PERFORMANCE ANALYSIS OF GAMMATONE FILTER USING STOCHASTIC COMPUTATIONS

[1] Mrs. Pushpalatha Pondreti, [2] Golajapu Jyothsna

[1]Assistant Professor, [2]PG Scholar
Dept. of Electronics and communication Engineering
JNTUK, Andhra Pradesh, India.

Abstract:
The Gammatone filter is the most widely used auditory filter because of it's impulse response is similar to Basilar membrane response. Using stochastic computation, a power and area hungry multiplier used in a digital filter is replaced by a simple logic gate leading to an area efficient hardware. However, a straight forward implementation of the stochastic Gammatone filter has a small value of a filter gain. To improve the performance, gain balancing techniques are used. Gammatone filter was designed using stochastic computations and Gain Balancing Techniques i.e., Globally Gain Balancing Technique and Locally Gain Balancing technique based on L-Infinity norm which leads to huge reduction of area. Filter designed and analyzed using two cascaded fourth order sections achieves an even more area reduction of 21.1% in comparison with a four cascaded second order sections of IIR filter. The design and analysis are performed in Xilinx System Generator.

***Index Terms* - gammatone filter, infinite impulse response (IIR) filter, stochastic computation, globally gain balancing technique, locally gain balancing technique.**

I. INTRODUCTION

In Speech Processing, filtering phase plays a vital role. Among many audio filters Gammatone Filter is most widely used filter because of it's response is very similar to impulse response of Basilar Membrane. Basilar Membrane is nothing but the long string which is not uniform throughout it's length. The Frequency varies at each and every point from base to apex of string. Gammatone Filter can be efficiently designed in analog form but in this IC era there will be a problem of process variations especially CMOS process. So, Gammatone Filter implemented in digital domain. In this paper IIR filter used because it reaches the desired requirements with smallest order compared to Finite Impulse Response (FIR) filter. Implementing Gammatone Filter in IIR form requires adders, multipliers and delay elements among these requirements multipliers are occupying more area and power. In general, stochastic computation [1], [2] designed using digital circuits to represent data as streams of random bits, which leads us to replace area and power hunger multiplier by simple logic gate results in area-efficient hardware. Architectures of IIR filters based on stochastic computation have been presented in [9], [10].

II. GAMMATONE FILTER

A Gammatone filter is the product of a gamma distribution and a sinusoidal tone i.e.,

$$g(t) = at^{n-1}e^{-2\pi bt}\cos(2\pi f_c t + \varphi)(t > 0)$$

Where fc (Hz) represents centre frequency, and φ represents starting phase, n represents order of the filter, b represents bandwidth, a represents constant. This equation can represent the human auditory filter when n and b values are choosen to be 4 and 1.019 times Equivalent rectangular bandwidth (ERB) respectively [3]. The ERB can be approximated [4] as

$$ERB(f_c) = 24.7(4.37 f_c / 1000 + 1)$$

In this paper, a and φ is set to 1 and 0 respectively as in [5].

2.1 CONVERSION TO DIGITAL DOMAIN

Laplace Transform is used to convert gammatone impulse response to frequency domain and then Bilinear Transform is used to convert it in to digital IIR filter with center frequency, fc of 5 kHz and a sampling frequency, fs of 20 kHz.
The resultant transfer function is an eighth-order digital IIR filter as shown below

$$H(Z) = \frac{b_0 + b_1 z^{-1} + b_2 z^{-2} + \ldots + b_8 z^{-8}}{1 + a_1 z^{-1} + a_2 z^{-2} + \ldots + a_8 z^{-8}}$$

Where $b_0, b_1, \ldots, b_8$ and $a_1, a_2, \ldots, a_8$ are filter coefficients.

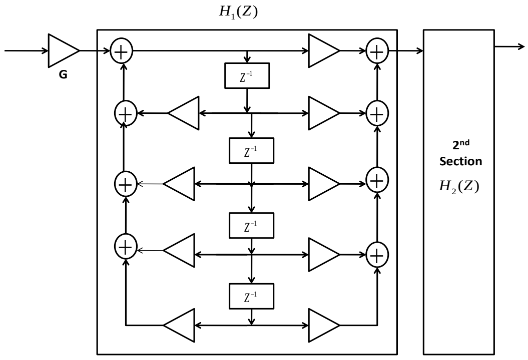


Figure.1. Two cascaded fourth-order Sections of IIR filter

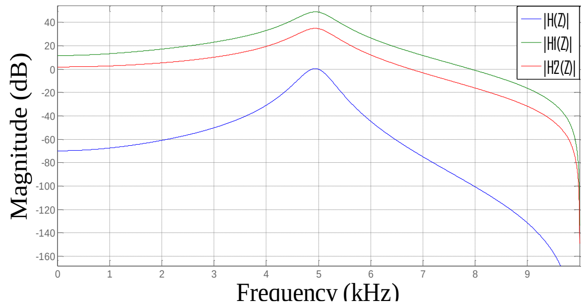


Figure.2. Magnitude response using Bilinear Transform.

2.2 Cascaded fourth order sections

The eighth-order IIR filter is factorized to form two fourth-order sections as given below

$$H(Z)=G\prod_{k=1}^{2}\frac{b_{0k}+b_{1k}z^{-1}+b_{2k}z^{-2}+b_{3k}z^{-3}+b_{4k}z^{-4}}{1+a_{1k}z^{-1}+a_{2k}z^{-2}+a_{3k}z^{-3}+a_{4k}z^{-4}}$$

$$=G\prod_{k=1}^{2}H_k(Z)=G\prod_{k=1}^{2}\frac{N_k(Z)}{D_k(Z)}$$

Where G denotes gain and $N_k(Z)$ denotes feed forward block and $1/D_k(Z)$ denotes feedback block.Fig.1 shows the cascaded fourth order sections of IIR filter. Fig.2 shows the individual section magnitude responses and complete response of the filter.

III. Stochastic computation

In stochastic computation, continuous information is represented by a stream of random bits which are frequency of ones in a two formats i.e., unipolar coding and bipolar coding format. Unipolar coding format can represent only positive values where as bipolar coding format can represent both positive and negative values. The probability of occurring '1' to be P_a for a sequence of bits a (t) i.e., a=P_a, ($0 \le a \le 1$) in unipolar coding and is a = (2 *P_a -1), ($-1 \le a \le 1$) in bipolar coding. A multiplier is simply designed using a simple logic gate [6], as a two-input AND gate in unipolar coding or a two-input XNOR gate in bipolar coding shown in Fig. 3(a) and (b). In bipolar coding as shown in Fig. 3(b), the output of XNOR produces

$$(1-P_a)*(1-P_b) + (P_a*P_b) = ((1-a)*(1-b) + (a+1)*(b+1))/4= (a*b+1)/2 = (c+1)/2 = P_c$$

Fig. 3(c) shows a two-input multiplexor which acts as a scaled adder. The output probability, P_c, is P_s *(P_a+ P_b), where P_s is a probability of a selector input which is based on multiplexor equation.

3.1 Normalization of coefficients

The gammatone filter is designed using the IIR filter by cascading two fourth-order sections as shown in Fig. 1.
In this paper Bipolar coding format is considered. In the filter, the absolute values of filter coefficients $b_{0k}, b_{1k}, b_{2k}, b_{3k}, b_{4k}$ are greater than '1' but Bipolar coding format can represent value from −1 to 1 [7].The values greater than '1' are to be normalized as

$$n_k=\frac{1}{m_k}$$

$$m_k \ge \max(|b_{0k}|,|b_{1k}|,|b_{2k}|,|b_{3k}|,|b_{4k}|)$$

Where $m_k=\{2^l \mid l=0,1,2...\}$
After performing normalization the transfer function is derived as

$$H_k(Z)=\frac{n_k(b_{0k}+b_{1k}z^{-1}+b_{2k}z^{-2}+b_{3k}z^{-3}+b_{4k}z^{-4})}{1+a_{1k}z^{-1}+a_{2k}z^{-2}+a_{3k}z^{-3}+a_{4k}z^{-4}}\cdot\frac{1}{n_k}$$

IV. Gain Balancing Technique

In straight forward implementation i.e., conversion of gammatone filter to digital domain then cascading and applying normalization yields a gain value of 6.795×10^{-5} which is very small value. The value of the gain is very small to represent in 10-bit binary number was almost equal to zero. To overcome this problem of accuracy, Gain balancing techniques based on [8] are used. Gain balancing techniques are Globally Gain Balancing (GGB) technique [8] and Locally Gain Balancing Technique [8]. In

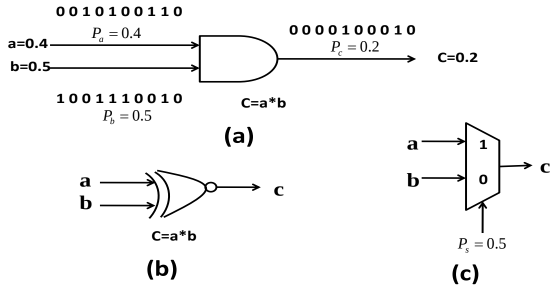


Figure.3. (a) Multiplier in unipolar coding (b) Multiplier in bipolar coding. (c) Scaled adder.

Table -1: Summary of GGB and LGB gain values and normalization values for each section

k	n_k	G_k	g_{0k}	g_{1k}
1	0.125	0.0036	0.042	0.0856
2	0.5	0.0183	0.042	0.4296

GGB technique the multiplication with gain is removed instead gain at each section G_k calculated using L-Infinity norm as shown below

$$G_k = \frac{1}{\max|H_k(e^{j\omega})|}$$

Then the transfer function becomes as

$$H(Z) = \prod_{k=1}^{2} G_k H_k(Z)$$

In the locally gain-balancing (LGB) technique, g_{0k} is first calculated using L-Infinity norm of

$$g_{0k} = \frac{1}{\max|1/D_k(e^{j\omega})|} = \frac{G_k}{g_{1k}}$$

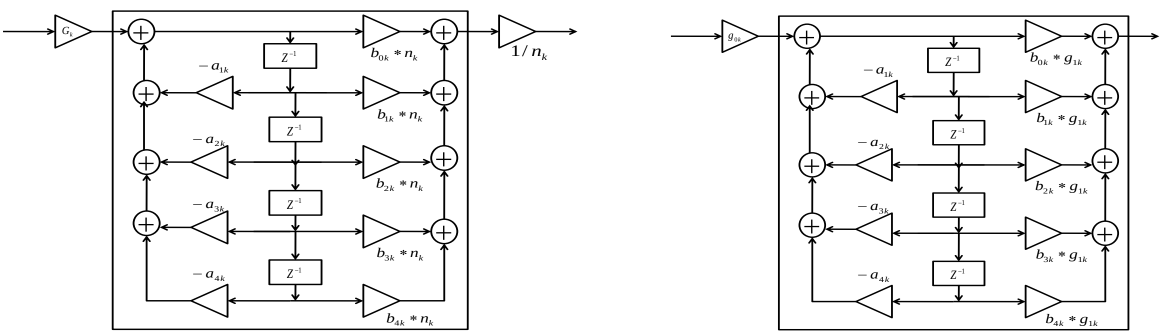
Then, g_{1k} is calculated using the above equation with the obtained values of G_k and g_{0k}. Then the transfer function will be

$$H_k(Z) = g_{0k}\frac{g_{1k}(b_{0k} + b_{1k}z^{-1} + b_{2k}z^{-2} + \ldots + b_{8k}z^{-8})}{1 + a_{1k}z^{-1} + a_{2k}z^{-2} + \ldots + a_{8k}z^{-8}}$$

The circuits based on GGB and LGB are shown in Fig.4 (a) and Fig.4 (b) .Gain values based on GGB and LGB are calculated for individual sections and the values are tabulated in Table-1.It is observed that the gain values based on GGB and LGB are greater than original gain value which leads to representing a value in less number of bits while maintaining the accuracy.

V. Circuit Implementation

In this paper bipolar coding format was chosen and for this coding format, XNOR gate acts as a multiplier. So, multipliers in IIR filter are replaced by XNOR gates and adders are replaced by multiplexor which acts as a scaled adder. This scaling factor can be compensated by using left shifters. Stochastic to Binary converter (S2B) [8] acts as a delay element. Input to the circuit is in binary form but for stochastic computations the stream should be in stochastic form so, Binary to stochastic converter (B2S) [8] is used. After replacing all elements, the circuit becomes as shown in Fig.5 (a). For B2S a digital comparator and a Linear Feedback Shift Register (LFSR) are required as shown in Fig.5 (b). For S2B a 10-bit counter and a D-Flip flop are required as shown in Fig.5 (c). The output from this converter is obtained after 2^{10} clock cycles which is the amount of delay. The complete circuit was designed in by using blocks in the library and also for the blocks S2B and B2S uses black boxes which allows dumping verilog code in to that box. The circuits are implemented in Xilinx System Generator as shown in Fig.6 and Fig.7



(a) (b)

Figure.4. fourth-order sections based on the (a) GGB and (b) LGB.

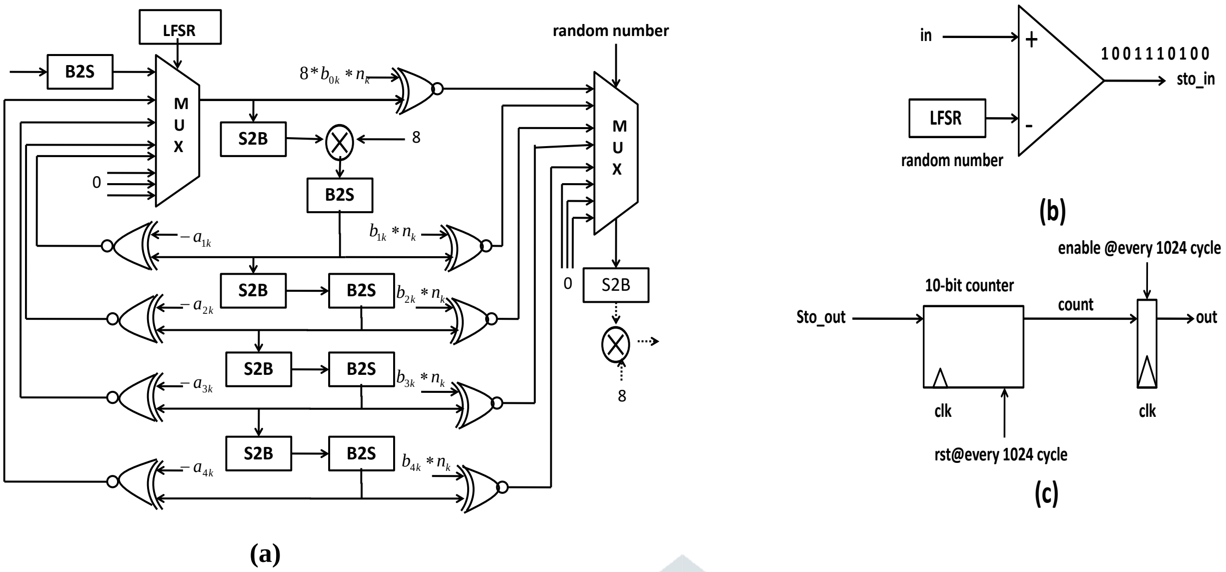


Figure.5. Fourth-order IIR filter based on stochastic computation in bipolar coding. (a) Using normalized coefficients. (b) B2S converter. (c) S2B converter.

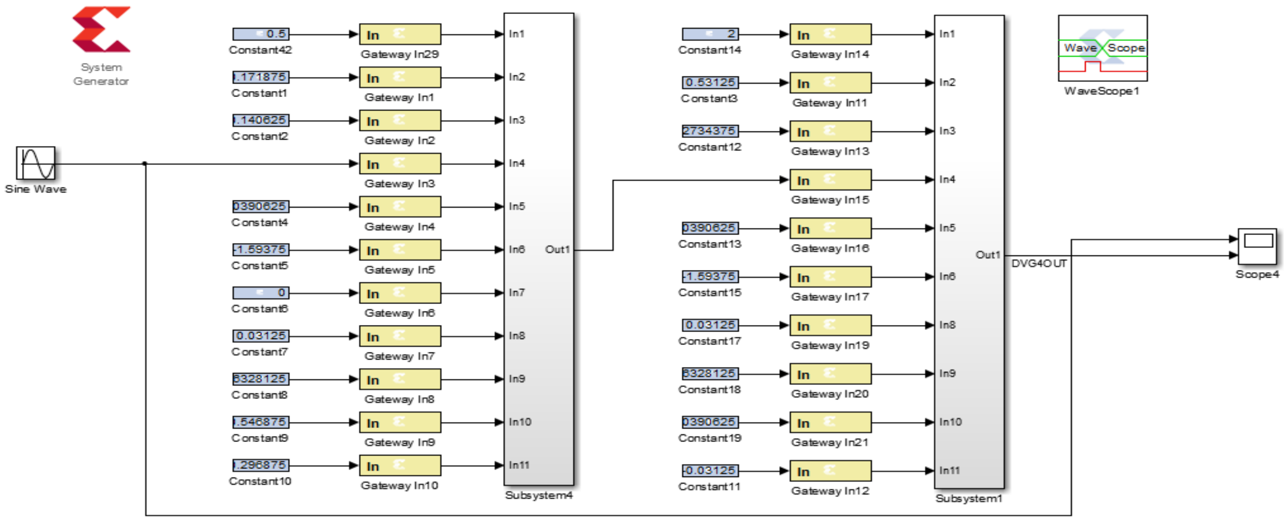


Figure.6. Circuit implemented in Xilinx System Generator

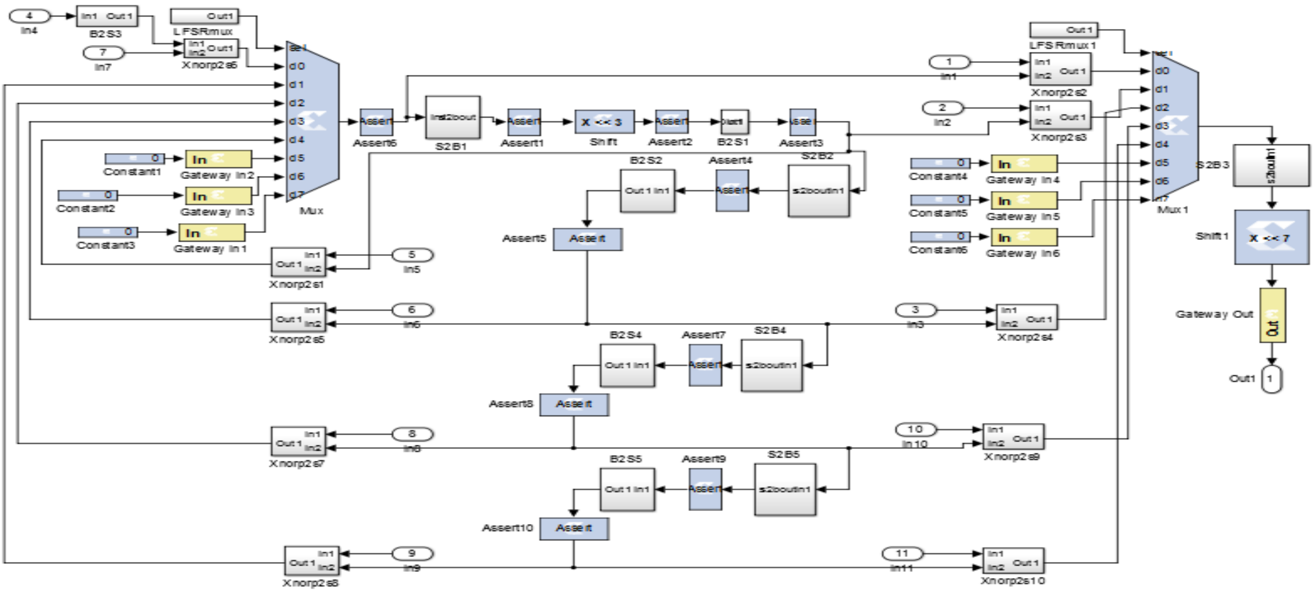


Figure.7. Internal circuit of subsystem.

VI. Results And Discussion

The performance of two cascaded fourth order sections of gammatone filter based on stochastic computation is compared with gammatone filter designed using four cascaded second order sections. Using the design of two cascaded fourth order sections leads to reduction in number of LUTs. Dynamic power, delay are reduced as shown in Table-2. Dynamic Range is defined as the maximum to minimum ratio.Dynamic ranges of gammatone filter based on straight forward implementation, Global Gain Balancing (GGB) Technique and Local Gain balancing (LGB) Technique are summarized in Table-3 for both 2nd order and 4th order sections.

Table -2: Performance comparison

	2nd order sections	**4th order sections**
Area(LUTs)	473	373
Dynamic Power	111.32mW	76.95mW
Delay	9.823ns	9.606ns

Table -3: Summary of Dynamic Ranges

	2nd order sections	**4th order sections**
Straight forward implementation	0.31dB	0.612dB
GGB	1.8dB	1.84dB
LGB	2.14dB	2.922dB

References

[1] B. R. Gaines, “Stochastic computing systems,” Adv. Inf. Syst. Sci.Plenum, vol. 2, no. 2, pp. 37–172, 1969.

[2] B. D. Brown and H. C. Card, “Stochastic neural computation. I. Computational elements,” IEEE Trans. Comput., vol. 50, no. 9,pp. 891–905, Sep. 2001.

[3] R. Patterson and J. Hoddsworth, “A functional model of neural activity patterns and auditory images,” Adv. Speech Hearing Language Process., vol. 3, pp. 547–553, 1996.

[4] B. Grasberg and B. Moore, “Derivation of auditory filter shapes from notched-noise data,” Hearing Res., vol. 47, nos. 1–2, pp. 103–108, 1990

[5] W. Ngamkham, C. Sawigun, S. Hiseni, and W. Serdijn, “Analog complex gammatone filter for cochlear implant channels,” in Proc. IEEE Int.Symp. Circuits Syst. (ISCAS), May 2010, pp. 969–972.

[6] B. D. Brown and H. C. Card, “Stochastic neural computation. I. Computational elements,” IEEE Trans. Comput., vol. 50, no. 9,pp. 891–905, Sep. 2001.

[7] N. Onizawa, S. Koshita, and T. Hanyu, “Scaled IIR filter based on stochastic computation,” in Proc. IEEE 58th Int. Midwest Symp. Circuits Syst. (MWSCAS), Aug. 2015, pp. 297–300.

[8] Naoya Onizawa, Shunsuke Koshita, Shuichi Sakamoto,Masahide Abe, Masayuki Kawamata, and Takahiro Hanyu, “Area/Energy-Efficient Gammatone Filters Based on Stochastic Computation” in IEEE Transactions on Very Large Scale Integration (VLSI) Systems (Volume: 25 , Issue: 10, Oct. 2017)

[9] K. Parhi and Y. Liu, “Architectures for IIR digital filters using stochastic computing,” in 2014 IEEE International Symposium on Circuits and Systems (ISCAS), June 2014, pp. 373–376.

[10] N. Saraf, K. Bazargan, D. Lilja, and M. Riedel, “IIR filters using stochastic arithmetic,” in 2014 Design, Automation and Test in Europe Conference and Exhibition (DATE), March 2014, pp. 1–6.

.