An Adaptive Transversal Filter for GNSS Receiver: Implementation and Performance Evaluation

*Geon Woo Lee[1], Jin Kyu Choi[2], Dongho Shin[3], Youngil Kim[4], Chansik Park[5], Dong-Hwan Hwang[6], Sang Jeong Lee[7]

[1] Department of Electronics Engineering, Chungnam Nat'l Univ. (E-mail: liiiv@cslab.cnu.ac.kr)
[2] Korea Ocean Research & Development Institute. (E-mail: jkch0525@moeri.re.kr)
[3] Agency for Defense Development. (E-mail: snoopy@add.re.kr)
[4] Agency for Defense Development. (E-mail: youngil@add.re.kr)
[5] School of Electrical and Computer Engineering, Chungbuk Nat'l Univ. (E-mail: chansp@chungbuk.ac.kr)
[6] School of Electrical and Computer Engineering, Chungnam Nat'l Univ. (E-mail: dhhwang@cnu.ac.kr)
[7] School of Electrical and Computer Engineering, Chungnam Nat'l Univ. (E-mail: eesjl@cnu.ac.kr)

Abstract

One-sided and two-sided ATF for GNSS receiver are deigned, implemented and evaluated in this paper. The difference of filter characteristics such as the location of zeros and the frequency response is reviewed and examined with experiments. NLMS adaptation algorithm is adopted for updating the weighting coefficients of the 12-tap FIR filter. The performance of ATF is evaluated using real signals consisting of the signals from GPS simulator and the signal generator. The output of ATF is fed into the SDR to evaluate SNR and the position accuracy. The complexity of implementation is also compared and the effects of the time delay and the phase delay are examined. The experimental results show that one-sided and two-sided ATF give similar performance against single tone CWI.

Keywords: ATF, NLMS, Phase delay, Time delay, Complexity.

1. Introduction

The interference immunity of GNSS(Global Navigation Satellite System) can be significantly enhanced by mitigating the interference prior to correlation of the received signal. There are many interference mitigation methods which can be classified as the pre-correlation processing and the post-correlation processing techniques.

Temporal filtering is one of the pre-correlation techniques and is useful to excise narrow-band (or partial-band) interferences. Temporal filtering can be implemented in 3 different domains: time, frequency and amplitude domain.

ATF(Adaptive Transversal Filter) is a time domain temporal filter with an adaptive tap weight. It is composed of a digital FIR (Finite Impulse Response) filter predicting the incoming interference and an adaptation algorithm estimating the tap weight. FIR filter can be implemented in two types; direct form and linear phase form. The former is referred to as one-sided transversal filter and the latter is referred to as two-sided transversal filter[1].

The SNR performance of two filters has been already analyzed in aspect of rejecting CWI(Continuous Wave Interference) in the spread-spectrum signal[2].

This paper designs and implements two filters and evaluates the interference mitigation performance using the GPS software receiver. Both ATFs have 12 taps and use NLMS(Normalized Least Mean Squares) algorithm. The output of ATF is fed into the SDR (Software Defined Receiver) to evaluate the acquisition and tracking performance. The performance of interference mitigation is evaluated by two measures; SNR(Signal to Noise Ratio) and the position accuracy. Finally the complexity of implementation is discussed.

2. ATF

ATF is composed of two parts; one is the FIR filter and the other is the adaptation algorithm.

2.1 FIR filters

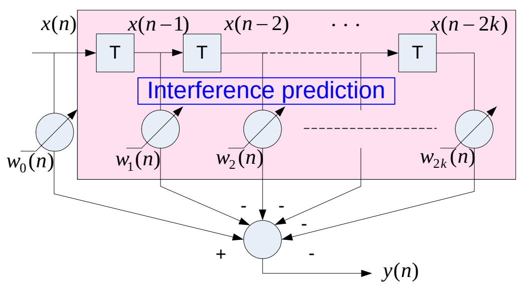

Figure 1. One-sided Transversal filter

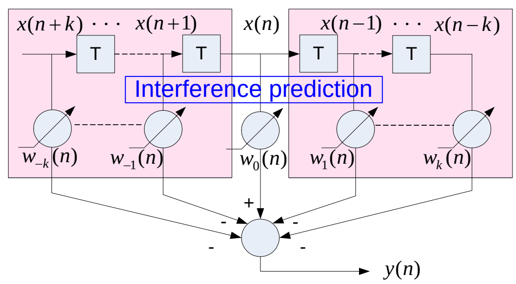

Figure 2. Two-sided Transversal filter

Figure 1 and 2 represent the two types of FIR filter structure. The first has the direct form and the second has the linear phase form. The direct form uses only the past samples for predicting the narrow-band interference whereas the linear phase form uses both the past and the future samples for predicting it. Equation (1) and (2) show the outputs of two filters[2].

$$y(n) = w_0(n)x(n) - \sum_{i=1}^{2k} w_i(n)x(n-i), \quad w_0(n) = 1 \qquad (1)$$

$$y(n) = w_0(n)x(n) - \sum_{\substack{i=-k \\ i\neq 0}}^{k} w_i(n)x(n-i), \quad w_0(n) = 1 \qquad (2)$$

Output of the filter $y(n)$ is the difference between the desired signal $x(n)$ and the sum of the weighted tap input signals. Equation (3) and (4) are the transfer functions of the two filters.

$$H(z) = w_0 z^0 - w_1 z^{-1} \cdots - w_{2k-1} z^{-2k+1} - w_{2k} z^{-2k}, \; w_0 = 1 \qquad (3)$$

$$H(z) = -w_k z^0 - w_{k-1} z^{-1} \cdots + w_0 z^{-k} \cdots - w_k z^{-2k}, \; w_0 = 1 \qquad (4)$$

2.2 Adaptation algorithm

LMS algorithm is widely used for its simple structure and good performance. Normalized LMS algorithm is a kind of LMS algorithm with data-dependent step size. It is more complex than the LMS but its convergence rate is faster. Equation (5) represents the NLMS.

$$w_i(n+1) = w_i(n) + \frac{\mu}{\|x(n-i)\|^2} y(n)x(n-i) \;\; (i = 1, \cdots, 2k) \qquad (5)$$

ATF output $y(n)$ is the error between desired signal $x(n)$ and the sum of the weighted tap input signals. The step size μ is normalized by the square sum of the tapped delay input signal $x(n-i)$ and the NLMS algorithm is convergent in mean square sense if $0 < \mu < 2$ [3].

3. Performance evaluation

3.1 Experimental setup

A GPS simulator and a signal generator are used for making the input signal of ATF. Figure 3 shows the experimental setup.

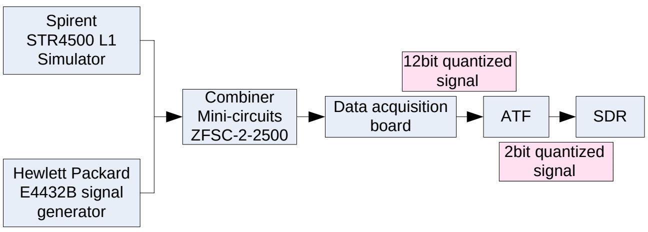

Figure 3. Experimental setup

The data acquisition board produces 12 bit sampled data in order to accommodate interferences with 40dB JSR. The output of ATF is converted to 2 bit data through AGC-like algorithm. The performance of ATF is evaluated using software GPS receiver. Two test scenarios are considered. In the first scenario, CWI is applied from the beginning for evaluating the acquisition performance. In the second scenario, CWI is applied during tracking in order to test the effect on tracking. CWI is applied into the 50 kHz away from the center frequency.

3.2 Transversal filter characteristics

Figure 4, 5, 6 represent the characteristics of one-sided ATF when CWI with 35dB JSR is applied. Figure 4 depicts zero locations. By two zeros, one notch is generated and it is exactly located at the frequency of CWI. It is noted that one-sided ATF has not linear-phase property so that it cause phase distortion.

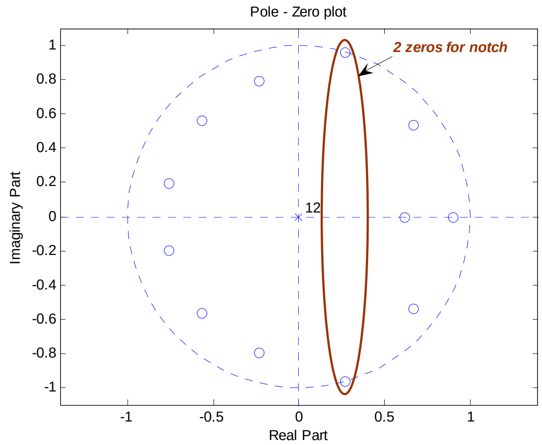

Figure 4. Zeros of one-sided ATF

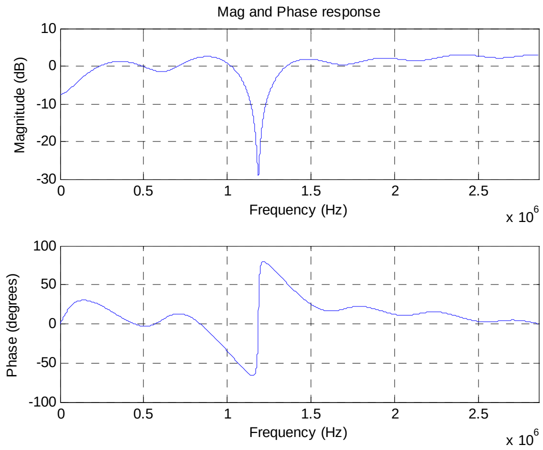

Figure 5. Frequency response of one-sided ATF

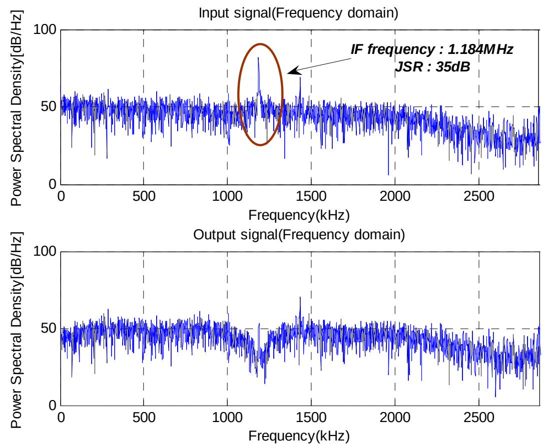

Figure 6. Input and output spectrum of one-sided ATF

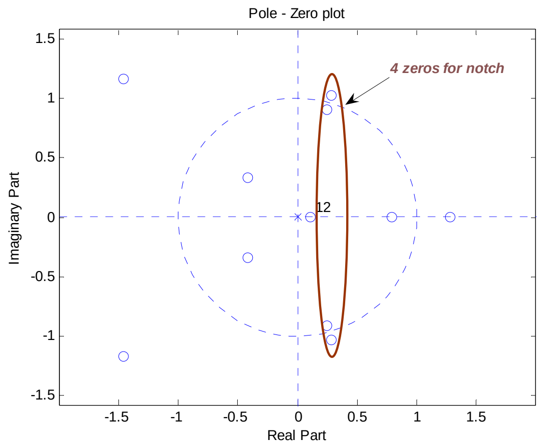

Figure 7. Zeros of two-sided ATF

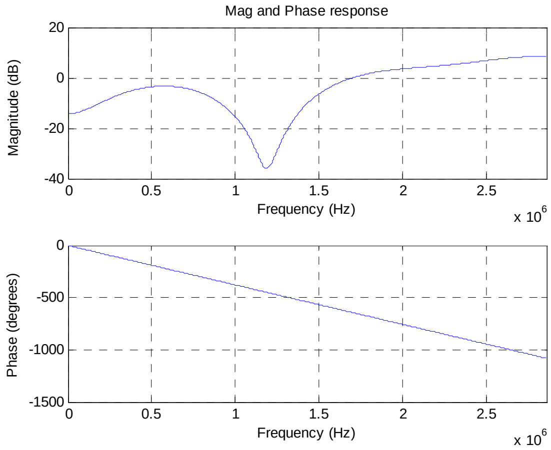

Figure 8. Frequency response of two-sided ATF

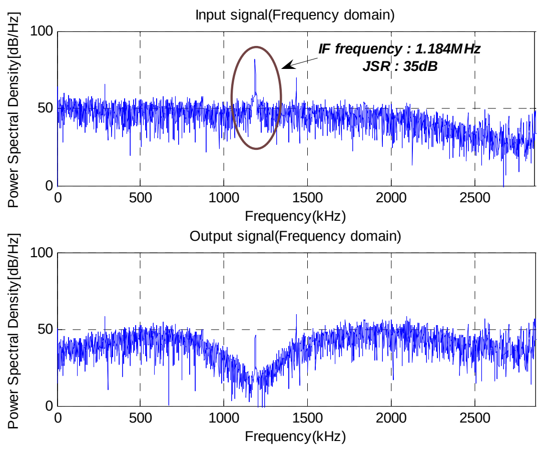

Figure 9. Input and output spectrum of two-sided ATF

Figure 7, 8, 9 represent the characteristics of two-sided ATF. Zero locations are illustrated in Figure 7. Four zeros are used for generating one notch. While two-sided ATF has the linear phase property, the notch width is wider than that of one-sided ATF so that more magnitude distortion can be expected.

3.2.1 Effect of phase delay

The phase response of one-sided ATF has non-linear characteristics as shown in Figure 5. If the phase response of the system is linear, the group delay is constant. If it is non-linear, the group delay is not constant and the phase distortion occurs [4]. To evaluate the effect of the phase delay, GPS codephase is measured. Codephase indicates the independent time parameter for the PRN waveform which is often expressed in units of chips [5]. It can be transferred to range between the satellite and receiver by changing the chip to second.

Table 1. Range error by the difference of codephase

SV	One-sided ATF [m]	Two-sided ATF [m]
3	0.68	0.03
14	-0.18	0.75
18	-0.18	2.17
29	-1.04	0.17
26	1.10	2.89
21	-1.61	-0.40
16	-1.33	0.02
22	2.54	2.03
15	0.11	0.17
6	2.96	3.60

Table 1 illustrates the range error obtained by differencing the codephase between non-filtered signal and filtered signal. The test signal does not contain the interference. SV represents the satellite PRN number. The results in Table 1 show that the phase delay does not produce large influence to the receiver performance.

3.2.2 Effect of time delay

Two-sided ATF uses the past and future samples and the reference signal is extracted from the middle of filter taps. Therefore, if the 12 taps are used, it causes the 6 taps time delay by the future samples.

Because the sampling frequency is 5.714MHz, one tap delay is 175 $[ns]$ so that 12 tap two-sided ATF has 1.05 $[\mu s]$ time delay. The effect of 1.05 $[\mu s]$ time delay on the GPS receiver can be calculated as the range error. It is about 315m ($1.05[\mu s]\times 3\times 10^{8}[m/s]$) . However, this time delay will be considered as the common bias and compensated in the GPS receiver.

Next, the time delay of 1.05 $[\mu s]$ may cause errors in the position of satellites or high dynamic vehicles. For example, the velocity of satellite with speed of 3,874[m/s] has the line-of-sight component of 929[m/s]. The time delay of 1.05 $[\mu s]$ can cause a range error of 0.00097545 [m] in the satellite position, which can be ignored.

3.3 Receiver performance

The SNR and the position accuracy are used to evaluate the ATF performance. The SNR of the input signal is about 10dB. The experiment was done according to two scenarios. In the first scenario, CWI was applied from the beginning. In the second scenario, CWI was applied from the GPS receiver was tracking the GPS signal. Applied CWI had JSR 25dB, 30dB and 40dB.

Figure 10, 11 presents the SNR in the GPS receiver. Maximum and minimum SNR are marked and the mean of 10 channels is also expressed in Figures. SNR decreases as JSR increases. When the applied CWI had 40dB JSR, signal acquisition was impossible.

Figure 12 shows the horizontal positioning error when the interference was applied from the beginning of the experiment. Figure 13 depicts the vertical positioning error. The positioning performances of two cases are much similar to each other.

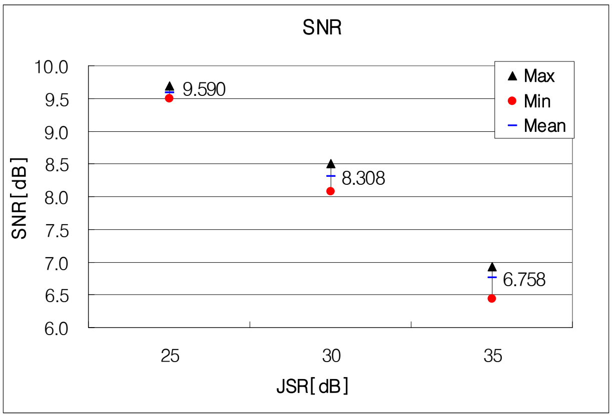

Figure 10. SNR versus JSR (One-sided ATF)

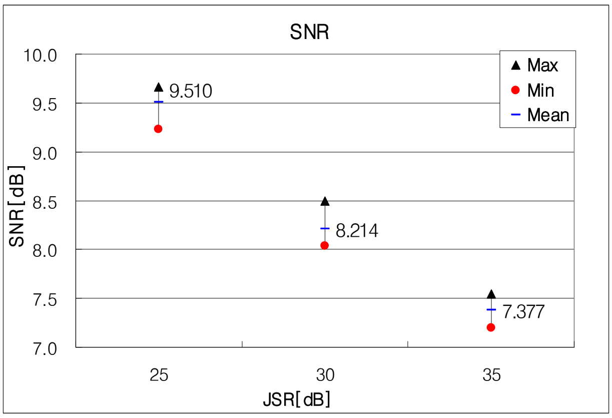

Figure 11. SNR versus JSR (Two-sided ATF)

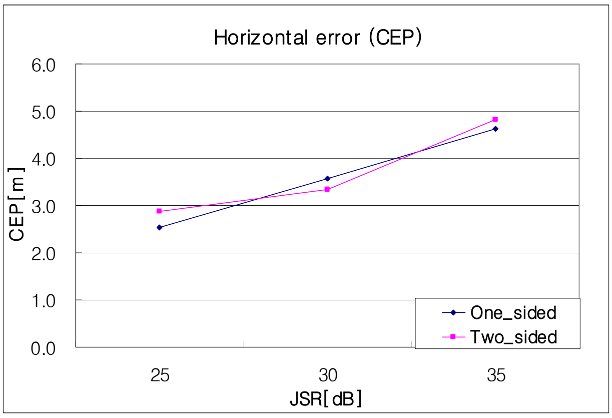

Figure 12. Horizontal positioning error

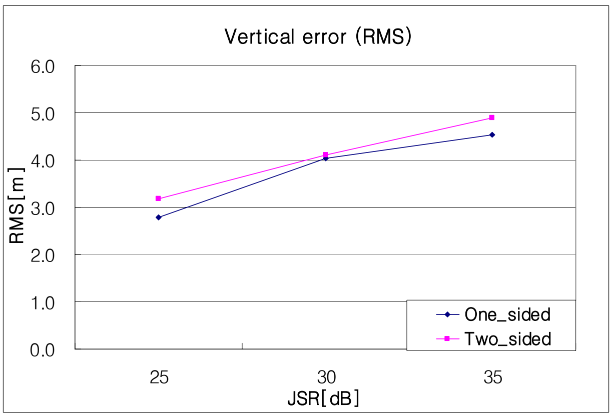

Figure 13. Vertical positioning error

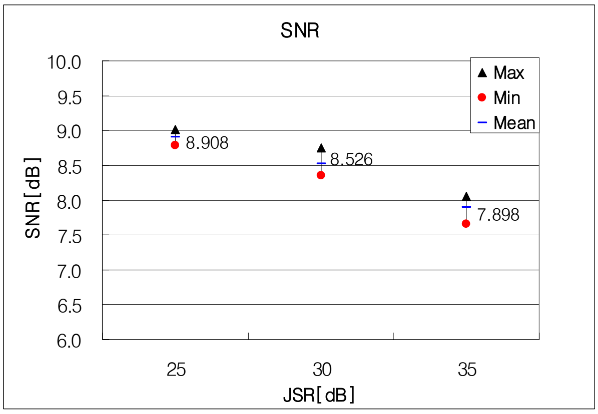

Figure 14. SNR versus JSR (One-sided ATF)

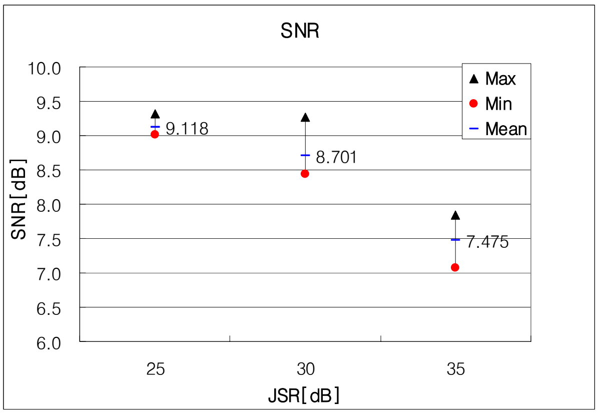

Figure 15. SNR versus JSR (Two-sided ATF)

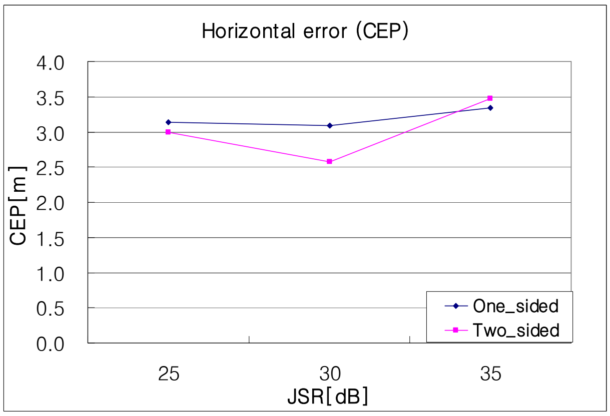

Figure 16. Horizontal positioning error

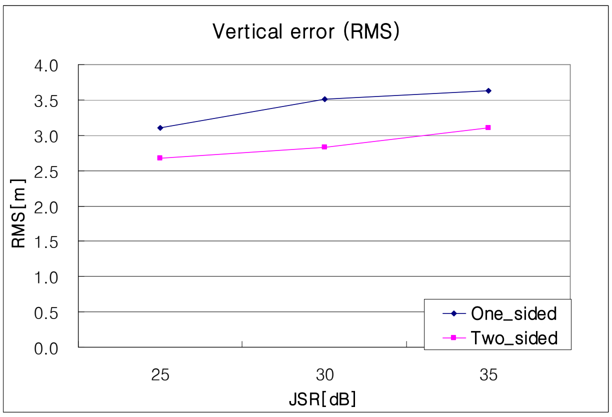

Figure 17. Vertical positioning error

Figure 14, 15 shows the SNR in the GPS receiver when the interference was applied when the GPS receiver is tracking the GPS signal. SNR decreases as JSR increases. When JSR was 40dB, the GPS receiver lost the GPS signal.

Figure 16 shows the horizontal error when the interference was applied when the receiver is tracking the GPS signal. The performances of two-sided ATF are slightly better than that of one-sided ATF, but the differences are less than 1m.

3.4 Complexity considerations

The number of computations for an N-tap filter is summarized in Table 2 and 3. Two-sided ATF requires less operation than the one-sided ATF in the adaptation algorithm. In the case of parallel processing, processing time of two filters is same as the sum of 4 multiplexers and 2N adders[6].

Table 2. The number of operations for one-sided ATF

	Multiplication	Add
FIR filter	N	N
Adaptation algorithm	2(N+1)	2N-1

Table 3. Number of operations for two-sided ATF

	Multiplication	Add
FIR filter	N	N
Adaptation algorithm	(3N)/2+2	2N-1

4. Conclusions

One-sided and two-sided ATF for rejecting narrow-band interference in the GNSS receiver are designed and evaluated. Performances of two types of ATF are evaluated. One-sided and two-sided ATF show almost same performance when the single –tone CWI under 35dB JSR is applied regardless of the signal acquisition status. The effects of phase distortion and time delay on the FIR filter are also evaluated by the experiment. It can be concluded that the GNSS receivers with any of two ATFs will show satisfactory performance against the CWI under 35dB.

References

1. Laurence B. Milstein, “Interference Rejection Techniques in Spread Spectrum Communications,” *Proceedings of the IEEE*, vol. 76, pp. 657-671, No. 6, 1988.
2. Loh-Ming Li and Laurence B. Milstein, “Rejection of Narrow-Band Interference in PN Spread-Spectrum Systems Using Transversal Filters,” *IEEE Trans. Commun.*, vol. COM-30, No. 5, 1982.
3. Bernard Widrow and Samuel D. Stearns, *Adaptive Signal Processing*, Prentice-Hall, Inc., 1985.
4. Rodger E. Ziemer and William H. Tranter, *Principles of Communications*, John Wiley and Sons, Inc., 2002.
5. Elliott D, Kaplan and Christopher J. Hegarty, *Understanding GPS: Principles and Application*, 2nd Edition, Artech House, Inc., 2006.
6. Joseph Petrone, “Adaptive Filter Architectures for FPGA Implementation,” ms thesis, Department of Electrical and Computer Engineering of Florida State University, 2004.
7. Simon Haykin, *Adaptive Filter Theory*, 3rd Edition, Prentice-Hall, Inc., 1996.
8. Alan V. Oppenheim and Ronald W. Schafer with John R. Buck, *Discrete-time Signal Processing*, 2nd Edition, Prentice-Hall, Inc., 1998.