Extending Narrow-Correlator Technology To P(Y) - Code Receivers: Benefits and Issues

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BIOGRAPHY

Mr. Steven Karels is Manager of the Time Space Position Information Section of TASC's Electromagnetic Systems department Mr. Karels is responsible for analysis and simulation of vehicle navigation involving integrated sensors such as Global Positioning System (GPS), inertial measurement devices lasers and radars. Mr. Karels received his B.S. in Physics from California State Polytechnic at San Luis Obispo, California (1968). an M.S. in Electrical Engineering (1974) and an Engineer's Degree in Electrical Engineering (1976) from the University of Southern California

Mr. Thomas Macdonald is the department manager of the Electromagnetic Systems department and is also the Program Manager for TASC support to the Range Applications Joint Program Office (RAJPO). As such, he has managed all of TASC's support programs for RAJPO and has been a major contributor to GPS n-i-service cost benefit studies. He has also provided key GPS receiver technology expertise and has been directly involved with identification and analysis of key technical and implementation issues. He has supported the design of test range system architectures, including integration of airborne avionics, ground-based control systems and data links. He has explored the performance of advanced GPS concepts, including DGPS. Mr. Macdonald received his B.S. (1969) and his M.S. (1972) in Electrical Engineering from M.I.T. and an Engineer's Degree in Electrical Engineering from M.I.T in 1975.

Dr. Mats Viggh has served as a consultant to TASC in the areas of mathematical modeling and computer-based analysis of sensor. communication, and navigation systems. Most recently. his work has focused on analyzing advanced GPS receiver and signal processing concepts. Dr. Viggh received his M.S. in Electrical Engineering (1955) and his Ph.D. in Electrical Engineering (1958) from the Royal Institute of Technology, Stockholm, Sweden.

Mr. Robert Balla is lead systems engineer in the U.S. Army, Ground Based Radar Project Office, Program Executive Office Missile Defense. Mr. Balla's areas of responsibility include developing the GBR fire control requirements for the Theater High Altitude Area Defense(THAAD) hit-to-kill interceptor. Specific activities include trade studies and research and development projects for advanced tracking algorithms, coordinate registration, and alignment and calibration techniques. Mr. Balla received his B.S.E.E. degree from Virginia Polytechnic Institute and State University Blacksburg, VA in 1978.

ABSTRA CT

The objective of this study was to investigate the benefits of extending narrow-correlator techniques, currently used in some commercial applications (i.e., NovAtel), to P(Y)-code military GPS receivers. An analysis was conducted on the performance of standard C/A-code, narrow-correlator C/A-code, standard P(Y)-code, and a hypothetical narrow-correlator P(Y)-code GPS receiver. The effects of multipath on the code tracking loops for each candidate system were analyzed. Estimates of code loop ranging performance versus carrier to noise density (C/N0) levels were obtained for each of the four candidate cases. Both ground and aircraft multipath errors were estimated. Differential GPS error budgets were generated for each of the candidate systems. Issues such as GPS Space Vehicle (SV) output RF bandwidth versus receiver performance are considered and recommendations regarding the GPS SVs are presented The study indicates that the additional improvements in overall GPS receiver performance obtained in commercial GPS receivers over standard C/A-code receivers may be extended to military (P(Y)-code) GPS receivers but only if the GPS SV spectral output is permitted to increase.

INTRODUCTION

The use of narrow-correlator spacing technology has bun demonstrated in sae C/A-code GPS receivers and improved ranging performance and multipath resistance have been reported in the open literature. One of the earliest and key papers in the theory of narrow-correlator spacing in GPS receivers, written by A. J. Van Dierendonck [1] et al., describes the theory of operation for the NovAtel commercial line of GPS receivers. TASC has reviewed this paper and extended the analysis to a hypothetical narrow-correlator PO-code GPS receiver.

As discussed in Reference 1. the selection of one chip correlator spacing in P(Y)-code GPS receivers was historically based on four issuer

1. The advantages in noise reduction are not present if a tau-dithered Delay Lock Loop (DLL) is used. In such a loop, a single correlator is time shared for the early and late signals. The noise that accompanies these signals is uncorrelated because of the time lag between early and late signal-plus-noise samples.

2. The early receivers were usually of the P(Y)-code variety. Since a P(Y)-code chip is already relatively narrow (compared to C/A-code), reduced correlator spacing makes the DLL discriminator very narrow. It was feared that Doppler and other disturbances would cause loss of code lock.

3. Narrower correlator spacing requires faster clocking of the early/late gating. Early in the GPS program, this was a major technological problem.

4. Because the original error budget was dominated by Space Segment errors, there did not appear to be any end-to-end performance advantage in improved ranging performance.

With the advance of technology, most current GPS receivers perform early and late (or early minus late) correlation simultaneously thus negating the first issue. The concern over loss of code lock has been mitigated by the use of carrier-aiding techniques. The third issue will be overcome as technology improves and faster A/D implementations become available. The fourth issue is addressed in this paper.

The advantages of *narrower correlator spacing in a non-coherent DLL discriminator include reduction of tracking errors due to noise and multipath. Noise reduction is obtained with narrower correlator spacing because the noise components of the early and late signals are correlated and tend to cancel each other, provided that the early and late processing is simultaneous (not dithered). Multipath effects are reduced because them-coherent DLL code discriminator is less distorted by the delayed multipath signal.

GPS Performance Analysis

A narrow-correlator GPS receiver, as does a *conventional* GPS receiver, uses samples from a comlator driven by an "on-time" pseudorandom sequence and one driven by an "early-minus-late" local sequence in a 'dot-product" delay discriminator. The pseudo random code sequence is used for determining user position. For the CIA-code, the sequence consists of 1000 nsec chips; for the P(Y)-code, the chips are 100 nsec, thus affording more precise ranging accuracy than the C/A-code. Typically, the early and late sequences are offset by one chip. In narrow-correlator GPS receivers, the early and late sequences are offset by as little as a tenth of a chip.

Pseudorange accuracy improves with reduced spacing between the early and lace local code sequences be-cause the noise in the early and late channels becomes partially correlated and tends to cancel out As the correlator spacing decreases. the slope of the code discriminator curve becomes less steep, which results in a decreased range accuracy (see Figure 1). The slope can be restored by increasing the receiver bandwidth (see Figure 2). The reason for the decrease in discriminator slope, as the correlator spacing decreases, is that the cross-correlation function for the local code and the received code sequence becomes "rounded" near the peak unless the passband of the RF and IF filters are increased.

Although ranging performance improves with a wider passband, a wider receiver passband implies a higher sampling rate (-20 MHz for a half-power bandwidth of 8 MHz). Furthermore, the amount of data to be processed increases significantly.

Despite the increased bandwidth and data processing burden, narrow-correlator technology offers several substantial advantages in GPS receiver performance, as

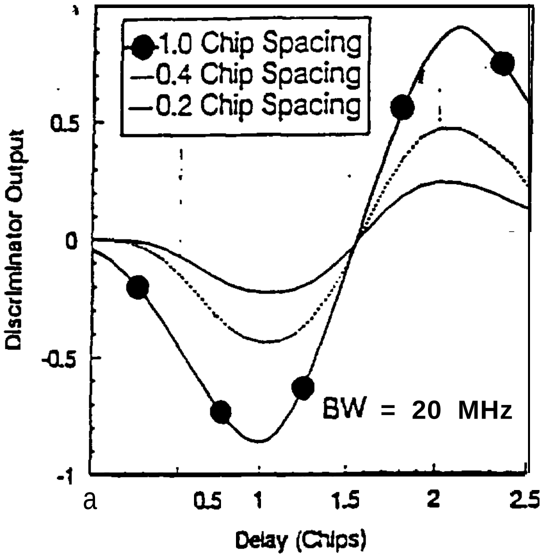


Figure 1 GPS Receiver Discriminator Outputvs. Chip Delay for Different Correlator Spacings

Multipath Error Budget

To estimate the impact on a measurement error budget, the following assumptions were made:

1. Ground reflection: 20 dB Signal-to-Multipath Ratio (SMR), uniformly distributed
2. Aircraft fuselage reflection: 20 dB SMR exponentially distributed. sigma = 2.0 m

The multipath contribution can be estimated by integrating over the correlator response. Figure 7(a) and (b) present multipath error as a function of SMR for the ground reflection and aircraft reflection conditions. respectively. Taking the multipath errors at an amplitude ratio of 0.1 (or 20 dB), the measurement improvement is about 62 percent for the ground reflection case and 13 percent for the aircraft reflection case.

The total GPS receiver measurement error budget for the standard (one chip correlator spacing) P(Y)-code GPS receiver and a hypothetical narrow-correlator GPS receiver are shown in Table 1. The analysis indicates that a 50 percent reduction in receiver measurement error is possible.

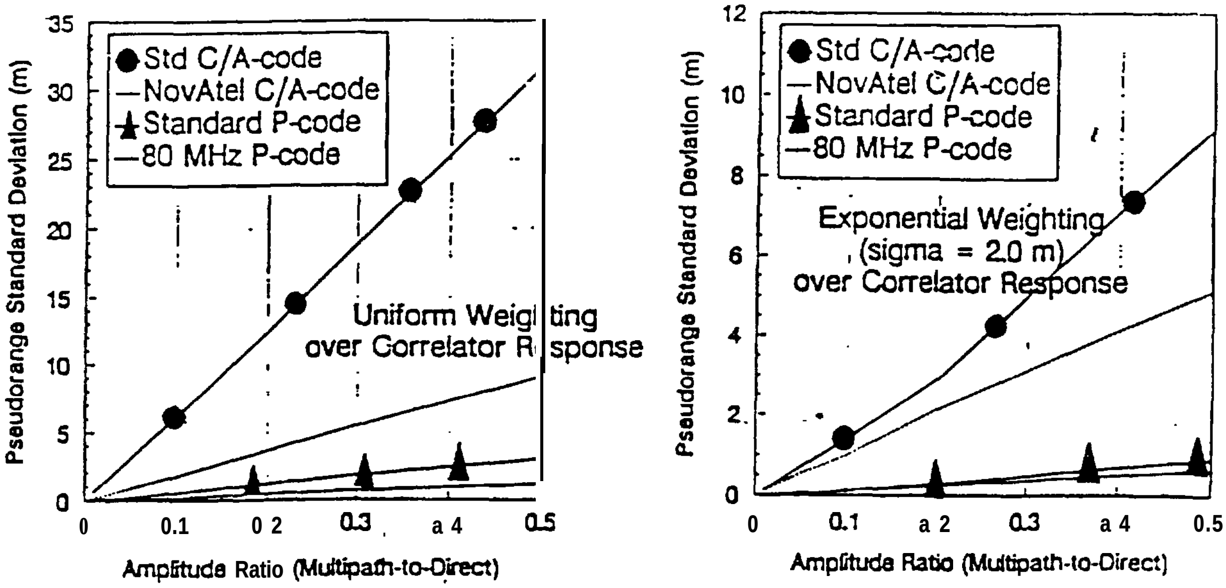
ISSUES

To fully realize the potential of narrow-correlator technology applied to P(Y)-code GPS receivers, several issues must be studied and potential changes made to the GPS system. They are:

1. GPS Satellite Vehicle Transmitted RF Bandwidth
2. Ionospheric dual-frequency delay compensation techniques
3. Antenna performance over the larger RF bandwidth
4. A/D converter sampling rates and linearity requirements
5. Increased interference susceptibility due to a wider RF receiving bandwidth
6. Interference and multipath susceptibility due to the higher bandwidths and possible change of coherence properties of GPS signals reflected from terrain and buildings.

Table 1 Receiver Measurement Error Budget

PARAMETER	STANDARD	NARROW-CORRELATOR
Ranging Precision (m)	0.28	022
Ground Multipath (m)	0.60	0.23
Aircraft Multipath (m)	0.14	0.14
Receiver Error- RSS (m)	0.68	0.34



(a) Ground Reflection

(b) Aircraft Multipath

Figure 7 Multipath Errors vs. Amplitude Ratio compared to a conventional one-chip correlator spacing GPS receiver, notably:

- Significant improvement in range resolution
- Reduced susceptibility to multipath effects
- Shorter recovery time after loss of track [2]
- Fewer computations required for resolving wavelength ambiguities in applications where carrier phase is used for ranging.

The latter is particularly important for kinematic GPS and attitude determination systems.

Narrow-correlator technology has a significant effect on two major performance aspects: ranging precision and multipath susceptibility. Fit improvements in ranging precision are considered.

Improvements in Ranging Precision

An analysis was conducted comparing the ranging precision of four alternative receiver implementations (a 20 millisecond integration time was assumed for all four cases):

1. A standard C/A-code GPS receiver – 2 MHz bandwidth, I.0 chip spacing
2. A NovAtel C/A-code GPS receiver – 8 MHz bandwidth, 0.1 chip spacing
3. A standard P(Y)-code GPS receiver – 20 MHz bandwidth, 1 .O chip spacing
4. An advanced P(Y)-code GPS receiver – 80 MHz bandwidth, 0.2 chip spacing

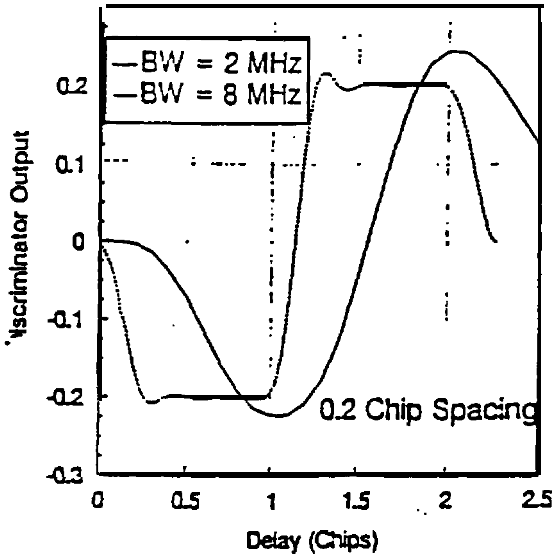


Figure 2 GPS Receiver Discriminator Output vs. Chip Delay for Two Receiver Bandwidths

A ranging precision comparison is shown in Figure 3. The ranging error curves show a potential improvement in ranging **precision (at nominal C/N0 conditions) of** about 23 percent for the advanced P(Y)-code GPS receiver over that of a conventional P(Y)-code GPS receiver.

Multipath Rejection

The second area of major improvement is reduced sensitivity to multipath. Figure 4(a) and 4(b) show the multipath susceptibility for the standard and narrow-cot-relator P(Y)-code GPS receivers, respectively. Each plot shows the range error, in meters, induced by multipath for various direct-to-indirect amplitude ratios (AR) and phase differences. Note the significant improvement in multipath rejection afforded by the narrow-correlator technology.

Optimal Correlator Spacing Design

Results from both analysis and experiments provide conclusive evidence that realization of the potential benefits from narrow correlator spacing requires a pre-correlator bandwidth substantially larger than the conventional 2/Tc, where Tc is the chip duration. For the NovAtel C/A-code GPS receiver, that bandwidth is near 8 MHz, i.e., about 8/Tc. As shown in Figure 5, that yields a minimum ranging uncertainty for a cot-relator spacing close to 0.15 chips.

Scaling the NovAtel design data to those of a P(Y)-code GPS receiver yields a bandwidth of 80 MHz, and an optimal correlator spacing close to 0.2 chips, cf., Figure 6. Note that C/N0 is 3 dB less for the P-code case, due to lower transmitted power than for the C/A-code carrier.

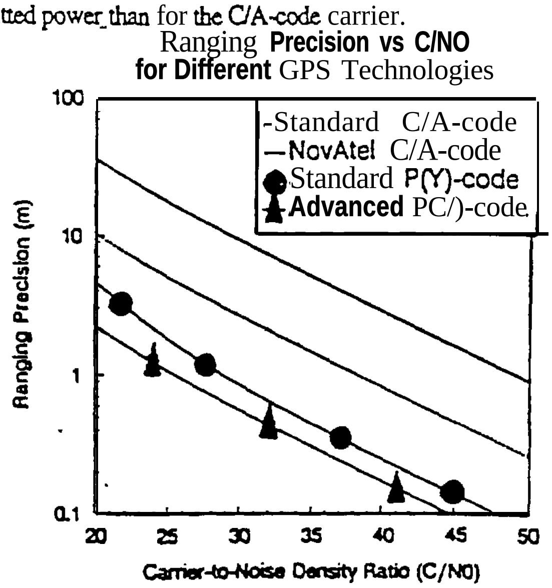
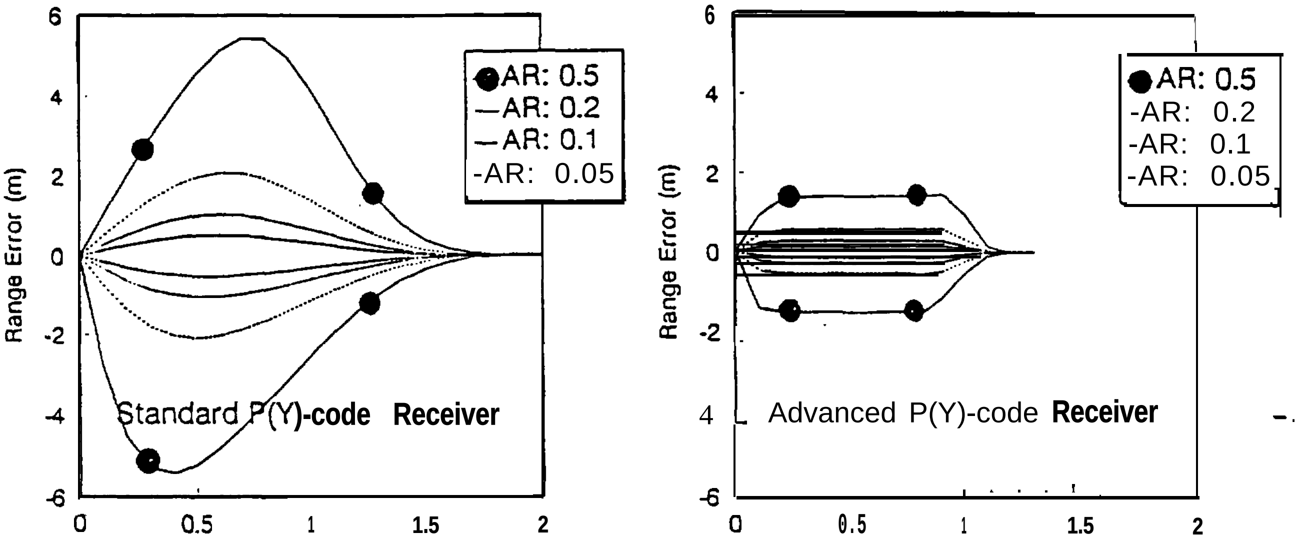


Figure 3 Ranging Precisions vs. C/N0 for Different GPS Receiver Technologies



(a) Standard P(Y)-code

(b) Narrow-correlator P(Y)-code

Figure 4 Multipath Susceptibility vs. Multipath Delay

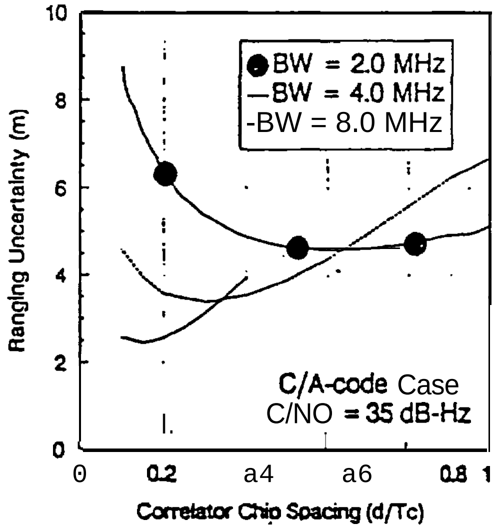


Figure 5 **Ranging Uncertainty vs. Chip** Spacing, **C/A-code**

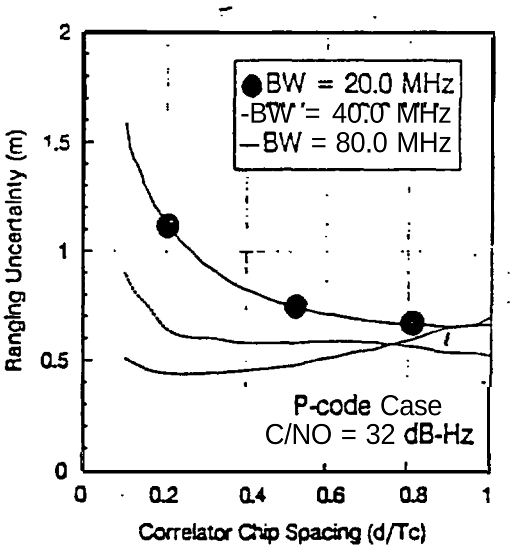


Figure 6 **Range Uncertainty vs.** chip **Spacing, P(Y)-code**

To effectively use the narrow-correlator technology at P(Y)-code, the GPS signals transmitted from the SVs must have an RF bandwidth as wide or wider than the receiver RF bandwidths. This will require a change to the GPS SV circuitry and may have other effects in system operation, frequency approval, etc.

The use of dual-frequency techniques to compensate ionospheric delays needs to be analyzed. Higher order effects may need to be considered in narrow-correlator GPS receiver designs.

Antennas will need to provide uniform performance over the entire GPS signal bandwidth or at least their properties must be studied and suitable compensation techniques applied.

Proper A/D circuitry and design will have to be implemented to accommodate the higher bandwidths. Higher sampling rates and improved linearity are needed

Interference and multipath susceptibility effects need to be studied and thoroughly analyzed

SUMMARY

In summary, narrow-correlator technology has potential benefits to P(Y)-code GPS receivers but additional studies are required on both technical implementation issues and operational impacts.

REFERENCES

1. Theory and Performance of Narrow Cot-relator Spacing in a GPS Receiver, AJ. Van Dierendonck. AJ. Systems, and Pat Fenton and Tom Ford, NovAtel Communications Ltd. Proceedings of National Technical Meeting, U.S. Institute of Navigation, Washington. DC, 1992. pp. 115–124.
2. GPS Signal Availability in an Urban Area — Receiver Performance Analysis, T.E. Megland, G. Lachapelle, and H. Gehue, Department of Geomettics Engineering, The University of Calgary. IEEE Plans ‘94. Las Vegas, 11–15 April 1994. pp. 1/7–3/7.

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