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DESIGN OF MULTIBAND ANTENNA USING TRANSFORMATION OPTICS METHOD (TOM) FOR WIRELESS APPLICATIONS

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***Abstract*—With well-known features like compactness, ease of fabrication, low design costcompactness, ease of fabrication, and low cost of design, microstrip-based antennas are a logical choice for antennas in wireless communication systems. The effectiveness of a microstrip-based antenna is directly related to the elective dielectric constant of the substrate used in patch antenna construction; there are several methods for modifying the material's characteristics, and many scientists are working on it. One of the most prevalent and widely used methods is EBG material, although physics already has a methodology that is neglected in the development of metamaterials: Transformation Optics (TO). The findings indicate that the inclusion of stretched TO enhances the multiband functioning of the antenna when compared to distorted Stretched TO, compressed TO, and antennas without too. Stretched TO additionally enhances antenna gain by 0.67 dB at 6 GHz frequency band when compared to an antenna without TO (1st design). The gain enhancement is considerably greater at higher frequencies of 9.3 GHz, with a value of 3.25 dB. The use of distorted TO improves gain at a lower frequency of 5.4 GHz. The use of compressed TO improves the gain at higher frequencies of 8.9 GHz by 2.73 dB.**

Keywords - Transformation Optics (TO); FR4; lumped parameters; Metamaterials; printed Impedance resonator; Broadband, Antenna Gain, etc.

I. INTRODUCTION

When Smith et al. released their foundational study on a structured material with concurrently negative permeability and permittivity at microwave frequencies in 2000, the term "metamaterial" first emerged in the literature [1].The principal sponsor of the Metamaterials Congress, the European Union's Metamorphose Network, describes a metamaterial as "an arrangement of artificial structural components meant to create favorable and unexpected electromagnetic characteristics." [2]

A microstrip antenna's geometry consists of a dielectric substrate of specific thickness d with full metallization on one of its surfaces and a metal "patch" on the other. The substrate is typically thin (d). The metal patch on the front surface can be of various forms, but the rectangular shape illustrated in Figure is the most common.

Various ways can be used to excite the antenna (Pozar, 1992; Pozar and Schawbert, 1995). One popular way is to feed the microstrip antenna from a microstrip line, connecting it at one of its edges. The microstrip line can be supplied via a feeding circuitry or directly from a signal source linked across the microstrip line and the ground plane.The microstrip antenna emits the most radiation in the broadside (perpendicular to the substrate) direction and, ideally, no radiation in the end-fire (along the substrate's surface). The size of the antenna is normally chosen so that it resonates at the working frequency, resulting in a real input impedance.

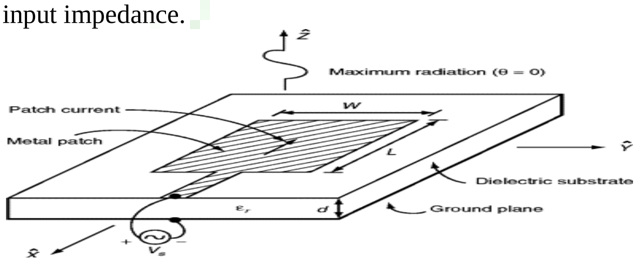

Fig: - 1 Microstrip antenna

This needs the length of the antenna, L, to be around half a wavelength in the dielectric medium for a rectangular microstrip antenna. The antenna width, W, on the other hand, controls the input impedance level. Consider the microstrip antenna to be a rectangular chamber with open

sides. The radiation is caused by the fringing fields that pass through the open sidewalls.
The structure, however, is largely a resonant cavity with a little amount of fringing radiation. As a result, the radiation's bandwidth is restricted in contrast to the bandwidth of the antennas mentioned previously. However, the limited bandwidth is adequate for a variety of communication applications. Readers may be interested in Balanis (1997) and Carver and Mink (1998) for some analytical modelling of a microstrip antenna (1981). Carver and Mink (1981) propose the following simple and approximating formulae for the radiated electric field components of a microstrip antenna:

$$E_\theta = \frac{sin\, sin\left(\frac{kWsin\theta sin\quad \emptyset}{2}\right)}{\frac{kWsin\theta sin\quad \emptyset}{2}} cos\, cos\left(\frac{kL}{2} sin\theta cos\emptyset\right) cos\emptyset$$

1.1

$$E_\varphi = -\frac{sin\, sin\left(\frac{kWsin\theta sin\quad \emptyset}{2}\right)}{\frac{kWsin\theta sin\quad \emptyset}{2}} cos\, cos\left(\frac{kL}{2} sin\theta cos\emptyset\right) cos\emptyset$$

1.2

theory of memory element
It is critical to establish the essential elements and fundamental parameters, as well as the definition of the proposed antenna configuration, well before the design validation process begins. This is necessary to ensure that the simulation process is carried out accurately and without mistake.

a) Transformation optics

Transformation optics is a subfield of optics that uses metamaterials to generate spatial changes arising from coordinate transformations that may direct specific wavelengths of electromagnetic light. This enables the creation of novel composite artificial devices that would not be possible without metamaterials and coordinate transformation. The computing capacity that became accessible in the late 1990s permits predefined quantitative values for the constitutive parameter’s permittivity and permeability, which cause localised spatial fluctuations. The sum of all the constitutive characteristics generates an effective value, which produces the expected or desired consequences.

Coordinate transformations

Transformation optics has its roots in two research projects and their findings. They were published in the same issue of the peer-reviewed journal Science on May 25, 2006. The two publications present plausible hypotheses for bending or distorting light in order to electromagnetically conceal an item. Both publications use a Cartesian mesh to map the initial configuration of the electromagnetic fields. Twisting the Cartesian mesh, in essence, changes the coordinates of the electromagnetic fields, which conceals a particular item. As a result of these two articles, transformation optics is born.[3]

Developments

This field's advancements are centred on developments in transformation optics research. Transformation optics is the foundation for investigating a wide range of theoretical, computational, and experimental discoveries from the physics and engineering fields. The multidisciplinary approaches to material investigation and design foster understanding of their behaviours, qualities, and possible uses in this discipline.
A beam of light (in the optical limit) will follow lines with a constant coordinate if a coordinate transformation can be determined or described. The transformations are subject to limitations, which are stated in the references. In general, though, many transformations can be used to achieve a certain aim. Many changes may be used to construct the standard cylindrical cloak (which was originally simulated and proved experimentally). A linear coordinate mapping in the radial coordinate is the simplest and most commonly utilised. There is a lot of current study on the benefits and drawbacks of different types of transformations, as well as what characteristics are desirable for realistic transformations. The broadband carpet cloak is an example of this: the transformation utilised was quasi-conformal.

Mimicking celestial mechanics

The interactions of light and matter with spacetime predicted by general relativity may be examined using a new class of artificial optical materials with exceptional light-bending abilities (which is actually electromagnetic radiation). This study connects the rapidly developing science of artificial optical metamaterials to celestial mechanics, allowing for the investigation of astronomical events in a laboratory context. A newly developed class of carefully engineered optical media may simulate the periodic, quasi-periodic, and chaotic movements found in celestial objects subjected to gravitational forces.

Battlefield applications

Transformation optics has potential combat uses. Metamaterials' varied qualities can be customised to practically any practical purpose, and transformation optics demonstrates that space for light may be twisted in almost any arbitrary fashion. This is regarded as giving warriors on the battlefield additional powers. Metamaterials provide both short-term and long-term benefits in military circumstances.[4]
For example, rapidly identifying whether a cloud in the distance is innocuous or an aerosol of hostile chemical or biological warfare is quite difficult. However, with the development of new metamaterials, the possibility to perceive objects smaller than the wavelength of light exists, which has yet to be reached in the far field.[4]
The rectangular Microstrip patch antenna is the most often utilised form of Microstrip antenna. Because it is easier to fabricate, has a more sturdy design, and is, of course, quite simple to handle.
A patch antenna is a low profile antenna that has more advantages than other types of antennas. They are less expensive, easier to transport and install, and integrate with other electronic media more easily than traditional antennas. The picture depicts the fundamental structure of the patch antenna [5], which consists of a flat plate on the

ground plane and a conductor in the centre of the cable that serves as the feed probe to couple electromagnetic energy in or out of the patch. We can also determine the rectangle patch's field distribution.

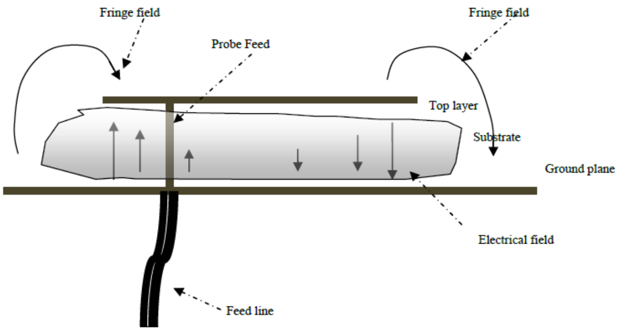

Fig: - 2 The basic structure of the patch antenna

Patch Antenna Materials

In the wide range of antenna models there are different structures of Microstrip antennas, but on the whole, we have four basic parts in the antenna [6]:

They are: -

The patch

Dielectric Substrate

Ground Plane

Feed Line

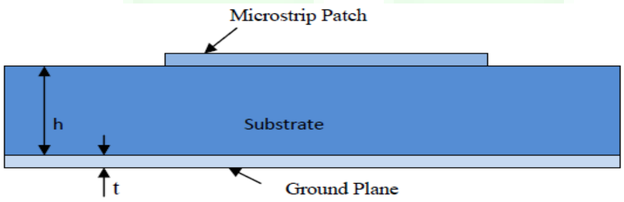

Fig: 3 Side view of Microstrip Rectangular Patch Antenna

The dielectric substance is frequently referred to as a substrate.' [7] The dielectric constant [8], price of the material, loss modulus tangent, surface adhesion qualities for conductor coatings, and simplicity of production are all factors to consider when choosing a substrate[9].

III. DESIGN AND SIMULATION RESULTS

1st Design of Single Meandered Slot Patch Antenna Model

The suggested first structure is essentially a simple H-slot slot impedance resonator. The total dimensions of the suggested are 32 mm 26 mm with a 1.6 mm thickness in this design, the feed line is 6 mm 4.5 mm, and the region of excite is 6 mm and 12 mm distant from the origin. The H-slot, which serves as an impedance resonator, is 17 mm long and 3 mm wide. The patch is rectangular in shape, with dimensions of 23 mm 17 mm, and is 4.5 mm from the source in the x-axis and 4.5 mm originating in the y- axis.

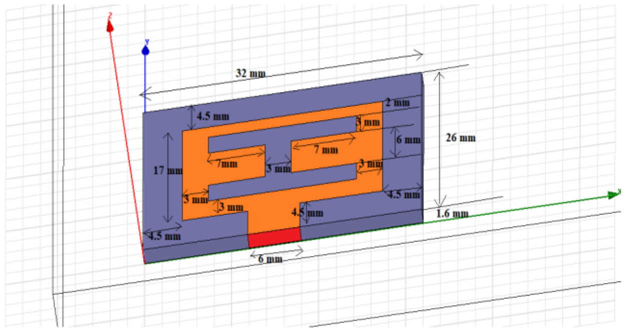

Figure 4.Top view of H-Slot antenna for design 1

2nd Design of Stretched TO Patch Antenna with FR-4 substrate.

The 2 designs aimed to establish, like the first, is an H-slot antenna with extended transformation optics. We used extended transformation optics on the H-slot of the basic patch in this design. The suggested design has an overall diameter of 32 mm 26 mm with a thickness of 1.6 mm. In this design, the feed line has a dimension of 6 mm 4.5 mm and the point of stimulation has a dimension of 6 mm and is 12 mm distant from the source. The H-slot is altered with TO to have a length of 17 mm, a width of 3 mm, and a stretched dimension of 8 mm between the two ends of the H-slot.

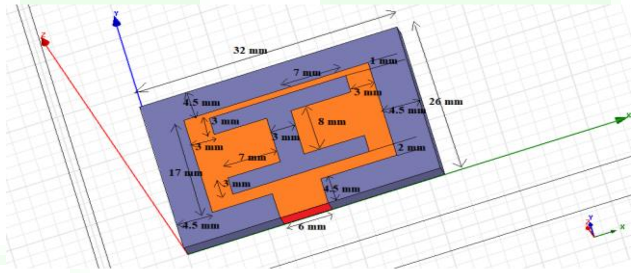

Figure 5Top View of Stretched TO antenna for design 2

3rd Design of Stretched TO Patch Antenna with Distortion

The 3rd proposed model is another H-slot antenna with stretched transformation optics, this time with a distortion in the basis H-slot due to excessive y-axis stretching. In this design, we used stretched transformation optics on the H-slot of a basic patch in the y-axis, causing the rear end of the H-slot to deform owing to excessive stretching. The suggested design has an overall diameter of 32 mm 26 mm with a thickness of 1.6 mm. In this design, the feed line has a dimension of 6 mm 4.5 mm and the point of stimulation has a dimension of 6 mm and is 12 mm distant from the source.The H-slot is altered with TO to have a length of 17 mm, a width of 3 mm towards the back end, and a width of 4 mm close to the end of the y-axis. The semi of the h-slot is 3 mm wide altogether, with stretched dimensions of 9 mm between the two ends of the h-slot. The extended H-slot is stretched up to a 1 mm margin toward the y-end. axis's.

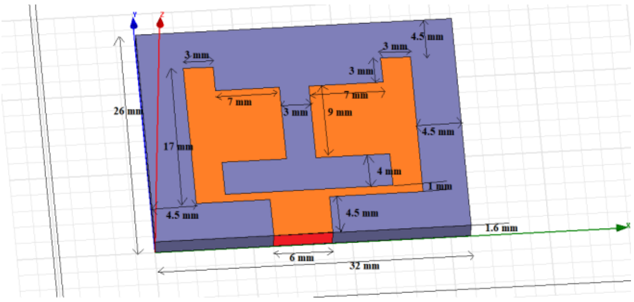

Figure 6Top View of Distorted Stretched TO antenna for design 3.

4th Design of Compressed TO Patch Antenna without Distortion

The final design concept is another H-slot antenna with compressed transformation optics and no deformation in the y-axis. In this design, we used compressed transformation optics on the H-slot of a basic patch in the y-axis, such that the back end of the H-slot is compressed and has a 6.5 mm margin. The fourth suggested antenna design has an overall dimension of 32 mm 26 mm with a 1.6 millimeter thickness. In this design, the feed line has a dimension of 6 mm 4.5 mm and the point of stimulation has a dimension of 6 mm and is 12 mm distant from the source.The H-slot is altered with squeezed TO and has a long of 9 mm and a width of 1.5 mm at the back end and 1.5 mm towards the tip of the y-axis. The half of the H-slot has a dimension of 1.5 mm throughout with a compressed dimension of 4.5 mm between both the two sides of the H-slot. The squeezed H-slot has a 3 mm gap in the distal tip of the y-axis and a 6.5 mm space in the back end of the y-axis.

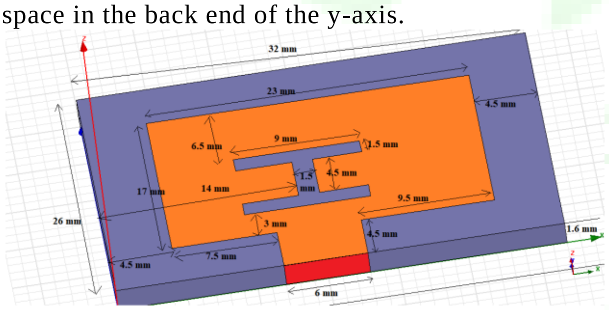

Figure 7 Top View of Compressed TO Patch Antenna for design 4

IV. SIMULATION RESULTS

First Proposed Antenna Design

hickness of Material mm)	ielectric Constant r	adiating Frequency (GHz)	eturn Loss S11 In dB)	andwidth (MHz)	SWR	ain (dB)	xial Ration (dB)
.6	.4	.4	22.33	75	.16	0.78	6.67

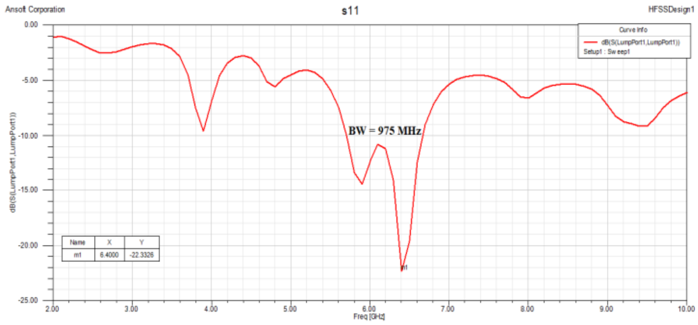

Figure 8 Return loss of simulation result for Design 1

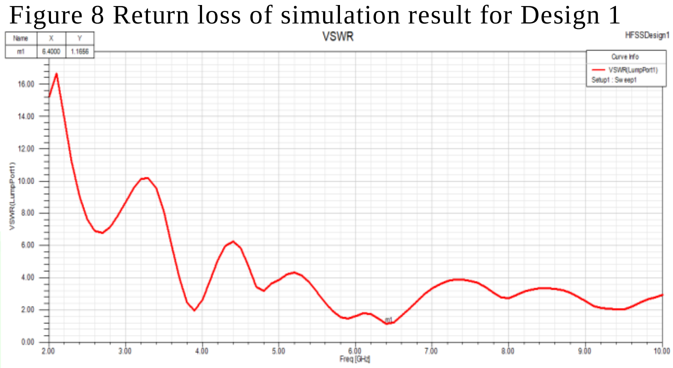

Figure 9 VSWR of simulation result for Design 1

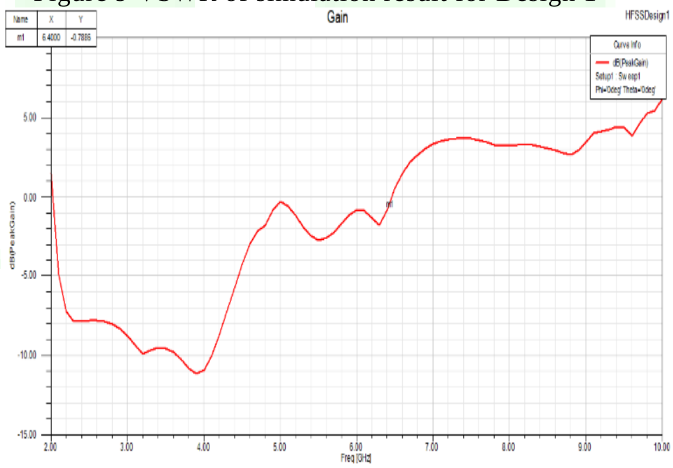

Figure 10 Gain in dB of simulation result for Design 1

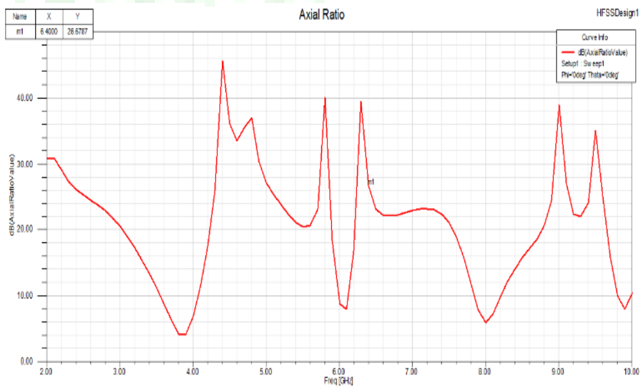

Figure 11 Axial Ratio in dB of simulation result for Design 1

Second Proposed Antenna Design

hic kne ss of Mat eria l mm)	ielec tric Con stant r	adia ting Freq uenc y (GH z)	eturn Loss S11 In dB)	and wid th (M Hz)	SWR	ain (dB)	xial Ration (dB)
.6	.4	.8	14.20	40	.48	1.18	7.44
		.3	13.16	70	.56	0.11	9.61
		.3	13.50	00	.53	.25	8.47

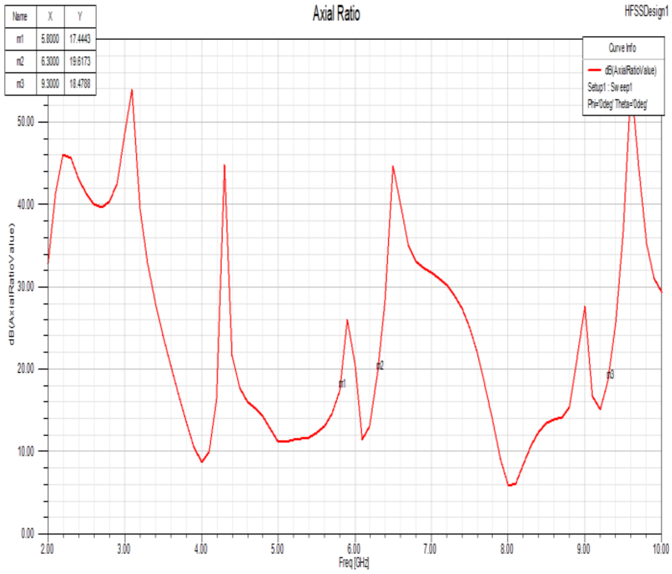

Figure 15 Axial Ratio in dB of simulation result for Design 2

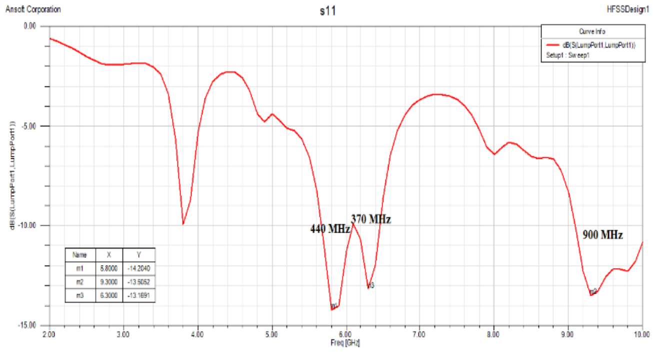

Figure 12 Return loss of simulation result for Design 2

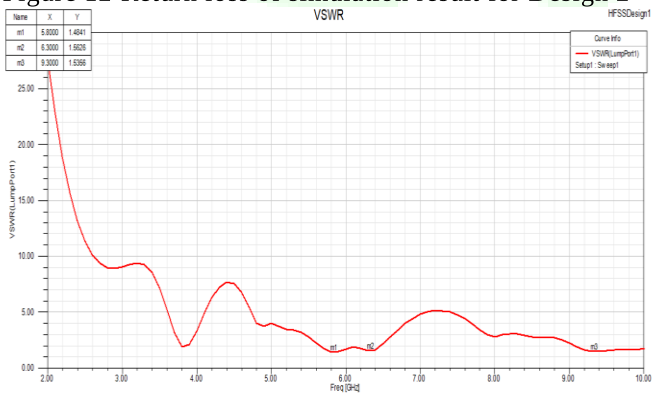

Figure 13 VSWR of simulation result for Design 2

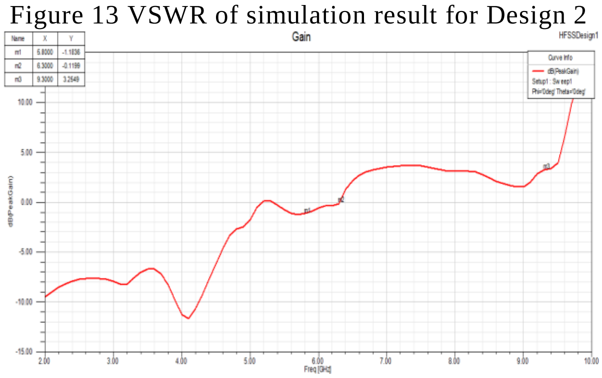

Figure 14 Gain in dB of simulation result for Design 2

3rd Design of Stretched TO Patch Antenna with Distortion

Thic of l (mm	ielec tric Con stant r	adia ting Freq uenc y (GH z)	etur n Loss S11 In dB)	and wid th (M Hz)	SW R	ain (dB)	xial Rati on (dB)
1.6	4.4	.4	15.87	10	.38	.24	0.64
1.6	4.4	5.4	15.87	51 0	1.38	1.24	20.6 4

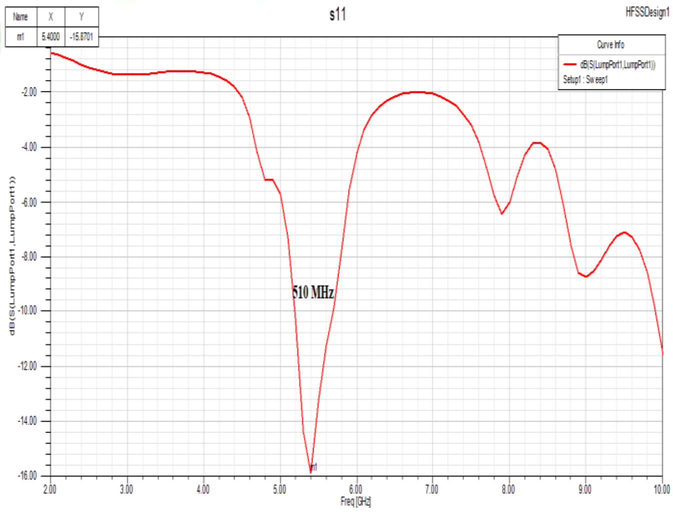

Figure 16 Return loss of simulation result for Design 3

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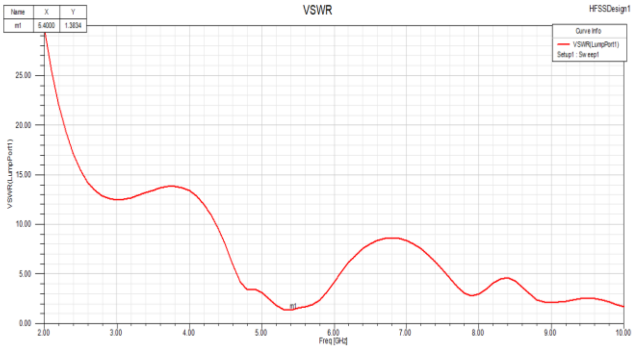

Figure 17 VSWR of simulation result for Design 3

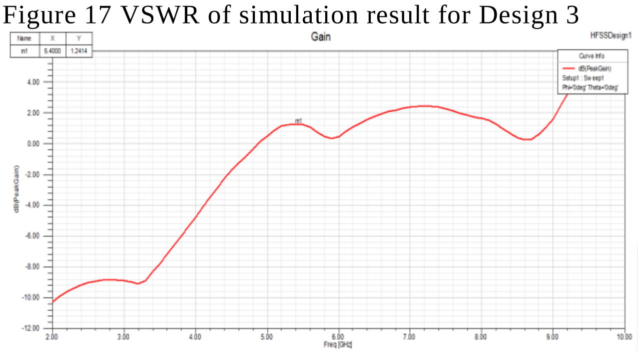

Figure 18 Gain in dB of simulation result for Design 3

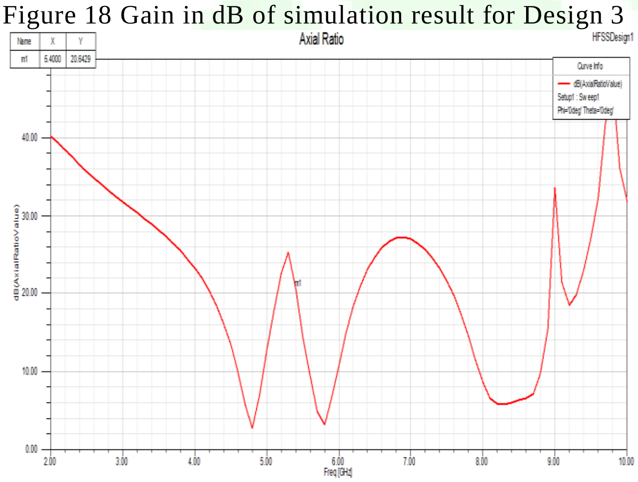

Figure 19 Axial Ratio in dB of simulation result for Design 3

4th Design of Compressed TO Patch Antenna without Distortion

hickness of Material mm)	ielectric Constant$_r$	adiating Frequency (GHz)	eturn Loss S11 In dB)	andwidth (MHz)	SWR	ain (dB)	xial Ration (dB)
.6	.4	.8	24.98	43	.11	1.13	1.11
		.9	14.84	70	.44	.73	5.86

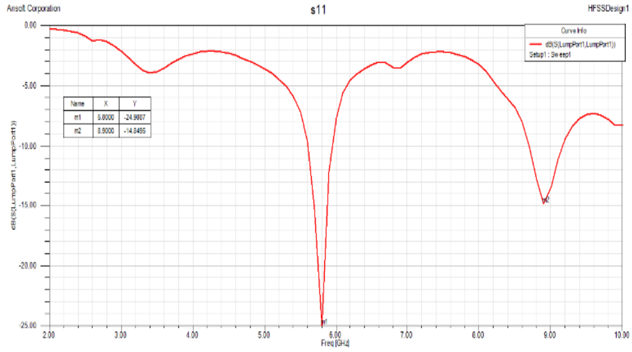

Figure 20 Return loss of simulation result for Design 4

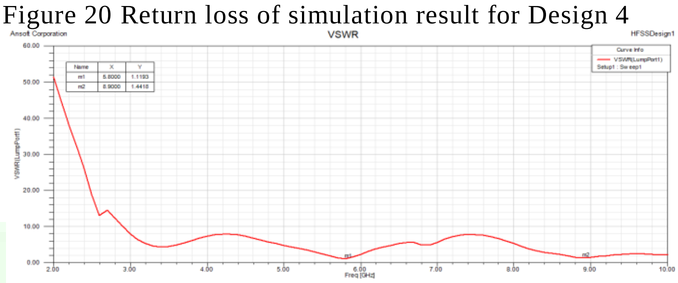

Figure 21 VSWR of simulation result for Design 4

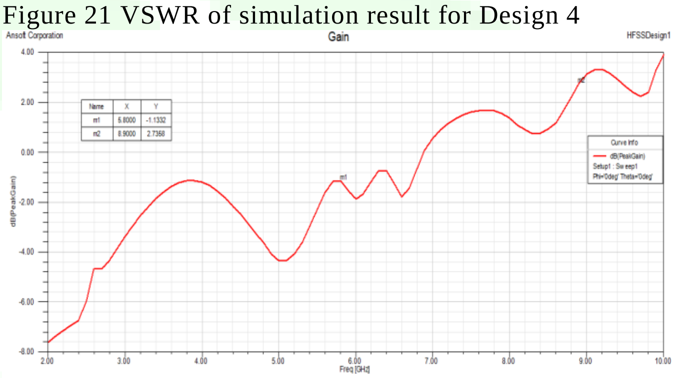

Figure 22 Gain in dB of simulation result for Design 4

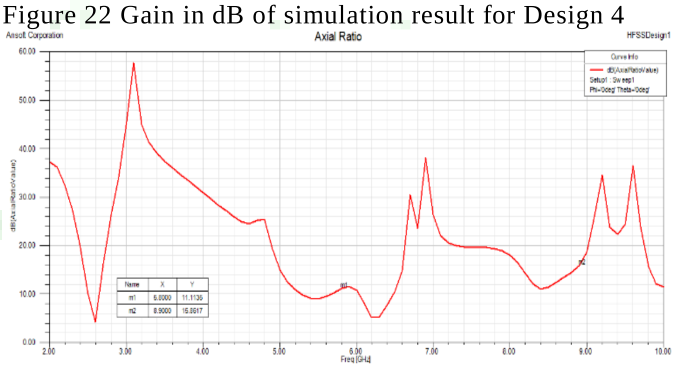

Figure 23 Axial Ratio in dB of simulation result for Design 4

V.CONCLUSION AND FUTURE WORK

Various antennas based on transformation optics are described in this dissertation, and the simulation results of all proposed designs are investigated using HFSS simulation software. In this paper, we offer four patch antennas based on transformation optics. Ultimately, the fourth design is a compressed transformation optics-based H-Slot antenna in which the basic H-Slot on the proposed antenna patch is compressed in both the X and Y axes.

When we compare the results of all proposed designs, we can observe that the best results in terms of multi-operating band are obtained in the second design of Stretched TO antenna. We have three bands of operation in these circumstances, with bandwidths of 440 MHz, 370 MHz, and 900 MHz at center frequencies of 5.8 GHz, 6.3 GHz, and 9.3 GHz, respectively. The results show that the addition of stretched TO enhances the multiband functioning of the antenna when compared to distorted Stretched TO, compressed TO, and antennas without TO.After reviewing the simulation results, we can conclude that the second proposed design with triple (Multiple band) band of operation improves major performance parameters of patch antennas such as bandwidth and antenna gain for application in the 2 GHz to 10 GHz wireless communication frequency range.

Further research can be conducted to develop various TO, such as conformal mapping. In patch antenna design, we may create a connection between TO and the effective dielectric constant of the substrate material. We may also optimize the patch and ground arrangement for improved axial ratio and circular polarization. We may also expand our study into multiband operation and develop multiple analytical models for the patch antenna's various impedance structures.

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