Ambient intelligence architecture of MRPM context based 12-tap further desensitized half band FIR filter for EEG signal

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Abstract

The half band filter constructed with cascade structure of FIR filter reduces the insensitivity of frequency response due to coefficient quantization. The coefficient insensitivity can be further reduced by desensitized half band FIR filter. A digital desensitized filter incorporates a first and a second half band filter joined in a cascade between an input and the output of the digital filter. The design for analyzing the electroencephalogram (EEG) signals with the half band finite impulse response (FIR) filter architecture. In this work the 12-tap further desensitized FIR half band employs an efficient modified Russian peasant multiplier (MRPM) with a square root carry select adder (SQRT CSLA) stage has been used to reduce the hardware in multiplier and accumulate (MAC) unit. The proposed filter design is used to analyze the EEG signals with reduced hardware in the health care monitoring for ambient environment. The proposed method offers 38.5% reduction in No. of LUTs, 47.49% reduction in No. of slices, 8.16% reduction in delay (ns) and 29.80% reduction in power (mw).

1 Introduction

Filter is a device that removes the unwanted signals. Filters have two uses, signal separation and signal restoration. In Peng et al. (2017) proposed low frequency reconfigurable filters. It is power efficient filter; the filters are orthogonally programmed for noise analysis. In Abuelmaatti et al. (2017) presented the low frequency filter based on the current feedback operational amplifier (CFOA) for biomedical and bio seismic applications such as ECG, EEG etc.

In Zhoa et al. (2016) described the filter for biomedical applications and it's operated at low frequency. Accurate biomedical signal is achieved by using low pass Bessel filter. Area can be saved by capacitor reuse method. The design achieves higher cutoff frequency range. In Saurabh et al. (2016) designed the tunable band pass filter for biomedical applications. It is mostly suitable for EEG, ECG, EOG equipments. The designed filter is used for an ECG

application with the gain of 63.2 dB in the higher corner frequency. In Xin Dang et al. (2017) described a conceptual categorization and logical movement for children with autism based on motion and EEG features. The algorithm achieves 93.3% for good positive results.

In Deshmukh and Keote (2015) described polyphase FIR filter with bypass multiplier gives reduction in an area and delay as compared to polyphase FIR filter with add multiplier as well as shift multiplier. Polyphase structure comprises of sub blanks which obtains output at different delays. In Subbulakshmi et al. (2014) discussed about the filter bank algorithm for biomedical applications.

Filter bank is used to optimize the algorithm and minimize the delay of the circuit. In Manzo et al. (2014) proposed the optimal scheduling for aircraft departure to reduce the throughput delay. Kumar and Logashanmugam (2004) presented the Booth multiplier in FIR filter using Modified carry save Adder (MCSA) and carry save adder (CSA). The usage of modified booth multiplier in the filter avoids unwanted area consumption; likewise delay can be reduced and power can be consumed by modified carry save adder circuit. In Hande and Ersoy (2017) described the multi-resident context index activity for tracking and recognition

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in smart environments for reducing the complexity using bootstrap filter. In Kumar and Rabi (2014) described the low-complexity multiple constant multiplication (MCM) operation decrease the difficulty of the DSP processor. The novel filter design is suitable high performance and area efficient applications. In Lai and Lin (2014) presented the digital signal sampling rate with up sampler, down sampler along with adder, multiplier and a delay has been modified by multi rate digital signal processing system. In Demosthenous et al. (2010) presented the low pass filter for biomedical application; the designed filter is hardware efficient. The presented scheme helps to detect potential and spikes in the noisy signals. It also offers higher reduction in hardware utilization. In Enokido et al. (2011) described a context based unlimited power utilization-based algorithm to achieve the power utilization for communication-based applications.

The Fig. 1 represents the ambient health care monitoring system using FPGA. The EEG sensor is connected to the FPGA board with the battery backup schemes. Compared to the existing method the proposed method results in reduced number of slices, optimized power and delay with high performances in the analysis of EEG signal. The following sections are organized with the existing Russian peasant multiplier (RPM) in Sect. 2 were discussed. In Sect. 3 is briefed with the proposed method followed by the analysis of the proposed work with existing method in Sect. 4 and concluded with future scope of the work in Sect. 5.

2 Related work

2.1 Russian Peasant multiplier

RPM is one of the finest algorithm for multiplication. It depends on the rule "Multiply-Divide". To multiply and divide the digital data implementation, the left shifter and right shifter are used. The adders, left shifters, right shifters and 2:1 multiplexers are used in RPM. It is the easy method to multiply the two 'n' bit values was described widely in Kumar and Rabi (2016). In this multiplication, it consists of three steps,

Fig. 1 Ambient EEG health care monitoring system

- Partial product generation (PPG)
- Wallace tree reduction (WTR)
- Final addition unit (FAU)

The modified Russian Peasant multiplier structure has been illustrated in Fig. 2. In modified digital Russian Peasant Multiplier (MDRPM) uses only left shifters for providing PPG results. Reduced Wallace tree generation (RWTG) has been developed to reorder PPG result. Combination of 5–2, 3–2, 4–2 compressors and half adders are used in reduced Wallace tree multiplier in the four different stages of partial products reduction step. The addition of two 'n' bit data is carried out by using 16-bit modified SQRTCSLA (MSQRT CSLA).

Carry generation block in the traditional SQRT CSLA takes extra time to compute the process of addition. The SQRT CSLA using reduced CG block have only few number of AND gates and OR gates used to generate the carry output where as in conventional SQRT CSLA, more number of AND gates and OR gates are used. The MSQRTCSLA has been included into DRPM as explained in UthyaKumar and Kamalraj (2017).

3 Proposed method

3.1 MRPM based further desensitized 12-tap half band FIR filter

The digital signal processing is one of the major tasks in an ambient intelligence system for the analysis of EEG signal where the half band filters are the fundamental blocks. Numerical McClellan-Parks program is the only possible program to design the Equiripple (ER) Half-band FIR filters. The half band FIR filter is executed with the three various categories. That is, conventional half band FIR filter, desensitized half band FIR filter and further desensitized FIR filter. The hardware blocks of the further desensitized filter has been reduced by the method of doubling the extracted block of $(1 + {}^{z-1})$ which offers reduced insensitivity to coefficient quantization when compared to conventional half band filter and desensitized half band filter.

In the 12-tap further desensitized half band FIR filter with MDRPM is proposed for EEG signal analysis. The structure of context based 12-tap further desensitized half band FIR filter is shown in Fig. 3. 12-taps FIR filter uses 12 multiplication and accumulation units to get the allowing and blocking frequency path. In Z^{-2} transformation = delay elements, $X[z]$ = input samples, b [1, 2, 3 ...n] = filter coefficients and $Y[z]$ = output sample. The dotted lines in Fig. 3 denote the integration of proposed MRPM MAC unit into further desensitized half band FIR filters.
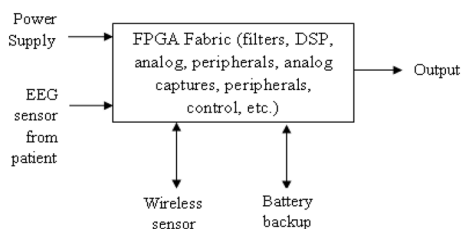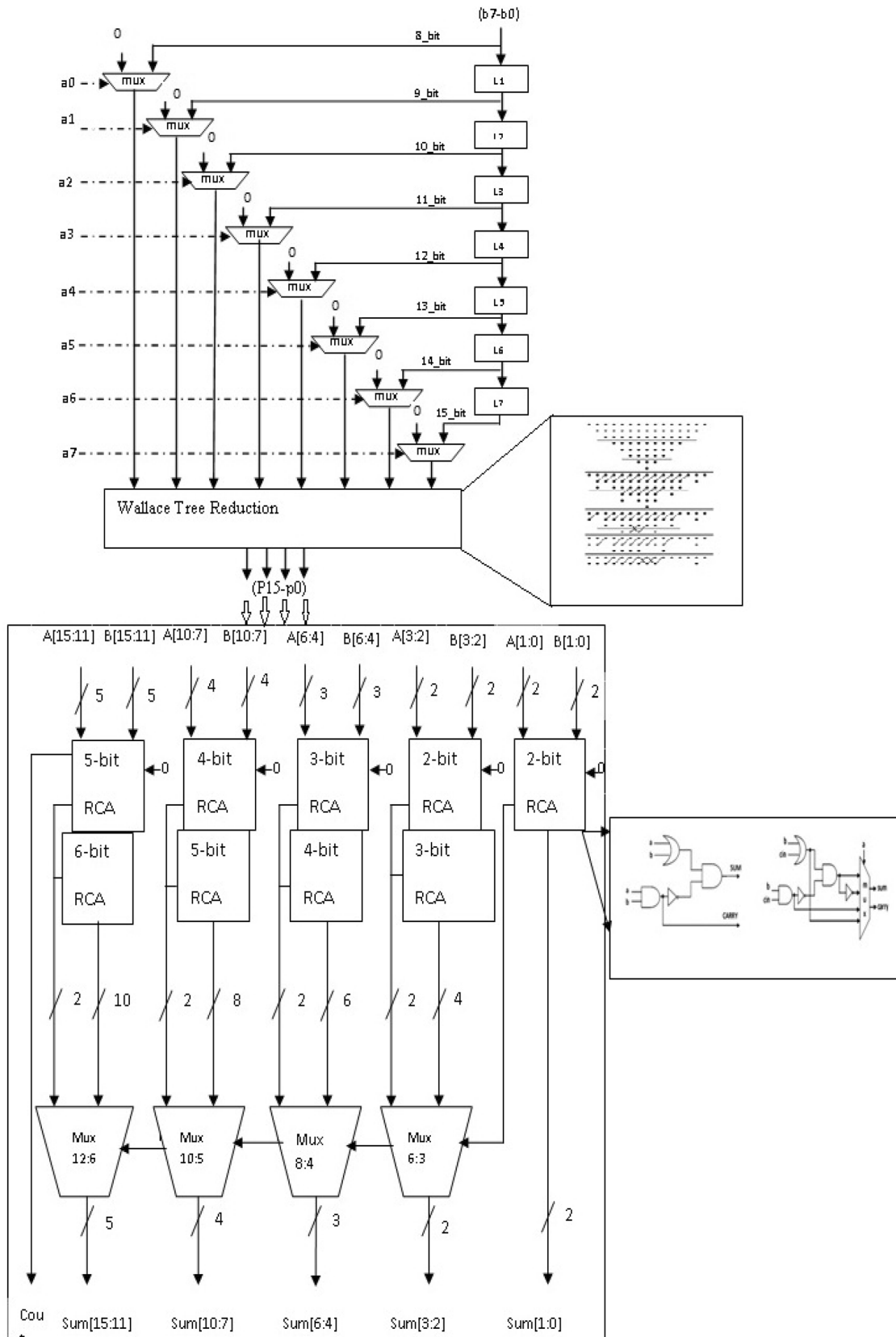
Fig. 2 Modified Russian Peasant multiplier structure for 16 bit

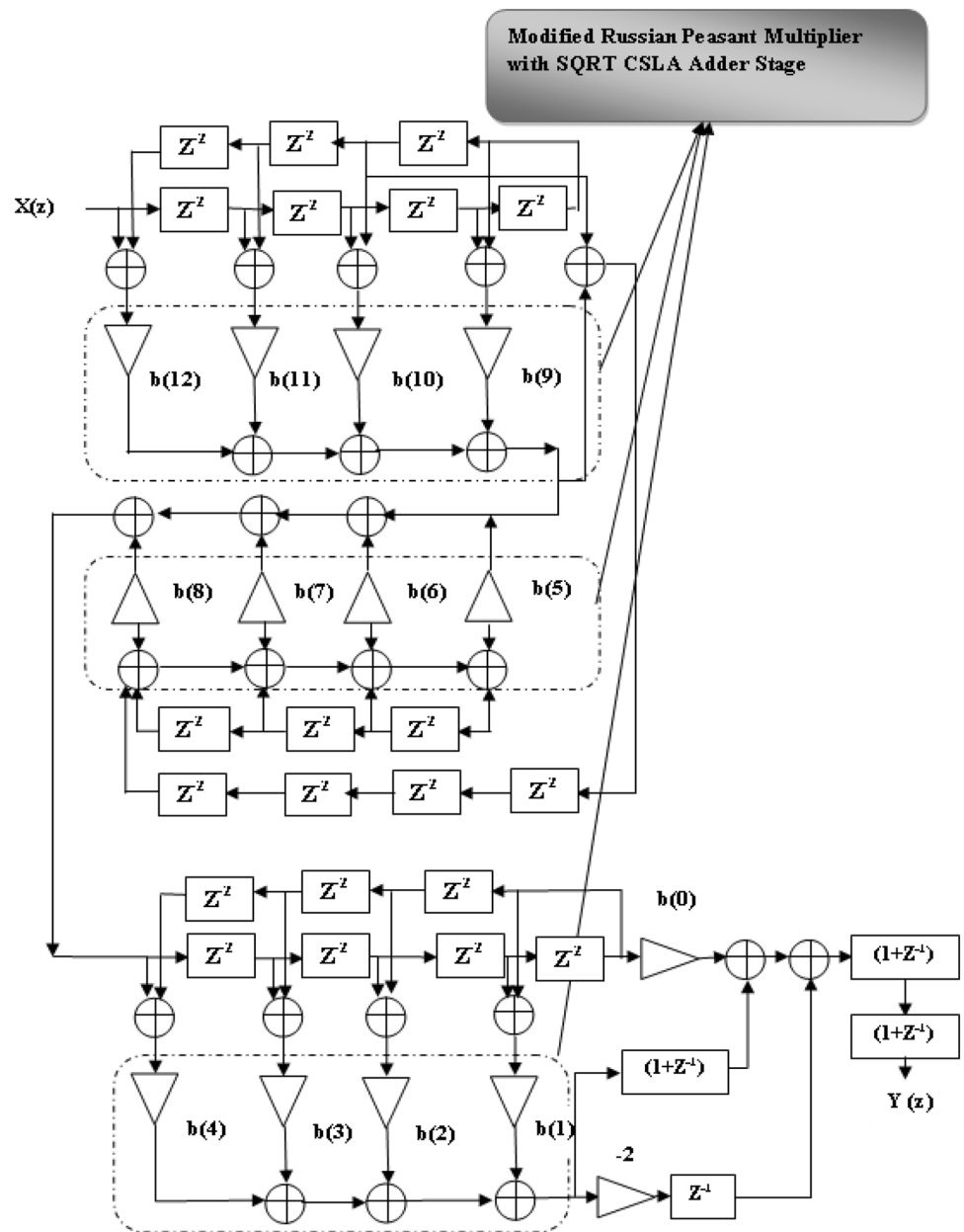**Fig. 3** Proposed architecture of MRPM based 12-tap further desensitized FIR filter

Table 1 shows the comparison of various Half- band filter structures. From the table it is observed that the number of coefficient, adder stages and the registers required to implement the 12 tap further desensitized half band filter is reduced in Mehrnia and Wilson (2015).

Half band FIR Filter with Gaussian noise has been designed for biomedical applications. A filter has two input, one is EEG signal (EEG signal is achieved by changing the characteristic like amplitude and frequency of the sine wave signal). Second input is Gaussian noise signal (manually

Table 1 Comparison analysis of half-band filter structures

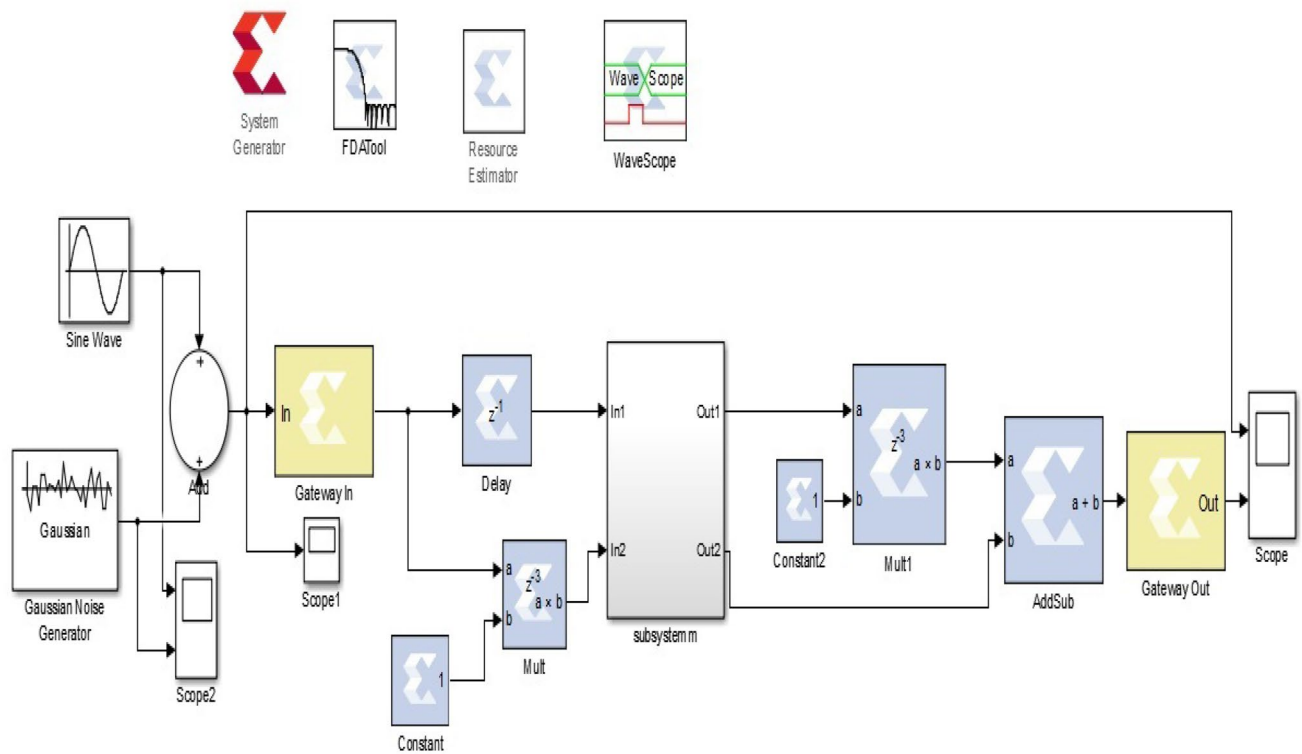| Filter structure order N	Co-efficient	Requirement of the adder stages	Requirement of the registers
Conventional half-band filter	N + 2/4 + 1	N/2 + 3	N
Desensitized half-band filter	N + 2/4	N/2 + 2	N
Further desensitized Half-band filter	N + 2/4	N/2 + 1	N

Fig. 4 Design of 12-tap Half Band Filter for Biomedical Approach

Fig. 5 EEG Signal Input without half band filter using SIMULINK

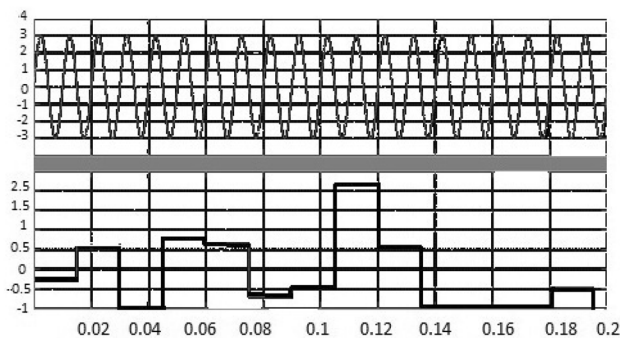**Fig. 6** Waveform of output EEG signal based half band filter using SIMULINK

added signal). Both the signals are combined using the summation system. The combined signal enter into the Xilinx based MAC unit for removing the noise signal. The implementation of the filter was done by using Xilinx system generator. Subsystem of the filter contains 12-tap process for efficient filtering operation. Also, filter design using MATLAB Xilinx system generator as shown in Fig. 4.

Figure 5 shows the EEG sine wave input with Gaussian noise. In this simulation, input (sine wave) is given as 3v so that the output was driven with distorted noise output (square wave) without using filter. The output is viewed by using scope.
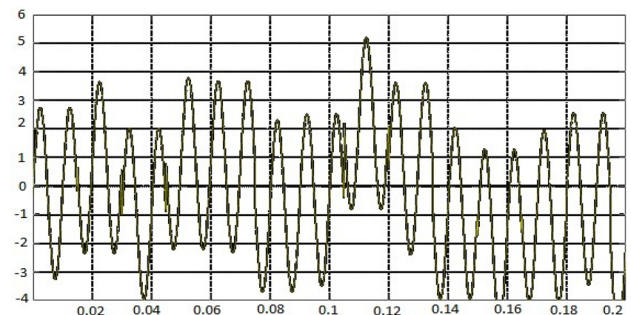
By using half band filter the output signal is shown without distortion illustrated in Fig. 6.

4 Results and discussion

The structure of further desensitized FIR filter with modified Russian peasant multiplier has been designed by using Verilog HDL. The simulation result of the 12-tap further desensitized filter has been simulated by using modelSim XE 6.3C and the design is synthesized using Xilinx ISE 12.4.

The simulation result of proposed MRPM based 12-tap further desensitized half band FIR is shown in Fig. 7. In this figure the multiplier and multiplicand act as input to the first module and the output of the first block is given as the input to reduced Wallace tree multiplier. The output of the multiplier block is given as the input of SQRT CSLA. The output was simulated using Xilinx ISE 12.4.

Table 2 clearly illustrates comparison analysis of further desensitized FIR filter and proposed MRPM based 12-tap further desensitized half band FIR filter. Compared to further desensitized FIR filter, the proposed method offers 38.5% reduction in No. of LUTs, 47.49% reduction in no. of slices, 8.16% reduction in delay (ns) and 29.80% reduction in power (mw).

The chart performances of conventional and proposed context based further desensitized FIR filter is shown in the Fig. 8 and it clearly shows that the performance of the proposed method is found to be very effective.

electroencephalogram (EEG) signals is done with the reduced number of logical elements by using the proposed method. The ambient intelligent architecture for EEG analysis is optimized by the modified Russian Peasant multiplication (MRPM) with the modified square root carry select adder (MSQRT CSLA) and further desensitized half band FIR filter architecture. The MRPM offers reduced area in the MAC unit and the further desensitized half filter is more insensitive to coefficient quantization with reduced number of hardware which offers low area and low power. When compared to 12 tap desensitized half band FIR filter, the proposed 12-tap further desensitized half band FIR filter with MRPM offers 38.5% reduction in No. of LUTs, 47.49% reduction in No. of slices, 8.16% reduction in delay (ns) and 29.80% reduction in power (mw). In future, the proposed architecture can be optimized with parallel and pipeline method and adaptive filter method for biomedical applications.

5 Conclusion

The 12-tap further desensitized half band FIR filter with modified Russian Peasant multiplier (MRPM) has been proposed for EEG application. The analysis of
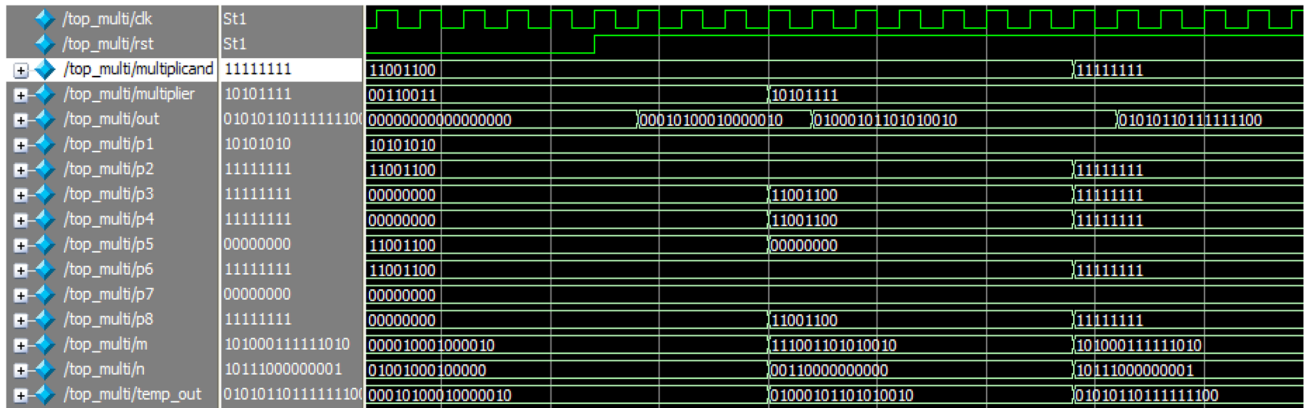

Fig. 7 Simulation Result of MRPM based 12-tap further desensitized half band FIR filter

Table 2 Comparison analysis of further desensitized FIR filter and proposed MRPM based 12-tap further desensitized half band FIR filter

Parameter	No of LUTs	No of occupied slices	Delay (ns)	Power (mW)
Further Desensitized FIR filter	1612	1478	104.62	1.134
Proposed MRPM based 12-tap further desensitized half band FIR filter	991	776	96.081	0.796

(a) No. of LUTS

(b) No. of occupied slices
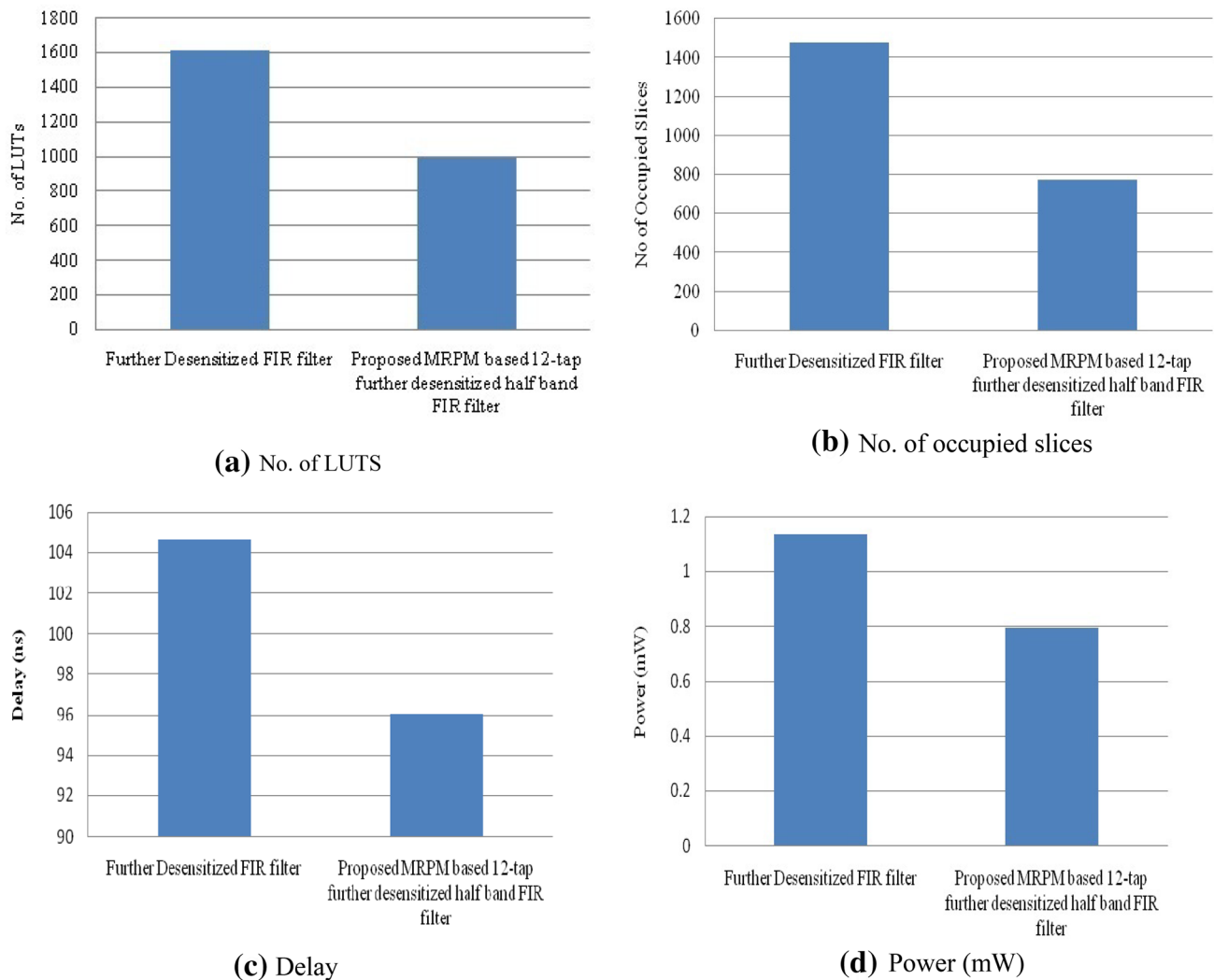
(c) Delay

(d) Power (mW)

Fig. 8 Performance evaluation of conventional and proposed context based further desensitized FIR filter in terms of **a** no. of LUTs, **b** no. of occupied slices, **c** delay (ns) and **d** power (mW)

References

Abuelmaatti MT, Khalifa ZJ, Dhar SK (2017) New CFOA-based low frequency filters for biomedical and seismic applications. In: IEEE regional symposium on micro and nan electronics (RSM), pp 96–99

Alemdar H, Ersoy C (2017) Multi-resident activity tracking and recognition in smart environments. J Ambient Intell Humaniz Comput 8(4):513–529

Demosthenous P, Nicolaou N, Georgiou J (2010) A hardware-efficient low pass filter design for biomedical applications. In: IEEE Conference on Biomedical Circuits and Systems (BioCAS), pp 130–133

Deshmukh RM, Keote R (2015) Design of polyphase FIR filter using bypass feed direct multiplier. In: IEEE international conference on communications and signal processing (ICCSP), pp 1640–1643

Enokido T, Aikebaier A, Takizawa M (2011) an extended power consumption-based algorithm for communication-based applications. J Ambient Intell Humaniz Comput 2(4):263–270

Gunasakaran K, Manikandan M (2014) Area efficient design of reconfigurable FIR filter using Russian Peasant multiplier with modified carry select adder. Int J Innov Res Stud 3(12):138–151

Kumar DJ, Logashanmugam E (2014) Performance analysis of FIR filter using booth multiplier. IEEE international conference on current trends in engineering and technology (ICCTET), pp 414–417

Kumar CU, Rabi BJ (2014) Area efficient FIR filter using graph based algorithm. In: International conference on current trends in engineering and technology (ICCTET), pp 495–498

Kumar CU, Rabi BJ (2016) Design of modified Russian Peasant multiplier using MSQRTCSLA based adder

Lai X, Lin Z (2014) Optimal design of constrained FIR filters without phase response specifications. IEEE Trans Signal Process 62(17):4532–4546

Manzo R, D'Apice C, Nicola CD, Moccia V (2014) Optimal scheduling for aircraft departures. J Ambient Intell Humaniz Comput 5(6):799–807

Mehrnia A, Willson AN (2015) Further desensitized FIR halfband filters. IEEE Trans Circuits Syst I Regul Pap 62(7):1815–1824

Peng SY, Lee Wang TY, Huang HC, Lai MR, Lee CH, Liu LH (2017) A power-efficient reconfigurable OTA-C filter for low-frequency biomedical applications. In: IEEE transactions on circuits and systems I: regular papers, pp 1–13

Saurabh BK, Kumar YN, Patidar S, Vasantha MH (2016) Design and implementation of tunable bandpass filter for biomedical applications. In: IEEE international symposium on nanoelectronic and information systems (NIS), pp 43–46

Subbulakshmi N, Manimegalai R (2014) A survey of filter bank algorithms for biomedical applications. In: IEEE international conference on computer communication and informatics (ICCCI), pp 1–5

UthyaKumar C, Kamalraj S (2017) Comparison of modified Russian Peasant multiplier based 12-TapFIR filter and Multiplierless12-Tap FIR filter. J Eng Appl Sci 12(4):6703–6709

Xin Dang R, Wei G, Li (2017) An efficient movement and mental classification for children with autism based on motion and EEG features. J Ambient Intell Humaniz Comput 8(6):907–912

Zhao T, Liu X, Zhang G, Su Y (2016) Design of a programmable and low-frequency filter for biomedical signal sensing applications. In: International congress on image and signal processing, biomedical engineering and informatics (CISP-BMEI 2016), pp 1746–1750