Patch Antenna Size-Reduction Parametric Study

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Abstract **─** Size-reduction techniques are applied to a circular UHF patch antenna, by varying parameters to better predict its desired resonant frequency. Specifically, slits are introduced into the patch, which are parametrically varied to determine the optimum slit dimensions for maximum size reduction. Further studies determine the optimum location for the probe feed, to achieve 50Ω input impedance for different slit lengths.

Index Terms **─** Antenna size reduction, patch antenna slits, slotted UHF antenna.

I. INTRODUCTION

Patch antennas typically resonate with dimensions that are near one-half wavelength, $\lambda/2$ [1], which can be cumbersomely large at UHF frequencies. This large size is reduced by a factor of approximately $1/\sqrt{\varepsilon_r}$ by using higher permittivity ($\varepsilon = \varepsilon_o\varepsilon_r$) material. However, the decreased bandwidth caused by higher permittivity can make this approach unattractive. In an attempt to focus on size-reduction techniques rather than exotic materials, we chose to use common FR4 printed circuit-board material for our UHF patch-antenna size-reduction analysis. FR4 has relative permittivity, ε_r of approximately 4.5 at UHF, which should reduce patch dimensions nearly 50%, if no other size-reduction techniques were used.

The addition of slits in a circular patch antenna has proven to reduce the patch radius by nearly an additional 50%, beyond the effects of permittivity alone [2,3,4]. However, the choice of slit dimensions has so far been an iterative approach. In this paper, we present the results of a parametric study of the slit dimensions in Fig. 1, in order to aid in the optimum design of size-reduced circular patch antennas.

II. SLOTTED PATCH DESIGN

To compare the results of the parametric study, an ordinary circular patch, without slits, was simulated in ANSYS Electromagnetic Desktop, a commercial finite element solver (i.e., HFSS). The patch was simulated with a radius, r of 4.5*cm*; dielectric thickness of 1.7*mm*; dielectric constant, ε_r of 4.5; and was probe fed at a distance of 0.45cm from the center of the patch. The theoretical resonant frequency can be calculated by:

$$f = \frac{1.8412c}{2\pi r\sqrt{\varepsilon_r}}. \quad (1)$$

where f, is the resonant frequency, and c is the speed of light [1]. Equation 1, along with the previously defined parameters, predicts resonance at 921*MHz*; HFSS simulations showed the resonance to be 914*MHz.*

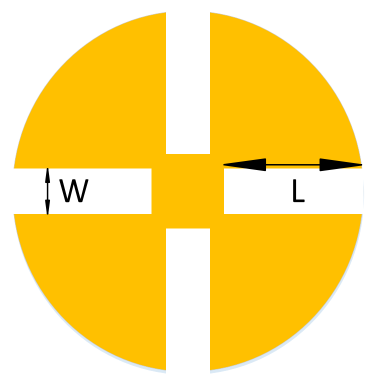


Fig. 1. Mask of the slotted circular patch antenna. L is the slit length and W is the slit width.

III. SLIT DIMENSION OPTIMIZATION

The length, L and width, W of the slits in Fig. 1 were incrementally changed in HFSS, in an attempt to estimate their effects on the resonant frequency. These two parameters were considered independently to determine if each could be fine-tuned for different purposes, even though their combined dimensions add to the increased effective circumference of the circular patch. As expected, increasing both L and W decreased the resonance frequency. However, the input impedance, at a particular feed point, appeared to change unpredictably as both W and L were increased. When the width, W was held at

Submitted On: September 28, 2018
Accepted On: October 12, 2018

a constant 1*mm* and the slit length, L was increased, the resonant frequency monotonically decreased. This statement is equivalent to stating that for a fixed resonant frequency, the patch antenna can be reduced in size as the slit lengths increased. The input impedance also changed as the slit dimensions changed; however, we found that it could be fine-tuned, by simply changing the location of the feed point.

For the first parametric study, we fixed the location of the feed point, in order to avoid introducing too many degrees of freedom at once, thus isolating the effects of the slit length and width. The corresponding reduction in the patch radius, as L increased, can be seen in Fig. 2, indicating that the only limit to the size-reducing benefit of increasing slit length, L is the physical radius itself, i.e., increasing L continued to reduce the physical size of the antenna until L nearly equaled the radius, r. Of course at that point, the patch would be separated into two halves. The data in Fig. 2 suggests that the original patch radius, which resulted in a resonant frequency of 914*MHz*, can be made resonant at 470*MHz* by the addition of slits that almost meet in the center of the patch, i.e., 98% of the radius, r. Without these slits, the circular patch antenna would require a radius of 8.8cm in order to be resonant at 470*MHz*, instead of 4.5cm (51% of 8.8*cm*).

As previously suggested, the slit width, W can also be increased, in order to decrease the patch radius for a desired resonant frequency. To explore the effects of changing slit width, W, the next parametric study held the slit length, L at a constant 95% of the radius, r.

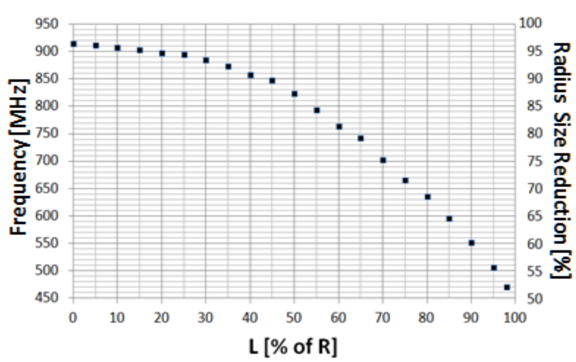


Fig. 2. Change in resonant frequency/size reduction vs. change in slot length, L.

One pair of slits were removed, as shown in Fig. 3, simply to allow the width of the slits to increase without interfering with the orthogonal pair, and thus cutting the patch into four quadrants. The symmetric pair of vertical slits, depicted in Fig. 1, are only necessary for circular polarization. In fact, for certain unique applications, a second resonant mode could be created by making one pair of slits different lengths than their orthogonal counterparts. However, the polarization for this second resonant mode would be orthogonal to the first.

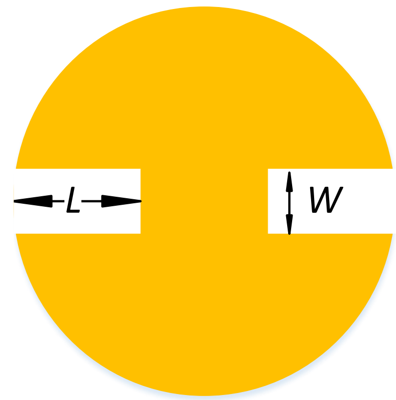


Fig. 3. Two-slit patch allows W to vary with fewer restrictions.

The size-reducing benefit of increasing slit width, W while holding L constant, is evident in Fig. 4, due to the fact that the resonant frequency decreased as the slit width increased. However, this is not without some design limitations. Four orthogonally oriented slits shown in Fig. 1 are required for circular polarization, which limit the relationship between L and W, in order to prevent the slits from touching one another. Also, the input impedance changes significantly with changes in W, when the feed-point location is held constant. In order to counteract this impedance variation, one would need to find the optimal feed point for each L/W combination, in order to achieve a desirable input impedance. Although time consuming, finding the optimal feed point can be done using known methods [5,6]. These methods are constrained only by the available area to place the feed point. Various combinations of W and L were simulated in HFSS, with the geometry depicted in Fig. 1, in order to find a predictable pattern [7]. The results, shown in Fig. 5, indicate that as W was varied for several different values of L, a well-behaved relationship emerged for small values of W/L, i.e., $W < 0.05L$. As W exceeded $0.05L$, the effects of L appear to dominate that of W, i.e., diminishing returns for increasing W beyond $0.05L$.

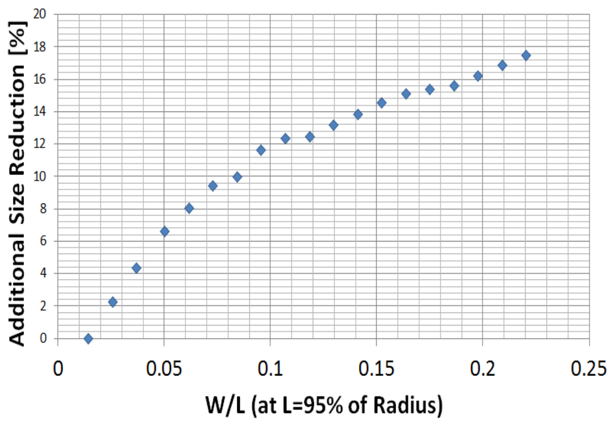


Fig. 4. Size-reducing benefit of increasing width, *W*. *L*=95% of patch radius, *r*.

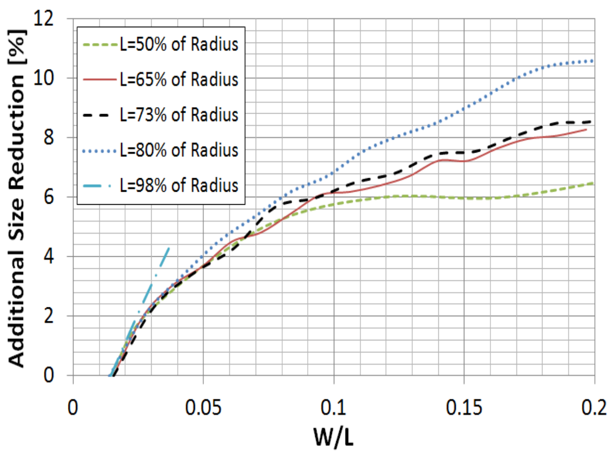


Fig. 5. Size reducing benefit of increasing width, *W* for *L* = 50%, 65%, 73%, 80%, and 90% of radius, *r*.

IV. FEED LOCATION

As previously stated, a desired impedance match can be found for each slit-length/width combination, by relocating the probe feed point. To find a trend in the feed location that would aid in the design of circular patches with slits, we explored the optimum feed-point location as a percentage of patch radius, for successively longer slits. The slit width of the circular patch was fixed at 1.37% of the radius (0.62mm). Using HFSS, the antenna feed point was relocated along the dashed radial line in Fig. 6, for successively longer slit lengths, *L* in order to achieve a matched input impedance of 50Ω. Figure 7 plots the relationship between the probe-feed location and the slit length, both normalized to the patch radius.

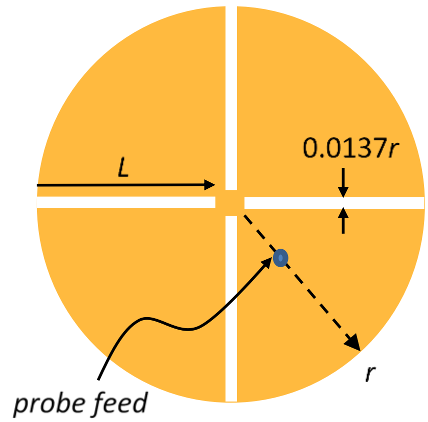


Fig. 6. Probe feed relocated along dashed radial line, to match input impedance to 50Ω, for each successively longer length, *L* for fixed width, *W* = 0.0137*r*.

It is clear by the nearly linear trend shown in Fig. 7 that the probe feed must be relocated closer to the center of the patch, as the slit length increases, i.e., for maximum size reduction [8]. If the slit length is 98% of the radius, the patch antenna must be probe fed at 14.5% of the radius, from the center of the patch. In this case, the slit width-to-length ratio is 0.014. From the results in Fig. 5, increasing the slit width up to 0.03*L* would result in beneficial patch-size reduction. Therefore, the optimum slit width should be set to 0.03*r*, for a slit length of 0.98*r*. The simulated S_{11} parameter for this design is shown in Fig. 8. The radiation pattern is shown in Fig. 9.

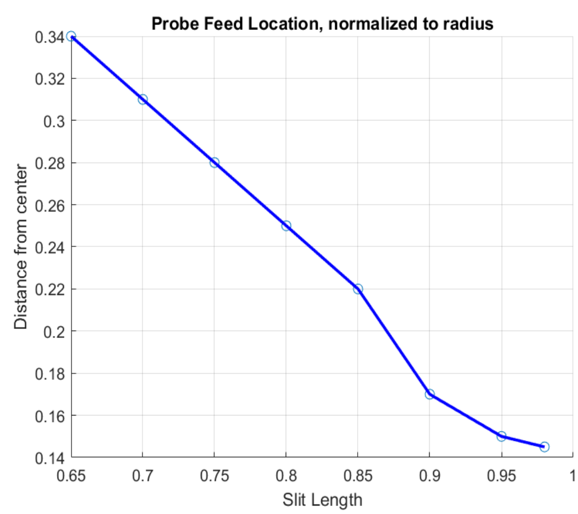


Fig. 7. Probe-feed location vs. slit length, *L* both normalized to the patch radius, *r*.

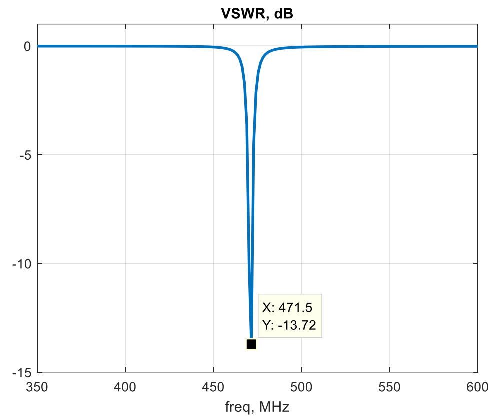
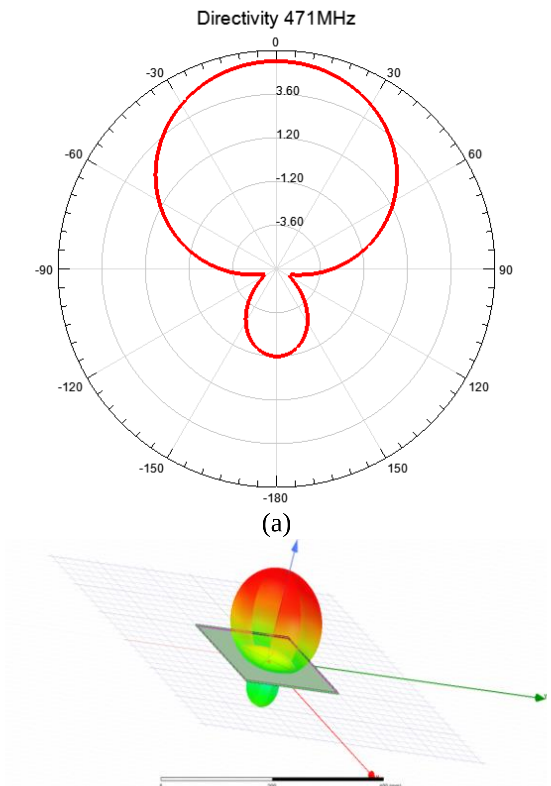


Fig. 8. S_{11} parameter, of the slotted circular patch, with radius r = 4.5*cm*, simulated with HFSS.



(a)

(b)

Fig. 9. Patch antenna radiation pattern: (a) E-plane and (b) 3D plot.

V. CONCLUSION

A parametric study of slit dimensions in a circular patch antenna was performed in order to characterize the size-reduction benefits of these slits. It was shown that as the slit length and width increase, the resonant frequency of the patch decreases. However, as the slit width reaches approximately 5% of its length, the slit length tends to dominate the size-reducing benefits. Near optimum size reduction can be achieved by making the slit lengths as close to the radius as possible, without actually touching, while the slit width is less than 5% of its length. This will maximize the available patch area, in order to locate the feed point for minimum *SWR*.

Another parametric study was conducted, in order to find the optimum probe-feed location for various slit lengths. The slit width was set to 1.37% of the radius, while the slit length was varied. The trend was linear, until the feed point approached very close to the center of the patch. This nearly linear trend showed that for increasing slit lengths, the optimum feed point should be located closer to the center of the patch, in order to achieve a matched 50Ω input impedance.

Summarizing the results of these parametric studies, the best results for reducing the physical size of circular patch antennas can be obtained by (1) making the slit length as long as physically possible, i.e., 98% of the radius; (2) setting the slit width to 3% of the radius (increasing the slit width any further provides diminishing returns and makes impedance matching more difficult); and (3) locating the probe feed at approximately 14% of the radius, from the center of the patch. By following these design rules, a 9-cm diameter, circular-patch antenna was made to resonate at 471*MHz*, with a 50Ω input impedance. That frequency would require a 17.6-cm diameter, i.e., nearly twice the diameter, without slits. This represents a size reduction of approximately 50%, beyond the effects of permittivity alone.

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