Design of Low-cost Microstrip Antennas for Glonass Applications

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Abstract— A new design procedure for low-cost circularly polarized microstrip antennas is proposed. Instead of the conventional truncated-corner square microstrip topology, a rectangular patch with four truncated corners and an equal number of stubs is utilized here. As an application, a Glonass receiver antenna is designed. Comparisons between experimental and simulated results are presented, revealing very good agreement.

1. INTRODUCTION

The design of microstrip antennas as low-cost radiators for mobile communications can be challenging. Additional complexities are introduced into the conventional microstrip design when the FR4 laminate is used as the antenna substrate, due to its high loss tangent and inaccurate relative permittivity. The high losses in the antenna laminate have a direct effect on its radiation efficiency. Consequently, for higher efficiency, thicker substrates must be used [1]. In case, for instance, a probe-fed truncated-corner square microstrip antenna (TCSMA), frequently used for achieving circular polarization (CP), is designed following the conventional procedure, an extra limitation is posed if the patch is printed on a thick substrate: its inherently inductive input impedance can not be properly matched to a 50-Ω SMA coaxial connector. In addition, the frequency where its axial ratio is best does not coincide with the frequency where its return loss is best [2].

To overcome these limitations, a new design procedure is proposed here. Instead of the conventional topology (a square patch with two truncated corners), the new procedure utilizes a rectangular patch with four truncated corners. Besides, stubs are added to each corner to compensate for the inaccuracy of the FR4 relative permittivity. This new patch topology gives the antenna designer more flexibility and the ability to properly compensate for the undesirable reactive inductance.

2. CIRCULARLY POLARIZED MICROSTRIP ANTENNAS

Antennas produce circularly polarized waves when two orthogonal field components with equal amplitudes and in-phase quadrature are radiated. Probe-fed microstrip patches, classified as resonator-type antennas, can satisfy these requirements. Various configurations capable of CP operation have been reported [3], but square and circular patches are largely utilized in practice. Square and rectangular patches for Glonass applications are discussed below.

2.1. TCSMA Design

For Glonass applications, receiver antennas have to be right-hand circularly polarized over an operating range from 1.598 to 1.609 GHz. Besides, their return loss, axial ratio and radiation efficiency have to meet specific requirements over the same frequency range [4]. TCSMA radiators that are manufactured with high quality materials can comply with these specifications. Use of low-loss RF laminates with high dielectric constant in their fabrication is currently expensive. Therefore, low-cost solutions are welcome since both market and technology are now ripe for mass production [5].

The design of a TCSMA radiator printed on FR4 substrate of $\varepsilon_r = 4.31$, thickness $= 1.524$ mm, and loss tangent $= 0.02$ for GPS applications has been recently presented [2]. However, such high loss tangent dramatically affected its axial ratio (AR) and degraded its gain, resulting in poor radiation efficiency of only 35%, which is unacceptable from a practical point of view.

By increasing the FR4 thickness to 6.2 mm, a new TCSMA radiator with the geometry shown in Figure 1 on a finite ground plane ($70 \times 70\,\text{mm}^2$) was designed for operation at 1.6035 GHz resulting in the following patch dimensions: $S = 41.1$ mm, $C = 9.35$ mm, and $P = 9.55$ mm. Corresponding input impedance, axial ratio and return loss simulated with the *HFSS* package are shown in Figures 2 and 3.

As seen from these figures, the input reactance at the operating frequency is too large ($X_{in} = j30.8\,\Omega$), so the antenna is not properly matched to the 50-Ω SMA coaxial connector. In addition, the frequency where its axial ratio is best does not coincide with the frequency where its return loss is best. The following antenna parameters were also obtained: directivity $= 6.08$ dB, 3-dB

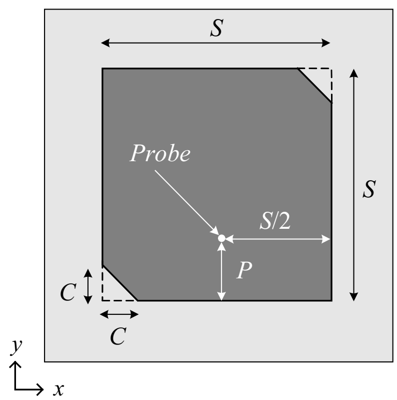

Figure 1: Typical geometry of the TCSMA radiator.

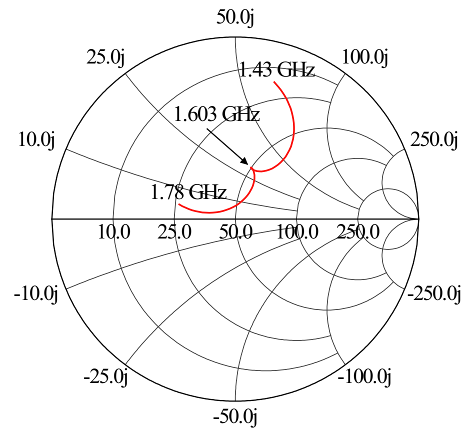

Figure 2: Input impedance of the TCSMA radiator.

AR bandwidth = 52.7 MHz (3.28 %) and radiation efficiency = 68.4%. Although these parameters comply with the Glonass requirements, return loss at 1.6035 GHz (-10.65 dB) is not acceptable. To overcome this limitation, fractal gap capacitors can be used to match the antenna to the coaxial feed line [2]. However, a different procedure is implemented next.

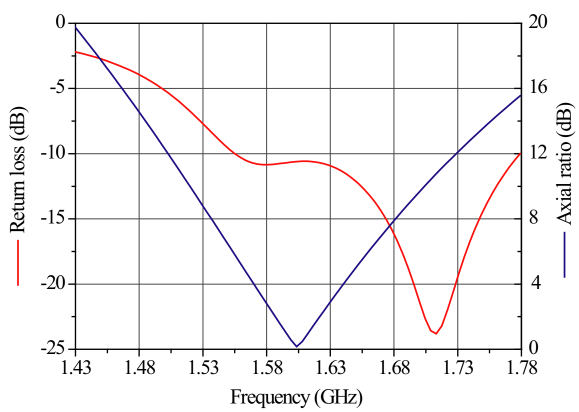

Figure 3: Axial ratio and return loss of the TCSMA radiator.

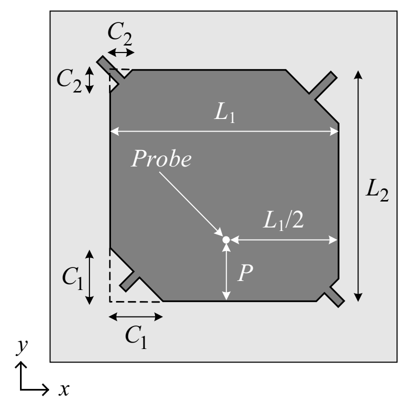

Figure 4: Proposed geometry for the TCRMA radiator.

2.2. TCRMA Design

As previously mentioned, the use of a low-cost laminate adds complexity to the antenna design due to the inaccuracy of its relative permittivity. To compensate for this effect, a topology consisting of four truncated corners with a stub added to each corner, as shown in Figure 4, is proposed. By proper trimming of each stub length, frequency deviations can be compensated for. Moreover, the new topology utilizes a rectangular patch (TCRMA) instead of the square one described in [2]. These new additional parameters (i.e., the patch sides L_1 and L_2) provide more flexibility to the antenna designer.

Keeping the FR4 thickness the same as before, i.e., 6.2 mm, a TCRMA radiator on a finite ground plane ($70 \times 70\,\mathrm{mm}^2$) has been designed ($L_1 = 40.2$ mm, $L_2 = 42.5$ mm, $C_1 = 10$ mm, $C_2 = 4$ mm, $P = 7.25$ mm, length of the large stubs = 5.5 mm, and length of the small stubs = 3.5 mm) for operation at 1.6035 GHz, resulting in the following antenna parameters: directivity = 6.12 dB, 3-dB AR bandwidth = 52.5 MHz (3.27%), and radiation efficiency = 68%.

The corresponding input impedance, axial ratio, and return loss over the frequency range are shown in Figures 5–7. Simulated and experimental input impedance results show very good agreement. As expected, the microstrip antenna with the new geometry exhibits very good AR (0.39 dB) and return loss (-33.7 dB) characteristics at 1.6035 GHz, without any capacitive gaps. These are clearly excellent results from a practical point of view. A photo of the antenna prototype that was built is shown in Figure 8. The θ- and ϕ-components of the far electric fields radiated by

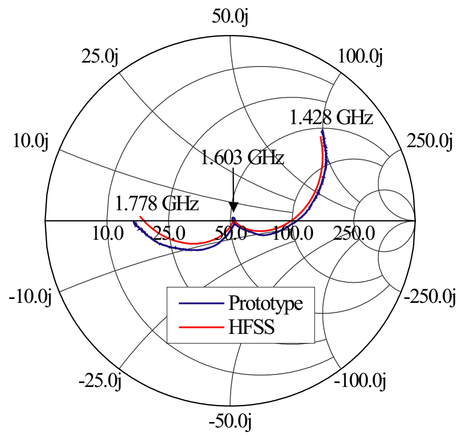

Figure 5: Input impedance of the TCRMA radiator.

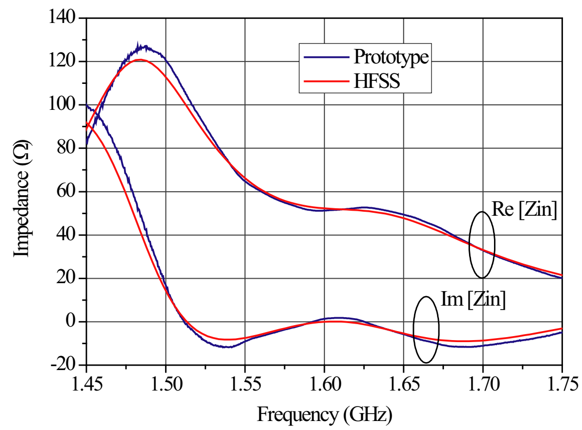

Figure 6: Input impedance of the TCRMA radiator.

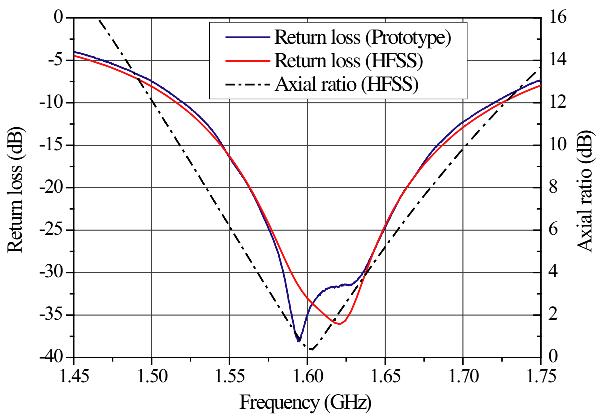

Figure 7: Axial ratio and return loss of the TCRMA radiator.

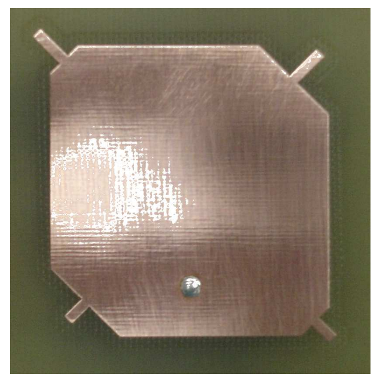

Figure 8: Photo of the Glonass antenna prototype.

the antenna are also analyzed. Experimental and simulated radiation patterns for the E_θ and E_ϕ components, plotted in the xz-plane, are shown in Figures 9 and 10, respectively.

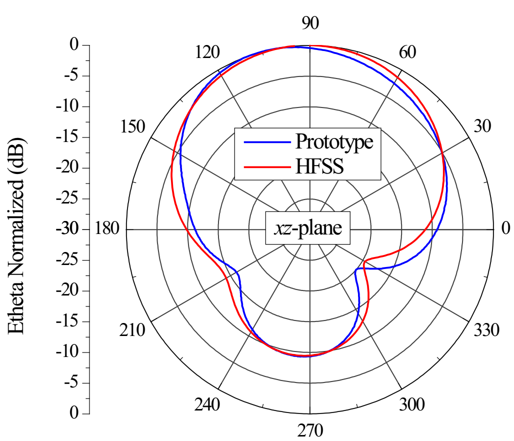

Figure 9: E_θ radiation pattern: xz-plane.

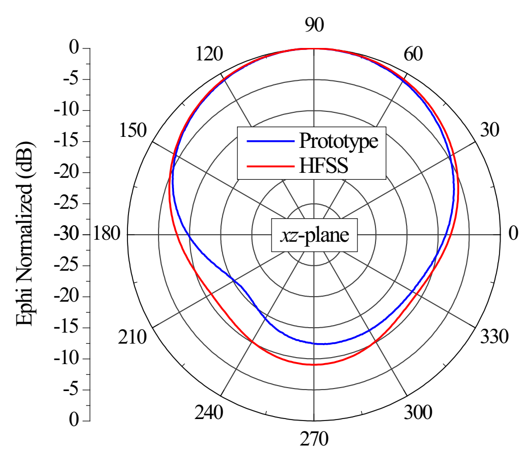

Figure 10: E_ϕ radiation pattern: xz-plane.

Results for the yz-plane are presented in Figures 11 and 12. Simulated and experimental results for this important parameter also show very good agreement.

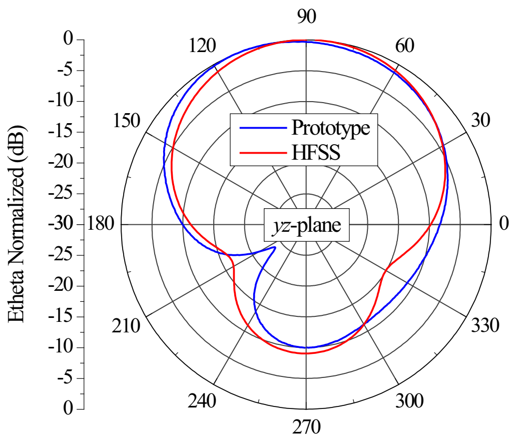

Figure 11: E_θ radiation pattern: yz-plane.

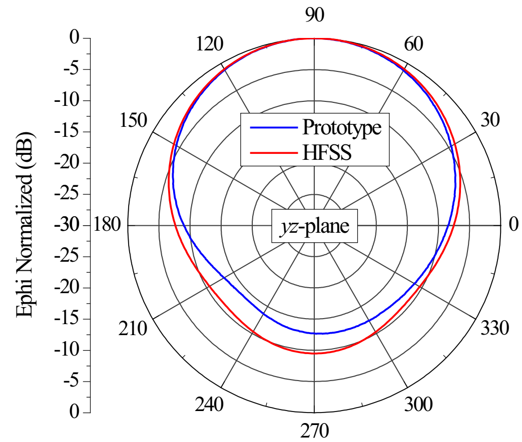

Figure 12: E_ϕ radiation pattern: yz-plane.

3. CONCLUSIONS

The design of a probe-fed truncated corner microstrip antenna on a low-cost substrate (FR4) for Glonass applications is reported. To meet design requirements, thicker substrates have to be used, but the input impedance of such antennas is inherently inductive. To overcome this problem, a new topology using a rectangular patch, rather than the usual square one, is introduced. Experimental and simulated results demonstrate it is feasible to design a thick FR4 microstrip antenna with very good AR and return loss at 1.6035 GHz without capacitor gaps or any other matching technique. This new topology can be a significant contribution to the design of low-cost circularly polarized microstrip antennas.

ACKNOWLEDGMENT

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