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***Research paper***

# High gain tapered slot antenna design and link budget analysis for inter-satellite link at 60GHz

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## Abstract

The latest solution for Global Connectivity is Inter-satellite communication. Inter-satellite communication will able to connect two or more satellites directly and hence efficient data transfer is possible with less delay. Choice of frequency is key concern for inter-satellite communication. In this paper, precisely mentioned about importance of millimeter range frequency band for inter-satellite links (ISL) and more focused on the Tapered Slot antenna (TSA) design at 60 GHz. In the design, Substrate Integrated Waveguide SIW feed and corrugation techniques is used to achieve high gain and narrow beam width. Power Divider is used to design two-element TS antenna of 23 dB. For further outlook of antenna design link analysis is also calculated.

***Keywords***: *TS antennas, Inter-satellite Links, Substrate Integrated Waveguide (SIW).*

## 1. Introduction

With the advance in space technology there is scope to widen the application of satellite communication (SC) for Fully Global Connect. One such key area can be project is Inter-satellite communication(ISC). In the traditional SC, ground station plays an important role to communicate with satellite constellation. Basic process involved between ground station and satellite is uplinking, downlinking and amplifying. The coverage area of one Geo-satellite is one-third of earth surface. Inter-satellite links (ISL) provides direct connection between satellites which are placed on orbits and to some extent can eliminate the earth stations. Now a day there is greater attention on direct communication between satellites, so that coverage area is increased and also possible to reduce time delay when compared to satellite communication. For fast transmission of information, a high speed Inter-satellite link has to be designed. In the past 3 decades ISL have seen in different Inter-satellite linking systems [4].

Now a day there is increased attention in the field of millimeter wave technology. Especially 57-64 GHz band is enormously focused. Technically, as the frequency increases wavelength get shorter. 60 GHz belong to high frequency range for that reason wave length is shorter and also absorption by atmospheric molecules is also high. Therefore, mm-wave band is not well fit for outdoor communication. The major advantage of mm-wave band is high bandwidth of 7GHz [5] and high data rate in terms of Gbps. Indoor communication can well utilize these advantages. Above the earth surface oxygen molecules are absent therefore absorption rate is less and can achieve long range high speed connections. This advantage clearly states that mm-wave frequency can be used in space application. when satellites are placed in higher orbits the interconnection between them is possible with mm-wave technology. This paper mainly focused on the TS antenna design at 60GHz so that high speed and reliable transfer is achieved. Planar antenna structure is preferable when compared with conventional antennas because planar antennas are of small size, low profile and comfort to mount on satellites.

For ISLs high gain and narrow beam width is preferable. At millimeter wave frequency band, the losses in the planar micro strip circuit is high. For that reason, substrate integrated waveguide (SIW) technique is used to obtain an antenna result with low loss, low beam width and high-power handling [6][7]. In this paper, assuming that each satellite is considering to be point-to-point irrespective of their relative position but practically this condition is not possible. Further, Beam forming network proved to be better choice for construction of multibeam antenna or antenna array. Fig. 1 shows the inter-satellite link. For understanding purpose [7] Yu Man Cheng et al. have developed SIW based butler matrix with low side lobes for slot antennas.

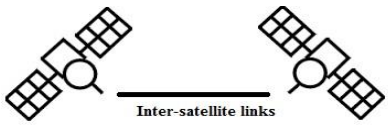


**Fig. 1**: Inter-satellite link

Important parameters need to address for ISL, includes high gain, narrow beam width. Many Research papers highlighted TS antenna is capable to maintain these parameters.

Further, in case of designing array system, antenna width is to be considered. corrugation technique is used to reduce antenna width without any degradation in the radiation pattern [9]- [10]. This paper proposed Antipodal structure of TS antenna with SIW fed and two-element array of Antipodal TS antenna and calculated link

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analysis for the ISL. For the basic understanding of phased array referred [11] but this paper is the initial step for designing array and beam forming. In this paper, for single element gain is 19 dB and for two element 23 dB.

## 2. Design and simulations

In [12] [15][16] authors have designed ALTSA and has a gain of 16.2 dB. The size of antenna should consider in case of designing array antenna. Fig shows the single element Antipodal TS antenna design. Fig is designed in HFSS simulation tool. Table II lists the dimensionality of the antenna shown in fig

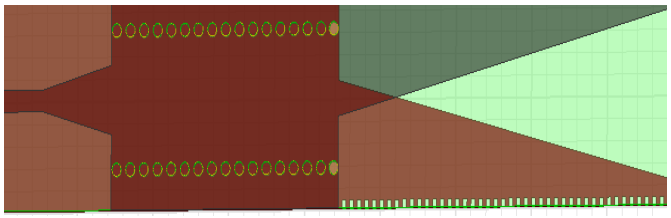

**Fig. 2:** Corrugated single element TS antenna [12]

The TS antenna performance is related to the thickness of the substrate and the dielectric constant.

$$f_{substrate} = t\left(\sqrt{\varepsilon_{eff}} - 1\right) / \lambda_{0,} \quad (1)$$

$$0.005 \leq f_{substrate} \leq 0.03.$$

Also it should be noted that
The substrate chosen for design is RT/Duroid 6002 with the dielectric constant of 2.94. The substrate thickness of 0.381 mm has been chosen for the design. The diameter of the via is given by (2) and the space between the vias is given by (3). where $\lambda_g$ is the guided wavelength.

$$Dvia < \lambda_g / 5 \quad (2)$$

$$P < 2Dvia \quad (3)$$

**Table 1:** Dimension of antenna element [12]

| Parameter | Value (mm) |
|---|---|
| Dimension of TS antenna | 46.54 |
| SIW Dimension | 24.45 |
| Taper Dimension | 5.32 |
| Microstrip Line Dimension | 1.8 |
| ALTSA Width | 8.98 |
| Overlapping Area Width | 1.4 |
| Taper Width | 4.22 |
| Width of Microstrip Line | 0.6 |
| Effective Width of SIW | 5.2 |
| Diameter of Vias | 0.4 |
| Pitch of Vias | 0.80 |
| Width of corrugation | 0.2 |
| Space between Corrugation | 0.4 |
| Dimension of corrugation | 1.65 |

Ansys HFSS simulator is used for designing TS antenna. Two element TS antenna with corrugation technique was performed. SIW power divider was used as a power feeder to the antenna array. Fig. 4 shows the TS antenna array design. Simulated S-parameter Power divider results are shown in Fig.5.

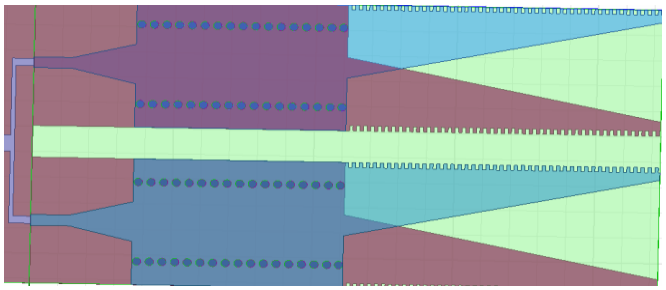

**Fig. 4.** Two element TS antenna with Power Divider

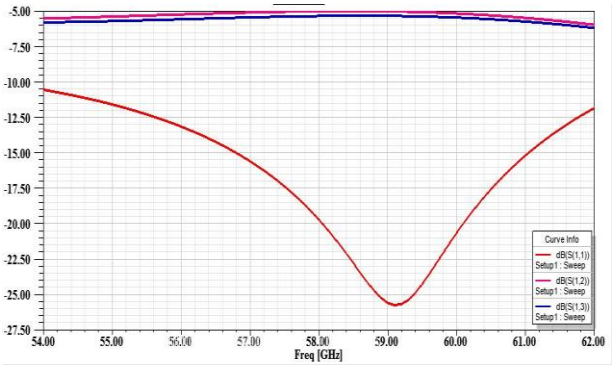


**Fig.5** Returnloss of SIW Powerdivider

The magnitude of S11 and S21 are acceptable range. Fig. 6 shows the S11 for the antenna array. It is observed that return loss is in acceptable range from 59-64 GHz. The Radiation pattern of two element TS antenna is shown in Fig 7 with a gain of 23 dB. Therefore, for reliable ISL this TS antenna is adaptable. Table III mentioned the performance of the single element TS antenna and Two element TS antenna with reference to [12]. When compared to the antenna design in reference [12] [15] [16] TS antenna structure is similar but the main difference is how the input feed drives the power to the output is important and also size of antenna is compact in size when compared to above references. In [12] [15] [16], SIW structure design dimension is large and not appreciable in the array structure. Now a day, availability of high frequency millimeter devices are more therefore this paper consider specifications of high end devices to achieve 23 dB.

**Table 2:** Performance Parameter OF ALTSA Array

| Antenna Performance | single element TS antenna | Two element TS antenna |
|---|---|---|
| Gain (dB) | 19 | 23 |
| Beamwidth (Degree) | 40 | 30 |
| Front to Back Ratio (dB) | 27.83 | 18.3 |
| Return loss(dB) | -13 | -15 |

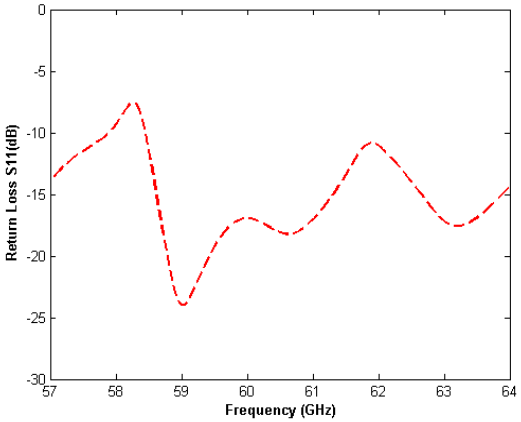


**Fig. 6.** Return loss of antenna array.

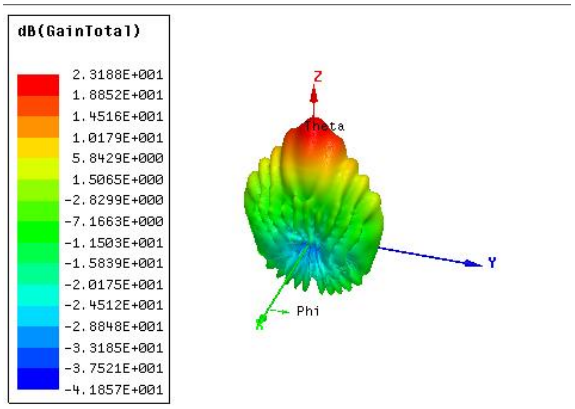


**Fig. 7.** 3D radiation pattern of two-element TSA

## 3. Link analysis

Factors like Available and permitted output power, available bandwidth, receiver sensitivity, antenna gains, radio frequency, environmental conditions can impact the system performance in the Inter-satellite communication. For basic understanding of performance, with the help of MATLAB these parameters are theoretically studied. Table IV shows the link budget analysis. First parameter to be consider is distance between two satellites [13]. As mentioned, angular separation is not mentioned.

$$R=2(R_0+H_0)\sin(A_s/2) \quad (4)$$

Where R is the distance between satellites, R0 is the radius of earth, H0 is the altitude and As is the angular separation between satellite. Major consideration in ISL is selection of transmission power, this has a direct impact on high gain and directivity and minimum interference with other systems.

Depending upon Altitude and range, different power levels are used by satellite systems, hence system design should be capable enough. For the design of satellite system first consider the altitude, range and power levels which to be feed to the antenna. From the simulated results 23 dB gain is considered.

The path loss $PL$ is calculated from the formula.

$$PL(dB) = -10log\left[\frac{G_tG_r\lambda^2}{(4\pi)^2d^2}\right] \quad (5)$$

Path loss is increases significantly over distance as shown in fig. 8.

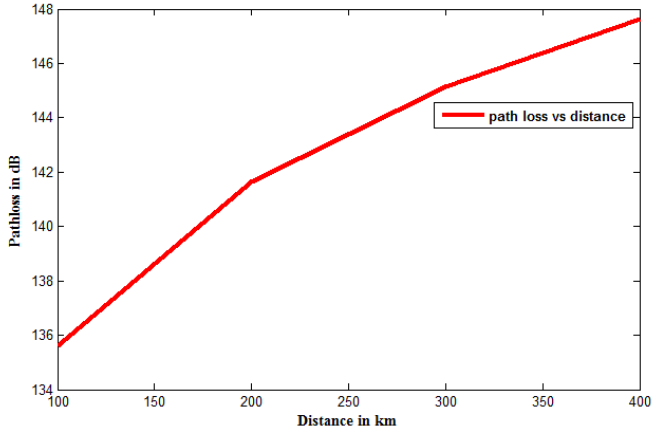


**Fig.8.** Path loss vs distance

ISL are operated above the earth atmospheric level where vacuum is medium. therefore, signal propagation is faster in vacuum when compare to traditional satellite communication. In this analysis assumed medium is vacuum and no losses are considered. Received power (Pr) is calculated as

$$P_r = P_tG_tG_r\left(\frac{\lambda}{4\pi d}\right)^2 \quad (6)$$

where, $\lambda$ is the wavelength in meters and $d$ is the distance in meters.$P_t$is the power transmitted, $P_r$ is the power received, $G_t$ is the transmitting antenna gain, $G_r$ is the receiving antenna gain and $d$ is the distance between the transmitter and the receiver.,$G_t$ and $G_r$ are both 23 dB. Fig.9 shows the received power. Analysis carried on two element TS antenna.

**Table 4:** Link Budget Analysis

| Parameter | Specification |
|---|---|
| Satellite path | LEO |
| Altitude from ground | 600 km |
| ISL Band | V-band |
| Operating frequency | 60 GHz |
| Output from Transponder | 1W |
| ISL Distance | 220 km |
| Angular separation ($A_s$) | 19 Deg |
| Transmitter antenna gain | 23 dB |
| Receiver antenna gain | 23 dB |
| Transmitted power | 1 W |
| Path loss | 143 dB |
| Received power | -64 dBm |
| SNR | 20.5 dB |

Further, noise power at the input in a receiver is given by [14]. For astronomy applications noise extremely low. Implementation loss are not considering.

$$P_{noise} = 10log(KT_{sys}) + 10\,log(B) + NF_{rx} \quad (7)$$

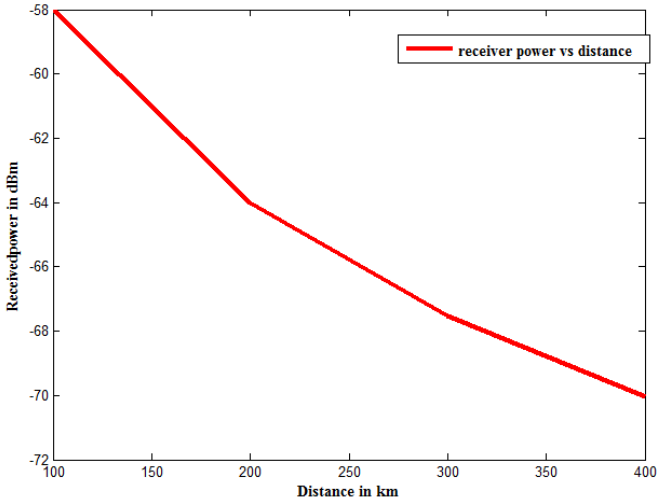


**Fig.9**: Received powervs distance

where $P_{noise}$ is the noise power in dBm, $K$ is the Boltzman's constant, $T_{sys}$ is the system temperature, $NF_{rx}$ is the noise figure of the receiver in dB and $B$ is the bandwidth of the signal in Hz. $NF_{rx}$ is assumed to be 6 dB.$KT_s$ is the Effective receiver noise energy density at the receiver.$k$is Boltzmann's constant=-228.6(dB-Hz/K) and $T_s$is the effective system noise temperature (dB-K).

The signal to noise ratio can be calculated by the equation

$$SNR(dB) = P_r - P_{noise}$$

Where $P_r$is received power and $P_{noise}$is calculated from equation (7). From the above link equations Table V compared the performance of inter-satellite communication system with single element and two element TSA.

**Table 5:** Summary Of Link Budget Analysis

| Antenna performance | single element TS Antenna | TS Antenna array (1 x2) |
|---|---|---|
| Transmitting antenna and receiving antenna gain (dB) | 19 | 23 |
| Power Received (dBm) | -59 | -62 |
| Path loss (dB) | 138 | 143 |
| Estimated ISL distance (Km) | 170 | 240 |

## 4. Conclusion

High gain and efficient TS antenna based on SIW technology with power divider was presented in this research for satellite communications at 60GHz. The simulated gain of single element antenna is 18 dB, while 23 dB is obtained for the 1x2 antenna array.

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