Microstrip Patch Antenna: Comparing Performance of a Rectangular and a Circular Patch at LTE Bluetooth and GSM Frequencies

Nsikan Nkordeh, Francis Idachaba, Oluyinka Oni

ABSTRACT: The demand for smaller, conformable antennas with desired properties has made antenna Engineers to device better ways of making antennas. The patch antenna comes to the rescue, as it provides the features needed in antennas used in the telecoms, meteorological and military industries, where light weight low profile antennas are required. The Microstrip patch antennas comes in different shapes and configuration, the most common being circular and rectangular. This paper takes a close look at the performance characteristics of the rectangular and circular Microstrip antennas , comparing different antenna parameters like directivity, E and H planes Half Power Beam Width (HPBW) vis-à-vis the dimensions and size(area of patch). Five frequencies (0.9Ghz,1.8Ghz ,1.9Ghz and 2.3Ghz and 2.4Ghz) are used in computing the configurations-these frequencies correspond to that of GSM, LTE and Bluetooth ; results from this paper can be used in building practical antennas for phones and laptops or any Bluetooth enabled device.

***Keywords*: Microstrip Patch Antenna, Rectangular, Circular Patch, Dielectrics.Directivity**

I INTRODUCTION

Microstrip antennas are desirable due to their light weight, conformability and low cost. The Microstrip antenna is made up of a very thin metallic patch placed a small fraction of wavelength above a ground plane in a dielectric substrate ($h < \lambda_{o,}$ usually $0.003\ \lambda_o \leq 0.005\ \lambda_o), where \lambda_o =$ free space wavelength. For example the rectangular patch antenna is approximately a-one half wavelength long section of a rectangular Microstrip line [1]. Microstrip Patch Antenna are typically used at frequencies between 1GHz to 100GHz.[1] .The Microstrip patch antenna is designed so its pattern maxima is normal to the patch; this can be achieved by choosing the appropriate excitation technique.

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The Microstrip patch antenna consist of a radiating patch on one side of the dielectric substrate which has a ground plane on the other side. Microstrip Patch Antennas come in conformable shapes like square, rectangle, elliptical, circular etc.

Microstrip Patch Antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. In the design of patch antennas, there has to be a compromise between the antenna's dielectrics value, dimensions (i.e. thickness and size) and the antenna performance-these variables affect the antenna performance. For good antenna performance, a dielectric with low value but high thickness is required, as this provide better efficiency, larger bandwidth and better radiation. However, such a design leads to antenna of larger size. In order to reduce the size, a higher dielectric constant should be used, but this results in a Microstrip with less efficiency and narrow bandwidth due to its high quality factor [[5]

Some advantages of Microstrip Patch Antenna

-Light weight and low volume

-Supports both dual and triple frequency operation

-Supports both linear and circular polarization

-low fabrication cost

-low profile planar configuration

Major disadvantages of MPA

-Narrow bandwidth

-Low efficiency

-Low gain

-Extraneous radiation from feeds and junctions

-Poor end fire radiator except for tapered slot antenna

-Lower power handling capacity

-Surface wave excitation

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Microstrip Patch Antenna generally have very high quality factor (Q) .High Quality factor, which is inherent in Microstrip Patch Antenna leads to lower efficiency and narrow bandwidth. The Quality Factor represents the loss associated with the antenna; increasing the thickness of the dielectric substrate will reduce Q, but this will increase the size of the MPA. The surface wave contribution responsible for high Q can be reduced by the use of photonic bandgap structure [3]. To achieve high performance like high bandwidth, high efficiency, high gain vis-a-vis a conformably small size, the feeding method used is very important

II OPERATION OF A MICROSTRIP PATCH ANTENNA

A Microstrip Patch Antenna is made of a radiating patch placed on a dielectric substrate, with a ground plane on the other side. The EM waves fringe off the top parts into the substrate, reflecting off the ground plane and radiate off into the air. Electromagnetic radiation occurs mainly due to the fringing fields between the patch and the ground at the edges; this is because the dimensions of the patch are finite along the length and width. The amount of fringing depends on the ratio of patch length (L) and substrate height (h) . Since for Microstrip antennas $L/h \gg 1$, fringing is reduced; this must be taken into account when designing as this influences the resonant frequency of the antenna. The region between the conducting patch and the ground plane acts as the region between a transmission line and the ground plane with both ends open, which leads to a standing waves in the dielectric. In designing a Microstrip Patch Antenna, we obtain both the effective dielectric constant (ε_{reff}) and dielectric (ε_r)[6]. The ε_{reff} is needed to account for the fringing fields and the wave propagation in the line. Most of the fields lie in the substrate while others line in the air; the phase velocity in air and in the substrate will be different, which makes it impossible for it to support pure Electric-Magnetic (TEM) mode of transmission. In analysis, we assume the quasi-TEM mode of transmission.). The value of the effective dielectric constant is usually constant at low frequencies, increasing monotonically as frequency increases, and ends up approaching the value of the dielectric constant at higher frequencies. For $W/h > 1$,

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \qquad (1)$$

The fringing effect causes the Microstrip patch look electrically bigger than its physical dimensions. In the analysis of the Patch, we take this into account by assuming an extension to the patch at both ends (for rectangular /square patch) ΔL; ΔL is a function of the effective dielectric constant, ε_{reff} , and the width-to-height ratio (W/h) and can be represented by the ratio

$$\frac{\Delta L}{h} = 0.412\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \qquad (2)$$

For the dormant TM_{010} $mode$,the effective Length of the patch is given by

$$L_{eff} = L + 2\Delta L \qquad (3)$$

The resonant frequency is given by

$$(f_r)_{010} = \frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_0\varepsilon_0}} = \frac{v_0}{2L\sqrt{\varepsilon_r}} \qquad (4)$$

v_0 is the velocity of light in free space. Equation (4) does not take account of the fringing effect. When the fringing effect is taking care of, (4) becomes

$$(f_{rc})_{010} = \frac{1}{2L_{eff}\sqrt{\varepsilon_{r\,eff}}\sqrt{\mu_0\varepsilon_0}}$$

$$= \frac{1}{2(L + \Delta L)\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}}$$

$$= q\frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_0\varepsilon_0}} = q\frac{v_0}{2L\sqrt{\varepsilon_r}} \qquad (5)$$

Where

$$q = \frac{(f_{rc})_{010}}{(f_r)_{010}} \qquad (6)$$

q is called the fringing factor, i.e length reduction factor.

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Note: As the substrate height increases, fringing also increases and leads to larger separation between the radiating edges and the lower resonant frequencies.

III DESIGN OF RECTANGULAR MICROSTRIP PATCH ANTENNA

In designing a rectangular Microstrip antenna, we specify some parameters: dielectric constant of the substrate,ε_r, the resonant frequency ,$f_r(Hz)$, and the height of the substrate , $h(cm)$ .To obtain good impedance matching , an inset cut(x_0) as shown in fig3 is made. The length of the inset controls the impedance matching

Procedure: Specifyε_r, $f_r(in\ Hz)$ $and\ h$

After these parameters have been specified, determine the effective dielectric constantε_{reff}, using (1). The width of the patch, W , is calculated using:

$$W = \frac{1}{2f_f\sqrt{\mu_0\,\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (7)$$

Once W is calculated, use (2) to determineΔL, the extension of the length due to fringing. The actual length of the path L is determined using the formula

$$L = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}\sqrt{\varepsilon_{reff}}} - 2\Delta L \qquad (8)$$

IV DESIGN OF CIRCULAR MICROSTRIP PATCH ANTENNA

The circular Microstrip antenna can be analyzed conveniently using the cavity model, it is modelled as a cavity, the modes supported by the circular patch antenna can be found by modelling the patch, the ground plane and the material between the two as a circular cavity. The dominant mode is TM_{110}^z where z is taken perpendicular to the patch; the model analysis assumes that substrate height is small $(h \ll \lambda)$. Using the TM_{110}^z mode, the resonant frequency is given by

$$(f_r)_{110} = \frac{1.8412}{2\pi\sqrt{\mu\varepsilon}} = \frac{1.8412v_0}{2\pi a\sqrt{\varepsilon_r}} \qquad (9)$$

Where v_o is the speed of light in free space

Note: Equation (9) does not take note of fringing effect.

In designing the circular Microstrip patch antenna, a correction is introduced by using an effective radius, a_e instead of the actual radius,a where

$$a_e = a\left\{+\frac{2h}{\pi a\varepsilon_r}\left[ln\left(\frac{\pi a}{2h}\right) + 1.7726\right]\right\}^{1/2} \qquad (10)$$

Due to the fringing effect, which gives rise to (8), the resonant frequency (9) for the dominant TM_{110}^z would have to be modified to

$$(f_r)_{110} = \frac{1.8412v_0}{2\pi a_e\sqrt{\varepsilon_r}} \qquad (11)$$

The actual radius,a is found using

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{\frac{1}{2}}} \qquad (12)$$

Where F is given by

$$F = \frac{8.791x\ 10^9}{f_r\sqrt{\varepsilon_r}} \qquad (13)$$

Design Procedure

1. Specify the ε_r,f_r(in Hz), and h (in cm)
2. Determine the actual radius a of the patch using (12) and then proceed to determine effective radius a_e by using (10)

V SIMULATION

Having gone through the analysis and design procedures for the circular and rectangular Microstrip patch antennas, Mathlab will be used in comparing some antenna characteristics of both rectangular and circular patch antenna

$f_r(Ghz)$ =Resonant Frequency

ε_r = Dielectric constant of substrate

$h(cm)$ = height of substrate

$W(cm)$ =Physical Width of Patch

$L_e(cm)$ =Effective length of Patch

L(cm)=Physical Length of Patch

R(cm)=Physical radius of patch

$R_e cm)$ =Effective radius of patch

E-HPBW =E-Plane High Power Beam Width

H-HPBW = H-Plane High Power Beam Width

Table 1 Data Table For Rectangular Patch Antenna

$f_r(Ghz)$	ε_r	$h(cm)$	$y_0(cm)$	$W(cm)$	$L_e(cm)$	L (cm)	Surface Area (m^2)	E-HPBW (deg)	H-HPBW (deg)	Directivity,(DB)
0.9	4.5	0.25	1.5	10.05	8.05	7.82	78.59	180	80	5.9
0.9	2.3	0.25	1.5	12.93	11.09	10.84	140.21	96	76	7.0
1.8	4.5	0.25	1.5	5.025	4.1	3.87	19.44	180	80	6.0
1.8	2.3	0.25	1.5	6.47	5.61	5.35	34.61	94	76	7.0
1.9	4.5	0.25	1.5	4.7607	3.8892	3.6598	17.42	180	80	6.0
1.9	2.3	0.25	1.5	6.1275	5.3217	5.0622	26.94	94	76	7.07
2.3	4.5	0.25	1.5	3.9328	3.2335	3.005	11.81	180	80	6.03
2.3	2.3	0.25	1.5	5.0619	4.4141	4.1551	18.34	94	76	7.08
2.4	4.5	0.25	1.5	3.77	3.1	2.88	10.84	180	80	6.0
2.4	2.3	0.25	1.5	4.85	4.23	3.98	19.28	94	76	7.0

Table II Data Table For Circular Patch Antenna

$f_r(Ghz)$	ε_r	$h(cm)$	$y_0(cm)$	R (cm)	$R_e(cm)$	Surface area	E-HPBW (deg)	H-HPBW (deg)	Directivity, (DB)
0.9	4.5	0.25	1.5	4.52	4.606	44.59	180	84	6.041
0.9	2.3	0.25	1.5	6.23	6.417	61.53	96	80	7.248
1.8	4.5	0.25	1.5	2.23	2.304	21.99	180	84	6.043
1.8	2.3	0.25	1.5	3.05	3.212	30.15	96	80	7.253
1.9	4.5	0.25	1.5	2.107	2.183	13.95	180	84	6.043
1.9	2.3	0.25	1.5	2.888	3.044	26.19	96	80	7.254
2.3	4.5	0.25	1.5	1.732	1.804	9.423	180	84	6.044
2.3	2.3	0.25	1.5	2.367	2.516	17.6	96	80	7.257
2.4	4.5	0.25	1.5	1.66	1.73	16.36	180	84	6.044
2.4	2.3	0.25	1.5	2.26	2.41	22.35	96	80	7.257

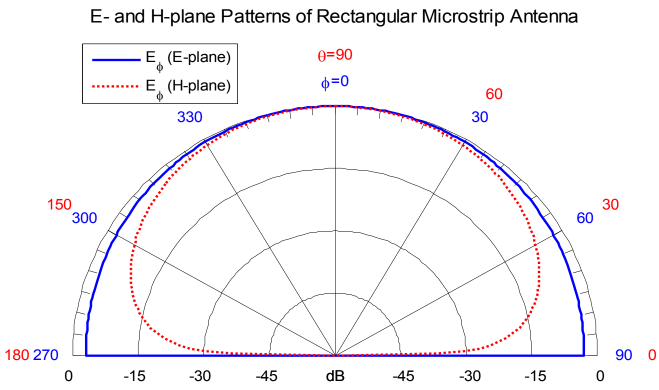

Fig 1. Rectangular Resonant Freq=0.9Hz, dielectric=4.5, substrate height=0.25cm

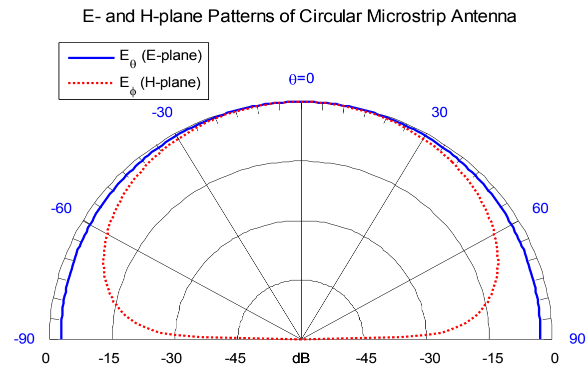

Fig 2. Resonant Freq=0.9Hz, dielectric=4.5, substrate height=0.25cm

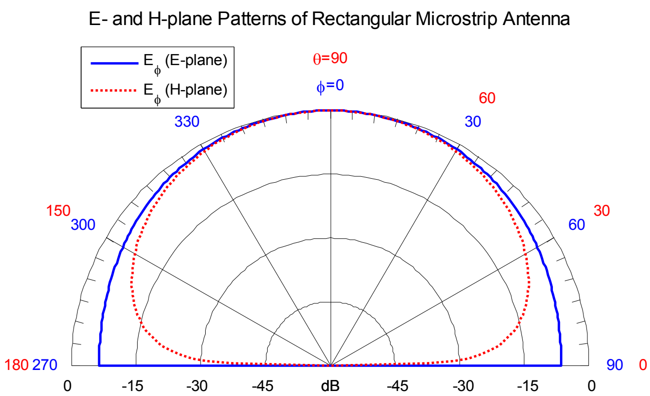

Fig 3.Rectangular MPA: E-H plane pattern: Resonant Freq=0.9Hz, dielectric=2.32, substrate height=0.25cm

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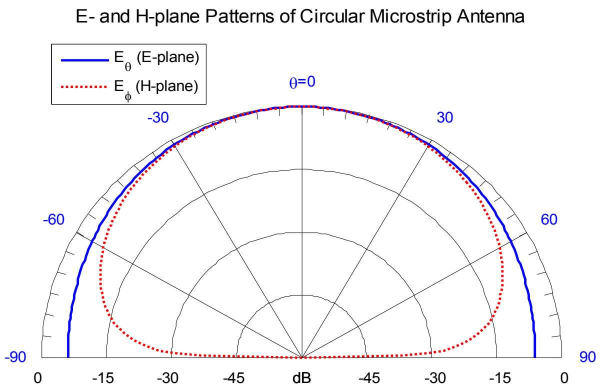

Fig 4. Circular MPA: E-H plane pattern: Resonant Freq=0.9Hz, dielectric=2.32, substrate height=0.25cm

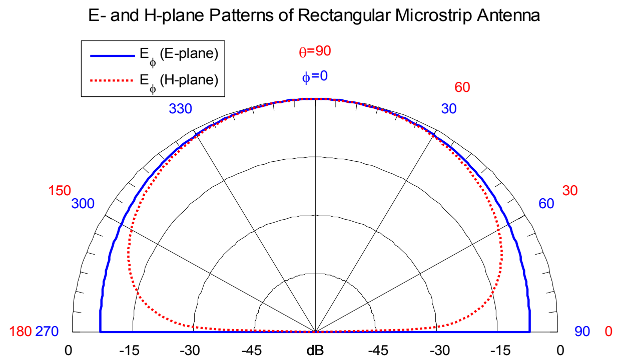

Fig 7 Rectangular: E-H plane: Resonant Freq=2.4Hz, dielectric=2.32, substrate height= 0.25cm

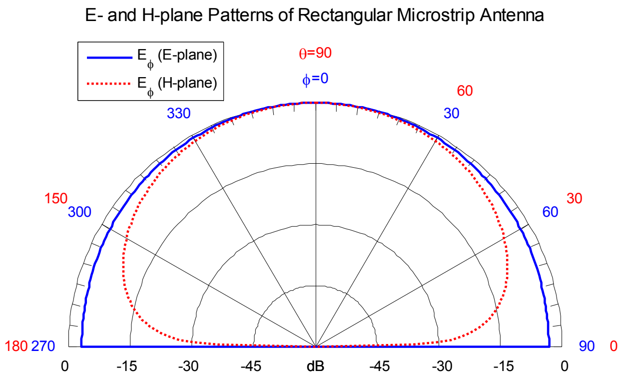

Fig 5 Rectangular: E-H plane: Resonant Freq=1.8Hz, dielectric=4.5, substrate height=0.25cm

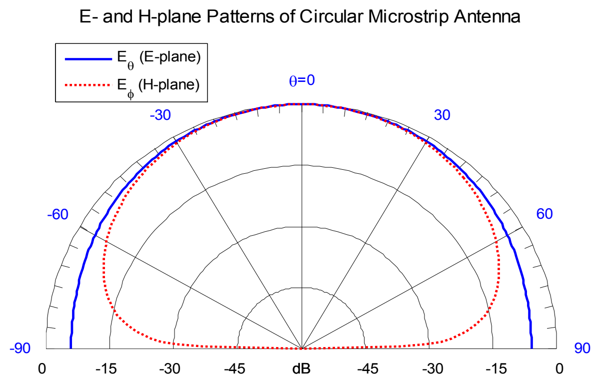

Fig 8. E-H plane: Resonant Freq=2.4Hz, dielectric=2.32, substrate height= 0.25cm

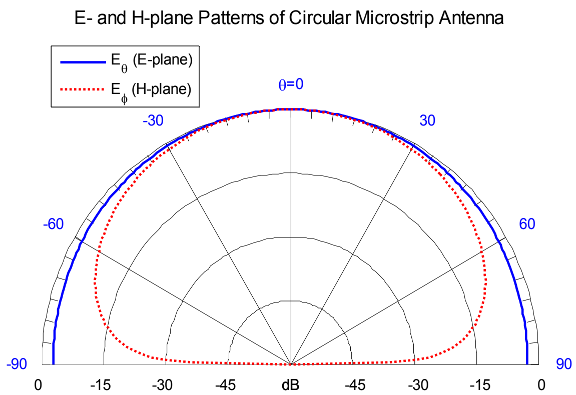

Fig 6 Circular: E-H plane: Resonant Freq=1.8Hz, dielectric=4.5, substrate height=0.25cm

VI RESULTS AND CONCLUSION

In this work, specific frequencies have been chosen-0.9Ghz, 1.8 GHz, 1.9 GHz, 2.3 GHz and 2.4 GHz-these frequencies corresponds to that of GSM, LTE and BLUETOOTH. These frequencies are very important in designing antennas for Mobile phones and Bluetooth-enabled devices. Two types of materials, roger (with a relative dielectrics ε_r of 4.5) and duroid (with a relative dielectrics,$\varepsilon_r$of 2.32) have been used as substrate .The tables shows how the choice of dielectric constant affects different antenna parameters at these four important frequencies, for a rectangular and a circular Microstrip Patch antenna. A common trend is noticed in this work - to obtain a smaller patch antenna (in terms of size, amount of

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material used), a material of higher dielectrics (the Rogers dielectric 4.5 gives an antenna of smaller size than duroid the dielectric) needs to be used, for both the rectangular and circular Microstrip patch antenna. In this era of miniaturization, incorporating a small antenna in a mobile phone or any device is a desired quality. When compared with each other, to obtain the same directivity, a circular Microstrip Patch antenna will need less size (material) than the corresponding rectangular one at any particular frequency. For example, from the table, to get a directivity $\approx 6dB$, at frequency of 0.9 GHz using Rogers,$\varepsilon_r = 4.5$ (for a rectangular (5.98dB), we need a patch antenna with material area of $78.59m^2$ while for a circular patch operating at the same frequency, we need a patch of material with area of $44.59m^2$.This is a significant result, both in material savings, size conformity and aesthetics , as it shows that high miniaturization can be achieved by using circular Microstrip Patch than rectangular (in a ratio ≈ 1:2)

Directivity is a quantitative measure of an antenna's ability to concentrate radiated power per unit solid angle in a particular direction; it is a very important antenna parameter especially in RADAR systems. Microstrip Patch antennas generally have low directivity when compared to dipoles and some other types of antenna due to their relatively large High Power Bandwidth (HPBW) both in the E and H planes. From the tables and plots, the use of material with lower dielectric constant improves the directivity, both for circular a rectangular Microstrip patch (hence at any frequency duroid gives a better result than Roger).

In conclusion, this work has shown that circular Microstrip patch antenna gives better performance, enhances the concept of miniaturization when compared to the rectangular Microstrip Patch antenna

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