A Three Dimensional Choke Ring Ground Plane Antenna.

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BIOGRAPHY

Waldemar Kunysz obtained a BSEE from the Technical University of Nova Scotia in 1989. From 1991 to 1995 he worked on phased array antennas for Microwave Landing Systems with Micronav Inc. From 1995 to the present he has been with NovAtel Inc. He has published several technical papers and proceedings articles for various conferences. His current research interests include antenna theory and design, multipath mitigation techniques, ultra-wideband (UWB) technology, genetic algorithms and electromagnetic compatibility.

ABSTRACT

A novel conical choke ring ground plane is proposed for GPS antennas used in precise geodetic applications. The proposed choke ring configuration allows better reception of low elevation angle GPS satellites and improved multipath rejection. The proposed ground plane is composed as a three-dimensional array of coaxial slots. To further reduce the reception of multipath signals generated below the horizon, an additional array of coaxial slots is disposed underneath the ground plane. This arrangement reduces the overall weight of the structure.

This paper will describe the mechanical structure of the three-dimensional choke ring ground plane, as well as present test results of the new design compared with traditional two-dimensional ground planes.

INTRODUCTION

The consistency of the phase center offsets of GPS antennas is important when trying to achieve geodetic measurements which are accurate at the millimeter level. The absolute stability of the phase center is less important than repeatability of the phase center. The absolute stability of the phase center is modeled and results published on the Geo++ [1] and NGS [2] websites. In practice, there is some variation between the model and the actual response of an individual antenna. The choke ring antennas have been known to provide most consistent performance from the point of phase center repeatability of phase center variation between randomly sampled production units of a given type of choke ring antenna design. These variations are very repeatable and predictable, usually within 1mm [3]. The extensive use of this type of antenna in the IGS global network makes it a defacto standard in the community.

An inherent disadvantage of the typical choke ring design is reduced antenna gain at low elevation angles (below 20°). The reduced antenna gain is translated to lower number and signal strength of tracked satellites; therefore lower quality of the signal, poorer VDOP and position accuracy.

This paper outlines a design effort to mitigate the inherent disadvantage of insufficient gain near horizon while preserving its attributes, such as stable phase center, pattern symmetry for amplitude, phase and group delay.

Various choke ring configurations were tested using two antenna elements: Dorne & Margolin C146-10 antenna element and NovAtel GPS-702 "Pinwheel™" antenna element.

3D CHOKE RING DESIGN

A typical choke ring antenna is machined from a single billet of aluminum and consists of three to five concentric ring structures. The choke rings are usually a quarter wavelength deep, in order to create a high impedance surface that prevents propagation of surface waves near the antenna and excitation of undesired modes. The net effect is a very smooth controlled pattern with low susceptibility to multipath. We could refer to such a ground plane as a 2D choke ring ground plane (see Figure 2).

To improve the reception of low elevation angle satellites, consecutive adjacent rings are lowered (in z-plane) with respect to each other to create a "pyramid"-like structure, in order to move the apparent line-of-sight that joins the top of the rings from horizon level to some angle α below the horizon. For simplicity, we can denote this type of choke as a "3D" choke ring ground plane (See Figure 1). A multi-depth choke ring configuration for ultra-wideband antennas was first proposed almost 20 years ago by Thomas L. Blakney [4]. The current configuration for GPS application is a modification on the original Blakney design.

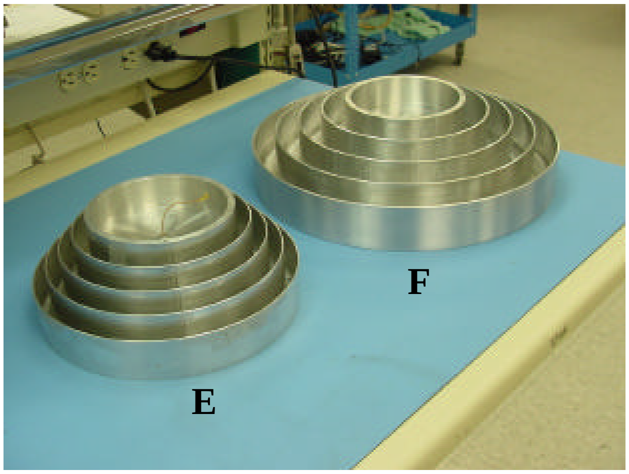

Figure 1. Sample of two 3D Choke Ring Ground Planes

The spacing between adjacent choke rings was kept the same for a given 3D choke ring design. This value, however, may be varied between adjacent rings in order to optimize the choke ring performance. The best way to tackle this problem is to use Uniform Theory of Diffraction (UTD). Preliminary simulations were done using UTD and two prototypes (denoted as "E" and "F") were constructed to evaluate various options of the design.

There were a total of six different choke rings evaluated. Four different 2D choke rings (labeled from "A" to "D") and one 3D choke ring ("E") are shown in Figure 2.

Figure 2. Sample of four 2D and one 3D Choke Ring Ground Planes.

The largest choke ring "A" had a diameter of 430 mm. The 3D choke ring "E" was the smallest of all the units.

The major design characteristics of each choke ring design are listed below in Table 1.

Choke Ring	Choke Type	Choke depth
A	2D	5 L1 and 5 L2
B	2D	4 L1 and 4 L2
C	2D	5 L2
D	2.5D	3 (1 L1)
E	3D	4 L1/L2
F	3D	4 L1/L2

Table 1. Choke Ring Design Details

Note 1: L1 indicates choke depth tuned to L1 frequency
L2 indicates choke depth tuned to L2 frequency
L1/L2 indicates broadband choke depth

The Choke Ring "D" has been labeled as 2.5D since it employs three chokes of different depth with only one tuned to L1 band.

It would appear, intuitively, that due to the nature of their construction, choke rings "E" and "F" should be most sensitive to multipath originated below or near the antenna horizon. The next sections presents the test results that proves otherwise.

LOW ELEVATION TRACKING

In order to make a comparison between different choke ring designs, each choke ring was tested twice using a Dorne & Margolin C146-10-1 antenna element and NovAtel GPS-702 "Pinwheel™" antenna element (see Figure 3).

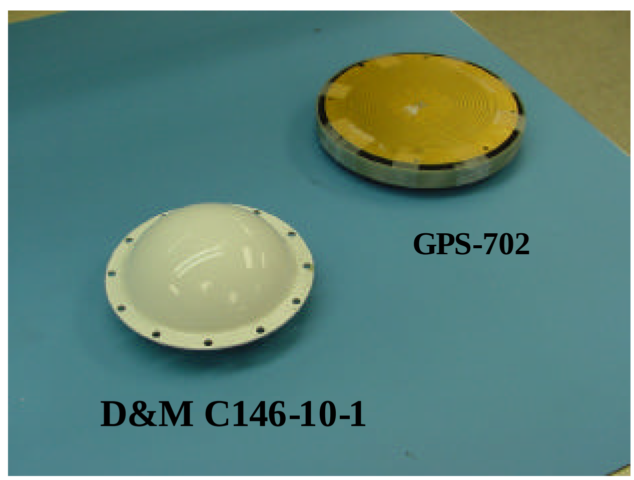

Figure 3. D&M and GPS-702 antenna elements.

An antenna with a given test choke ring was mounted approximately 1 meter above the ground and data was collected with the same receiver. The NovAtel "Skyplot" software was used to compute various figures of merit such as average C/No, average code-carrier standard deviation and actual vs. expected number of epochs for each elevation angle.

The quality of low elevation tracking was measured by computing the ratio of observed-to-expected number of epochs. Ideally this ratio should be 1 (100%). This ratio will be less than 1 for low elevation angles (below 20°) due to inherent antenna amplitude pattern roll-off and interference from multipath signals. In our test scenario, multipath had its largest effect on tracking performance at the elevation angle of 6° (See Figures 4-7). It's quite apparent that 3D choke rings (labelled "E" and "F") provide the best tracking and lowest susceptibility to multipath.

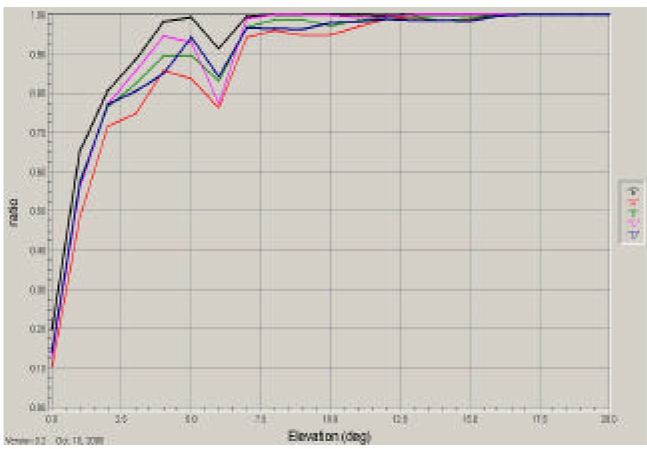

Figure 4. L1 Low Elevation Angle Tracking with GPS-702 Antenna.

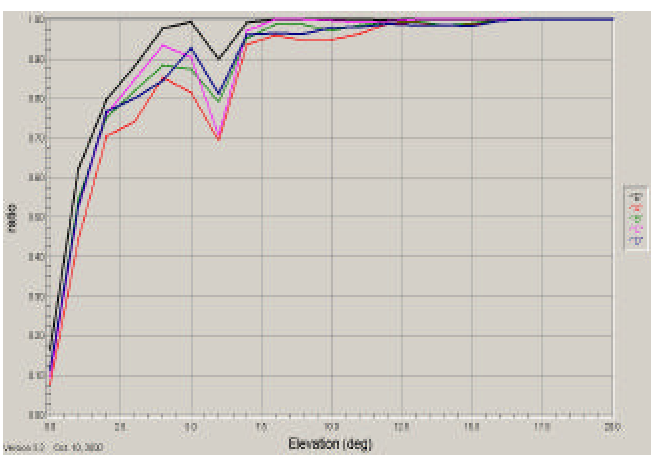

Figure 5. L2 Low Elevation Angle Tracking with GPS-702 Antenna.

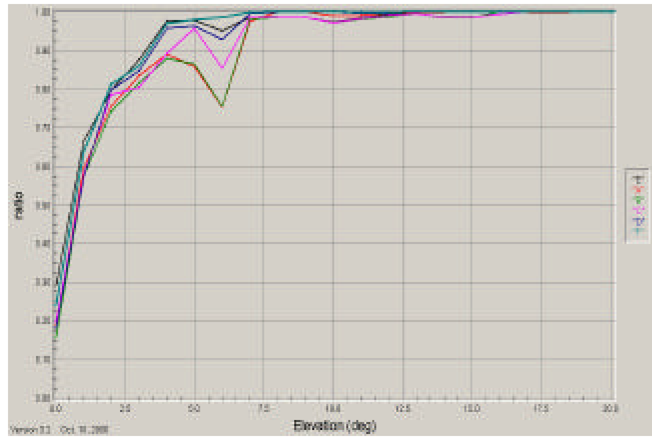

Figure 6. L1 Low Elevation Angle Tracking with D&M C-146-10 Antenna.

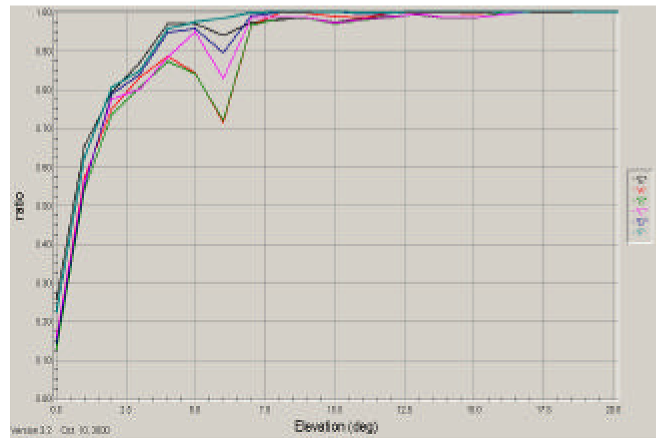

Figure 7. L1 Low Elevation Angle Tracking with D&M C-146-10 Antenna.

A cumulative tracking capability from 0° to 10° elevation angles is shown in Table 2 (below).

Choke Ring	GPS-702 Antenna		D7M C-146 Antenna	
	L1	L2	L1	L2
"A"	73.9%	72.4%	76.6%	74.8%
"B"	78.6%	76.8%	77.0%	75.6%
"C"	78.8%	77.9%	79.3%	78.3%
"D"	76.2%	65.0%	82.6%	81.3%
"E"	84.4%	83.3%	85.3%	84.4%
"F"	81.3%	80.3%	85.7%	85.2%

Table 2. Overall Low Elevation Angle Tracking (0°-10°)

An improvement of almost 10% in low elevation tracking can be observed from Table 1. Over a period of a 24-hour tracking session, that would translate to several thousands of extra observations. One observation that can be made is that a choke ring design should be optimized for a given antenna in order to maximize its overall performance.

MULTIPATH PERFORMANCE

NovAtel's post-processing software, "Skyplot", was used to determine the level of multipath signal generated at the antenna output port. The level of multipath (in mm) is plotted against the elevation angle for various choke ring and antenna configurations, see Figures 8-11.

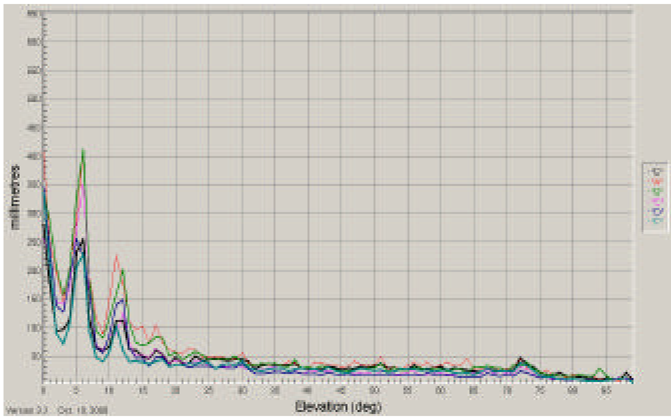

Figure 8. L1 Multipath Performance with D&M C-146-10 Antenna.

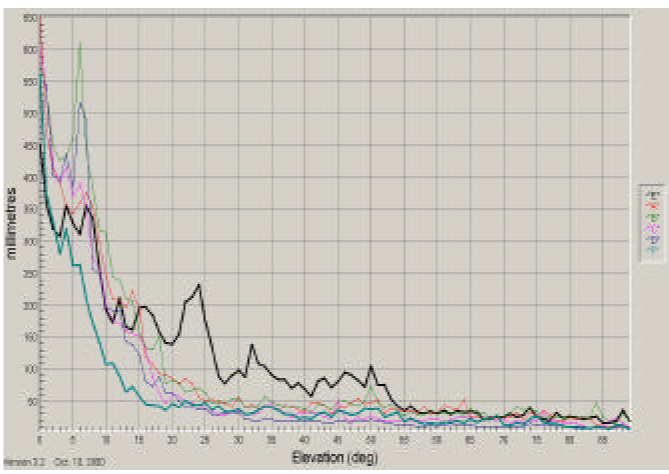

Figure 9. L2 Multipath Performance with D&M C-146-10 Antenna.

As mentioned in the previous section, any choke ring design should be optimized for a given antenna. We can see a drastic improvement in performance between chokes "E" and "F" for D&M antenna at L2 frequency (see Figure 9).

GPS-702 antenna multipath performance appears to be more consistent than D&M C-146-10 antenna L2 band for various choke ring configurations.

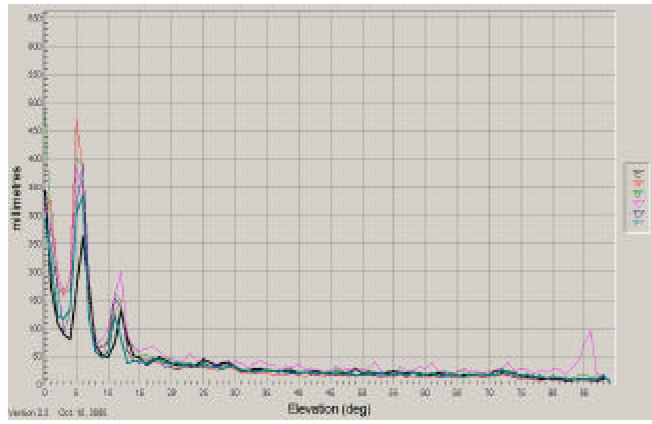

Figure 10. L1 Multipath Performance with GPS-702 Antenna.

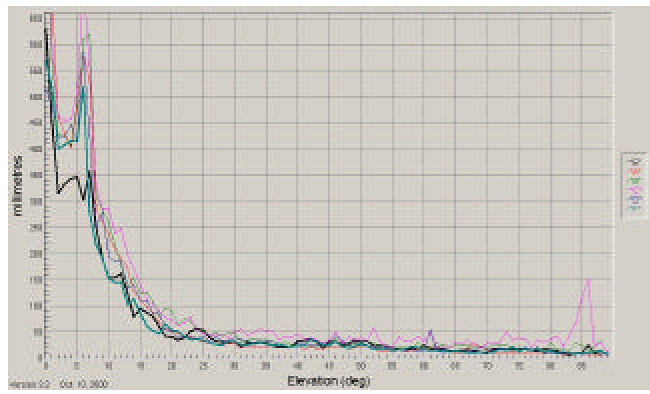

Figure 11. L1 Multipath Performance with GPS-702 Antenna.

ANTENNA PATTERN UNIFORMITY

Choke ring antennas are known for very smooth, with minimal ripple, amplitude and phase pattern. The next few graphs display the standard deviation of amplitude variation in azimuth plane for a given elevation angle. Since this data is based on GPS measurements, they do include the contribution of amplitude variation from various satellites. These variations are assumed constant over the time of the measurement campaign and are treated as a constant bias for each measurement. The 3D choke ring antenna performed as good or better from the point of view amplitude pattern symmetry (see Figures 12 –15).

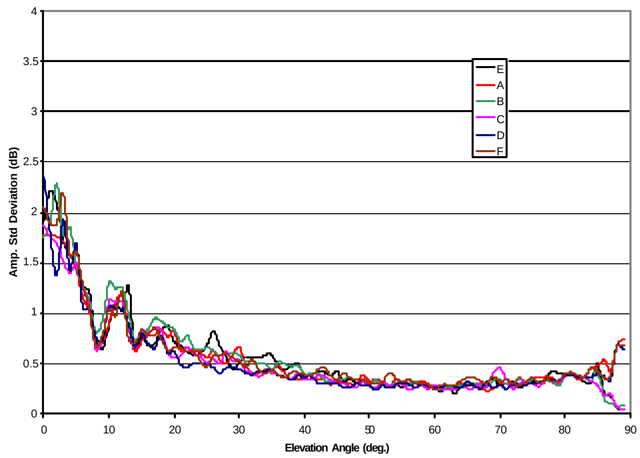

Figure 12. L1 Amplitude Pattern Symmetry with GPS-702 Antenna.

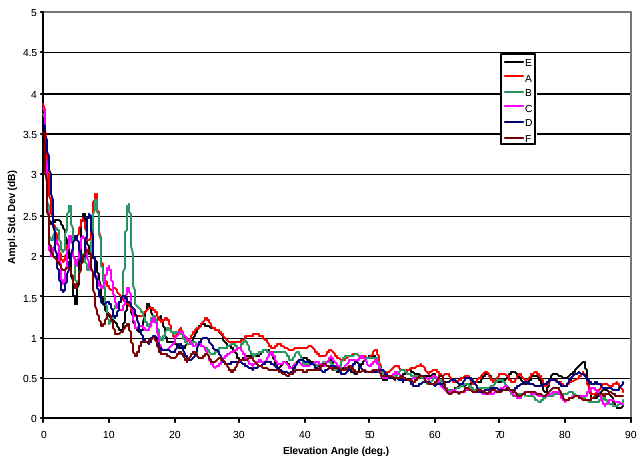

Figure 13. L2 Amplitude Pattern Symmetry with GPS-702 Antenna.

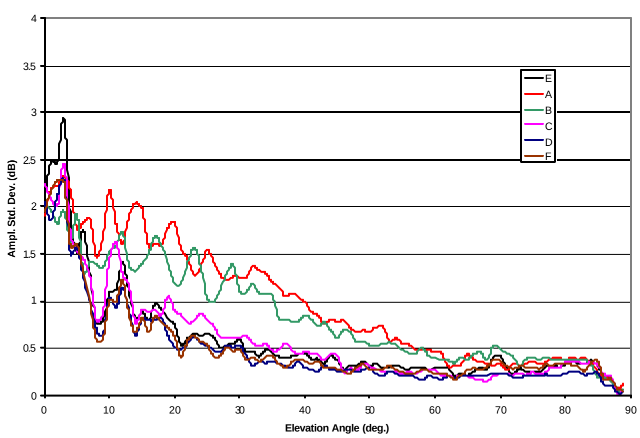

Figure 14. L1 Amplitude Pattern Symmetry with D&M C146-10 Antenna.

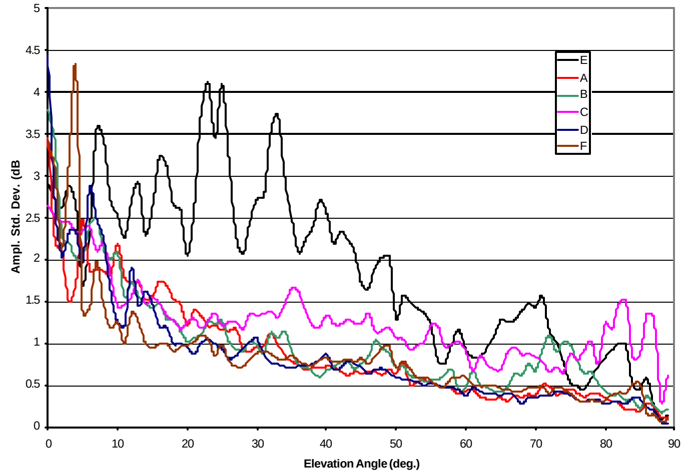

Figure 15. L2 Amplitude Pattern Symmetry with D&M C146-10 Antenna.

Again, from Figure 15, we can see the importance of designing the choke ring that suits a particular antenna. The difference between 3D choke rings “E” and “F” is quite large, as is a degradation of L1 performance when using chokes “B” and “C” (Figure 14).

CONCLUSIONS

A novel conical choke ring ground plane was proposed for GPS antennas used in precise geodetic applications. The proposed choke ring configuration allows better reception of low elevation angle GPS satellites and improved multipath rejection. The proposed ground plane does not degrade other performance characteristics (i.e. pattern symmetry) that are typically associated with 2D choke ring ground planes.

One should keep in mind that any choke ring design should include the effect of interacting with the antenna element itself. A dramatic performance improvement can be made if such effects are taken into account and the design is optimized to properly interface with a given GPS antenna element.

ACKNOWLEDGMENTS

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