Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 3, No. 2, March : 2024

METAMATERIAL PATCH ANTENNA FOR BIO MEDICAL APPLICATION

Vipul Verma, Shashank Shekher Yadav, Student, Dept. Of Electronics and Communication, ABES Engineering College
Dr. Manidipa Roy, Dr Priyanka Bhardwaj, Professor, Dept. Of Electronics and Communication, ABES Engineering College
Dr Sanjay Singh, HOD, Dept. Of Electronics and Communication, ABES Engineering College

Abstract

This introductory article provides a modern review of metamaterials, demonstrating their precise meaning, classification, and applications in the field of antennas and radio frequency identification (RFID) devices. More importantly, this article presents advances in microwave applications of metamaterial structures. Metamaterials offer unique features that can be used in many areas, especially 5G communication. These systems require high performance, more data, computing power, good budgeting, large contracts and low power consumption. These requirements can be met by developing an antenna design that operates in a wide frequency band, provides good gain, can operate in multi-bands, has a small structure, is recyclable and provides ease of production. Much research has focused on developing meta surfaces to achieve the following goals: increasing bandwidth, improving efficiency, and reducing antenna size and cost. The following sections provide a detailed description of such operations. Also, general instructions can be found in the section below. In addition to the applications mentioned above, smart meta surfaces can also be designed to facilitate frequency and polarization tuning. Recent advances in printing and manufacturing technologies have led to the integration of metamaterial antennas into materials and devices, enabling versatile applications and complementing RFID devices. In summary, this article provides an overview of different types of metamaterials and their role in improving performance and applications in 5G and 6G communications.

Key Words- 5g, metamaterials, meta surfaces, performance improvements

I. Introduction

Metamaterials are generally defined as artificial or man-made media with unique properties that cannot be found in nature. Alternatively, metamaterials can be described as a class of artificially created structures with properties that cannot be obtained from natural materials. This category includes materials with special and unusual properties that do not occur in nature. In many cases, it is the specific size, shape, or geometry of a metamaterial that determines its unique and desirable properties. Metamaterials have the ability to manipulate various phenomena such as light, electromagnetic waves, sound, mechanical properties, and gravitational properties. The disruptive advent of wireless technology in the late 20th and early 21st centuries has led to exponential improvements in performance, including improvements in energy efficiency and cost-effectiveness. Wireless technology also meets the requirements for high-performance antennas and distribution systems. As 5G and 6G grow in popularity, there is a need for wireless technologies that are proven cost-effective and deliver high data rates. With each passing day, the number of new technologies, including 5G and 6G communication systems, is increasing significantly, and antenna designs are also being modified a lot to meet their requirements and basic requirements. Solving this problem requires compact, geometrically simple, low-profile, high-data-rate, and ultra-wideband antennas that can be mass-produced. These conditions and requirements have been radically improved with the introduction of metamaterials and meta structures into the market

.

II. Literature Review

Metamaterials are composite media that can be engineered to exhibit unique electromagnetic properties. These materials are designed at the micro- or nano-scale, with structures and arrangements that give them unique and often counterintuitive properties. Metamaterials can be composed of various materials, such as metals, ceramics, polymers, or composites. The distinctive feature of metamaterials is that their properties are determined by their structure rather than their composition.

This allows researchers to manipulate and control properties like electromagnetic behaviour, sound propagation, and thermal conductivity in ways that were previously not possible with conventional materials. Metamaterials have led to the development of numerous groundbreaking applications, including: Electromagnetic Cloaking, Energy Harvesting and Absorption, Medical imaging. Microwave and Antenna Engineering. Metamaterials often challenge conventional material properties and have opened new possibilities in engineering and science.

2.1 TYPES OF METAMATERIALS

Here, metamaterials are classified based on permittivity and permeability, as shown in Figure 2. Figure 2. Classification of metamaterials based on permittivity and permeability in Figure 2. Quadrant 1 represents materials with both positive permittivity and permeability values. This applies primarily to dielectric materials. The second quadrant represents materials with negative and positive permittivities below the plasma frequency. These include metals [3-6], ferroelectrics, and extrinsic semiconductors. Quadrant 3 represents materials with both negative permittivity and permeability values. This substance does not occur in nature. Quadrant 4 represents materials with negative permittivity and positive dielectric constant below the plasma frequency. Contains ferrite material.

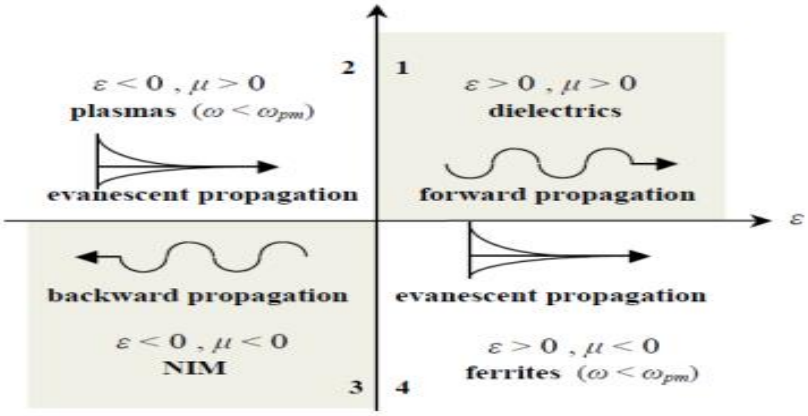


Figure 2. Classification of Metamaterial on the Basis of Permittivity and Permeability

2.2 ROLE OF METAMATERIALS IN PATCH ANTENNA

Many exotic applications of the metamaterials exist. Many researchers are endeavouring to amend the accomplishment of microwave, wireless communications, microelectronics, and optical scheme utilizing these incipient metamaterials. By utilizing metamaterials, the radiated power of the antenna could be enhanced. The main features of metamaterial like negative permittivity and permeability can be exploited for making electrically small, highly directive, and reconfigurable antennas. These antennas also demonstrate the improved efficiency, bandwidth performance and ameliorate the beam scanning range of antenna arrays. These antennas also support navigation systems, communication links, surveillance sensors command & control systems. Light emanating is rejected and controlled by wide film angles, for aerospace applications using nano-composites utilising metamaterial technology. Thin film technology advanced with metamaterial nano-composites is utilized to amplify the solar cell efficiency by amassing light from wide angles and by absorbing it over the spectrum of interest. The Extraordinary properties of MTMs and their latent applications in cloaking expeditiously drew attention from agencies like DARPA and NATO. Immensely colossal scale metamaterials with customized electromagnetic properties have been utilized for shipboard applications as well.

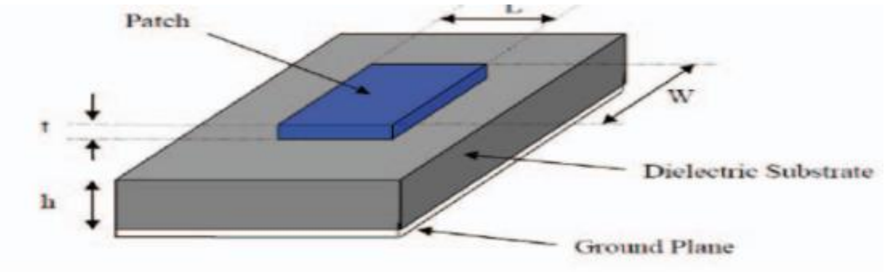
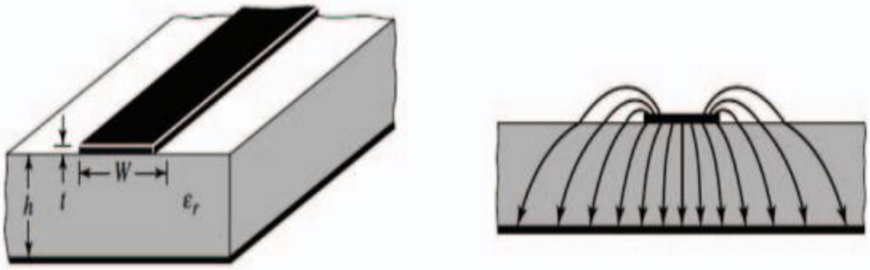


Fig. 1 Geometry of patch antenna [6]

Patch antennas are **important** components **of** wireless communication systems, and their performance directly **affects** the efficiency and reliability of communication networks. **Integrating** metamaterials into patch antennas has shown **promise to improve performance** and **address** some of the limitations of conventional antenna designs. One of the key advantages of metamaterials in patch antennas is **that they can** achieve negative permittivity and permeability, which can be **used** to create electrically small antennas. Electrically **compact** antennas are **smaller than** traditional antennas, making them ideal for applications where space is limited or a discreet antenna profile is preferred. **Integrating** metamaterials **into** patch **antenna designs allows for** highly **directional** and reconfigurable **antennas that provide the** flexibility to **adapt to a variety of** communication **scenarios.** Enoch et **al.** used **metamaterials** as **substrates** [7]. **Layers** of copper **mesh** separated by foam were used as metamaterial. This metamaterial **had a** plasma frequency **of approximately** 14.5 GHz. **A monopole** antenna fed by a coaxial cable was used as **the** excitation **source,** and the **radiating portion** of the monopole was **located** approximately at the **centre** of the metamaterial substrate. A ground plane **has been** added to the **board. The** best directivity **was at a frequency of 14.65 GHz. Snell's law states that the rays refracted in metamaterials are very close to normal. As a result, better directivity was obtained** at 14.65 GHz. **me. right.** used the same technique **to achieve** high directivity as in **[7] [8].** He used dipole **antennas** instead of **non-monopole antennas as the radiation source** [7]. Y. G. Ma et **al. proposed** that the directivity of **electromagnetic radiation can** be improved by embedding the source in an anisotropic metamaterial with **an** effective permittivity or **an** effective **permittivity close to** zero [9]. The difference between this [9] and Enoch et **al.'s method** [7] **is** the problem of impedance mismatch between the ε-near-zero (ENZ) matrix and **the** surrounding air. The metamaterial used was anisotropic with **an** effective **dielectric constant close to** zero, allowing it to **adapt to** the surrounding **environment** at **appropriate polarization.** By using **an** anisotropic **plate,** the emitted wave received in **the atmosphere** exhibits the **following** plane wave **characteristics:** the straight wavefront parallel to the interface shows when it is propagating along ± x axis [10]. It was shown that the high directivity can be supported by this anisotropic matrix.

Zhongjing Wang, et al., designed a left-handed metamaterial cover [11] to enhance the gain and directivity of antenna. This left-handed metamaterial cover was designed with a microstrip line, two symmetrical triangular split ring resonators printed on the substrate. There were also two gaps cut on the metal ground plane which made it DGS. This left-handed metamaterial cover has negative permittivity and permeability in various frequency bands. When the left-handed metamaterial cover was placed above the antenna, the gain and directivity of antenna was increased and resonant frequencies were shifted towards lower side.

Filiberto Bilotti, et al., proposed a compact circular patch antenna [12] loaded with metamaterial. in his previous work, he assumed the metamaterial as an ideal isotropic material. Here he presented the same structure with its cavity model analysis to optimize the position and orientation of the unit cell structures. The metamaterials unit cells were embedded underneath the patch. These metamaterials used were mu negative metamaterials. The patch was designed to resonate at 0.5 GHz using the formulas given in [13]. Magnetic field was very high between metamaterial and dielectric whereas it was zero at the centre of the patch. After SRR inclusions, antenna resonates at 0.565 GHz with electrically small dimensions of the patch. He also proposed [14] again miniaturized patch antenna with mu negative loading. A theoretical analysis of magnetic field distribution underneath the patch is done. This helps to find out the position, arrangement, and alignment of magnetic unit cell underneath the patch.



(a) Microstrip line

(b) Electric field lines

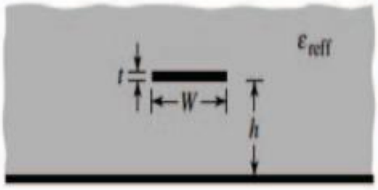


Fig.2 Microstrip line and electric field [7]

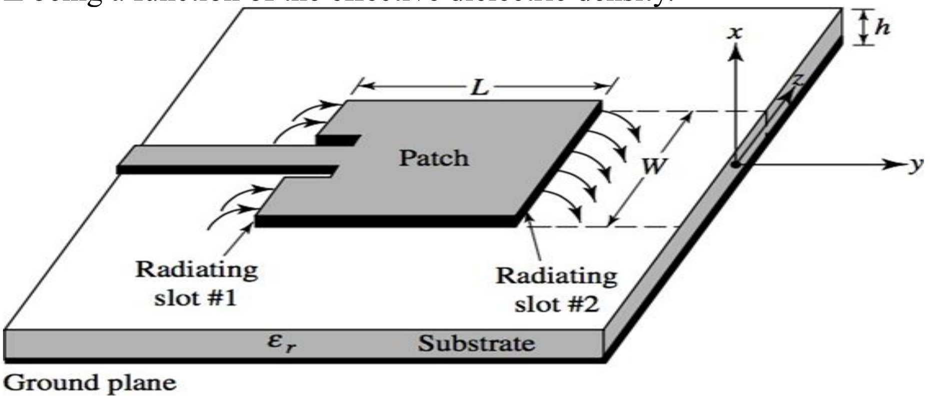
In conclusion, the integration of metamaterials into patch antennas has emerged as a transformative approach, offering a plethora of benefits ranging from improved performance and efficiency to expanded applications in various fields. The ongoing research and development in this area continue to unlock new possibilities, positioning metamaterial-enhanced patch antennas as pivotal components in the evolution of communication and technology.

2.3 BANDWIDTH ENHANCEMENT

Marco A. Antoniades, et al., presented a printed monopole antenna loaded with metamaterial to achieve broadband dual mode operation. The metamaterial used was negative refractive index transmission line. The metamaterial loading was adjusted to support even mode current at 5.5 GHz which transforms the antenna into short folded monopole. At 3.55 GHz, the ground plane radiates due to in phase current along its top edges. The ground plane radiates a dipole mode orthogonal to folded monopole mode, thus resulting a wideband of 4.06 GHz.

2.4 Proposed Antenna

Microstrip antennas are becoming increasingly advantageous due to their light weight and coffee value, they can make full use of microwave frequencies and can be readily mounted on printed circuit boards. The largest microstrip patch antenna typically contains 12 steel foil "patches" on the bottom of the top of the board, with a metal foil ground plane on the opposite side of the board, and the patches are typically rectangular, square, round, and oval. We usually always use plunge feed and coaxial feed methods. Because it is easy to understand and is provided as input. It can be seen that the patch antenna is a low-profile antenna because its structure has the correct radiation potential, and the radiation of the microstrip antenna is due to the threshold of the patch open surface. The length of the radiating point is half the wavelength, so the electric object is positioned vertically opposite the open surface, but the electric field is equally distributed horizontally, as can be seen in Figures 1 and 2. This type of microstrip antenna is easy to fabricate due to the simple two-dimensional physical geometry of the upper elements 1. Rectangular antennas are implemented at ultra-high frequencies (300 MHz --- 3 GHz), as this is determined by the size of the antenna. Wavelength of the resonant frequency. For the most important plane E, the domain scale increased with period at each break, with the distance Δ being a function of the effective dielectric density.



The patch, situated on the top surface of the board, can take various shapes such as rectangular, square, circular, or elliptical, providing flexibility in design. The chosen shape is based on the specific The proposed microstrip patch antenna utilizes commonly employed feed techniques, such as inset feed and coaxial feed. These techniques offer simplicity in understanding and ease of achieving desired input matching, contributing to the overall efficiency of the antenna. requirements of the application. This design allows for ease of customization and adaptation to different form factors.

These antennas are known for their straightforward fabrication processes, thanks to their simple 2-dimensional physical geometry. This simplicity in manufacturing contributes to cost-effectiveness and makes them particularly suitable for mass production. The rectangular microstrip antenna, as proposed, is designed for operation in the ultra-high frequency range (300 MHz to 3 GHz). The dimensions of the antenna are critical, impacting the wavelength at the resonant frequency. For optimal performance in the E plane, the patch's size, along with its length, is extended at each end by a distance Δ, which is a function of the effective dielectric constant Incorporating metamaterial elements into the microstrip patch antenna design introduces novel possibilities for enhancing its performance.

Metamaterials can be strategically employed to manipulate electromagnetic waves, allowing for customized control over parameters such as refractive index, dispersion, and impedance. Discuss how specific metamaterial structures or layers are integrated into the antenna to achieve desired effects. Examine how metamaterial elements contribute to the tunability and reconfigurability of the microstrip patch antenna. Metamaterial-based tuning mechanisms offer the ability to dynamically adjust the antenna's operating frequency, polarization, or radiation pattern.

By incorporating these aspects into the proposed antenna section, we provide a comprehensive view of how metamaterials can elevate the capabilities of the microstrip patch antenna in terms of performance, tunability, and adaptability to diverse applications.

2.5 ADVANTAGES OF PROPOSED ANTENNA

1. **Miniaturization**: Metamaterials can be designed to exhibit unique electromagnetic properties, allowing for the creation of compact and small antennas. This is particularly useful in applications where size constraints are critical, such as in portable devices or space-constrained environments.
2. **Tuneable Properties**: Metamaterial antennas can be designed to have tuneable electromagnetic properties, allowing for dynamic control of their performance. This tunability can be exploited to adjust the antenna's frequency, bandwidth, and other characteristics, making them versatile for different communication standards and scenarios.
3. **Improved Gain and Directivity**: Metamaterial structures can enhance the gain and directivity of antennas, enabling improved signal strength and coverage. This is especially beneficial in long-range communication systems and scenarios where a high level of directive radiation is required.

4. **Reduced Mutual Coupling**: Metamaterials can be engineered to minimize the mutual coupling between closely spaced antennas. This is particularly valuable in antenna arrays, where minimizing interference between adjacent elements is crucial for maintaining the performance of each individual antenna.
5. **Bandwidth Enhancement**: Metamaterial antennas can be designed to provide broader bandwidths compared to traditional antennas. This is advantageous in systems that require the transmission or reception of signals over a wide range of frequencies.
6. **Stealth and Cloaking**: Metamaterials can be used to create antennas with reduced radar cross-sections, making them less detectable by radar systems. This is particularly relevant in military applications where reducing the visibility of antennas is a critical requirement.

III. Conclusion

Several challenges must be addressed before metamaterials can achieve widespread adoption. A notable technical hurdle involves the cost vs accuracy trade-off associating with existing antennas Until an affordable sensor capable of detecting obstacles and drop-offs across various operating conditions and surface materials is developed, liability concerns will constrain the use of meta materials and meta surfaces. Standardizing protocols of antennas is another technical concern, as the lack of a universal protocol complicates the integration of metamaterials and meta surfaces.

Even if these technical barriers are overcome, challenges related to clinical acceptance and reimbursement persist. Third-party payers are unlikely to reimburse clients for the expense of metamaterials and meta surfaces until their efficacy and cost-effectiveness are proven. However, gathering the necessary evidence for efficacy requires enough metamaterials and meta surfaces, to be prescribed, a task hindered by the shortage of technicians trained in metamaterials. Given the complexity and cost of, metamaterials and meta surfaces significant resources and infrastructure, typically possessed by major metamaterials manufacturers, are required for familiarization and training efforts.

While these challenges may seem daunting, it's crucial to recognize that metamaterials and meta surfaces technology is ready for commercialization. The initial successful commercialization of metamaterials and meta surfaces in different parts of world may involve marketing them as devices suitable for a long period of time. As sensor technology advances, the range of environments where metamaterials and meta surfaces can safely operate is expected to expand.

IV. Future Work

Microwave Concepts based on metamaterials: - Metamaterial technology in microwave components offers advantages such as smaller, lower-noise versions of conventional components (waveguides, filters, and antennas). Microwave filters can greatly benefit from metamaterial technology, as it has been demonstrated that left-handed metamaterials can be created based on planar transmission lines. The use of both split ring resonators (SRRs) and complementary split ring resonators (CSSRs) can be used to create metamaterial filters for use at microwave frequencies. These filters can be manufactured in much smaller sizes than traditional flat filters. Antennas can greatly benefit from metamaterial technology. Small size, low cost, high bandwidth, and good efficiency are desirable characteristics of integrated antennas. Since existing antenna optimization techniques did not have a significant impact, metamaterials were studied to improve antenna performance. Much research has been conducted on the development of small antennas based on metamaterials. These metamaterial-based antennas are proposed to allow miniaturization of antenna size while maintaining excellent emission characteristics. It can also provide improved bandwidth efficiency. SRRs and other planar structures have been used in some antenna designs to improve radiation performance and minimize size. Other proposed designs include artificial magnetic materials with an SRR stack underneath the patch antenna. However, achieving high bandwidth still remains a challenge for metamaterial-based antennas. Many approaches have been proposed to increase throughput. Research in this area is still ongoing. Wireless power transfer: - Several commercial applications have been developed over the past decade, including wireless charging of mobile devices and wireless powering of radio frequency identification (RFID) tags. However, these applications are limited by distance limitations as well as the efficiency of current wireless power transfer technologies. Researchers at Duke University's Centre for Metamaterials and Integrated Plasmonic (CMIP) have discovered a way to use metamaterials to wirelessly transmit energy over much greater distances. The wireless transfer of energy from a source to a receiver is accomplished using electromagnetic near-fields. However, the distance between the source and receiving objects must be very small. Typically, it should be no more than a few feet. Metamaterials could potentially play an interesting role in wireless energy transfer because they can manipulate and focus the near field in the same way that lenses focus or change visible light.

Reference:

1. C. Caloz and T. Itoh, Electromagnetic Metamaterials: Transmission Line Theory and Microwave Applications, Wiley, New York, 2004

2. S. Lim, C. Caloz, and T. Itoh, "Metamaterial-based electronically controlled transmission-line structure as a novel leaky-wave antenna with tuneable radiation angle and beamwidth," IEEE Trans. Microwave Th. Tech, vol.52, no.12, pp.2678-2690, Dec. 2004

3. J. B. Pendry, A. J. Holden, W. J. Stewart and I. Youngs, “Extremely Low Frequency Plasmons in Metallic Meso Structures”, Phys. Rev. Lett., vol. 76, (1996), pp. 4773-4776.

4. J. B. Pendry, A. J. Holden, D. J. Robbins and W. J. Stewart, “Low Frequency Plasmons in Thin Wire Structures,” J. Phys. [Condensed Matter], vol. 10, (1998), pp. 4785-4809

5. D. F. Sievenpiper, M. E. Sickmiller and E. Yablonovitch, “3D Wire mesh photonic crystals”, Phys. Rev. Lett., vol. 76, (1996), pp. 2480-2483

6. D. F. Sievenpiper, E. Yablonovitch, J. N. Winn, S. Fan, P. R. Villeneuve and J. D. Joannopoulos, “3D Metallo-Dielectric Photonic Crystals with Strong Capacitive Coupling between Metallic Islands”, Phys. Rev. Lett., vol. 80, (1998), pp. 2829-2832.

7. S. Enoch, G. Tayeb, P. Sabouroux, N. Guerin and P. Vincent, “An metamaterial for directive emission”, Phys. Rev. Lett., vol. 89, no. 21, no. 213902, (2002)

8. I. Wu, W. Wang, J. Pacheco, X. Chen, T. Grzegorczyk and J. A. Kong, “An study of using metamaterials as antenna substrate to enhance gain”, Progress In Electromagnetics Research, PIER, vol. 51, (2005), pp. 295-328. International Journal of Hybrid Information Technology Vol.8, No.11 (2015) Copyright ⓒ 2015 SERSC 211

9. Y. G. Ma, P. Wang, X. Chen and C. K. Ong, “Near-field plane-wave-like beam emitting antenna fabricated by anisotropic metamaterial”, Applied Phys. Lett., vol. 94, no. 044107, (2009).

10. J. B. Pendry, D. Schurig and D. R. Smith, “Controlling Electromagnetic Fields”, Science, vol. 312, no. 1780, (2006).

11.] Z. Wang, B. Li and L. Peng, “Application of Novel Left-handed Metamaterial Structure in Antenna Cover”, iWEM Proceedings, IEEE, (2012)

12. F. Bilotti, A. Alù, N. Engheta and L. Vegni, “Miniaturized Circular Patch Antenna with Metamaterial loading”, Proc. 'EuCAP, Nice, France, (2006).

13. A. Alù, F. Bilotti, N. Engheta and L. Vegni, “Radiation properties of sub-wavelength resonant patch antennas filled with a pair of DPS, DNG, and/or SNG metamaterial blocks”, Dig. USNC/CNC/URSI National Radio Science Meeting, Washington, DC, USA, (2005), pp. 113

14. F. Bilotti, A. Alú and L. Vegni, “Design of Miniaturized Metamaterial Patch Antennas With muNegative Loading”, IEEE Transactions on Antennas and Propagation, vol. 56, no. 6, (2008), pp. 1640- 1647.

15. Y. Dong and T. Itoh, "Metamaterial-based antennas", Proc. IEEE, vol. 100, no. 7, pp. 2271-2285, Jul. 2012