Wider Band Single-Patch Micro Strip Antenna with side feeding at E-Band

Nebojša Pupavac and Branko Kolundžija, *Fellow, IEEE*

***Abstract*— Microstrip antennas (MSAs) have several advantages such as being lightweight, small in volume and low in cost, as they are manufactured using printed-circuit technology which allows for mass production. However, the types of applications of MSAs are restricted by the antennas' inherently narrow bandwidth (BW). The application of interest in this paper are low-cost short-range outdoor radar sensors operating 77-81 GHz and long range at 76-77 GHz band. The aim of this study is to propose a new antenna design that can cover both bands with a significant margin. Various shapes of single-patch antennas are designed using the WIPL-D software platform, which was utilized for optimizing the antenna matching and achieving a wider bandwidth.**

***Index Terms*—radar sensor; micro strip antenna; patch antenna, radiation pattern, cross polar discrimination.**

I. Introduction

Microstrip antennas (MSAs) are commonly used due to their lightweight and low-cost design, but they have some disadvantages compared to conventional microwave antennas, including narrow bandwidth, lower gain, and lower power-handling capability. MSAs typically have 1–5% BW which is the major limiting factor for the widespread application of these antennas [4]. For the outdoor radar application, the aim is to achieve a minimum of 6,4% (76-81 GHz). Additionally, some radar applications require a wide field of view in both azimuth and elevation planes, necessitating antennas with wide beams in both H and E-planes. Single-patch antennas have over 60° HPBW (half power beam width) in both planes which is sufficient to reach FoV of over 110°.

Microstrip patch antenna elements can be fed by a variety of methods. These methods can be classified into two categories: direct or indirect contact. In the direct contact technique, the power is fed directly to the radiating patch using a connecting element such as a microstrip line or coaxial connector. In the indirect contact scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch. For E-Band design it is very common to have the mmWave circuitry on the same PCB and the very same substrate to reduce losses, so this paper will only analyze microstrip feeding.

Microstrip antennas can be fed using various configurations of microstrip line feeds. In Edge-fed schemes, the feeding line starts from the edge of the patch, while in inset feed, the microstrip line starts from a location inside the patch. The purpose of the inset cut in the patch is to match the impedance of the feeding line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position and impedance of the line. The Inset-fed scheme is an easy feeding method that provides ease of fabrication and simplicity in modeling, as well as efficient impedance matching.

Fig. 1. Standard patch antenna feeding from radiating edge.

Fig. 1 shows two most common feeding options where feeding line comes from the radiating edge.

In this paper, a new way for broadening the bandwidth of the micro strip single patch antenna is proposed by means of changing the feeding edge. Several models with feeding from a non-radiating edge are analyzed and compared with the more common Inset feeding (from the radiating edge), showing significantly wider bandwidth. Results of the optimized models are described in the following chapters and the optimal model is selected for more detailed analyses.

II. Radiating Edge Micro Strip Feeding

We will start from an Edge-fed microstrip patch antenna model at 79 GHz. The layout of the single patch antenna is shown in Fig. 2. A substrate thickness is H_{sub}=127µm, with relative permittivity ε_r=2.9, and loss tangent $\tan\delta = 0.0017$, while cooper thickness is estimated as T=33µm.

The starting patch width (W) and length (L) are calculated using the standard approximation [1],

$$W = \frac{c_0}{2 f_r \sqrt{\frac{\varepsilon_r + 1}{2}}}, \quad (1)$$

$$L = \frac{c_0}{2 f_r \sqrt{\varepsilon_{eff}}}, \quad (2)$$

where ε_{eff} is given by:

Nebojša Pupavac is with the School of Electrical Engineering, University of Belgrade, 73 Bulevar kralja Aleksandra, 11020 Belgrade, Serbia (e-mail: nebojsapupavac@gmail.com), (https://orcid.org/0000-0001-7851-7649)

Branko Kolundžija is with the School of Electrical Engineering, University of Belgrade, 73 Bulevar kralja Aleksandra, 11020 Belgrade, Serbia (e-mail: kol@etf.bg.ac.rs), (https://orcid.org/0000-0003-2663-4143)

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$$\varepsilon_{\mathrm{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{t}{W}\right)^{-\frac{1}{2}}. \quad (3)$$

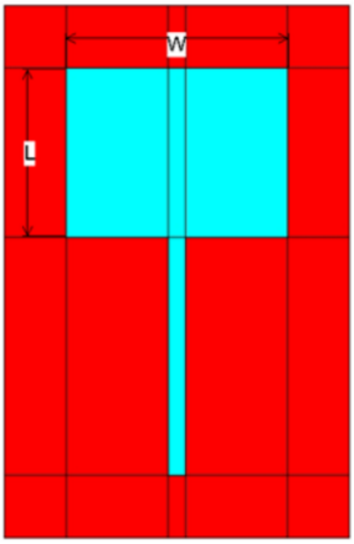

Fig. 2. Single rectangular patch antenna.

Antenna matching is achieved by adjusting the length of 0.1 mm wide feeding line using software package for electromagnetic modeling WIPL-D Pro [6]. Parameter S11 over desired frequency bandwidth is shown in Fig. 3.

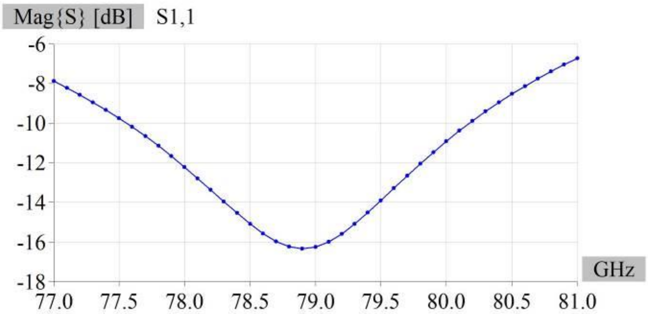

Fig. 3. Parameter S11 for a single microstrip patch antenna.

To achieve better matching Inset-fed antenna model (Fig. 4) is designed using WIPL-D.

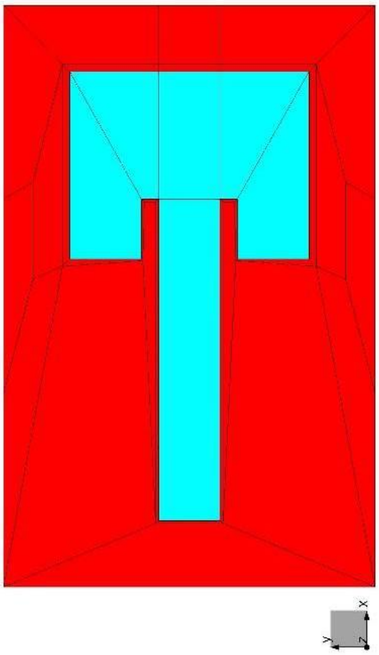

Fig. 4. Inset-fed Antenna WIPL-D model.

The Optimizer was configured to achieve S11 lower then −10 dB from 76 to 81 GHz. The result was better than Edge-fed but still could not fulfil the requirement. Fig. 5 shows that single-patch Inset-fed offers wider matching, as expected, but it is still not wide enough to cover short- and long-range applications.

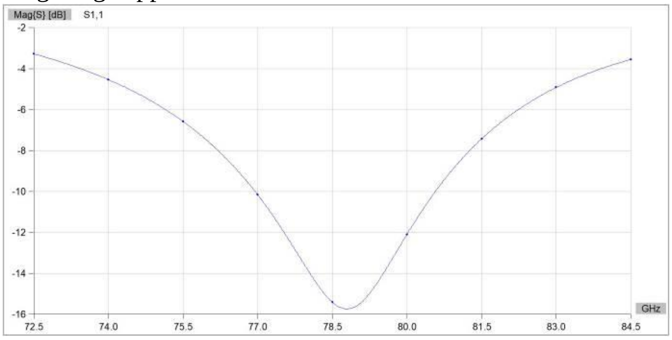

Fig. 5. Inset-fed Antenna Return Loss.

III. BASIC SIDE-FED ANTENNA DESIGN

Feeding from non-radiating edge is proposed to achieve better matching while keeping the line width close to 50Ω MS line width as seen in the Inset-fed antenna. This time the goal is to reach −10 dB return loss bandwidth even wider than 76-81 GHz.

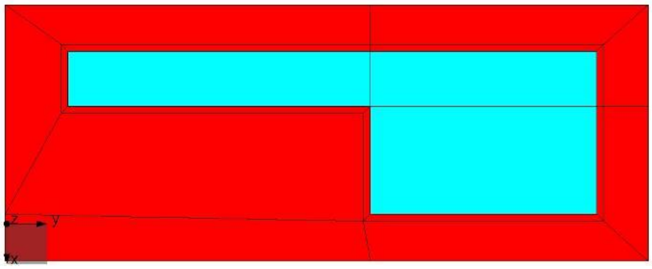

Fig. 6. Side-fed Antenna model.

After optimization of the parameters, the Side-fed antenna (Fig. 6) provides much better matching. Fig. 7 shows that Side-fed antenna has −10 dB return loss bandwidth from 76 GHz to 81.8 GHz.

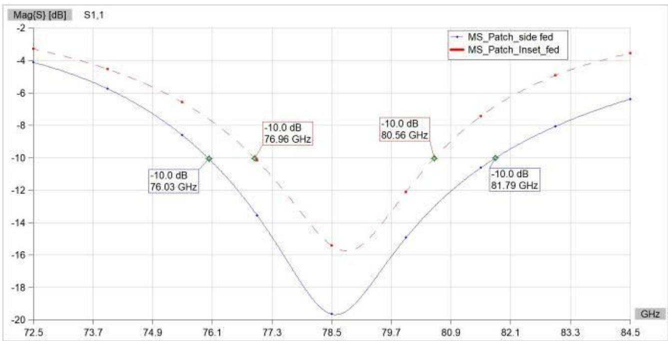

Fig. 7. Side- and Inset-fed Antennas matching comparison.

Besides better matching, as shown on Fig. 7 , the side feeding could be more convenient for some MIMO (multiple input – multiple output) configurations, by means of reduced losses and easier phase matching among antennas in array.

An even wider bandwidth could be achieved by combining side and inset feeding (Fig. 8).

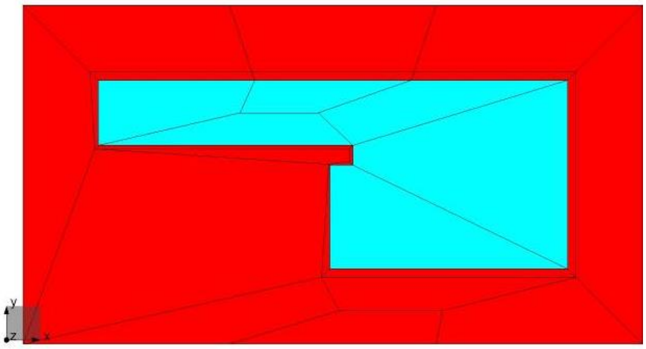

Fig. 8. Side-fed Antenna with Inset feeding.

Fig. 9 shows that broa dBand matching could be achieved with Side-fed antenna, which allows significant margin for practical implementation if we consider substrate parameter and other tolerances of the PCB process.

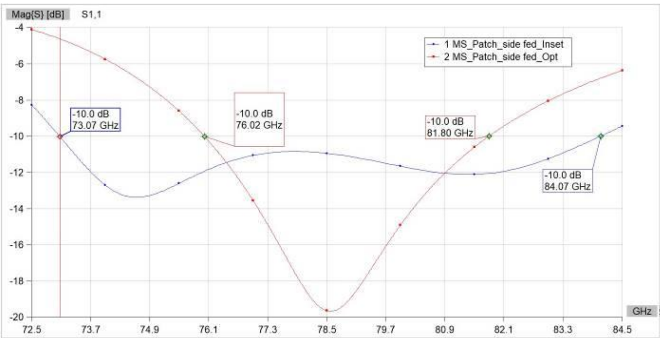

Fig. 9. Improved Matching of the Side-fed antenna.

IV. Main Radiation Properties

All the antennas are optimized to achieve as wide BW as possible while keeping S11 lower than −10 dB. Besides matching, for short range radar application, it is very important to achieve HPBW (half power beamwidth) as wide as possible, while the gain in main direction should be kept at high level over wide BW.

Fig. 10 shows the gain at main direction (z-axes in the WIPL-D models) of tree antenna models shown on Fig. 4, Fig. 6 and Fig. 8.

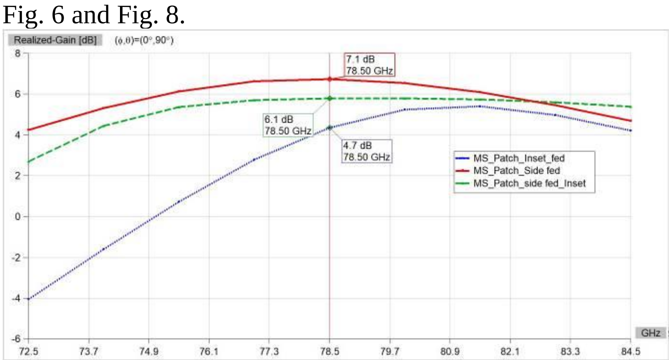

Fig. 10. Total Realized Gain in main direction.

Radiation pattern in azimuth plane with the standard fed antenna (from radiating edge Fig. 4) is assumed to be orthogonal to the feeding line and for Side-fed antennas it is obviously parallel with the feeding line. Fig. 11 shows that the standard Inset-fed (Fig. 4) and side fed antenna with inset (Fig. 8) have wider HPBW around 80° while the Side-fed antenna (Fig. 6) has narrower beam (HPBW≈60°).

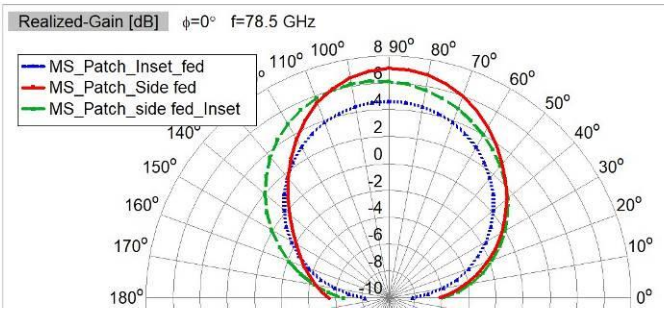

Fig. 11. Radiation Patterns in azimuth plane at central frequency

Due to the standard Inset-fed model symmetry the azimuth plane radiation pattern is absolutely symmetrical, but the elevation plane pattern is significantly degraded. This behavior could be explained by the feeding line influence, which is not noticed in the case of two side-fed antennas at central frequency. Fig. 12 shows that side fed antennas have no degradation in elevation plane while the HPBW is significantly wider (HPBW≈90°).

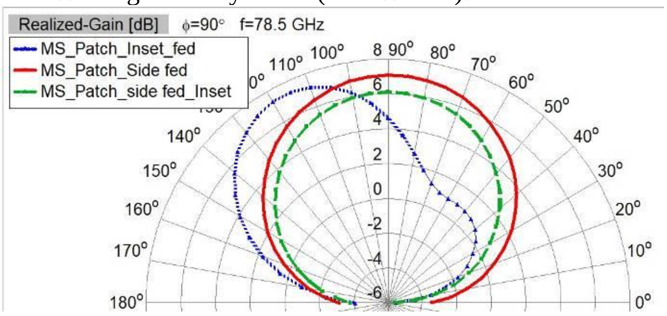

Fig. 12. Radiation Patterns in elevation plane at central frequency.

Another important radiation parameter is undesired cross-polarized radiation.

V. Polarization of Antennas

Polarization of an antenna in a given direction is defined as the polarization of the wave transmitted (radiated) by the antenna.

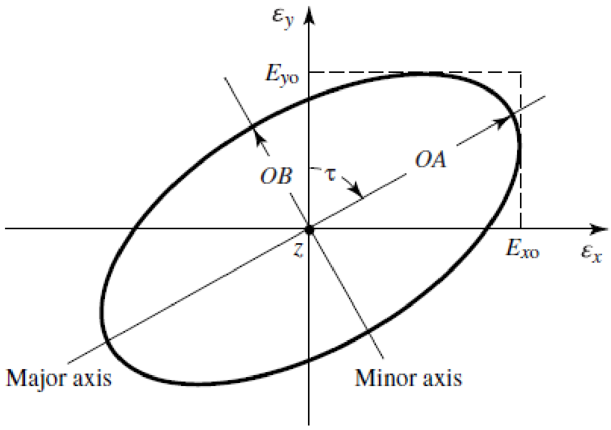

Fig. 13. Polarization ellipse [3].

In this paper the polarization is taken to be the polarization in the main direction which in this case the z-axes. It is assumed that MS patch antennas have elliptical polarization, where the curve traced at a given position as a function of time is, in general, a tilted ellipse, as shown in Fig. 13

The ratio of the major axis to the minor axis is referred to as the axial ratio (AR or e-ellipticity in WIPL-D), which tends to infinity in case or linear polarization and tends to 1

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in circular polarization. The tilt of the ellipse, relative to the y axis, is represented by the angle τ on Fig. 13 and by the angle β in WIPL-D (Fig. 15).

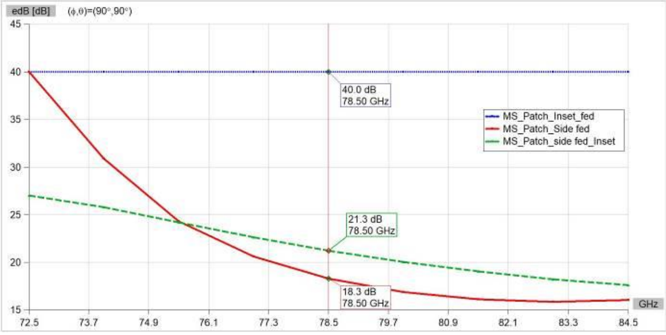

Fig. 14. Elipticity in dB.

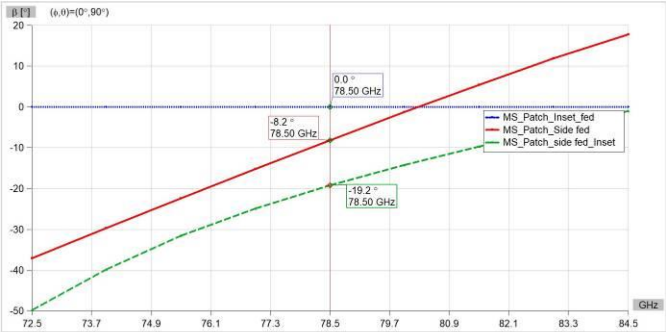

Fig. 15. Tilt angle of ellipse.

Figures 14 and 15 show that standard Inset-fed antenna has almost linear polarization in the main direction over the whole BW of interest while Side-fed antennas have lower axel ratio (around 20 dB ellipticity at central frequency) which is changing with frequency. Standard fed antenna has no tilt (β=0°) over the whole BW, while tilt angle of the side fed antennas changes with frequency.

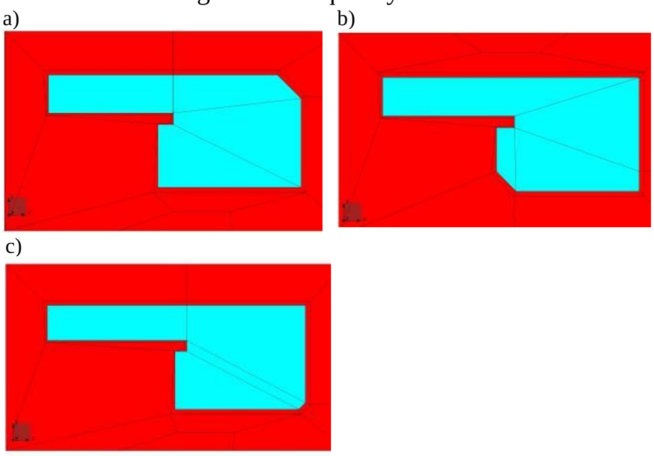

Fig. 16. MSA models with side feeding and cut corner:
a) Side-fed Inset right top corner cut (MS_Patch_side_fed_Inset_CRtop)
b) Side-fed Inset left bottom corner cut (MS_Patch_side_fed_Inset_CLbot)
c) Side-fed Inset right bottom cut (MS_Patch_side_fed_Inset_CRbot)

To improve polarization properties additional three Side-fed Inset models are proposed with a modified top right, bottom right and bottom left corner as shown on Fig. 16. The same matching optimization is done to achieve the highest possible BW.

Fig. 17, Fig. 18 and Fig. 19 show characteristics of four Side-fed antennas with Inset feeding.

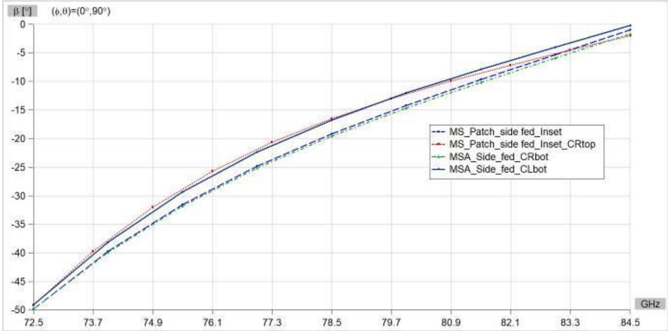

Fig. 17. Tilt angle of ellipse of Side-fed antennas with Inset feeding.

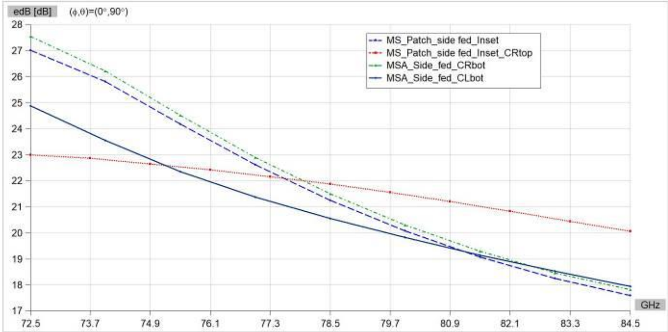

Fig. 18. Elipticity of Side-fed antennas with Inset feeding in dB.

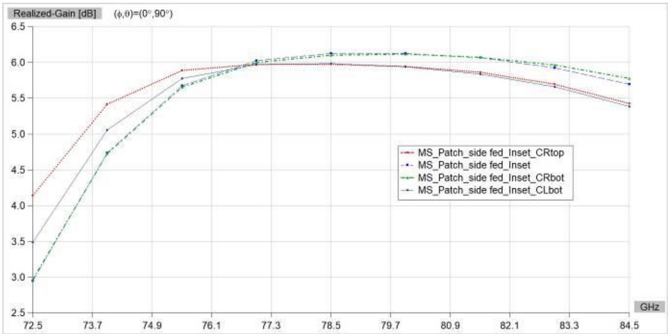

Fig. 19. Gain comparison of Side-fed antennas with Inset feeding.

After careful analysis of the radiation characteristics, the top right corner modification shows the best performance over the widest BW.

VI. THE SELECTED SIDE FED PATCH ANTENNA PROPERTIES

The Side-fed antenna with Inset and top right corner cut (Fig. 16a) has also the widest −10 dB return loss bandwidth as shown on Fig. 20. The achieved BW of 11.5 GHz represents around 14.6% of relative BW.

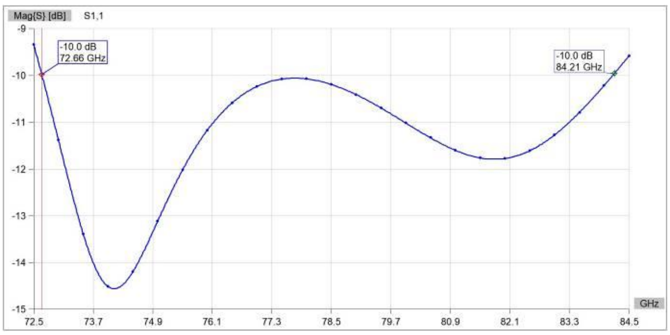

Fig. 20. Selected Antenna Matching.

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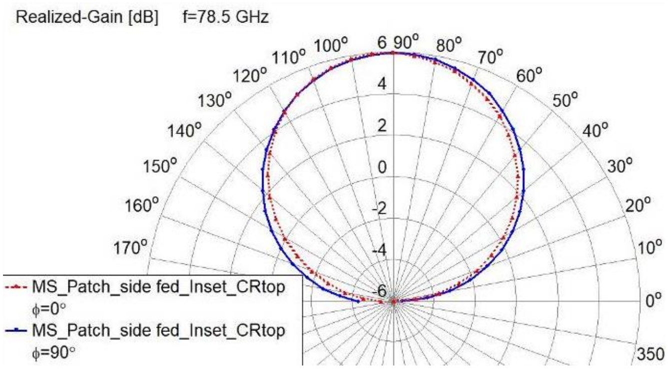

Fig. 21. Selected Ant. Radiation Patterns in azimuth and elevation plane at 78.5 GHz.

At central frequency both Azimuth and Elevation patterns look symmetrical.

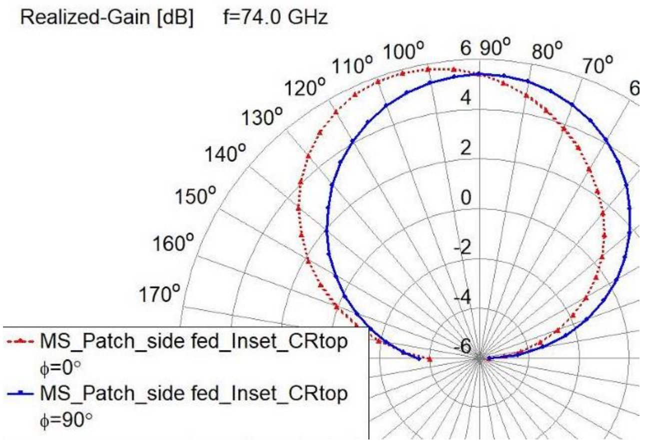

Fig. 22. Selected Ant. Radiation Patterns in azimuth and elevation plane at 74 GHz.

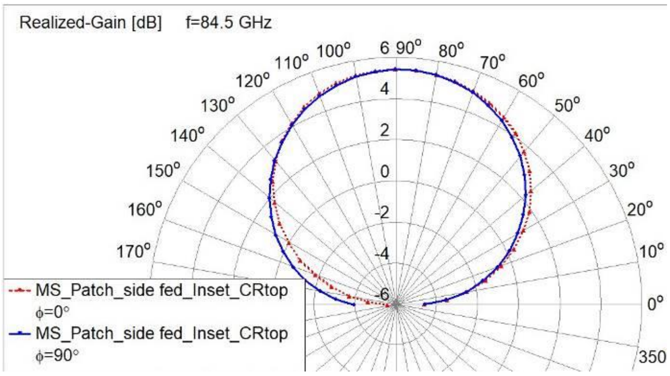

Fig. 23. Selected Ant. Radiation Patterns in azimuth and elevation plane at 84.5 GHz.

Radiation patterns show no significant degradation even if frequency is outside desired 76-81 GHz BW as seen on Fig. 22 and Fig. 223. Cross polar discrimination (XPD) is not so good on lower frequencies as seen on Fig. 24, which is caused by the tilt angle (Fig. 15). The XPD could be improved by rotating the antenna in xOy plane which could compensate the tilt angle on central frequency and improve XPD at lower frequencies.

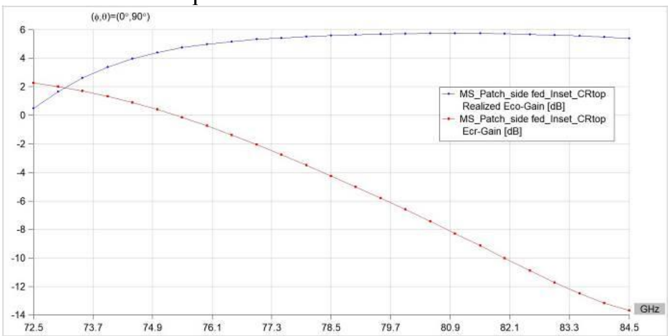

Fig. 24. Realized Co-Polar vs. Cros-Polar Gain.

VII. Conclusion

In this study, the main objective was to widen the bandwidth of a single patch microstrip antenna, which typically has a bandwidth of 1-5%.

The results showed that antenna's matching could be controlled over a wider BW by changing the feeding edge. With Side-fed patch, −10 dB return loss relative BW could be wider than 10%.

The antenna BW can also be defined in terms of the radiation parameters. It is sometimes defined as the frequency range over which radiation parameters such as the gain, HPBW, and sidelobe levels are within the specified minimum and maximum limits.

The above definitions for BW are applicable to a linearly polarized MSA. For a circularly polarized MSA, the BW is generally limited by its AR as the frequency range over which AR is less than a maximum limit (e.g., 3 or 6 dB). In the case of Side-fed antennas it is noticed that AR is around 20 dB, and it is frequency dependent. Also, the polarization is tilted by the frequency dependent tilt angle, so it cannot be easily compensated by MSA rotation.

Since the main applications of interest are different radar MIMO systems, the polarization problem should be further investigated.

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