COMPARE COMPACT UHF ANTENNAS

Approaches were applied to miniaturize two different types of antennas for applications at UHF, without losing performance when losing physical volume.

SMALLER WIRELESS DEVICES demand smaller antennas. To serve the needs of ultrahigh-frequency (UHF) wireless communications devices, two compact slot antenna designs were examined—namely, a hollow central annular slot (HCAS) antenna and a spiral slot antenna (SSA). These proposed antenna designs are extremely compact, yet provide excellent electrical performance compared to larger versions and types of antennas.

Miniaturizing an antenna inevitably results in a tradeoff between size and performance since antenna electromagnetic (EM) performance is so closely tied to its size. This is espe-
Table 1: Comparative Volume of the Compact Antennas.

<table>
<thead>
<tr>
<th>Hollow Central Annular Slot Antenna (HCASA)</th>
<th>Spiral Slot Antenna (SSA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna Volume (mm)</td>
<td></td>
</tr>
<tr>
<td>35×35×1.6</td>
<td>26×26×1.6</td>
</tr>
<tr>
<td>Antenna Volume Relative to the Free Space Operating Wavelength (λ₀)</td>
<td></td>
</tr>
<tr>
<td>0.11λ₀×0.11λ₀ X 0.005λ₀</td>
<td>0.08λ₀×0.08λ₀ X 0.005λ₀</td>
</tr>
</tbody>
</table>

1. These diagrams show the (a) top and (b) bottom views of a conventional annular slot antenna.

2. These views show (a) top and (b) side views of a hollow central annular slot antenna (HCASA) along with (c) top and (d) side views for a spiral slot antenna (SSA).

cially true for UHF applications, where reducing the size of an antenna leads to smaller and lighter-weight systems, enhancing portability and minimizing EM interference with other electronic devices. Therefore, it is very desirable to miniaturize the antenna in order to scale down the system size.

There are, however, many limitations inherent to using a compact antenna, since size is proportional to wavelength. One miniaturization approach is to alter the geometry of the antenna so that the electrical length of the current path is increased.¹ The size of a microstrip patch antenna can be reduced by using a dielectric circuit material with high relative dielectric constant. But a high dielectric constant material may also have higher dissipation factor, resulting in degradation of gain and radiation efficiency. As a result, it is necessary to develop alternative methods for patch antenna miniaturization through structural changes in the patch.

Many antennas have been reported for UHF applications, with many efforts made at miniaturization. For example, resonant patch antennas can be miniaturized using artificial magnetoelectrics.² Further compactness of these antennas has been achieved through loading, using dielectrics, resistors, shorting pins, or meandering microstrip lines.³ However, such loading can result in increased loss, additional circuit complication, or added fabrication cost.

Antennas for portable devices include inverted-F antennas (IFAs), planar inverted-F antennas (PIFAs), and printed planar monopole or loop antennas.⁴⁻⁹ But some of these antennas require large ground planes, which is an unwanted limitation for portable devices.¹⁰⁻¹²

By performing calculations on resonant slot length, two compact antennas were developed in this report for use in UHF applications. It has also been shown that antenna slots can be folded or coiled in spiral configurations to operate at lower frequencies in a low profile by maintaining almost the same slot length. The antennas were all designed for use at 920 MHz. Some impedance-matching measures were needed to optimize the antennas for use at these low frequencies.

The antenna designs are promising since they don’t require large ground planes for good radiation patterns.

As shown in Fig. 1, a conventional annular ring slot microstrip antenna was
PIN DIODE LIMITERS
1 WATT CW 1 - 40 GHz
(Very High Frequency)

- Very High frequency Wide Band
- 1 Watt CW Power Handling Capability
- Fast Response & Short Recovery Time (10 nsec typical)
- Hermetically Sealed Module

Typical Performance θ + 25 Deg. C (Preliminary)

<table>
<thead>
<tr>
<th>MODEL</th>
<th>FREQ. RANGE (GHz)</th>
<th>MAXIMUM INSERTION LOSS (dB)</th>
<th>TIP LEAKAGE (pC)</th>
<th>MAX LEAKAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>UP132A</td>
<td>1 - 20</td>
<td>3.0</td>
<td>&gt;10</td>
<td>&gt;10</td>
</tr>
<tr>
<td>UP232A</td>
<td>2 - 20</td>
<td>3.0</td>
<td>&gt;10</td>
<td>&gt;10</td>
</tr>
<tr>
<td>UP133A</td>
<td>18 - 26</td>
<td>3.0</td>
<td>&gt;10</td>
<td>&gt;10</td>
</tr>
<tr>
<td>UP143A</td>
<td>10 - 40</td>
<td>4.5</td>
<td>&gt;10</td>
<td>&gt;10</td>
</tr>
<tr>
<td>UP144A</td>
<td>1 - 40</td>
<td>4.5</td>
<td>&gt;10</td>
<td>&gt;10</td>
</tr>
<tr>
<td>UP545A</td>
<td>2 - 40</td>
<td>4.5</td>
<td>&gt;10</td>
<td>&gt;10</td>
</tr>
<tr>
<td>UP246A</td>
<td>20 - 40</td>
<td>4.0</td>
<td>&gt;10</td>
<td>&gt;10</td>
</tr>
</tbody>
</table>

Notes: 1. Insertion Loss and VSWR (2 : 1) tested at -10 dBm.
2. Power rating derated to 20% @ +125 Deg. C.

COMPARING UHF ANTENNAS

Miniaturizing an antenna inevitably results in a tradeoff between size and performance, since EM performance is so closely tied to its size.

3. These plots show the return-loss performance levels for the HCASA and SSA miniaturized designs.

![Graph showing return loss performance levels for HCASA and SSA miniaturized designs.]

This equation is valid as long as a thin substrate is used for the annular ring antenna. The antenna dimensions are: $R_o = 33$ mm, $R_i = 30$ mm, SW = 3 mm, FW = 3 mm, FL = 16 mm, and FD = 35 mm. The overall area of this conventional antenna is limited to 70 x 70 mm.

Figure 2 shows configurations for two compact microstrip slot antennas. Both are designed on low-cost FR-4 substrate, with height $h_s = h_c = 1.6$ mm, $e_r = 4.4$, and $\delta = 0.02$. The first antenna is a hollow central annular slot antenna (HCASA), which consists of an annular slot with the central portion etched out from the ground plane. The second is a spiral slot antenna (SSA) having an optimized spiral slot in the ground plane. Both antennas are fed by 50-Ω microstrip lines, making the antennas suitable for integration with wireless device circuit boards. The volumes of the miniature antennas are compared in Table 1.

Analysis was performed on the miniaturized antennas to better understand design and optimization processes. To better gauge the interaction of key parameters, only one parameter was changed at a time, while keeping the other parameters unchanged. For the hollow central annular slot antenna (HCASA), the mean circumference of the slot can be
It has also been shown that antenna slots can be folded or coiled in spiral configurations, so as to operate at lower frequencies in a low profile by maintaining almost the same slot length.

The design parameters are achieved as follows: \( L_s = 35, W_s = 35, R_{31} = 17, SW_c = 3, SS_c = 1, FW_c = 3, FD_c = 17.5, \theta = 45. \)

The spiral arm of a spiral slot antenna (SSA) can be represented as:

\[
r(\psi) = a + r_a, \quad (\psi_s < \psi < \psi_c)
\]

where:

\[
r(\psi) = \text{the radial distance from the origin to the arbitrary point on the center line of the spiral;}
\]

\[
a = \text{the spiral constant;}
\]

\[
\psi = \text{the winding angle;}
\]

\[
\psi_s = \text{the spiral start angle;}
\]

\[
\psi_c = \text{the spiral end angle; and}
\]

\[
r_a = \text{the radial distance from the origin to the initial point of the spiral line.}
\]

The mean arc length of the Archimedean spiral, \( C(\psi, \varphi) \), in polar coordinates between \( \psi_s \) and \( \psi_c \) is given by Eq. 1:

\[
C(\psi_s, \varphi) = a \int_{\psi_s}^{\psi_c} \sqrt{1 + \varphi^2} \, d\varphi
\]

From calculus, for the simplification of a variable \( \psi \) representing the angle in radians starting from \( \psi = 0 \) radians and wrapping counterclockwise around a pole until reaching an angle of \( \psi = \psi_c \) radians, the spiral angle can be derived as:

\[
(\text{See top equation in box, p. 58.})
\]

so that Eq. 1 can be rewritten as Eq. 2:

\[
(\text{See Eq. 2 in box, p. 58.})
\]

where, for the proposed Archimedean spiral antenna:

\[
\psi_s = 1.17\pi \text{ and } \psi_c = 2.56 \pi.
\]

Solving Eq. 2, the length of the arc is found as 90.91 mm. This also corresponds approximately to 0.46\(\lambda_g\) where \( \lambda_g \) is the guided wavelength at 920 MHz. This indicates that the proposed miniaturized spiral antenna slot acts like a magnetic dipole for the resonant frequency. The geometry of the antennas is defined by the following parameters: \( L_s = 26 \text{ mm}, W_s = 26 \text{ mm}, R_{31} = 11.7 \text{ mm}, SW_c = 3 \text{ mm}, SS_c = 1 \text{ mm}, FW_c = 3 \text{ mm}, \) and \( FD_c = 13 \text{ mm.} \)

Figure 3 depicts the return losses of the proposed HCASA and SSA anten-
Table 2. Comparing the spiral antenna with conventional annular slot and miniaturized antennas.

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Return Loss</th>
<th>Smith Chart Resistance (Ω)</th>
<th>Area of the Antenna (mm)</th>
<th>Reduction of antenna area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Annular Ring Slot Antenna</td>
<td>100</td>
<td>50</td>
<td>70x70</td>
<td>Ref. (0%)</td>
</tr>
<tr>
<td>Hollow Central Annular Slot Antenna</td>
<td>-10</td>
<td>50</td>
<td>35x35</td>
<td>75</td>
</tr>
<tr>
<td>Spiral Antenna</td>
<td>-10</td>
<td>50</td>
<td>26x26</td>
<td>86.2</td>
</tr>
</tbody>
</table>

The return loss curve shows that both proposed antennas are excited at 920 MHz. The return loss was measured at 16.2 MHz (913 to 922 MHz) while the SSA exhibits an impedance bandwidth of 11.2 MHz (913.8 to 925 MHz). Maximum return losses of -18 dB and -12 dB were obtained at the respective resonant frequencies of the HCASA and SSA antennas. These slight degradations are in accordance with the well-known classical fundamental limits of small antennas.

Figures 4(a) and 4(b) show the S- and H-plane radiation patterns for both the HCASA and SSA designs at 920 MHz, with both producing omnidirectional radiation patterns. For the HCASA, the cross-polarization values in the S and H planes is below 24 dB, while for the SSA it increases to 15 dB. This shows the extremely low losses of the annular ring with respect to frequency which is the ratio of W/R, increases. This increases the greater surface wave to produce diffraction at the dielectric edge, leading to higher cross-polarization levels.

These antenna designs can be used to produce almost symmetrical radiation patterns. One of the significant advantages of a symmetrical radiation pattern is that the maximum power direction would always be in the horizontal direction and would not shift to different directions at different frequencies. This is why these antennas are quite suitable for portable omnidirectional applications and wireless services.

Figure 5 shows the input impedance characteristics of the HCASA and SSA designs with respect to a conventional reference antenna. As is obvious from this comparison, the reduction factors of the compact HCASA and SSA designs are 75% and 86.2%, respectively, which makes them ideally suited for designs that require miniature antennas in the UHF range.

In summary, many wireless communications systems are dominated in size by the dimensions of the antenna. But by applying some techniques, it was possible to miniaturize two different types of antennas for use at UHF. Compared to an ordinary annular slot antenna operating at the same frequency, the volumes of these two experimental antennas were reduced by as much as 75% and 86.2%. The volumes of the two antennas are 0.11cm x 0.11cm x 0.005cm for the HCASA and 0.08cm x 0.08cm x 0.005cm for the SSA, where λc is the free-space operating wavelength. The compact antenna designs were also found to pro-
4. These plots show the radiation patterns (E & H-planes) for the two miniaturized antennas: (a) HCASA and (b) SSA.

5. This plot shows the input impedance for the miniaturized HCASA and SSA designs.

References