

Precision GPS Surveying After Y-Code



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INTRODUCTION

Although it's not a foregone conclusion, [Van Dierendonck, 1991], it is accepted that data from both the L1 and L2 frequencies is necessary for efficient high accuracy GPS survey. It may come as a piercing insight into the obvious that the way to increase survey efficiency and accuracy begins with the three basic premises:

- 1) Use all available observables.
- 2) Measure them accurately.
- 3) Use optimal signal processing techniques which offer the best SNR (Signal-to-Noise Ratio), jam immunity and multipath rejection.

When the P-code is available, the above suggests we correlate with the P-code on L1 and L2, and use this range and phase data in conjunction with that derived from the C/A code processing. Without exception, no codeless technique recovers GPS signal information as well as one which makes use of the modulating code. When AS (Anti-Spoofing) is activated, the P-code on the L1 and L2 carriers is replaced with Y-code. This precludes the use of traditional P-code correlation techniques. The Y-code is the modulo two sum of the P-code and the encryption code W.

This paper compares four fundamental approaches to recovering L2 carrier and code phases in the presence of AS:

- 1) Squaring
- 2) Cross-correlation
- 3) Code-correlation followed by squaring
- 4) Tracking the underlying P-code and W-code in the Y-code

SQUARING

Squaring or auto-correlating the L2 produces a half-wavelength carrier signal at twice the center frequency of the L2 signal. This technique is shown in Figure 1.

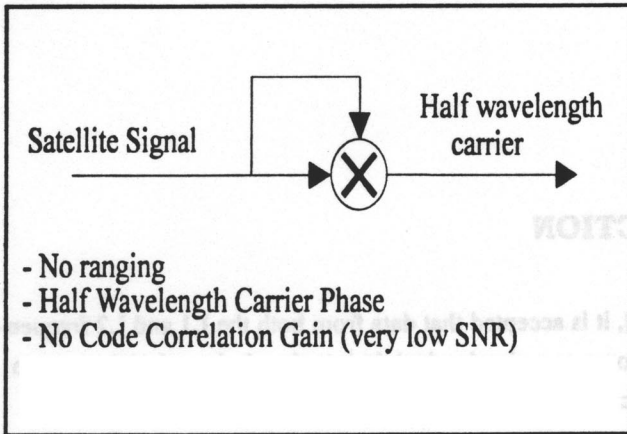


Figure 1. Squaring

If the L2 signal is passed through a filter which is loosely matched to the P-code spectrum prior to squaring, a spectral component at the chip rate whose phase matches the phase of the L2 component at the L2 subcarrier appears. The techniques of squaring the L2 signal to recover the half-wavelength carrier signal and the L2 subcarrier were invented by Charles Counselman III and are covered by U.S. Patent numbers 4,667,203 and 4,894,662 respectively. Counselman used the product of the UxL (Upper cross Lower) to synthesize these observables. UxL is more immune to jamming than squaring; however, the results are much the same. Squaring, as a means of recovering the L2 information, has substantial drawbacks.

First, squaring the received L2 signal results in a very low SNR, roughly 30 db lower than that obtained by correlation with the code.

Second, the squaring process halves the wavelength of the L2 carrier. This rules out the use of the 86 cm L2-L1 widelane observable. The resulting codeless wide lane is 34 cm.

CROSS-CORRELATION

The method of cross-correlating the L1 and L2 signals involves introducing a variable delay in the L1 signal path, maximizing the correlation between the L1 and L2 signals by adjusting this delay, and noting the corresponding delay. This process is shown in Figure 2.

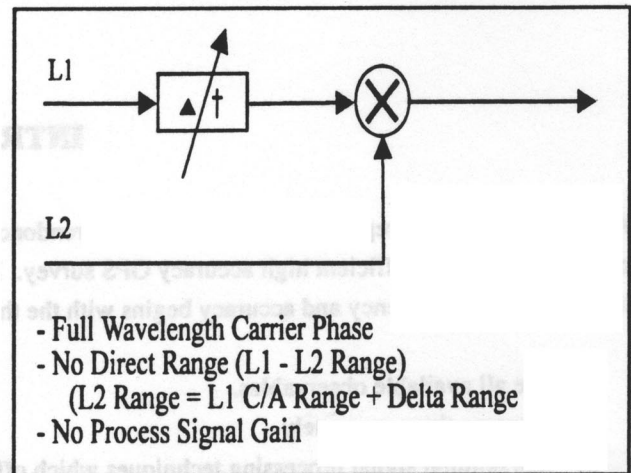


Figure 2. Cross Correlation

Two observables result from this process: the range difference between the L1 and L2 signals and a beat-frequency carrier (i.e. the L2 carrier phase minus the L1 carrier phase).

Because the transmitted power of the L1 precision ranging signal is twice that of its L2 counterpart, cross-correlating the L1 and L2 signals results in a 3 dB SNR improvement over squaring the L2 signal. The pseudorange difference between the L2 and L1 codes and the beat-frequency carrier are used with the C/A code observables. The L2 observables suffer a SNR degradation of 27 dB when cross-correlating is used instead of correlating with P-code.

CODE CORRELATION SQUARING

This method, shown in Figure 3, involves correlating the L2 Y-code signal with a locally generated replica of the underlying P-code, narrowing the bandwidth and subsequently squaring.

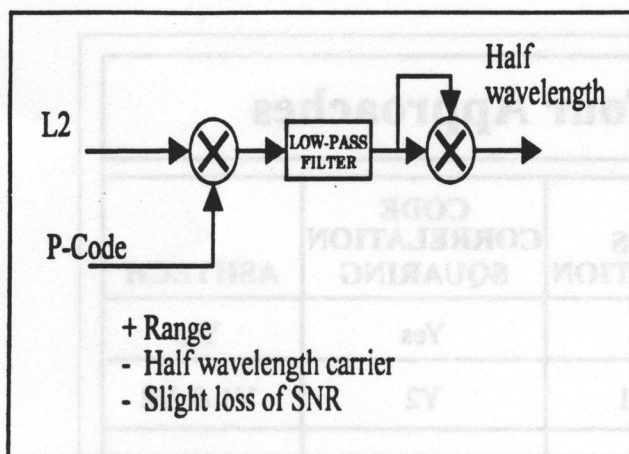


Figure 3. Code Correlation Squaring

This method affords substantial advantages over traditional squaring. The most significant benefit is in the area of SNR; correlating with the P-code and filtering prior to squaring yields a 13 dB SNR improvement. It also yields the L2 P-code range, which is useful in determining carrier phase cycle ambiguities. Finally, mixing with the P-code improve the jam-immunity and multipath performance. This technique was invented by Keegan and is covered by U.S. Patent number 4,972,431. Unfortunately, it also results in a half-wavelength carrier phase observable. This method yields an SNR which is 17 dB lower than that obtained by correlating with the P-code.

ASHTECH TECHNIQUE

The Ashtech technique makes use of the fact that the Y-code is the modulo two sum of the P-code and a substantially lower rate encryption code W. As shown in Figure 4, the incoming L1 and L2 signals are correlated with locally generated replicas of the underlying P-code signals, the bandwidth is reduced to that of the encryption code, and finally, applied to the opposite frequency signal processing.

Fundamentally, this technique derives an estimate of the encryption bit transmitted on the L1 and L2 signals and uses this estimate to mitigate the effect of the encryption code.

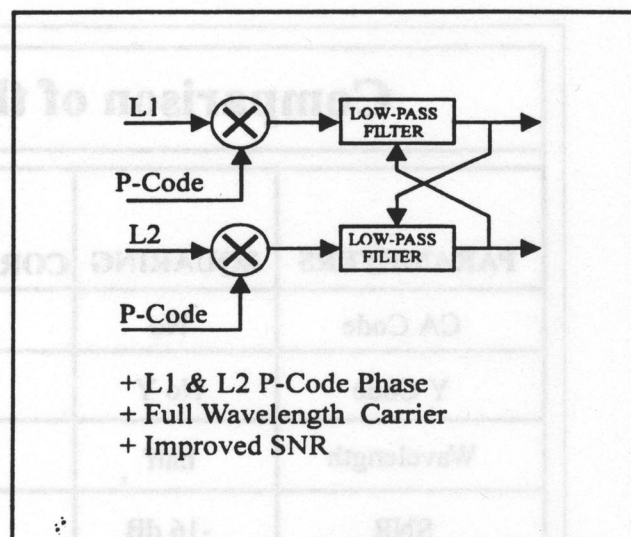


Figure 4. ASHTECH Approach

Compared with traditional cross-correlation, there are some very substantial advantages. Since the bandwidth is restricted by about a factor of 20 prior to the cross-correlating step, the SNR of the resultant observables is improved by a factor of 20. It doesn't end there. As this method mixes with the P-code and filters prior to cross-correlating, it is intrinsically much more jam-immune than traditional cross-correlating. Further, the L1 AND L2 Y-code ranges are available. These are precisely the same observables as obtained by correlation with the P-code. Full wavelength L1 AND L2 carrier phases from direct tracking of the code are available. Finally, a whopping 13 dB of SNR improvement over cross-correlation is achieved.

Compared with code correlation squaring, the Ashtech technique has two advantages.

First, the SNR of the Ashtech technique is higher by 3 dB.

Second, and more significantly, the Ashtech technique results in a full wavelength L2 carrier phase observable, as well as range and phase observables from the L1 Y-code signal.

A comparison of the above methods are summarized in figure 5.

Comparison of the Four Approaches

PARAMETERS	SQUARING	CROSS CORRELATION	CODE CORRELATION SQUARING	ASHTECH
CA Code	No	Yes	Yes	Yes
Y Code	No Y	Y2 - Y1	Y2	Y1 & Y2
Wavelength	half	full	half	full
SNR	-16 dB	-13 dB	-3 dB	0 dB

Figure 5. Approach Comparison

The Ashtech method is covered by US patent number 5,134,407 (Lorenz et. al.) July 1992. Other patents pending.

CONCLUSION

None of the above techniques work as well as correlating with the true P-code if it is available. However, in the presence of Anti-Spoofing, the Ashtech technique offers the best performance of any known method.

REFERENCES

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BIOGRAPHY

Javad Ashjaee is president and CEO of Ashtech Incorporated. Ashtech markets GPS system hardware and software.

Robert Lorenz is a senior design engineer at Ashtech, with a BS in Electrical Engineering and Computer Science.