SIW Based Wideband Horn Antenna

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Abstract: In this paper, we have proposed CSRR (complementary split ring resonator) loaded Substrate Integrated Waveguide (SIW) horn antenna. The whole system is designed on a single substrate, having advantages of small size, low profile, and low cost, etc. The design process and simulation results of a CSRR-loaded SIW horn antenna at K-band and Ka-band are presented. The proposed antenna is an outstanding choice for K, Ka bands and even higher frequency synthesis. It has well-behaved gain and suitable reflection coefficient value less than 1.5 (-10dB S11 and VSWR<1.5). The simulated gain of antenna attains 7.48±1dB over majority of the bandwidth and with radiation efficiency of 85%. The simulation has been done using full-wave package, High Frequency Structure Simulator Software (HFSS) based on Finite element method (FEM).

Keywords: Substrate integrated waveguide (SIW), CSRR (Complementary Split Ring Resonator), bandwidth, insertion loss, High Frequency Structure Simulator.

1. INTRODUCTION

To facilitate enrich the demands of a wider bandwidth in support of exploding data transmission, the operating frequency of satellite and wireless communication systems have been increasing to the high range frequencies [1]. To migrate from low frequency bands to high frequency bands provide wider bandwidth and low atmospheric absorption. It also gives the capability of long range wireless data transmission for point to point communication. There are various applications, such as Imaging and communication satellites, uplink in the Ka band and downlink between Ku-band. All these type of applications require light weight, low cost, and high gain antennas, which constitute most critical parts of such systems.

Most suitable antennas for such kind of applications are from planar structure. However, this type of antennas like microstrip antennas suffers from serious losses particularly at bends and discontinuities by increasing frequency [2]. Although numerous planar antennas have been studied for Ka band communication and radar systems in which the increasing of frequency accompanied with the decreasing of radiation efficiency due to the inherent losses on the microstrip feeding network. Non-planar structure is the alternate for planar structure that provides low losses and high power handling capacity. However, it is difficult to configure the non-planar structure to planar active components.
So, SIW was proposed to overcome the mentioned hurdles [3]. It enjoys not only the advantages of non-planar features, but also other benefits, namely, compact, low cost, lightweight, easy to manufacture using PCB technique and other planar processing technologies, and also being easily connected to coplanar waveguide utilizing a wideband and uni-planar transition [4].

SIW structure consists of arrays of metallic posts created in a planar substrate. There various devices are designed and fabricated using these techniques. One of the vital application of this technique is horn antenna. It has numerous of applications because of its simplicity, wide bandwidth, and high gain. However, the dimension of the antenna becomes smaller with increased frequency (due to the shorter wavelength). It required a micromachining fabrication process [5].

SIW based horn antennas are less costly and can easily be interfaced with CPW or microstrip line [6-8]. However, its bandwidth is not wider and they radiates in parallel to the substrate that is not suitable for many practical applications [9]. So it is required to make a structure having wider bandwidth and better gain.

Recently, it is found that the inclusion of SRR (Split Ring Resonator) and CSRR (Complementary Split Ring Resonator) not only improve the gain, it also increases the bandwidth of filters as well as antenna [10-12]. This type of structures is based on metamaterial concepts.

In this paper, CSRRs structure is first cut from the ground plane in order to increase the bandwidth of a simple microstrip patch antenna. The sub-wavelength resonances can be chosen to realize an electrically small antenna. On the other hand, the higher modes of the CSRRs are selected to merge with the main resonance of the patch antenna. For this, the CSRRs rings are embedded to the boundary of the patch. On account of the wider bandwidth the right-handed resonance will yield to the design. Then, the CSRRs structure is modified with crossovers that are installed in the structure of a traditional MA. More details of the design principles of the proposed antennas are described and their simulation results are shown.

2. Antenna Configuration

As shown in fig. 1, it contains the basic horn antenna configured using planar technology (SIW technique). Integration of rectangular waveguide and horn antenna using SIW technology provide compact structure and ease of fabrication [13]. It shows that the horn antenna is created with the use of metallic vias (It connects top and bottom plane of the structure). Taper type of microstrip feed line is use for the microstrip to waveguide transition [13-16]. In this design, the dominant mode is TE10 and we have taken the center frequency 21.5GHz. For the propagation of fundamental mode, the width a and thickness b should be selected from, where is free space wavelength and is permittivity of dielectric medium.
Figure 1. SIW based Horn antenna implemented in HFSS

Table I: Dimension of tapper feed line

| Parameter | Dimension (mm) |
|-----------|----------------|
| P         | 1.42           |
| L1        | 20.45          |
| L2        | 15             |
| a         | 8.60           |
| W         | 2.88           |

This structure is simulated by using HFSS, it is full 3D EM solver based on FEM (finite element method). The Scattered parameter of this structure is shown in fig. 2. As shown in fig. 2, this structure is resonant at three different frequencies 21.28GHz (21.2 GHz to 21.82 GHz), 24.2GHz (24.00 GHz to 24.30 GHz) and 26.4GHz (26.2 GHz to 27 GHz) respectively. It gives -10dB bandwidth is more than 250MHz. Fig. 3 show the gain plot of the antenna that contains more than 7dB gain. The radiation pattern in E-plane and H-plane is also shown in fig. 4. In this pattern, there is few side-lobes generated which is happened due to air gap between two posts of the SIW structure.
From the above structure, it gives bandwidth is around 250-800MHz so to increase the bandwidth of antenna we have to reduce the net inductance of resonant frequency. It is known that reduction of inductance will reduce quality factor and ultimately increase the bandwidth. There are various techniques to modify the reactance of patch either by DMS (Defected microstrip Structure) or DGS (Defected Ground Structure). Introduction of CSRR (Complementary Split Ring Resonator) either in DMS or DGS will change the bandwidth of the antenna.

CSRR is dual counterparts of SRR. Hence, a dual electromagnetic behavior of them is expected according to the duality theorem. The incident electric field needs to be polarized in the axial direction of the resonator. In this manner, CSRRs are etched on center line of the microstrip technology (in ground plane). The CSRR topology and equivalent circuit model are illustrated in fig. 5. The CSRR unit cell was designed to operate around 21.2 GHz. The geometry of the cell is as follows: $c = d = 0.3$ mm, $g = 0.6$ mm and the global size is 7.4 mm $\times$ 3 mm.

![Figure 5: (a) CSRR and (b) its equivalent electric circuit](image)

The CSRR itself can be described as an LC resonant; the resonant frequency is described by the following expression [6]:

$$f = \frac{1}{2\pi \sqrt{L_c C_e}}$$

(1)If the equivalence capacitance of the CSRR is increased, the resonant frequency shifts towards the lower frequency. Fig. 6 shows the simulated scattering parameter of CSRR loaded SIW antenna. As shown in fig. 6, this proposed antenna resonates three different frequencies 21.7 GHz (K-band), 24.2
GHz (K-band) and 27.13 GHz (Ka-band) respectively. Inclusion of CSRR in ground plane is shifted the resonant frequency to the lower resonant frequency while it increased bandwidth around 600 MHz at first resonant frequency in K-band and 400MHz at 3rd resonant frequency in Ka-band. However, inclusion of CSRR in ground plane also reduces the radiation efficiency and return loss.

Finally, we have introduced another split ring into CSRR for improving response, the structure of 3 CSRR is shown in fig. 8a and its equivalent circuit is shown in fig. 8b. Fig. 9a, 9b and 9c shows the top, bottom and side view of the proposed antenna.
The scattering parameter of the proposed antenna is shown in fig 10, it is also resonates at three resonant frequencies 21.2GHz, 24.24GHz and 27.13GHz having a bandwidth of 1060MHz, 400 MHz and 410 MHz respectively. The electric filed distribution and VSWR (Voltage Standing Wave Ratio) are shown in fig 11 and fig 12. This antenna gives gain of 6dB at 21.2GHz frequency that is shown in fig 13.

Figure 10: S11 of multiple CSRR-loaded SIW horn antenna
Figure 11: The electric field distribution of the proposed antenna.

Figure 12: VSWR plot of proposed Antenna
Figure 13: 3D plot Gain of multiple CSRR-loaded SIW horn Antenna

Figure 14: Radiation plot of CSRR loaded SIW horn antenna
Figure 15: Group delay of CSRR loaded SIW horn antenna
Table II: Comparison of SIW antenna without and with loaded CSRR

| Parameters                  | SIW based Horn antenna without loaded CSRR | SIW based Horn antenna with loaded CSRR | SIW based Horn antenna with loaded CSRR + 1 extra split ring |
|-----------------------------|--------------------------------------------|-----------------------------------------|-------------------------------------------------------------|
| Resonant frequency GHz      | 21.26                                      | 21.7                                    | 21.26                                                       |
| S11 in dB                   | -21.75                                     | -25                                     | -43                                                         |
| Bandwidth in MHz            | 200                                        | 550                                     | 1060                                                        |
| Gain in dB                  | 7.07                                       | 6.7                                     | 6                                                           |

3. CONCLUSION:

It is concluded from the proposed designs that inclusion of CSRR in SIW based horn antenna provides better gain, wider bandwidth (four times the without CSRR in SIW horn antenna) and multiple resonant frequencies. This type of structure is very compact and will be used in LEO to LEO satellite communication where more than one antenna is required for tracking to other satellite.

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