Electrically small antennas: The art of miniaturization

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Abstract— We are living in the technological era, were we preferred to have the portable devices rather than unmovable devices. We are isolating our self rom the wires and we are becoming the habitual of wireless world what makes the device portable? I guess physical dimensions (mechanical) of that particular device, but along with this the electrical dimension is of the device is also of great importance. Reducing the physical dimension of the antenna would result in the small antenna but not electrically small antenna. We have different definition for the electrically small antenna but the one which is most appropriate is, $ka < 1$ where k is the wave number and is equal to $k = 2\pi/\lambda$ and a is the radius of the imaginary sphere circumscribing the maximum dimension of the antenna. As the present day electronic devices progress to diminish in size, technocrats have become increasingly concentrated on electrically small antenna (ESA) designs to reduce the size of the antenna in the overall electronics system. Researchers in many fields, including RF and Microwave, biomedical technology and national intelligence, can benefit from electrically small antennas as long as the performance of the designed ESA meets the system requirement.

Keywords— *electrically small antenna, microstrip patch antenna*

I. INTRODUCTION

Electrically large antennas with dimensions of a portion of a wavelength are well explored for proficient launch and reception of electromagnetic signals. The half wave dipole and quarter wave antenna are typical examples. However, in some instances, distinctly in low frequency and handy applications, the dimensions of a wavelength related antenna become impractical. For these purpose the technocrats need to carved the dimensions of the antenna in such a way that it satisfies the limit of electrically small antenna. Antenna is said to be electrically small when its largest physical dimension is much smaller than the wavelength at which it operates; these antennas are commonly found in the portion of the radio frequency spectrum spanning from VLF to MF (3 - 3000 kHz). At these frequencies, such antennas are employed in maritime communications, air and coastal navigation, as well as local broadcasting. An antenna's effective electrical length can be

changed without changing its physical length by adding reactance, (inductance or capacitance) in series with it. Small loop antennas are often referred to as magnetic antennas. This is because they mostly respond to the magnetic component of an electromagnetic wave and transmit a large magnetic component in the extreme near field (<1/10 wavelength distance).

II. PROBLEMS WITH ELECTRICALLY LARGE ANTENNAS

This is the world of miniaturization technocrats want to embedded the every component into a single unit and to make it more handy as per the requirement of the changing technology.

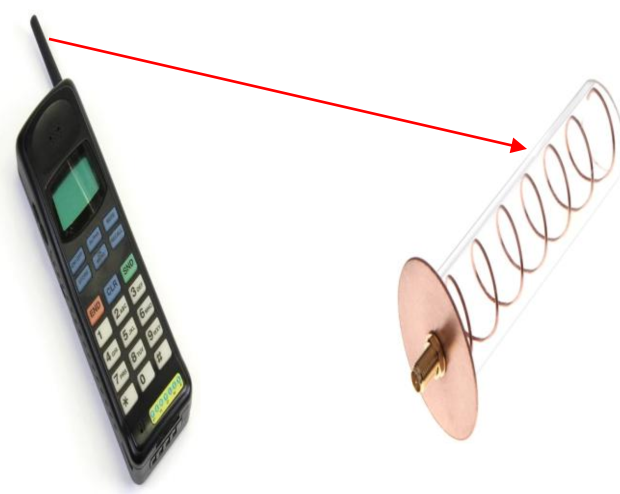

Fig-1, The antenna used in the mobile phone of 1990's.

The mobile phones which were used during the 1990's are having the antenna which is to the exterior of the internal circuitry. This makes the device looks more bulkier and perhaps the most costlier. And these types of antenna could be easily 'detuned' by the nearby objects, which is the critical disadvantage of these types of antennas. Now if we want to design the antenna for the RFID application we cannot go with the traditional design of the antenna. An RFID tag requires the

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printed antenna whose size is very small as compared to the operating wavelength of the antenna.

Again if we want to embedded the antenna in the device itself the dimension of the antenna should be compatible with the dimension of the device. Now a days the electronic devices are shrinking to such an extent that the whole accessories along with the antenna unit could be of 4.5 inch or even less than that.

Fig-2, The mobile phone of current technology.

PCS (Personal communication system) devices have become an integral part of everyday life. The need to design the light weight, small and handy mobile communication devices is increasing rapidly, which emphasizes the RF engineers to create the optimal antenna for the mobile application. Thus, the size of the electronics required for mobile application has decreased heavily during the past two decades, but the performance has increased. But the size of the antenna is not explored so far as compared to size of the electronic circuit. The dimensions of the antenna are related to the wavelength of the frequency of its operation and not with the latest technology. The antenna could be reduced but with the sacrifice of bandwidth, gain and efficiency. The technique of miniaturization dealt with the adjustment i.e the dimensions are shrinked but the characteristics changes compared to that of the large antenna.

The current technologies which demand the electrically small antenna are the MIMO system in wireless communication where more than one antenna is needed for the reception of signal. To integrate more than one antenna in such a small circuit is a tedious task, ESA being the good candidate for the MIMO system. The other application which demand an electrically small antenna is RFID, an RFID tag consist of mainly memory chip and a trans receiver the size of the tag is typically very small it is one of the growing field of digital communication the antenna used in such tag could be such that the dimensions are of less than the operating wavelength of the antenna.

III. ELECTRICALLY SMALL ANTENNA (ESA)

An ESA is an antenna that satisfies the condition $ka < 1$ 'k' is the wave number $2\pi/\lambda$ 'a' is the radius of the minimum size sphere that encloses the antenna .

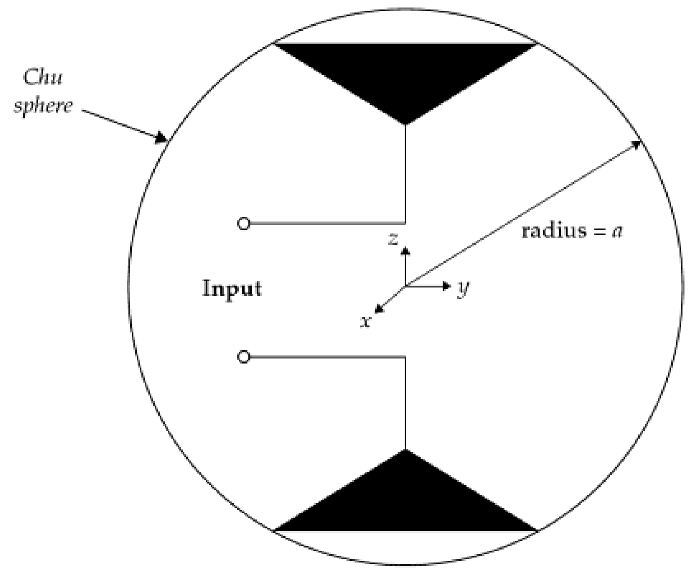

Fig-3, An Electrically small antenna, the largest dimension of the antenna are enclosed within the sphere of radius a.

The antenna here inside the imaginary sphere would be the one with such characteristics of the electrically small antenna the dimensions of which are directly related to the operating wavelength of the antenna. 62 years past wheeler published his paper which theoretically proves the fundamental limit on achievable parameter called electrically small antennas (ESAs). As the electronic devices continuously reducing in size the demand for the electrically small antenna is growing. But the miniaturization of electrically small antennas is still a challenging issue for the RF engineers because of the fundamental limits that needed to overcome for the performance improvement of ESAs. According to Wheeler's paper an ESA is one whose maximum dimension is less than $\lambda/(2\pi)$. This relation is often expressed as: $ka < 1$. $k = 2\pi/\lambda$, λ is the free space wavelength, a is radius of sphere enclosing the maximum dimension of the antenna. One year later to the publication of Wheeler's work, Chu derived a theoretical relationship between the dimensions of an antenna and its minimum quality factor. This relation can be expressed as Qchu = $1/(ka) + 1/(ka)3$. With decreasing electrically size, ESAs exhibit decreasing radiation resistance, increasing reactance, decreasing efficiency, and an increasing Q, which is

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equivalent to a decreasing bandwidth. ESAs are high impedance mismatch relative to the characteristic impedance of common transmission lines.

IV. DESIGN OF ESA FOR GPS APPLICATION

The technocrats in the past two decades have diverted their attention towards the microstrip patch antennas only because of the numerous advantage related to this particular type of antenna it had got the planar geometry which make it to be easily integrable with the existing circuit of application. Presently this field has been considered as one of the influential field of the antenna engineering. A unique and elementary single band antenna is presented which is fed by a 50 ohm coaxial line having a low-profile antenna structure with meandering the portion of the patch In this research, a meandered line electrically small microstrip patch antenna is designed having the return loss bandwidths which suits for GPS application (GPS L5 1.176 GHz) and having the frequency band range from 1167 MHz to 1187 MHz and the resonating frequency is at 1176 MHz, the simulation results for return loss, impedance bandwidth, radiation patterns, and gain are also discussed herein. Meandering line are adopted to disturb the flow path of the surface current, by ultimately offering the local inductive effect.

An electrically small antenna is being designed to operate within the limits of the acceptable frequency. The synthesis of more than one antenna for MIMO (multiple input multiple output) application in each mobile terminal is a challenging task. Electrically small antennas are the right applicants for these applications. Meander line antennas are typical electrically small antennas which are being preferred in MIMO systems. The electrically small antenna is developed by meandering the line from the patch.

Designing of the Antenna

i) Designing of the width of the

$$w = \frac{c}{2fo\left(\sqrt{\frac{\epsilon r+1}{2}}\right)} \qquad [1]$$

Here, fo is the center frequency, εr is relative permittivity and c is the speed of light.

$$leff = \left(\frac{c}{2fo\sqrt{\epsilon reff}}\right) \qquad [2]$$

$$\epsilon\, reff = \frac{\epsilon r+1}{2} + \frac{\epsilon r-1}{2}\left(\frac{1}{\sqrt{\frac{1+12t}{w}}}\right) \qquad [3]$$

$$\Delta L = 0.412t\left(\frac{(\epsilon reff+0.3)\left(\frac{w}{t}+0.264\right)}{(\epsilon reff-0.258)\left(\frac{w}{t}+0.8\right)}\right) \qquad [4]$$

$$L = Leff - 2\Delta L \qquad [5]$$

Equation [2] – [5] are used for designing the length of the patch. Also t is the thickness of the substrate which is taken as 1.5mm

Here in the design we have meandered the patch just to make it compact and to reduce the dimension just to integrate the antenna with the thickness of the mobile devices bearing thickness less than 1cm. Top view of the design is shown in figure 4.

TABLE I
DIMENSION LIST

Title	Measurement
Length of the rectangular patch (L)	25mm
Width of the rectangular patch (W)	25mm
Substrate thickness	1.5 mm
Dielectric Constant of Substrate	4.4

TABLE II
MATERIAL LIST

Title	Material
Patch	PEC
Substrate	FR-4 Epoxy
Ground	PEC

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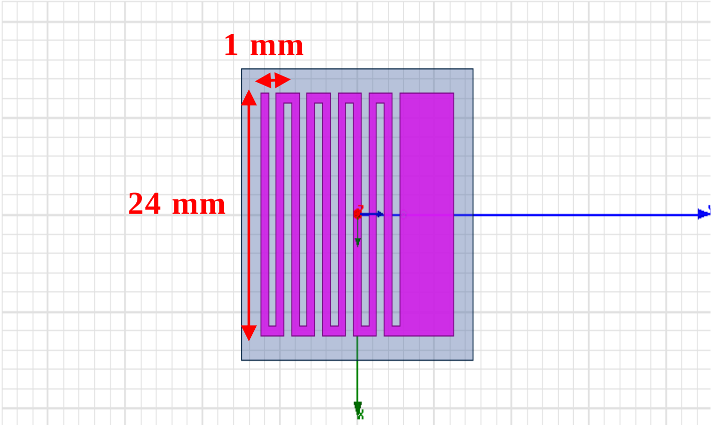

Fig-4, Top view of the proposed design of electrically small antenna.

From the patch nine (9) slots of 24 x 1 mm^2 is being meandered to enhance the path for the surface current flow and to have the better fringing fields out of the radiating patch and hence to improve the radiation characteristics of the electrically small microstrip patch antenna.

Simulation results and Discussions

The simulation of entire stuff is completed on HFSS 14, it is one of the best accepted simulator of the RF antenna worldwide and in industries too. Figure 2 shows the Return loss (S11) of the design the return loss we are getting is around -12dB for the center band frequency of 1.176 GHz for GPS application.

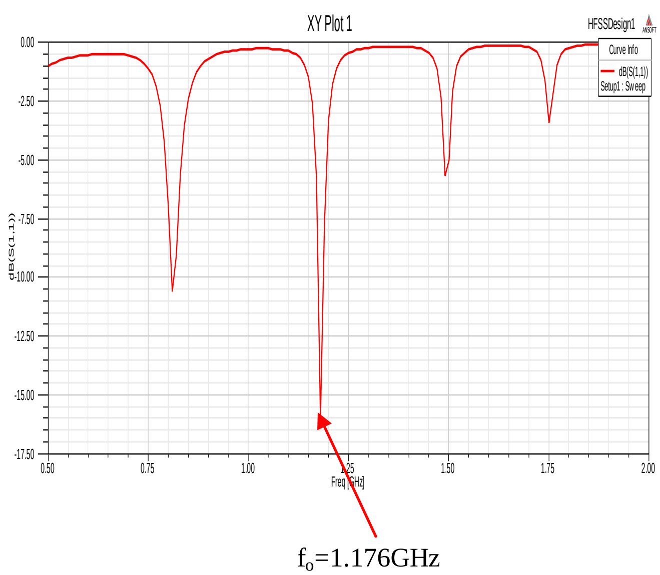

Fig-5,Return loss (S11) of the Meandered ESA.

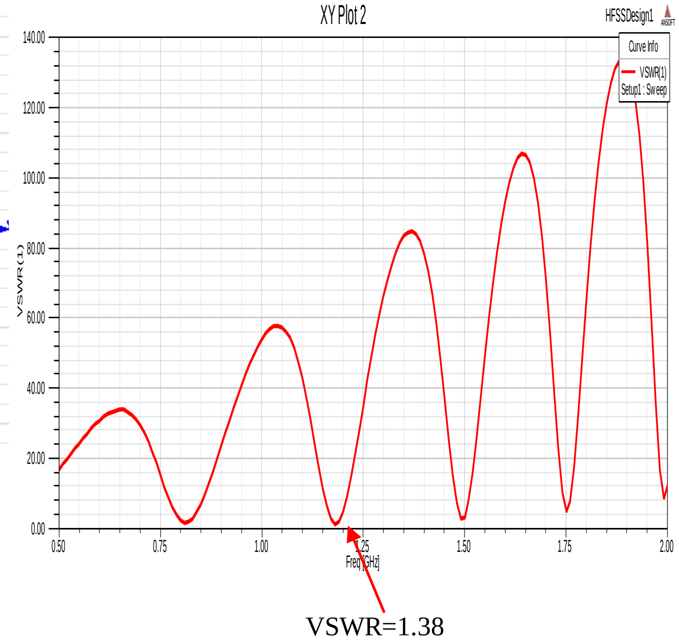

Fig-6, Plot of VSWR of the meandered ESA

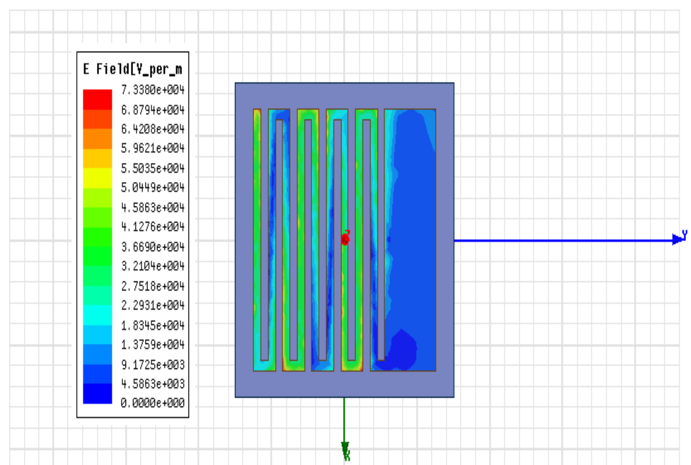

Fig-7 plot of Electric field intensity (V/m) of electrically small antenna

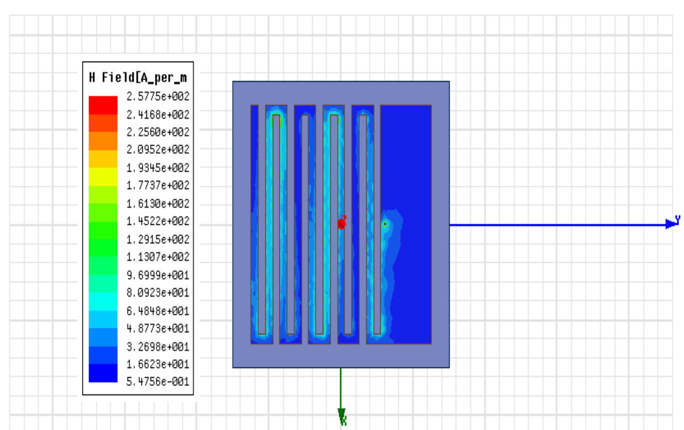

Fig-8 Plot of Magnetic field intensity (A/m) of electrically small antenna

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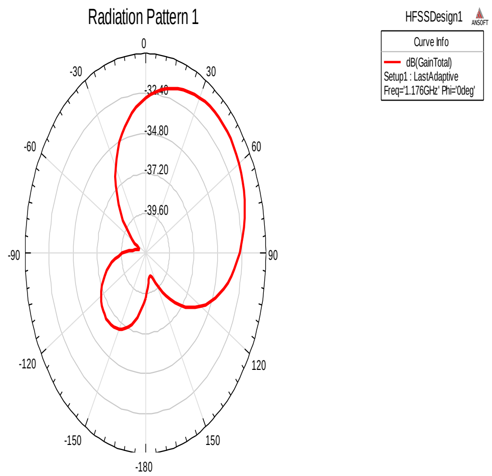

Fig-9, Radiation Pattern Of the Meandered Line Patch Antenna.

V. Conclusion

Micro strip patch antenna is one of the dynamic fields in the RF; these antennas have the great potential to cope up with any application because of their numerous advantages. A meandered line electrically small micro strip patch antenna is designed and simulations results show that this antenna would give optimum performance with the GPS application of center frequency of 1.176 GHz. The Return loss of the antenna is below -10dB from 1.167 GHz to 1.187 GHz. The antenna is electrically small having ka = 0.51, which is good candidate for the integration with the present day technology.

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