A Review of Antenna Miniaturization Techniques for Wireless Applications

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Introduction: For JPL/NASA's mission to Mars, the UHF frequency has been selected for the primary in-situ communications between orbiting satellites and other small vehicles, such as rovers, landers, sample-return canisters, soil penetrator, etc. The required omni-directional low-gain antennas used on these small vehicles must be small in size and low in mass in order to conserve overall system volume and mass. At the UHF frequency of 400 MHz, a conventional half-wave low-gain resonator, with a dimension in the order of 37 cm, would be prohibitively large to mount on some of the small vehicles. Consequently, antenna miniaturization techniques must be developed in order to have successful future Mars missions.

Several miniaturization techniques have been identified, in particular, for printed low-profile antennas. These include the use of high dielectric-constant material[1], the introduction of slots on the resonating patch[2,3], the folding of a single-layer patch into a two-layer structure[4], the inverted-F configuration[5], the use of a shorting post[6], the quarter-wave-patch approach[7], the genetic algorithm[8], and the use of photonic band-gap material[9]. The antenna size reductions achieved by using these techniques range from 1/5 to 1/10 of the free-space wavelength (λ_o). Antennas, with dimensions smaller than 1/10 λ_o, generally suffer significantly from poor efficiency and narrow bandwidth. These techniques, although presented for the Mars exploration programs, can certainly be applied to wireless terrestrial and mobile/satellite communications. For example, at the L-band frequency of 1.6 GHz, the antenna sizes would be four times smaller than those at the 400 MHz and should be in the few-centimeter region, which can be fitted easily onto a mobile hand-held cellular phone.

Antenna miniaturization descriptions: The most popular technique in reducing the size of a printed antenna is to use high-dielectric-constant (ε_r) material for its substrate. In doing so, the guided-wavelength underneath the patch is reduced and, hence the resonating patch size is also reduced. The reduction ratio[1] is approximately related to square root of ε_r. A conventional patch antenna, useing ε_r of 2 to 3, has a dimension about $0.35\lambda_o$. With an ε_r of 10, the patch size reduces to about $0.2\lambda_o$. To further reduce the size, slots can be introduced onto the resonating patch[2,3]. In doing so, the current on the patch or the field underneath the patch will resonate from one edge of the patch and take longer path around the slots to reach the opposite edge as illustrated in Fig. 1. This longer path, in essence, reduces the resonant frequency or the physical size of the antenna. Depending on the length of the slots, a 10% to 20% size reduction can be achieved. As an actual demonstration, a recently developed antenna[3] using ε_r of 10 and four slots, shown in Fig. 2, achieved a patch diameter of 11cm ($0.15\lambda_o$) at the frequency of 400 MHz. Four slots, instead of two, are used to achieve either circular or dual polarization. This antenna, when mounted on the Mars sample return spherical canister with a diameter of 15cm, is shown in Fig. 3. Because the canister is an electrically small structure, the antenna provided a nearly complete spherical coverage as shown in the measured patterns given in Fig. 4.

The third technique is to fold[4] the complete single-layer patch antenna (including substrate and ground plane) to form a two-layer structure and hence reduce the planar dimension by half. The configuration of the folded half-wave patch is illustrated in Fig. 5 and the folding of a quarter-wave patch is shown in Fig. 6. By folding a quarter-wave patch with a substrate ε_r of 10, the achieved antenna size at 400 MHz is 11.4cm x 3.8cm x 1.5cm. The fourth technique is to use the planar inverted-F configuration[5] as shown in Fig. 7

where the width dimension (W) of the short-circuited plate is significantly smaller than L_1 (approx. $0.2L_1$) and the dimensions L_1 and L_2 are each on the order of 1/8 λ_o. Another technique, very similar to the inverted-F method, is the use of a circular patch with a shorting post[6] as illustrated in Fig. 8. This patch achieved a diameter of $0.1\lambda_o$ with an ε_r equal to 4.81. Both the inverted-F and the shorting post methods, although they can achieve size reduction, generally radiate very high cross-pol field. In certain applications, high cross-pol field is not a concern as long as the radiation is omni-directional and the antenna has a good input impedance match.

Two other recently emerging techniques also worth mentioning here. One is the use of "genetic" optimization algorithm[8] to minimize the size of wire type or printed antennas, while optimize their RF performance. This antenna optimization is very similar to human's biological genetic evolution where biological configurations adapt to optimal fitness to the natural environment by a huge number of chromosome sets with binary type of genetic decisions. The antennas designed by this technique generally don't have a conventional shape. For example, by using this technique, an odd-shaped small wire antenna[8] as shown in Fig. 9, achieved circular polarization with hemispherical radiation coverage. The second emerging technique employs the "photonic band-gap" material[9]. In the case of electromagnetic application, the material is also best called the "electromagnetic band-gap" material. This material, acts very similar to a frequency selective surface, will reflect or transmit through only a certain band of electromagnetic energy. This material comes in various forms. One uses a thin slab of dielectric material with many equally spaced holes as shown in Fig. 10. It offers the opportunity to print a dipole element on a small piece of thin substrate with hemispherical radiation, instead of the need for the conventional quarter-wave spacing from a larger ground plane. At UHF, the quarter-wave spacing will result in an undesirable large-volume antenna.

Conclusion: Several antenna miniaturization techniques, in particular for printed structures, are briefly presented here. These techniques have wide application in the areas of space telecommunications and planet in-situ communications, commercial wireless mobile communications, and military systems.

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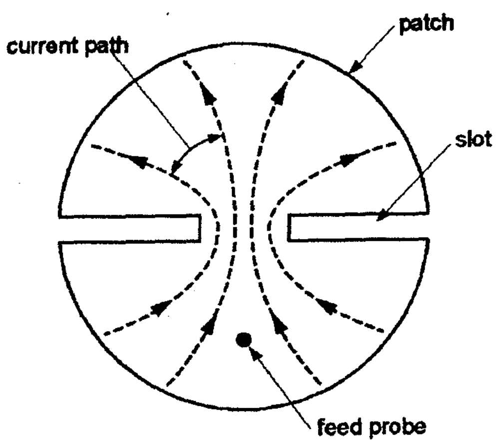

Figure 1. Patch with slots yields longer patch length of current flow.

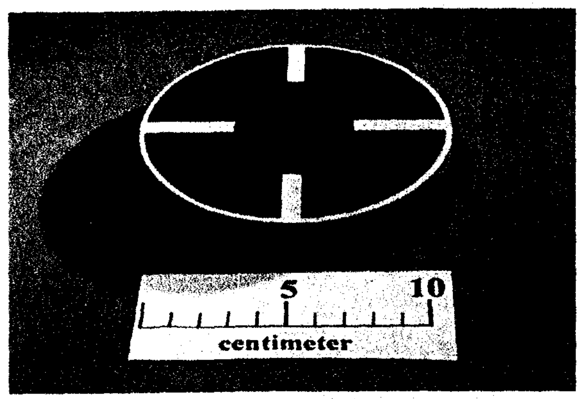

Figure 2. Circular patch with slots and high dielectric constant substrate.

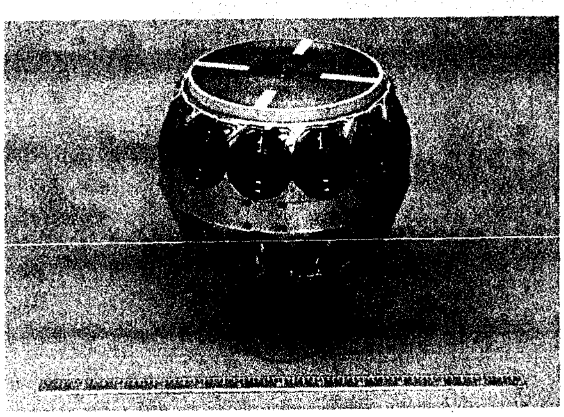

Figure 3. photo of the miniaturized patch antenna mounted on spherical canister covered with solar cells.

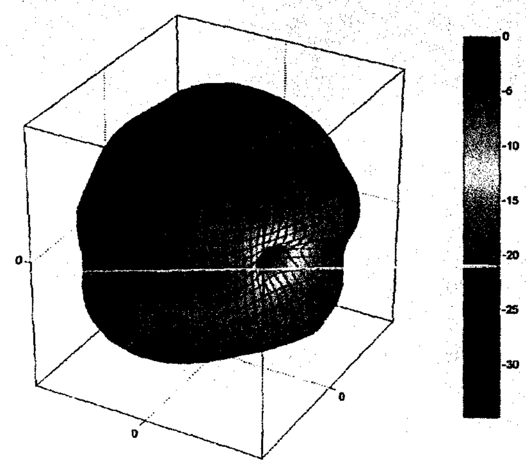

Figure 4. Measured 3-D pattern of the patch antenna mounted on the canister.

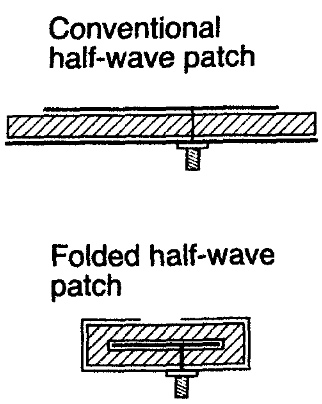

Figure 5. Folding of a half-wave patch.

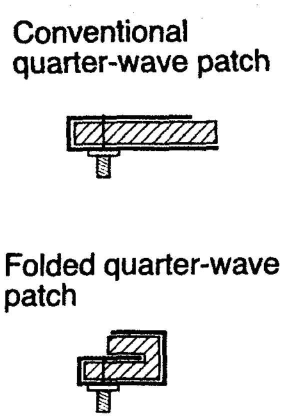

Figure 6. Folding of a quarter-wave patch.

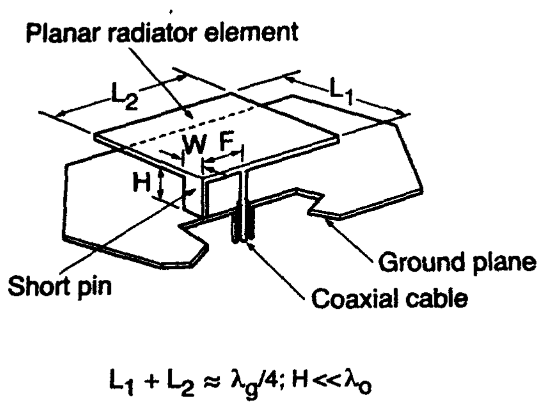

Figure 7. Inverted-F patch antenna.

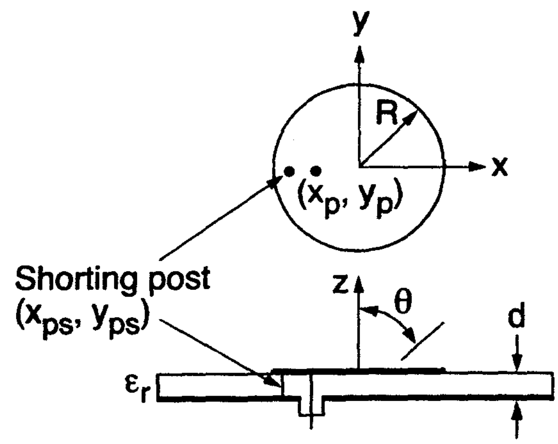

Figure 8. Circular patch with a shorting post.

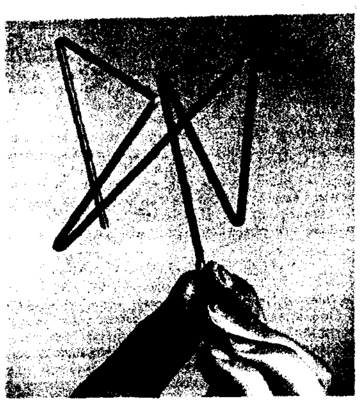

Figure 9. Circularly polarized wire antenna designed by genetic algorithm. (Courtesy of D. S. Linden.)

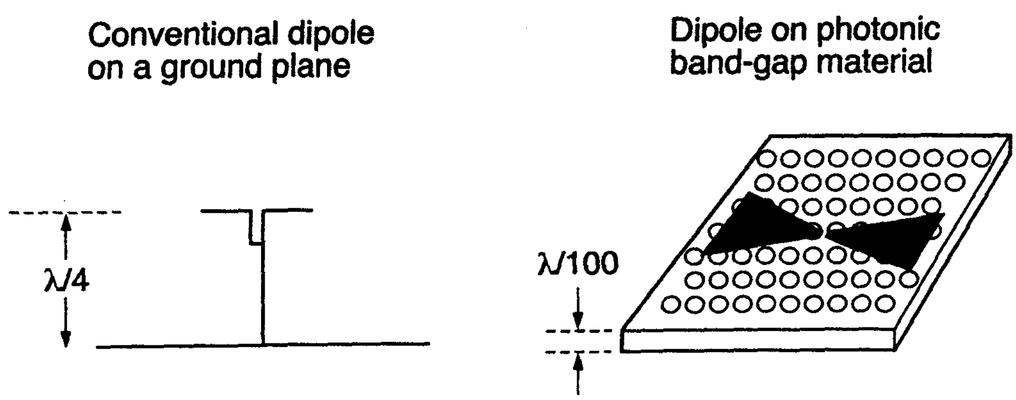

Figure 10. Antenna height reduction utilizing photonic band-gap material