Article

Design and Analysis of Single-bit Ternary Band-pass Digital Filter

Kardan Journal of Engineering and Technology
2 (1) 76–85

Kardan Publications
Kabul, Afghanistan
DOI: 10.31841/KJET.2021.14
https://kardan.edu.af/Research/Kardan_journal_of_engineering_and_technology.aspx#

Zahid Ali
Chandar Kumar
Chaman Lal

Abstract

Recently, various general-purpose sigma-delta modulation based general purpose DSP algorithms have been reported that possess simpler multiplier complexity, lower power consumption and less chip area features. Here in exploration, our goal is to carry on designing a ternary-bit DSP algorithm in which significant design element is a sigma delta modulator. The formation sigma - delta (SDM) has an amount of very pleasant and attractive possessions and inborn linearity which is extensively consumed in communication systems. Signal is sampled more than that of Nyquist rate commonly word used oversampling and classically have a very short word length (i-e one-bit, binary or ternary) in sigma delta modulation technique. In this paper the design and simulation of ternary Band pass digital filter using sigma-delta modulation done in Mat-lab at different over-sampling ratio and compare it to multi-bit Band pass digital filter.

Keywords: *Sigma-Delta Modulation, Single-bit, Ternary, Over-sampling ratio*

Mr. Zahid Ali, *Department of Electronic Engineering, Mehran University of Engineering and Technology, Jamshoro, Sindh, Pakistan. <zbashirk@yahoo.com>*
Mr. Chandar Kumar, *Department of Electronic Engineering, Mehran University of Engineering and Technology, Jamshoro, Sindh, Pakistan. <chamanlal@indus.edu.pk>*
Mr. Chaman Lal, *Department of Science and Technology, Indus University Karachi, Sindh, Pakistan. <chander.malhi@yahoo.com>*

Introduction

Recently, various general-purpose sigma-delta modulation based general purpose DSP algorithms have been reported that possess simpler multiplier complexity, lower power consumption and less chip area features. Processing signals in single-bit format has several advantages. The single-bit format contains only two symbols in its alphabet {-1, 1}. This makes multiplication with single-bit signals trivial. The reduced complexity is available when multiplication is undertaken in the single-bit format. While multi-bit multiplications require complex circuits, The Ternary filter having Ternary taps {i.e., +1, -1, and 0}. The Ternary nature of the coefficients allows a straight forward application of filter. Efficiency can be increased further if the entry in the Ternary filter is in the form of single-bit. Ternary format of bit stream (+1, 0, -1) used instead of binary is to reduce quantization error because of extra zero state and enables greater accuracy. Recently, it has been reported that single-bit Ternary digital filters have better area-performance compared to their counterpart multi-bit at equivalent spectral performance [1, 2]. In [2, 3], mathematical model of low pas filter has been developed to guess the required performance results in stop band attenuation at worst. Furthermore, well-organized filtering of innovative bit-stream configuration is anticipated in [4]*, and Exploration of ternary FIR-filter at diverse oversampling-ratio and acquired the result in MATLAB that indicated the influence on the structure and enactment of stable ternary-FIR filter in terms of stop-band attenuation and also estimate the area performance-tradeoff at diverse oversampling-ratio thru created were stated in [5] and in [6] which revealed the contrast of sigma-delta modulation founded short word length & multi bit techniques. In this paper we considered the sigma-delta modulation-based ternary bandpass-like digital filter via FFT interpolation techniques at diverse oversampling-ratio and compared the result to multi-bit bandpass digital filter in terms of stop band-attenuation.

The remnants of this paper ensues as follow: In section-II, Single-bit Bandpass Filter Design Techniques is discoursed. In section-III, Ternary Bandpass Filter Generation in MATLAB. In section-IV, Simulations and Results and in section-V, Conclusion and Future Recommendation.

2. System Design for Single-bit Ternary Bandpass Digital Filter

Sigma Delta Modulation (ΣΔM) are widely used in in AD and DA conversion levels due to their inherent linearity and accuracy. And it is also clear that SDM encoded of the FIR filter coefficients or single-bit Ternary digital filters have better area-performance compared to their counterpart multi-bit at equivalent spectral performance [1, 2, and 3]. Recently, design techniques of DSP that have been reported in [1, 2, and 9] known as short word length (SWL). Of these techniques, allegedly the first single-bit Ternary FIR filter was proposed in [3]. This pattern consists of two parts, the Ternary filter and an IIR remodulator as shown in diagram 1. Another newer method that starts with the selection of the target response (TR) to generate the single-bit Ternary filter also proposed. Mentioned target response must undergo a stage called interpolation before the SD modulated Ternary form of the filter. The Ternary created form of tapes must have flat pass band response in the pass band of interest (*f1→fo*). The overall design transfer function was derived and the filter then simulated at a different amount of OSR values. And so, found that the appeared single-bit filter produced a target response output equivalent

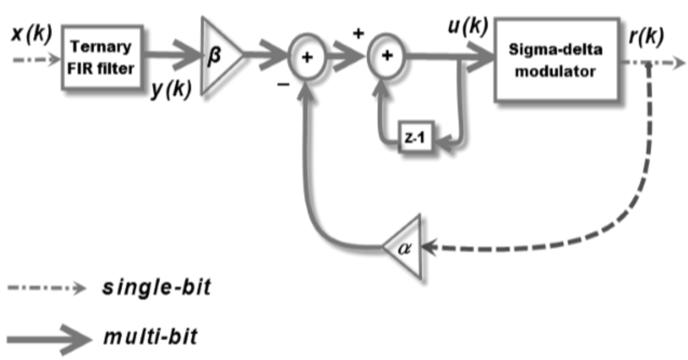

Figure 1: *General diagram of single bit FIR filter [3].*

Adopting the same proposal, a narrowband Bandpass SDM proposed in [8] (Figure-2). Again, it comprises two sections: The Ternary filter followed by the multi-bit to single-bit re-modulation generally SDM. Unlike single-bit lowpass filters, the authors have proposed a simple Bandpass ΣΔ re-modulation having efficient architecture and less sensitivity stability in comparison with the IIR re-modulator. Filter coefficients were encrypted to the Ternary format with the passage of Bandpass target response through an 8^{th} order ΣΔM with optimum coefficients. It was found that the generally frequency response of the proposed method stood very similar to the original target response through MATLAB simulations.

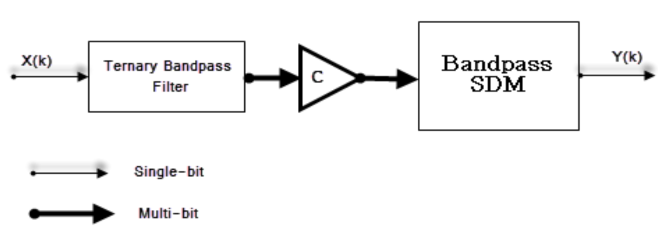

Figure 2: *Single-bit Ternary Bandpass Digital filter [7].*

2.1 Ternary Bandpass filter

The Ternary nature of the coefficients allows a straight forward application of filter. Efficiency can be increased further if the entry in the Ternary filter is in the form of single-bit (+1, 0, -1) used instead of binary is to reduce quantization error because of extra zero state and enables greater accuracy. The configuration of the Ternary filter figure 3 is displayed.

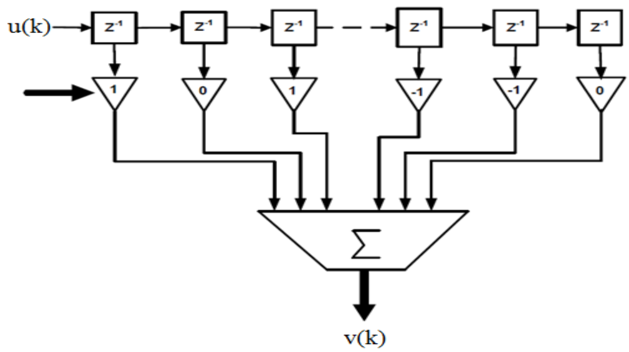

Figure 3: *Block diagram of Ternary FIR filter [3].*

The output of FIR filter *v* (k) can be prominent by the convolution of Ternary stream of taps *hj* and *u* (k) input signal. If the order of the filter is *N* then the output of the filter is given by

$$v(k) = \sum_{i=0}^{N} h_j u_{k-j}, \qquad h_j \in \{1,0,-1\}$$

The Ternary format of taps can be developed by the use of second order of SDM so to obtain Ternary Bandpass response order 2nd sigma delta modulator is used. Bandpass SDM is designed from lowpass sigma delta modulator by simply transforming z^{-1} toz^{-2}. The essential requirements for this sigma delta modulator structure (Figure 4) are the quantizer output to be in a Ternary format and to acquire a flat pass band across the frequency band hunger.

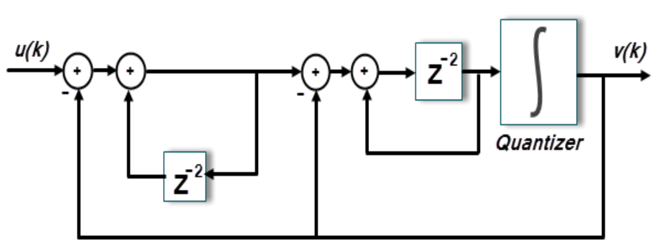

Figure 4: *2nd order Bandpass SDM [7].*

The z-domain transfer functions of the second order SΔM (Figure 4) is:

$$V(Z) = U(Z)Z^{-2} + E(Z)(1 - 2Z^{-2} + Z^{-4})$$

Where $U(Z)$ symbolize signal transfer function or the target response, $E(Z)$ is the noise transfer function. The distinctive filtering term $(1 - 2Z^{-2} + Z^{-4})$ is in control for the noise shaping effect in SDM.

3. Ternary Bandpass Filter Generation in MATLAB

The generation of a TFF in MATLAB initiates by selecting the Target response (TR) Ternary FIR filter's generation (e.g., in MATLAB) occurred. In the following sections I have used a Bandpass filter example, having specifications as follows: Sampling Frequency 8000Hz, lower stop band 0-1200Hz, pass band 1800-2000Hz, upper stop band 2500-4000Hz, pass band Ripple (δp) 0.05dB and Stop band Attenuation (δs) of 50dB. With the help of Remez Exchange Algorithm Target response was generated. The optimum order is found to be 25 of the filters for these given specifications. To meet the requirement of entry oversampling the sigma-delta modulator before encoding into the Ternary shape, the co-efficient should be scaled so work input at its peak under the maximum signal to quantization noise ratio (SQNR)will completely take advantage of the available dynamic range. From different techniques one of the energetic scaling techniques is FFT which has been applied here and also reported in [11]. The taps are encoded after scaling (i.e., oversampling) into Ternary format. Here it is worth noting that the use of a Ternary scheme with better SQNR for the coefficients results in comparison to binary [10].

The Ternary filters (i.e., with Ternary series of tapes) shows the similar impulse response as that of TR (particularly, in the pass band) but with a series of taps proportional to the OSR [12]. Output of the sigma-delta modulator is represented by Ternary coefficients r(k) and was determine adopting:

$$r(k) = \begin{cases} +1 & w(k) > \dfrac{\beta}{4} \\ 0 & -\dfrac{\beta}{4} < w(k) < \dfrac{\beta}{4} \\ -1 & w(k) < -\dfrac{\beta}{4} \end{cases}$$

Where $[-\beta/2 \;\; , \beta/2\,]$ is the sigma delta modulator's dynamic range, according to the filter specification given above used to simulate the Bandpass filter applied in MATLAB the coefficients in ternary format and the input binary stream developed at this stage and described below.

4. Simulations and Results

Ternary FIR filter was designed in MATLAB via FFT-interpolation at three different oversampling ratio (i-e 32,64 & 128). At the first stage Target Response was generated via Remez-Exchange algorithm as shown in fig.5.

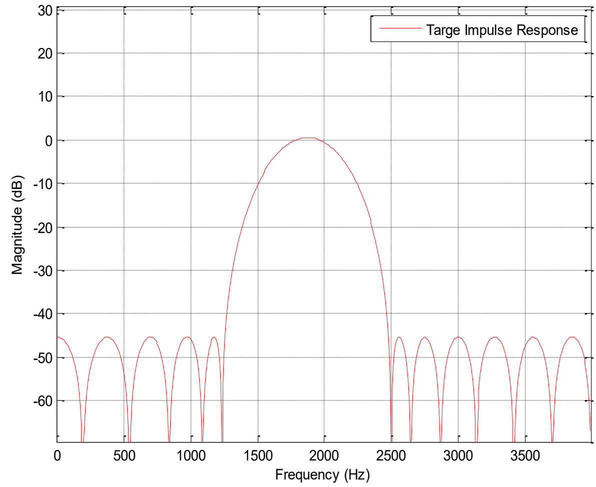

***Figure 5**: Target Response of Bandpass Filter.*

Target coefficients are ready to generate the binary and ternary coefficients. SDM process is now needed to get plausible results, as SDM works on OSR for that reason target coefficients are interpolated. Interpolation identified a set of function values at single data point's target coefficients are interpolated by factor 32, 64 and 128 shown as:

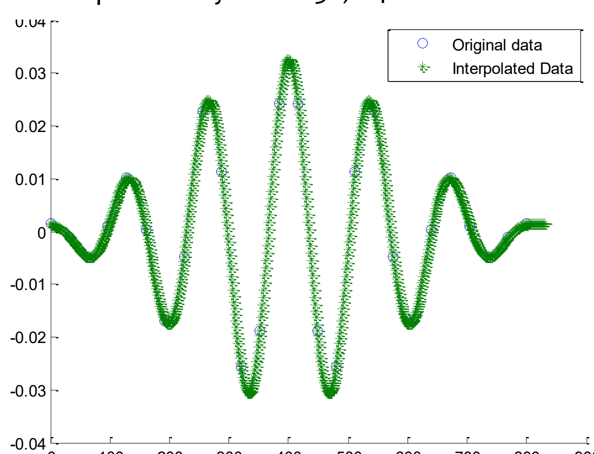

***Figure 6**: Interpolated TR (Target Response).*

After interpolating data is fed to sigma delta modulator to get single-bit output, 8th order of BP sigma delta modulator is used because of its inherent linearity, excellent noise shaping abilities. As described in section 3.3 that as with the lowpass case the Bandpass ∑ΔM is required to have a signal transfer function (STF) that will not unduly distort the Target

Response. And off course, its NTF to evaluate the simulations. Once an NTF is in hand, the designer can immediately begin to evaluate the modulator via simulation. These signal and noise frequency responses of the 8th order BPSDM used to encode the Ternary tapes are individually exposed in figure 4.4 and figure 4.5. The values for the constants are used as [6]:

$a_1 = 2^{-6}, a_2 = -2^{-3}, a_3 = 0.5, a_4 = -1, m_1 = 2^{-6}, m_2 = 0, and\ m_3 = 2^{-9}$...

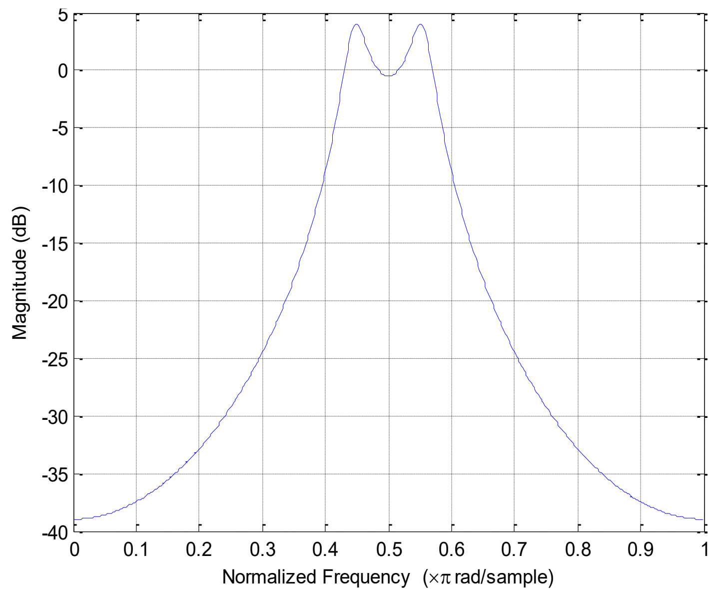

Figure 7: *STF of the 8th order SD Modulator.*

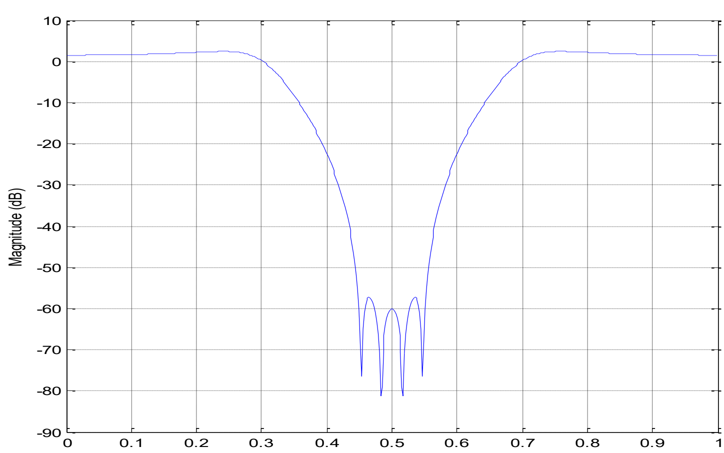

Figure 8: *NTF of the 8th order SD Modulator.*

To verify the NTF of the 8th order BPSDM, a simulation was undertaken in which a low power white noise signal was input to the BPSDM and resultant spectra were obtained the graph in figure 4.6 shown 8192 sample FFT of an average spectrum. The simulated NTF in figure 4.6 has the same shape as the theoretical NTF in figure 4.5.

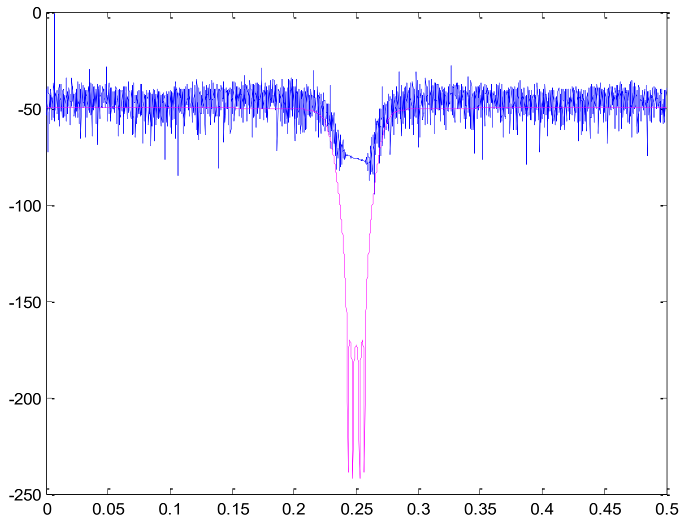

***Figure 9:** Simulated NTF of 8th order BPSDM with Noise.*

At this point the introduced gain by Ternary filter can be removed by multiplying the filter output before remodulation by the inverse gain denoted by C in figure 3.2. This factor reduces the amplitude of the input to the signal with a level which will not overload the chosen SDM used in the re-quantization process [6]. The re-quantization to the single-bit filtering domain of filtered signal requires usage of SD modulator that acquire SQNR greater than the stop band attenuation of the Ternary filter and also have greater bandwidth than the passband of Ternary filter.

The NTF and STF of the BPSDM can be obtained from equation given above as follows:

$$STF_{SDM} = \frac{V(Z)}{U(Z)} = Z^{-2}$$

$$and\ NTF_{SDM} = \frac{V(Z)}{E(Z)} = (1 - 2Z^{-2} + Z^{-4})$$

The NTF of the 2nd order BPSDM is shown in figure 4.7:

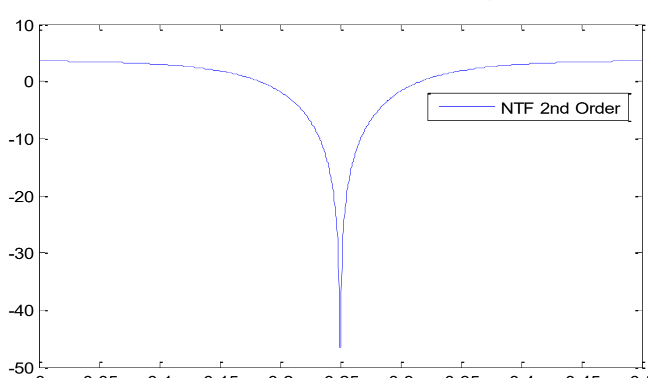

***Figure 10:** NTF for 2nd order BPSDM.*

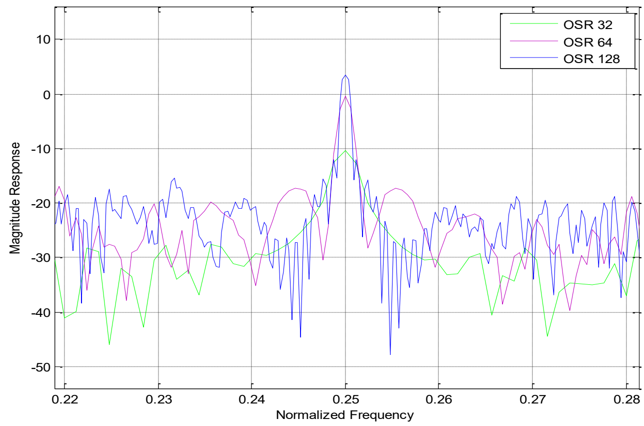

Figure 11: *Ternary Bandpass Responses for OSRs of 32, 64 and 128].*

Stopband Attenuation δs in dB at different OSR				
Filter order	TR	32 OSR	64 OSR	128 OSR
25	45 dB	13 dB	17 dB	16 dB

Table 1: *Stopband attenuation for SBTBPF at different OSR.*

The filtering-frequency response was determined via simulation. This response was-stimulated in MATLAB. This technique was recapped at changing over-sampling ratio and examined stop-band attenuation at 32, 64 and 128 over-sampling ratios with the FFT interpolation methods as discussed above.

4. Conclusion

This filtering system comprises of Ternary FIR filter flowed by sigma delta modulation based IIR filter of order two. The lowpass case was extended to the Bandpass case for the single-bit filter [6]. The structure of the Bandpass case is somewhat simplified, as no IIR filter with embedded ∑ΔM is used, but a simpler Bandpass re-modulating ∑ΔM instead. Results are presented for filter with oversampling ratios of 32, 64 and 128. The routine for creating the Ternary tap value is obtained in this research. These tap values are fashioned through optimization techniques or sigma delta modulation-based practice. Normalized Bandpass target response was produced by Remez exchange algorithm. After that, target response was then interpolated by the factors of 32, 64 and 128 and fed to the sigma delta modulator and concluded the conceivable results.

4.1. Future recommendation

There is still further research is needed on this single-bit filtering structure. The efficiency of implementation and stopband attenuation may be improved in the Bandpass case if an IIR filter structure is utilized

References

[1] P. W. Wong, "Fully sigma-delta modulation encoded FIR filters," IEEE Transactions on Signal Processing, vol. 40, no. 6, pp.1605–1610, 1992.

[2] C. Thompson, "Techniques in Single-Bit Digital Filtering," RMIT University, 2004.

[3] C. Thompson, P. O'Shea, Z. M. Hussain, and B. R. Steele, "Efficient Single-Bit Ternary Digital Filtering Using Sigma-Delta Modulator," IEEE Letters on Signal Processing, vol. 11, pp. 164-166, February 2004.

[4] Tayab D Memon, Paul Beckett, Amin Z Sadik, "Area-Performance-Power characteristics of FPGA-based sigma delta FIR filters", *Journal of Signal Processing Systems*, Vol. 70, 3- 275-288, 2013.

[5] Memon, T. D. & Beckett, P. 2013, "The impact of alternative encoding techniques on field programmable gate array implementation of sigma-delta modulated ternary finite impulse response filters", *Australian Journal of Electrical & Electronics Engineering*, Vol. 10, No. 1, pp: 107-116, 2013.

[6] Tayab D Memon, Paul Beckett, Amin Z.Sadik, " Sigma-Delta Modulation Based Digital Filter Design techniques in FPGA", International Scholarly Research Network ISRN Electronics Volume 2012, Article ID 538597, 10 pages doi:10.5402/2012/538597, Received 15 August 2012; Accepted 8 October 2012.

[7] D. Johns and D. Lewis, "IIR filtering on sigma-delta modulated signals," Electronics Letters, vol. 27, pp. 307-308, 1991.

[8] C. Thompson, Z. M. Hussain, and P. O'Shea, "A Single-Bit Narrowband Bandpass Digital Filter," *Institute of Engineers Australia (IEAUST) Electronic Journal* pp. 31-40, 2005.

[9] Z. Sadik, Z. M. Hussain, and P. O'Shea, "An adaptive algorithm for Ternary filtering", IEE Electronics Letters, vol. 42, pp. 420 - 420, March 2006.

[10] W. Ng, N. Wong, and T. S. Ng, "Bit-stream adders and multipliers for tri-level sigma delta modulators" IEEE Transactions on Circuits and Systems II: Express Briefs, vol. 54, pp. 1082-1086, 2007.

[11] C. Thompson, Z. M. Hussain, and P. O'Shea, "Performance of a new single-bit Ternary filtering system," in Proc. ATNAC'03, 2003.

[12] T. D. Memon, P. Beckett, and A. Z. Sadik, "Performance-Area Tradeoffs in the Design of Short Word Length FIR Filter," in 5th IEEE ICMENS, pp. 67-7, 2009.

[13] Leonid Yarslavsky. Tel Aviv University Israel' DSP in Experimental Research, "Fast Transform method in DSP theory, Application and efficient algorithms", 2011.

[14] S. S. Abeysekera and C. Charoensak, "Efficient Realization of Sigma- Delta (Sigma-Delta) Kalman Low pass Filter in Hardware Using FPGA," *EURASIP Journal on Applied Signal Processing*, vol. 9, p. 52736, 2006.