Superstrate Layer in Patch Antenna- A Review

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Abstract - Today's Communication devices support several applications which require higher bandwidth; such as mobile phones these days are getting thinner and smarter, but many applications supported by them require higher bandwidth. So micro strip antenna is used for performing these operations as their size is compact and they have a light weight. But this antenna when compared with other antennas has some drawbacks like narrow bandwidth, low efficiency and low gain. Various methods and techniques have been used to remove these drawbacks. One of the methods used to increase the efficiency and directivity of the antenna is the use of a superstrate layer. In this paper a review of different techniques used for compact and broadband microstrip patch antenna using superstrate layer is given.

Keywords – Microstrip patch antenna, Superstrate layer, EGB structure, Microwave Antenna, Mobile device antenna.

I. INTRODUCTION

A microstrip patch antenna is a narrow band, wide-beam antenna fabricated by etching the antenna element pattern in metal trace bonded to an insulating dielectric substrate with a continuous metal layer bonded to the opposite side of the substrate which forms a ground plane. Though the patch antenna has many advantages like light weight, low volume, low profile, ease of polarization, etc. it has some major drawbacks like low impedance bandwidth and low gain. Various methods and techniques have been used to remove these drawbacks. One of the methods used to increase the efficiency and directivity of the antenna is the use of a superstrate layer [1].

Superstrate layers or earlier known as cover layers, were first used to protect printed circuit antennas (PCA's) from environmental hazards, or were naturally formed (e.g. ice layers) during flight or severe weather conditions. Till then it was thought that this layer was adversely affecting the performance characteristics of the antenna. Only after the year 1985, it was discovered that the superstrate layer may prove beneficial or detrimental to printed antenna radiation characteristics, depending on the thicknesses of the substrate and cover, as well as relative dielectric and permeability constants [2].

II. SUPERSTRATE

The characteristics of superstrate layer were first studied in the year 1985 by David. R. Jackson. It was then found out that if a superstrate of proper parameter is taken then there is a vast increase in gain. This method was known as the resonance gain method, and it utilized a superstrate with either relative permeability **μ>>1** or relative permittivity **ε>>1**. According to this research by choosing the layer thicknesses and dipole position properly, a very large gain may be realized at any desired angle θ. This gain varies proportionally to either ε or μ, depending on the configuration. However, it was seen that the bandwidth was inversely proportionate to gain.

In 1985 another paper was published by David. R. Jackson [5] where he purposed some asymptotic formulas for resonance gain, beam-width and bandwidth. This paper highlighted the importance of refractive index of the substrate.

As the popularity of superstrate layer was increasing its effects on various other parameters were researched. Wen-ShyangChen and others published a paper in 1994 on the loading effects of superstrate layer on circular polarization. In this study two cases of a superstrate loading were discussed, in the first case the superstrate layer is directly loaded on the patch and in the other case the superstrate spaced away from the patch with a distance of a half wavelength or its multiples. In the latter arrangement, the superstrate not only serves as protecting layer, but also acts as a directive parasitic antenna, which considerably enhances the antenna gain. Fig. 1 shows the geometry of a superstrate-loaded rectangular patch antenna. The rectangular patch is with a dimension of L x W (4.26 cm x 4.152 cm) i.e. the aspect ratio (L/W) is 1.026. It is located on a grounded substrate at z = d. The substrate (region1) is of thickness d and the relative permittivity ε_1. The superstrate (region 3) is of thickness t and relative permittivity ε_3. The air is in region 2 and 4 with permittivity ε_0 and permeability μ_0. The patch is also assumed to be probe-fed at the position x_p, y_p(-0.49 cm, -0.477 cm), which corresponds to at the position about 0.385 times AC on the diagonal line.

In case of two-dimensional image, after a DWT transform, the image is divided into four corners, upper left corner of the original image, lower left corner of the vertical details, upper right corner of the horizontal details, lower right corner of the component of the original image detail (high frequency). You can then continue to the low frequency components of the same upper left corner of the 2nd, 3rd inferior wavelet transform.

The center operating frequency is 2131MHz. Under the above design parameters, the radiated fields of the patch antenna at $\theta = 0^O$ are with a 90^Ophase difference and unity axial ratio (or zero in dB). A protecting dielectric superstrate is then placed on the top of the patch with an air gap of the thickness. Two conditions of s=0 and s=0.5n$\lambda_o$were investigated.

It was seen that when the superstarte layer was spaced away from the patch, the loading effects on the antenna were considerably reduced. In this case the centre frequency for the CP radiation was slightly varied, and the 3 dB bandwidth and optimal feed position were almost not affected. For higher air gap thicknesses, the main-beam polarization property was also better [6].

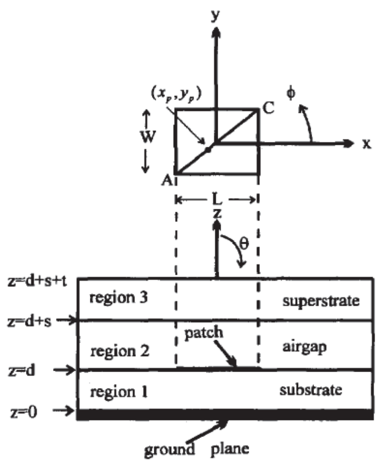

Figure 1. Geometry of the rectangular shape antenna used by the researchers.

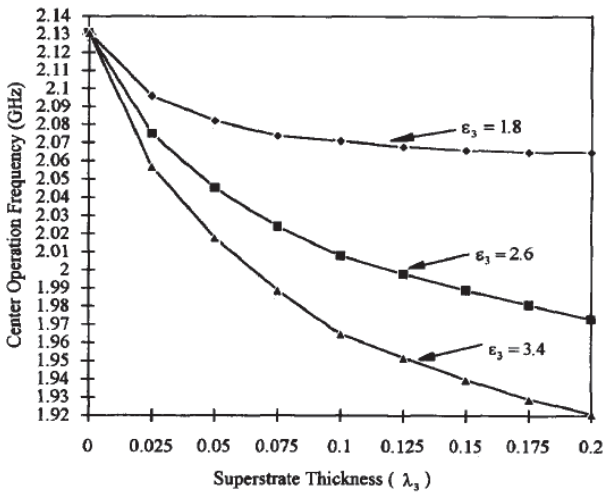

Figure 2. Variations of the centre operation frequency with superstrate thickness for ~3 = 1.8, 2.6, and 3.4; s = 0, d = 0.24 cm, €1 = 2.6, L= 4.26 cm, W = 4.152 cm.

By the year 2009 metamaterials such as electromagnetic band gap (EBG), Frequency selective surface (FSS), partially reflecting surface (PRS) and other periodic artificial material based on the low or zero refractive index, showed their predominance and became a popular choice for superstrate material. But they suffered from some drawbacks like narrow impedance and gain bandwidth. So, to remove these drawbacks, adaptive FSS superstrate was developed.

Figure 2 shows the model of the directive patch antenna with adaptive FSS superstrate. The FSS superstrate is composed of periodic strips along the x direction and cut wires loaded with tuneable lumped element capacitances in the y-direction. In reality, the microwave varactors are often utilized to tune the value of the capacitance by changing the bias voltage. The entire metal pattern is etched on the printed circuit board of Rogers TMM4 with relative dielectric constant of 4.5 and a thickness of 0.5mm. The unit cell of the proposed FSS superstrate is depicted in the Fig.2 (c), and its geometry parameters are given as follows: the width of the strips and cut wires is all set to be w=3mm, the gap between cut wires is assumed to be gap=5mm and the whole dimension of the unit cell is $a\times l=28\times28mm^2$.

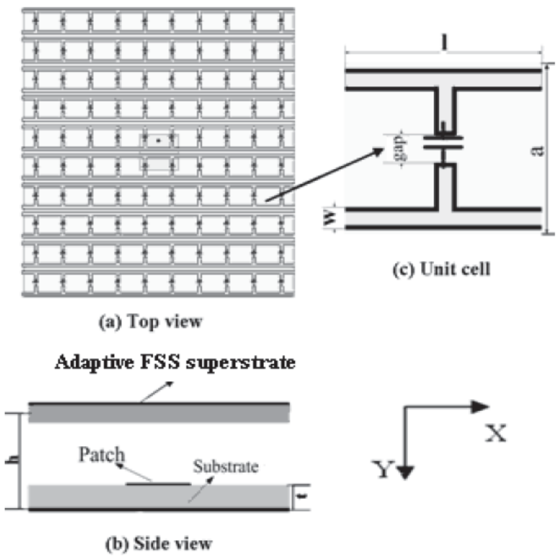

Figure 3.- Model of the directive patch using adaptive FSS superstrate. (a) Top view. (b) Side view. (c) Unit cell

It was observed that the transmission peak frequency was shifted from 2.78GHz to 2.62GHz as the capacitance value varies from 3pfd to 6pfd with a step of 1pfd. This technique showed that the loaded capacitance value can influence resonance peak frequency, when other parameters are kept fixed.It was found that the introduction of the adaptive FSS superstrate could make the antenna gain improved by about 10dB in comparison with the conventional patch antenna[7].

By now, not only many superstrate materials were developed, but various geometries were also developed and studied by many researches. Out of these designs the most popular designs are (a) dielectric layer superstrate, (b) EBG FSS layer superstrate, and (c) parasitic patch superstrate.

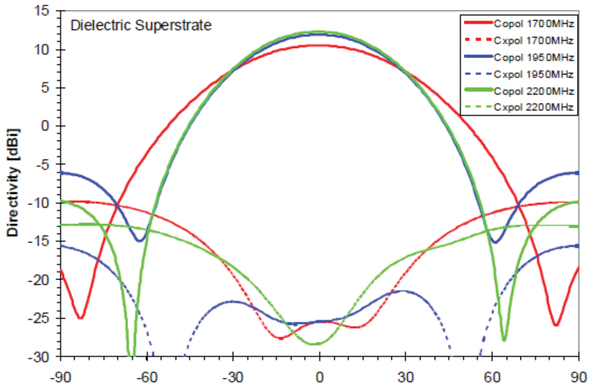

Figure 4. HFSS simulated patterns of ACP with dielectric superstrate.

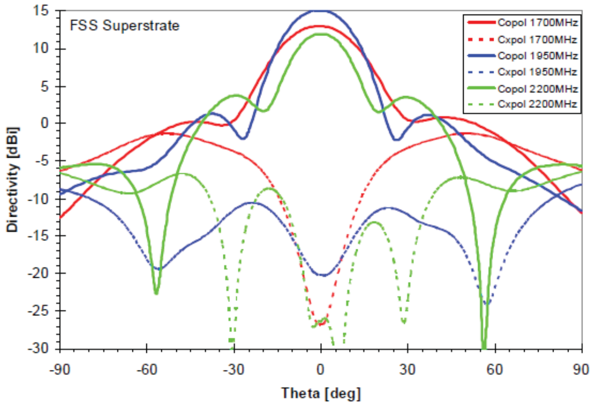

Figure 5. HFSS simulated patterns of ACP with EBG FSS superstrate.

It was seen that the gain in the overall antenna directivity of a superstrate antenna comes at the price of narrower frequency bandwidth. A dielectric superstrate tends to provide more desirable antenna performances and allow more flexibility in gain-bandwidth trade-off, while an EBG FSS or parasitic patch superstrate was more available and had a lower cost. The gain-enhancement effect of a superstrate on a large array was marginal. However, it was possible to use a superstrate to reduces can losses of a multi-beam antenna at the edge coverage[8] [12].

The next big development in superstrate came in the form of aperture coupled patch antenna which aimed for high directivity and bandwidth. These antennas could now work at broadband frequencies and mostly used metamaterials as superstrate and Electromagnetic bandgap (EBG) structures as antenna geometry. Up till now, most of the work was done onachieving wide-frequency band or multi-frequency band by a suitable design of FSS superstrate layer but now emphasis was given to the feeding source of the EBG antennas, especiallyfor the bandwidth of the return loss of the EBG antenna. With the advancement of technology the fabrication of more than one layer became possible, sonow double FSS layer structures were used to reduce the problem of directivity [9] [10] [13].

Another method to increase directivity is the use of parasitic elements. Earlier these systems suffered from the problem of low efficiency but this was resolved by using Fabry-Perot Cavity (FPC) structures. Placing superstrate above it results into increase in capacitive impedance and also has focusing effect which increases the effective aperture area thereby increasing the gain and directivity of the antenna[11].

The initial success of EBG structures led to the development of EGB substrates and perforated EGB structures. As we know in order to increase the efficiency of the antenna, the propagation through the substrate must be prohibited. The EGB structure helpsin prohibiting the surface waves of the antenna to propagate through the surface then the antenna radiates, more towards the main beam direction and hence its efficiency is increased, thereby increasing the directivity and gain.

The studies also highlighted that when the EBG material is used as superstrate, it gets illuminated by the fields radiated from the patch of antenna, and almost all of the dielectric elements of the superstrate are excited so that the field distribution on its surface is quite uniform. Now this superstrate works as an aperture antenna, the size of its aperture becomes large and this result in the drastic improvement of gain of the antenna and up to some extent bandwidth is also improved. Apart from this reduction in the side lobe was also observed[13].

The first perforated EBG structure was conceptualized and manufactured in 1991 by Eli Yablonovitchat, Bell Communications Research in New Jersey. Yablonovitch fabricated the crystal structure by mechanically drilling holes which were in millimeter radius. These holes were created into a substrate of high dielectric permittivity (perforated EBG). This structure creates a 3-D band gap. Use of this structure was not practical in few communication systems because 3-D nature of band gap reject incident energy from all directions. Today instead of 3-D, 2-D EBG structure is used in Microstrip Patch Antenna design so that incident energy in the band gap can be rejected only in one plane which is identical condition for Patch Antenna. Rejection of this energy in one plane results in improvement of operational bandwidth, gain and reduction of side lobe level [12].

The latest development in the field of superstrate is the use of graded index dielectric material. The graded index superstrate provides a matching layer with free-space and also reduces the quality factor of the dielectric resonator perpendicular to the surface with a high dielectric constant in contact with the slot antenna. The high dielectric material serves to reduce the size of the slot antenna significantly. In conjunction with the reduced aperture dimensions, the radiation pattern of the antenna is also modified. Through the application of the high dielectric constant superstrate; the slot antenna's physical dimensions are reduced to maintain the same resonant frequencies while also enhancing the antenna's front-to-back radiation efficiency. The graded index superstrate provides a matching layer with free-space and also reduces the quality factor of the dielectric resonator[14].

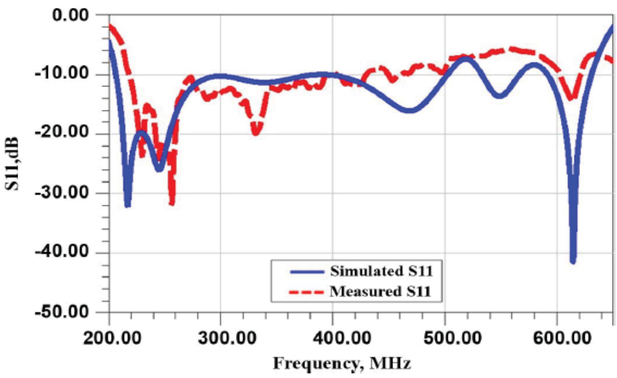

Figure 6. The measured and simulated reflection coefficient of the slot antenna with graded index and four parasitic elements.

III.CONCLUSION

In this paper various superstrate patch antennas are obtained. In particular the influence of dielectric materials along with EGB structures is projected. The simulation results shown reveal the effect of these devices on the transmission and reflection characteristics as well as overall performances of the antennas.

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