

# Super-Wide Impedance Bandwidth Planar Antenna Based on Metamaterial Concept for Microwave and Millimetre-Wave Applications

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**Abstract-** A novel configuration for a super-wide impedance planar antenna is presented based on a  $2 \times 2$  microstrip patch antenna (MPA). The antenna comprises a symmetrical arrangement of four-square patches that are interconnected to each other with cross-shaped high impedance microstrip lines. The antenna array is exciting through a single feedline connected to one of the patches. The proposed antenna array configuration overcomes the main drawback of conventional MPA of narrow bandwidth that is typically  $< 5\%$ . The antenna exhibits a super-wide frequency bandwidth from 20 GHz to 120 GHz for  $S_{11} < -15\text{dB}$ , which corresponds to a fractional bandwidth of 142.85%. The antenna's performance of bandwidth, impedance match, and radiation gain were enhanced by etching slots on the patches. The slotted microstrip patch essentially acts like a left-handed capacitance to exhibit metamaterial properties over a given frequency range. With the inclusion of the slot the maximum radiation gain and efficiency of the MPA have increased to 15.11 dBi and 85.79% at 80 GHz, which show an improvement of 2.58 dBi and 12.54%, respectively. The dimension of each patch antenna is  $30 \times 30 \text{ mm}^2$ . The results show that the proposed MPA is useful for various communications existing and emerging systems such as ultra-wideband (UWB) communications, RFID systems, massive multiple-output multiple-input (MIMO) for 5G, and radar systems.

**Keywords-** Array antenna, Microstrip Patch Antenna (MPA), Slot Antenna, Metamaterial, Multiple-Output Multiple-Input (MIMO), Radar, RFID systems, Millimetre-wave band.

## I. INTRODUCTION

Demand for antennas that possess desirable characteristics such as light weight, low profile and high gain have burgeoned significantly with the rapid development of modern wireless communication systems [1, 2]. Antennas implemented on microstrip medium exhibit some of these desirable properties

which makes them very popular in RF/microwave transceiver systems as they are compatible with integrated circuit technology and are relatively cheap and easy to fabricate [3-10]. In addition, microstrip patch antennas (MPAs) can be made to be conformal to planar and non-planar surfaces. The radiation mechanism arises from discontinuities at each truncated edge of the microstrip transmission line. The radiation at the edges causes the antenna to act slightly larger electrically than its physical dimensions, so in order for the antenna to be resonant, a length of microstrip transmission line slightly shorter than one-half a wavelength at the frequency is used. Various techniques have been developed previously to enhance the antenna's impedance bandwidth and reduce its physical footprint, and hence the MPA has become extensively used in various wireless communication applications. Nevertheless, conventional microstrip patch antennas still suffer from narrow impedance bandwidth which is typically less than 5% and low radiation efficiency [1-4]. In addition, the operation of MPA is restricted to the microwave band.

In this paper, we have proposed a simple method to overcome the main drawback of the conventional microstrip patch antenna, and thereby realised a super-wide impedance bandwidth antenna. The design of the antenna is based on implementing four interconnected square patches in close proximity and arranged in an array configuration. Each patch in the antenna is loaded with rectangular slot to improve its performance. This is implemented by simply etching a slot inside each radiating patch. The slot essentially like series left-handed capacitance to exhibit metamaterial properties over a given frequency range [11-13]. The proposed microstrip patch antenna design is applicable for various communications existing and emerging systems such as ultra-wideband (UWB)

communications, RFID systems, massive multiple-output multiple-input (MIMO) for 5G, and radar systems.

## II. PROPOSED MICROSTRIP ANTENNA STRUCTURE

The proposed antenna structure is composed of four-square patches in a  $2 \times 2$  arrangement, as shown in Fig. 1. The antennas are interconnected with a cross-shaped high-impedance line. Unlike conventional microstrip antenna arrays the proposed antenna array is excited through a single feedline connected to one of the antennas. The design of the square patches is based on conventional theory, which is widely available and not repeated here. The dielectric substrate used is high frequency ceramic-filled PTFE composites by Rogers RO3003 with dielectric constant of 3, loss-tangent of 0.001 and thickness of 0.13 mm.

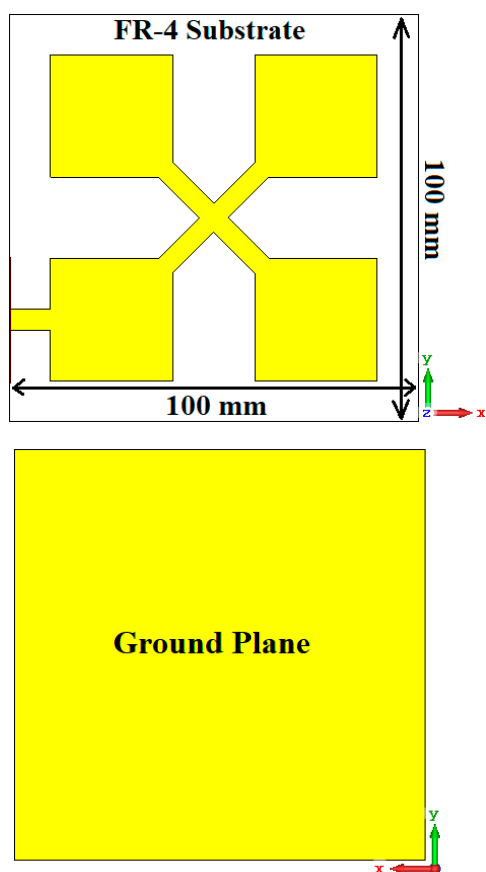


Fig. 1. The proposed microstrip antenna array.

The reflection-coefficient response in Fig. 2 of the proposed MPA array structure shows its impedance bandwidth extends from 20 GHz to 120 GHz for  $S_{11} < -10$  dB with four narrow band-notches at 62.5, 77.5, 97.5, and 120 GHz. To improve the array's performances the four patches are loaded with a rectangular slot as depicted in Fig. 3. It was necessary

to optimize the dimensions of the slots to enhance the reflection-coefficient response of the antenna array, which is shown in Fig. 3. With the slots the reflection-coefficient is significantly improved. Now, the impedance bandwidth from 20 GHz to 120 GHz is achieved for  $S_{11} < -17.5$  dB with no narrow band-notches.

The radiation gain and efficiency of the antenna array with no slot and with slot are shown in Figs. 4 and 5, respectively. These figures show with no slot the antenna gain and efficiency reach a peak of around 12.53 dBi and 73.25% at 80 GHz, respectively, however with application of slot the optimum gain and efficiency improves to 15.11 dBi and 85.79% at 80 GHz, respectively. Therefore, an average improvement of 2.58 dBi and 12.54% on the maximum radiation gain and efficiency have achieved, respectively. The details of the radiation properties have tabulated in Table I.

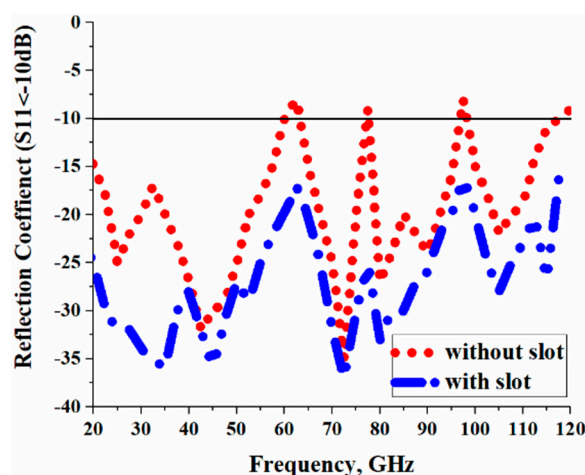


Fig. 2. Reflection-coefficient ( $S_{11} < -10$ dB) response of the microstrip antenna array without slot and with slot.

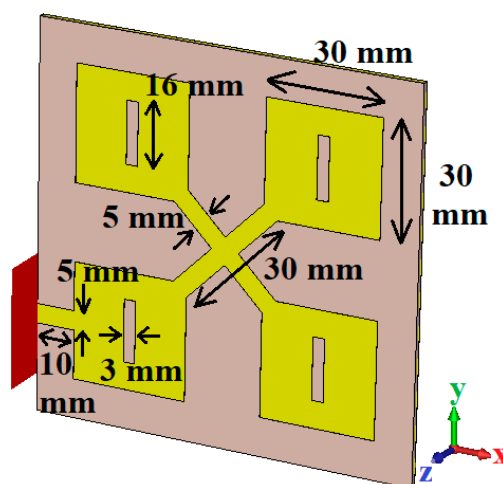


Fig. 3. Configuration of the proposed microstrip antenna array based on simplified composite right/left-handed (SCRLH) MTM

transmission lines [11-13]. Both structures have same ground-plane as in Fig.1. Structural parameters that were modified have been annotated.

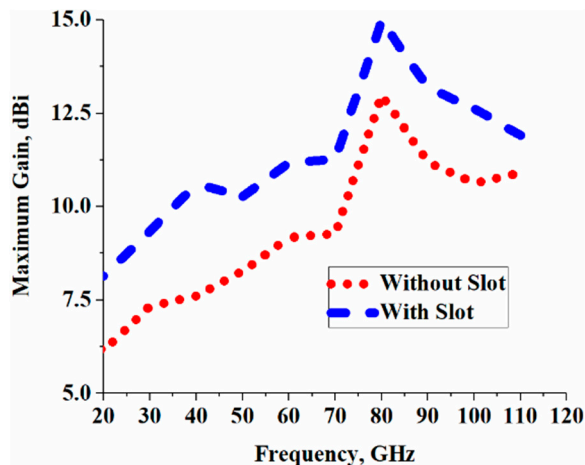


Fig. 4. Gain response for both cases “with no” slot and “with slot”.

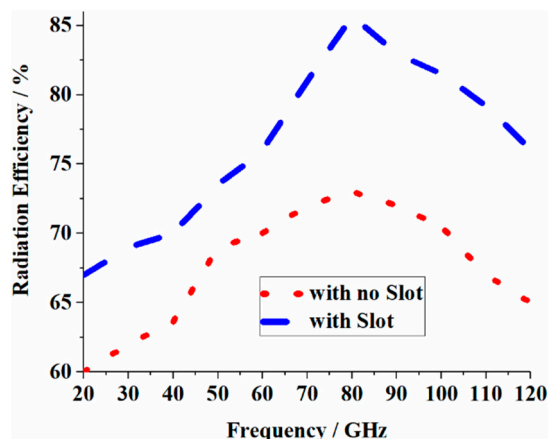


Fig.5. Radiation efficiency response for both cases “before apply the slot” and “after apply the slot”.

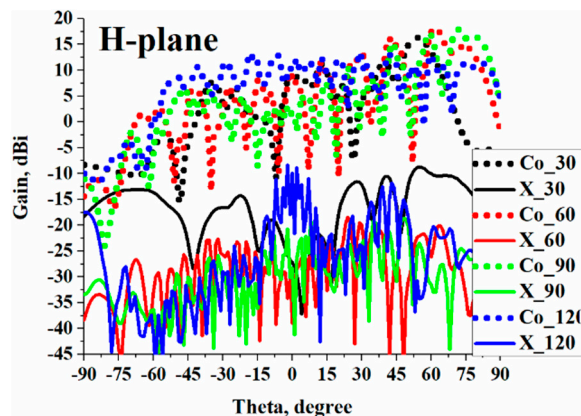
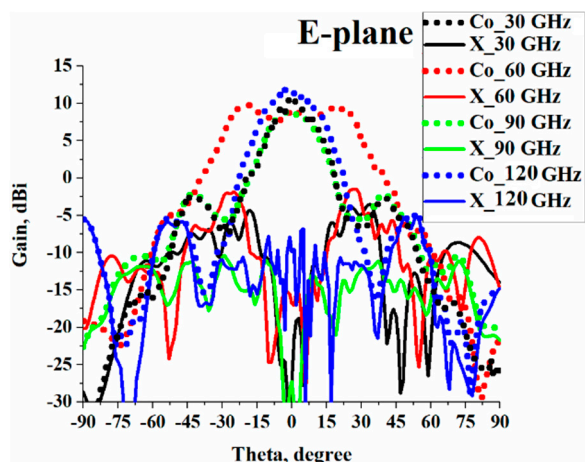


Fig. 5. Co- and Cross-radiation patterns of the proposed microstrip antenna arrays with slots in the E- and H-planes at spot frequencies over its operating band.

TABLE I. RADIATION PERFORMANCE PARAMETERS

Radiation gain (with no slot)		
Minimum	Maximum	Average
5.75 dBi	12.53 dBi	8.4 dBi
Radiation gain (with slot)		
7.88 dBi	15.11 dBi	12.1 dBi
Improvement		
2.13 dBi	2.58 dBi	3.7 dBi

Radiation efficiency (with no slot)		
Minimum	Maximum	Average
60.82%	73.25%	66.12%
Radiation efficiency (with slot)		
67.41%	85.79%	78.16%
Improvement		
6.95%	12.54%	12.04%

Co- and cross (X) polarization radiation patterns of the proposed microstrip antenna array in the E- and H-planes are shown in Fig. 6 at spot frequencies of 30, 60, 90, and 120 GHz in its operating range. This shows the antenna is directional in the E-plane with sidebands about 15 dB down from the main beam. It is observed that at 60 GHz the beamwidth doubles and the gain drops down by an average of 3 dB. In the H-plane the beamwidth extends from around  $-50$  to  $+80$  degrees and the radiation gain varies with frequency. In both planes the cross polarization is significantly below the main beam.

## CONCLUSION

A novel configuration for a  $2 \times 2$  microstrip patch antenna based on metamaterial concept is shown to exhibit super-wide impedance bandwidth extending from 20 GHz to 120 GHz for  $S_{11} < -15$  dB, which corresponds to a fractional bandwidth of 142.85%. The average radiation gain of the antenna is  $\sim 10$  dBi. The proposed antenna structure overcomes the narrow bandwidth of conventional microstrip patch designs. The antenna can be used at microwaves and millimetre-

wave applications including UWB, RFID systems, massive MIMO for 5G, and radar systems.

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