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A Review of Metamaterials in the Domain of Microstrip Patch Antennas

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ABSTRACT

Printed antennas particularly Microstrip antennas has very attractive features in it and hence has a variety of applications. The main idea in drafting this paper is to give an over view of works carried in this type of antenna research.

Keywords: Microstrip antennas (MPA), Transmission lines, Metamaterial, Zero order resonators, multi resonances, polarization

I. INTRODUCTION

Literature related to antennas, spectrum classification and MPA, MTM design

The development of Microstrip Patch Antennas (MPA) incorporating Metamaterials (MTM's) began from the year 1999 after Pendry suggested his novel structures of SRR and Thin Wire exhibiting negative permeability and permittivity. In this primary version, these structures were relatively bulky i.e. they had more thickness.

Initially MTM application was more towards microwave optics and cloaking devices. Later on efforts were made by many researchers for utilizing it in antenna design due to its peculiar property. A key demerit of the initial metamaterial configurations was the three-dimensional nature of the synthesized structures – they were more like bulk materials. Later, many researchers have proposed planar Meta structures to achieve a more practical configuration; to reduce fabrication difficulties and to satisfy the need of On-Board requirements. [1-4]. There is another domain which emerged along with MTM that is Fractal antennas. Mandelbrot, a French and American mathematician coined the word "fractal" in 1975. It is derived from the Latin word "fractus" [5]. More information is available I [6-8]. During this literature review, more emphases are given to MTM based antennas, Fractal antennas, Optimization Techniques and not MPA's in general. The latter is a broad field in itself and is beyond scope of the present research topic. A brief flow illustrating the route of progress in the field of antennas and metamaterial-based antennas is given first. **K. F. Lee** and **K. F. Tong** have explained the historic growth of MPA, different methods of creating slots, various design criteria for creating slots that cause dual , triple band resonances, different band width enhancement technique as well as the overall growth of such planar antennas are elaborately explained [9].

To know the recent progress in MTM, an article by **G. V. Eleftheriades** is referred. The author discussed or reviewed all facts about MTM like negative refractive index, negatives permittivity and permeability. Particularly the author explained all about SRR, equivalents, methods to extract parameters and about the MTM lens which may find application in antenna domain [10]. Use of lens for antenna design is also an emerging field of research now.

L. Anthony ***et al.*** explained very clearly the concept of CRLH TL and different equivalents when a TL is loaded with capacitor and inductor separately as well as together. They have given various equivalents and derived relevant expression for parameter extractions. This paper forms a core paper of reference for analyzing such structures for antenna application [11].

A MTM antenna with five Spiral resonators on both sides is proposed by **J. Zhu** and **G. V. Eleftheriades** Thus they have utilized CRLH structures as elements for bandwidth enhancement. In their work, they have used two different patches with staggered unit cells of spiral resonator energized together by some common feed [12].

Y. Kwon Jung and B. Lee clearly established an approach by which a microstrip RFID reader antenna features are improved with size reduction and they also respond at dual frequencies. For this they utilized CRLH technique, in designing directional couplers to feed a slotted patch and thereby they have shown the bandwidth enhancement, dual resonances [13].

The use of artificial magnetic conductors (AMC) structures that is capacitive loaded loops (CLL) on one of the layers of a printed dipole antenna is studied by **E. Aycan** ***et al.*** **.** [14]. The CLL is found to create increased FBR or larger directivity value creating a highly focused antenna.

F. Falcone ***et al.*** proposed a microstrip line with stop band features instead of the usual pass band feature utility by employing CSRR on the ground layer of such lines and this concept may be extended for applications like jammer [15].

On other hand, **R. Marques** ***et al.*** simulated two types of SRRs that is edge coupled- and broadside coupled SRRs in which a comparative analysis of these two structures have been carried and their suitability for the design of metamaterials in antennas have been suggested [16].

Band width criteria is addressed by **Ha. Jaeguen** ***et al.*** where they proposed a patch with CSRR and interdigitated capacitors (IDC) for size reduction. They also proved that the antenna has a wide band width with a reasonable gain of 3.6 dBi [17].

Mohammed M. Bait-Suwailam ***et al.*** used single-negative magnetic metamaterials (broadside coupled split-ring resonators) in order to reduce mutual coupling between high-profile antennas. This finds application in MIMO systems [18].

The propagation characteristics of the annular ring microstrip antenna (ARMSA) on metamaterial substrate are determined by **C. de. Fatima** ***et al.*** [19]. The resonant frequencies and return losses are proved to be dependent of the metamaterial when a spectral domain analysis is carried out.

Magneto-dielectric substrate for miniaturisation is suggested by **F. Farzami** ***et al.*** where a rectangular microstrip antenna is miniaturized using a magneto-dielectric substrate which is compact by itself and is in turn designed using a metamaterial structure that can reduce the antenna dimensions by increasing the constitutive parameters of the substrate. This aspect is elaborated theoretically and experimentally in [20].

Generally many researchers proposed the MTM-TL approach in the design of antennas like etching inductors/capacitor on patch as well as inductor in shunt to ground or by periodical load and this forms the key aspect in upcoming discussion of the literature survey.

A. **Mehdipour** ***et al.*** Studied the effect of CSRR, CRLH structures on a monopole antenna showing size reduction and triple band resonance. The network equivalent of CSRR is derived from the technique of CRLH, from which the resonance of CSRR is found. The CSRR is then added to the antenna design, leading to its betterment [21].

Two Phi shaped SRR placed back - back miniaturizing the MPA effectively is suggested by **S. Vipul** ***et al.*** This may find utility in space applications [22]. They have also claimed that this structure is easily realizable.

H. M. Lee has suggested a modified planar antenna by designing a single unit cell of MTM using CRLH technique. Metal insulator metal (MIM) capacitor and microstrip stub inductors are used in this design as elements of CRLH. The design equations for design of micro strip stub inductor and capacitor are also explained in [23]. **J. D. Baena** ***et al.*** studied the equivalents of SRR and CSRR [24]. They have also extracted the parameters of these structures both analytically as well as experimentally, particularly for microstrip technologies.

Flexible substrates were emerging then. **X. Cheng** ***et al.*** used CSRR in a flexible substrate to miniaturize the size of antenna down to 74%. This finds application in medical implantable antennas but the gain is found to be negative, which is a pre-requisite for such applications [25].

C. Wenquan ***et al.*** proposed the use of CSRR on the ground of MPA specially for beam steering while no metamaterial loading is seen on patch [26].

The resonant frequency of circular split ring resonator is derived by **M. Labidi** ***et al.***. and they thoroughly analyzed how resonant frequency of the ring varies due to change in dimension of various parameters of the ring like width, length, spacing between the rings. This may serve as a reference paper for understanding the dependence of resonant frequency on various parameters of the resonator for any researcher [27].

R. Azhagumurugan and **P. Indumathi** utilized CSRR in reducing the cross talk. They have effectively utilized CSRR in jamming cross talk by fabricating PCB with CSRR and have also reported that stop bands of CSRR can be effectively used for suppression of unwanted signals [28].

In certain articles MTM is not used in antenna design but in feed component accessories like power dividers. **C. Wenquan** ***et al.*** proposed microstrip antenna with radiation pattern selectivity and polarization diversity using metamaterial by using power dividers and switches. This may find application in mobile phones [29].

X. Mi. Yang ***et al.*** studied and proposed an efficient approach to suppress the mutual coupling effect between microstrip patch antennas using wave guided metamaterials [30]. This may be compared with the one in similarity as proposed by Mohammed M. Bait-Suwailam *et al.* . which is for MIMO application.

Z. Bayraktar ***et al.*** proposed design synthesis of matched impedance thin planar composite magneto-dielectric metasurfaces, which involves optimizing thin, metasurfaces comprised of a periodic array of electrically small and rotationally symmetric metallic unit cells [31].

Spiral resonator (SR) structures were usually designed on patch for miniaturisation purpose. But **K. Buell** ***et al.*** have shown that spiral resonators may also be kept in between two patches for good impedance match. This finds application in super directive arrays [32].

S. Vipul ***et al.*** discussed the major growth of MTM based MPA highlighting some major breakthrough in their article, this paper may be referred for learning the overall progress in the field recently **[33].**

M. Hosseini and **David M. Klymyshyn** discussed EBG with MTM in their paper. Radiation characteristics of an open-circuit electromagnetic band-gap transmission line are utilized successfully to demonstrate a new low-profile antenna that have high radiation efficiency [34]. Nowadays MTM structures are used as EBG for effective design.

J. **Naqui** ***et al.*** designed a transmission line with both SRR, CSRR on it introducing new modes. They have shown that these structure needs to be orthogonal and slight shift may cause new modes [35].

Need for MTM in MIMO system is also on demand nowadays. P. **Mookiah** and **Kapil R. Dandekar** proposed magnetic permeability enhanced metamaterial which will enhance the features of antenna array of a multiple- input multiple-output (MIMO) communication system [36].

A CSRR based filter having differential microstrip lines are suggested by **J. Naqui** ***et al.*** This filter will have a sharp resonating characters like stop and pass bands. Such filter may be used along with antennas for improved features [37].

More recently **M. S. A. Rani** ***et al.*** proposed a transparent antenna with silver coated substrate having CSRR in its design exhibiting stop band characteristics. This can be used in WLAN antenna as good interference suppressor [38].

H. Kang and S. Lim have most recently published an article with eighth mode substrate integrated waveguide using CSRR structures in it. This antenna finds dual application of WLAN, GPS besides miniaturization and adequate gain [39].

M. R. C. Mahdy ***et al.*.** shown in their article the utility of MTM for another application, like mode change of a RMPA. They achieved better radiation performance for interface resonance mode, by introducing modified TM_{060} modes. Also proper choices of materials, for different goals in antenna design are explained [40]. This may be compared with the article proposed by J. Naqui for inferring some results if additional modes need to be created.

A comparative paper, showing SRR, CSRR, CRLH structures impact on patch antenna design are presented by **R. Maryam** ***et al.*** recently. They have proposed CRLH based size reduced antennas. SRR, EBG and CRLH ZOR based antennas are also presented with achieved results in this article [41].

E. Lheurette ***et al.*** have simulated omega type SRR loaded wave guide for X, Ku bands. They proved its negative permeability nature and thus have suggested this results which may be applied for any microwave device design [42].

Use of both double positive (DPS), double negative (DNG) material in antenna design are also done by some researchers. **J. Zhu** and **G. V Eleftheriades** have suggested dual-band rectangular patch antenna loaded with a pair of conventional double-positive (DPS) and μ negative (MNG) metamaterial blocks, this in turn have created good matching in design of the antenna [43].

One can find lot of rectangular MPA with MTM design but very few researchers have touched elliptical patch design with MTM. **Pai Yen Chen** and **A. Alu** have designed elliptical patch antenna filled with a double-positive dielectric shell along with MNG which is found to have enhanced band width [44]. The authors have clearly and aptly bombarded the freedom available when an elliptical patch is chosen instead of rectangular and circular patch.

X. Mi. Yang ***et al.*** studied embedded meander-line (EML) array in the ground plane under the patch, which creates a MTM environment thus claiming miniaturization and surface wave suppression [45].

Circular polarization is needed in some wireless application like GSM. **S. Jahani***, et al.* proposed two circularly polarized compact antennas with size reduction of 40%, 60% using helical meta structures. The unit cell extraction of these structures are carried out first and then this concept is used effectively in antenna design [46].

H. Attia ***et al.*** have proposed an analytical method to analyze Far- field radiation of a MPA. This method can be used by researchers in analyzing Far- field pattern of any antenna after introducing any change in its design. [47].

Stacked patches is good old technique for bandwidth enhancement, but **R. O. Ouedraogo** ***et al.*** Proposed CSRR in a dual layer patch antenna, in which CSRR is placed over one of the substrate with its dimensions being optimized by applying genetic algorithm. This concept is used successfully for miniaturization [48].

Pai Yen Chen and **A. Alu** loaded negative permeability on an elliptical patch. They proposed the structure to increase the aperture efficiency and gain performance [49]. This is an improvement suggested by them when compared with their previous article.

Meta substrates were emerging a lot in last decade. **Z. Liu** ***et al.*** have showed an improvement in gain when a substrate integrated with SRR structures were used. The suggested application is WLAN [50].

M. Selvanayagam and **G. V Eleftheriades** proposed CSRR as a matching element in the design of an MPA especially for Wi-Fi applications [51. This approach is different in the sense that CSRR is not loaded on antenna design but is placed externally as matching element.

L. Peng ***et al.*** used CSRR as EBG structure on patch. They demonstrated use of EBG for size reduction up to 28%. Further, They have also created dual resonance through this approach [52]. This concept may also be noted in the article proposed by M. Hosseini.

Though many researchers have attempted for resonant frequency, **F. Billoti** ***et al.*** suggested effectively, equivalent of spiral resonators and SCSRR structures with the maximum number of turns or rings that can be simulated using these structures. This forms a key paper in referring the analytical formula to compute the resonant frequencies of such structures [53].

D. Yuandan ***et al.*** proposed a novel radiating structure using metamaterial and proved that the antenna gain may be increased considerably for such radiators by use of RIS and mushroom shaped CRLH structures [54].

Many researchers added meta structures on patch and substrate of antenna design, **J. Malik** and **M. V. Kartikeyan** suggested that the proper use of circular CSRR (CCSRR) along with a rectangular slot in ground creates dual resonance which may find application in WLAN, WIMAX **[55].**

S. Vipul ***et al.*** used elliptical SRR structures in design of MPA structures for its overall improvement [56] They discussed their design with radiation pattern showing that pattern is conserved.

Optimization techniques are quite often used by researchers in their article **M. R. Vidyalakshmi and S. Raghavan** derived the resonant frequency expression for CSRR structures and has compared different optimization techniques like genetic algorithm and neural networks for its optimization [57].

P. Baccarelli ***et al.*** have proposed a planar metamaterial layer formed by dog bone shaped conductors separated by a very thin substrate. This structure is analysed for natural mode and is suggested for leaky wave antenna application [58].

S. Thankachan ***et al.*** have shown the utility of CSRR structures in a MSA with a small rectangular slot to give a compact blue tooth antenna, both MSA as well as CSRR are designed at same frequency there by increased return loss and increased bandwidth is shown in the proposed structure [59].

Many novel shapes of SRR were **introduced** by many researchers ever since it is proposed. **J. G. Joshi** ***et al.*** proposed a diamond shaped ring resonator in the design of five planar antennas and have shown improvement in antennas radiating features [60].

L. Benard ***et al.*** have shown RIS structures (that are two dimensional structures) can be used in a two layer configuration for gain improvement. The RIS may be inductive or capacitive in nature. The inductive RIS are usually employed to improve the gain of antennas [61].

A size reduced patch is proposed by **Ali A. Saleh** and **A.S. Abdullah** etching CSRR structures and by etching a L shape slot on the ground plane. The proposed antenna has a size reduction and this antenna resonates at two frequencies and is suggested for WIMAX, WLAN applications [62].

N. Kumar and **S. C. Gupta** proposed a new infinite shaped split ring resonator [63] and have proved its left handness through parameter extraction in HFSS® simulation and consecutive program to extract its negativity by using the well-known formulae suggested by Smith.

There are various topologies of SRR, CSRR. **M. Durán-Sindreu** ***et al.*** have discussed many types of SRR, SR, duality, equivalents and expressions to find resonant frequency and the effect of these components when designed with antennas [64].

CSRR is utilized effectively in substrate integrated wave guide design. A capacitor is also used to change the frequency of the circuit making it a frequency selective structure (FSS). This is proposed by **D. E. Senior** ***et al.*** [65].

Instead of standard geometry**, P. K. Singhal** ***et al.*** defined variable C shaped structures on patch and have studied and proved its left hand nature in their work. The proposed antenna has improved gain, good impedance match and similar radiation pattern as normal MPA [66].

S. Eggermont ***et al..*** have shown the utility of CSRR structures in a leaky wave antenna to suppress surface waves while others have shown transmission line (T.L) based approach for zero order resonators and leaky waves with gain and bandwidth improvement [67].

Usually many articles are noted with coaxial, microstrip line (MSl) feed. Very few are seen with coplanar feeds like the one done by **C. Zhou** ***et al.*** in [68]. They have used a coplanar waveguide (CPW) feed along with CSRR structure on patch and it is simulated using CRLH structures.

F. Billoti ***et al.*** suggested meta substrates below the patch and it can be simulated using ring structures [69]. They have arranged the SRR below the patch and has clearly explained how SRR are excited showing negative permeability. Use of low temperature co-fired ceramics (LTCC) substrates was recently noted in some articles. **I. K. In. Kim** and **V.**

V. Vardhan presented a LTCC substrate using SRR metastructures for the design of an meta resonator antenna, which is of multilayered configuration. They also demonstrated the improvement of antenna features due to use of metastructures [70].

L. W. Li ***et al..*** proposed a single resonant structure and double resonant structure in which they have used single and double spiral resonator, cylindrical rod and double split resonators. They have also proved that these structures to be LHM through both numerical as well as theoretical methods based on TL analysis [71].

Various topologies of SRR and a methodology of extraction of their parameters are described as flow by **B. I. Wu et al**. This paper is also often referred by researchers in finding details about extraction (both simulation, experimental [72].

MTM is used for mode change of patches like the one proposed by **M.C. Tang *et al.*** .. Complementary electronic resonator structures (CELC) are designed to modify the modes of patch. The CML structures are also introduced effectively in this article [73]. This may be compared with the work done by J. **Naqui**.

Most Recent Literatures in the Domain of MTM

Metamaterial Zeroth Order Mode Resonator, for arrays is explored in this article [74]. 2 X 2 and 2 X 3 array configurations, the EFS reaching > 25% of maximum SAR in the 3.5 cm deep plane is 100% and 91% of the array aperture area are reported. An ultra-compact chiral metamaterial (CMM) using triple-layer twisted split- ring resonators (TSRRs) structure was proposed, that functions as a multi-band circular polarizer. Good performances and compact design are achieved.Linear-to-circular polarization convertor with focusing metasurface is handled effectively, Feeder is changed in position for attaining re-configurability.

Circular sector patch antenna loaded with a periodic metamaterial topology is presented. Quasi - Monopolar pattern at multiple modes; an impedance matching network and a dual-band semicircular patch antenna are presented.A left-handed metamaterial which acts as a lens is employed to improve the performance of a Microstrip Patch Antenna.

The left-handed metamaterial used in this work is a three-dimensional periodic structure which consists of circular split ring resonators and thin wires. A novel concept of using slotted ground structure and a single circular split ring resonator (SRR) to achieve multiband operation from a miniaturized UWB antenna is discussed wideband integrated photovoltaic (PV) solar cell patch antenna for 5GHz; Wi-Fi communication is presented and discussed. The design consists of a slot loaded Patch Antenna with an array of complimentary split ring resonators (cSRR) etched in the ground plane [74-79].

II. CONCLUSION

From the exhaustive literature review, it is inferred that MTM can be used effectively in design of compact antennas with improved gain, Bandwidth and multi resonances.

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