CRLH based Leaky-wave Antenna Using Modified Minkowski Fractal on SIW with Tunable Frequency Band

Anirban Sarkar, Moitreya Adhikary, Abhishek Sharma, Animesh Biswas, M. J. Akhtar
Dept. of Electrical Engineering
Indian Institute of Technology Kanpur
Kanpur, India
anirban.skr227@gmail.com

Abstract—**In this paper, a composite right/left-handed (CRLH) based frequency tunable compact high gain leaky-wave antenna (LWA) is proposed at Ku-band. For miniaturization purpose, the modified Minkowski fractal geometry is utilized and by incorporating with suitably placed varactor diodes, the frequency tunable leaky-wave antenna is designed in planar environment. By changing the position of varactor diodes the operating frequency range of the antenna is shifted from 15-16.2 GHz to 14-15 GHz with the beam scanning range of 32° and 30° respectively. The obtained peak gain is 16.7 dBi. Full-wave simulations are performed in HFSS.**

Keywords-Composite right/left-handed (CRLH), Frequency tunnablity; leaky-wave antenna; beam-scanning

I. INTRODUCTION

The rapid growth in wireless broadband services demands new standards to provide high degree of mobility and enhanced data transmission. Recently, fractal based antennas are becoming very popular due to its ability to be integrated with several planar circuits and for miniaturization. Fractal is a recursively generated structure having self-similar shape, which means that some of the parts have the same geometrical shape as the whole object but at different scale [1]. Thus it is feasible to accommodate a long geometry within limited space. Besides this, the SIW is a very good alternative of conventional waveguide because of its several significant advantages like low loss, low cost, ease of fabrication etc. Several SIW based leaky-wave antennas have already been proposed in the past literature [2], [3].

In this paper, a modified Minkowski fractal is utilized in designing full space scanning LWA. It was first introduced by Hermann Minkowski in the form of representation and definition of geometries. Various fractal array antennas are designed based on Minkowski geometry for WiMAX and several MIMO applications [4]. The proposed geometry shows a maximum radiated peak gain of 16.7 dBi within the operating bandwidth of 7.6% having the beam scanning range of 32°. Incorporating with varactor diode, the antenna is made frequency tunable.

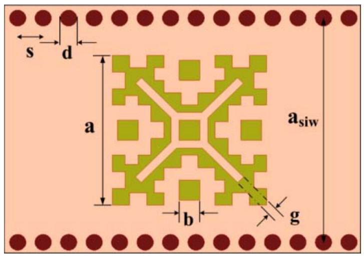

Figure. 1. Modified Minkowski fractal unit cell. Dimensions are: a=7.5mm, a_{siw}=11.2mm, b=1mm, g=0.4mm, s=1.2mm, d=0.8mm.

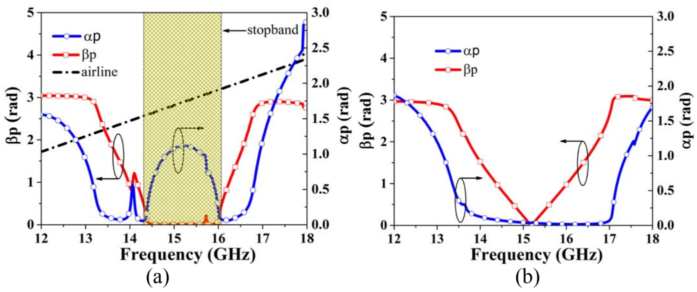

Figure. 2. CRLH TL (a) Unbalanced, (b) Balanced

II. UNIT CELL DESIGN

A. Modified Minkowski Fractal Unit Cell Design

First, the modified Minkowski fractal unit cell is designed in SIW environment. It comprises conventional fractal (after two iterations) with five separated patch segments which is symmetrical in nature. The via-wall gives the shunt inductance whereas the modified fractal geometry is responsible for series capacitance. So, the designed unit cell shown in Fig 1 is acting like a CRLH transmission line (TL). The dispersion diagram of the said unit cell is shown in Fig. 2(a) where the propagation constant (considering the effect of n unit cells) and attenuation constant are depicted. The high value of attenuation constant in the stop-band region supports the unbalance condition of the TL. By properly choosing the value of the design parameters, the balanced condition is achieved shown in Fig. 2(b). The dimensions of the unit cell is chosen such that the excited

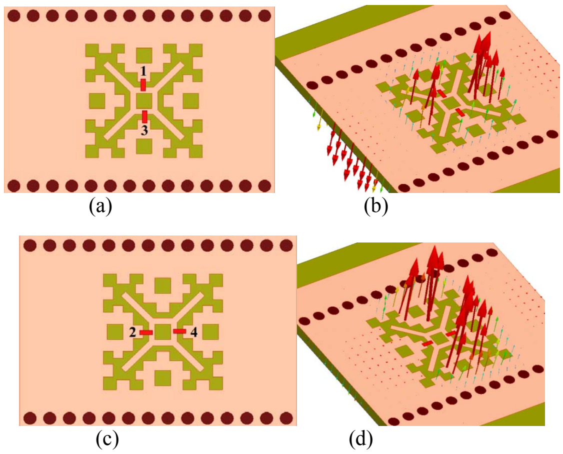

Figure. 3. (a) Unit cell with diodes are at position 1&3, (b) E-field vector distribution of 3(a), (c) unit cell with diodes are at position 2&4, (d) E-field vector distribution of 3(c),

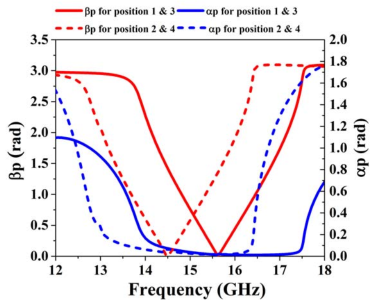

Figure. 4. Shifting of balanced frequency point with positions.

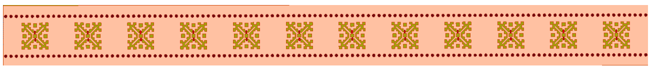

Figure. 5. Layout of the LWA (not to scale).

n=-1 harmonic falls under the fast wave region (β<k_0). The left side from the balanced point (where β=0) corresponds to left-handed region and reverse corresponds to right-handed region.

B. Tunable Unit Cell Design

Two combinations of varactor diode pair are exploited into the unit cell of Fig. 1 to make it frequency tunable. In the first configuration, a pair of varactor diodes (shown in Fig. 3(a) are placed with a capacitance variation from 0.5-1.2 pF. Due to this, the maximum E-field vector distribution (Fig. 3(b)) is observed at either side of the diode positions. Similar effect is observed when diodes position is reversed which are shown in Fig. 3(c) & (d). The corresponding dispersion graph is depicted in Fig. 4 where the shifting of balanced frequency point is noticeable from 15.6 – 14.5 GHz. Diodes are at position 1 & 3 are responsible for higher frequency band and other for lower frequency band.

III. Leaky-wave Antenna Design and Analysis

For designing leaky-wave antenna, unit cell shown in Fig. 3(a) is placed periodically with the periodicity p=15mm shown in Fig 5. The working range of the antenna is from

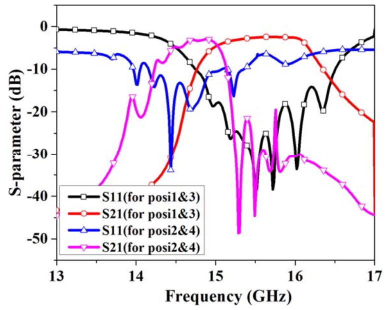

Figure. 6. Shifting of frequency band based on different configurations.

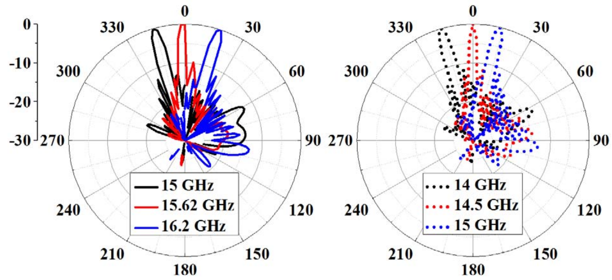

Figure. 7. Normalized radiation patterns for different frequency bands.

15-16.2 GHz where n=-1 spatial harmonic is fast wave in nature. In the LH region (15-15.6 GHz) the radiation from the antenna is in backward direction where as in RH region it is in forward direction. The direction of main radiated beam can be calculated using equation given in [2]. The proposed antenna is designed on Rogers RT/Duroid 5880 with the dielectric constant of 2.2, loss tangent of 0.0009 and height of 0.787 mm. When diodes are placed at position 2 & 4, the working range is shifted to 14-15 GHz. S-parameter responses are shown in Fig. 6 where the shifting of frequency band is observed. The normalized radiation patterns are shown in Fig 7 where backward to forward beam scanning through broadside is observed in visible space. The maximum peak gain is achieved is 16.7 dBi for 12 unit cells. The proposed antenna can be a potential candidate for several wireless applications such as long-distance radio telecommunications, Ku-band satellite applications, radar, terrestrial broadband etc.

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