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An insight on transparent antennas

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Abstract: *This paper mainly discusses about the Transparent Antenna's introduction, design, their feeding methods, the future scope and finally transition from 2D to 3D.*

I. Introduction

Satellites have always played an important role in space. Their contributions for space research, extended global communications and surveillance have been instrumental for the advancement of the information age. As part of the effort to create this outer space network, satellites have evolved from simple transmitters to complex systems that incorporate a myriad of technologies into a single location. Cost and weight are always key issues for successful satellite deployment. Groups of researchers and budget-tight companies employ smaller and cheaper satellite solutions that are usually custom made for a specific application. These small satellites, such as USUsat1,shown in Fig.1.have created a constant demand for cheaper systems that do more with less [1]. Limitations on the size of these small satellites leave barely enough room for solar cells, which are necessary to power the satellite. This repeatedly impedes the placement of other external elements such as antennas. Without the required surface area for tropical antennas, often complex and failure prone antennas that must be deployed in orbit are used. This adds substantially to cost and labor hours as well as the potential for failure. Two solutions have arisen to mitigate the difficulty of solar cell and antenna integration. The first solution entails the placement of a slot antenna on the back side of the solar cell [7]. This solution has been proven effective if custom built solar cell antennas are assembled for small satellites, but is not viable if the small satellite is being built from off-the-shelf components. The second solution suggests the placement of meshed see-through copper antennas, such as the one seen in Fig.2, on top of the solar cell [9]. See-through meshed antennas are still in the early research phase, but show some promise as transparent antennas.

This paper considers another type of transparent antenna that can be integrated on an off- the shelf solar panel. Indium Tin Oxide (ITO) antennas on solar cell panels. ITO antennas have been used for various types of antenna applications including [5], [6] and [3]. ITO has been shown to have high optical transparency while maintaining effective RF conductivity [5]. These properties could potentially make ITO a good candidate for the application of optically transparent antennas for solar cells, but many of these antennas have failed to meet expectations for efficiency while retaining transparency. This paper will analyze the effect of ITO materials on patch antenna design. The tradeoff between optical transparency and electrical conductivity will be evaluated for a wide range of frequencies. Methods to better predict the skin effects on patch antenna and their impact on antenna efficiency are also described. Another challenge for ITO and meshed patch antenna design is how to feed the antennas. Soldering a copper feed line to the ITO antenna melts the ITO, making the antenna worthless. Proximity feed, is used instead. The full understanding of that feed and its effects on efficiency gain, polarization and antenna matching is the second major contribution of this research. It is important to note that the application of transparent antenna design concepts is not limited to transparent oxides(TCOs), but can be applied to other emerging technologies that utilize materials with lower conductivity values, such as conducting fabrics.

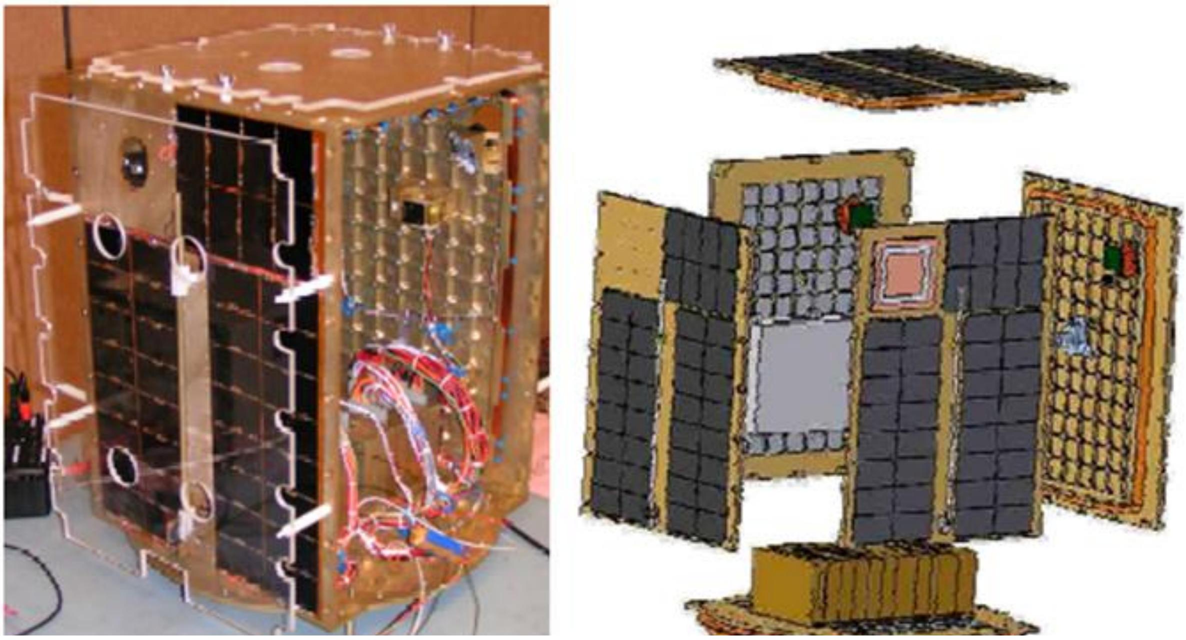
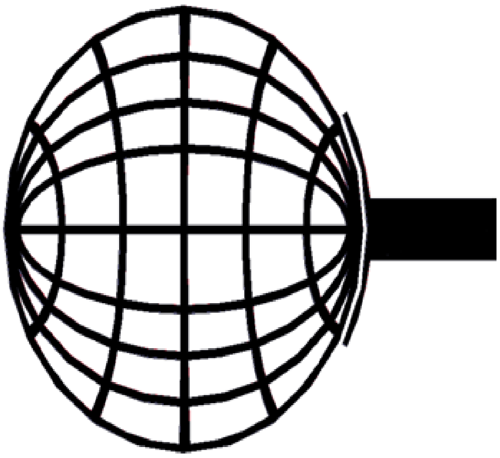


Figure1 ;USUsatl - TOROID [1]



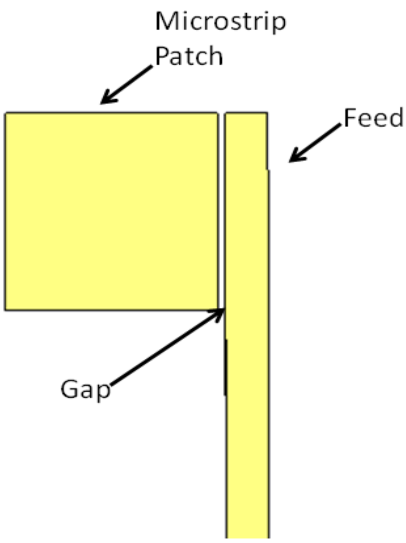


Figure 2: Meshed see-through copper antenna [16] Figure 3: Proximity coupled feed for a patch antenna

II. Transparent Antenna Design

1.1 ITO (Indium Tin Oxide) Antennas

Monopole and patch antennas have been made with ITO [5]. It was found that patch antenna radiators are not as effective or as monopole antennas. Efficiency is controlled by how much current runs on the ITO imperfectly conducting antenna surface. In [5] PIFA (Planar Inverted F Antenna) was found to have a higher radiation resistance, because it behaves like a cavity and excites a larger current on the whole patch. The trapezoidal monopole requires less current to be excited on its surface and therefore is more efficient [5]. None of the previous designs have been placed on a solar cell. [6], [3] and [5] have found that ITO antennas optical transparency is inversely proportionalto the sheet resistivity and therefore ITO antennas have poor conductivity. This results in atradeoff between transparency and efficiency for ITO antennas for solar cell applications.

Chemical spray deposition, DC sputtering and RF sputtering are a few of the methods usedfor performing ITO deposition [3].

1.2 Meshed Patch Antennas

An alternative to antennas made of transparent materials are meshed antennas. Although theoptical transparency of meshed antennas is typically lower than ITO antennas, meshed antennashave higher efficiency and overall gain [9]

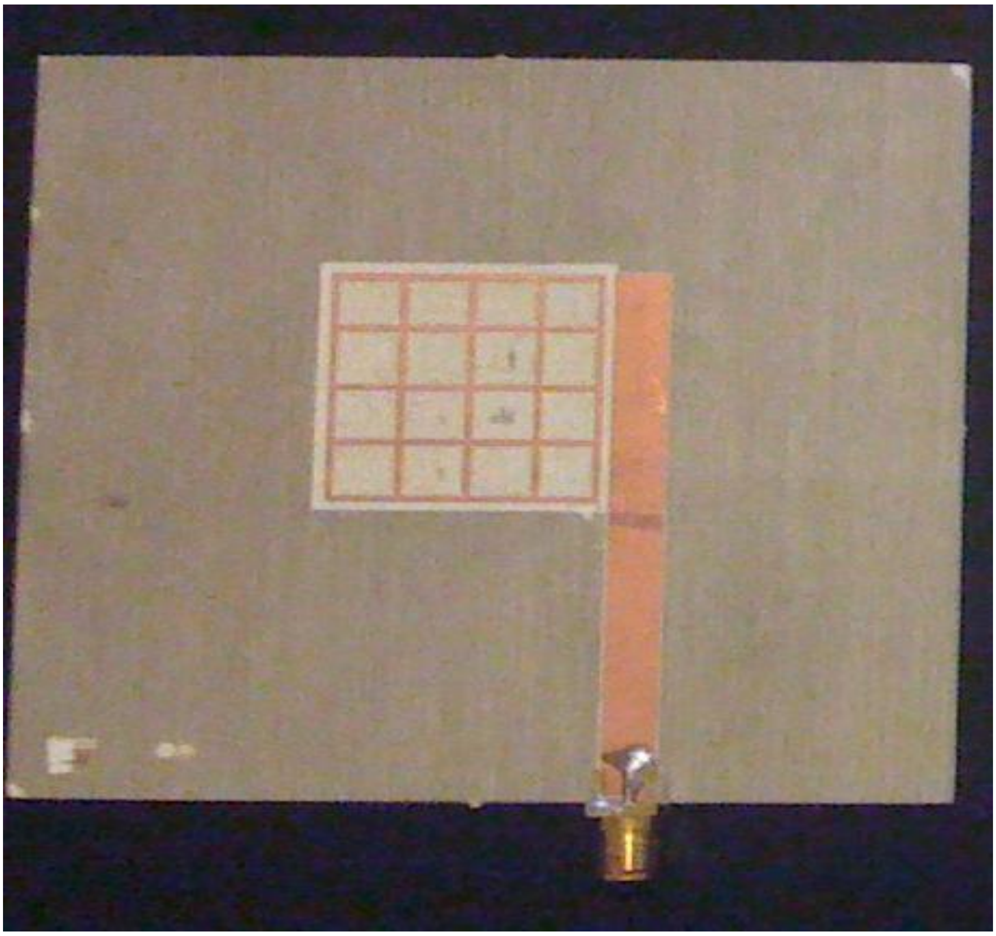


Figure 4: Meshed and solid patch antennas resonant at 2.4 GHz

1.3 Integrated Solar Cell Antennas

Integrated solar cell antennas have been developed with great success. They provide virtually no obstruction or degradation to the solar cell and still are able to maintain high gains and radiation efficiency [7].The SOLANT (SOLarANTennas) design incorporates a slot antenna in the ground plane ofa solar panel [7]. With this design solar panels are able tofunction at their maximum capacity because the antenna blocks no light to the solar panel. The SOLANT design was able to achieve gains of up to 30 dBi.The integrated slot antenna design requires antennas to be custom fabricated, which is cost prohibitive for small satellites.

III. Feeding Methods For Transparent Antennas

2.1 Direct Microstrip Feed

The direct microstrip feed is the oldest and the most traditional feeding technique that workswell when the antenna can be printed on a single layer. For patch antenna designs, quarter wave transformer or inset fed techniques have been developed to provide better matching [2].These feeding techniques do not work well with meshed antennas. Visible feed lines on top ofsolar cells shadow the energy generating cells. Furthermore, the possibility of integrating meshedprinted patch antennas onto the line feed is difficult due to the fragile and unreliable bond ofmesh lines and feed. For the reasons mentioned above, alternative techniques must be employedfor optimally feeding of mesh antennas.

2.2 Coupled Microstrip Feed

An alternative approach to the direct feed described above is using a coupled feed. A passivefeed works with a rectangular patch element that is capacitive or inductively coupled to amicrostrip feed line. The capacitive coupling depends on the dimensions of the patch as well asthe width of the gap between the patch and the feed [2]. At higher frequencies, this arrangementhas very low coupling and bandwidth.Proximity fed antennas are a good alternative to more common direct feed methods due tothe absence of direct connection between the antenna and the feed line. This type of coupledfeed mitigates some difficulties between meshed copper bonding and frees up more solar cell areafor increased power efficiency.

2.3Passive feed method for meshed microstrip patch antennas

Recent advancements in transparent patch antenna designs have enabled the placement ofantennas above the surface of solar cells [9] and on transparent surfaces, such as automobilewindows [4]. Optically transparent antenna designs can be made of see-through meshed forms[9] or out of transparent materials such as Indium Tin Oxide (ITO) [8]. Much of the difficulty offeeding these antennas is attributed to the poor bonding of conductive materials, such as copper,to feed meshed see-through patch antennas. Furthermore, when implementing antenna arraysthe difficulty of feeding optically transparent microstrip patches without blocking the powerharvesting area of a solar cell can also be a challenge. Notwithstanding these shortcomings, aco-planar electromagnetically coupled passive feed method for transparent antennas can be considered.This feed is inexpensive and easy implementation of a feed line that can be usedtopically on solar cells or other transparent surfaces without blocking its light transmission.

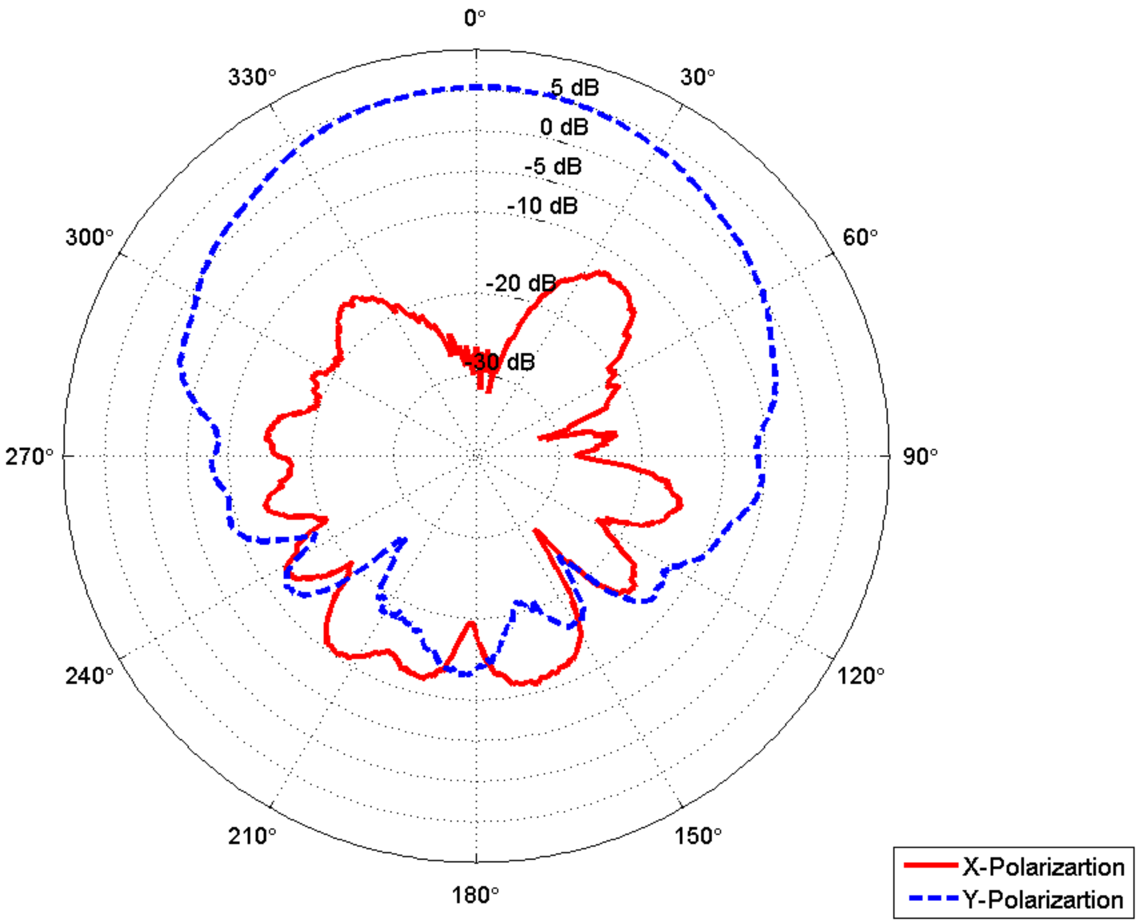


Figure 5: Radiation pattern of E-Plane in dB of a solid patchantenna fed through a passivefeed with an inductive configuration

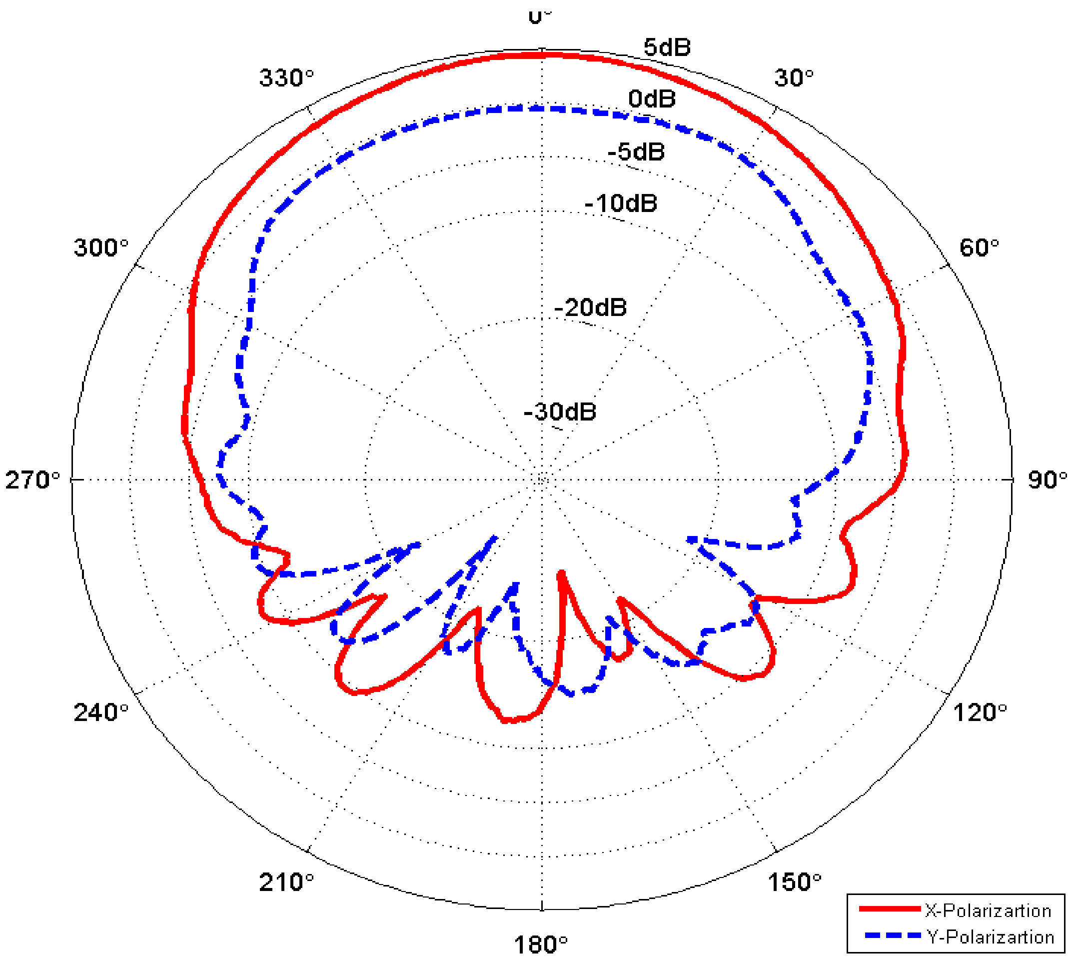


Figure 6: Radiation pattern of E-Plane in dB of meshed patch antenna fed through a passivefeed with a capacitive configuration

2.4 Co-planar Electromagnetically Coupled Feed

A common configuration of a passive coupled feed is addressed as a two layer structure wherethe feed line is placed underneath the antenna [2]. In case of feeding antennas placed on anexisting structure such as a solar cell, coupled feeds must be modified to feed the antenna from its side.

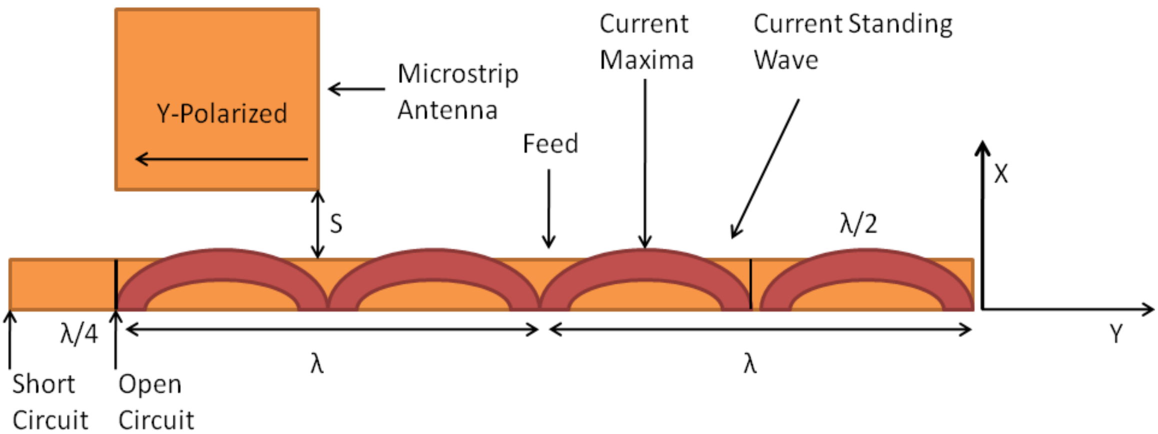


Figure 7: Geometry of a co-planar electromagnetically coupled feed

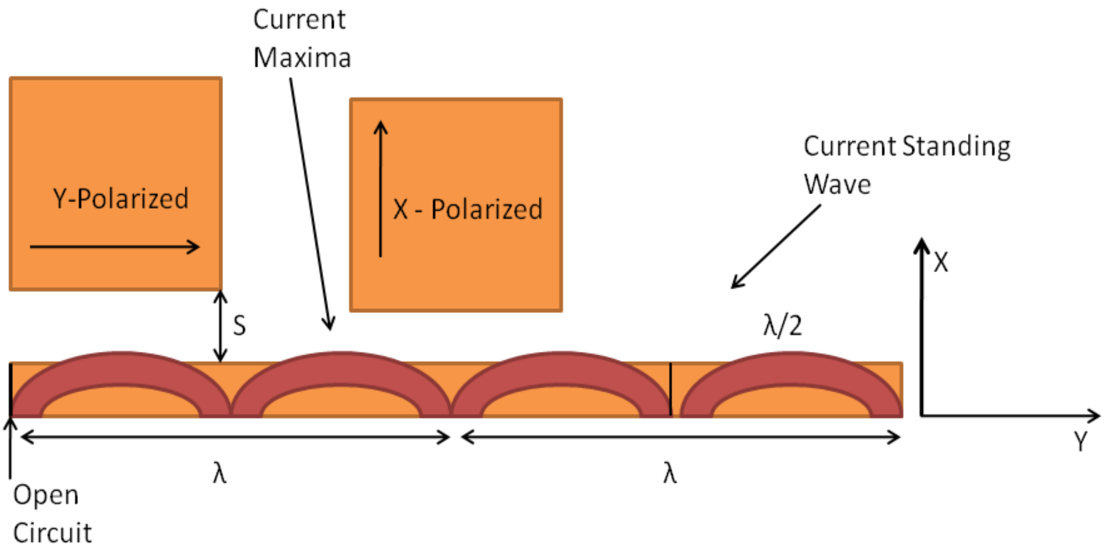


Figure 8: Direction of polarization for different rotation rectangular microstrip patches

IV. Future Work

Although this paper has mainly discussed the use of transparent antennas on solar cells, theapplicationfor such antennas is not limited to solar cells on small satellites. These transparentantennas can be also used in other areas such as windshields of cars and even as transparent circuits. The present state of TCOs has not matured enough to allow the implementation of TCOs in antenna design at microwave frequencies of 100 MHz to 10GHz but can be used at frequencies above 10GHz. This work gives some guidelines and requirements sothat antenna engineers and material's scientists can push the boundaries and enable the usageof such materials. The use of transparent TCOs can enable implementation of transparent RFcircuits for aviation, transportation and consumer electronics. Once TCOs are improved for useat frequencies of 300MHz to 10 GHz, the implementation of passive feeds will help with additional challenges such as bonding of TCOs to copper. Furthermore, co-planar coupled feeds can be used to feed materials that are more difficult to bond, such as the feeding of fabric antennas etc.

V. Transparent Antennas: From 2d To 3d

Transparent antennas are very attractive. They can be integrated with clear substrates such as window glass, or with solar cells to save surface areas of satellites. Transparent antennas are normally realized using (2D) planar structures based on the theory of patch antenna. The optical transparency can be obtained by fabricating meshed conductors or transparent conductors on an acrylic or glass substrate. Transparent designs using the meshed-conductor approach are straightforward because optical signals can pass through the opening of the meshes, while microwave signals can be transmitted or received by the conductors. The transparency and antenna property can be optimized by refining the width of the mesh. In the transparent-conductor approach, transparent conductive films are used as radiators. Commonly used transparent conductive films include indium tin oxide (ITO), silver coated polyester film (AgHT), and fluorine-doped tin oxide (FTO). A sheet resistance of at least 1-2 ohm/square is required to obtain an optical transmittance of around 70%. However, antennas made of such transparent conductor films are not efficient because of the high sheet resistance. This is one of the major obstacles to the widespread application of transparent antennas.

For a long time, transparent antennas have been of planar (2D) structures. Very recently, 3D transparent antennas have also been developed. This is a new topic. The principle of 3D transparent antenna is based on the theory of dielectric resonator antenna; the resonance is caused by the whole 3D structure rather than a confined cavity as found in the patch-antenna case. For glass, it is usually assumed that its refractive index is ~1.5, giving a dielectric constant of ~ 2.25. This value is too low for a DRA to have good polarization purity. However, it was generally overlooked that this dielectric constant was obtained at optical frequencies instead of microwave frequencies. Recently, a dielectric constant of ~7 was measured for glass at 2 GHz and this value is sufficient for obtaining a good radiator. Since crystals are basically glass, they can also be used for antenna designs. It has been experimentally found that the lighting and antenna parts do not affect each other because they are operating in totally different frequency regions. Finally, 3D transparent antennas can be designed as aesthetic glass (or crystal) wares or artworks. This idea is especially useful when invisible antennas are needed due to psychological reasons.

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