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ISSN:2147-6799 **www.ijisae.org** **Original Research Paper**

Efficient Design of CMOS Bi-Quad BPF and Performance Evaluation Using MLP Neural Network for Bio-Medical Applications

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Abstract*:* Development of chip design includes analog, digital and mixed signal IC design and filters are the main part of it. In this article, performance measure of Gm-C based structure of a CMOS biquad filter for suitable wireless applications using ANN was examined. This paper proposes the CMOS based biquad analog bandpass continuous time filter with low power consumption. This proficient analog filter is designed using cadence with 90nm technology. The achieved gain of the proposed biquad filter is4.73 dB for310Hz to 2.7KHz by the projected structure and the planned filter topology ultimately suppresses the noise with 1.2uV/Sqrt(Hz). It also achieves IIP3(Third order input intercept point) of 3.4dB at1.8v.The proposed Gm-C based structure produces enhanced linearity and gain and the established design is validated by comparison its results using Multilayer perceptron neural network with Back propagation algorithm. It is inferred that MLP also produces comparable results with that of cadence simulation

Keywords: Biquad Analog filter ,Third order input intercepts point (TIIP3), Multi layer perceptron, output noise and Gm-C structure.

1. Introduction

Analog filters play an important role in wireless communication. The CMOS based filter designs are appropriate for low voltage wireless applications.The different competentconstraints such as power consumption, gain(usingGm-C and source follower based designs),output noise and THD andthird order inputintercept point (IIP3)[1],[2]. The switched capacitor based filters do not supports the lower frequency wireless applications. Filter with specific bandwidth from a few frequency to high frequencies are more suitable for signal conditioning [3],[4]&[5].The inductor based approach for filter design is also not proficientbecause of fabrication issues (bulkier)while designing in circuit level for certain middle orderexpected frequencyapplications. The transconductance –Capacitor filter design methods are most preferable for Bandpass frequency applications and the cut-off frequency is decided by the factor of gm/C[6],[7].The filter circuit process the less amplitude signals are essential to exhibit adequate input referred noise (INR) and distortion to elude input degradation [8].By the use of op-amp based approach contributes the high linearity and improved gain [9].

The probable frequency band is attainedthrough fine-tuning the C [10], [11] and Gm. The high frequencytuning for multiband applications designs are implemented in [12],[13].Anyhow the conditions of biasing is to be adjusted to tune the frequency with high linearity and gain for subthreshold based source followerdesigns[14],[15],[16]. In this paper design of 4th order biquad filter and its performance analysis are discussed using multilayer layer perceptron neural network. The rest of the paper iscategorized as follows. Section 2 gives details of related work and section 3 describe the basic filter topology. The proposed filter design is discussed in section 4, 5 depicts about MLP architectureand section6illustratesresults and discussion with conclusion in section 7.

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2. Related Work

Source follower with Feedback will help to achieve good gain and distortion reduction because of isolation. The improved sallenkeybiquad filter is implemented using the source follower gives the 29.3MHz bandwidth while utilizing a SallenKeyfilter is designedwith the help ofbetter source follower and two capacitors which gives 29.3 MHz of bandwidth and the power of 2.3mW[1].The 2nd order tunable Butterworth LPF is realizedbased on the subthreshold source follower [2] achieves 4-100Hz for bio-signal applications. Thefilter is designed in 180nm technology and consumes 25.9nW with the gain of-3.25dB.The keybases of noise are studied and several capacitor values were used to tune the frequency. The conventional source follower and flipped source follower method based filters were related with wideband subthreshold source follower and designed in [5].The constructionof the filter is based on the common gate(CG) active feedback loop, input cross coupling to increase gain of the filter with tunable frequency of 50 to 450MHz, 15 dB noisefigure and IIIP3 is 12dB.The switched capacitor type network gives a simplified filter circuit model is implemented and accurate transfer function with low noise is obtained. The second order Butterworth biquad filter is designed for giving better performance for RF receivers[6].The fourth order op-amp based programmable active biquad filter is implemented to achieve high gain without common mode feedback amplifier minimises the current and easier to implement. To improve the linearity, a source follower using NMOS transistors generates the common mode output while consumes 19mW supplied by

1.8v [9].A low power high efficient filter is implemented to obtain higher shift frequency. It consumes less power and compact filter fabricated 130nm technology. The obtainedresults of the filter utilizes 0.5mA with 0.7v supply voltage. It is centred at 1.65 MHz with 0.9-MHz with the voltage gain of 8.1dB [7]. The inductor less biquad design with cross coupled NMOS transistor design are appropriate for higher frequency band-pass multi-band or multi-mode SDR applications [10].This filteroperatesin 1.2v with Q factor of 2 to 8.The simulatedoutcomes indicates the frequency of 2 to 5GHz and power is 4.8mW.

3. Filter Basic Topology

The MOS transistor which suitablybiasedin a weak inversion saturation and a differential Gm cell is associatedwith a negative feedback manner as shown in Fig.1is prepared by small signal operation of the MOS transistor[3]. I_b is used to bias the Gm with zero V_{bs} and disregarding channel length modulation is with subthreshold factor (n) and thermal voltage UT.

$$Gm=\frac{Ib}{nUT}$$

(1)

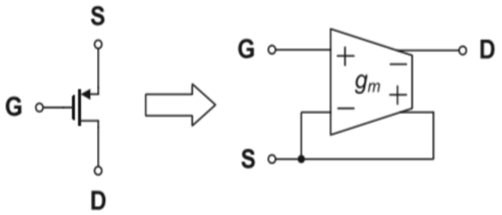


Fig 1.Macro model of single MOS transistor[3]

Fig 2.gives the possible realization of single branchGm-C based filter design. The low pass and high pass responseisobtainedfrom the circuit shown inFig.2.The MOS transistors M1 & M2 are shares the bias current I_b and cascaded to form a design between source and ground potential.

The macro model of M1 and M2 MOS transistor in Fig.1 helps to analyse the filter design directly by the equation$H_{lp}(s)=\frac{Vlp(s)}{Vin(s)}=\frac{1}{1+s(C1Gm1)}$(2)

The capacitor c2 is not involved in the above equation .2

$$H_{hp}(s)=\frac{Vhp(s)}{Vin(s)}=\frac{-s(\frac{c_1}{Gm_2})}{(1+s(\frac{c_1}{Gm_1})} \quad (3)$$

The c2 is added to the Hp node and the transfer function will be

$$H_{Bp}(S)=\frac{VBp(s)}{Vin(s)}=\frac{-sc1/Gm2}{1+s(\frac{c_1}{Gm_1})(1+s(\frac{c_2}{Gm_2}))} \quad (4)$$

The V_{dd} is considered for appropriate bias in weak inversion saturation and V_{CM} is measured. In Fig.2 making V_{ss}=0, $V_{dd}=V_{inpp}+V_{sg}+2V_{sdsat}$ It can be framed as

$$V_{dd}=V_{inpp}+U_T(\ 8+n \ln Ib/\ ID0)(5)$$

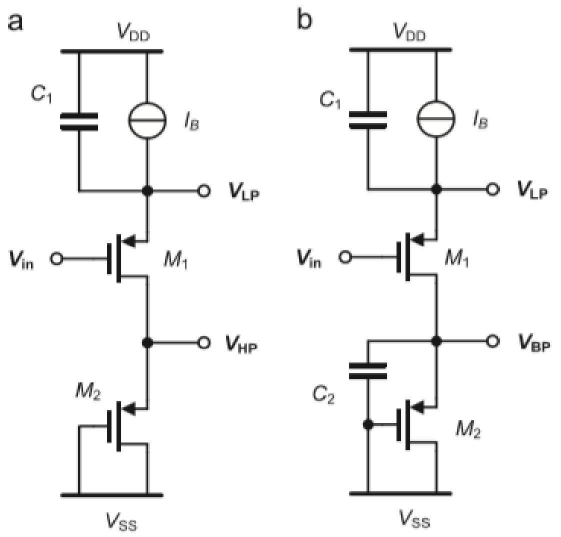


Fig2.a) Single branch filter [3] b) Low pass and Band pass filter.[3]

The zero bias current ID0 and the applied voltage is included.This can be obtained byV_{dd}equationthat there are a fixed term of $8U_T$=200 mV which helps to relate the cut-off frequency of the filter and $V_{cm}=V_{ss}+V_{sg2}$.The V_{cm}gives the new value for V_{dd} to be minimum of $2V_{sg}+V_{sdsat}$

$$V_{dd}=V_{inpp}+U_T(2+n \ln (I_b/ID0))(6)$$

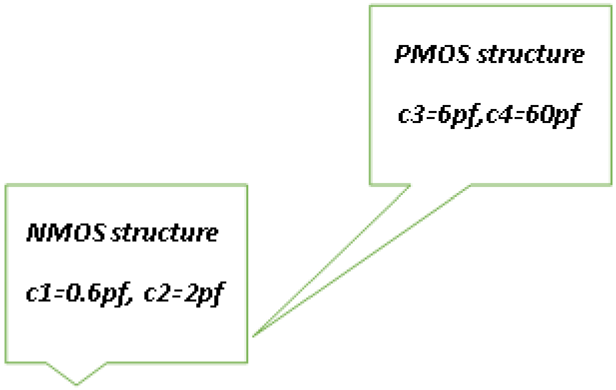
The Cut off frequency (ω) and Quality factor (Q) is

$$\omega=Gm\frac{c1}{c2},$$

$$Q=\sqrt{c1/c2}$$

4. Proposed Fourth Order Biquad Filter

The Fig3 shows the proposed biquadfourth order bandpass filter with NMOS and PMOS based structure. The current consumption and bias voltage requirements is obtained based on the transfer function equation 3 as per the filter order .The bias point in weak inversion region saturation ,V_{dd} and V_{cm} is to be considered to accomplish bandpass filter response from the structure.



This makes the low power based design,I_b in the range of 6nA-11nA is used to achieve the frequency range of 217Hz to 4.5KHz.The 90nm technology is used to design the fourth order biquad filter with M1 and M2 transistors arranged to achieve symmetry. The Gm-C based structure utilizes the V_{dd} as 1.8 v and bias voltage is supplied as0.6v.The cascadeGm-C structure increases the required V_{dd} to avoid the body effect and the output is take between the NMOS and PMOS structure.

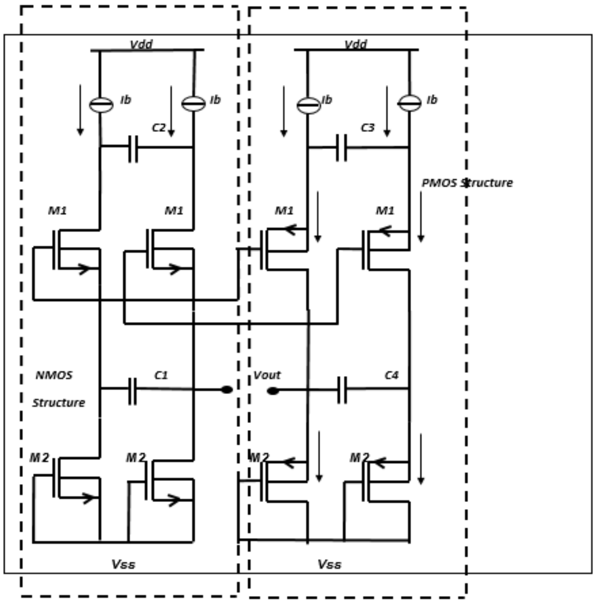


Fig 3.Proposed biquad bandpass filter with NMOS and PMOS structure

5. MLP Architecture

Neural network is one of the categories of deep learning technology used for classification, prediction and regression purposes. It also comes under the category of artificial intelligence and it has mainly 3 layers such as input, hidden and output layer[18]. The principle behind the neural network is, if we apply the inputs and output label is given, with the help of random weights it will train and produces the output.This process continues till the difference between target (label) and output is less. Here MLP neural network[17] is utilized to validate the performance of the designed filter. Figure shows the general architecture of a neural network with 3 hidden layers with input and output layer. No. of neurons in the input is decided by the no. of features extracted from the input and no. of hidden neurons are decided by the user. According to the no. of outputs required in the output, neurons are used at the output layer. Figure 4 shows the general architecture of a MLP ANN which is also a kind of supervised neural network.

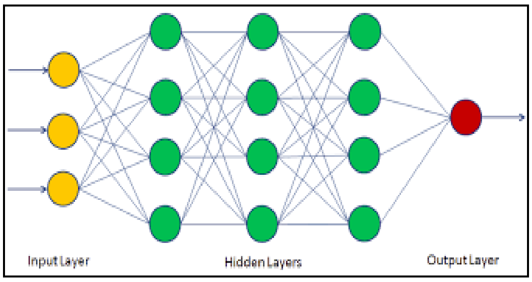


Fig.4 MLP ANN architecture

In this proposed work, 2 input neurons corresponding to base current and frequency as input features are used. Then 3 hidden layers with no. of neurons 10,18 and 10 is selected randomly with one output neuron. In the hidden layer the output of a neuron k is given by,

$$Zk = f(\sum_{j=1}^{N} WjXj) \qquad (7)$$

Number of neurons is denoted by N,Xj is the output of the jth input layer neuron,Wjis the weight to be calculated and f($\sum WjXj$) is a non linearactivation function[19],[20]. In the outputlayer,the output of the neuron s is given by

$$Ys = \sum_{k=1}^{M} WkZk \qquad (8)$$

Where M is the number of neurons in the hidden layer,Z_k is the output of the kth hidden layer and Wk is the weight to be calculated. Then this output is compared with the target value to obtain the performance measure of our proposed network which is taken as minimum mean squared error.

6. Results and Discussions

The proposed filter utilizes 7nA from 1.8vsupply. The simplified design is shown in Fig.3 with required V_{dd} and bias voltage. Thebandpass response of the designed filter is shown in Fig.4.which produces the gain of 4.7dB at 745Hz and the bandwidth of 310Hz to 2.7KHz gives better result than[2] and[3].The capacitors c1=0.6pf, c2=2pf, c3=6pf and c4= 60pf are used to achieve the expected frequencies.

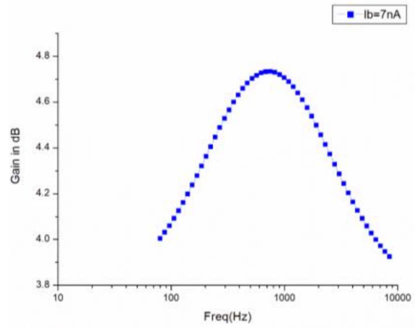


Fig5.Bandpass response with gain of 4.7dB

The Band pass responses for different I_b values is shown in Fig.5.The different results are presented for I_b values from 5nA to 10nA.For different values of I_b,the frequency and bandwidth is tabulated in Table1.The output noise is shown in Fig.6.The noise plot is taken for 10Hz to 10KHz and the design produces the noise is 1.2uV/sqrt(Hz)which gives better result than [1],[14]

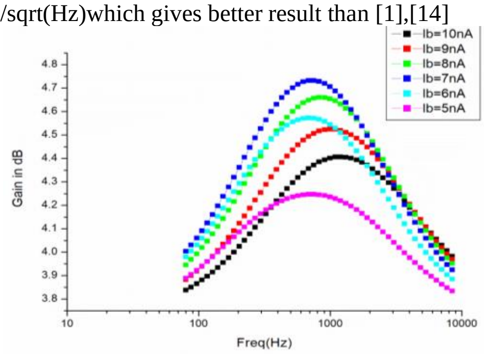


Fig.6a.Bandpass gain for different values of Ib.

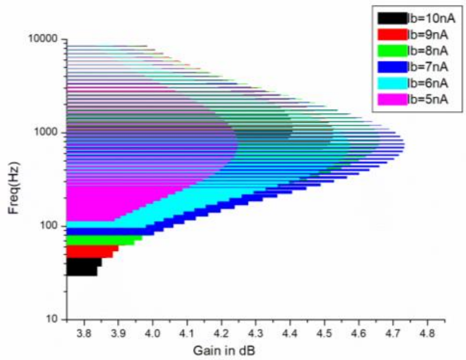


Fig.6b Bandpass gain for different values of Ib

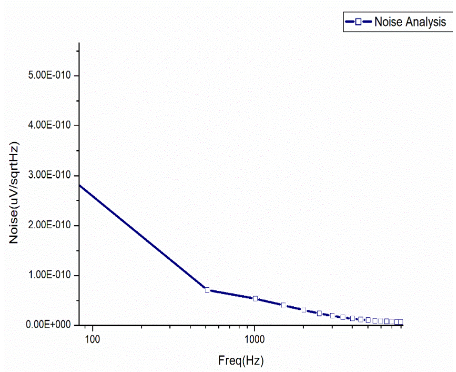


Fig.7 output noise of the proposed biquad filter

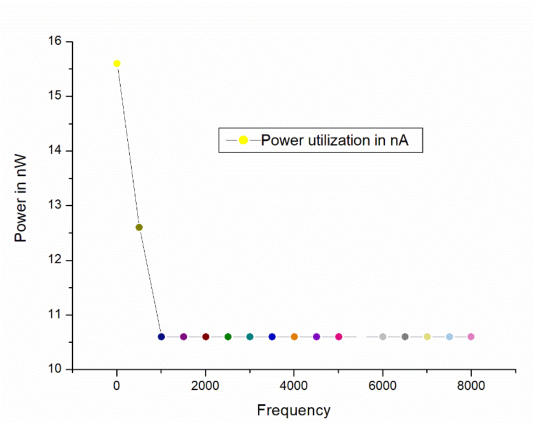


Table for BW and Gain for various Ib is given in table 1.

Table1. The BW and gain vales for different values of I_b

V_{dd}(v)	V_b (v)	I_b(nA)	Bandwidth	Centre Frequency	Gain (dB)
1.8	0.6	10	391Hz-3.7KHz	1.2KHz	4.28
1.8	0.6	9	365Hz-3.16KHz	1.07KHz	4.3
1.8	0.6	8	314Hz-2.41KHz	852Hz	4.56
1.8	0.6	7	310Hz-2.7KHz	745Hz	4.73
1.8	0.6	6	230Hz-2.2KHz	718Hz	4.57
1.8	0.6	5	217Hz-2.1KHz	710Hz	4.24

The bandwidth of the filter is tuned digitally with different values of capacitors. The gain is maintained 4.7dB to 3dB for the frequency ranges from 217Hz to 3.7 KHz. The Power utilized for the filter is 10.5nW comparatively low power with other filter design .The third order input intercept point measured which is positive response as 3.4dB with first order frequency 2K and third order frequency 4K gives the good result for this proposed topology. The reduction of THD is also is possible for this approach.

The different values are taken and compared with other works with this designed fourth order biquad filter gives better performance in bandpass frequencies canbe applicable for suitable wireless applications.ig.8 output noise of the proposed biquad filter

Table 2.Performance Comparison with the existing works

References	**Proposed work**	**[1]**	**[7]**	**[5]**	**[8]**	**[10]**	**[2]**	**[14]**	**[3]**
Technology (nm)	90	45	130	180	350	65	180	350	180
V_{dd}(v)	1.8	1.2	0.7	1.8	0.9	1.2	1.8	3	0.5
Order	4	4	4	2	4	4	2	4	4
Gain(dB)	-1.6	2.3	8.1	0	-0.05	-6.7	-3.25	0	-2.55
IIP3(dB)	3.4	26.8	-9.41	26-31.5	-11.02	-	-	-	-
Bandwidth	320-Hz 3.2KHz	12.8MHz	0.9MHz-1.65MHz	50-450MHz	100Hz	250-2500MHz	100	100	3.2KHz-19.7KHz
noise	1.2uV/sqrt(Hz)	177.35uVrms	-	<15	8uVrms	14.2 V/sqrt(Hz)	8.985 uVrms	29uVrms	90uVrms

Machine learning techniques are playing role in recent days for various fields and neural network is the subset of it. All real time problems can be solved using these techniques with different algorithms and architecture. In this work a simple MLP is considered for and our filter design with MLP producescomparable results with that of simulation tool [21,22]. Total no. Of samples considered are 308 and out of that, No. of samples considered for training is 70%, testing is 10% and validation is 20%. The activation function utilized in our work for hidden layers are Tansig [23]and for output layer it is linear function only. Levenberg-Marquardt algorithm is considered here for training the network. The proposed MLP architecture is shown in figure 9.Two variables taken for training is frequency, base current and gain is considered here as target. Minimum mean squared error(MSE) is considered here as performance measure of the MLP network which is the difference of predicted and output value. Present designed neural network producesbest validation performance at .006839 at epoch 5 which is shown in figure10. Table 3 depicts the predicted and output value of the proposed network.

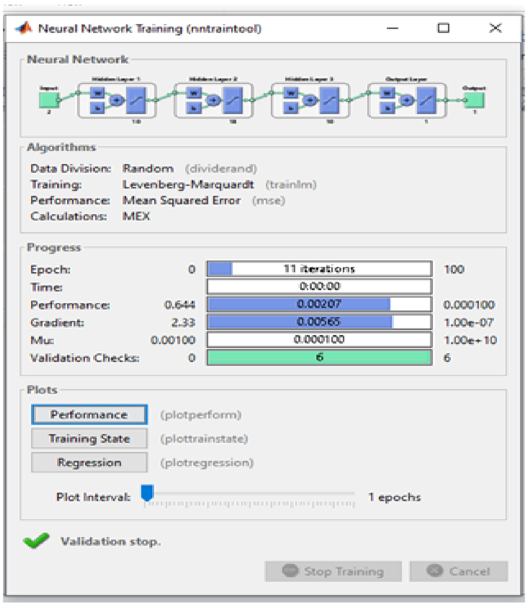


Fig.9 MLP neural network training performance

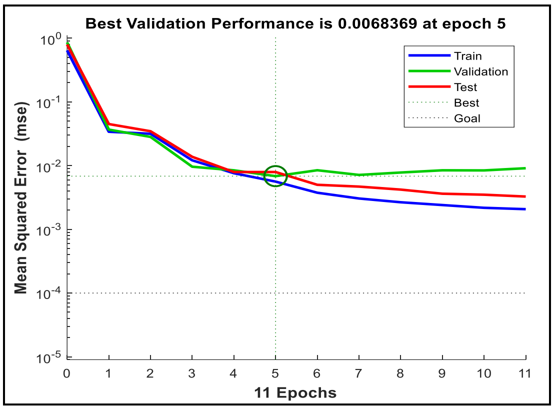


Fig.10 MLP neural network output performance

Table 3 Performance measure MSE of MLP

Target	NN output	Error
4.043	4.1280	-0.0850
4.164	4.1800	-0.0160
4.245	4.2201	0.0249
4.247	4.2609	-0.0139
4.229	4.0565	0.1725
4.087	3.8992	0.1878
3.897	4.2025	-0.3055
4.1208	4.3443	-0.2235
4.5578	4.5212	0.0366
4.088	4.5289	-0.4409
3.9481	4.2017	-0.2536
4.092	4.4071	-0.3151
4.631	4.0914	0.5396
4.716	4.0017	0.7143
4.732	4.0995	0.6325
4.244	4.1145	0.1295
4.0604	4.6024	-0.5420
4.063	4.5856	-0.5226
4.188	4.5731	-0.3851
4.478	4.5505	-0.0725
4.424	4.1304	0.2936
4.238	4.1440	0.0940
4.205	4.1149	0.0901
3.934	4.4862	-0.5522
4.191	4.3310	-0.1400
4.401	4.2685	0.1325
4.406	4.2506	0.1554
4.384	4.0454	0.3386
4.318	4.10368	0.2143
4.22	4.282842	-0.0628
4.164	4.383395	-0.2194

6. Conclusion

In this high linearity low pass biquad filter using 90nm technology has been offered for biomedical applications. A low power gain improved structure utilizes the Gm-C based structure and improves the filter performance .The measured performance authorizes that the presented procedure is advantageous to better linearity. This article recommends the implementation based on the Gm-C based biquad lower band topology utilizes the power of 10.5nW. The designed filter obtains the gain of 4.7 dB for 310Hz-2.7KHz and achieves IIP3(Third order input intercept point) of 3.4dB with output noise is 1.2uV/sqrt(Hz) and consumes 1.8v.The proposed filter design gives the better performance and Trained neural network model is simulated and results are comparable with that of the simulation tool and the best validation performance i.e mean squared error is obtained as .0068369. Hence this high performance proposed filter design is appropriate for various biomedical applications.

Conflicts of interest

The authors declare no conflicts of interest.

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