The Physical Foundation, Developmental History, and Ultra-wideband Performance of SMM (Spiral-Mode Microstrip) Antennas

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I. Introduction

This paper reviews the physical foundation, developmental history, and ultra-wideband (UW) performance of the SMM (spiral-mode microstrip) antenna [1-3]. This paper is inspired by the recent article on self-complementary (SC) antennas by Mushiake [4], and shares with it considerable physical insight and technical relevance. However, it is worth pointing out that an SC structure offers only a real constant impedance, not necessarily a useful radiation pattern; both are needed to qualify as a UW or even frequency-independent (FI) antenna and this is where the geometries of spiral, log-periodic (LP), etc. come into play. Additionally, for practical reasons it is often necessary that the antenna be amenable to conformal mounting on a platform; this is accomplished by the SMM antenna, as discussed below.

II. From Self-complementary (SC) Antenna to Frequency-independent (FI) Traveling-wave (TW) Antenna

As pointed out in [4], the theoretical foundation of the real constant impedance for planar FI antennas is their SC geometry, not their spiral, equi-angular, LP, sinuous, or fractal feature. Without the SC feature, many FI antennas would not have a real constant impedance. As an example, practical spiral antennas generally are of the SC Archimedian type, not the equi-angular or LP types. As another example, LP dipole arrays generally do not have full-fledged ultra-wideband performance. They often have dips in the main beam which, though mild-looking and as small as a 3-dB drop, could give rise to a disastrous 20-dB drop in link budget.

Last but not least important, to be useful an SC antenna must also be truncated to a practical finite size. All these requirements can only be met by the traveling-wave (TW) antennas. Specifically,

1. UW as a rule is achieved only by TW antennas [2]. Thus an FI antenna is invariably a TW antenna.
2. An SC structure supports TW on an FI basis.
3. For an FI antenna, radiation must be completed satisfactorily within the truncated antenna structure via the TW throughout the prescribed bandwidth.

III. From FI (Frequency-independent) TW (Traveling-wave) Antennas to Conformable Multimode SMM Antennas

Antenna are often mounted on a platform and thus required to be conformal and low-profile. For such platform-mounted applications the truncated SC antenna appears to be an ideal candidate except for the problem that it radiates on both sides of the antenna plane. For several decades, the general solution was to use an absorbing material on one side of the planar SC antenna to dissipate the undesired power. Although this approach generates a useful pattern, it also pays the price of a 3-dB loss in gain and an elevated antenna noise temperature. As a result, almost every serious spiral antenna engineer has attempted to replace the absorber with a conducting ground plane. After many failed attempts, a paper eventually declared that this was impossible. This misconception was shared by many until the advent of the SMM antenna.

The SMM antenna is a traveling wave structure [1-3], as illustrated in Fig. 1 in cylindrical and rectangular coordinate systems (ρ, ϕ, z) and (x, y, z). It consists of an UW planar structure such as an SC structure. The ultra-wideband planar 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, which can be non-planar.

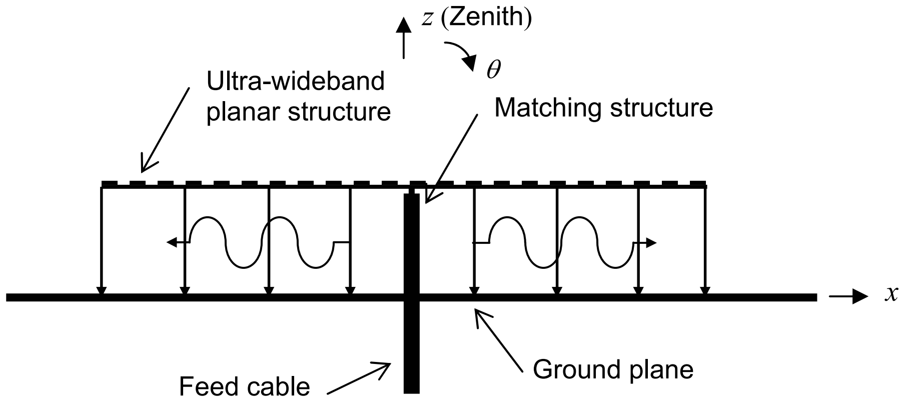

Fig. 1. Basic concept of the SMM antenna.

Without loss of generality, and in view of the reciprocity theorem, we consider only the transmit case. As can be seen, a mode-m SMM wave is launched at the feed point, where a matching structure ensures impedance-matched launch of an SMM wave. The SMM wave is a TW which is supported by the planar UW structure and the ground plane, and radiates away as it propagates outwardly.

The electromagnetic fields can be expressed in terms of wave functions, which are solutions to the scalar wave equation, given by

$$\Psi_n = \exp(jn\phi) \int_0^\infty g\,(k_\rho)\, J_n(k_\rho \rho)\, \exp(jk_z z)\, k_\rho\, dk_\rho \quad (1)$$

The mode-m wave corresponds to the case of n = 0, 1, 2,… in Eq. (1). The various patterns of the SMM antenna are depicted in Fig. 2. This unique multimode feature is being exploited to achieve multifunction performance on a single aperture, or to generate pattern-diversity to overcome problems such as multipath fading. Further details will be presented in a separate publication [5].

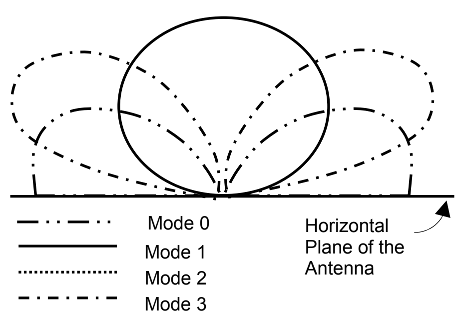

Fig. 2. Various patterns of the SMM antenna.

IV. The Roles of Magnetic Current and Charge in Antenna Theory

Mushiake [4] correctly pointed out that both the theoretical foundation and the historical development of the self-complementary antenna stem from the fact that the electric and magnetic quantities are treated on an equal basis. It is worth commenting that indeed the representation of the Maxwell equation with full duality has significantly contributed to the development of both hardware (as in the case of the SC antenna) and software (as in the electromagnetic analysis codes). In the context of macroscopic electromagnetic theory for a linear, isotropic medium, a magnetic current or magnetic charge is a full-fledged observable as electric current or electric charge [6].

Recently, a certain type of spiral antennas was called a “spiral slot” to distinguish it from other existing spiral antennas. Unfortunately, such a nomenclature could only add confusion and misconception in antenna theory.

As shown in Fig. 3, the exterior fields (for $z > 0$) of a planar antenna is often represented by an equivalent magnetic current $\mathbf{M} = -\, \boldsymbol{n} \times \mathbf{E}$ on a perfect electric conducting half plane S at $z = 0$, since the appropriate Green’s functions have been well developed for these planar half-space problems.

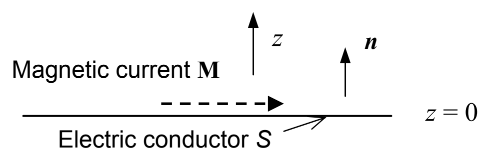

Fig. 3. Equivalent problem for exterior fields (z > 0).

Since the tangential **E** fields on a perfectly conducting surface vanish, only the “slot” part of the spiral has a non-vanishing source, the magnetic current $\mathbf{M} = -\, \boldsymbol{n} \times \mathbf{E}$ on the slot aperture. Therefore, from a theoretical point of view, emphasizing the “slot” feature of a spiral antenna is in essence a confusing and misleading idea. Furthermore, since the broadband characteristics of the spiral antenna is rooted in its SC feature, not its spiral configuration, to emphasize the non-metallic slot part of the spiral antenna as something new and important is inconsistent and counter-productive.

V. Ultra-wideband Performance of Mode-1 SMM antenna

Ultra-wideband gain-pattern performance over a 10:1 frequency range has been demonstrated experimentally for the mode-1 SMM antenna, some of which have been reported [2]. Its radiation property is well understood from the viewpoint of the TW antenna, in which case the TW propagates along the microstrip lines and slotlines, and radiation is from the magnetic current **M** over the the slotlines, with the appropriate Green’s functions for the boundary *S*, as discussed in the preceding section. Thus the quality of the gain pattern depends on maintaining a pure mode-1 SMM wave on *S*.

VI. Ultra-wideband Performance of Mode-0 SMM antenna

Ultra-wideband gain-pattern performance over a 10:1 frequency range has been demonstrated experimentally with a WEO mode-0 SMM antenna over 1-10 GHz [3]. It is worth noting that it has an even wider pattern bandwidth over 0.5-10.0 GHz (a 20:1 bandwidth). Further broadening of its impedance bandwidth, thus its gain bandwidth, is highly feasible. Its resistance and reactance over 0.5-1.0 GHz are shown in Fig. 4. Physical limitation of this antenna will be discussed later [7].

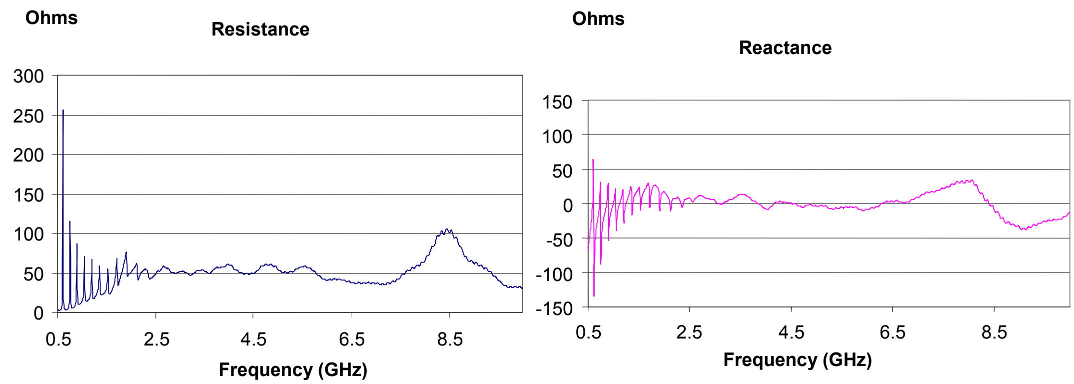

Fig. 4. Measured resistance and reactance of a mode-0 SMM antenna over 0.5-10.0 GHz.

VII. Conclusion

The physical foundation and ultra-wideband performance of SMM antennas are reviewed in the context of traveling-wave antenna theory. The developmental history of the SMM antenna from self-complementary antennas to conformable frequency-independent antennas is discussed and clarified. It can be stated that the SMM antenna now has a full-fledged 10:1 gain bandwidth, which is much larger than other low-profile conformal antennas, for both mode-1 and mode-0. Further size reduction improvement and performance enhancement for this new antenna are highly feasible.

References

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