Ultra-wideband Omnidirectional Conformable Low-Profile Mode-0 Spiral-Mode Microstrip (SMM) Antenna

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I. Introduction

Over the past half century, there have been continued and vigorous research efforts to develop ultra-wideband omnidirectional antennas that are conformable and low-profile to the mounting platform, driven by many important applications including the latest software-defined radios. For the present discussion, we define ultra-wideband as having a gain bandwidth greater than 2:1 between the highest and the lowest frequencies of operation (f_H over f_L), and low-profile as having a height of $\lambda_L/5$ or less (λ_L being the wavelength at f_L). (The gain bandwidth is the ultimate performance parameter with impedance matching, efficiency, and pattern all accounted for.)

Unfortunately, most reported efforts seem to have fizzled out over time. In most cases their fates were doomed from the beginning by the well-known and well-established theory born over half a century ago, which proclaims a fundamental physical limitation on the gain bandwidth of an omnidirectional antenna when its size, and in particular its height, is reduced.

In 1997 an omnidirectional low-profile conformable antenna with a 9:1 bandwidth (2-18 GHz) was reported [1]. It was a mode-0 SMM (spiral-mode microstrip) antenna design [1-3] with a diameter of 2.5 inches ($0.424\lambda_L$) and a height of 0.125 inches ($0.021\lambda_L$). However, that antenna suffered from a low gain (specifically, low efficiency) at the low end of its operating frequencies and also an excessive tilt of the beam peak in elevation pattern above the ground plane.

This paper reports a refined mode-0 SMM antenna design whose performance has been sufficiently enhanced to excel existing state-of-the-art ultra-wideband low-profile conformal omnidirectional antennas in the literature.

II. Ultra-wideband Omnidirectional Mode-0 SMM Antenna

The SMM antenna is a traveling wave (TW) antenna [1-3], as illustrated in Figure 1 in cylindrical and rectangular coordinate systems (ρ, ϕ, z) and (x, y, z). Without loss of generality, and in view of the reciprocity theorem, we consider only the transmit case. As discussed in [1-3], the electromagnetic fields can be expressed in terms of wave functions, which are solutions to the scalar wave equation, given by

$$\Psi_n = \exp(jn\phi) \int_0^\infty g\,(k_\rho)\, J_n(k_\rho\rho)\, \exp(jk_z z)\, k_\rho\, \mathrm{d}k_\rho \qquad (1)$$

The mode-0 SMM wave corresponds to the case in which $n = 0$ in Equation (1). The SMM wave is a TW that radiates as it propagates along the planar broadband structure and the ground plane.

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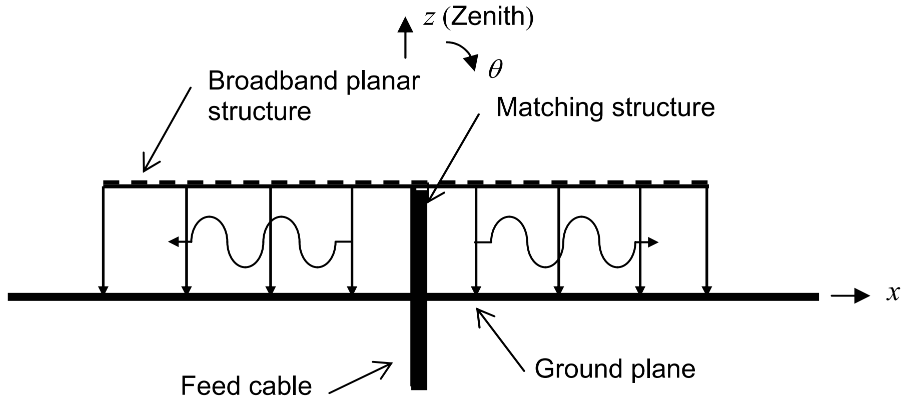

Figure 1. Mode-0 SMM antenna in transmit operation.

As can be seen, a mode-0 SMM wave is launched at the feed point, where a matching structure ensures transformation of the coaxial mode in the feed cable into a mode-0 SMM wave. The planar broadband structure, such as a multiarm spiral, is of a finite and preferably small diameter, and the ground plane also has a finite diameter dictated by the mounting platform; both planar structures are conformal to the surface of the platform, obviously within certain limitations. The edge of these two planar structures presents a discontinuity which could disrupt the propagation of the traveling wave. A major thrust of the design process is to optimize the matching structure and the broadband planar structure to minimize the reflection.

III. Measured Performance for Mode-0 SMM Antenna

Figure 2 shows the measured SWR of a mode-0 SMM antenna 5.7-inch in diameter and 1.06-inch in height, mounted on a conducting ground plane of 1-ft diameter.

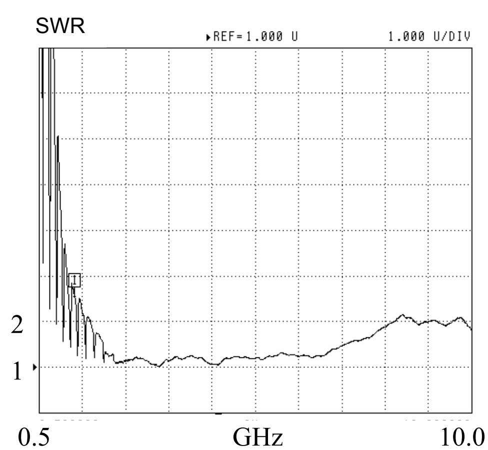

Figure 2. Measured SWR of mode-0 SMM antenna.

Representative measured azimuth and elevation patterns are shown in Figure 3. The polarization is parallel to the $\boldsymbol{\theta}$ vector, like that of a monopole parallel to the *z* axis.

This antenna has an omnidirectional pattern bandwidth significantly wider than even the 0.5-10.0 GHz range (a 20:1 bandwidth) shown in Fig. 3. However, its gain drops rapidly below 1 GHz, to approximately -14 dBi at 0.5 GHz. The gain drop is mainly due to impedance mismatch. Using 1-dBi as a yardstick for antenna gain, its gain bandwidth covers from 1.0 GHz to beyond 10.0 GHz, a gain bandwidth wider than 10:1.

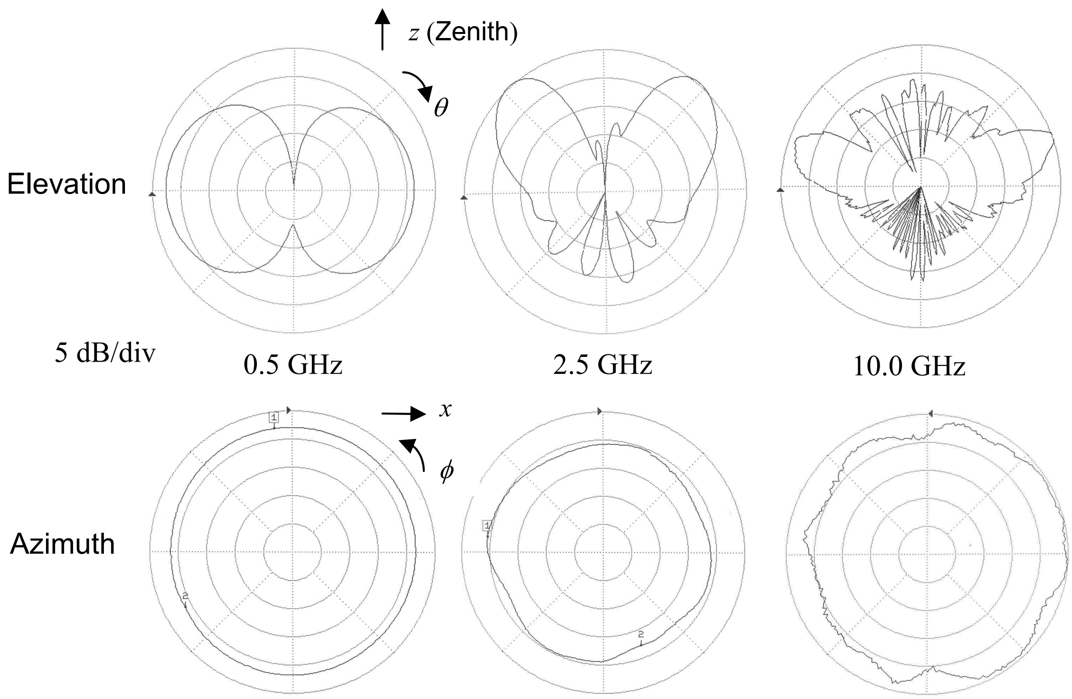

Figure 3. Representative azimuth and elevation patterns for the mode-0 SMM antenna.

Preliminary experimentation indicates that further improvement of impedance matching at lower frequencies, and thus a broader gain bandwidth, is feasible. A potentially even wider pattern bandwidth appears also achievable, especially since the mode-2 (which has a pseudo omnidirectional pattern) can be excited at higher frequencies where the antenna diameter is electrically large enough to support the mode-2.

VI. Comparison with Other Omnidirectional Conformal Broadband Antennas

Table 1 compares WEO's mode-0 SMM antenna with other top-performance ultra-wideband, low-profile, conformable, omnidirectional antennas as defined here.

Table 1. Comparison of similar ultra-wideband conformal omnidirectional antennas.

Antenna / Parameter	Conical monopole	Goubau multielement monopole	Mode-0 SMM antenna
Gain bandwidth*	**7:1**	**Estimated 2:1**	**10:1**
Pattern bandwidth	16:1	No data	20:1
Height (in λ_L)**	0.2	0.065	0.09
Diameter (in λ_L)**	0.26	0.185	0.48

* Minimum gain = 1 dBi

** λ_L = wavelength at low end of the gain bandwidth

Note that the criterion for gain bandwidth is set here to be 1 dBi minimum at the beam peak over the prescribed bandwidth, and that the dimensions are in λ_L, which is the wavelength at the low end of the gain bandwidth. The data for the conical monople are based on WEO's internal measured data, which are consistent with those for the closely related biconical dipole such as the US shipboard 200-1300 MHz antenna model AS-2812. The Goubau antenna [4] does not have full-fledged gain pattern data in the literature. But its implied 2:1 gain bandwidth appears to be valid based on unpublished research on a similar multielement antenna independently carried out by this senior author in 1972.

In a formal publication later, Table 1 will be considerably expanded with more antennas included. For example, the annular slots, or their equivalent patch type or magnetic loop type, could be included for comparison in Table 1. However, they tend to have shortcomings in either impedance or pattern bandwidth. In fact, the mode-0 SMM antenna can be considered to be continual rings of annular slots or magnetic current (or self-complementary electrical current) similar to the mode-1 case. Another antenna that could be, but is not, included in the comparison is WEO's slow-wave antenna [5].

Note that the multielement Goubau antenna is of the resonant type, which is inherently limited in bandwidth. The conical monopole antenna and the SMM antenna are of the traveling-wave type, inherently broadband as discussed in [3]. It is also worth pointing out that the theory on the inherent gain-bandwidth limitation on omnidirectional antennas is applicable to wideband TW antennas only in an oblique, indirect manner.

It is worth noting that this mode-0 SMM antenna has an omnidirectional pattern bandwidth over 0.5-10.0 GHz (a 20:1 bandwidth). Although its gain drops at lower frequencies, it remains a useful -14 dBi at 0.5 GHz. Further broadening of its impedance bandwidth, thus its gain bandwidth, is highly feasible.

V. Conclusion

An ultra-wideband low-profile platform-conformable omnidirectional antenna based on the mode-0 SMM antenna has been developed. Its 10:1 gain bandwidth is slightly larger than that of the well-established conical monopole, yet its height is less than a half. Compared with other well-known low-profile omnidirectional antennas with a gain bandwidth over 2:1, its gain bandwidth of 10:1 is much larger. Further size reduction improvement and performance enhancement for this new antenna are highly feasible.

References

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