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Gain Enhancement Techniques of Microstrip Patch Antenna: A Review

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Abstract:

Recently, a lot of research has been carried out on different techniques to improve the performance of microstrip patch antenna (MPA). Here, we have overviewed and summarized various techniques which has been invented in past to improve the gain and of the MPA. The addition of frequency selective surface (FSS), metallic reflectors, metamaterial, parasitic patches, air gap, superstrate, shorting pins, defective ground structure and partial substrate removal are some known techniques to improve antenna gain. This paper helps to decide the best technique of gain improvement for MPA.

Keywords:

Microstrip patch antenna, Antenna gain, Shorting pin, Arrays, Photonic crystal, Photonic band gap, Superstrate, Metamaterial, Reflectors.

1 . INTRODUCTION

As the trend continues towards miniaturizing transmitters and receivers. Antenna size reduction comes at the expense of a reduced gain. demand of high gain, compact antennas is the need of modern portable wireless communication devices. Waveguide antenna [1-2] and lens antenna [3-5] are few examples which provides high gain but due to large size and weight, they are not good candidate for wireless communication systems. On other hand, MPAs are small in size, light in weight, conformal, and easy to fabricate hence most suitable candidate for modern wireless communication systems. There are three types of losses, namely dielectric loss, conductor loss, and surface wave loss which limits the gain of a patch antenna and restricted it from a wide range of applications. In past few years, a lot of efforts have been made by researchers to enhance the gain of the conventional MPA like, superstrate loading, metamaterial resonating structures, ladder-like directors, EBG structures, polarization rotation metasurface (PRMS) around the antenna, reflective surfaces, shorting pins, adding artificial magnetic conductor (AMC) Gain Enhancement of a CPW-Fed Monopole Antenna Using Polarization-Insensitive AMC Structure, metallic reflectors, frequency selective surface (FSS), substrate removal technique and combination of different methods [6-16].

In this paper, various gain enhancement techniques are investigated theoretically and compared to decide which technique is most appropriate for gain improvement of MPAs. The MPAs which are considered in this paper are of different shapes and sizes. The various parameters are compared and listed in the table 1 to decide which is the most suitable for the design.

2. GAIN ENHANCEMENT TECHNIQUES

Recently a number of gain enhancement techniques were developed for different types of MPAs. A detailed discussion of some of these techniques is illustrated below.

2.1 Antenna Array

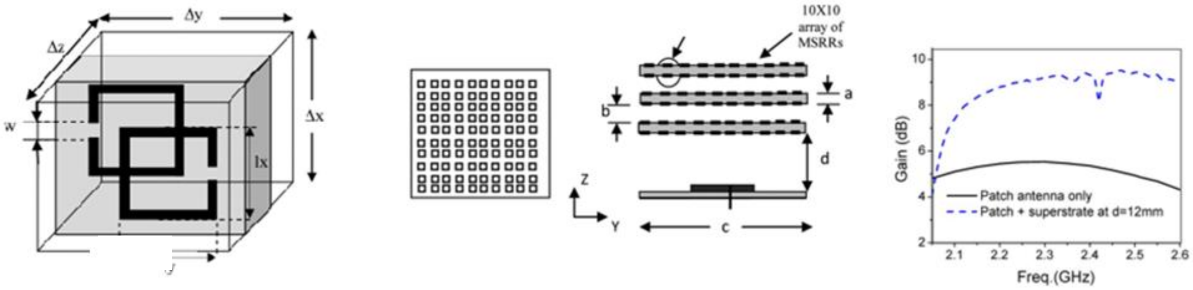
The challenge of high gain is becoming an important topic in MPAs design. Array antennas focuses their transmission and reception energy on a specific direction to achieve higher radiation gain, while the added feeding networks are always difficult to design and the antenna size is always electrically large. Generally speaking, the configuration of the element and feed network is a key part in a panel MPA design. Many MPA arrays have been designed and investigated in past few years. In 2016, Chu et al., [17] proposed a substrate integrated waveguide (SIW) technology based millimeter-wave filtering monopulse antenna array with gain of 8.1 dBi at 29.25 GHz.

(a) (b)

Fig 1: (a) Unit cell (b) 8x8 MPA array [18]

In 2016, Habib Ullah et al. [18] proposed a new zero-index meta surface (ZIM) structure by embedding a 8x8 set of unit cell over the patch antenna to enhance the overall gain with a coaxial probe fed circular patch antenna was designed. An improvement of gains by 133.40%, 73.30% and 72.06% at resonant frequencies 3.7 GHz, 8.95 GHz and 10.3 GHz, respectively. The performance characteristics of the proposed ZIM cover-incorporated antenna make it suitable for ultra-wideband (3.4–4 GHz, 6.45–8.2 GHz and 10.0–10.9 GHz) applications as shown in Fig 1

Attia et al. (2009) [19] proposed a novel engineered magnetic superstrate to enhance the gain and efficiency of a MPA. The superstrate was designed of SRR unit cells. A 4x1 patch antenna array with superstrate was used to achieve resonance at 2.2GHz, results in 3.4dB gain enhancement and 17% efficiency enhancement. These improvements were achieved while having any substantial increase in MPA size and an insignificant effect on its bandwidth. The gain enhancement is a function of the distance between the patches and superstrates as shown in Fig 2.



(a) (b) (c) (d)

Fig 2. Geometry of a patch antenna covered by an engineered magnetic superstrate. (a) MSRR unit cell. (b) Top view. (c) Side view, and (d) Gain of the microstrip antenna before and after using the artificial magnetic superstrate for different distances between the antenna and superstrate

2.2 Metamaterial

Metamaterial can be defined as an artificial engineering material having unique features which control magnitudes, phases, and polarizations of electromagnetic (EM) waves [8-9, 20-22]. Metamaterial was initially observed by Veselago (1968) [23] and predicted that the EM wave in a medium flow directly opposite the direction of energy in the left handed materials having negative material properties. In 2000, Smith and Kroll [24] experimentally verified the theory predicted by Veselago by placing periodic structures of slip ring resonator in a negative refraction material. Scientists and engineers have tested varied ways to bring this artificial material into practical applications, especially in antennas [25-28]. In last two decade, many researchers utilized these metamaterial substrates for improving performance of MPA. Metamaterial structures act as a director when the refractive index of added structures is higher than the substrate. These directors re-radiate in the same direction as the antenna does and hence increase the gain of an antenna. The shape of the metamaterial structure may vary according to the operating frequencies of the design. Lubkoswski et al. (2009) [29], show the advantages of using metamaterials in improving gain and directivity of the antenna and noted that directivity of antenna is improved for low dielectric materials especially at high frequencies. Song et al. (2011) [30] proposed L-shaped left handed material for enhancing the gain of the patch antenna. The model uses periodic metamaterial structure around the patch in order to suppress the surface wave and thereby enhancing gain of the antenna. One more method of improving gain of the conventional antenna is by embedding metamaterial inspired 3D resonator structures in the Low Temperature Co-Fired Ceramic (LTCC) Substrate (Liu et al., 2013 [31]). This achieves a compact structure achieving narrow beamwidth and also it increases the fabrication complexity of the antenna. Gao et al. (2016) [32] presented metamaterial inspired dual layer rectangular ring structure integrated around the periphery of patch antenna for improving gain and bandwidth of the antenna. Pires et al. (2013) [33] presented a metamaterial inspired wired antenna instead of traditional planar structured metamaterials discussed above. However these antennas achieve poor gain in the operating frequency. Brown et al. (1998) [34] fabricated bowtie antenna on photonic crystal substrate and measured the radiation properties (Brown and Parker, 1993) [35]. They observed that in planar antenna modeled on conventional silicon substrate, most of the power is radiated in to the substrate and hence reduces the gain and directivity of the antenna. Li et al. [36], proposed a different approach to increase the bandwidth and gain of a MPA. The planer metamaterial patterned structures applied directly on the upper patch and bottom ground of the substrate which formed a capacitive-inductive equivalent circuit. Thus, a backward wave was induced which travelled along the plane of patch. Therefore, the radiation along the patch direction was enhanced which in turn increased the bandwidth and gain.

In 2013, Mandal et al. [37] presented a high gain wideband. U-shaped patch antenna with two equal arms on Poly Tetra Fluoro Ethylene (PTFE) substrate. An inverted U-shaped slot is introduced on the circular or square shaped ground plane just under the U-shaped patch. Maximum impedance bandwidth of 86.79% (4.5GHz-11.4GHz) is obtained with a circular shaped ground plane with diameter 36mm. The proposed antenna is simple in structure compared to the regular stacked or coplanar parasitic patch antenna with a gain of 4.1dBi and is suitable for wireless communications. A high gain compact monopole MPA was discussed by Aidin.et.al [38] where a monopole MPA is loaded by zeroth-order resonator and CSRR unit to improve the overall gain of antenna.

To achieve wideband characteristics of the antenna with gain enhancement, Fabry Perot resonator antenna was designed by Yuejun.et.al [39] by using Chessboard Arranged Metamaterial Superatrate antenna (CAMS). The upper surface of the CAMS is designed to reduce the radar cross section based on the phase cancellation principle and bottom surface is used to enhance the gain based on the Fabry Perot resonator cavity theory.

2.3 Photonic Crystal or PBG

In general, photonic crystals are material structures whose electric or magnetic susceptibility varies periodically in one, two, or three dimensions. When such structures are illuminated by a beam having a wavelength comparable to the spatial period of the crystal, two effects occur. First, the variation of susceptibility within a period causes point-like electromagnetic scattering that can often be described by an angular dependent cross section. Second, the periodic variation causes distributed scattering usually described by an electromagnetic dispersion relation that is modified substantially from the typical linear relation for propagation through linear, isotropic, and homogeneous materials. This modified form of scattering leads to the nomenclature of photonic crystal because the distributed scattering and modified dispersion relations that occur for photons are analogous to the distributed scattering and band dispersion that occur for electrons in an atomic crystal.

In last few decades the growth of photonic crystal plays a major role in the field of microwave circuits and antennas due to their enhanced propagation characteristics and to suppress harmonics frequencies and hence many researchers utilize photonic crystal substrate in microwave and antenna applications. Yablonovitch et al. (1989) [40], experimentally demonstrates the propagation of electromagnetic waves in the photonic crystals like glass substrate and achieves a bandwidth of 2 GHz around 6.5 GHz operating frequency. Horii and Tsutsumi (1999) [41] presented microstrip patch antenna having two-dimensional photonic bandgap (PBG) in the ground plane to suppress harmonic frequencies of the antenna. However these glass substrates have high permittivity and permeability compare to traditional substrates and makes the antenna less suitable at higher frequencies.

2.4 Electron Band Gap (EBG)

EBG structures was first introduced in 1987 [42-43], a significant effort has been developed to realize them for perfect lenses. Recently, there has been considerable research effort in the EBG structure for antenna application to suppress the surface wave [44] and improve the radiation performance of the antenna.

The EBG structures also reflect back a part of the energy that circulate along the substrate of the antenna, thus acting as reflecting walls across the antenna and thereby the cavity effect. With elite rows of EBG structures, minus energy is reflected back and the parasitic effect becomes prevailing. This contributes to the significant enhancement in the bandwidths. As the number of rows is increased, more of the energy circulate along the substrate is reflected back and the cavity effect becomes prevailing. This in turn enhances the Q-factor of the cavity made by the EBG structures surrounding the antenna and come down the bandwidths of the antenna. On the other hand, front to back ratio (FBR) of the antenna enhances with the number of EBG rows surrounding the antenna, as anticipated, due to the suppression of surface waves [45].

Patil and Joshi [46], proposed a fractal electromagnetic band-gap (EBG) MPA structure. The MPA is fed by a driven terminal and is integrated within a fractal electromagnetic band-gap structure, on same substrate to raise the antenna gain. Halim Boutayeb [47] et al proposed new design of MSA introducing cylindrical EBG structure which enhanced the gain of 2.9 dB as compare to conventional MPAs.

2.5 Superstate

Superstrate materials are used to enhance the gain of the antenna by creating an in-phase electric field on the top of the superstrate as shown in fig. 2. The phase of radiation can be controlled by changing the radius of holes created inside the superstate to reduce the permittivity or by adding metamaterial structures on the top of the superstrate. This results in the improvement of front to back ratio hence the gain of the design is improved [6-7]. In 2012, Li et al. [48] proposed a metamaterial unit cell with low refractive index and it is optimized to enhance the gain of the patch antenna and beam focusing ability. The effective material parameters of the unit cell are extracted, and the unit cell forms a planar three-layer metamaterial structure used as a superstrate for gain enhancement of a patch antenna at 10GHz has a 7.8dBi. The measurements have shown that the effective refractive index of the metamaterial under normal incidence is close to zero over a frequency range from 9.45GHz to 10.7GHz. The proposed superstrate is optimized along with the antenna to enhance its beam-focusing ability, taking into account the oblique wave incidence from the radiation source.

2.6 Shorting pins and Slotted ground plane

The gain of a monopole antenna can be increased by increasing the effective electrical size of a monopole antenna. This increment can be observed by shorting the metallic patch with the ground using metallic pins. The diameter of pins can be optimized as per the design. Adding shorting pins into the design results in an increase in the current density and more uniformity on the surface. The flow of current on patch and ground is in the same direction and results in superposition of radiation. Hence the gain of antenna is increased.

A novel circular polarization (CP) design of a single-feed equilateral-triangular microstrip antenna with enhanced antenna gain is presented. This CP design is obtained by placing three triangular slots at properly locations below the eq uilateral-triangular radiating patch in the ground plane. By adjusting one of the triangular slot's side lengths slightly longer than that of the others, two orthogonal near-degenerate resonant modes for CP radiation can be excited. Measured antenna gain in this study can easily be increased by 3.3 dBi (5.1 dBi versus 1.8 dBi), as compared to the same height, substrate material, operating frequency and radiating patch shape of a regular equilateral-triangular microstrip antenna without triangular slots in the ground plane [49].

2.7 AMC/HIS/FSS

The artificial magnetic conductor (AMC) is a type of metamaterial which introduces an in-phase reflection within the band gap of a desired frequency. AMC surface, also called the meta-surface, high-impedance surface (HIS), or reactive impedance surface, has been widely used as an artificial ground plane or reflector to enhance performance of many different antenna types while achieving profile miniaturization [50]. An artificial magnetic conductor (AMC) surface was proposed by Sievenpiper [51-52] and has widely investigated.

Use of structures like frequency selective surface (FSS), artificial magnetic conductor (AMC) or metal plates are very popular in gain enhancement of monopole antenna. These structures act as a reflector and place below the patch antenna at an optimum distance to create in-phase radiation with the main lobe of radiation. The backward radiations generated by monopole antenna are reflected by the reflector and adds to the main radiation and hence increase the gain in boresight direction.

2.8 Substrate Removal

A technique for gain enhancement of microstrip antenna is a partial removal of the substrate as shown in fig. 5. Removal of substrate results in the reduction of dielectric losses and surface waves. The reduction in losses results in gain enhancement of microstrip antenna. Improvement of MPA gain has been proposed by Rao and Dinesh [16] by using partial substrate removal in a multiple-layer dielectric by suppression of surface wave losses beneath the substrate surface by embedding a low-dielectric (air) void. The designed patch has a size of 12 × 8 mm2 and gives a gain of 4.035 dB at 6.479 GHz.

3. CONCLUSION

Various techniques were examined by the researcher for the purpose of gain enhancement of a MPA, such as: array, metamaterial, superstrate structure, PBG, EBG, Shorting Pin, change of dielectric material, partial removal of substrate etc. All these methods individually enhance the gain of MSA is being proved by researches. This review concluded the main research directions in the past several years and it has important value for the MPAs research community. Still there is scope for improving gain of the antenna by hybridization techniques.

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