A Review of GPS Antennas

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***Abstract*-A GPS antenna must be able to cover most part of the sky in order to receive several satellites' signals. To achieve this, the antenna has to provide a broad radiation beam and additional requirements which include low gain and right-handed circular polarization with a low axial ratio. An appropriate antenna is a crucial element of the GPS terminal to perform accurate positioning within a short acquisition time. This article describes the properties of GPS antennas and presents a gallery of various antenna types.**

Keywords- Global Positioning System; GPS antennas; Helix antennas; Microstrip antennas

I. INTRODUCTION

Global Positioning System (GPS) services have gained substantial attention in recent years. The well-known United States GPS satellite constellation has been joined by two newer global satellite networks: Russia's GLONASS (***Glo****balnaya* ***na****vigatsionnaya* ***s****putnikovaya* ***s****istema* or Global Navigation Satellite System) and the European Union's developing system, Galileo. Altogether, these systems will provide worldwide location services for mobile platforms; air, sea, and ground vehicles; individuals; and mobile assets.

To pinpoint any one location on the Earth's surface, a GPS system uses as many as ten satellites traveling in different orbital trajectories. An appropriate antenna constitutes a crucial component in achieving precise positioning with minimal acquisition time. The antenna's range should cover most part of the visible sky in order to receive signals from as many satellites as possible; this necessitates a broad radiation beam. Furthermore, antenna gain should be sufficiently low to provide an acceptable signal-to-noise ratio. Typically, the gain of GPS antennas within the full coverage zone ranges from -3 dBic to 5 dBic.

The antenna's operational frequencies must correspond to the frequency allocations of the satellite systems in use (GPS: 1559-1610 MHz and 1215-1240 MHz, GLONASS: 1593-1611 MHz and 1243-1249 MHz and 1193-1209 MHz, Galileo: 1559-1592 MHz and 1215-1300 MHz and 1164-1215 MHz), and the antenna should be right-handed circularly polarized. The antenna's axial ratio (AR)—the ratio between the radiated power at the main roll angle and the radiated power at the minor roll angle - is also an essential factor in quality reception. When a satellite is at the zenith, it is not difficult for an antenna to achieve an AR of 1 to 3 dB; the AR achieved when a satellite is near the horizon is much higher. The relation between AR and cross polarization is formulated in equation (1) and illustrated in Fig. 1 and Fig. 2.

$$Cross - Pol = (\sqrt{AR} - 1)^2 / (\sqrt{AR} + 1)^2 \qquad (1)$$

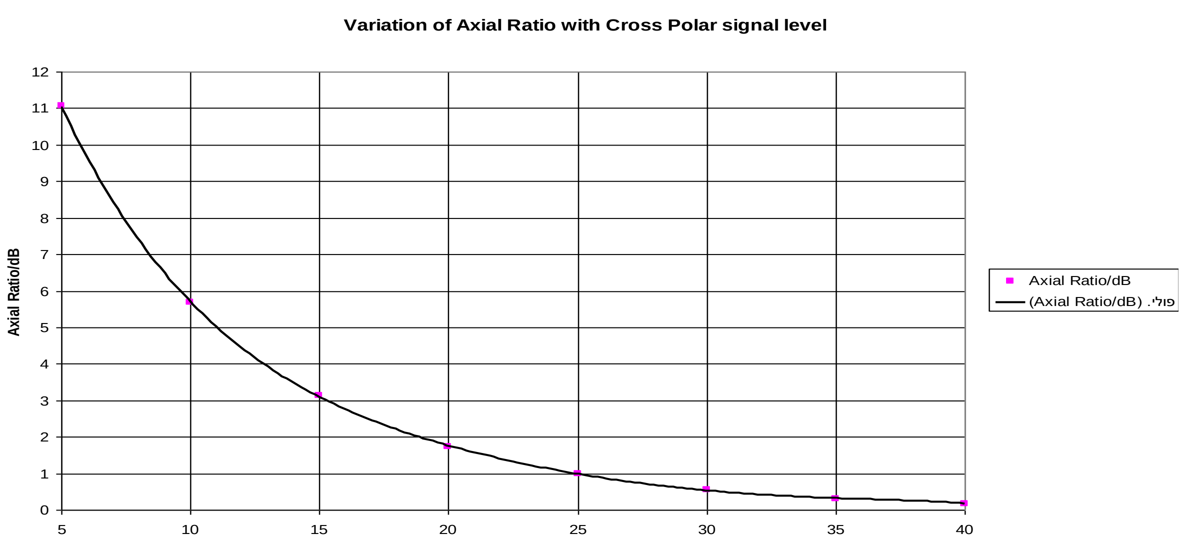

Fig. 1 A general relation between cross-polarization and AR in circularly polarized antennas

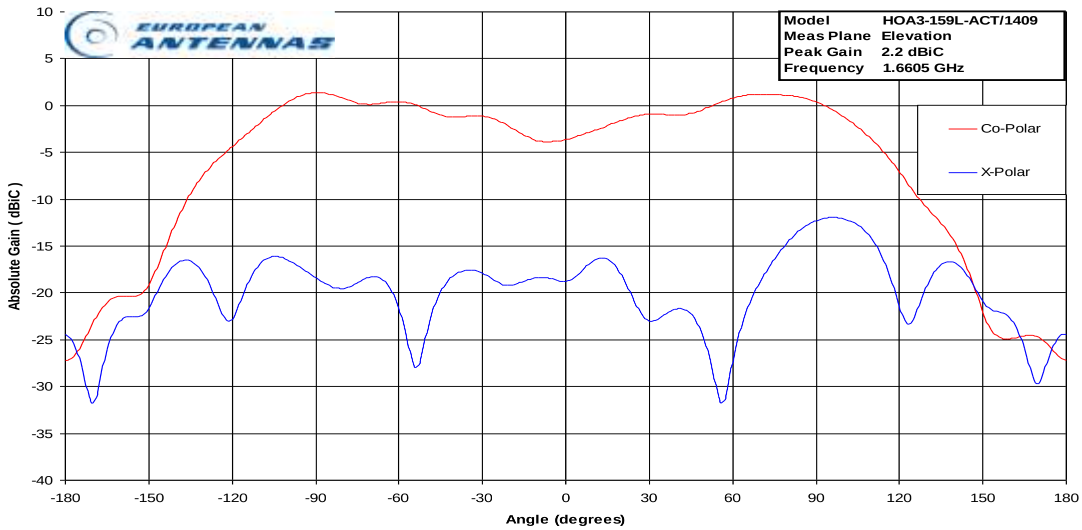

Fig. 2 An illustration of radiation patterns in two polarizations (right-handed and left-handed) from which the AR can be derived (European antennas)

There are numerous types of GPS antennas as described in many textbooks [1]-[27] and as industrial products [28]-[44]. The more popular among them include high-quality quad-helix antennas with exceptional coverage and low axial ratio; miniaturized helix antennas, externally-installed microstrip antennas, small ceramic patches, small spirals and chip antennas for internal and hand-held devices. Antenna designers continue to face the challenge of miniaturizing antennas and integrating them into small printed boards while maintaining acceptable performance. Additional design goals for high-end applications include achieving better cross-polarization through the control of antenna surroundings and designing antennas for each specific GPS constellation.

II. HELIX ANTENNAS

Helix antennas have a reputation for their simplicity and superior axial ratio. According to their diameters, helix antennas are commonly categorized into two groups: axial mode and normal mode antennas. Axial-mode antennas, which are better-suited for GPS than normal-mode antennas, are characterized by the circumference C such that $3\lambda/4<C<4\lambda/3$. The typical pitch S is $S = 0.2$ to $0.3\ \lambda$ and the opening angle at the head of the helix is $\alpha = \arctan(S/C)$. The number of turns is N and the overall length is $L = NS$.

Equations (2)-(4) [13] capture, respectively, the radiation resistance Rr, the directivity D, and the beamwidth Θ.

$$Rr = 140(C/\lambda) \tag{2}$$

$$D = 15(C/\lambda)^2 (NS/\lambda) \tag{3}$$

$$\Theta_{3dB} \cong 50(C/\lambda)\sqrt{N(S/\lambda)} \tag{4}$$

The radiation pattern can be approximated by (5)

$$E\theta \sim E\phi \sim \frac{\sin(\pi/2N)\cos(\theta)\sin(N\Omega/2)}{\sin(\Omega/2)} \tag{5}$$

Where

$$\Omega = kS(\cos\theta) - \pi(2 + 1/N) \tag{6}$$

And the axial ratio is given by (7) as follows:

$$AR = (2N+1)/(2N) \tag{7}$$

Transmission antennas found in GPS satellites (Fig. 3) are typically axial-mode helix antennas with low AR.

Fig. 3 Transmission antennas in GPS satellites

Axial-mode helical antennas can be considered as the most appropriate antennas for GPS because their large volume enables ample coverage to be achieved even as far as the horizon. These antennas are associated with typical gains of 5 to 7 dBic at the zenith and -3 to -6 dBic at the horizon, and with typical AR values of 1-2 dB at the zenith and 3-6 dB at the horizon. Axial-mode helix antennas manufactured by companies such as European Antennas, Satimo and Tecom are good choices for aerial and nautical platforms in which performance is important (Fig. 4). A number of helical antennas utilize double or quad coils. Compared with single-coil and bifilar helical antennas, the quad-helix-antenna (QHA), in which four arms are fed with equal amplitudes and relative phases of 0°, 90°, 180° and 270°, is a superior choice. The height of the QHA is $\lambda/2$, and its diameter is $\lambda/4$ (Fig. 5-6).

Fig. 4 High-quality helix antennas (SATIMO)

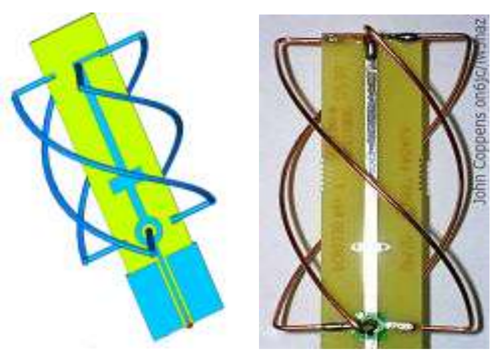

Fig. 5 Quad Helix (COPPENS)

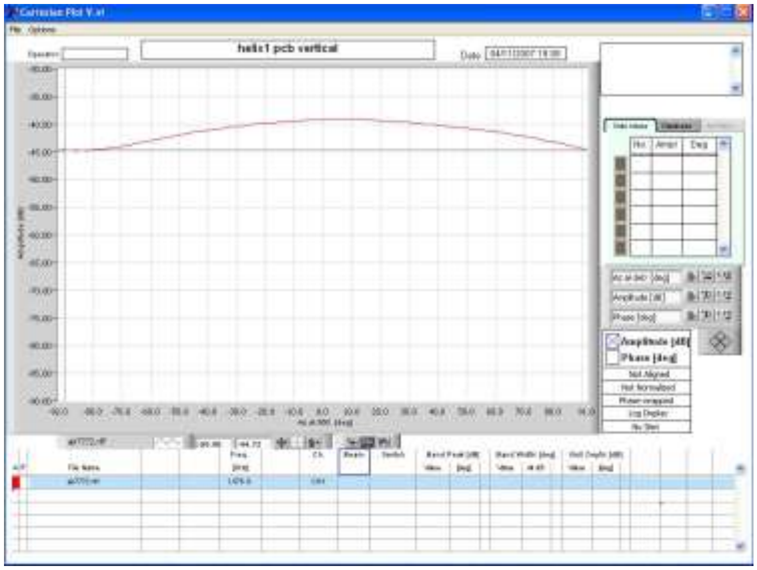

Fig. 6 Quad Helix Elevation pattern (from horizon to horizon).Gain values are from 5 dBic (zenith) to -1 dBic (horizon)

The QHA is considered as one of the best GPS antennas because of its excellent coverage and Axial Ratio at low angles of coverage. It is also relatively unaffected by the presence of the user or other objects in the vicinity of the antenna.

A dielectric loaded quad helix is made up of copper tracks situated on a high-dielectric ceramic cylinder (Fig. 7). The dielectric cylinder measures only 10-20 mm, making this antenna most useful in applications where unobtrusive integration is essential. Since the antenna is balanced and miniscule, there is little potential for interaction with the printed circuit board (PCB) contents or human contact.

Dielectric loaded quad helix antennas produced by Sarantel, Maxtena, Skycross and others are also available with Low Noise Amplifiers (LNA). The amplifiers influence the noise figure (typically yielding values of 1 to 2 dB) and gain (typically 20 to 35 dB). A high-quality antenna needs to be well matched (VSWR < 1.5) and have high efficiency (>50%). To avoid the problem of de-tuning caused by proximity to metals, Sarantel offers a number of plastic covers to place on the antennas. These covers effectively negate any de-tuning effects.

Fig. 7 Miniature Quad Helix 18 x 10 mm (SARANTEL)

III. MICROSTRIP PATCH

The microstrip patch antenna is the natural choice for mobile terminals in which size constraints, price concerns and easy PCB integration must be taken into account. These inconspicuous antennas which are commonly only 2–4 mm thick can be fabricated on low dielectric substrates ($\varepsilon r = 2$ to 6), with typical element size of 30–60 mm, or on high dielectric substrates ($\varepsilon r = 20$ to 100), with typical element size of 15–25 mm.

The microstrip patch covers the sky fairly well with the typical gain of 3 to 5 dBic towards the zenith and -5 to -8 dBic at 10° above the horizon. The resonance frequency fc is given by [17]:

$$fc = c/[2(L+2\Delta L)\sqrt{\varepsilon eff}\,] \quad (8)$$

Where c is the speed of light; L is the patch actual length; ΔL is a theoretical extension of the patch at each side; and εeff is the effective dielectric constant, Good approximations for ΔL and εeff are:

$$\varepsilon eff = (\varepsilon r + 1)/2 + (\varepsilon r - 1)/2\sqrt{(1 + 10h/w)} \tag{9}$$

Where r is the relative dielectric constant of the substrate; h is the thickness of the substrate; W is the Width of the patch,

$$\Delta L = \frac{0.412h(\varepsilon eff + 0.3)[(w/h) + 0.264]}{(\varepsilon eff - 0.258)(w/h + 0.8)} \tag{10}$$

Circular polarization in microstrip antennas is accomplished by using a non-symmetrical square, edge chamfering, or internal slots with a non-centered feed point. The quality factor (Q) of the resonator is directly related to the narrow bandwidth, in the vicinity of 1% which is sufficient for the GPS application.

Fig. 8 and Fig. 10 depict microstrip antennas manufactured by Cobham and Laipac; these antennas are characterized by low dielectric substrates and relatively large size, and are suited for external installations. The performance of a microstrip patch depends on both the patch size and the dimensions of the ground plane. If the ground plane is less than 50 mm, the center frequency is shifted (Fig. 11), the gain decreases (Fig. 12), and the axial ratio deteriorates. The antenna is also sensitive to its immediate surroundings, e.g., the presence of metals and other objects.

Fig. 8 Full size patch antenna (Sensor Systems, now COBHAM)

For a satellite at the zenith, the gain of a microstrip patch antenna is 5 to 8 dBic (depending on the size of the patch and the size of the ground). For a satellite 10° above the horizon, the antenna's gain is only -3 dBic to -5 dBic. The AR at the zenith is 1-3 dB (depending mainly on the clearance area) and the axial ratio at 10° above the horizon is 6-10 dB (far from being optimal). It is possible to organize microstrip patches in arrays and adapt them to cylindrical, conical or spherical surfaces in order to attain the desired level of coverage.

Fig. 9 Microstrip patch elevation pattern (from horizon to horizon. Gain values are from 7 dBic (zenith) to -6 dBic (horizon). The beamwidth values (at 3 dB) are 75° to 80°

Fig. 10 Patch antenna with magnetic mounting (LAIPAC)

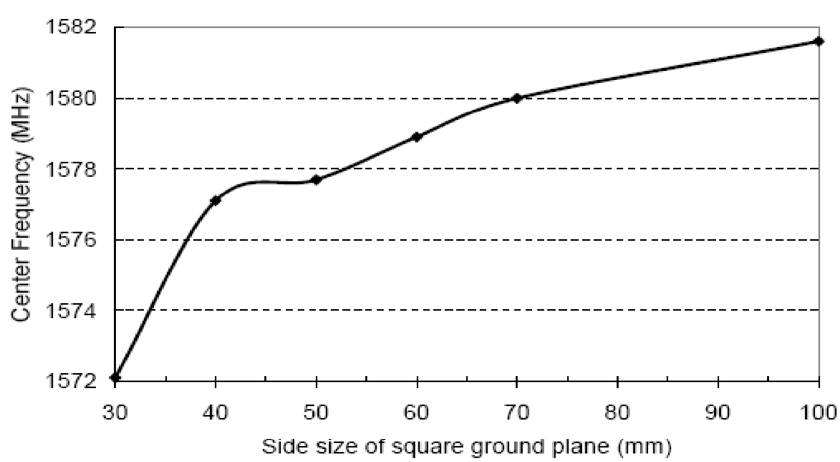

Fig. 11 Resonant frequency of microstrip patch as a function of the size of the ground plane (LAIPAC)

Fig. 12 Gain of microstrip patch as a function of the size of the ground plane (LAIPAC)

Many companies, including u-blox, Taoglas and Inpaq, offer small microstrip antennas printed on high dielectric constant substrates ($\varepsilon r =$ 40 to 80; see Fig. 13). These antennas are small enough to be integrated into portable, mobile and hand-held devices (Fig. 14). The typical size of the antenna patch is between 25 × 25 mm and 15 × 15 mm. Designers of mobile devices should take into account that these antennas typically perform below the advertised levels. Antenna manufacturers usually test the antennas on a cleared ground plane measuring 50 × 50 mm or even 70 × 70 mm. Typical gains with a sufficiently large ground plane are 2 to 4 dBic at the zenith, but in the absence of an appropriate ground plane the maximal gain may drop to below 0 dBic.

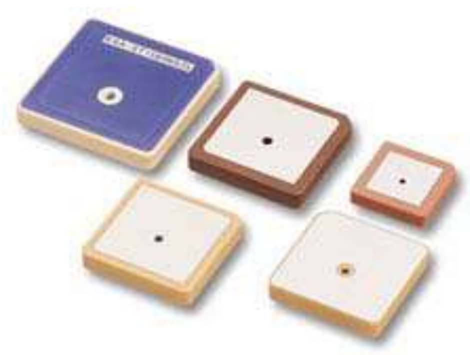

Fig. 13 Miniature ceramic patch antennas (U-BLOX)

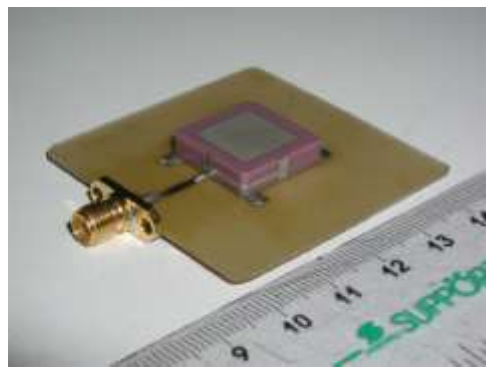

Fig. 14 Ceramic patch antenna mounted on PCB

Radio signals that are broadcasting near a GPS receiver (e.g., cellular phones, WiFi modems and even digital clocks) can interfere with the GPS signal. Two useful means of overcoming this problem are (i) inserting a band pass filter at the antenna terminals, (ii) using absorbent materials to minimize coupling with other antennas or devices. Another source of interference is the PCB itself, whose contents can de-tunes the center frequency of the microstrip patch. Such de-tuning can be overcome by adding dielectric sheets to the patch. Alternatively, Taoglas (Fig. 15) offers a set of patches with different frequencies, enabling the PCB designer to select the optimal patch for the specific PCB structure.

Fig. 15 A set of patches at different frequencies

IV. WIRE AND CHIP ANTENNAS

In some cases, lower-end antenna solutions, namely a simple linear polarized wire such as a strip monopole or a PIFA (Printed Inverted F Antenna) - is sufficient. Such solutions are appropriate mainly in cases where the user is willing to accept relatively weak signals, or in products for which navigation is not a central feature. Compared with right-handed circularly polarized antennas, monopole antennas are characterized by a 3 dB loss by polarization and lower gains (-3 to -6 dBil). Fig. 16 depicts a design of two flat spirals, one on either side of an integrated receiver.

Chip antennas are even smaller than monopoles, with dimensions of only a few millimeters (Fig. 17 shows a chip antenna manufactured by Pulse, and Fig. 18 shows an antenna by Antenova). These antennas require relatively large ground planes. Typical gains of chip antennas are -10 to -6 dBi, even with ground planes of 30-40 mm.

Fig. 16 Printed dual spiral 35 x 7 x 2 mm (ANTENOVA)

Fig. 17 Chip antenna 3.2 x 1.6 x 1.1 mm (PULSE)

Fig. 18 Chip antenna (ANTENOVA)

V. HIGH- END APPLICATIONS

Some applications, such as land surveying and scientific experiments, rely on highly accurate measurements, and therefore require large, high-quality antennas. Such antennas must suppress cross-polarized signals associated with multi-path interference. Three-dimensional co-centered choke rings (Fig. 19), or, alternatively, printed rings, constitute possible solutions for overcoming cross-polarization.

Phase variation across the radiation pattern poses an additional concern in high-accuracy applications. Appropriate calibration of the antenna can compensate for such variation. Moreover, some applications require multiple satellite constellations; broadband antennas that cover all navigation frequencies (1224 to 1616 MHz) in a single aperture can be implemented for this purpose (Fig. 20).

Fig. 19 Choke rings for reduced cross-polarization (LEICA)

Fig. 20 An antenna for GPS, GLONASS and Galileo (NOVATEL)

Fig. 21 Hand-held GPS device with internal antenna

VI. CONCLUSIONS

The performance of a GPS device is critically dependent on its antenna. The antenna determines how many satellites are detected and their signal strengths. Antennas influence the accuracy and acquisition time of the positioning process. High-accuracy applications require high-end antennas that cover the sky, with gain between 5 dBic to -3 dBic.Such antennas should be right-handed circularly polarized with AR of 1 dB (at the zenith) to 6 dB (at the horizon). For applications requiring less accuracy, as in the case of hand-held devices (Fig. 21) or when the navigation is not the primary function, adequate reception can be achieved with lower-end antennas, and even with linearly polarized antennas, particularly when LNA are incorporated. Antenna size varies from 10-15 cm to 1-2 cm, depending on the specific structure and the dielectric materials. Small ceramic or chip antennas, which are usually integrated into PCBs, may not perform according to advertised specifications, due to test and implementation conditions. Such antennas are frequently subjected to de-tuning of the frequency, which can be corrected in various ways. Likewise, filters and EMC absorbers can minimize interference from close radio signals.

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