High-Performance Universal GNSS Antenna Based on SMM Antenna Technology

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ABSTRACT – A class of high-performance low-cost GNSS antennas that cover all three GNSS services (GPS/GLONASS/Galileo) is presented. The designs are based on the ultra-wideband SMM antenna, which has a phase center inherently more stable with angular and frequency variations than other antenna types. The antenna is low-cost and platform conformable. Size reduction using the slow-wave antenna technology and the magneto-dielectric antenna technology is discussed.

I. Introduction

GNSS (Global Navigation Satellite System) receivers covering both US GPS (Global Positioning System) and Russian GLONASS are now employed globally. Europe's own GNSS, named Galileo, is scheduled for operation in 2008, after launching its first satellite in December 2005. In anticipation of such a new market need for receivers handling all three GNSS carriers, two receiver chips were announced in 2006.

The spectra of GPS, GLONASS, and Galileo spread densely across 1.164 – 1.610 GHz, covering a frequency bandwidth of 446 MHz or an octaval bandwidth of 1.383:1, as displayed in Fig. 1. To cover the densely populated multiple GNSS bands, an antenna with continuous and broad instantaneous bandwidth appears highly desirable or even necessary. Furthermore, conventional multiband antenna approaches employed in GPS and GPS/GLONASS are no longer viable solutions due to their large phase center movement over wide frequency range.

If we add stringent physical requirements, such as low-profile and conformability to platform, the antenna design problem becomes very challenging.

It is interesting to note that the uniquely suitable antenna technology needed to handle all three GNSS services was already in place in 1991, when Georgia Tech announced a GPS/GLONASS antenna designed by a research team led by the senior author (GPS World, 1991), using the newly invented SMM (Spiral-Mode Microstrip) antenna (Wang and Tripp, 1994; Wang, 2000). Unfortunately, market need at the time for a GPS/GLONASS antenna was insignificant in the immediate post-cold-war environment. As a result, continued development in the 1990s at WEO was a "technology driven" business venture that gained little external support.

Since 2001, with the emergence of Europe's Galileo system and its launch of the first satellite in December 2005, WEO resumed its efforts. Though still sporadic due to limitation of resources, WEO in early 2006 started the development of a Universal GNSS Antenna with a continuous bandwidth of 1.1 – 2.0 GHz, covering all GPS/GLONASS/Galileo bands. In order to gain market interest, the bandwidth of the antenna was broadened to cover other L-band satellite communication systems. The goal was to be in the market by 2008, the year in which the full constellation of Galileo's 30 satellites is scheduled to be in orbit and in operation. This paper discusses one prototype model and its related design concepts.

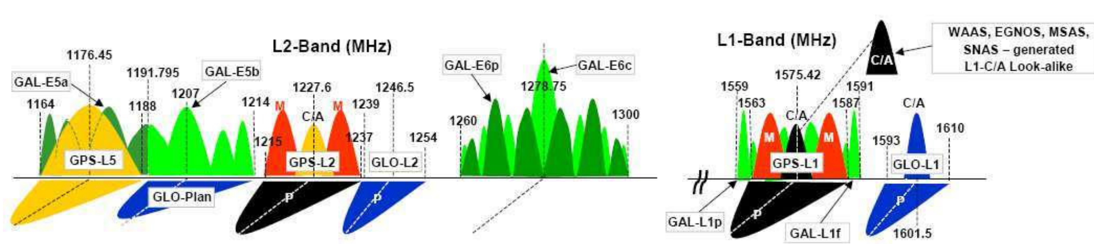

Fig. 1. Frequency spectrum for GPS/GLONASS/Galileo.

II. Design of a Universal GNSS Antenna

A prototype model for the Universal GNSS Antenna covering GPS/GLONASS/Galileo is shown in Fig. 2 (cross sectional view of the layout) and Fig. 3 (photograph). It is an SMM antenna 11.5 cm in diameter and 3.0 cm in height. The spiral is a 4-arm self-complementary Archimedean spiral. Its broad bandwidth makes it stable, reliable, and tolerant to environmental changes. Its low-profile conformable form factor makes it suitable for platform mounting.

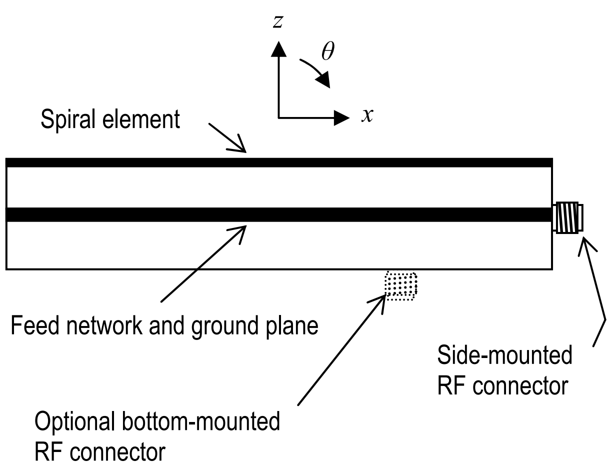

Fig. 2. Cross sectional view for layout of Universal GNSS Antenna.

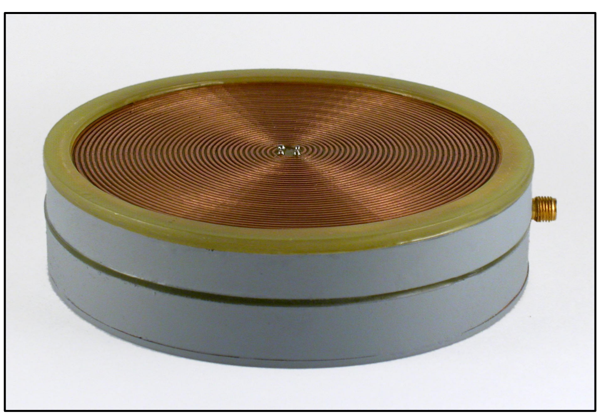

Fig. 3. Photo of Universal GNSS Antenna.

III. Radiation Characteristics

Figs. 4 and 5 show measured SWR and a typical RHCP (right-hand circular polarization) elevation pattern, respectively, for the antenna in Figs. 2-3. The antenna has a stable phase center (PC), which will be discussed in the next section. Although this prototype exhibits fairly good performance, as an SMM antenna we expect better performance. Indeed, the next phase of the product development work will be focused on the specific requirements in the marketplace, from which we will optimize the design with tradeoffs between performance, cost, and other issues.

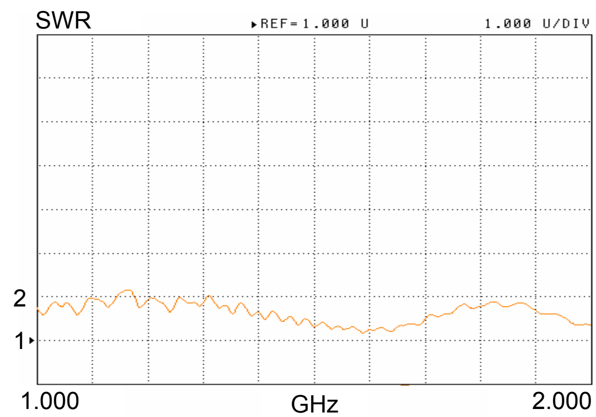

Fig. 4. Measured SWR.

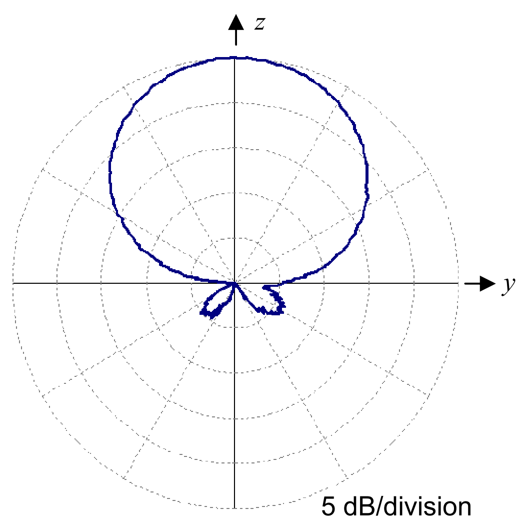

Fig. 5. Typical measured radiation pattern.

As will be discussed in the following sections, there are paramount inherent advantages in the SMM antenna technology for GNSS applications. Therefore, it should be straightforward to achieve further improvements for the Universal GNSS Antenna tailored to specific market needs and user preferences. We expect acceleration in product development, and will present the most recent data in the symposium.

IV. Phase Center Stability

The phase center (PC) of the SMM antenna is inherently more stable with angular and frequency variations than any other antenna types except for the slow-wave antenna (Wang and Tillery, 2000) and the magneto-dielectric antenna (Wang and Tripp, 1996), which share some common features with the SMM antenna and will be discussed in the next section. Their PC stability is rooted in the structural symmetry and thinness of these three antennas. Because of the achievable symmetry of their radiating structure, including the spiral, the ground plane, the feed, etc., their PC can be made symmetrical about the vertical axis z. Therefore, their PC is theoretically at (0, 0, Z_{pc}), the center of the spiral, if the effects of the radome are negligible. Z_{pc} is a function of the elevation angle θ and the frequency f.

The radiation of the SMM antenna can be represented, on the basis of current equivalence principle, as the emission from an array of planar magnetic current elements (or annular slots) as shown by the senior author (Wang, APS, 2005; Wang, ISAP, 2005; Wang et al, 2006). Specifically, the non-metal part of the spiral antenna, which one may call the “spiral slot,” is an equivalent magnetic current. (As a side note, a certain type of spiral antenna was called by some as a “spiral slot” to distinguish it from other “metallic” spiral antennas. One must be careful in using and interpreting such a nomenclature to avoid confusion and misconception.)

The PC of an infinite planar array of infinitesimal thickness is on the plane *per se*, that is, at $Z_{pc} = 0$. For a practical SMM antenna, or any other antenna, with finite dimensions, Z_{pc} is not 0 but rather a function depending on the equivalent current on the surface $z = 0$ beyond the extent of the antenna. As a general rule, the thinner the planar antenna the smaller Z_{pc} is; and the smaller the current on the edge of the antenna, the smaller Z_{pc} is.

Since the SMM antenna can be designed to have its power radiated before the spiral-mode traveling wave reaches the periphery of the spiral, it is inherently superior to other antennas regarding its PC’s angular and frequency stability; this will be briefly reviewed as follows. (The theoretical foundation of this analysis, including the implicit invoking of the reciprocity theorem, can be found in textbooks in advanced electromagnetics (Wang, 1991).)

The patch antenna has sidelobe problems which manifest substantial edge current. Although techniques such as the electronic band-gap materials can be employed to reduce its sidelobes, the spatial and frequency variations of its PC remain. The problem of PC movement becomes insurmountable for a broadband patch antenna, whose broad bandwidth can only be realized by increasing its thickness, resulting in larger PC movement.

Other antennas attempting to achieve broadband or multiband coverage of all three GNSS services are expected to have a much larger dimension in the z axis for its radiating structure, and larger current on the periphery of the antenna, causing much larger PC movement. Because of the large frequency bands involved in GPS/GNSS/Galileo, it is impractical and even impossible to compensate or correct such PC movement at the receiver as sometimes performed in narrowband GPS services. Thus, none of them enjoy the advantages of the planar spiral, which has essentially had its radiation completed before the spiral-mode wave reaches the periphery of the spiral.

V. Other Issues: Platform Compatibility and Size Reduction

The last decade has been marked with a series of major efforts in reducing the size of GPS antennas, including the CRPAs (Controlled Radiation Pattern Antennas), which have one to seven pattern nulls adaptively steered to the direction of incoming jamming noises to suppress them. These adaptive pattern nulls are generated by either RF beaming forming or signal processing after detection and downconversion. It is worth noting that apparently these efforts have not overcome the physical limitations established by the classical Chu theory, which sets an upper bound on the gain-bandwidth of an antenna due to its electrical size (Chu, 1948).

However, the senior author noted two decades ago that the premises on which the Chu theory had been derived were overly restrictive or impractical, especially for antennas which must tradeoff gain-bandwidth for size reduction. Recently, interest and research in this topic of practical importance, as well as the controversies, intensified. To contribute to this important and difficult problem, the senior author published his findings (Wang, IWAT and PIERS, 2005; Wang, 2006) by pointing out the shortcomings in the Chu theory when applied to real-world antennas. In particular, a traveling-wave antenna, such as the spiral antenna, mounted on a platform is not subject to the rigid Chu limitation. As a result, size reduction for the GNSS antenna beyond the Chu limitation should be feasible.

To reduce the size of traveling-wave antennas, the senior author and his colleagues had conceived the magneto-dielectric antenna (Wang and Tripp, 1996) and the miniaturized slow-wave antenna (Wang and Tillery, 2000). However, these techniques have been hampered by the lack of workable low-cost low-loss high-permittivity dielectric materials, as well as the lack of practical and appropriate low-loss high permittivity/permeability magneto-dielectrics at frequencies above 500 MHz.

Fortunately, over the past few years, practical low-loss dielectric materials, such as LTCC (low-temperature co-fired ceramic), LCP (liquid crystal polymer), and high-permittivity ceramic materials, have become available, often at low cost as well. And low-loss magneto-dielectric materials for frequencies up to 1 to 3 GHz are recently reported to be available. The use of magneto-dielectric materials with equal relative permittivity and permeability (ε_r and μ_r), for $\varepsilon_r = \mu_r = 2.0, 4.0, 5.0$, etc. at another laboratory was observed to achieve antenna size reduction without significant degradation in performance (Buell, 2005; Mosallaei et al, 2004), as envisioned in (Wang and Tripp, 1996).

VI. Conclusions

A class of high-performance low-cost GNSS antennas with a continuous bandwidth covering GPS/GLONASS/Galileo services is presented. The designs are based on the SMM antenna technology, which has a phase center inherently more stable with angular and frequency variations than other antenna types. Size reduction using the slow-wave antenna technology and the magneto-dielectric antenna technology, which share some common features with the SMM antenna, is now feasible with the newly available magneto-dielectric materials. Other advantages of this antenna are low cost and platform-conformability.

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