Design of SIW fed Antipodal Linearly Tapered Slot Antenna with Curved and Hat Shaped Dielectric Loading at 60 GHz for Inter-Satellite Communication

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Abstract—A substrate integrated waveguide (SIW) based antipodal linear tapered slot antenna (ALTSA) with dielectric loading at 60 GHz for inter-satellite communication applications is presented. The antenna gain is 18.18 dB at the frequency of interest with good efficiency of 95.1%. The antenna is designed using Rogers RT/Duroid 6002 material with dielectric constant 2.94 and thickness 0.254 mm. Also, Rogers Ultralam 1217 with dielectric constant 2.17 and thickness of 1 mm is used for dielectric loading. A curved dielectric loading along with the hat shaped dielectric loading is added to the antenna to form a dielectric guiding structure, which narrows the beamwidth. To reduce the cross-polarization levels and relative side-lobe levels, rectangular shaped corrugation is used in the antenna design. Ansys HFSS software tool is used for the simulation of antenna.

Keywords—antenna design; antipodal linear tapered slot antenna; dielectric loading; inter-satellite communication; substrate integrated waveguide.

I. INTRODUCTION

The 60-GHz band wireless high speed applications have received much attention from engineers recently. The FCC has allocated the license-free band that operates in between 57-64 GHz. The 60 GHz band frequency spectrum has been assigned to permit high speed multi-gigabit communication links. It allows very high data rate with security in data transmission. In 60 GHz band, the propagation characteristics are limited by high levels of rain attenuation and oxygen absorption [1, 2]. But in space application the performance will not be affected by rain fall and oxygen absorption. In applications like millimeter wave radar requires combining antenna in the systems design with high gain, good band-width and low side lobe level (SLL) [3]. These types of antennas have a relatively low profile and it is easy for integrating with other planar circuit devices [4].

The linear tapered slot antenna (LTSA) is a very good candidate for millimeter wave space applications. The main objective of space communication is to provide direct connectivity between two or more satellites via inter-satellite links (ISL) or cross links. Fig. 1 shows the inter-satellite communication link. Using ISL the constellation formed from clusters of several satellites can communicate with each other when necessary. To some extent this can eliminate the ground stations as the information is routed through satellites in different orbits. Satellites in different orbits can communicate with each other at high speed using ISL. Generally two type of ISL will be required for each satellite. They are inter-orbit ISL and intra-orbit ISL [5]. In the past 30 years ISL have been seen in large platforms [5, 6] like TDRSS and Iridium etc. Some of them are listed in Table I.

Fig. 1. Inter-satellite communication links.

<table>
<thead>
<tr>
<th>Satellite Launch Year</th>
<th>Satellite Name</th>
<th>Frequency used for ISL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994-2003</td>
<td>MilStar I/IId</td>
<td>60 GHz</td>
</tr>
<tr>
<td>2010</td>
<td>AEHF SV-I</td>
<td>60 GHz</td>
</tr>
<tr>
<td>1976</td>
<td>LES-8 and 9</td>
<td>36, 38 GHz</td>
</tr>
<tr>
<td>1983-2013</td>
<td>TDRSS</td>
<td>C, Ku, Ka</td>
</tr>
<tr>
<td>1997</td>
<td>Iridium</td>
<td>23 GHz</td>
</tr>
<tr>
<td>1998</td>
<td>Spot-4</td>
<td>Optical</td>
</tr>
</tbody>
</table>

LTSA belongs to the end fire travelling wave antenna class, which has ideally infinite bandwidth. Compared to other wideband antennas, the LTSA has a reasonably low profile, and symmetric beam. An antipodal linear tapered slot antenna
(ALTSA) for 60 GHz Radio link is presented in [7]. Antenna is fed by a microstrip feed and a substrate-integrated waveguide (SIW). SIW is a type of rectangular waveguide which is made in a dielectric substrate by using via-holes without using the solid fences. These via-holes can be either metallic cylinders or dielectric posts with a permittivity different from the background medium. Because of the ease of integration of SIW structure with other feed networks, it is also seen as a good candidate for feeding variety of antennas. The efficient features of the SIW structure makes it a good choice to design array antenna feeds. In this paper, SIW based antipodal linearly tapered slot antenna (ALTSA) with dielectric loading at 60 GHz for inter satellite communication applications is proposed. Ansys HFSS software is used for the simulation of antenna.

II. ANTENNA DESIGN

![Antenna geometry](image)

Fig. 2. Antenna geometry (a) full design (b) ALTSA top (c) ALTSA bottom.

The cut-off frequency is given by

\[ f_{c,mm} = \frac{c}{2 \sqrt{\varepsilon_r}} \left( \frac{m^2}{a} + \frac{n^2}{b} \right) \]  \hspace{1cm} (1)

where \( c \) is the speed of light in free space, \( f_{c,mm} \) is the cut-off-frequency, \( a \) is the width and \( b \) is the height of the waveguide. For rectangular waveguide, TE_{10} mode is the dominant mode. So the width of SIW will be equal to width of rectangular waveguide, which is given by [8].

\[ a = \frac{c}{2 f_{c10} \sqrt{\varepsilon_r}} \]  \hspace{1cm} (2)

where \( c \) is the speed of light in free space, \( f_{c10} \) is the lowest cut-off-frequency of SIW, that is cut-off-frequency of TE_{10} mode. The gap between the vias and via diameter will also play a major role. If the gap is more, leakage will be more. The diameter of via should be less than [8]

\[ d \leq \frac{\lambda g}{5} \]  \hspace{1cm} (3)

where \( d \) is the diameter of via and \( \lambda g \) is the guided wavelength. Further, the gap between the vias \( s \) should be [8]

\[ s \leq 2d \]  \hspace{1cm} (4)

The SIW effective width is given by [7]

\[ W_{ef} = W_{siw} - 1.08 \frac{d^2}{\pi} + 0.1 \frac{d^2}{W_{siw}} \]  \hspace{1cm} (5)

where \( W_{ef} \) is the effective width of SIW, \( W_{siw} \) is the SIW width.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dielectric Substrate: RT/Duroid (( \varepsilon_r=2.94, h=0.254)mm)</th>
<th>Value mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALTSA Length</td>
<td>La</td>
<td>39.1</td>
</tr>
<tr>
<td>ALTSA Width</td>
<td>Wa</td>
<td>6.8</td>
</tr>
<tr>
<td>Microstrip Line Width</td>
<td>Wm</td>
<td>0.65</td>
</tr>
<tr>
<td>SIW Effective Width</td>
<td>W_{siw}</td>
<td>3.1</td>
</tr>
<tr>
<td>Diameter of Vias</td>
<td>d</td>
<td>0.5</td>
</tr>
<tr>
<td>Pitch of Vias</td>
<td>s</td>
<td>0.68</td>
</tr>
<tr>
<td>Corrugation Width</td>
<td>Wc</td>
<td>0.25</td>
</tr>
<tr>
<td>Space between Corrugation</td>
<td>W_{cs}</td>
<td>0.2</td>
</tr>
<tr>
<td>Length of corrugation</td>
<td>Lc</td>
<td>0.6</td>
</tr>
</tbody>
</table>

For the proposed design, the design in [9] is taken as reference. Some modification is done to [9] by continuing the SIW plated vias along the antenna length and a hat-shaped dielectric loading is added. Rogers/Duroid 6002 is used as the
substrate and hat shaped dielectric loading. Also, another dielectric slab of Rogers Ultralam 1217 is inserted on top of the hat shaped dielectric loading for further increasing the gain. The corrugation structure reduces the side lobe level and cross polarization. Dielectric loading helps to narrow the beamwidth. The dimension of the antenna is given in Table II.

III. SIMULATION RESULTS

The designed antenna is simulated in Ansys HFSS. Fig. 3 shows the simulated return loss of the antenna. It is observed that the return loss is below -10 dB from 55 GHz to 65 GHz. The return loss is -23 dB at 60 GHz. The 3D gain of the antenna is shown in Fig. 4. It is observed that the gain of the antenna is 18.18 dB. The radiation pattern of the antenna is shown in Fig. 5. It is observed that the side lobe level in E-plane is 13 dB below the main lobe level. Similarly, the side lobe level in the H-plane is 11 dB below the main lobe level. Further, the 3 dB beam-width in E-plane is observed to be 20° and the 3 dB beam-width in H-plane is observed to be 36°. The performance of the designed antenna is compared in Table II. In [7] only rectangular corrugation is used in the outer edges of the tapered flares. The gain of the antenna is 16.2 dB. In [9] diamond slot dielectric loading and rectangular corrugation is used. The gain of the antenna is 16.2 dB. In this work with the dielectric loading the gain is observed to be 18.18 dB. Also, the return loss, bandwidth and the 3 dB beamwidth of the proposed antenna is found to be good.

IV. CONCLUSION

The SIW fed corrugated ALTSA array with Curved and Hat Shaped Dielectric guiding structure has been designed and simulated for 60 GHz based inter-satellite wireless communications. The designed ALTSA has good return loss, small size and good gain. It is suitable for the space communication applications at 60 GHz for high speed data transfer between the satellites.

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References


