

Word length Optimization for Fir Filter Coefficient in Electrocardiogram Filtering

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Abstract— In very large scale integration (VLSI) implementation of Digital Signal Processing (DSP) applications, digital filter coefficients play an important role. Therefore word length optimization of filter coefficient is desirable to minimize cost and power requirement. In this paper a brief study of effects of Q16.14 and Q8.7 word lengths format on ECG signal is discussed.

Keywords: Data format, coefficient word-length, FIR filter, Electrocardiogram (ECG), FDA tool.

I. INTRODUCTION

In electronic technology, the development of VLSI-DSP application are taking place rapidly. The VLSI implementation of Digital signal processing (DSP) applications demands high speed and low power digital filters. Hence to meet these requirements, the order of the digital filter must be as small as possible and the number of bits required to represent filter coefficients should be minimum. DSP applications are usually implemented in embedded systems with fixed-point arithmetic to minimize cost and power consumption. The fixed point implementation requires the word-length (WL) optimization of functional units to prevent overflow and excessive quantization noise, while minimizing hardware cost and power consumption [8].

In section II, the FIR digital filter is described through convolution sum and same approach is used for filtering of ECG signal. In section III, details ECG signal are described. In section IV, Q16.14 and Q8.7 data format with frequency response is described. In section V, the implementation of various approach provided in [8] are shown. Section VI shows the simulink models of these approaches. Section VII shows stimulation results.

II. DIGITAL FILTER

A digital filter is a system that performs mathematical operations on a sampled, discrete-time signal to reduce or enhance certain aspects of that signal. There are two types of digital filter i.e. Finite Impulse Response (FIR) and Infinite Impulse Response (IIR). In general, an FIR filter is described by the convolution sum given by equation (1).

$$y(m) = \sum_{k=0}^M b_k x(m-k) \quad (1)$$

The response of such a filter to an impulse consists of a finite sequence of $M+1$ sample, where M is the filter order. Hence, the filter is known as a Finite-Duration Impulse Response (FIR) filter. The output $y(m)$ of a FIR filter is a function of the input signal $x(m)$.

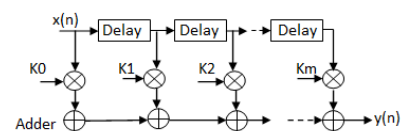


Figure 1: The realization of M-tap FIR filter

The realization of equation (1) for M-tap FIR filter is as shown in the figure 1. FIR filter can be design by various methods such as Least-square, Window, Equiripple, etc. In this paper, the frequency response and filter order for various design methods are calculated using FDATool of matlab and finally it has been decided to use Equiripple FIR filter as it gives minimum order with acceptable frequency response.[7]

The Equiripple FIR design uses the Remez/Parks McLellan algorithm to design a linear phase FIR filter. Remez/Parks McLellan designs have equal ripples in both Passband and stopband as per specifications. For removing noise from a noisy ECG signal, an FIR low Pass Equiripple filter is designed as per the specifications given in Table 1. [6]

Table1: FIR filter specifications

Filter Parameter	Value
Pass band frequency	50Hz
Pass band attenuation	1dB
Stop band attenuation	30dB
Stop band frequency	350Hz
Sampling frequency	800Hz

abbreviations for any actual words but were chosen many years ago for their position in the middle of the alphabet. The electrical activity results in P, QRS, and T waves that are of different sizes and shapes. When viewed from different leads, these waves can show a wide range of abnormalities of both the electrical conduction system and the muscle tissue of the hearts 4 pumping chambers [3].

Table2: ECG signal details

INTERVAL	Time(ms)
R to R interval	0.60 to 1.2 sec
P wave	80
PR interval	120 to 200
PR segment	50 to 120
QRS complex	80 to 120
ST segment	80 to 120
T wave	160
ST segment	320
QT interval	420 in hear rate of 60bpm

The frequency response and coefficients for specification shown in table1 is as shown in figure 2 and figure3 respectively. Here the coefficient are unquantized and are in Double precision floating point format.

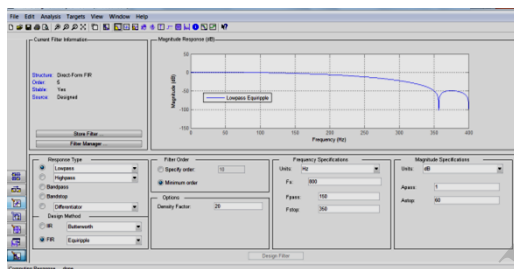


Figure 2: Frequency response for Double precision floating point format.

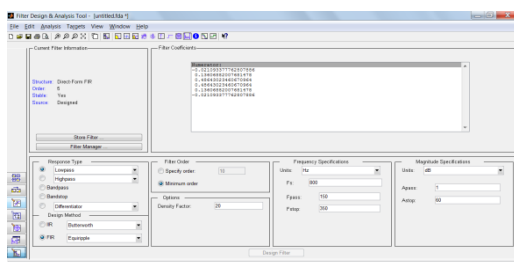


Figure 3: Coefficients for Double precision floating point format.

III. ECG SIGNAL DETAILS

The ECG records the electrical activity that results when the heart muscle cells in the atria and ventricles contract. Atrial contractions show up as the P wave. Ventricular contractions show as a series known as the QRS complex. The third and last common wave in an ECG is the T wave. This is the electrical activity produced when the ventricles are recharging for the next contraction (repolarizing). Interestingly, the letters P, Q, R, S, and T are not

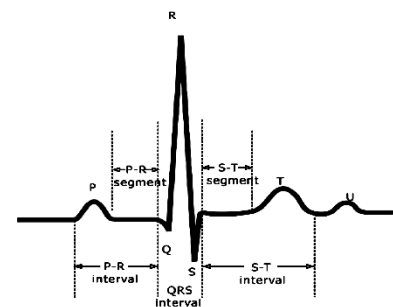


Figure 4: Standard ECG Signal

IV. DATA FORMAT

A. Quantization to Q16.15 format:

Using the FDA Tool, the designed filter is quantized to a Q16.14 fixed point numeric representation format. In Q16.14 format the total wordlength is of 16 bits, out of which the most significant bit (MSB) is used to represent the sign of the number and 14 bits are used to represent fractional wordlength of coefficient. The frequency response for Q16.14 format is as shown in figure 4 and quantized coefficients are shown in figure 5.

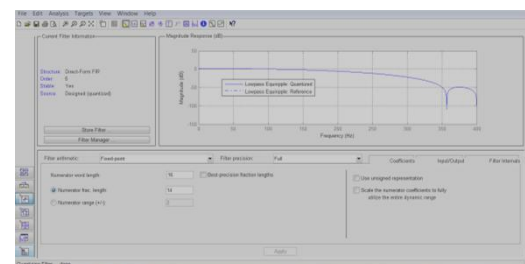


Figure 4: Frequency response for Q16.14 format.

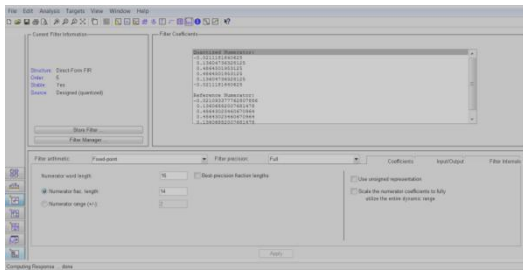


Figure 5: Coefficients for Q16.14 format.

B. Quantization to Q8.7 format:

We can see the effect between the reference frequency response and quantized frequency response in figure 6 and figure 7 show the reference and quantized coefficients with Q8.7 representation format. Here, the total word length is 8 bits and the number of bits available for representing the fractional magnitude is 7 [6][7].

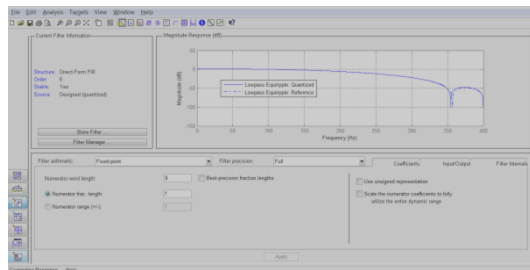


Figure 6: Frequency response for Q8.7 format.

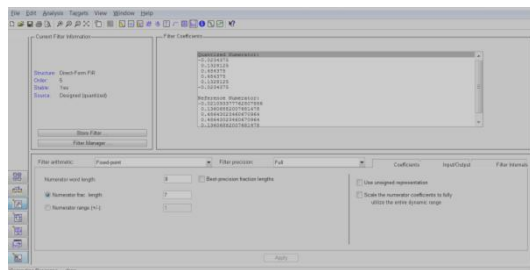


Figure 7: Coefficients for Q8.7 format.

V. IMPLEMENTATION OF ALGORITHM FOR FILTER COEFFICIENT WORDLENGTH OPTIMIZATION

The optimization time can be reduced by reducing the number of variable in an implementation and this can be done by grouping the signal. The signals can be grouped based on two ideas; one is using the signal flow graph analysis and the other is based on the hardware sharing information. The signal grouping based on the graph analysis is used for determining the minimum WL and the grouping based on hardware sharing is used for final WL determination. The signals that are connected by delays or multiplexers are grouped. In addition, the signals connected

by adders are also grouped. On the other hand; multipliers or quantizers break the signal grouping. Since the output WL of multiplication is the sum of two input WLs, quantization is definitely needed in most systems, especially when the output is used for the multiplications. There are a few approaches regarding the WL decrease or quantization of multiplied signals [8].

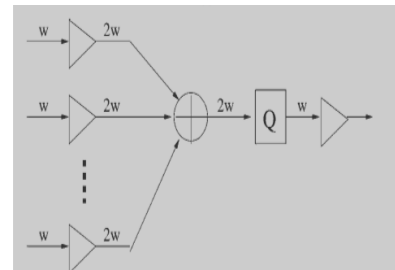


Figure 8: Realization of first approach

The first approach is implemented by conducting quantization before multiplication. The realization of first approach is as shown in figure 8 and algorithm 1 show the implementation.

Algorithm 1(multiplier input quantization)

$u \leftarrow \text{ECG}$ $v \leftarrow \text{coefficients}$ $M \leftarrow \text{length}(u)$ $N \leftarrow \text{length}(v)$ $k \leftarrow m+n-1$ $u \leftarrow \text{zeros}(1, k-m)$ <i>samples</i>	<i>inputs to convolution sum</i> <i>calculating number of samples in 'u' and 'v'</i> <i>convolution loop</i> <i>zero padding to make equal in both 'u' and 'v'</i>
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for $k_1=1:k$ $w(k_1)=0$ } <i>initialization</i> for $j=1:k_1$ $\text{mul} = Q_{m,n}(u) * Q_{m,n}(v)$ } <i>quantization of inputs</i> $\text{new } w(k_1) = \text{previous } w(k_1) + \text{mul}$ end end	
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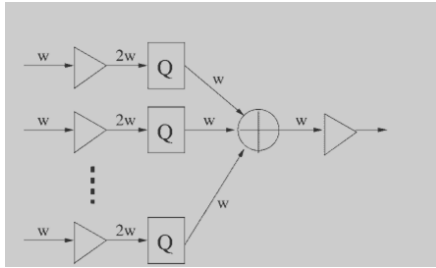


Figure 9: Realization of second approach

The second approach is implemented by conducting quantization after multiplication. The realization of second approach is as shown in figure 9 and algorithm 2 shows the implementation.

Algorithm 2(multiplier output quantization)

```

u ← ECG } inputs to convolution sum
v ← coefficients }

M ← length(u) } calculating number of
N ← length(v) } samples in 'u' and 'v'

k ← m+n-1 } convolution loop

u ← zeros(1,k-m) } zero padding to make equal
v ← zeros(1,k-v) } in both 'u' and 'v'

for k1=1:k
    w(k1)=0 } initialization
for j=1:k1
    a = (u)* (v)
    mul = Qm,n(a) } quantization of
multiplication
    new w(k1) = previous w(k1) + mul
end
end
    
```

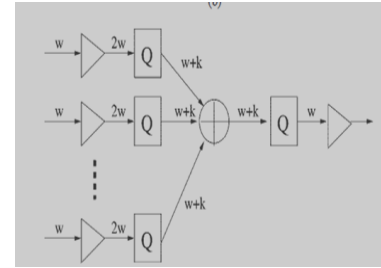


Figure 10: Realization of third approach

The third approach specified in [8] is the combination of two models. The quantizers is used at the multiplier outputs as well as at the output of a final adder as shown in figure 10 and algorithm for the same is given in algorithm 3. This method intends to optimize both adder and multiplier WLs.

Algorithm 3(multiplier input-output quantization)

```

u ← ECG } inputs to convolution sum
v ← coefficients }

M ← length(u) } calculating number of
N ← length(v) } samples in 'u' and 'v'

k ← m+n-1 } convolution loop

u ← zeros(1,k-m) } zero padding to make equal
v ← zeros(1,k-v) } in both 'u' and 'v'

for k1=1:k
    w(k1)=0 } initialization
for j=1:k1
    a = Qm,n(u)*Qm,n(v) } quantization of inputs
    mul = Qm,n(a) } quantization of multiplication
    new w(k1) = previous w(k1) + mul
end
end
    
```

VI. SIMULINK MODEL FOR PROPOSED ALGORITHM

All three algorithm are implement in simulink, the coefficient are quantized by using fixed point converter block as shown in figure 11,12 and 13.

i. Model for algorithm 1:

In first algorithm, as mention the wordlength of coefficient is fixed to $Q_m.n$ format. The ECG signal is applied to model by loading the signal in workspace of matlab. Figure 11 show the simulink model for algorithm 1 in which wordlength of coefficient is quantized at the input of multiplier.

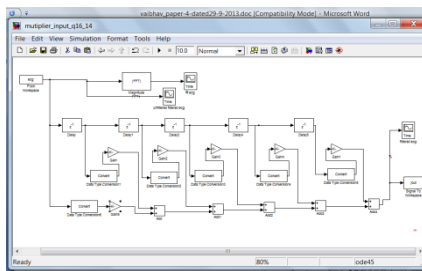


Figure 11: Model for algorithm 1

ii. Model for algorithm 2:

In second model as shown in figure 12, the quantization is done at the output of the multiplication.

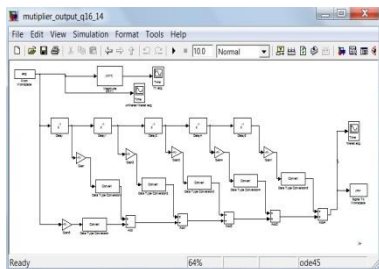


Figure 12: Model for algorithm 2

iii. Model for algorithm 3:

In third model the quantization is provided at input and the output of multiplier as well as the output of adder is also fixed to $Q_m.n$ format

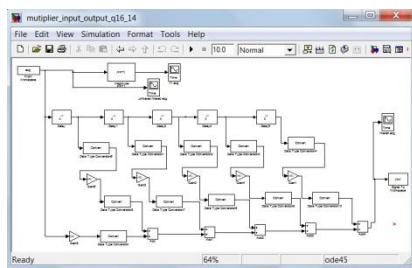


Figure 13: Model for algorithm 3

VII. STIMULATION RESULTS

The models proposed in [8] are with implented with $Q_{16.14}$ and $Q_{8.7}$ data format. The results so obtain after optimization of wordlength are compare with the unoptimized wordlength results.

1) Unoptimized wordlength:

In this,the wordl-length is kept unquantized and result so obtain is as show below.

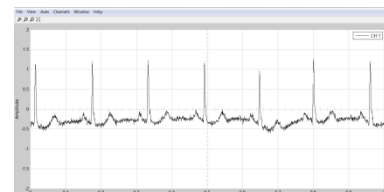


Figure 14: Unfiltered ECG

Figure 14 show the unfiltered ECG signal and figure 15 show the frequency response for unfiltered ECG signal.

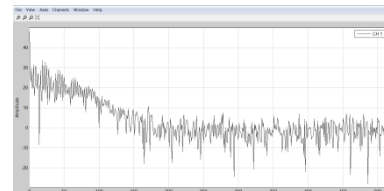


Figure 15: Frequency Response for Unfiltered ECG

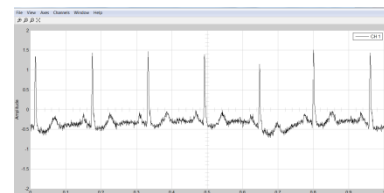


Figure 16: Filtered ECG

Figure 16 show the filtered ECG signal and figure 17 show the frequency response for unfiltered ECG signal.

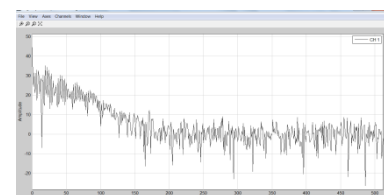


Figure 17: Frequency Response of Filtered ECG

2) Optimized to $Q_{16.14}$ format:

a. For Model 1:

Figure 18(a) show the filtered ECG signal after application of $Q_{16.14}$ format before the multiplication block. The frequency response for unfiltered and filtered ECG signal is as shown in figure18(b) and figure18(c) respectively.

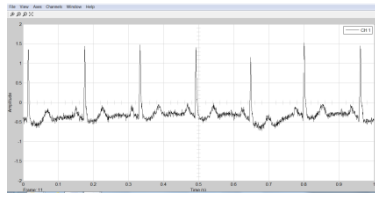


Figure 18(a): ECG after application of algorithm 1

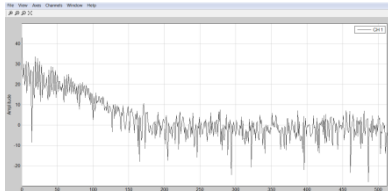


Figure 18(b): Frequency Response for filtered ECG

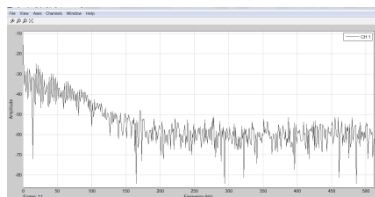


Figure 18(c): Frequency Response for filtered ECG

b. For Model 2:

Figure 19 show the filtered ECG signal after application of Q16.14 format after the multiplication block. The frequency response for filtered ECG signal is as shown in figure19 (b).

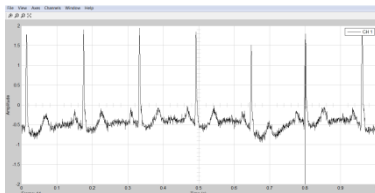


Figure 19(a): ECG after application of algorithm 2

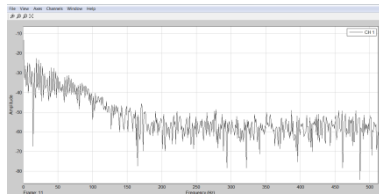


Figure 19(b): Frequency Response for filtered ECG

c. For Model 3:

Figure 20(a) show the filtered ECG signal after application of Q16.14 format before and after the multiplication block. The frequency response for filtered ECG signal is as shown in figure 20(b).

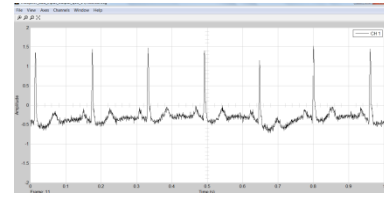


Figure 20(a): ECG after application of algorithm 3

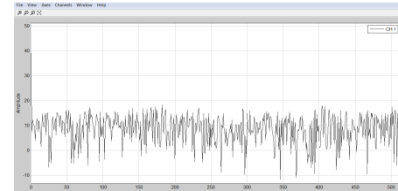


Figure 20(b): Frequency Response for filtered ECG

3) Optimized to Q8.7 format:

a. For Model 1:

Figure 21(a) show the filtered ECG signal after application of Q8.7 format before the multiplication block. The frequency response for filtered ECG signal in Q8.7 format is as shown in figure 20(b).

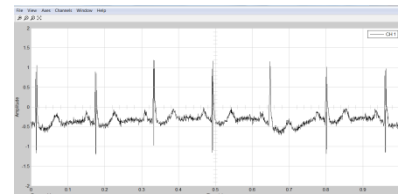


Figure 21(a): ECG after application of algorithm 1

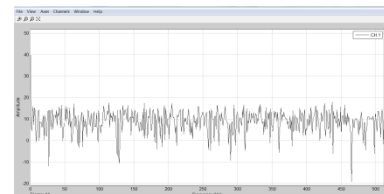


Figure 21(b): Frequency Response for filtered ECG

b. For Model 2:

Figure 22(a) show the filtered ECG signal after application of Q8.7 format after the multiplication block. The frequency response for filtered ECG signal in Q8.7 format is as shown in figure 22(b).

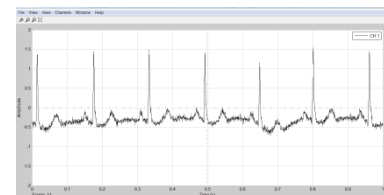


Figure 22(a): ECG after application of algorithm 2

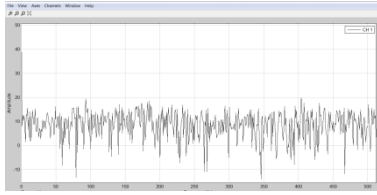


Figure 22(b): Frequency Response for filtered ECG

c. For Model 3:

Figure 23(a) show the filtered ECG signal after application of Q8.7 format before and after the multiplication block. The frequency response for filtered ECG signal in Q8.7 format is as shown in figure 23(b).

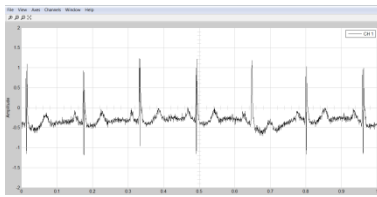


Figure 23(a): ECG after application of algorithm 3

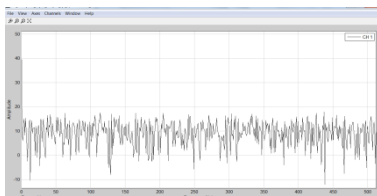


Figure 23(b): Frequency Response for filtered ECG

CONCLUSION:

Digital filter used for different application require different wordlength. This paper discusses the effect of Q16.14 and Q8.7 data format on FIR filter coefficients word-lengths used for ECG signal filtering. In this paper the effect of conducting quantization at different level of

designs are shown. As per the methods proposed in [8] the quantization is conducted at the input and output of multiplications and additions.

From stimulation results we can see that for Q16.14 data format the results are similar to unoptimized coefficient results. Whereas of Q8.7 there are some changes in the amplitude level of ECG signal. The frequency response for the Q8.7 format is somewhat flatten as compare to the frequency response for Q16.14 format. But the response for the Q16.14 format is nearly similar to the unoptimized word-length results

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