Design and Realization of a Conical Beam Slot Antenna for Mobile Direct Broadcasting Satellite Application

Md Zahidul Islam[1], Mst. Nishat Yasmin Koli[2] and Karu P. Esselle[2]
Department of Engineering
[1]Rajshahi University of Engineering and Technology, Rajshahi, Bangladesh
[2]Macquarie University, Sydney, Australia
[1]imzahid30@gmail.com, nishat.ruet09@gmail.com

***Abstract*—This Paper investigates a satellite on the move DBS (Direct Broadcasting System) receiver for receiving signal in K-band. An radially arrayed slot antenna has been designed and implemented with circular polarisation. The antenna has five concentric rings made with slots to achieve conical beam, better directivity, gain and wider frequency bandwidth. The antenna supports waveguide structure, air cavity and dielectric materials. From the simulation and measurement results we can see that our antenna has achieved the required technical specification. The antenna has demonstrated a maximum gain of 21.4 dBi at 20.6 GHz with an operational frequency bandwidth from 19 GHz to 22 GHz. The antenna has successfully satisfied the condition of circular polarisation with appropriate radiation patterns. At operating frequency 20 GHz, the antenna has achieved a directivity of 20.4 dBi with side lobe level as low as -14.8 dB.**

Keywords RAS, mobile DBS, conical beam, K-band, slot antenna

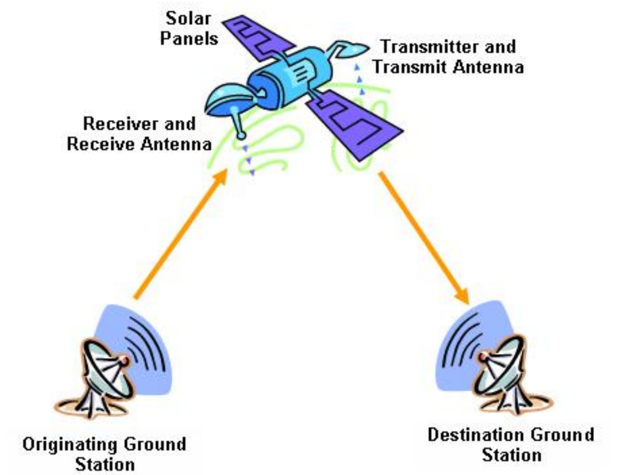

Fig. 1: Satellite on the move DBS receiver.

I. Introduction

Recent year have witnessed a strong demand of microwave antennas in different communication systems such as in television, high-speed wireless LAN, satellite reception and mobile communication. The satellite communication market on moving vehicles such as aircrafts, trains, buses, and ships is now increasing [1]. Also there is a growing demand for broadband data communication services such as voice communication, web browsing, video streaming, high speed data transfer and so on. High frequency and high gain antennas have been at the center of interest for mobile satellite applications. Among the diversity of microwave antennas, satellite communication commonly uses parabolic dish antennas [1]–[3].

Parabolic dishes are mounted on a stabilized platform. Despite giving a pretty good gain and efficiency, the use of parabolic dishes on moving air, land, and sea vehicles are constrained by air resistance and snow build-up [4]–[6]. Also its heavy mass is difficult for manufacturing and deployment. Another solution is a flat and thin microstrip array antenna to maintain the continuous connection with the moving vehicle but the antenna provides poor efficiency when the gain is high [6], [7]. Many literature suggest several challenging techniques to overcome the limitations of this antenna. RAS antennas were originally designed for direct broadcast from satellite application at 12 GHz in Japan [2], [8], [9]. Due to its compact structure, high efficiency and high gain characteristics, RAS antennas have been proposed for satellite on-board applications ever since [10]–[12]. Figure 1 and Figure 2 show the antenna with good stability to receive signal from satellite while one the move [13].

To achieve a working direct broadcast satellite (DBS) system on mobile platform a more beneficial and efficient antenna is needed which has good stability to receive the signal from satellite while on the move. The main objective of this research is to design a low cost, low profile and high-gain DBS reception antenna which will provide the continuous connection with the satellite signal without any phase array or mechanical beam steering system.
Waveguide slotted antennas are planar DBS reception antennas popular for high efficiency and high gain [14], [15]. In this paper, we have designed and investigated radially arrayed slots (RAS) antenna with conical beam pattern to cope with the problems encountered in microstrip array and parabolic antennas. The RAS antenna is a lightweight, planar antenna suitable for DBS reception, with advantages including high gain, low cost, high radiation efficiency, The antenna utilises waveguide, which maintains the outward travelling waves.

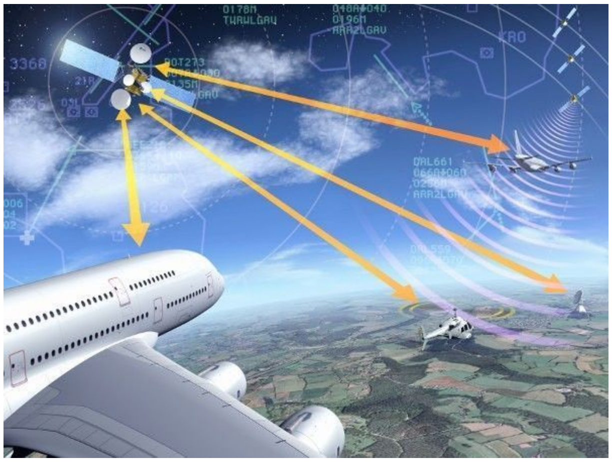

Fig. 2: Transmitting and receiving satellite signal in mobile platform.

II. Configuration and Operational Principle of RAS antenna

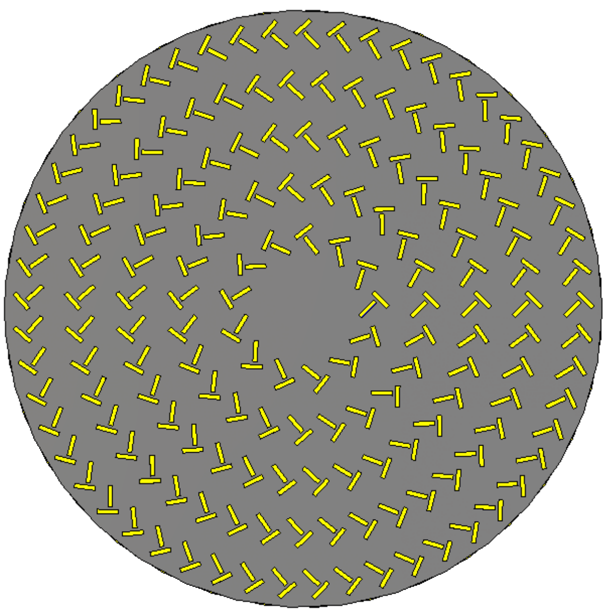

Fig. 3: Front plate with radiating slot elements.

Construction of a radially arrayed slot antenna is presented in Figure 3 and Figure 4. The basic structure consists of two metallic conducting plates with an air-cavity and dielectric slab forming an waveguide like structure. The front is consisted with radiating slots. The radiating elements are arrayed such a way that their radiation are added in phase towards the beam direction. The orientation of slots is in such a direction so as to transmit and receive the signal waves with proper polarisation, and proper coupling inside the waveguide cavity. Figure 3 shows the front plate with radiating slot elements. Dielectric materials are used widely in the design of slot antennas.

In the design of RAS antenna, grating lobes affect the overall performance of the antenna. Dielectric materials are used to reduce the risk of grating lobes in the direction of main lobe. They provide a measure of their effect that is related to the permittivity of the material. Permittivity is a quantity which

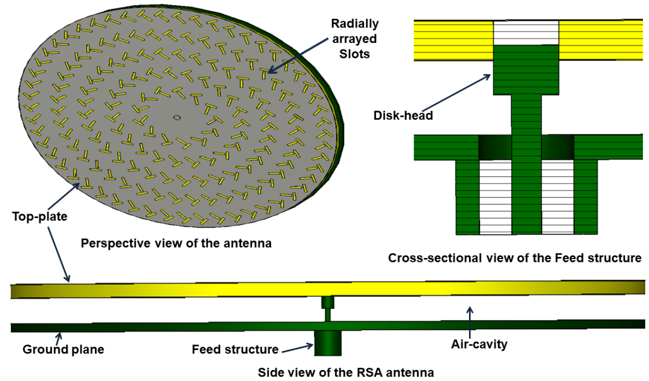

Fig. 4: Prospective view of radially arrayed slot antenna.

describes the effect of a material in an electric field: the higher the permittivity, the ability of the material is more to reduce any field set up into it. The dielectric constant $\epsilon_r > 1$ was chosen here to suppress the grating lobes. The power is fed into the waveguide via a rear mounted coaxial to waveguide transition feed. The transition feed is consisted with disc ended head ensures proper matching of the radial waveguide to the coaxial transmission line.

The disk ended head converts the power from transverse electromagnetic (TEM) transmission line mode to TEM cavity line mode. The energy radiated from the disk-ended feed probe travels outwardly into the waveguide cavity. The dielectric material filling the cavity creates a slow wave structure and minimizes reflection inside the coaxial transmission line. An area of radius ρ_{min} around the center on the radiating surface is left unmodified for stability of the travelling wave before the slots are encountered.
The slots are arrayed on the radiating surface in a specified distribution so that a greater percentage of the energy in the cavity forms a conical beam with a specific polarization. Energy not radiated by the antenna is either reflected back or lost to the space outside the wave cavity. In this case, the lost energy escapes via an open edge.

III. Technical Specification

In this research, the target design is used for SOTM (satellite-on-the-move) DBS receiver which operates at K-band. The antenna should also has conical beam pattern with bandwidth > 2 GHz. The detail of technical specifications can be seen as Table I below.

TABLE I: Technical Specification

Frequency	20 GHz
Polarization	Circular
Slot Length, L	4.91 mm
Slot Width, W	1 mm
Antenna Radius, R	177 mm
Number of Slot pairs	166
Slot Pair Types	Concentric

IV. Feeder

This RLSA antenna is fed by a coaxial adaptor in the mid bottom of the antenna which emitting an outward travelling wave. The excitation mode is coaxial mode. Here, we used a 50 ohm SMA connector that has 6.4 mm height inner conductor. The coaxial probe is coated with Teflon to feed the signal into the cavity.

V. Simulation Results

The antenna design was simulated using CST Microwave Studio. Figure 5 shows the return loss of the antenna. The return loss bandwidth is 500 MHz from 19.6 GHz to 20.1 GHz.

Figure 6 shows the radiation efficiency and total efficiency of the antenna. The antenna efficiencies have enhanced significantly. Radiation efficiency is more than 95% from 19 GHz to 22 GHz. At 20 GHz the total efficiency is 90.6% and radiation efficiency is 95.2%.

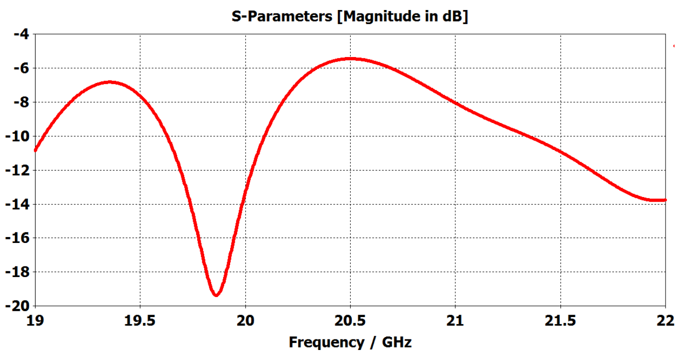

Fig. 5: Return loss of the RAS antenna.

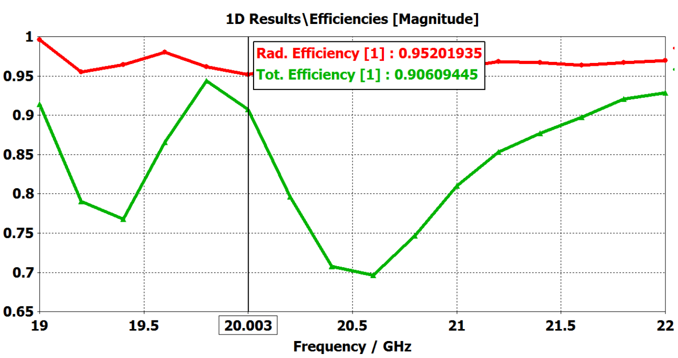

Fig. 6: Total efficiency and radiation efficiency of the antenna.

Figure 7 shows the simulated radiation pattern of the RAS antenna at 20 GHz. We can see from Figure 7 that simulated RAS antenna has conical radiation pattern. The maximum gain achieved with the radiation beam is 20.6 dBi.

Figure 8 shows the axial ratio of the RAS antenna which is below 3-dB level that satisfies the circular polarisation condition. Figure 9 and Figure 10 show the simulated radiation pattern in cartesian plots at 20 GHz. The side lobe level obtained at 20 GHz was -14.8 dB. The radiation pattern is symmetrical and the first side lobe level -14.8 dB indicates the normal antenna operation. Figure 9 shows us the radiation pattern in elevation plane and Figure 10 shows us the radiation pattern in azimuth plane.

The aperture amplitude and phase are almost uniform over the aperture. The directivity of the antenna has shown in

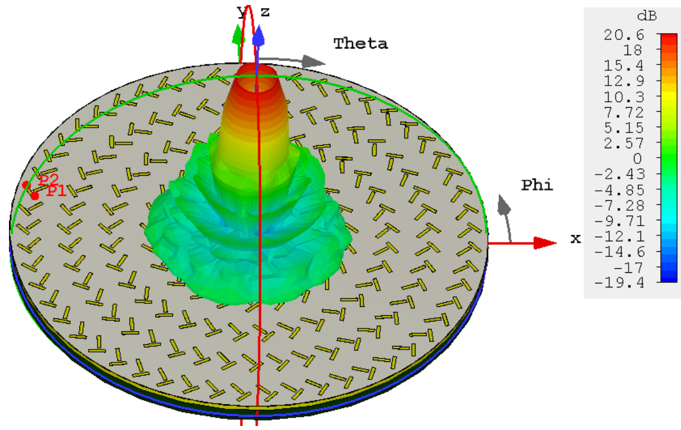

Fig. 7: Simulated radiation pattern of the RAS antenna at 20 GHz.

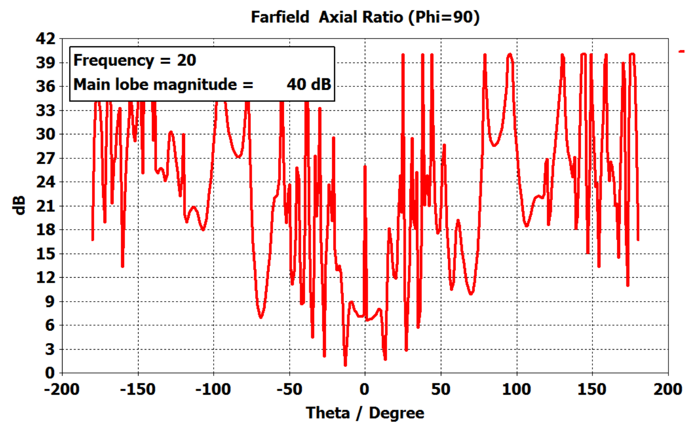

Fig. 8: Axial ratio of the RAS antenna.

Figure 11. The antenna has demonstrated a maximum gain of 21.4 dBi at 20.6 GHz.

Figure 12 shows the realised gain of the RAN antenna at the frequency of maximum directivity i.e, 20.6 GHz in polar coordinates. The maximum gain is demonstrated as 19.6 dBic at 20.6 GHz. The angular beamwidth is 5.6 degree. The side lobe level is as low as -15.2 dB. We can see that our optimized RAS antenna has provided better performance than previously obtained models and also fulfilled the technical specification.

VI. Conclusion

A SOTM DBS receiver has been designed and implemented successfully based on radially arrayed slot antenna which operates at K-band. This RAS antenna has five concentric array slot pairs to achieve conical beam, better gain and wider frequency bandwith compared to others model. This RAS antenna has conical beam and circular polarization, with 20.4 dBi dBi at 20 GHz, operational frequency bandwidth about 4 GHz and axial ratio is below 3 dB level. The high potential of RAS antennas as well as the validity of their analysis and the design are fully demonstrated in this paper. Therefore our optimised antenna has passed the technical specifications and appropriate for satellite on the move DBS receiver. Moreover, this low cost implementation of RAS antenna will decrease the

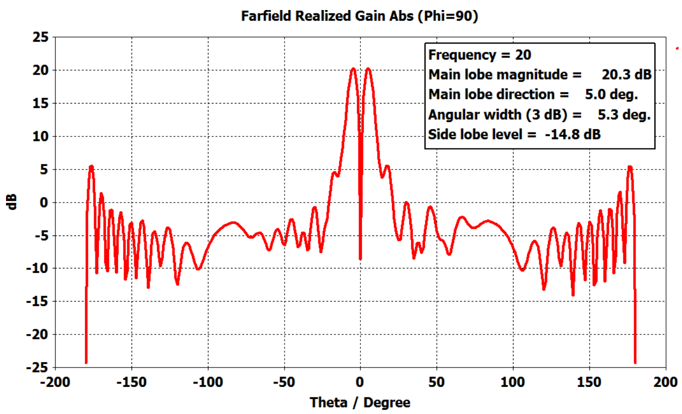

Fig. 9: Simulated radiation pattern in elevation plane at 20 GHz.

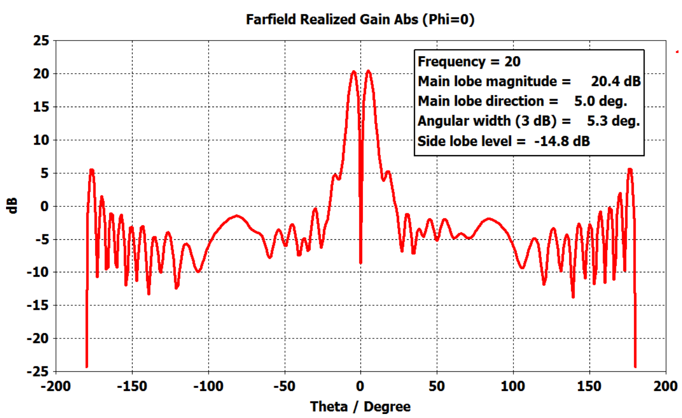

Fig. 10: Simulated radiation pattern in azimuth plane at 20 GHz.

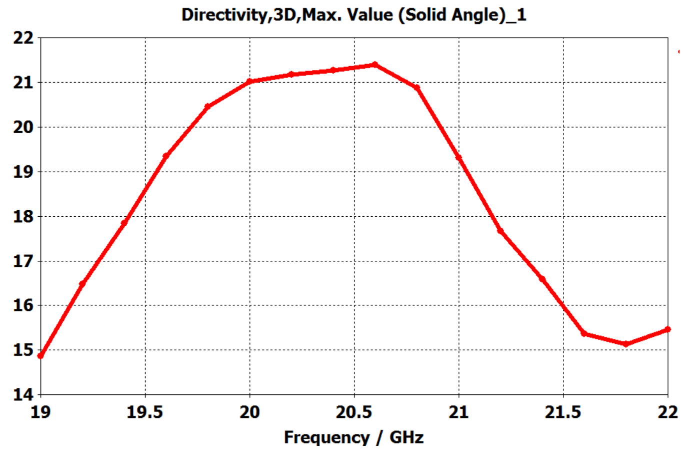

Fig. 11: Directivity of the radially arrayed slot antenna.

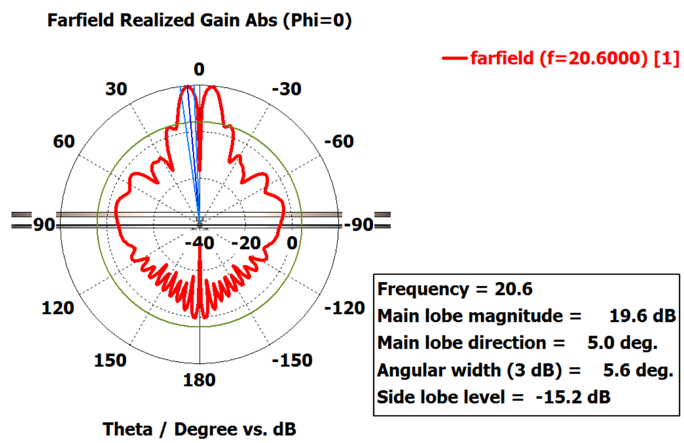

Fig. 12: Realised gain of the antenna at 20.6 GHz.

DBS deployment and manufacturing at public trains, ships and buses all over the world.

REFERENCES

[1] M. Takahashi, J. I. Takada, M. Ando, and N. Goto, "A slot design for uniform aperture field distribution in single-layered radial line slot antennas," *IEEE Transactions on Antennas and Propagation*, vol. 39, no. 7, pp. 954–959, Jul 1991.

[2] M. Ando, K. Sakurai, and N. Goto, "Characteristics of a radial line slot antenna for 12 GHz band satellite TV reception," *IEEE Transactions on Antennas and Propagation*, vol. 34, no. 10, pp. 1269–1272, 1986.

[3] Y. Liu, H. Xiao, and G. Lu, "Design of a high gain circular polarized radial line slot antenna," in *2014 Seventh International Symposium on Computational Intelligence and Design*, Dec 2014, vol. 2, pp. 490–493.

[4] C. W. Yuan, S. R. Peng, T. Shu, Z. Q. Li, and H. Wang, "Designs and experiments of a novel radial line slot antenna for high-power microwave application," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 10, pp. 4940–4946, Oct 2013.

[5] M. Albani, A. Mazzinghi, and A. Freni, "Automatic design of CP-RLSA antennas," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 12, pp. 5538–5547, Dec 2012.

[6] S. Peng, C. W. Yuan, T. Shu, J. Ju, and Q. Zhang, "Design of a concentric array radial line slot antenna for high-power microwave application," *IEEE Transactions on Plasma Science*, vol. 43, no. 10, pp. 3527–3529, Oct 2015.

[7] P. W. Davis and M. E. Bialkowski, "Linearly polarized radial-line slot-array antennas with improved return-loss performance," *IEEE Antennas and Propagation Magazine*, vol. 41, no. 1, pp. 52–61, Feb 1999.

[8] M. Ando, T. Numata, J. I. Takada, and N. Goto, "A linearly polarized radial line slot antenna," *IEEE Transactions on Antennas and Propagation*, vol. 36, no. 12, pp. 1675–1680, Dec 1988.

[9] P. W. Davis and M. E. Bialkowski, "Experimental investigations into a linearly polarized radial slot antenna for DBS TV in Australia," *IEEE Transactions on Antennas and Propagation*, vol. 45, no. 7, pp. 1123–1129, Jul 1997.

[10] S. I. Zakwoi, T. A. Rahman, I. Maina, and O. Elijah, "Design of Ka band downlink radial line slot array antenna for direct broadcast satellite services," in *2014 IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE)*, Dec 2014, pp. 159–162.

[11] M. Takahashi, M. Ando, N. Goto, Y. Numano, M. Suzuki, Y. Okazaki, and T. Yoshimoto, "Dual circularly polarized radial line slot antennas," *IEEE Transactions on Antennas and Propagation*, vol. 43, no. 8, pp. 874–876, Aug 1995.

[12] J. M. Fernandez Gonzalez, P. Padilla, G. Exposito-Dominguez, and M. Sierra-Castaner, "Lightweight portable planar slot array antenna for satellite communications in X-Band," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 1409–1412, 2011.

[13] TS Lim and KG Tan, "The development of radial line slot array antenna for direct broadcast satellite reception," *International journal of electronics*, vol. 94, no. 3, pp. 251–261, 2007.

[14] M. Sierra-Castaner, M. Sierra-Perez, M. Vera-Isasa, and J. L. Fernandez-Jambrina, "Low-cost monopulse radial line slot antenna," *IEEE Transactions on Antennas and Propagation*, vol. 51, no. 2, pp. 256–263, Feb 2003.

[15] I. M. Ibrahim, T. A. Rahman, M. I. Sabran, and M. F. Jamlos, "Bandwidth enhancement through slot design on RLSA performance," in *2014 IEEE Region 10 Symposium*, April 2014, pp. 228–231.