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Design of Transparent Rectangular Patch Antenna for 5G Applications

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Abstract: ***Transparent antennas are meant for their optical transparency. This paper analyzes the rectangular patch antenna designed using meshed conductors and solid ground planes. Meshing the antennas makes it as optically transparent and the antenna's transparency is based on the mesh geometry. Even there is a tradeoff between the antenna's efficiency and the visual see-through ability of the patch antenna with meshed structure, it is able to tune the antenna by refining mesh lines. Material handling, fabrication process and the increased impedance are the important factors limiting the refining of the mesh lines, which also cause loss in efficiency of the antenna. Both the performance and antenna transparency is improved by a mesh refined with small line width (q). Also, by removing certain mesh lines, the antenna transparency is improved without affecting the antenna efficiency. This paper briefly explains the relation between the gain, transparency and the mesh structure of the antenna.***

Keywords: ***Transparent antennas, Optical transparency, Mesh rectangular patch..***

I. INTRODUCTION

Communication not at all linked in today's world than it is now, much of which happens wirelessly. Any system that communicates wirelessly does so through an antenna. Devices today often have multiple antennas for different protocols, particularly cellular devices. Generally, Wi-Fi, GPS, GSM and Bluetooth are well known and become standard features. Communication has not all more linked in today's world than it is now, much of which happens wirelessly. We've seen these antennas evolve and the trend is clear: Lesser, lighter, and powerful. Cellular phones of today have innovative antennas that do not protrude from the phone, enabling the device maker to concentrate more on aesthetics. As the antenna room in these devices becomes more crowded, it is needed to develop new and more innovative solutions to meet the demand. Obviously, antennas that can suit various shapes have an advantage higher than their fixed equivalents, and now many companies are already designing completely versatile products.

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The need for see-through products goes far beyond displays. Examples of complete see-through USB devices, LED screens and even models of smartphones have been identified. It summates one more extent of difficulty for the antenna designers, since using transparent materials they will have to meet or beat the similar work features as rigid and opaque antennas.

Optically transparent antennas possess potential applications for automotive wireless applications as receivers / transmitters. They can be built into the window of the car, thus preserving the artistic taste of the car. These antennas also be incorporated into the electronic equipment display of wireless communication and a transparent conductor with conductivity close to that of copper and visibility close to that of glass is needed to manufacture these antennas. The attractive possibility is to develop optically transparent antennas in order to improve their position in downtowns through percolating different areas, including translucent areas like car windows and buildings. Similar antennas can be stamped on alike translucent substrates from transparent and conductive surfaces. Fig.1.1 shows the transparent meshed rectangular patch antenna,

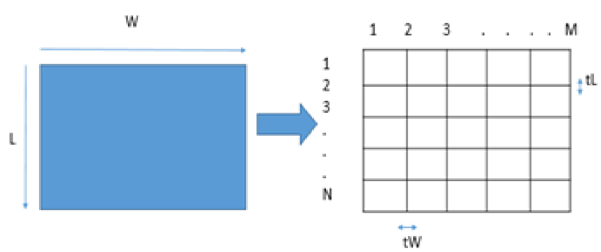

Fig. 1.1 Rectangular patch antenna design with mesh structure.

II. RELATED WORK

Yasin et al. (2011) has designed a visually see-through patch antenna using meshed conductors and conductive transparent films. They compared and analyzed the performance and transparency of the antenna. For S band applications, meshed antennas result in high efficiency and high transparency. By using meshed structure, antenna can be designed for the transparency up to 90% with the efficiency more than 60%. Indium Tin Oxide (ITO) films are less transparent than conductive mesh structures. In case of using ITO films, optical transparency up to 80% can be achieved with efficiency less than 60% at the frequency of 2.5GHz.

The efficiency of patch antenna designed using ITO can be expanded in the progress ofmaterial processing.

Saberin J. R. et al. (2012) has designed an antenna with transparent conductive oxides (TCOs). Through thin film deposition on substrates, the visual see-through ability of transparent conductive oxides is achieved. But the thin film deposition creates some electrical challenges. This work shows the equations of limiting light transmissions, absorptions and reflections via a transparent conductor. It also explains the antenna's efficiency designed with TCO and its electrical conductivity.

Yasin et al. (2013) has designed a meshed patch antenna with circular polarization. There are two square patches in the proposed antenna and at two different frequencies, the antenna generates two orthogonal linear polarizations. The two patches are excited using common proximity feed line and a phase difference of 90 degree can be achieved between the two resonant frequencies. The antenna is highly compatible with solar panels. The results measured for the antenna design includes 3-dB axial-ratio (AR) bandwidth of 15MHz, gain of 5.15dBi at the frequency of 2.47GHz.

Azini et al. (2013) has designed a see-through single pole antenna for the radiating frequency of 2.3GHz. In this, both the patch and the ground plane are designed using AgHT-4. The antenna's substrate is made up of glass. The simulated and measured results of the impedance bandwidth are 41.89% (2GHz to 3.06GHz) and 90.91% (1.5GHz to 4GHz) respectively. The antenna's output gain is 3.16dBi. The simulated and measured results moreover similar for radiation pattern and return loss. Ryan et al. (2014) has designed a patch antenna with circular polarization. The optical transparency up to 70% is achieved using wire-mesh patch. The antenna is fabricated on ceramic substrate, which is less in cost and results in simplified construction. One patch is incorporated with metamaterial loading to control the phase difference among the orthogonal modes of the patch. This in turn provides dual band circular polarized radiation. The antenna efficiency of 70% and 78% are achieved at the frequency of 2.35GHz and 2.73GHz respectively.

III. PROPOSED SYSTEM

We need to select the frequency of operation and a dielectric substrate by using which the antenna is going to be designed to build a micro strip patch antenna. The estimation of the parameters is as follows. Fig. 3.1 shows the meshgeometry,

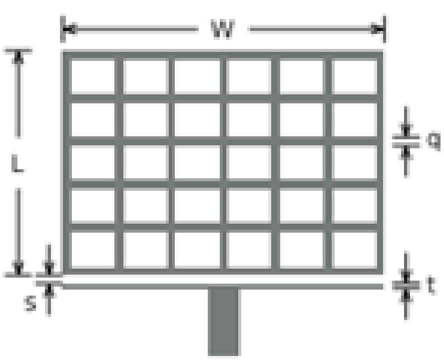

Fig. 3.1 Mesh geometry

$$W = C_0 / 2fr \sqrt{(2 / \varepsilon_{r+1})}. \qquad (1)$$

Where, W= Patch width
C_0= Speed of light
ε_r= Dielectric constant value

The necessary criteria for the design process of a micro strip patch antenna is the efficient refractive index of a patch. The radiations travel through air from patch to ground and via the substratum (called fringing), both the air and the substrates have different dielectric values, so the value of effective dielectric constant is needed to compensate for this. Use the following equation to calculate the value of the effective dielectric constant,

$$\varepsilon_{reff} = (\varepsilon_r+1)/2 + (\varepsilon_r-1)/2[1 + 12h/W]^{-1/2}, \ (2)$$ Where,

W/h>1.

Electrically the antenna size is decreased by a quantity of (ΔL) due to fringing. The real length increase of the patch (ΔL) should therefore be determined using the following equation,

$$\Delta L/h = 0.412[(\varepsilon_{reff}+0.3)\,(W/h+0.264) / (\varepsilon_{reff}-0.258)\,(W/h+0.8)] \qquad (3)$$

Where 'h'= height of the substrate.

The patch's length (L) must now be determined using the equation below,

$$L = [C_0/(2fr\sqrt{\varepsilon_{reff}})] - 2\Delta L. \qquad (4)$$

Now, a patch's dimensions are established. A substrate's length and width is equal to the ground planes. Use the following equation to determine the length of a ground plane (Lg) and the width of a ground plane (Wg),

$$Lg = 6h + L \qquad (5)$$

$$Wg = 6h + W \qquad (6)$$

There are different methods for feeding the micro strip patch antenna, such as feed line method, coaxial probe feeding method, etc.

These meshed patches optical clarity is defined as a percentage of the patch's search area. For instance, the formula for calculating the transparency (Trect) of a rectangular meshed patch having W (width) by L (length) dimensions is as follows,

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$$T_{rect} = [1 - A_{conductor} / A_{patch}] \quad (7)$$

$$T_{rect} = [(L.W - q\,[M.L+N.W] + q^2.M.N)/\,(L.W)].100\% \quad (8)$$

Where M is parallel to the patch length, N is the number of lines orthogonal to the patch length, and the similar thickness of the mesh line is q.

IV.PROPOSED ANTENNA DESIGNS

The antennas are designed with the substrate of glass epoxy. The patch of the antenna is meshed and the ground plane is designed as a solid structure. In the proposed design, antennas are excited with the technique of micro strip line feed.

Three different antennas are designed with the following parameters,

Table 4.1 Geometry of proposed antenna designs.

Antenna	Length of the patch (Lp) in mm.	Width of the patch (Wp) in mm.	q(mm) Line Width	M (No. of current path lines)	N (No. of orthogon al lines)
A	45	38	0.4	18	8
B	45	38	0.5	14	8
C	45	38	0.6	10	8

The table 4.1 shows the different antenna designs by varying the no. of current path lines (M) and the linewidth (q).

A. Antenna design A

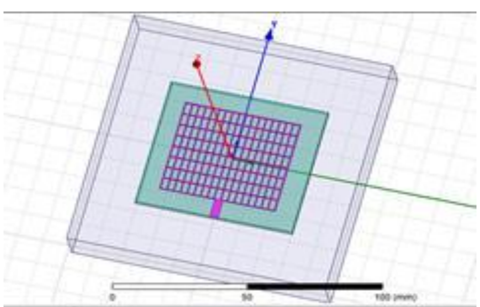

Fig 4.1 Design of transparent rectangular patch with M=18 and N=8.

The Fig 4.1 shows the design of transparent rectangular meshed patch antenna with the length and width of 45.6mm and 38.6mm respectively and with the no. of parallel lines(M) = 18, no. of orthogonal lines(N) =8 and linewidth(q) of 0.4mm.

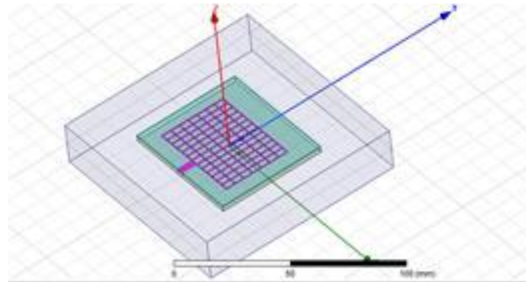

Fig 4.2 Design of transparent rectangular patch with M=14 and N=8.

The Fig 4.2 shows the design of transparent rectangular meshed patch antenna with the length and width of 45.6mm and 38.6mm respectively and with the no. of parallel lines(M) =14, no. of orthogonal lines(N) = 8 and linewidth(q) of 0.5mm.

B. Antenna design C

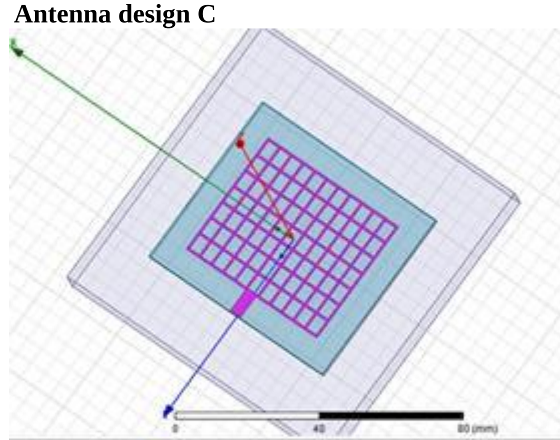

Fig 4.3 Design of transparent rectangular patch with M=10 and N=8

The Fig 4.3 shows the design of transparent rectangular meshed patch antenna with the length and width of 45.6mm and 38.6mm respectively and with the no. of parallel lines(M) = 10, no. of orthogonal lines(N) = 8 and linewidth(q) of 0.6mm.

V. RESULT AND DISCUSSION

A. Return loss

Return loss is the power loss in the signal reflected through a transmission line by discontinuity. Normally, this is expressed in decibels. In other words, if all the power was passed to the load, an infinite loss of return would occur. There is an open or short circuit termination, all power will be restored and no return loss will occur.

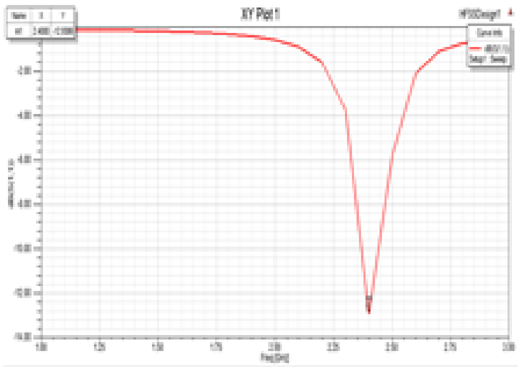

Fig 5.1 Simulation result of return loss of the antenna design 10*8.

The Fig 5.1 shows that in design 1, the return loss achieved is about -12.9 dB. For the patch length (Lp) =45.6mm and patch width (Wp) =38.6mm, the antenna resonates at the 2.4 GHz band of frequency. This implies that the antenna has minimum return loss (< -10dB).

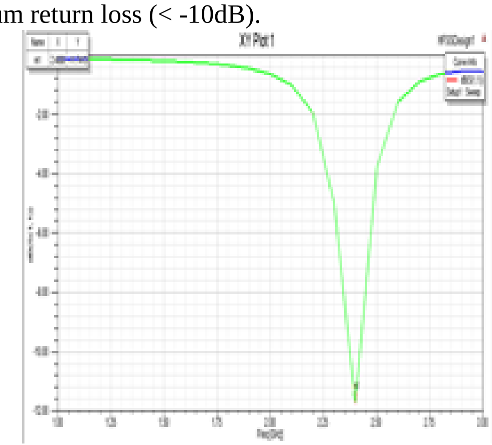

Fig 5.2 Simulation result of return loss for antenna design 14*8.

The Fig 5.2 shows that in design 2, the return loss achieved is about -11.7 dB. For the patch length (Lp) =45.6mm and patch width (Wp) =38.6mm, the antenna resonates at the 2.4 GHz band of frequency. This implies that the antenna has minimum return loss (< -10dB).

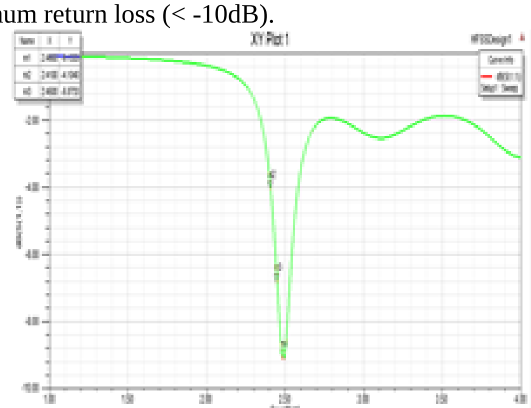

Fig 5.3 Simulation result of return loss for antenna design 18*8.

The Fig 5.3 shows that in design 3, the return loss achieved is about -7 dB. Which implies that the antenna has poor return loss when compared with the design 1 and design

2. For the patch length (Lp) =45.6mm and patch width (Wp) =38.6mm,

the antenna resonates at the 2.4 GHz band of frequency.

B. Gain

The important performance characteristics that blends the directivity of the antenna with the electrical efficiency is the power gain of an antenna. The gain explains how well the antenna transforms radio waves coming from a given direction into electrical power in a receiving antenna. If no direction is defined, "gain" means the maximum gain value of the antenna. A gain plot is called the gain pattern direction.

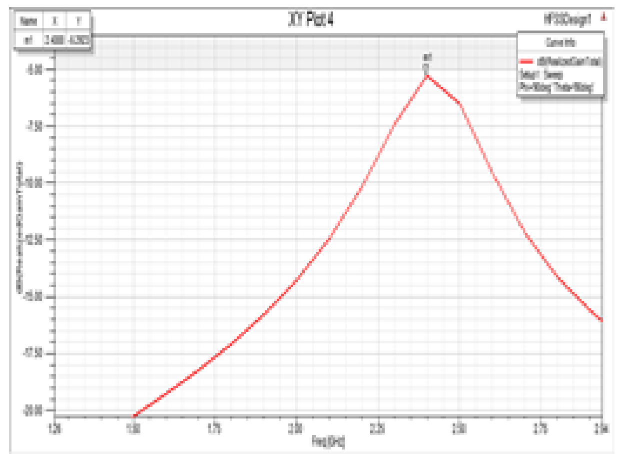

Fig 5.4 Simulation result of antenna gain for design 10*8.

The Fig 5.4 shows that in design1, the gain achieved is about

-5.2dB. For the patch length (Lp) =45.6mm and patch width (Wp) =38.6mm, the antenna resonates at 2.4 GHz band of frequency. Which is sufficient for short range communication at 2.4GHz band of frequency.

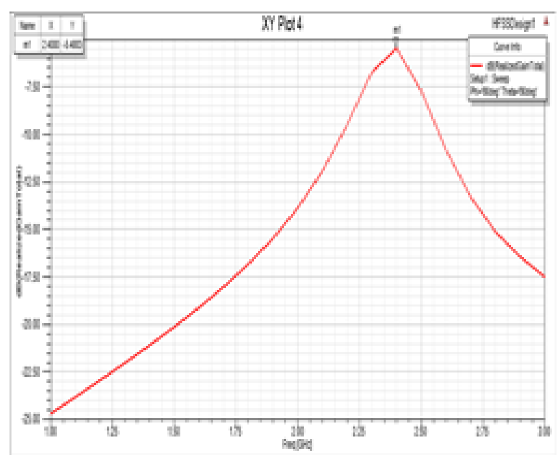

Fig 5.5 Simulation result of antenna gain for design 14*8.

The Fig 5.5 shows that in design1, the gain achieved is about -5.5dB. For the patch length (Lp) =45.6mm and patch width (Wp) =38.6mm, the antenna resonates at 2.4 GHz band of frequency.

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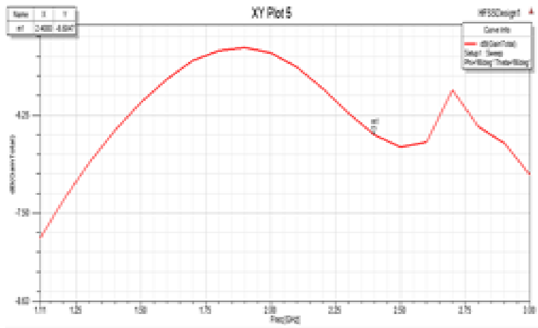

Fig 5.6 Simulation result of antenna gain for design 18*8.

The Fig 5.6 shows that in design 3, the gain achieved is about

-6.5dB. For the patch length (Lp) =45.6mm and patch width (Wp) =38.6mm, the antenna resonates at 2.4 GHz band of frequency. Which is less when compared with the previous designs 1 and 2.

C. Radiation pattern

A graphical representation of the antenna radiation is the power variance that an antenna radiates. This change in power is the angle of arrival detected in the far field of the antenna. Graphically, the antenna is surrounded by a sphere and the electric / magnetic fields (far-field radiation fields) are measured at a distance equal to the sphere radius.

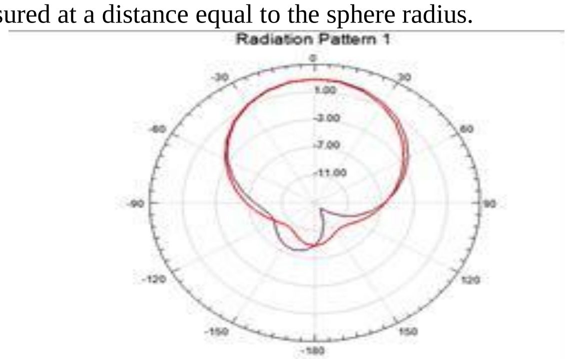

Fig 5.7 Simulation result of radiation pattern for design 10*8.

The Fig 5.7 represents the graphical representation of radiation pattern for the patch length (Lp) =45.6mm and patch width (Wp) =38.6mm represents the power variation radiated by the antenna design1 at the angle of Phi=90 degree (H-Plane) and Phi=0 (E-Plane) degree.

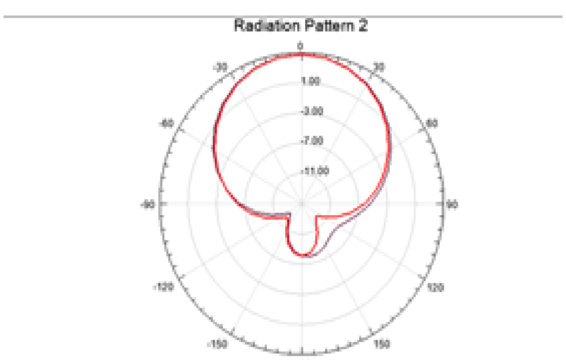

Fig 5.8 Simulation result of radiation pattern for design 14*8.

The Fig 5.8 represents the graphical representation of radiation pattern for the patch length (Lp) =45.6mm and patch width (Wp) =38.6mm representing the power variation which the antenna design1 radiated at the angle of Phi=90 degree (H-Plane) and Phi=0 degree (E-Plane).

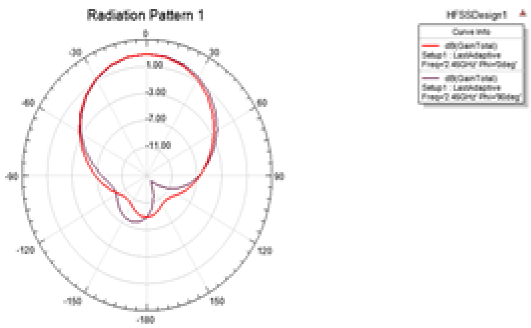

Fig 5.9 Simulation result of radiation pattern for design 18*8.

The Fig 5.9 represents the graphical representation of radiation pattern for the patch length (Lp) =45.6mm and patch width (Wp) =38.6mm representing the power variation which the antenna design1 radiated at the angle of Phi=90 degree (H-Plane) and Phi=0 degree (E-Plane).

VI. COMPARISON OF ANTENNA DESIGN A, B AND C

In the previous existing design, only the number of mesh lines is varied with constant line width (q) which resulted in compromising between the efficiency and see-through ability of the antenna.

In the proposed design, the number of current path lines are increased with decreasing line width (q). This method of refining the mesh structure helps to avoid the compromise between the efficiency and the transparency of the antenna.

Table 6.1 Comparison of antenna designs 1, 2 and 3

Ant enn a desi gn	No. of curre nt path lines (M)	No. of orthogo nal lines (N)	Line width (q) in mm.	Return loss in dB.	Gain in dB.	Tra nsp aren cy in (%)
A	18	8	0.4	-13	-5.5	76
B	14	8	0.5	-11	-5.5	74
C	10	8	0.6	-7	-6.5	72

The Table 6.1 shows that the gain and transparency of the antenna for the patch length

(Lp) =45.6mm and patch width
(Wp) =38.6mm can be

improved simultaneously by refining the mesh structure and also by varying the linewidth (q).

VII. CONCLUSION AND FUTURE SCOPE

The proposed rectangular meshed patch antennas provide the consistent assumption that the linewidth can be optimized to maximize the transparency and performance of a meshed antenna. From the above analysis it seen that for the antenna design of 18x8 and for the linewidth (q) of 0.4mm, the return loss (S_{11}) =-13dB, gain=-5.5dB and transparency of 76%. For the antenna design of 14x8 and for the linewidth(q) of 0.5mm, the return loss(S_{11}) =-11dB, gain=-5.5dB and transparency of 74% and for the antenna design of 10x8 and for the linewidth(q) of 0.6mm, the return loss(S_{11}) =-7dB, gain=-5.5dB and transparency of 72%. It is noted that the conductive ink printed antennas efficiency were low. The reasons for this are slightly different for the two types of printing. For the screen-printed antennas, the poor output is because of the ink consistency, ink layer thickness and printed lines smoothness. In most printing methods, the thickness of the ink layer is comparable to the skin depth, and therefore high loss is exhibited. It is challenging to achieve sufficiently smooth lines using screen printing and as a result there is an inevitable loss due to the edge diffraction. The first two reasons for lower efficiency for the inkjet printed and screen-printed prototypes are same, while the third is due to the antenna assembly itself.

Inkjet printing yields straight lines, but have to print the structure on a transparency using a non-specialized industrial inkjet printer and then mount the transparency on the antenna substrate. It adds an additional substratum layer and a little amount of air between the transparency and the plexiglass substrate. It is also be remembered that copper tape can be used as the ground plane in both forms of prototyping, and this can also result in additional loss. Finally, the plexiglass has a higher loss tangent that further contributes to low efficiency. When refining the linewidth to improve a meshed patch antenna's efficiency, there is an upper limit of efficiency for each transparency. This is due to a loss that results from meshing a non-perfect conductor. Such a loss is higher for antenna with higher transparency and meshed structure.

The gain for the transparent rectangular meshed patch antenna is less because the plexiglass substrate has a higher loss tangent that contributes to low efficiency. There is an additional layer of substratum in inkjet printing as well as a small amount of air between the transparency and the plexiglass substratum which contributes to low efficiency in manufacturing. Hence the future work is to analyze and improve the output gain of the transparent meshed patch antenna.

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