Probe-fed semi circular microstrip antenna vis-à-vis circular microstrip antenna: a necessary revisit

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Abstract. Microstrip patch antenna of semicircular geometry has been investigated in view of miniaturization of conventional circular geometry. The precise operating frequency of the semicircular microstrip patch antenna is the most significant parameter to be determined in order to design such antenna system to achieve the optimum performance. In the present investigation an improved formulation is presented for accurate determination of the resonant frequency of semicircular patch. Also, the radiation property of such patch is thoroughly investigated. Through comparisons are documented amongst the circular and semicircular patches. It is revealed that, the semicircular patch offers more better radiation performance compared to circular.

1. Introduction

The circular geometry of the microstrip antenna is the most common geometry which has been studied, analyzed and implemented for over last three decades[1]-[4]. In the present era, the scientists and engineers are looking for tiny devices, which can be implemented in miniaturized wireless communication equipment without hampering the performance. In that scenario, semicircular patch antenna is a good choice which can produce such typical qualities like tininess, light weight and compatibility with MMIC along with acceptable radiation performance. In fact, semicircular patch is very advantageous where the space is the key factor to organize a patch with conventional geometry. In fact, 50% of patch area reduction can be achieved using semicircular patch for a particular resonant frequency compared to conventional circular patch geometry. Hence, the accurate determination of mode as well as its radiation performance of a semicircular patch is very important in this scenario.

The electric field beneath the patch and eigen functions of circular sector antennnas were presented in [5]. Generalized transmission line modeling of sector antenna has been found in [6]. But all these papers indicated above fail to predict resonant frequencies of sector antenna accurately. In fact, in all of those investigations, the concept of fringing is not considered. Nevertheless the issue of fringing can not be avoided for accurate computation of dominant mode and its resonant frequency. The effect of fringing has been considered in [7]-[8] for computation of resonant frequency of sector antenna. Still they fail to predict the accurate resonant
frequency. In fact, in these reports, the dominant mode of the sector antenna is not determined properly.

![Dielectric Substrate](image)

**Figure 1.** Schematic representation of semicircular patch (Top View).

The radiation characteristic of semicircular patch is also an important issue and it is least investigated topic in last two decades. On the contrary, the radiation property of circular patch is widely investigated. Plenty of works [9]-[10] have been reported to improve the radiation pattern of a conventional circular patch. In that scenario, hardly some investigation has been reported on radiation characteristic of semicircular patch. Lo et al.[11], and Richards et. al. [5] have analyzed the radiation characteristics of semicircular patch for the first time. However, in these reports, clear understanding of the radiation pattern of semicircular patch at its lowest order dominant mode is not apparent. In fact, in the article [5], the radiation patterns for two different modes are portrayed and comparison between them is discussed in terms of their radiation pattern. One very recent report [12] shows the modal analysis of circular sector patch. However, from [12], it is not apparent that whether the semicircular patch can be a best alternative of circular patch. Moreover, the investigation [12] does not deal with the radiation characteristics of the circular sector patch for the dominant mode.

In order to improve the shortcomings of the earlier studies, and also to offer the readers a clear understanding of the dominant mode of semicircular patch, its frequency and its radiation characteristic at its lowest order dominant mode, we have investigated both the circular and semicircular patches thoroughly. The mathematical derivations to determine the accurate dominant mode frequency are based on modified cavity model along with the accurate estimation of the fringing electric fields and resulting effective antenna dimension. Better radiation performance is revealed for semicircular patch compared to that of circular patch. Therefore, it is concluded that a patch of semicircular geometry with 50% reduced patch area becomes the most efficient and suitable alternative to a patch of conventional circular geometry.

**2. Theory**

A coaxially fed CSMA having radial dimension $a$, printed on a PTFE substrate ($\varepsilon_r$) with thickness $h_1$ is shown in Fig. 1. The antenna is fed at $\rho_c$ from centre as shown in the figure using a coaxial probe. In this present model, the top sectorial patch and ground plane act as PEC while three side walls are PMC. Hence, we may write the vanishing boundary condition of magnetic fields at PMC walls.

Thus, $\rho$ component of magnetic field,

$H_\rho = 0$ at $\rho = a$ for $\phi = 0$ to $\pi$ and $z = 0$ to $h$

$H_\phi = 0$ at $\phi = 0$ and $\phi = \pi$ for $\rho = 0$ to $a$ and $z = 0$ to $h$
As we know form \([12]\);

\[
A_z = B_{nm} J_n(k_{,\rho})(A\cos(m\phi)+B\sin(m\phi))\left[\cos(k_z z)\right]
\]

\[
H_\theta = -\frac{1}{\mu} \frac{1}{\rho} \frac{\partial A_z}{\partial \rho}
\]

\[
H_\phi(\rho = a) = \frac{1}{\mu} \frac{1}{\rho} B_{nm} J_n(k_{,\rho})(A \cos m\phi + B \sin m\phi)\left[\cos(k_z z)\right] = 0
\]

\[(1)\]

It is possible if

\[
k_{,\rho} = \chi_n'/a
\]

where, \(\chi_n' = \chi_{11} = 1.84\)

where, \(\chi_n'\) is the \(n\) th zero of derivative of Bessel function of order \(m\). Physically, \(m\) is the number of circumferential variation and \(n\) is the number of radial variation. From the chart of derivative of Bessel function it is found that the lowest root is 1.84 and it is happened when \(m = n = 1\). Therefore, the semicircular patch is having the same lowest order dominant mode (i.e TM\(_{11}\)) like conventional circular patch.

and, \(K_x = \frac{p \pi}{h}\) where \(p = 1, 2, 3\) as usual like conventional circular patch derived in \([13]\).

Hence,

\[
K_z^2 = K_{,\rho}^2 + K_x^2
\]

\[
f = \frac{1}{2\pi\sqrt{\mu \varepsilon}} \left(\frac{\chi_n'}{a}\right)^2 + \left(\frac{p \pi}{h}\right)^2
\]

\[(1a)\]

**Figure 2.** Magnitude of electric field on patch surface to explain the number of field variation in radial and circumferential direction
Hence, the zeroth order resonance frequency \( f_r \) is 
\[
  f_r = \frac{x_m c}{2m_a \sqrt{\varepsilon_r}} = \frac{1.84 c}{2m_{\text{eff}} \sqrt{\varepsilon_{\text{eff}}}}
\]
where \( c \) is the free space velocity.

Now to compute the resonant frequency accurately, one must incorporate the concept of effective dielectric constant and the effective dimension. Therefore, the final equation becomes 
\[
  f_r = \frac{1.84 c}{2m_{\text{eff}} \sqrt{\varepsilon_{\text{eff}}}}
\]
where, \( a_{\text{eff}} \) and \( \varepsilon_{\text{eff}} \) can be computed from [14].

Thus, it is interesting to note that, though the geometry of the patch is different, dominant mode is similar for circular and semicircular patch. Therefore for a particular operating frequency, one need not design the circular patch. Instead, a semicircular patch with 50% reduced patch area can be designed.

The magnitude of electric field over the patch is presented in Fig. 2. It is clear from the figure that, the number of field variation either in circumferential or in radial direction is 1. This confirms that the lowest order mode of semicircular patch is same as circular patch and it is TM\(_{11}\).

### 3. Results and discussions

The computed results using the present theory are compared with simulations and have been presented in Table-I. Comparison has been made between the lowest order dominant mode resonant frequency of circular and semicircular patches for wide variety of parameters. Computed results are in good agreement with the simulation results. The table shows that, the resonant frequencies are identical for both the circular and semicircular patches for a wide variety of parameters in each case.

| Patch radius \( a \) in mm | \( \varepsilon_r \) | \( h_1 \) in mm | Lowest order TM\(_{11}\) mode frequency at GHz |
|-----------------------------|-----------------|-----------------|---------------------------------------------|
|                             |                 |                 | Circular patch [sim] | Semicircular Patch [sim] | Semicircular Patch [Computed] [our] |
| 11.5                        | 2.65            | 1.5875          | 4.42                         | 4.40                         | 4.41                          |
| 10.7                        | 2.65            | 1.5875          | 4.72                         | 4.70                         | 4.68                          |
| 9.6                         | 2.65            | 1.5875          | 5.22                         | 5.20                         | 5.24                          |
| 8.2                         | 2.65            | 1.5875          | 6.07                         | 6.06                         | 6.10                          |
| 7.4                         | 2.65            | 1.5875          | 6.63                         | 6.61                         | 6.70                          |
| 50.0                        | 2.32            | 1.59            | 1.128                        | 1.129                        | 1.128                         |
| 50.0                        | 2.32            | 1.59            | 1.286                        | 1.284                        | 1.285                         |
| 50.0                        | 2.32            | 1.59            | 1.350                        | 1.345                        | 1.350                         |
| 3.0                         | 2.20            | 0.508           | 18.54                        | 18.45                        | 18.50                         |
| 3.7                         | 2.20            | 0.508           | 15.88                        | 15.86                        | 15.80                         |

The reflection coefficient profile for semicircular and circular patch of radius \( a = 30 \) mm on PTFE substrate with \( h = 1.575 \) mm, \( \varepsilon_r = 2.33 \) is presented in Fig. 3. It shows that the both the structures
resonate at same frequency i.e 1.82 GHz and their profiles are also identical. Nevertheless, semicircular patch offers better matching at its resonance compared to circular patch as is evident from Figure 3. Reflection coefficient profile for circular and semicircular patches.

![Figure 3](image)

Figure 3. Reflection coefficient profile for circular and semicircular patches.

Figure 4. H and E plane radiation patterns for circular and semicircular patches at dominant mode frequency. (a) H plane, (b) E plane.

![Figure 4](image)

Figure 4. H and E plane radiation patterns for circular and semicircular patches at dominant mode frequency. (a) H plane, (b) E plane.

the figure. Fig. 4. show the comparison between radiation properties of circular and semicircular patch separately in E and H planes. It is found that the gain of both the patches is around 6.4 dBi. However, it may be noted that, the cross polarization level is less for semicircular patch compared to circular patch in their H plane. The isolation between co-polarization to cross polarization radiation for semicircular patch is 32 dB while the same for circular patch is 26 dB. Furthermore, the H plane co-polarized radiation beam is broader in case of semicircular patch compared to that of circular patch. The 3 dB beam width of semicircular patch is around 1070 in its H plane while the same for circular patch is only 800. Therefore, around 34% of improvement in broadening the H plane beam width is evident from semicircular patch compared to that of circular patch. On the contrary, the cross polarization radiation is less in E plane for circular patch compared to semicircular patch. Around 32 dB of Co-Cross polarization isolation is revealed for circular patch in E plane while the same for
The semicircular patch produces same radiation profile in its dominant mode in comparison to circular patch. But it may be noted that, the semicircular patch have more better radiation performance particularly in H plane and partially in E plane compared to the circular patch as discussed above. Nevertheless, as it has 50% reduced physical area, this semicircular patch can be mounted on tiny device. Therefore, the semicircular patch is the most suitable alternative of circular patch for the scientific community looking for tiny antenna with improved radiation performance.

4. Conclusions
Semicircular patch is proposed to be an efficient and most suitable alternative of circular sectorial microstrip antenna for miniaturization and to obtain more improved radiation performance. This is obviously be required in the modern wireless era where, every devices are budding towards tininess and multi-functionality. Therefore, the present investigation is surely be helpful for scientist and practicing engineers to use such semicircular microstrip antenna on tiny wireless equipment.

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