicent M. Rodrigo, (2010). Optimization of Beam-Tilted Linearly Polarized Radial-Line Slot-Array Antennas. Antennas and Propagation Society International Symposium (APSURSI), IEEE.

Kamaruddin, R. A. A., Ibrahim, I. M., Rahim, M. A. A., Zakaria, Z., Shairi, N. A., & Rahman, T. A. (2015). Radial Line Slot Array (RLSA) Antenna Design at 28 GHz Using Air Gap Cavity Structure, *9*(2), 133–136.

Kelly, K. and F. Goebels Jr. (1964). Annular Slot Monopulse Antenna Arrays. Antennas and Propagation, IEEE Transactions on, 12(4): 391-403.

Kelly, K. (1957). Recent Annular Slot Array Experiments. In IRE International Convention Record. 1957. IEEE 1957. 131

Maina S. I., Ibrahim Z., (2017). Radial Line Slot Array Antenna At 28 GHZ With Modified Coaxial, Journal of Advanced Research in Applied, vol. Volume 7, no. Issue 1, 25-31.

McCullough, B. D. (1999), Assessing the Reliability of Statistical Software: Part II, the American Statistician, 53, 149-159.

Purnamirza, T., Kristanto, D., & Ibrahim, I. M. Bin. (2016). A Design of Compact Radial Line Slot Array (RLSA) Antennas for Wi-Fi Market Needs, *64*(October), 21–28.

Purnamirza, T., Rahman, T. A., & Jamaluddin, M. H. (2012). Journal of Electromagnetic Waves and The extreme beamsquint technique to minimize the reflection coefficient of very small aperture radial line slot array antennas, (July 2013), 37–41. https://doi.org/10.1080/09205071.2012.733491

Rahman, T. A. (2008). Novel and Simple Design of Multi-Layer Radial Line Slot Array (RLSA) Antenna Using FR-4 Substrate. IEEE, 843-846.

Regression Analysis, *Arpn Journal Of Engineering And Applied Sciences,* Vols. Vol. 9, , No. No. 7, 1107-1110.

Saeki, K., H. Ueda, J. Hirokawa and M. Ando (2010). Design of a Linearly Polarized Radial Line Slot Antenna with Reflection-Cancelling Posts. In Proceedings of the International Workshop on Millimetre Wave Wireless Technology and Applications.

Solomon I. Z. (2015). Optimization of a Linearly Polarized Radial Line Slot Array Antenna Design for Direct Broadcast Satellite Services. PhD Thesis Submitted to the Department of Electrical Engineering, Universiti Teknologi, Malaysia.

Sudo, K., J. Hirokawa, and M. Ando (2005). Analysis Of A Slot Pair Coupling On A Radial Line Filled With Double-Layer Dielectric. IEEE, 724-727.

Takahashi, M., M. Ando, N. Goto, Y. Numano, M. Suzuki, Y. Okazaki and T. Yoshimoto (1995). Dual Circularly Polarized Radial Line Slot Antennas. Antennas and Propagation, IEEE Transactions on, 43(8): 874-876.

Takahashi, M., J. I. Takada, M. Ando and N. Goto (1991). A Slot Design for Uniform Aperture Field Distribution in Single-Layered Radial Line Slot Antennas. Antennas and Propagation, IEEE Transactions on, 39(7): 954-959.

Tung Nguyen *et al*., (2012). A Radial Line Slot Antenna for an Elliptical Beam, IEEE Transactions on Antennas and Propagation, vol. VOL. 60, no. 12, 5531-5537.

Ueda H., Hirokawa J., Ando M., Amano O. and Kamata Y. (2008). A Light Weight Radial Line Slot Antenna With Honeycomb Structure For Space Use, IEICE Trans. Commun., vol. E91-B, No. 3, 871-877.

Ui Islam, M.R., L. Faisal, and T. Abd Rahman (2008). Simple Integrated System For Wireless Backhaul Networks. IEEE, 341-345.

Yamamoto, T., H., Ono, M. Ando, N. Goto and N. Ishii (1999). Near Field Distributions in Radial Line Slot Antennas for Surface Wave Coupled Plasma Generation. In Antennas and Propagation Society International Symposium, 1999. IEEE.

Zagghoul A. I., Gupta R.K., Kohls E.C., Sun L.Q. and Allnutt R.M. (2001). Low Cost Flat Antenna for Commercial & Military SATCOM Terminals, Lockheed Martin Global Telecommunications (LMGT) Systems & Technology Clarksburg, MD

Zakwoi, I. S. (2013). Optimization Of A Linearly Polarized Radial Line Slot, in Space Science and Communication (IconSpace), 2013 IEEE International Conference on, Melaka, Malaysia, 1-3.

Zhuo, F. (2005). Design of Radial Line Slot Antennas. Thesis Submitted to the Department of Electrical and Computer Engineering, National University of Singapore.