A Comparative Study on Two Types of Transparent Patch Antennas

Tursunjan Yasin[1], Reyhan Baktur[1], Cynthia Furse[2]

[1]Department of Electrical and Computer Engineering, Utah State University
Logan, UT 84322, USA
tursunjan.y@aggiemail.usu.edu, reyhan.baktur@usu.edu

[2]Department of Electrical and Computer Engineering, University of Utah
Salt Lake City, UT 84103, USA
cynthia.furse@utah.edu

Abstract

Properties of optically transparent patch antennas designed from meshed conductor and transparent conductive films are studied and compared. It is shown that at S band, meshed antenna provides the best antenna efficiency for the highest transparency. It is practical to design a 90% transparent meshed antenna with more than 60% transparency. Indium tin oxide (ITO) films, although less visible to human eyes than conductive meshes, at an optical transparency of 80%, provide an antenna efficiency of less than 30% at 2.5 GHz. AgHT (silver coated polyester film) film has lower transparency compared to ITO films for the same antenna efficiency. It is also shown that with the progress in material processing, the efficiency of an ITO patch antenna can be improved to be comparable to a meshed one. In addition, one can improve the efficiency of an antenna designed from ITO films by increasing the operational frequency.

1. Introduction

The advantage of optically transparent antennas is obvious. They can be integrated with clear substrates such as window glass for security, aesthetics [1], or integrated with solar cells to save surface real estate of small satellites [2]. Although the requirement on transparency may not be stringent when such antennas are used for security, at least 90% optical transparency is essential for solar cell integration. This paper surveys different design methods of transparent antennas and provides a comparison that states the antenna efficiency and transparency from two main design methods.

There are two methods to achieve optical transparency: (1) use of meshed conductor, and (2) use of transparent conductor. For the first class of antennas, the meshed antennas can be fabricated either from electroformed mesh, or from printing with conductive ink [2, 4]. For the second class, the antennas can be designed from transparent conductive materials such as indium tin oxide (ITO) and AgHT (a type of silver coated polyester film). In order to compare these two types of antennas, we chose to study them on the same plexiglass substrate with a thickness of 2mm, a loss tangent of 0.0057 and the permittivity of 2.6. The fundamental resonance was chosen to be at around 2.5 GHz and the study was achieved by using Ansoft's HFSS. The ground plane (i.e. the size of the plexiglass) is set to be large enough (105mm by 105mm) so that the antenna properties, including gain, become stabilized.

2. Meshed Patch Antennas

A sheet of meshed conductor is a very cost-friendly material to design transparent antennas. The openings in the conductor allow light to go through while the mesh can be still designed into effective radiators. Meshed patch antennas, compared to their solid counterparts, have higher surface resistance due to much less conductor coverage. Therefore, it is normal to have lower antenna performance for increased optical transparency [3]. This statement, however, is found not exclusive. Turpin et al. has shown that, for a rectangular meshed patch antenna, by refining the width of the mesh line, the efficiency of the antenna can be improved to be comparable to that of a solid patch [4].

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For a comparison, three sets of rectangular meshed patch antennas with different transparencies were studied. For each of them, copper was used for both the mesh and the solid ground plane. The thickness of copper is taken at least 20 times of the skin depth. The geometry of the rectangular meshed patch antenna is shown in Fig.1. The transparency of the patch is defined as the ratio of the area of the see-through area (i.e. area of the patch minus the total metal area) to the total area of the patch. It has been shown that, when the line-with of the mesh (q in Fig. 1) is fixed, increasing the transparency decreases the efficiency of the antenna [3].

In this study, we generated antennas with the transparency of 70%, 80% and 90%. For each fixed transparency, one can achieve the transparency by varying line-width and number of mesh lines. The efficiency of the meshed antenna as a function of line-width for each transparency is plotted in Fig. 2-4. It is clear that for a given transparency, the efficiency of a meshed antenna can be improved by refining line-width. From fabrication standpoint, achieving a line-width of 0.1mm or wider is easy. We were able to create those meshed or solid patch antennas from inkjet printing with conductive ink [5]. From Fig. 4, it is seen that with a line-width of 0.1mm, it is feasible to achieve an efficiency of more than 60% with an antenna of 90% transparency. This efficiency and transparency are adequate for solar cell integration and satellite communication.

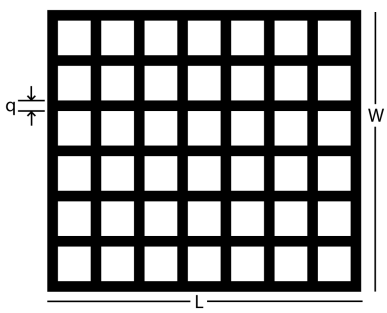


Fig.1. Rectangular meshed patch antenna

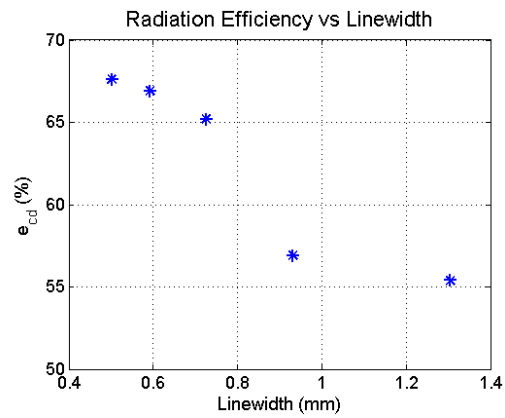


Fig.2. Radiation efficiency vs. mesh line-width (70% transparency)

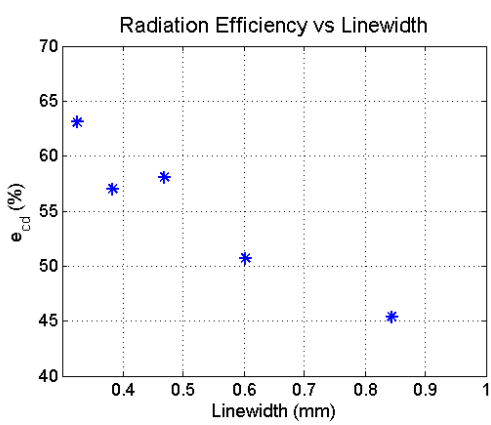


Fig.3. Radiation efficiency vs. mesh line-width (80% transparency)

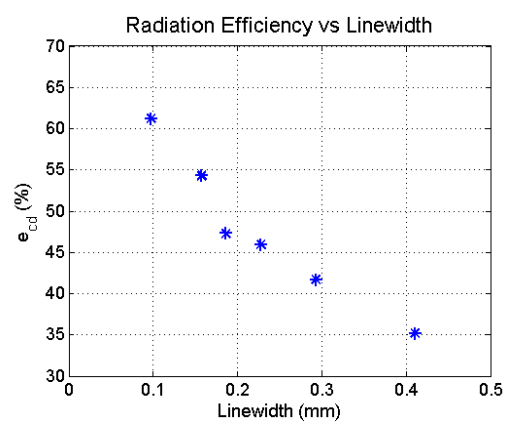


Fig.4. Radiation efficiency vs. mesh line-width (90% transparency)

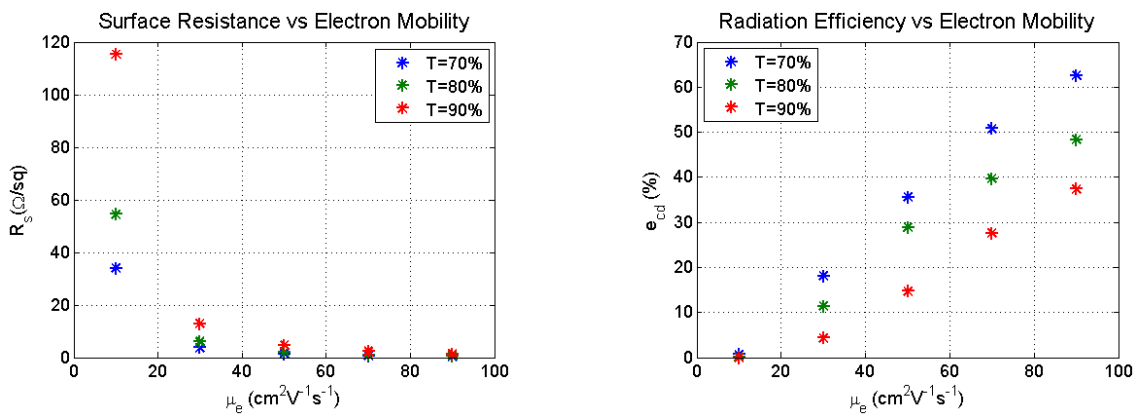
3. ITO Patch Antennas

ITO films have become perhaps the most popular transparent conductor due to its trade-offs in transparency, conductivity, and cost compared to other materials [6-9]. For an ITO film to be conductive in microwave band and transparent in visible spectrum, the material parameters have to be carefully designed [10, 11]. One important material parameter is the electron density, which adds to conductivity, and it is usually set to be 1.5×10^{21} cm^{-3} at the most so that it doesn't deteriorate the optical transparency. Therefore, the flexibility of adjusting the electron density is limited. The only parameter that can be tuned to optimize both electrical and optical properties of the transparent

film is the electron mobility of the film, and this property is limited by the progress in the material processing [10, 11].

The efficiency of a patch antenna is highly dependent on the conductivity, or the surface resistance, of the patch. The surface resistance of the ITO film was found to be inversely proportional to the electron mobility as shown in Fig.5-(a) [11]. The transparency is determined by the combined effect of the electron mobility and the film thickness [8]-[11]. Higher electron mobility gives rise to higher transparency, and reducing the thickness of the film also increases the transparency. On the other hand, reducing the thickness of the film increases the surface resistance and consequently degrades the antenna efficiency. To avoid the film being too thin (within an order of the skin depth), it is favored to keep the electron mobility as high as possible to achieve the minimum surface resistance and the optimal optical transparency. However, the highest electron mobility available with the current technology is about $50cm^2V^{-1}s^{-1}$, which provides a surface resistance of 4.6Ω/sq for an ITO film with 90% transparency. Such surface resistance is at least an order of 100 compared to a conductor sheet such as the copper sheet on a Roger's substrate.

We computed the efficiency of three patch antennas made from ITO films with transparencies of 70%, 80% and 90%. These three antennas were studied on the same substrate and copper ground plane as the meshed ones in section 2. For a fixed transparency, at a given electron mobility, the thickness of the film and surface resistance were determined as outlined in reference [11]. The material properties and thickness of the film were then entered in HFSS simulation to compute the antenna efficiency. The computed surface resistance of the ITO films for each transparency and the antenna efficiency are presented in Fig. 5.



(a) (b)

Fig. 5. Electron mobility effect on: (a) surface resistance, and (b) radiation efficiency

From Fig. 5-(b), it is clear that higher electron mobility results in higher efficiency of the antenna. When the electron mobility is fixed, higher transparency shows lower efficiency. This is because at a given electron mobility, in order to increase the transparency, the thickness of the film has to be reduced. Accordingly, there is a higher surface resistance and the comparability of the film thickness and the skin depth. At 2.5 GHz, with the current technology (i.e. electron mobility $\leq 50cm^2V^{-1}s^{-1}$), an ITO antenna of 90% transparency has an efficiency of less than 15%, which is very low for practical applications. For lower transparency such as 70%, the efficiency is still less than 40%. One can predict that, at a higher frequency, since the skin depth is thinner than at 2.5 GHz, it is possible to have less surface loss and consequently improved antenna efficiency. We tested the same ITO film with 80% transparency as the one in Fig. 5-(b) and obtained a 50% efficiency of the antenna when operating at 5GHz as its fundamental resonance.

4. AgHT Patch Antenna and Summary

Silver coated polyester film AgHT has also been used for transparent antenna application [12]. In general, the transparency of AgHT films is lower than 70% for an effective conductivity. Surface resistance of two typical AgHT films is listed in Table 1. It is seen that an AgHT film of 75% transparency has a similar surface resistance as a 90% transparent ITO film. This means the efficiency of the antenna will be lower than 20%. Therefore, in order to design an effective antenna from AgHT films, the transparency has to be sacrificed.

Table.1 Surface resistance comparison (AgHT data are from [12])

Material	90% ITO Film	75% AgHT-4 Film	82% AgHT-8 Film
Surface resistance (Ω/sq)	4.6	4.5	8

As a summary, for an S-band transparent patch antenna, meshed antennas provide the highest efficiency compared to antennas made from transparent conductive films. Even at 90% transparency, it is feasible to design a meshed patch antenna with efficiency higher than 50%. ITO or AgHT can only provide an antenna efficiency of less than 40% for transparency higher than 70%. For the same transparency, an ITO antenna can be made more effective than an antenna designed from AgHT film.

When designing antennas from ITO films, increasing operational frequency may improve antenna efficiency. For a meshed antenna, the efficiency may reduce for higher frequency due to the increased leaking of high frequency microwave signals through the mesh. But such effect is not prominent at 5GHz. When raising the frequency further higher, efficiency of a meshed antenna will be reduced. Meanwhile, at higher frequencies, the fabrication challenge of the meshed antenna is increased due to the size and very thin mesh lines, and thus it may not be practical to use meshed antennas in applications at Ku-band and above.

5. References

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