GPS/GLONASS Antennas and Ground Planes: Size and Weight Reduction Perspectives.

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ABSTRACT

Antenna ground plane (GP) plays the major role in reduction of multipath coming from underneath the antenna. Different types of GP are considered: flat (plane), impedance (Choke Rings), vertical structures. Theoretical treatment, computational results and basic limitations for broadband GPS/GLONASS/GALILEO operation are provided. Results of reduced size (up to the order of several centimeter) multipath-protected antenna developments are discussed.

Introduction.

Antenna ground plane continues to be one of the major factors restraining further decrease of user's equipment size and weight. In general case while using GNSS antenna at the open site Π-shape of antenna pattern is preferable: nearly constant coverage of upper semi-sphere and zero antenna pattern level for angles below horizon to mitigate multipath signals reflected from the ground. From general theorems it is clear that such performance cannot be achieved with antenna unit of finite size. Hence the use of ground planes with comparatively big size (of the order of 1-2 wavelengths which for GNSS signals gives about 20-40cm) has been viewed as necessary reasonable way to obtain good level of multipath protection. But with such common ground planes two circumstances have to be considered.

First, neither of ground planes could give protection against multipath signals originated by low elevation satellites. With such low elevation satellites multipath signals come from small angles below horizon. To provide necessary protection sharp cut-off behavior of antenna pattern near horizon needed. Flat-type structures aligned along horizontal plane cannot give such. Normally some level of multipath protection provided by common antenna ground plane starts from angles about 25-30 degrees elevation. So with low elevations antenna gain for direct signal plays the major role. But, as will be pointed out below, there exists a kind of trade between antenna gain level for low elevations and multipath protection given by ground plane for high elevations. Both two circumstances make reasonable ground plane size and antenna element choice dependent on each other.

So in the first Section an overview of commonly used flat metal and impedance ground planes is given. The second Section is dedicated to small-size vertical structures. On our opinion such structures could give sufficient level of antenna gain for low elevations and at the same time provide reasonable level of multipath protection. In the forth Section implementation examples and field test results are given.

And, some notes. It is common in antenna theory and engineering to treat mostly transmitting mode rather than receiving. This makes the analysis more simple. Equality of antenna pattern for these two modes of operation comes from reciprocity theorem. Also, neither of problems under consideration could be fully treated analytically while both qualitative and quantitative results could be obtained while treating corresponding 2-D problems. 2-D pictures shown below could be viewed as a cross-section of full 3-D objects with respect to one of the 2 major planes of symmetry. We will treat microstrip antennas as antenna elements. This is due to wide spread of such elements in to-day designs.

Our goal will be to estimate so-called down-up ratio. This is the proportion between antenna gain pattern magnitudes for some angle below antenna horizon and the same angle above the horizon. Assuming nearly mirror-type reflections from the ground this ratio gives an estimate for multipath suppression provided by the antenna ground plane. This ratio is equal to 1 (0dB) for zero elevation. We will calculate this ratio for 90degrees elevation (zenith) as reference level for comparison between structures.

It is well known that multipath phase error ψ_{mult} (assuming one multipath ray) is $\psi_{mult} = arctg((\alpha \sin(\varphi))/(1+\alpha\cos(\varphi)))$. Here α,φ - magnitude and phase of multipath ray related to direct one. In concerning antenna performance α is down-up ratio mentioned above. For small α we have $|\psi_{mult}| \le \alpha$. We will use α=-20dB as reasonable reference level. With such α ψ_{mult}=5.7degrees .

1.Conventional Ground Planes

For analytical evaluation simplified model of microstrip antenna shown on Fig.1 will be used.

According to such model radiation pattern of microstrip antenna could be approximated by radiation of 2 equivalent magnetic line currents $\mathbf{j}^{\mathbf{m}}$ placed onto the ground plane with the distance 2d equal to patch length in between them.

For the case of flat metal strip (ground plane) of 2a width the problem is known to be classical for wave diffraction theory. Good references are provided in [1]. But no results in simple closed form is available.

Due to reasons mentioned above we will focus on comparatively high elevation angles. For such angles we could use Kirchoff approach as giving sufficient accuracy. According to Kirchhoff approach electromagnetic field at the region below the ground plane is originated by equivalent sources on complementary parts expanding the ground plane up to infinite one. We will omit mathematical details due to limited printing space and discuss just results.

In case of metal ground plane equivalent sources are equivalent electric currents j^e which decay

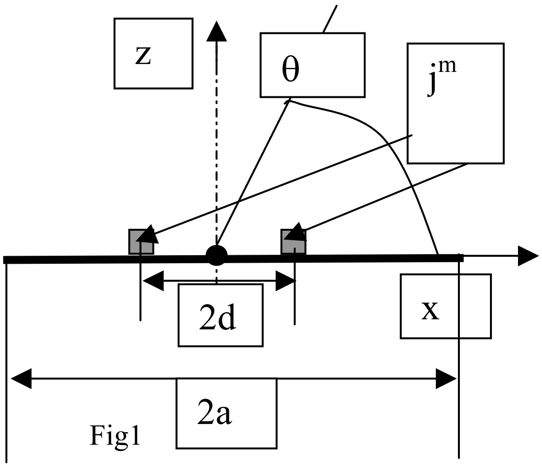

Fig1

inversely proportional to square root of distance from the source:

$$j^e \approx |x/\lambda|^{-1/2} \qquad (1)$$

Here λ is wavelength.

Due to such speed of decrease down-up ratio for high elevation angles close to zenith is:

$$\alpha \approx f_0(0)\left(2\pi\sqrt{\frac{a}{\lambda}}\right)^{-1} \qquad (2)$$

Here by $f_0(0)$ the magnitude of normalized antenna element gain pattern in horizon direction is denoted if big (theoretically – infinite) ground plane is used.

Physical content of (2) is quite clear. The less magnitude of $f_0(0)$ is - the more weak "illuminations " of ground plane edges are – the better multipath protection (smaller α) is. But certainly on the other hand the less $f_0(0)$ is – the poorer tracking of low elevation satellites is observed.

This trade between tracking of low elevation satellites and multipath protection for high elevations is common in practice. More detailed plots of down-up ratio versus elevation angle were obtained by exact numerical simulation of the problem using method of moments.

Two of such plots are shown on Fig2. We would need to mention that doubling the size (up to about 40cm diameter) adds only 3dB to multipath rejection capability in agreement with estimate of (2).

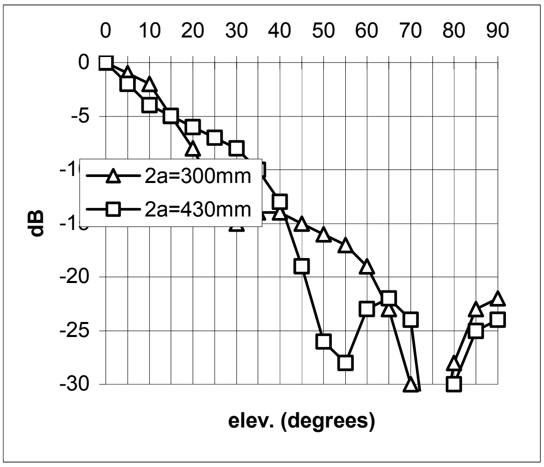

Fig2

As follows from (2), multipath protection of about –20dB level could be obtained by flat metal ground plane slightly less than wavelength size (about 17-18cm for GNSS signals). Though Kirchoff approach is not reliable for such comparatively small objects experiment shows that said multipath protection level is observed for said size. But further decrease of flat metal ground plane size leads to insufficient multipath rejection.

Let us turn to impedance ground planes and Choke Rings as their most known implementation. Impedance structures are known in antenna technique as structures which under certain conditions provide more rapid decay of equivalent sources on complementary parts of the ground plane versus (3). Different types of such structures could be used. The most known is grooves structure representing grooves machined in metal body of the ground plane . Such are Choke Rings ground planes basics of design of which are described in [2].

With impedance ground planes both electrical $j^{equiv.e}$ and magnetic $j^{equiv.m}$ equivalent currents flow at complementary parts of the ground plane. For capacitive surface impedance Z said currents decay as

$$\left|j^{equiv.e}\right| = \left|j^{equiv.m} / Z\right| \approx (x/\lambda)^{-3/2} \qquad (3)$$

providing down-up ratio for angles close to zenith as

$$\alpha \approx f_0(0)\frac{W_0}{Z}\left(\frac{W_0}{Z}-1\right)(2\pi)^{-2}(a/\lambda)^{-3/2} \qquad (4)$$

Here W_0=120π Ohms. What was said above considering the trade between antenna gain pattern for low elevations and multipath protection for high elevations is are also valid here. We need to mention more fast improvement of multipath protection with size increase due to “3/2 law” in (5). But also need to note that impedance Z is related to groove depth h as

$$Z \approx iW_0 tg(2\pi h/\lambda) \qquad (5)$$

So to get capacitive reactance groove depth h should be slightly more than the quarter of wavelength which makes about 60mm. Also as follows from (4), Z should be as close to resonance ($Z\to\propto$, $h\to\lambda/4+0$, (5)) as possible. This causes certain concerns with multi-frequency case especially with relationship to coming L5 signal. One of possible ways of creating multi-frequency Choke Ring was proposed in [3]. The attempt was made to keep groove depth close to the quarter of wavelength (hence – big Z) for both two (L1 and L2) frequencies.

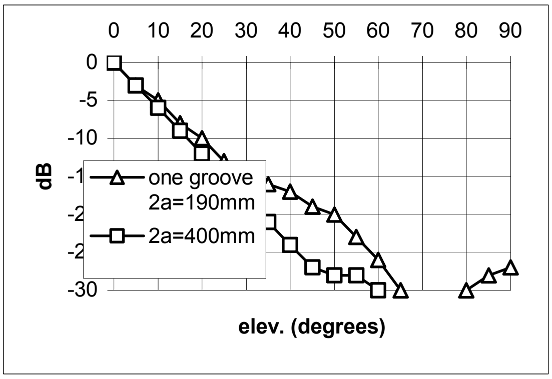

Fig.3

Calculated down/up plot for the structure with 1 groove is shown on Fig.3. As it is seen such structure provides better multipath suppression versus flat ground plane though at the expense of significant thickness due to groove depth. For comparison the plot for Choke Ring structure of 400mm diameter is shown also.

In general we would like to mention that conventional types of the ground planes could provide multipath rejection of 20dB when ground plane diameter is about one wavelength or bigger.

2.Small Size Vertical Structures.

During the last several years the interest for vertical antenna structures has increased. Such structures potentially could provide the desired sharp cut-off of antenna pattern for angles near antenna horizon. But structures described in literature [4] have rather big length. We will focus on small size vertical structures. On our opinion such structures could give sufficient level of antenna gain for low elevations and at the same time provide reasonable level of multipath protection.

First, let us mention that user GNSS antennas should have rather high degree of rotational symmetry with respect to vertical axes. Such a symmetry allows while theoretical treatment to consider only one half of the whole plane (in 2D modelling) using infinite metal boundary plane like a mirror. Fig.4 shows 2 magnetic line sources aligned vertically at the distance d from each other.

If magnitudes of those currents are equal and the second one is phase shifted by the amount of ($\pi-2\pi d/\lambda$) with respect to the first, then resulting gain pattern will be

$$f(\theta) \approx (1+\sin(\theta))/2 \qquad (6)$$

for any small $d<<\lambda$.

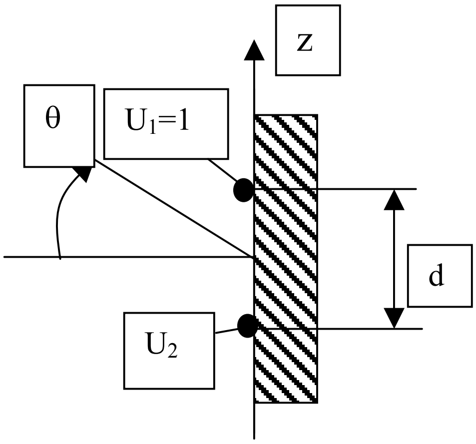

Fig4

(6) indicates a pattern with a null in down direction thus providing multipath suppression against reflections coming from the ground.

There could be different ways to implement such magnitude and phase relationship. We will consider the first source is primary and the second source is dependent driven by the first one. Calculated antenna gain pattern for that case is shown on Fig.5.

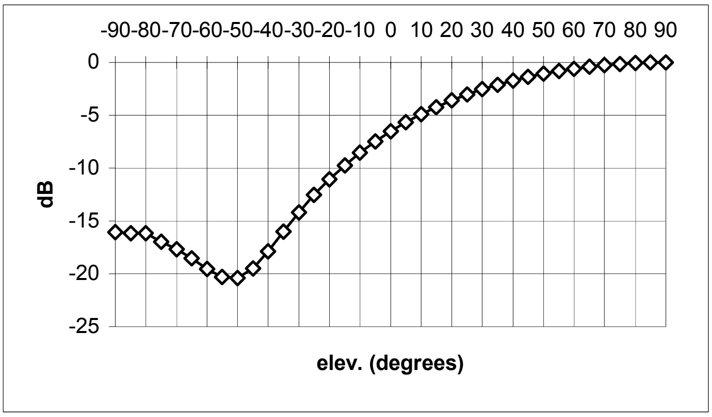

Fig5

The distance in between sources was 0.11λ which is about 2cm for GNSS signal. We need to note that in our simple model primary source does have omnidirectional gain pattern which is never practical case. Nevertheless directivity of both 2 sources is well seen.

So we may consider such a way as an opportunity [5] to come over ground plane size limitations discussed above. Though we would like to mention here that with the dimensions as above we are coming very close to so-called “superdirectivity” phenomena. Namely, reactive power stored in the close vicinity of the antenna increases greatly if to reduce size of a system while keeping desired properties of antenna gain pattern. This may become the main difficulty for future multi-frequency(L1,L2,L5) multi-system (GPS, GLONASS, GALILEO) developments.

3.Implementation examples.

First, let us consider the trade between antenna gain for low elevations and multipath suppression.

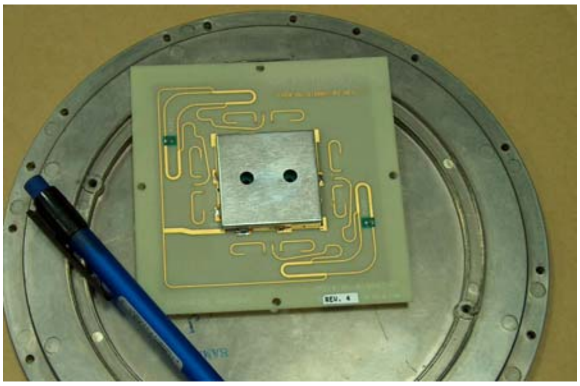

Fig8

On Fig.8 pictures of antenna sample is shown. This antenna has so-called slot excitation which provides decreased to some extent level of antenna gain in horizon direction.

Fig.9 shows measured antenna gain patterns for that antenna and conventional microstrip antenna with dielectric substrate. Ground plane size was approximately equal in both cases. We see that slot antenna gives better multipath protection in agreement with (2). This antenna gives an example of type of feednetwork design suitable for dual system GPS/GLONASS operation. As shown on Fig.8 symmetrical structure is used here providing broad bandwidth needed to cover joint GPS/GLONASS L1 band. The use of air as substrate contributes additionally to bandwidth increase.

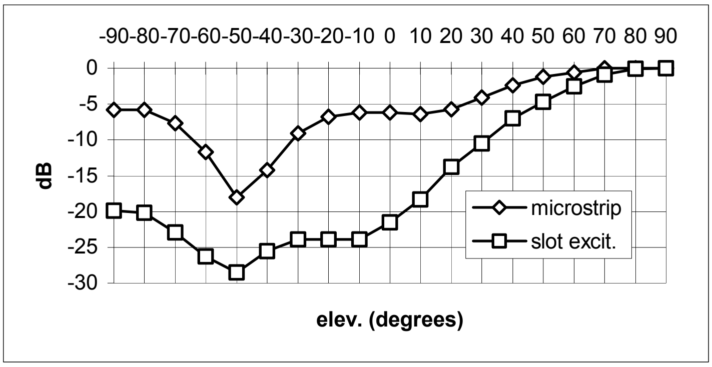

Fig.9

Fig.10 illustrates the value of joint GPS/GLONASS operation. This is relative time-to-fix diagram obtained with that antenna at the field site. Sampling rate here was 1 epoch in 2 seconds.

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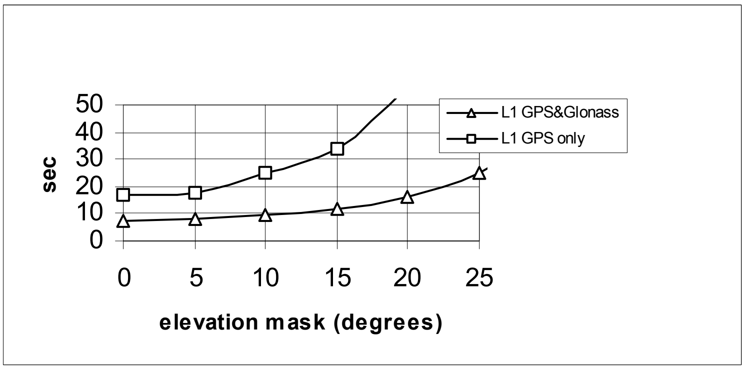

Fig.10

We see that for single frequency case addition of GLONASS satellites sufficiently decreases average fixing time.

Fig.11 is general view of vertical structure as discussed in Section 3.

Fig11.

For dual frequency GPS/GLONASS case this structure inscribes into a sphere of 9cm diameter.

Measured antenna gain pattern is shown on Fig.12. We see practically the same performance with conventional antennas on flat ground plane of about 1 wavelength (18-20 cm) diameter.

CONCLUSION

So here we have considered just one side of multipath protection problem – conventional ground planes operation and size and weight reduction by vertical stacked structures while keeping approximately the same level of multipath mitigation as said conventional ground planes.

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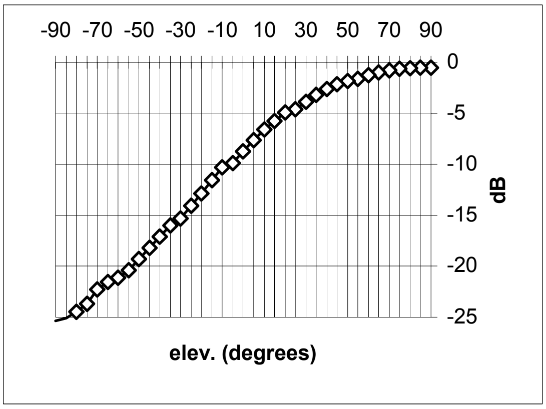

Fig12

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