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REDEFINING THE DIRECTIVITY VALUE OF RADIAL-LINES-SLOT-ARRAY ANTENNA FOR DIRECT BROADCAST SATELLITE (DBS) SERVICE

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ABSTRACT

The mathematical modelling for redefining the directivity for radial line slot array antenna (RLSA antenna) is considered. There exists directivity for RLSA antenna in the literature where this directivity was resulted from a function that is inversely proportional to the product of *3dB HPBW* half power beam width in the electromagnetic plane (Electric field '*E*' and magnetic field '*H*' planes) which was related to slots width of the RLSA antenna alone, however the case for slots length in the mathematical modelling of directivity for RLSA antenna has not been considered. This is seen not to sufficiently address the precise required directivity of RLSA antenna especially in direct broadcast satellite (DBS) service application area. This paper considers that a typical RLSA antenna is a rectangular waveguide that has length and width, which when evaluated would give the surface area of the slots on the radiation surface, and this has critical bearing at arriving at a better directivity for RLSA antenna. Basically, in the quest for the improvement of the RLSA antenna' directivity, slots area (*A*) of RLSA antenna and their corresponding effects on the *3dB HPBW in the electromagnetic plane* will be looked at. A new function describing an improved mathematical modeling for better directivity for RLSA antenna will be formulated. This will be done by looking at the aperture, *3dB HPBW* half power beam width in the *electromagnetic plane (E and H planes), and slot surface area* and will be used in the existing directivity expression for aperture antenna. This will be done to provide a more accurate evaluations of the directivity for RLSA antennas. A new directivity expression suitable for DBS service using RLSA antennas will thus be formulated.

Keyword— *Slots, slot area, slot width, RLSA antenna, 3dB HPBW, E-Plane, H-Plane, radial spacing, directivity, radiation characteristics.*

1. INTRODUCTION

Communication satellites are artificial satellites designed for use in space communication purposes. Its applications include but not limited to the following: telecommunication, broadcasting/multicasting, internet and multimedia service, real time monitoring service, navigation and global positioning system (GPS), tele-presence etc. Communications satellite provides unparalleled ubiquitous connectivity that no other communication technology can offer, because it has capability to cover large areas of the planet. A communications satellite can cover one-third of the earth planet, while it will take three communications satellites to cover the entire earth planet, irrespective of terrain/topography, political and geographical boundaries. The foregoing make communication satellite an indispensable part of our lives.

One of the applications of satellite communications is broadcasting satellite services. Broadcasting satellite services are intended mainly for direct broadcast to the home, sometimes referred to as direct broadcast satellite (DBS) service [1] in Europe it may be known as *direct-to-home* (DTH) service. An example is what DSTV (Digital Satellite Television) presently offers in Nigeria. Research works have explored how the directivity of satellite antennas can be improved. One of the key areas researchers have studied is the use of slotted waveguide antennas for which radial line slot array antenna (RLSA) is an example. RLSA antenna has been carefully chosen for DBS applications for satellite communication because of all aperture antennas, it is unmatched in terms of better directivity, which is strong enough to overcome path loss, atmospheric degradations, and the distance barrier of satellite communication. RLSA antenna has been considered because of its low cost of production and high efficiency, and the fact that also, there is no aperture blockage with RLSA antenna, as in the case of parabolic reflector antennas.

RLSA antenna has been good candidates for high gain applications since they were firstly proposed in 1980s,[2], [3], they were developed to substitute parabolic dishes in the DBS receivers due to their low profiles and simple configurations which make them suitable for the low-cost production. RLSA antenna being a directional antenna requires good radiated power to be able to overcome the 36,000km distance barrier of satellite communication. The key problem is accurately determining the directivity for RLSA, as the previous directivity for RLSA antenna [4],[5] has only considered the width of the slots in the formulation of the directivity relationship that generated the directivity for RLSA antenna, and has not taken slot area concentration into consideration. And as in the case of RLSA antenna, radiation comes from the slot concentration on the aperture only. It is in view of this problem, this paper proposes to formulate a better directivity model that gives a better directivity of RLSA antenna.

The quest for cost effective antennas with improved performance persists, at the end of 1950s, Kelly came up with the concept of a RLSA where he was able to achieve a constant shaped pencil beam by varying the positions of the feeding structure [6], [7], the authors showed its great applications and benefits in the early 60s [8], [9]. This antenna has the capability to transmit and receive constant-shape pencil beams by means of circular, linear or elliptical polarization. The antenna is made up of concentric annular rings of crossed slots. Fed from a rather complex formation, the aimed polarization was realised by exciting the antenna with the desired polarization modes Linear or orthogonal modes (circular or elliptical). The antenna is flexible, and has the same radiation pattern for all possible polarizations of interest.

By 1990s, the slotted waveguide theory was accepted and used by Goto and Yamomoto [10],[11],the authors proposed a different slot layout that would make circular polarization to be achieved from a double layered radial cavity, fed by a simple centrally located probe feeding structure. Their proposal simplified the feeding element, but the resulting double layer cavity which was necessary for maintaining constant amplitude aperture illumination made the design difficult to realize and hence makes it expensive to fabricate in communication systems. The slots layouts on the upper cavity surface has the form of a spiral array with each element in the array consisting of two slots spaced so as to be phased in quadrature, thereby forming a unit radiator of circular polarization This proposed antenna had removed the complexity of the feed structure, but added a manufacturing complexity due to its double layered nature, it requires an E-bend to get the radiated field to and from the upper and lower cavities respectively. Further work on this discovery continued with Takahashi et al [12] simplifying the manufacturing complexities encountered by the double layered cavity structure design with the introduction of the single layered structure which produced an intolerably tapered aperture field due to the natural decay of the outward travelling radial wave in the feeding cavity.

Development of the single and double layered versions of the RLSA antenna including circular and linear polarizations cases have been investigated in literatures [12-22] and [23] Advantages of the single layer RLSA antenna which makes it attractive for use in DBS applications include a potentially high radiation efficiency, extremely low profile, ease of installations and immunity to leaf, water and snow build up due to its flat surface. In spite of this outstanding flexibility there is an inherent flaw in this RLSA antenna performance especially when linear polarization is required. Further studies by researchers from Australia in the year 1995 continued in the quest for the design of the linearly polarized radial line slots array antennas LP-RLSA which was to be used for DBS services in Australia due to the launch of Octopus a communication satellite which carried Ku Band transponders along with other payloads to carter for their communication demands. From then Paul Davis successfully designed a 60 cm in diameter linearly polarized radial line slot array antenna in the year 1999 [23-25]

Investigation of the applications of the RLSA antennas for wireless LANs with researchers successfully fabricating a low profiled RLSA antenna at 5.5 GHz resonant frequency and was brought about in the year 2002 by Malaysian and Australian researchers [26]. Islam took the study further by investigating RLSA antenna design and tested it for outdoor point to point applications at 5.8 GHz, remarkably Islam suggested the FR4(Flame Retardant-4) materials to be used in place of dielectric materials at 5.8 GHz resonant frequency for wireless LANs [27], [26]. His discovery was so innovative owing to the fact that he factored in the cost of the material and ease of fabrication. In a bid to maximizing the potential of this remarkable slotted waveguide antenna, research for an innovative dual beam and multi-beamed, circularly polarized RLSA were carried out [28], [29]

According to [30] comparison was made for 600mm parabolic disc Ku antenna (12.25 - 12.75) GHz, and 600mm RLSA antennas. A radiation efficiency value of about 67% was achieved for RLSA over parabolic dish antenna, furthermore, Relationships between half power beam width (HPBW), slot widths (w) and antenna directivity (D) were studied, a new directivity resulting from the study was formulated for the Ku Band (12.25 - 12.75) GHz[4].

2. SLOT ANTENNAS

Slot Antennas are multiple slots on the metallic structure or surface (copper plate) capable of radiating or receiving Electromagnetic (EM) waves. Radial Line Slot Antenna (slotted waveguide antenna) is the concentric array of slots on the copper surface. The structure is composed of two metal plates that are divided apart by a distance *D*; the radiating surface is the upper metal that carries the slots pair arrangements; the rear plate has no slots on it and serves as the ground plate. Radial guide is the guide between these two plates, it is usually occupied with a slow wave material which represents the dielectric of choice also known as permittivity.

Directivity describes the ability of the antenna to focus its energy strongly in a particular direction. High directivity is required for seamless satellite communications because it is positioned about 36,000km away from sea level.

Associated with the pattern of an antenna is a parameter designated as beam width. The beam width of a pattern is the angular separation between two identical points on opposite side of the pattern maximum. There are a number of beam widths. One of the most widely used beam widths is the Half-Power Beam width (*HPBW*) [31] it is the angle between the two directions in which the radiation intensity is half the value of the beam, it is the defectiveness of a directional antenna [32]. It also means the angle where the transmitted power has dropped by 3 dB from the maximum power on either side of the main lobe of radiation where the intensity falls off by half power it is measured in degrees, as depicted in figure 1 below.

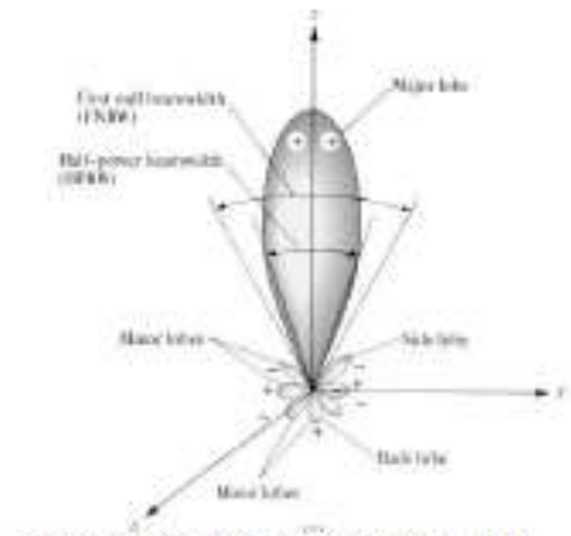

Figure 1 characteristics of antenna [31]

RLSA is a slotted waveguide antenna whose directivity indices is hinged on the contributions of the slots arrays, antenna aperture as well as the *3dB HPBW*. However a careful study by [4], [5] showed that the contributions from individual slot area on the antenna aperture is not considered in the antenna gain and directivity arrived at by previous studies. As a result, the authors in an attempt to consider contributions from the slots arrays only factored in slot width (w) and not the individual area occupied by each slot on the aperture and expressed the denominator which is the product of the *3dB HPBW* in E and H- planes respectively as a function of the slot width $f(w)$ as represented in the equation 1 below. Since the slot is rectangular, as depicted in figure 2:

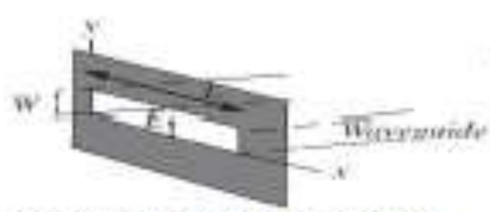

Figure 2 Slot of RLSA antenna [33]

It then implies that it has a length and a width which when evaluated will give the individual slot area. These would be eventually summed up to give a better directivity for RLSA antenna.

3. STRUCTURE OF RLSA ANTENNA

The structure is composed of two metal plates that are divided apart by a distance D; the radiating surface is the upper metal that carries the slots pair arrangements, however the rear plate has no slots on it.

Radial guide is the guide between these two plates, it is usually occupied with a slow wave material which represents the dielectric of choice also known as permittivity, this helps in lessening possible development of grating lobes. Grating lobes happen when the space of the radiating elements is approximately one free space wavelength or even more. Nevertheless, because of the dielectric sandwiched between the separation distance *D* (radial guide) between the plates, the spacing becomes reduced by a factor $\sqrt{\varepsilon r}$ which limits the dangers of grating lobe formation. Illustrative view of the RLSA antenna structure is seen in Fig 3 and Fig 4 respectively.

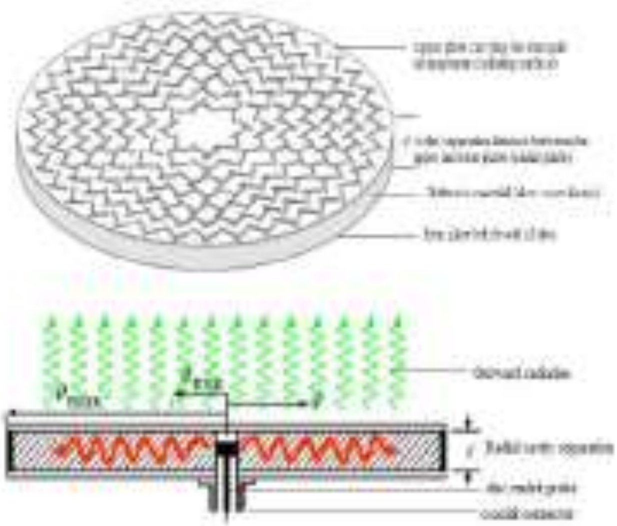

Figure 3 The Single layer of the RLSA Antenna Feeder and Radial guide Adapted from [3].

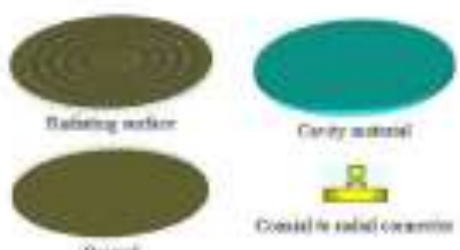

Figure 4 Components of RLSA Antenna [34]

3.1 Principles of Operation of Radial Cavity

To successfully describe how radial cavity works, understanding the role of electromagnetic waves propagating within it is key. The figure 5 below reveals the power flow [35], [36] within the radial cavity for single layered RLSA antenna.

Essentially feed probe plays a significant role in the operation of radial cavity, in that it converts power from the (Transverse Electromagnetic) TEM transmission line mode into a TEM cavity mode that travels inside the radial cavity.

The stabilization requirement of the feed probe is responsible for the reason why region of radius around the feed probe is left devoid of slots.

The configuration of the slots on the upper place surface must be designed in a manner that it couples as much energy in the cavity to forming radiated pencil beam. Energy that is not radiated by the slot will escape through the open edges of the radial cavity. It therefore becomes paramount that the slots on the upper plate be configured and designed to intercept sufficient current so as to produce good radiation irrespective of its polarization.

The magnetic field within the radial cavity can be further investigated. For easiness, the height of the radial cavity, D has to be limited to be less than one half of the guide wavelength.

$$D < \frac{\lambda g}{2}$$

Where D is the height of the radial guide, and λ_g is the guide wavelength.

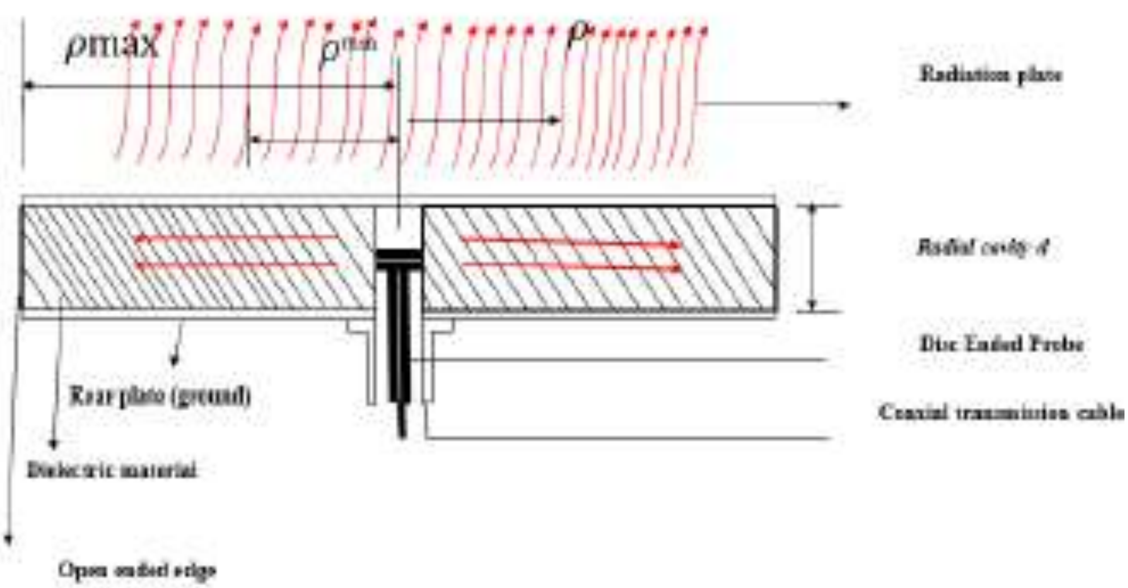

Figure 5: Power Flow within the Radial Cavity

4. FORMULATION OF NEW FUNCTION FOR RLSA ANTENNA (NUMERICAL DERIVATIONS)

Numerical expression for directivity (D_o) as it relates to measured and simulated E and H plane $3dB$ half power beam widths ($3dB$ $HPBW$) has been expressed and stated by [4], [5]. It relates product of E and H planes of the $3dB$ $HPBW$ as inversely proportional to the antenna directivity, to be a function of sloths width. [4], [5], looked at slots width variation in an RLSA antenna and its effect on the $3dB$ half power beam width ($3dB$

HPBW) for which a function was formulated that described the directivity for RLSA antenna. The function was used to study the directivity of the RLSA antenna. In line with these, the minimum number of slots in the first ring (n) =12 were used to manipulate slots concentration on the radiating surface.
RLSA Antenna directivity is thus expressed as:

$$D_0 = \frac{\theta_{3E}\,\theta_{3H}}{f(w)}[4] \qquad (1)$$

Where:

$$\theta_{3H} = H_{-plane}\, 3dB\ HPBW\ for\ (n) = 12$$
$$\theta_{3E} = E_{-plane}\, 3dB\ HPBW\ for\ (n) = 12$$

Mathematical formula for this form can be arrived as

$$(\theta_{3H}) * (\theta_{3E}) = f(w) \qquad (2)$$
$$(\theta_{3E}) * (\theta_{3H}) = f(w) \qquad (3)$$
$$\Rightarrow f(w) \Leftrightarrow (\theta_{3E}) * (\theta_{3H}) \qquad (4)$$

This formula of (1) achieved a directivity of [31.94 *dBi*]
Previous work done by [4] arrived at the foregoing directivity for RLSA antenna. However, this directivity was arrived at by considering only the width of a rectangular slot, and the length of the slot has not been considered. This work is therefore motivated by the fact considering the length, and the surface area of the slot would result in a better directivity for RLSA antenna.

In this study, the slot surface area will be considered for all possible number of slots, and for all possible radiation within microwave frequency for any concentric number of slots. The typical slot of an RLSA antenna is rectangular in shape, hence it has width and length, where slot area is mathematically given by:

$$\text{Slot Area } (mm^2) = \text{Slot width} * \text{Slot length} \qquad (5)$$

4.1 Proposed Function Formulation

Research work is ongoing on achieving better directivity for RLSA antenna, below is the approach we intend to use: first is to study the relationship that was achieved for directivity in the previous studies, and use it to establish a redefined directivity for the new study. For this work to bring about the improved directivity required for RLSA antenna, slot area will be used to improve the previous work for better directivity.

In the (6) below, the surface area of the slot of RLSA antenna is related to be a function of the *3dB HPBW* for E (Electric Field) and H (Magnetic Field) planes respectively as seen below.

x

$$D_{\varphi} = \frac{32{,}400}{f(A)} \qquad (6)$$

$$(\theta_{Ed}) \times (\theta_{Hd}) = f(A) = U(A) \Rightarrow (\theta_{Ed}) \times (\theta_{Hd}) \qquad (7)$$

$$(\theta_{Ed}) \times (\theta_{Hd}) = f(A) \quad \text{Equation} \qquad (8)$$

Where:

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

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

$A = Slot\ Area(mm^2)$

MATLAB regression tool will be used to generate the requisite function for the *3dB HPBW* for E (Electric Field) and H (Magnetic Field) planes respectively that would be used to eventually compute the new directivity for the RLSA antenna.

5. CONCLUSION

Development of an improved directivity for RLSA antennas–is imperative as the directivity of an antenna is a measure of its performance. Antennas are designed to radiate electromagnetic waves strongly in a single direction or over a narrow angle. This directional pattern ensures that; the power radiated is focussed in the desired direction thus the need to critically ascertain the viability of its value taking into cognisance all the parameters used in the evaluation with the view of achieving accurate value that cannot be misleading.

In view of the fact that the area covered by the concentric array of slots of a typical RLSA antenna has bearing on its directivity description. Essentially the directivity of the antenna remains a significant measure of radiation characteristic of directional antennas, hence it is paramount to have its good description in terms of its value that cannot be misleading.

Further work will involve implementation and validation of the improved RLSA directivity equation.

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