

# Test Results of a 7-Element Small Controlled Reception Pattern Antenna

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## BIOGRAPHY

Alison Brown is the President and CEO of NAVSYS Corporation. She has a PhD in Mechanics, Aerospace, and Nuclear Engineering from UCLA, an MS in Aeronautics and Astronautics from MIT, and an MA in Engineering from Cambridge University. In 1986, she founded NAVSYS Corporation. Currently she is a member of the GPS-III Independent Review Team and Scientific Advisory Board for the USAF and serves on the GPS World editorial advisory board.

David Morley is a Senior RF Engineer at NAVSYS Corporation. He has a BS in Electrical Engineering from the University of New Mexico. He is a member of Tau Beta Pi. In 1992 he received an Outstanding Performance award from Los Alamos National Laboratory for his work as a member of the GPS team responsible for supporting the launch and calibration of the GPS satellites. While at Los Alamos he was also the lead engineer for the Lunar Prospector project. Currently he is responsible for the design and development of GPS antennas and RF front-ends and integration into NAVSYS receiver products.

## ABSTRACT

NAVSYS miniature antenna array technology allows the antenna array size to be shrunk while still maintaining the same phase relationship between the received signals as for a conventional (half wavelength) full-size array, and so avoiding spatial aliasing. This innovation is accomplished by the use of a high dielectric superstrate installed over the antenna array pattern. This creates a lens effect on the received signals, which allows the half cycle phase relationship to be maintained between the antenna elements while reducing the physical separation between elements proportional to the reduction in the signal wavelength in the high dielectric superstrate.

A 7-element Small Controlled Reception Pattern Array (S-CRPA) antenna array has been built and tested by

NAVSYS, packaged in a 7" diameter. In this paper, the design of the S-CRPA is presented with test results showing its performance.

## INTRODUCTION

NAVSYS miniaturized GPS antenna array technology reduces the size of the over-all antenna array, while maintaining the same wavefront phase relationship between elements as a full-size antenna array. This technology enables GPS controlled radiation pattern antenna arrays (CPRAs) with anti-jamming capability to be installed on vehicles where their size has previously prohibited their use. This includes small munitions, such as Joint Direct Attack Munition (JDAM), and aircraft where size and weight constraints have previously precluded installation of a GPS CRPA, such as the GPS Antenna System (GAS) shown in Figure 1.

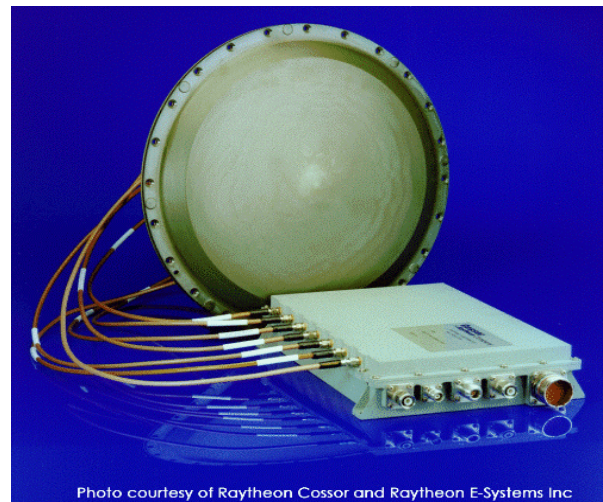
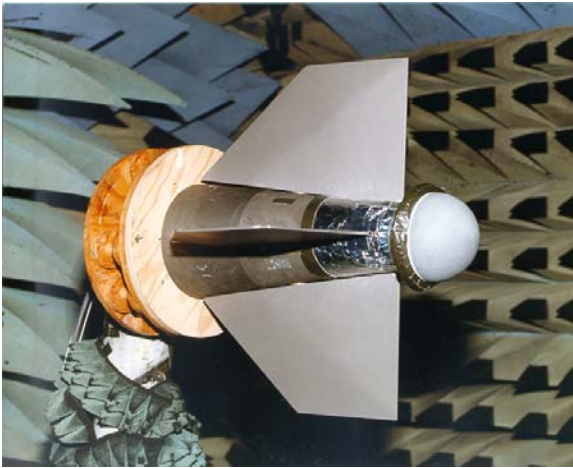


Figure 1 GPS Antenna System (GAS-1)



**Figure 2 Four-Element Mini-Array installed in tail-kit**

Under contract to the Office of Naval Research (ONR), NAVSYS built a four element miniaturized antenna array that can fit in a six-inch footprint<sup>1</sup>. In Figure 2, a picture is shown of this antenna array while being tested installed in a munition's tail-kit.

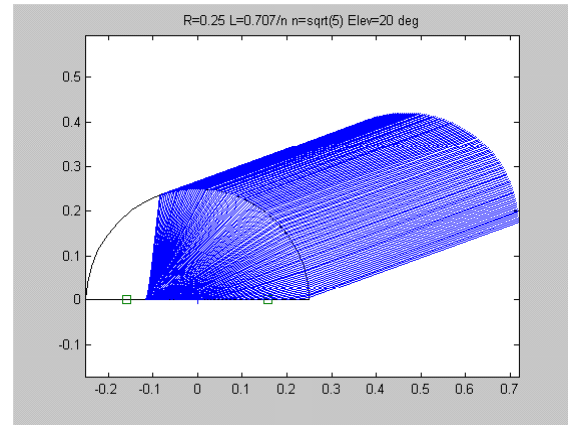
In this paper, a 7-element small CRPA (S-CRPA) based on our miniaturized antenna array technology is described. This is designed to be compatible with existing CRPA antenna electronics (AE), such as the GAS-1 AE shown in Figure 1, but packaged in a small form factor. Test results are also included showing the antenna array characteristics and performance when integrated with a digital beam-forming receiver.

#### MINIATURE ANTENNA ARRAY TECHNOLOGY

The miniaturized GPS antenna array technology shrinks the size of the individual antenna elements by designing small patch elements using a high dielectric substrate. This allows more antenna elements to be clustered closer together in the same over-all array footprint. The major innovation in the miniature array technology developed by NAVSYS, however, is the introduction of a shaped high-dielectric superstrate. This allows the same half-cycle phase relationship to be maintained between antenna elements as in a full-size array<sup>2</sup>.

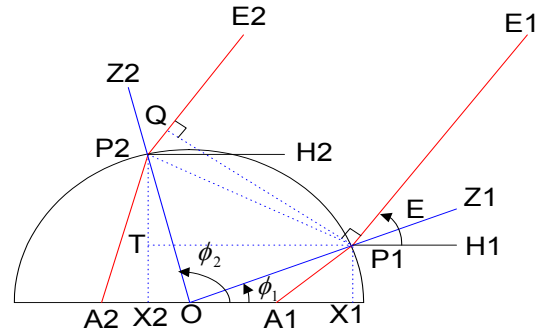
The dielectric lens geometry that creates this effect is illustrated in Figure 3. When the wavefront arrives at the lens, it is focused towards the antenna array plane. The wavelength of the RF signal within the lens is reduced by the dielectric constant, which results in additional phase delay being added to the signals arriving at the different antenna elements. The total phase difference between the elements can be calculated from the following equation, based on the lens geometry shown in Figure 4.

$$\theta_2 - \theta_1 = \frac{P_2 Q}{\lambda} + \frac{P_2 A_2 - P_1 A_1}{\lambda/n}$$

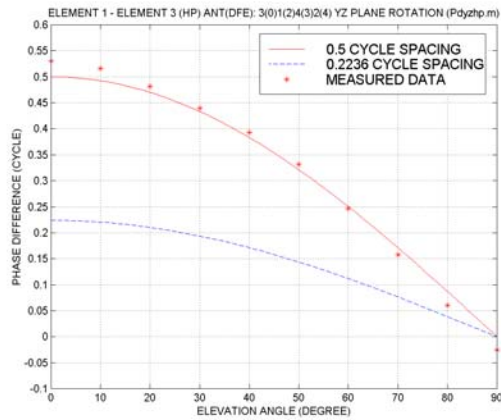


**Figure 3 Dielectric Lens Effect**

In Figure 5 the phase relationship is shown for a miniature antenna array with elements spaced apart by 0.2236 L1 cycles (4.24 cm). Without the dielectric lens effect, the phase difference of a wavefront arriving at the array (as shown by the blue line) varies from 0.22 cycles at the horizon to 0 cycles at the zenith. This would result in sub-optimum performance with the CRPA Antenna Electronics since the spatial phase separation is less than the 0.5 cycle spacing used with the full-size antenna array shown in Figure 1. The effect of the dielectric lens is to restore the phase spatial separation to a full half-cycle, as shown by the phase observations plotted in Figure 5. The miniature antenna array design enables the over-all size of a GPS antenna array to be shrunk while still providing equivalent anti-jam (A/J) protection to a full-size conventional GPS CRPA.



**Figure 4 Dielectric Lens Geometry**

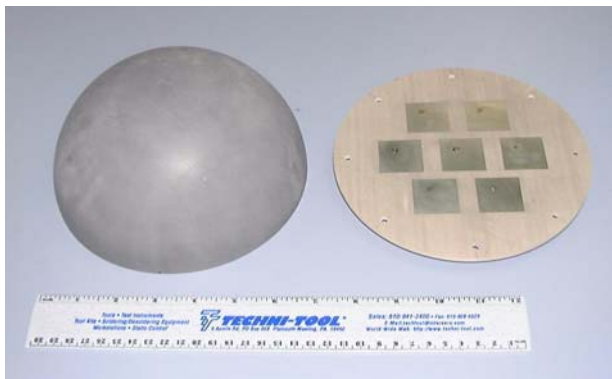


**Figure 5 Array Phase Relationship**

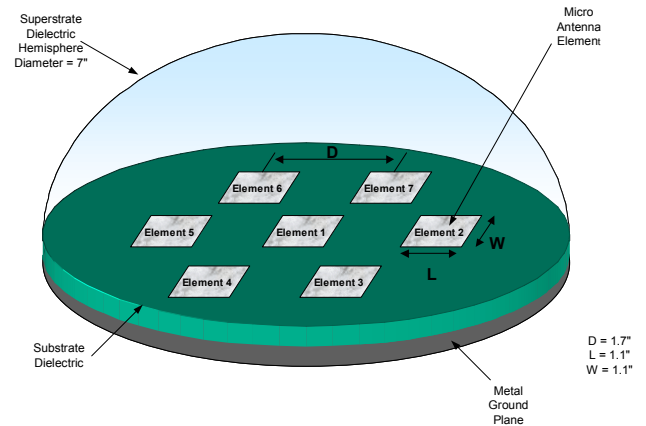
A key factor in the array performance is the number of antenna elements. The more elements available, the more precisely a null can be steered in the direction of a jammer, improving the overall signal-to-noise ratio (SNR) and also allowing flexibility in placing nulls on jammers. The number of jammers, which can be nulled by a GPS array, is equal to one less than the number of antenna elements (N-1). The more elements in a beam forming array, the greater the degree of directionality in the array and the greater the gain in the direction of the desired signals. The miniature antenna array technology was leveraged to produce a seven element small CRPA (S-CRPA).

**SMALL CRPA DESIGN**

The NAVSYS S-CRPA is shown in Figure 6. This has been designed to fit within a 7” diameter form factor. This is a 50% reduction in size from the existing 7-element GPS Antenna System (GAS), in use by the Department of Defense, which has a 14” diameter (see Figure 1). The physical dimensions of the array are shown in Figure 7.



**Figure 6 Seven Element S-CRPA (Hemisphere and Substrate)**



**Figure 7 Seven-element S-CRPA Dimensions**

**Table 1 Summary of NAVSYS’ S-CRPA**

Center frequency	1575.42 MHz (at L1)
Bandwidth	20 MHz (1575.42 +/- 10 MHz)
Input impedance	50 Ω
Polarization	right hand circular polarization (RHCP)
Array size	7 inches diameter
Array configuration	hexagon pattern
Number of elements	7
Element type	rectangular microstrip patch
Element size	$\propto \lambda/2$ by $\lambda/2$ inside substrate material
Element spacing	$\propto \lambda/2$ inside superstrate

The 7-element S-CRPA specifications are summarized in Table 1. The antenna elements are designed for receiving the GPS L1 frequency with sufficient bandwidth to receive both C/A code and P code versions of GPS data. The elements are arranged in the same hexagonal pattern with a center reference element used for the GAS-1 antenna

**ANTENNA ELEMENT MEASUREMENT RESULTS**

The S-CRPA antenna elements were each tested to measure their performance in receiving the GPS signals. The test results are summarized below.

Input Impedance

The input impedance of each of the seven elements is close to 50 ohms at the L1 frequency. A typical measured input impedance versus frequency is shown in Figure 8.

Voltage Standing Wave Ratio (VSWR)

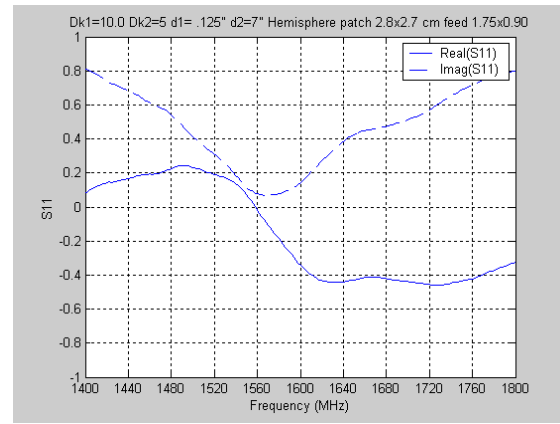
The measured VSWR for each of the seven elements is less than 2.0:1 within a frequency band of 1575.42 +/- 10.0 MHz. A typical measured VSWR versus frequency is shown in Figure 9.

### Reflection Coefficient

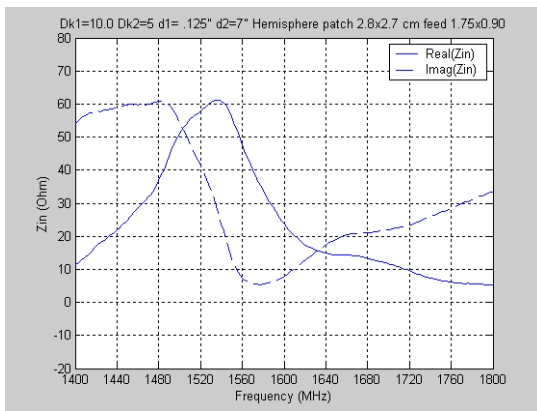
The measured reflection coefficient of the mini-array antenna elements is close to 0 within the L1 frequency band. A typical measured reflection coefficient is shown in Figure 10.

### Mutual Coupling

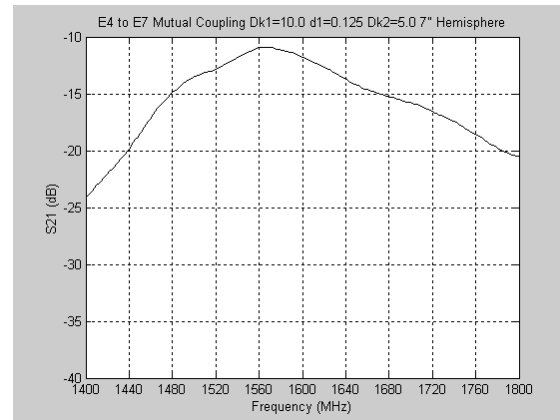
The transmission coefficient between the elements is used to indicate the mutual coupling between them. The strongest mutual coupling occurs between Element 4 and Element 7. The transmission coefficient as shown in Figure 11, is below  $-12$  dB in the L1 frequency band ( $1575.42 \pm 10$  MHz). The weakest mutual coupling occurred between elements 2 and 4 as seen in Figure 12 where the transmission coefficient remained below  $-24$  dB.



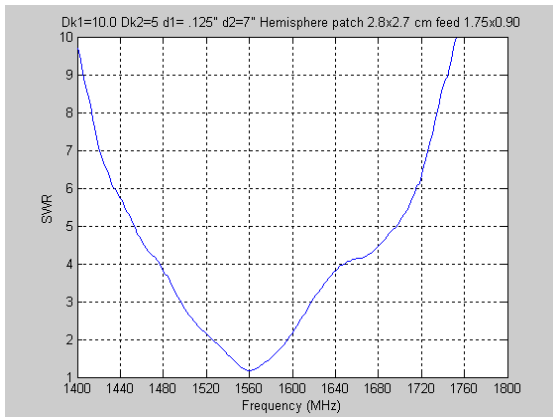
**Figure 10** The measured reflection coefficient of one element of the S-CRPA



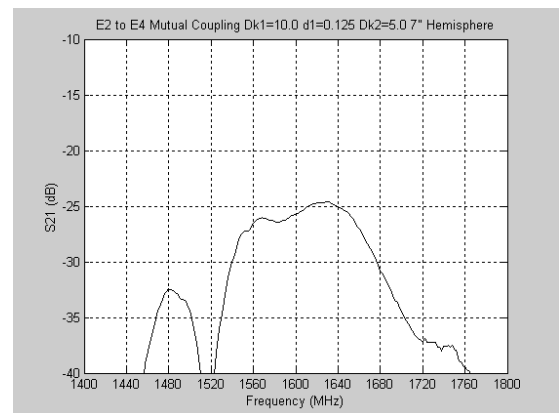
**Figure 8** The measured input impedance of one element of the S-CRPA



**Figure 11** The measured transmission coefficient between element 4 and element 7



**Figure 9** The measured VSWR of one element of the S-CRPA



**Figure 12** The measured transmission coefficient between element 4 and element 2

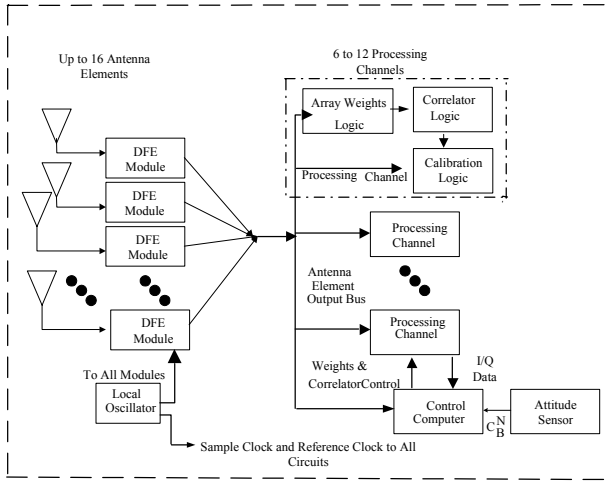
### S-CRPA GPS SATELLITE TRACKING TESTS

The S-CRPA was tested to compare its performance against a reference CRPA 7-element antenna array. NAVSYS' High-gain Advanced GPS Receiver (HAGR) antenna electronics were used to collect GPS observations



from both the S-CRPA and the reference CRPA antenna arrays.

The HAGR is a digital beam-steering GPS receiver. As illustrated in Figure 13, each antenna RF input is converted to a digital signal, and the digital signal from all of the antenna inputs are provided to the HAGR signal processing cards where the antenna weights are applied digitally before the satellite code and correlation signal processing is performed. In the current HAGR configuration, up to 16 antenna elements L1 and L2 can be supported. The HAGR includes both C/A and P(Y) code processing capability (L1 and L2) for up to 12 satellite channels<sup>3</sup>.



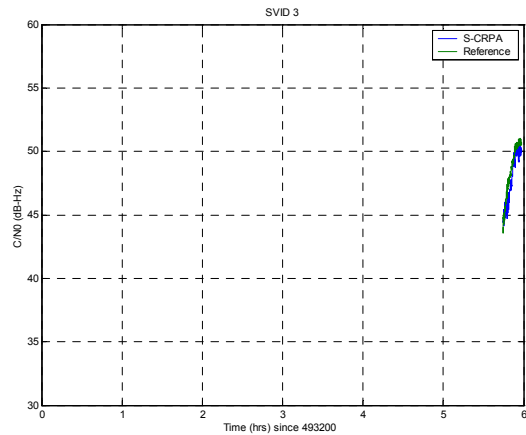
**Figure 13 P(Y) HAGR System Block Diagram**

A reference array was built using seven model AT575-97 single element GPS antennas from AeroAntenna Technology Inc. The antennas were mounted on a 12” diameter ground plane, spaced one-half wavelength apart (see Figure 14).

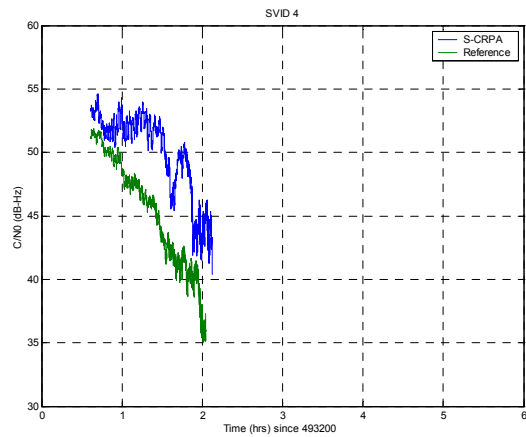


**Figure 14 S-CRPA and Reference CRPA**

A system calibration was performed on both of the antenna arrays using the digital antennas electronics to remove any phase offsets between elements. Data was collected to observe the measured C/N0 values from the different satellites tracked using beam-steering from the S-CRPA and reference antenna arrays. These results are shown in Figure 15 through Figure 29. The blue line in each figure represents the C/N0 values for the S-CRPA and the green line represents the same observation from the Reference antenna array. These test results show that the S-CRPA performance when tracking the GPS satellites is very similar to that provided by the Reference antenna array. On average, both the S-CRPA and the reference antenna array provided a gain improvement of around 7 dB as compared to a single element antenna.



**Figure 15 S-CRPA and Reference C/N0 (SV 3)**



**Figure 16 S-CRPA and Reference C/N0 (SV 4)**

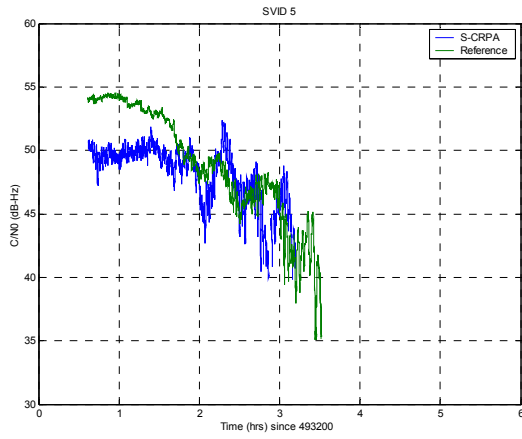


Figure 17 S-CRPA and Reference C/N0 (SV 5)

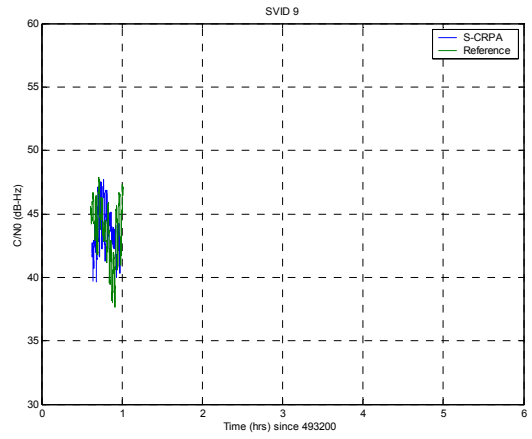


Figure 20 S-CRPA and Reference C/N0 (SV 9)

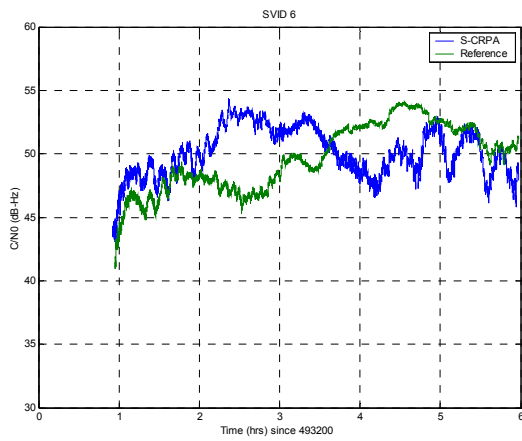


Figure 18 S-CRPA and Reference C/N0 (SV 6)

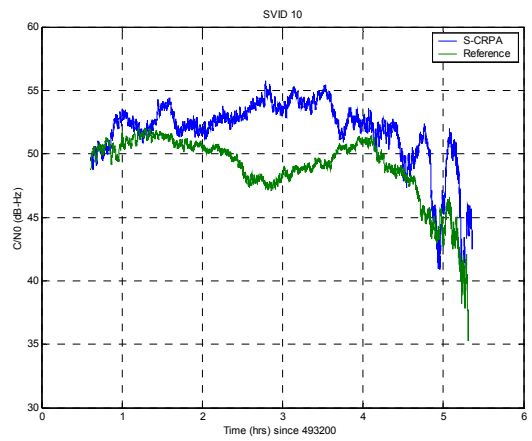


Figure 21 S-CRPA and Reference C/N0 (SV 10)

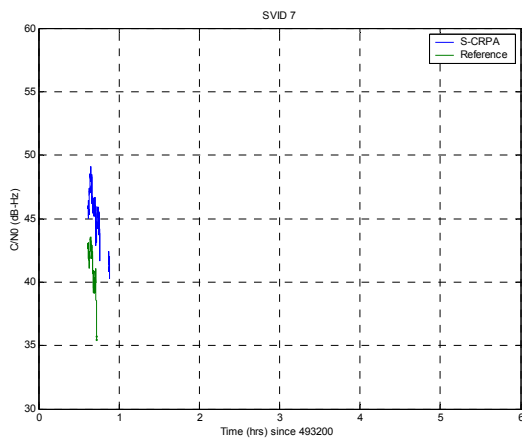


Figure 19 S-CRPA and Reference C/N0 (SV 7)

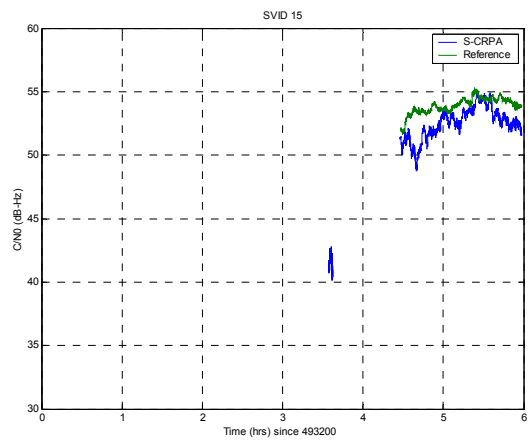


Figure 22 S-CRPA and Reference C/N0 (SV 15)

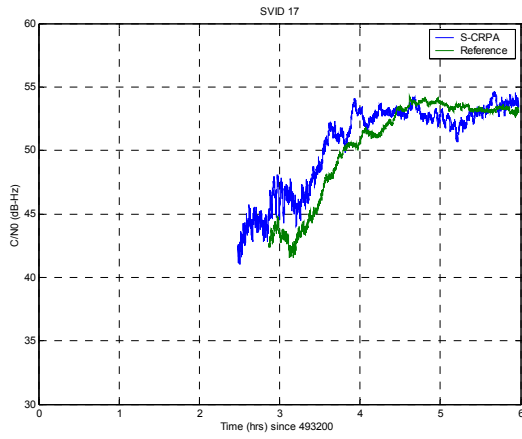


Figure 23 S-CRPA and Reference C/N0 (SV 17)

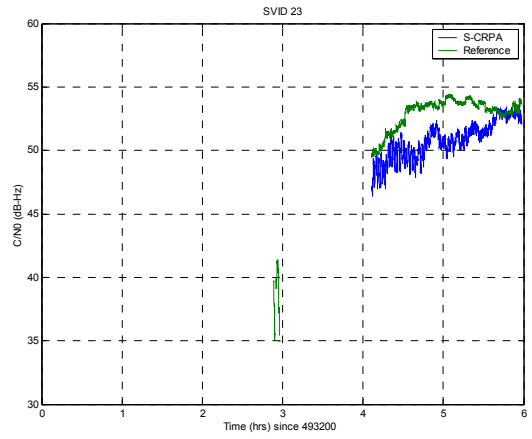


Figure 26 S-CRPA and Reference C/N0 (SV 23)

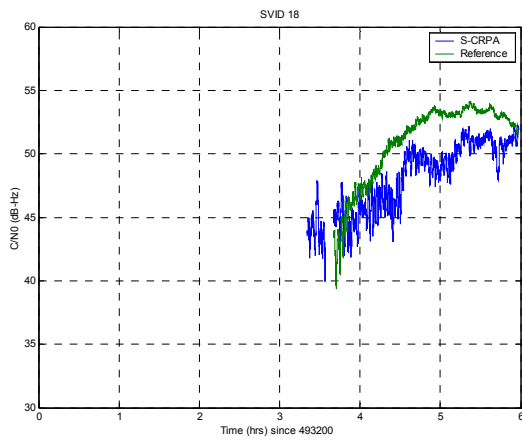


Figure 24 S-CRPA and Reference C/N0 (SV 18)

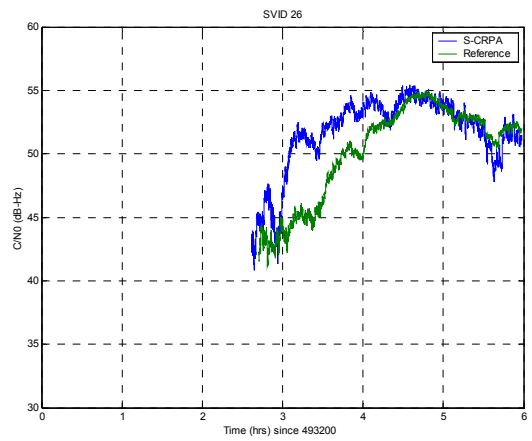


Figure 27 S-CRPA and Reference C/N0 (SV 26)

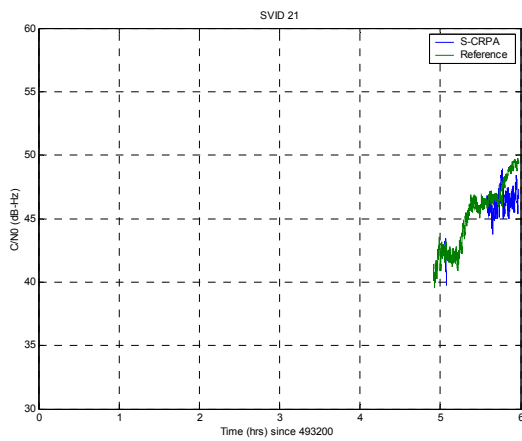


Figure 25 S-CRPA and Reference C/N0 (SV 21)

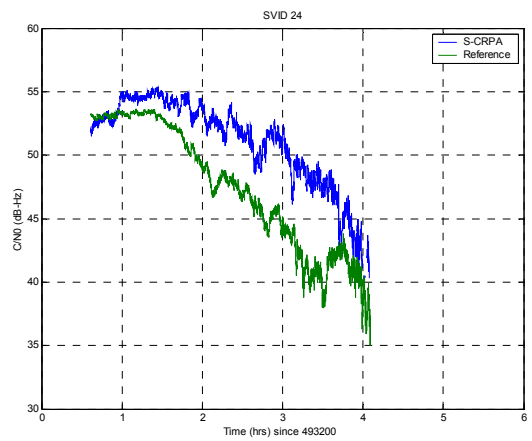
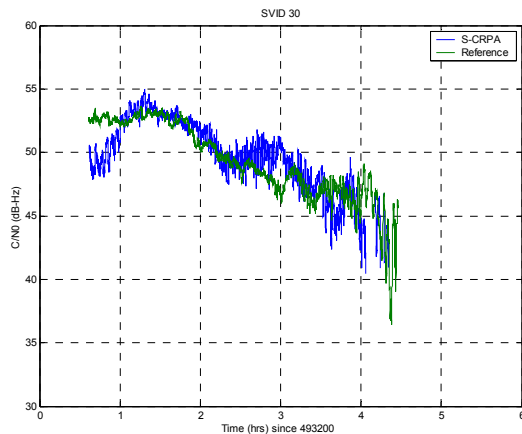


Figure 28 S-CRPA and Reference C/N0 (SV 24)



**Figure 29 S-CRPA and Reference C/N0 (SV 30)**

## CONCLUSION

In conclusion, the test results on the S-CRPA have demonstrated its capability to provide equivalent performance to a full-size 7-element CRPA when integrated with the HAGR digital beam-steering electronics. Testing is planned to be conducted later this year to evaluate the S-CRPA's GPS anti-jam performance when integrated with GAS-1 Antenna Electronics. The small size of the S-CRPA will allow it to be installed on a wide variety of different platforms, including aircraft, munitions and ground vehicles. NAVSYS is also currently developing an L1/L2 version of the S-CRPA which will be available in 2002.

Commercial applications for the S-CRPA also exist for precision GPS applications. The 7-element array provides +8dB of gain on each of the GPS satellites when operated with a beam-steering GPS receiver, such as NAVSYS' HAGR. This increases the tracked GPS satellite signal/noise ratio which improves the code and carrier phase errors. The antenna directivity also reduces the multipath errors further enhancing the GPS navigation accuracy<sup>4</sup>. For safety of life applications, such as aircraft landing using the Wide Area Augmentation System (WAAS) or Local Area Augmentation System (LAAS), the S-CRPA directivity also provides interference rejection, reducing the potential for GPS signal disruptions.

## ACKNOWLEDGEMENT

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- <sup>2</sup> U.S. Patent No. 6,246,369, "Miniaturized Phased Array Antenna System," Alison K. Brown, Peter K. Brown, Amir H. Matini, and John D. Norgard, issued June 12, 2001.
- <sup>3</sup> ["Test Results from a Digital P\(Y\) Code Beamsteering Receiver for Multipath Minimization,"](#) A. Brown, N. Gerein, Proceedings of ION 57<sup>th</sup> Annual Meeting, Albuquerque, NM, June 2001.
- <sup>4</sup> ["Multipath Characterization using Digital Phased Arrays,"](#) A. Brown, N. Gerein, and L. Savage, Proceedings of ION 57<sup>th</sup> Annual Meeting, Albuquerque, NM, June 2001.