Optimization of Radial Line Slot Array Antenna Feeder Design for Direct Broadcast Satellite Services

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ABSTRACT

Ka-Band transponders today in communication satellites requires high bandwidth to meet the demands for high data rates, as a result; modification of the feeder architecture for the Radial Line Slots Array Antennas (RLSA) to meet this dire need at 28GHz becomes pertinent. This paper presents Artificial Bee Colony (ABC) as a tool for optimization of beamsquint radial equations antenna feeder parameters such as exact precision on air gaps and dimensions suitable for the customization of the conventional SMA connector which guarantees enhanced bandwidth realization for the Ka Band (26 – 30) GHz required for Direct Broadcast Satellite Services (DBS) applications. Numerical solutions realized from the ABC algorithm using MATLAB computations were included in a visual BASIC program deposited into the macros of CST 2017 for pattern generation and antenna radiation characteristics computations. A radiation efficiency value of 97% was achieved, Bandwidth of 60.50% and Gain of 22dBi were achieved. Results were compared with earlier studies on Ka Band (26 – 30) GHz and shows remarkable improvement in bandwidth utilization using this optimal feeder optimization technique implored.

***Keywords*:** Beamsquint, DBS, bandwidth-efficiency, RLSA-Antenna.

INTRODUCTION

Radial Line Slot Array (Array) Antenna is an antenna that could radiate and receive constant-shape pencil beams with circular, linear or elliptical polarization. The antenna consists of concentric annular rings of crossed slots. It is a type of antenna that has better performance, reduce cost and ease of installation. Presently Linearly Polarized Radial Line Slots Array (LP-RLSA) Antenna Feeders design are used by Communication Satellites that are launched into space. These satellites referred to as High Throughput Satellites (HTS) are designed with Ka Band transponders and require high bandwidth. However, the commonly used RLSA Antenna feeder cavity found it application in satellite communication Industry. For example, in Australia, Linearly Polarized RLSA Antenna was used for Direct Broadcast Satellite (DBS) Services in their communication satellite known as Octopus which carried Ku Band transponders along with other payloads to carter for their communication demands. Presently RLSA antennas are being used for Ka -Band Communication Satellites that are launch into space design with Ka – Band transponders to provide high bandwidth required by the satellites.

Researches have been conducted by various experts and different optimization techniques have been implored in order to design RLSA antennas feeder cavity that will guarantee optimal bandwidth utilization. It was in this regard that a stable design of coaxial adaptor for RLSA Antenna feeder cavity was introduced [1]. The results show that the funnel probe may provide Return Loss (RL) below −25 dB throughout desired frequency band, and also exhibit much improved tolerance in manufacturing procedures. The analysis from stable design of coaxial adaptor for RLSA Antenna feeder made suggestions about the types of feeder design cavity with little or no information about actual RLSA antenna feeder design parameters and also no information on the directivity and bandwidth utilization by HTS.

DEVELOPMENT OF RLSA ANTENNA

Research for Antennas with improved

performance, ease of installation and low cost continued, until late 1950s, when Kelly introduced ideas of a Radial Line Slot Array Antenna(RLSA) [2], [3]. He demonstrated it use in the early 1960s. This antenna could transmit and receive constant-shape pencil beams with circular, linear or elliptical polarization. By 1990s, a slotted waveguide concept was introduced to provide alternative slots arrangement that could allow for circular polarization to be obtained from a double layered radial cavity [4]. RLSA Antenna is faced with inherent design challenges due to interference from design frequency due to slots orientations on the radiating surface. Other problems associated with RLSA antenna feeder is the reflections from slots pairs which lead to high Voltage Standing Wave Ratio (VSWR), which accounts for mismatched or poor radiation efficiency [5].

Beam squint technique and reflection cancellation technique are used to combat this challenge. Beam squint technique alter the orientations of slots pairs on the radiation surface without introducing additional slots; while reflection cancellation technique deals with addition of slots pairs to the radiating surface. The paper adopts beam squint technique because of its advantages over reflection cancellation method.

Beam Squint Optimization technique was deployed to reduce or minimize formation of grating lobes or high reflection coefficient [6]. Grating lobes causes reflection of slots pairs that add in phase at the antenna feed thereby resulting to poor radiation efficiency [7], [8]. It involves adopting radial equation of the beam squint method to reduce VSWR within the feeder cavity, there improving slots arrangement on the radiating surface of the slotted waveguide [9]. Beam squint benefits are varying user mounting positions since the beams could be squinted to desired squint angles which reduce visual pollution from obstructions observed in the roof mounted television receive only (TVRO) parabolic reflector antenna in used for DBS signal reception [10].

To further boost the performance of the RLSA Antenna, *Iliya et al., (2013)* introduced numerical solution of selecting feeder parameters to guarantee better bandwidth utilization. Parameters under consideration are the distance between the slots on the radiating surface known as phi (ϕ), height of the slots (Sp), cavity wavelength (λg) and theta (Θ), the angle between the adjacent slots which must be 90^0. This was to eradicate the arbitrary method of selection of phi. Arbitrary selection of design parameters for beam squinting method to solve the inherent return loss problems associated with the linearly polarized radial line slots array (LP-RLSA) design is time wasting and slows satellite design and manufacturing process.

The results show the numerical solutions computed using CST microwave studio (CST 2010); an antenna design software, and it was able to address the design time problem, return loss and manufacturing time. However, it did little on bandwidth utilization and directivity. Other techniques implored in RLSA feeder optimization used a single layer RLSA feeder design with polypropylene as the dielectric material for enhancing efficiency of RLSA antenna feed network [6]. The research focuses on the design of Ka Band Downlink Radial Line Slot Array Antenna feeder for DBS applications, at (21.4 - 22) GHz [11]. Solution to challenges of design complexities and manufacturing process where solved by using different bema squint angles [12], [13]. Designing RLSA antenna feeder for high bandwidth efficiency, high directivity, gain and free return loss, a syntactic foam and RT/duroid 5880 as dielectric materials used [14].

STRUCTURE OF RLSA ANTENNA

The standard structure of a single layer RLSA antenna feeder cavity is shown in figure (1). The feeder is excited through rear mounted coaxial to waveguide transition feed. Power conversion from Transverse Electromagnetic (TEM) transmission line mode to TEM cavity mode is achieved through disc end probe which ensures matching of the radial waveguide to the coaxial transmission line. The radiation from the feed travel radially outward into the cavity.

The dielectric material in the cavity creates slow wave which minimizes reflection in the coaxial transmission line direction. An area of radius ρmin at the centre on the radiating surface has no slots in order to guarantee stability of the wave. The radiating surface has slots that are arrange in a manner that provides greater percentage of the energy [15] in the cavity with pencil like beam with a particular polarization. The power not radiated on reaching the circumference of the RLSA feeder antenna is reflected back or lost to the free space outside the feeder cavity. To obtain uniform radiation over the surface, slots dimension is changed with respect to the maximum radius ρ_{max}.

$$I_{rad} = (5.8678 + 6.415 \times 10^{-3}\rho)\frac{1.2 \times 10^{9}}{f_0} \quad (1)$$

Where f_0 is the centre frequency and the height of the radial guide (d) is expressed as

$$d < \underline{\lambda g} \quad (2)$$

The Radial Line Slot equation can be expressed as:

$$Sp = \frac{\lambda g}{1 - \sqrt{\varepsilon r} * sin\theta T cos(\phi - \phi T)} \quad (3)$$

$$Sp = \frac{2\pi\rho min}{\Psi} \quad (4)$$

$$Sp = \frac{\lambda g}{1 - \sqrt{\varepsilon r} * sin\theta T cos(\phi - \phi T)} X \frac{2\pi\rho min}{\Psi} \quad (5)$$

$$Sp * S\phi = \frac{2\pi\rho min\lambda g}{1 - \sigma sin\theta T cos(\phi - \phi T)\Psi} \quad (6)$$

$$K = \frac{2\pi\rho min\lambda g}{\Psi} \text{ hence} \quad (7)$$

$$S\rho * S\phi = \frac{k}{\sigma sin\theta T cos(\phi - \phi T)} \quad (8)$$

S_ρ : Slots separation in the radial direction

S_ϕ : Slots separation in the azimuth direction

λg : Guard wavelength.

ρ_{min} : Minimum radius.

ρ_1 : Inner ring radii.

ρ_2 : Outer ring radii

Ψ : Number of slots in the first (innermost) ring

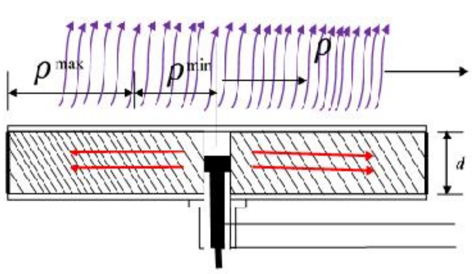

Figure 1: RLSA Antenna feeder cavity

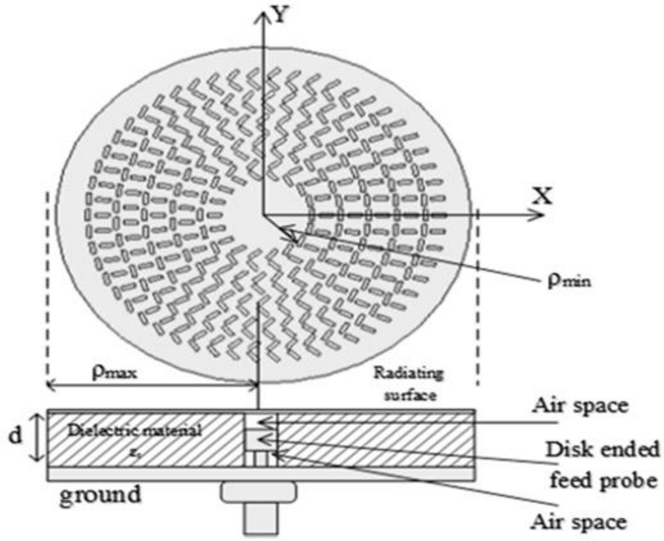

Fig. 2. Standard structure of RLSA Antenna

ARTIFICIAL BEE COLONY TECHNIQUE

ABC Optimization technique

In the basic model of the ABC, the algorithm mimics the process of searching for food sources by bees. The colony consists of three kinds of bees, namely, employed bees, onlooker bees and scout bees. Definitions of these bee types are presented below:

1. ***Employed bees*:** These have the responsibility of exploiting the food sources visited before and giving information to onlooker bees.
2. ***Onlooker bees*:** These are bees that wait in the hive (or dance area) to decide on the food source to visit based on information from the employed bees.
3. ***Scout bees*:** These randomly search the environment for new nectar sources (food sources) based on internal drive or external clues. Every food source has just one employed bee, and this equates the number of food sources to the number of employed bees. Also, when the food source discovered by an employed bee becomes exhausted, the employed bee automatically becomes a scout as the process of discovering new nectar sources continues.

This optimization technique was deployed in order to optimized control parameters of beam squint radial equation (3)

ABC description

Initialization is the process of producing the food source, sending the employed bee to the food source and measuring the nectar amounts (i.e. calculating the fitness). Each food source is a potential solution of the optimization problem. The bees randomly search the environment for a food source.

The initialization of the food source is modelled as:

$$Fitness_i = \begin{Bmatrix} \dfrac{1}{1+f_i} & f_i \geq 0 \\ 1+abs(f_i) & f_i < 0 \end{Bmatrix} \quad (9)$$

IMPLEMENTATION

The Artificial Bee Colony (ABC) Algorithm was used to obtain numerical solutions for the feeder cavity design parameters. This tool was deployed by [16] to evaluate feeder parameters such cavity height (h), cavity wavelength (λg), angle between unit radiators (θ) and height of the slots Sp) as well as the distance of separation between adjacent slots (ϕ_T). The paper used MATLAB computations of optimal solutions for squint angles and current flow lines within the range $0 = \theta_T = \pi$ to obtain $S_\emptyset$ as a function of θ_T, ϕ.

The study also used polypropylene as a dielectric material with relative permittivity value of 1.80 for the design in order to guarantee high bandwidth efficiency at 28GHz and values of optimal parameters obtained from MATLAB computations were inserted into the Visual Basic program in the macros of Computer Technology Simulation Microwave Studio (CST MWS) to obtain radiation efficiency, gain, directivity and pattern generation.

The study also verify the design to be sure it conforms with the specifications after the simulations once the simulations values are obtained, also, CST MWS simulation file were save as ***.dxf***. Simulation results obtained from CST were compared with recent works done using modified feeder design at 28GHz and equally measure the bandwidth efficiency.

RESULT AND DISCUSSIONS

Design of RLSA antenna with syntactic foam and RT/duroid 5880 dielectric materials and a multilayer feeder design method at 28GHz was achieved [14]. In their design and fabrication process, good results were obtained as compared to single dielectric filled cavity design, they introduced design complexity and high cost because of multilayered approach. Hence, we Used single layer linearly polarized RLSA feeder cavity design using polypropylene as the dielectric material because of it excellent characteristics such as chemical resistance, transmissivity, fatigue resistance, elasticity and toughness and chemical resistance that made it suitable as dielectric material at 28GHz to provide bandwidth improvement. The paper RLSA antenna CST perspective is shown in the figure 3.0.

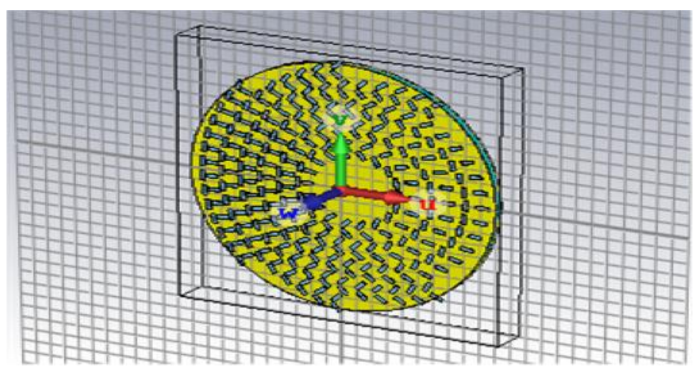

Figure 3. Radiation pattern CST perspective.

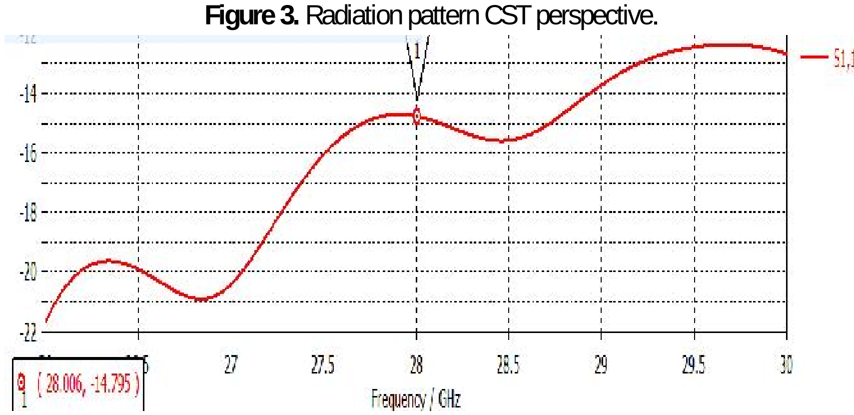

Figure 4. S-Parameter CST perspective

Fig. 4 shows that the Impedance Bandwidth (S11 dB) at 28GHz generated from CST is -14.795dB. The improved value of S_{11} represents a remarkable bandwidth utilization in Ka-Band for this study. In RLSA antenna design, values of impedance Bandwidth below -10dB signifies effective bandwidth utilization of Ka Band. The optimized value of S_{11} was achieved as a result of the beam squint optimization technique used and ABC tool deployed to optimize the parameters.

Fig. 5 shows the radiation performance such radiation efficiency, total radiation, gain, directivity and the 3d view of the signal. With the result obtained, remarkable optimization of the feeder cavity was achieved from the simulation results.

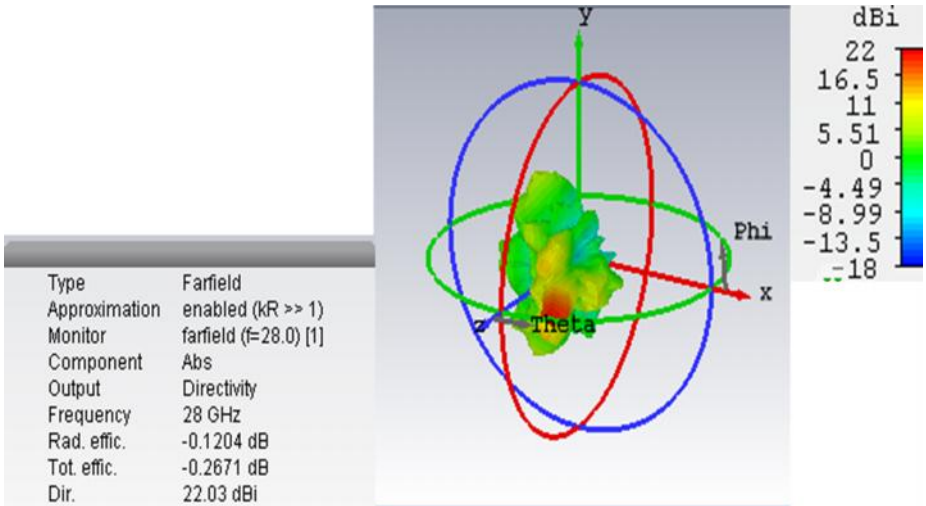

Figure 5. Radiation performance CST perspective

Table 1. Design parameters

Parameters	measurement
Frequency Band (GHz)	26 - 30
Center frequency (GHz)	28
Squint Angle (Deg)	20
Dish size (mm)	100
Dielectric material	1.80
Cavity height (mm)	3
Air gap (mm)	0.8
Thickness of dielectric (mm)	2.9

Table 2. Comparative analysis of the result

	[11]	[14]	Study[2017]
Frequency (GHz)	21.7	28	28
Directivity (dBi)	36.2	18.4	22.03
Bandwidth (%)	46.86	58.50	60.50
Rad. Efficiency (%)	96.01	96	97
Dish Size (mm)	600	100	100
Squint Angle (Deg)	20	20	20
Dielectric (εr)	2.22	2.22; 2.23	1.80
Gain (dBi)	36.2	18.13	22

Table 2 shows comparative performance in Ka Band between previous research done in downlink Ka Band at 21.7GHz, Uplink Ka Band at 28GHz and the study at 28GHz Uplink. The antenna diameter of the various research work under review and the current study are 600mm, 100mm and 100mm respectively.

The respective reflection coefficient performance and the equivalent directivities are equally shown. This is aimed at showcasing the improvements achieved with the study with the use of Ka Band design for the same application. Same antenna diameter provides over 2dBi directivity than the recent work done on the same Ka Band at 28GHz, this is a significant improvement.

CONCLUSION

This paper achieved RLSA feeder cavity optimization for Ka Band Up-link application at 28GHz, using beam squint technique and Artificial Bee Colony optimization method. The study also researches into the behaviour of some dielectric materials, which are used in the study as slow wave factor for Ka Band and the outcome of the research of dielectric materials led to the choose of polypropylene. The optimization techniques deployed in this paper were able to address the bottleneck of RLSA antenna; by providing solutions that yielded high radiation performance, high gain and directivity and optimal solution of bandwidth utilization as a result of significant reduction in reflection coefficients of the slots pairs of RLSA antenna.

High reflection coefficient has in the past be a major design problem associated with RLSA antenna, despite excellent features of the antennas such as high radiation performance, high gain and directivity, low cost, less design complexity, ease of installation and excellent immune to leaf and water. The computations from the CST results show that the study was able to achieved optimization of the RLSA feeder for Ka Band at 28GHz Uplink for DBS and the optimal solution for an improved bandwidth utilization was realized. Achieving this results for the paper has contributed greatly to the communication industry, as the new communication satellites that are launched into space are design with KA Band transponders that requires high bandwidth for their operation. MATLAB evaluation of the optimal solutions for the thesis were used on CST MWS' simulations platform, this gave improvement in the design procedures for optimal design parameters and showed some improvements in the radiation characteristics.

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