THE FIRST DUAL-DEPTH DUAL-FREQUENCY CHOKE RING

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BIOGRAPHY

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ABSTRACT

The new design of the choke ring ground plane for dual frequency geodetic surveying systems (patent pending) has been suggested. The groove depth is made different for two frequencies by means of a special diaphragm, which is put in each concentric groove of the ground plane. This allows optimizing the performance for L1 and L2 signals separately.

By the mathematical simulation, special dimensions of the ground plane were found out, the groove depth being smaller than the quarter of wavelength for L2 frequency. This enables one to improve performance for L2 signal. Using the above mentioned diaphragm improves the performance for both L1 and L2 bands.

INTRODUCTION

There are well-known choke ring ground plane designs for the multipath rejection in dual frequency systems. The said ground planes consist of a thick metal disk with deep choke grooves on the top surface. It is known [1] that for good performance groove depth has to be a little bigger than the quarter of the corresponding wavelength. So, in known designs it is not possible to select groove depths, which are optimized for both the GPS L1 and L2 frequencies. Usually the groove depth is chosen to be the optimal for L2 range. The optimal depth for L1 has to be by 30% less than the depth for L2. But decreasing the depth will cause the deterioration of the multipath rejection for L2-range because of the appearance of the surface wave above the ground plane when the depth becomes much less than the quarter of the wavelength of L2. Therefore, in all existing choke ring designs the multipath rejection is optimized for L2 signal with much less effectiveness for L1. That is why all the known designs can be called as single frequency ground planes.

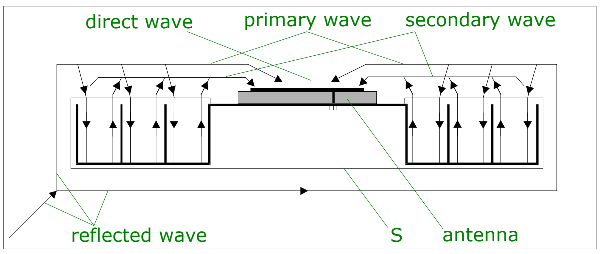
Here, in this paper, first of all the new design with the groove depth different for L1 and L2 signals is discussed. This is obtained by putting in each groove special diaphragm, which is transparent for L2 signal but rejects L1 signal.

Besides, by the new approach based on the numeric rigorous solution of the electromagnetic boundary problem, the groove depth was made less than a quarter of wavelength for L2 signal. It enables one to obtain much better performance for L2 as well.

ELECTROMAGNETIC FIELD IN THE GROUND PLANE VICINITY

In Fig. 1, the schematic view of the wave propagation in the ground plane vicinity is depicted.

Figure 1. Schematic view of wave propagation in the ground plane vicinity the groove depths



Being mounted in the center of the ground plane, the antenna receives the direct satellite signal and the signal reflected from the Earth surface.

The impact of the ground plane on the direct signal is important only for low elevation angles near the horizon direction. For these angles, the impact of the ground plane leads to the decrease of antenna's gain. For other directions in the upper semi-sphere, this impact is small and the choke ring ground plane works almost like the flat one.

The main purpose of the choke ring ground plane is to eliminate the electromagnetic wave reflected from the Earth surface.

As it follows from the electromagnetic diffraction theory the electromagnetic field of the reflected signal in the vicinity of the choke ring ground plane can be considered as a sum of two field waves. One of them is a field wave surrounding the ground plane along an imaginary conductive surface S (Fig1). This surface attaches to the top edges of grooves and continues to the backside of the ground plane. This wave is the same as the reflected wave in flat ground planes. We can call it the "primary" wave. The second wave is created by the electromagnetic field of the grooves. We call this wave the "secondary" wave.

The electromagnetic field in the grooves can be considered as a sum of two waves (Fig1). The first one propagates from the top edges of the grooves towards their bottom, and the second one propagates from the bottom towards the groove open ends. The first wave is exited by the above mentioned primary wave, and the second wave is the field reflected by the groove's bottom. This second wave causes the above-mentioned secondary wave.

The secondary wave like the primary one propagates along the ground plane towards the antenna and contributes to the total signal together with the direct signal from the satellite to the antenna. The objective of choke ring ground plane is for primary and secondary parts of reflected signal to substantially cancel each other and the direct signal to remain as the dominant one.

The phase relationship between the primary and secondary reflected waves at the antenna output depends on the difference in path lengths that each wave travels. The path difference is twice as much as. The amplitude ratio of the two waves depends on the characteristics of the antenna's element, its location on the ground plane, the width and the number of the grooves, etc.

If the amplitude of the primary and secondary waves are equal and the phase difference between them is 180 degrees, then two components of the reflected signal cancel each other at the antenna's output, so that multipath is suppressed.

As it follows from the said above, the groove depth has to be approximately equal to $\lambda/4$, where λ is wavelength. If it is less than the said distance the creation of a surface wave becomes possible. This wave will propagate along the groove structure if the depth is smaller than $\lambda/4$. The surface wave can destroy the required phase and amplitude ratios between primary and secondary waves and create resonance effects. That is why in the known designs the groove depth was a little bigger than $\lambda/4$.

Therefore, the groove depth depends on the wavelength of the intended signal and can be optimized for the intended frequency. As a result in all existing choke rings designs the multipath rejection is optimized for L2 signal, the effectiveness being less for L1 signal.

DESCRIPTION OF THE NEW DESIGN

In Fig.2, ground plane with slot filter in each groove is depicted.

For better performance in L1 band, here the new construction in each groove is arranged. Such a construction acts effectively as electromagnetic filter that reflects L1 signal (Fig2a) and passes waves of L2 signal (Fig2b). Therefore, groove depths become different for L1 and L2 signals. For L1 signal, it will be equal to the distance from groove open ends up to the said construction, and for L2 signal, it will be equal to the total groove depth. Therefore, multipath rejection can be optimal for both L1 and L2 signals.

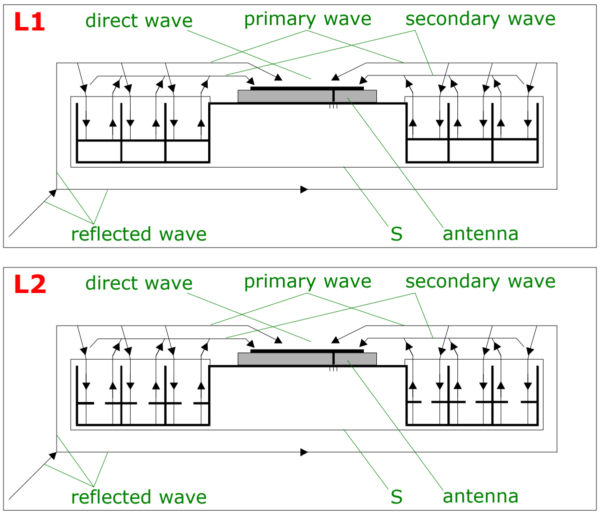


Figure 2. The ground plane with a slot filter in each groove

The main features of the filter construction are depicted in Fig.3. The electromagnetic filter includes a conductive ring (301) connected to the two groove walls (302), apertures (303) or "slots" of some shape made in the said ring and a feeding network (304) arranged in the vicinity of each slot. The feeding network consists of two stubs (305), (306). One end of each stub is shorted to the conductive ring near the slot edge and another end can be shorted or opened.

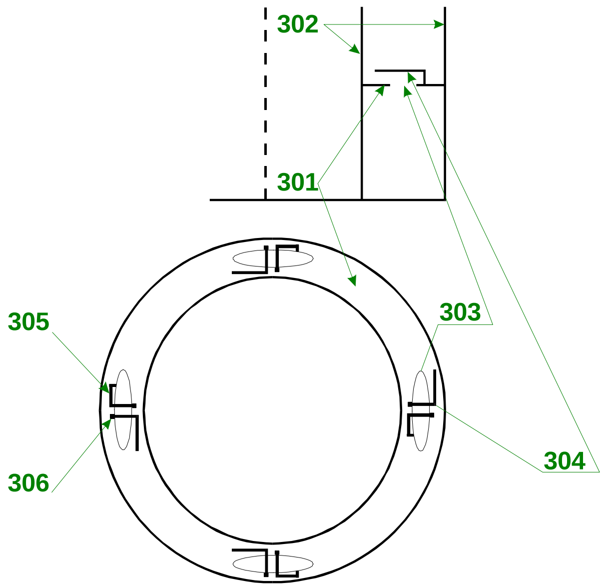


Figure 3. The main features of the filter construction

The feeding network (304) can be made of pieces of wires or as the microstrip circuit arranged on the single-layer-PC-board. In the last case, the said boards are mounted in the vicinity of slots (303). All the filter structure can be made on the base of the microstrip technology. In this case, the filter is the dual-layer-PC board. One layer is a metal ring with slots (303), and another layer includes the microstrip network (304).

A system of slots (303) of each filter together with the network (304) is tuned to be transparent for L2 signal. For L1 band slots (303) are shorted by means of the network (304), so the conductive ring (301) acts as the solid one. It becomes the groove's bottom for L1.

The dual frequency operation of the network (304) can be obtained as follows. One stub (for example, 305) must have zero input impedance near the slot for L1 frequency. If the opposite from slot end of this stub is shorted to the conductive ring, its length has to be $\lambda_{L1}/2$, where λ_{L1} — the wavelength of L1 signal. If the opposite end opened, then the length of this stub has to be $\lambda_{L1}/4$. The said stub shorts the slot for L1 signal. The length of another one (306) is chosen to make the entire system transparent for L2. The opposite from slot end of this stub can be shorted or opened. For better operation, several pairs of stubs can be connected to the each slot.

Total ground plane dimensions and groove depths like slot dimensions and the network (304) structure were chosen to obtain the necessary behavior within L1 and L2 bands. This was done numerically with the use of the electrodynamic wave analysis of the entire system.

WAVE ANALYSIS OF FILTER OPERATION

To obtain the geometry of the slot filter the full wave analysis of fields inside each groove was done. Fields inside each groove were expanded in a set of coaxial wave-guide modes. The problem of electromagnetic diffraction was solved as follows.

Near surface S (Fig1), the primary wave field has rather complex structure. In any case, this field can be expanded into a series of angular spectrum harmonics. For H_φ component, it is possible to write

$$H_j(r,j)=\sum_{p=-\infty}^{\infty} C_p(r)\cdot\exp(-ipj) \qquad (1)$$

Here r is the distance from the ground plane axis to the observation point and φ is the azimuth angle.

For right-hand circular polarized antennas with high azimuth-rotational symmetry of the pattern used commonly with choke ring ground planes the term of (1) with p = -1 is dominant one. All the other terms are parasitic. Their impact on antenna's output signal is small.

Choke ring grooves can be treated as shorted pieces of coaxial wave-guides.

From electrodynamic boundary conditions it follows, that primary wave excites in grooves electromagnetic field with the same angular spectrum as (1). Each term of this spectrum can be treated as a sum of coaxial wave-guide modes.

$$E_{mn}(r,j)=E_{mn}(r)(\cos(mj)+i\cdot\sin(mj)) \qquad (2)$$

From the above said the term with m = -1 is dominant one. It means that two orthogonal polarized TE_{11} modes with 90 degree-phase-shift between them are dominant. All the other modes are parasitic.

It is well known that propagating of the higher order terms of (2) has the wavelength bigger than the dominant one. It means that groove depth is not optimal for these modes. Cut-off modes of the secondary wave are excited by groove edges. For them, the groove depth is not optimal also. The said is not very important for ground plane without filters because, as it was mentioned above, non-dominant modes have comparatively small impact on antenna's output signal.

However, for the ground plane with filters the partial transformation of the dominant mode power into parasitic ones by filter slots is possible. This will lead to the increase of higher-order mode amplitudes and the decrease of the multipath rejection. This effect is canceled by the proper choice of the slot number in each groove.

Let slots be arranged periodically and N_{sl} be the number of slots in one groove.

Then field excited by slots can be written as follows

$$E(z,r,j)=\sum_{m=-\infty}^{+\infty} E_m(z,r)\cdot\exp(-i\cdot(N_{sl}\cdot m+1)j) \qquad (3)$$

Therefore, field radiated by slots can be treated as a sum of coaxial wave-guide modes with the angular period $N_{sl}m$ (m — an arbitrary integer). Because the only necessary mode is $ÒÅ_{11}$, all the others must be cut-off. This can be obtained by proper choice of N_{sl}.

Usually grooves width is small compared with wavelength and perimeter (the length of the circle with average radii R_{av} between walls). In this case, for eigenvalues calculation each groove can be seen as a piece of rectangular wave-guide, turned into circle.

From cut-off conditions for such rectangular wave-guide, it follows that

$$N_{sl} > 4\pi R_{av} / \lambda_{L2} + 1 \qquad (4)$$

For L1 signal slots are shorted and their impact is negligible.

Because of mentioned above angular periodicity of field, excited by slots, with the use of periodic array theory based on Floquett theorem it can be shown, that in any case it is possible to choose slot geometry in order of the diaphragm be transparent to L2 signal and, by means of slots shortage — reflect L1 one.

Such geometry for each groove and stub's configuration was chosen numerically using the method of moments. Here for slot magnetic currents representation a set of finite elements were used.

MEASURED AND CALCULATED RESULTS

The new ground plane was created for the dual-frequency dual-system performance (L1-L2 GPS-GLONASS). It is 320 mm in diameter with 3 grooves of 22 mm width each. The depth of grooves is 60 mm. The center part of the ground plane is 190 mm in diameter. The antenna is put at the bottom of cylindrical tube (a piece of circular wave-guide) at the distance 20 mm from the top. This ground plane is optimal for L2 and has comparatively well, but not optimal performance within L1 band.

So, the groove depth of this ground plane is smaller than the quarter of wavelength at low part of L2 band.

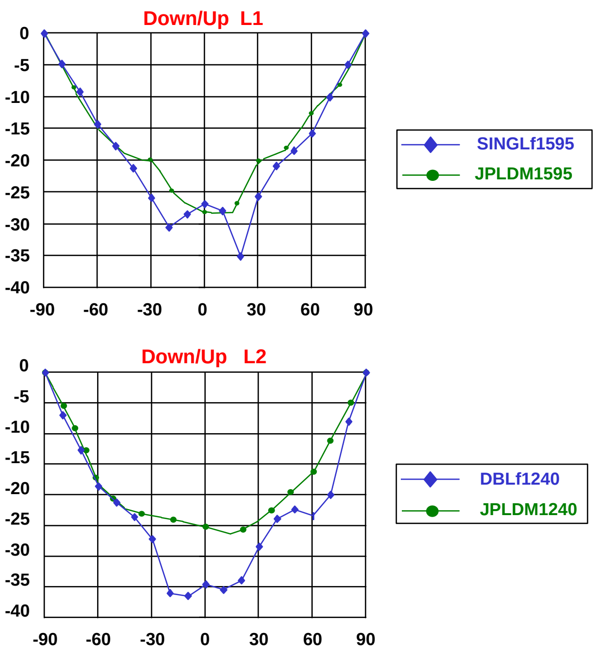


Figure 4. Charts of Down/Up behavior via angle between direction to satellite and zenith

In Fig. 4 charts of Down/Up-behavior via the angle between the direction to a satellite and zenith is depicted.

It can be seen that the performance for the L2 signal is by 6-8 dB better than for L1 signal. For comparison, the Dorne and Margolin antenna is shown also by dotted lines.

In Fig.5, the measured Down/Up-behavior of the same ground plane in L1 is depicted. The parameter of the chart is the groove depth. It can be seen that if the depth is smaller than 42 mm, then the multipath rejection becomes worse because of the excitation of the surface wave. If the depth is bigger than 50 mm, then the multipath rejection becomes worse also because of the wrong secondary wave phase. The optimal depth is 48+-3 mm. This result shows that demands for the distance between the slot filter and the groove edges are not too rigorous.

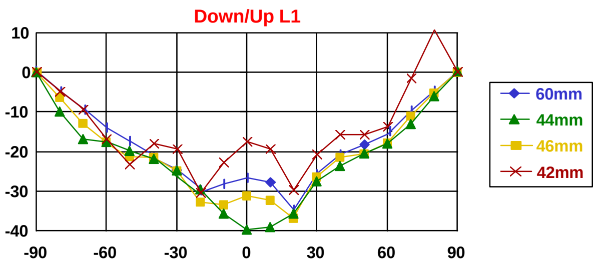


Figure 5. Measured Down/Up behavior of the same ground plane

So, the slot filter has to be arranged at ≈48 mm distance from groove edges. The distance between the filter and the groove bottom will not exceed 12 mm.

Figure 6. The difference between two ground planes behavior for L1 signal

In Fig.6 the difference in behavior of two ground planes for L1 signal is shown. One ground plane was described above in the text. It is tuned for L2 signal. Another one is of the same dimensions but optimally tuned for L1 by the proper choice of the groove depth. It can be seen that for some angles the difference is as much as 12 dB.

In Fig.7 the general view of the dual-frequency dual-system ground plane with filters is depicted.

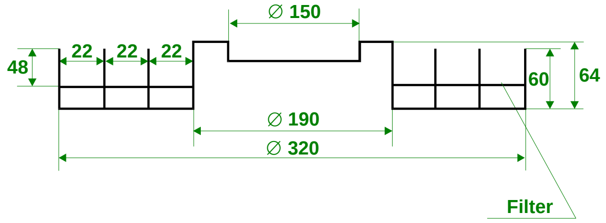
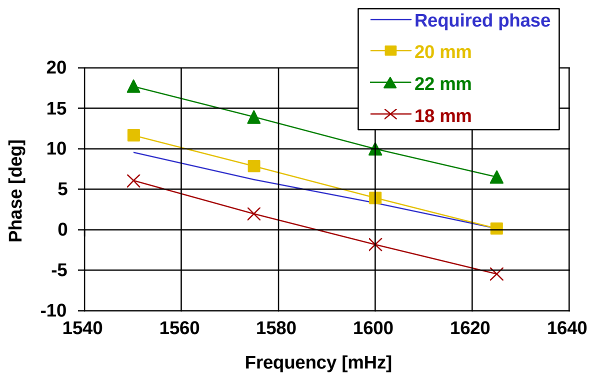


Figure 7. General view of dual- frequency dual- system ground plane with filters

To get such filter parameters as slots' lengths, their radius and the distance from filters to the bottom (the height of the diaphragm placement) of each groove of the choke ring were represented as a piece of the shorted coax wave-guide with a diaphragm. As it was shown above the exciting field in coax wave-guide is a falling TE_{11} mode. As the result of numerical analysis, the phase of the reflection coefficient of this mode at the point of coax opening was calculated. To provide dual band operation this phase in L1 band should be the same as for the shorted piece of coax wave-guide of length 48 mm without the diaphragm. In L2 band, this phase should be the same as for a piece of coax wave-guide with length of 60 mm. The number of slots on each diaphragm was chosen to cut-off coax wave-guide modes that are higher than TE_{11}. So in the first groove diaphragm there are 6, in the second one, there are 8, and in the third there are 10 slots. Two stubs were inserted into each slot. One of them shorts the slots in L1 band, while in L2 band two stubs help to make slot transparent.

Though one of stubs provides zero impedance at the center of the slot, the impact of the shorted slot on reflection coefficient phase is not negligible. Therefore, for providing the required phase one should increase the distance between the diaphragm and the groove bottom. Fig. 8 shows the reflection coefficient tuning by changing the diaphragm height.

Figure 8. Reflection coefficient tuning by changing diaphragm height



The required phase (smooth line) corresponds to the groove of depth of 48 mm without diaphragm. As one can see, the appropriate height of the diaphragm is 20 mm.

Fig.9 shows measured Down/Up ratios for several diaphragm heights. As one can see, the best Down/Up ratio corresponds to the calculated height of 20 mm.

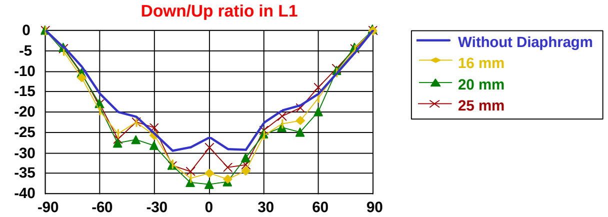


Figure 9. Measured Down/Up ratios for several diaphragm heights

The length of the second stub is tuned to provide the required phase of the reflection coefficient in L2 band. Fig.10 shows that the appropriate stub length is equal to 9 mm. With this length of the stub, the diaphragm is transparent and Down/Up-ratio is the same as in the original choke ring with the depth of the groove 60 mm.

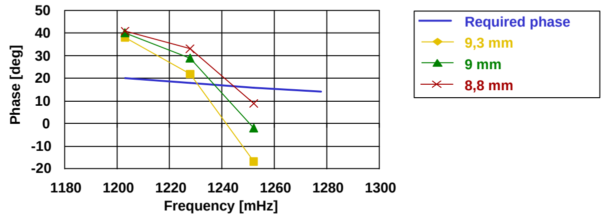


Figure 10. Reflection coefficients phase in L2 versus stub length. Height of the diaphragm is equal to 20 mm

REFERENCE

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