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A Review on Optically Transparent Antenna

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Abstract—*In this paper, the antennas that have the transparency in the visible region of human eye are explored. Ways of achieving transparency and there various ways of feeding developed are discussed. A survey is carried out on enhancing the efficiency of the optically transparent antennas and there ways of fabrication. The current and the future perspective of the optically transparent antennas are discussed lastly.*

1. INTRODUCTION

With the advent of the microstrip patch antennas by Sir Deschamps in 1953 [1], the antenna technology got paved in a new track of its development, which suitably caters to meet the recent requirements of mobile communication systems because of its advantages such as low profile, light weight, compactness etc. But day to day growing need for the wireless communication technology requires lager spectrum for its better outreach to each individual. Hence there lies a requirement of mounting more antennas, which again had to face the problem of space constraint. Later on, efforts were emphasized on mounting the antennas on the glass panels of buildings, automobiles windows, etc.[2] where there lies some void space with very less inbuilt materials other than glass; this also meets the requirement of being optically transparent in nature required for some certain communication systems. This mounting of antennas on such without deviating much from its transparency results as the creation of the concept of the transparent antennas.

2. ACHIEVING OPTICAL TRANSPARENCY IN ANTENNAS

The concept of optically transparent antenna (OTA) got initiated from see-through antennas [3, 4] which were developed during the early 1990's after the works reported on dichroic microstrip antennas [5] in the late 1980's. The see through antennas share the same concept of geometrical structure as that of the dichroic antenna which are designed with meshed structure comprising of fine conducting strips, rather than a continuous metallic distribution, mounted on transparent dielectric. Works were reported by *Koichi Ito et al.* on see through antennas with different meshed spacing which was further made transparent by the use of fine parallel lines instead of mesh. It was observed that with the increase in the mesh spacing the bandwidth increases with a declination in its gain. However, as reported, the gain was improved by about 5dB by plating the mesh spacing with silver instead of nickel [4]. The cross-polarization can be enhanced by selecting the proper meshed line width where the co-polar pattern remains almost the same. It also reduces the resonant frequency down by 20% which again can be a technique for size reduction [6]. Being transparent, research are going to integrate it over the solar cell for its used in the satellites solar panels. The transparency of a meshed antenna is defined as the percentage of the see through area of the patch and can be derived as [7];

$$A_{trans} = \frac{A_{antenna} - A_{metal}}{A_{antenna}} \times 100\,\% \qquad (1)$$

The transparency of an antenna can also be achieved by the use of transparent conductive material prepared with oxides of zinc, cadmium, tin, indium, AgHT, flourine doped tin etc. Although, these materials are widely used in different applications such as solar cells, electromagnetic shielding and touch panel controls [8]. Attempts have been carried out for using these materials as a core product on designing OTA. From literature it has been found that the first optically transparent microstrip antenna was reported by *Simons* and Lee designed by using transparent conducting material (AgHT-8 optically transparent conductive coating on a polyester sheet) [9]. Various works on designing OTA with different optically conductive material has been reported from time to time [10-14]. In attempt to make the antennas optically transparent by using transparent conductive material, one has to face various limitations of the material itself. Skin depth losses are introduced while seeking a high optical transparency, which stuck with the requirement of thin transparent conductive oxide deposition which again reduces the antenna efficiency. Further the efficiency of the OTA get reduces due to the ground-effect losses in the ground plane and increase in the surface resistance due to relative low conductivity [15]. It is observed that a high transparency (about 95%) can be achieved with the specific resistance of a film exceeding 5 ohm per square. The resistance of a square metal surface when the film thickness'd' is greater than the skin depth 'δ' can be estimated from the *Leontovich* boundary condition as [16];

$$R_o = R_m \delta / d \qquad (2)$$

where

$$R_m = 34.41\sqrt{\mu_r / (\sigma\lambda)}$$

$$\delta = 1/\sqrt{\pi_r f \mu \sigma}$$

$\boldsymbol{\mu_r}$ = relative permeability of the metal

$\boldsymbol{\sigma}$ = specific dc conductance (S/m)

3. FABRICATION METHODS

From the above stated discussion it is obvious that there will be some trade-off between the spectral and electrical performance while designing an optically transparent antenna. So it will be an utmost importance for a designer to have a careful consideration and look upon the requirement while designing an OTA. This designing part also includes the fabrication techniques; various ways of fabrication methods that has been reported for fabricating OTAs are discussed in this section.

4. INK-JET PRINTING PROCESS

It has been reported that the OTA fabrication can be achieved through ink-jet printing process by *Yasin et al.* [17]. The antenna was fabricated on a polyethylene terepthalate transparent sheet using silver conductive ink. Using this fabrication technique it is possible to create antenna flexible in nature with very fine geometry as well as variety of shapes. Same techniques have been adopted by *Khaleel et al.* for characterization of polyamide film and conductive inks [18]. One more advantage of this technique is that conformal antennas can be fabricated easily than the other conventional methods. However, the drawback of this fabrication process is its high cost on pursuing the printer as well as high volume manufacturing becomes impractical.

5. REMOVAL PROCESS

This process of fabrication is a cost effective one dealing with standard photolithographic wet etching process. Firstly, the conducting metal is deposited over the substrate using sputtering process and then by using photolithographic wet etching the unwanted portions are etched away which results in a grid design. *Hautcoeur et al.* used gold on a piece of corning glass substrate for designing a meshed monopole antenna in the 60 GHz ISM band which shows a similar electrical characteristics with that of and conventional monopole in the same range of operating frequency [19].

6. THIN FILM DEPOSITION TECHNIQUE

This technique is generally used for fabricating the OTA with transparent conductive oxides. These types of metal oxides are usually deposited within a high vacuum chamber by electron beam evaporation process or by sintered or metallic magnetron target [20]. Using these techniques the metal oxides can be deposited on various types substrate material including polyamide.

7. FEEDING OF THE OTA

In any antenna communication systems the feeding or exciting the radiative element plays a crucial role. Unlike the conventional patch antenna designed by using pure metal one have to face the limitations of soldering the SMA port to a transparent oxide. In this situation the meshed antenna has its advantage over the other OTA's designed by using transparent oxides. Basically most conventional type of feeding antenna feeding is done at the edges or the coaxial probe feeding, since the meshed antenna comprises of metallic lines the feeding line can be directly attached to the antenna at the edges or even it can be drilled at the required position having a junction for placing the probe.

B. Levin et al. reported a work on a conical feed transparent antenna where the transparent radiative film is excited via two conical shaped metallic strips placed at the edge of the transparent film making it suitable for UWB applications. The use of the conical shaped metallic sheets for feeding transparent metal has the advantage of creating a uniform distribution of currents along the radiator cross section [21]. A nonthermal soldering method has been introduced by *T. Peter et al.* for feeding the radiator with the SMA port where a coat of silver paint is used on the exposed areas for making the connection [22]. This improves the connection performance of the OTA over the conventional soldering technique.

8. TECHNIQUES FOR IMPROVING EFFICIENCY OF OTA

Due to the reduction in the conducting area of the meshed antenna and the inbuilt material property of transparent conducting oxides, the OTA faces degradation in its performances. However, with a little trade-off with its transparency the efficiency of an OTA can be enhanced up to a reasonable level. The efficiency of a meshed antenna can be enhanced by decreasing the mesh spacing that is by increasing the number of grid lines which again leads to decrease in its transparency [4].

The efficiency of the OTA fabricated by using transparent conducting oxides can be enhanced by increasing the mobility as well as by increasing the electron density of the metal oxides. This will meet the requirements of the electrical conductivity with a decrease in the surface resistance. *Mohammad R. Haraty et al.* shows an increase in the gain of an OTA by using gold nano layer deposition over the ITO which is due to the decrease in the ohmic loss of the antenna [23]. Moreover, the efficiency of OTA can be increased by applying a highly conductive coating in the form of very narrow strip to the selective areas of high current densities [24].

9. CURRENT AND FUTURE PERSPECTIVE OF OTA

Requirement of mounting antennas over constraint volume is becoming a challenge for the antenna designers nowadays. However, attempts are made for designing optically transparent antenna to overcome such limitations. Research is going for enhancing the performance of the antennas. OTAs are being reported for its use in applications such as ultra wide band application, wireless access point, energy harvesting, automobile applications [25-27]. The OTAs are being integrated over the solar panels of the satellites, which solve the problem space constraint and helps in miniaturization of the satellites [28-30].

Overcoming the intrinsic limitations of the transparent conducting oxides such as low electrical conductivity, high surface resistance, ground-effect losses might turn the transparent conducting oxides into a potential commercial product for efficient designing material of the OTA. Further, improvement in the feeding techniques and other new upcoming ideas for enhancing efficiency will surely impose a positive impact on the development of OTA.

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