

DESIGN OF ANALOGUE FILTERS USING CYPRESS PSOC

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ABSTRACT

In this paper, we are going to learn a new technique to implement the analogue filters using PSoC. It is a mixed-signal array IC chip called Programmable System-on-Chip, employed from Cypress Semiconductors. Previously to design any filter we need to implement the circuit using softwares like Cadence, Mentor Graphics etc and we have to check the functionality of that circuit. Instead of going for a long process, we can use PSoC software which is a simplest method to implement the filters. PSoC makes use of the switched capacitor technology with topology to build second order filters. We can save design time, board space, power consumption by using this technique. Microcontroller, Analog and Digital components are integrated in it. PSoC is also known as Software Configurable Silicon. This paper consists of filters, types of filters, their functions and the new method to implement the analog low-pass and analog band-pass filters.

Keywords: *Bandpass Filter, Butterworth Filter, Chebyshev Filter, Bessel Filter*

1. INTRODUCTION

Filter is a common term which is used to pass the desired portion of the particle and stops the unwanted portion of the particle. Filters are of many types. For example, a fuel filter in a vehicle can pass the desired gasoline and stops the undesired dust particles. But we are not discussing but normal filters. Here we are discussing about the filters which pass the signals of desired frequency and rejects the unwanted frequency signals. These filters are known as Electronic Filters. These filters are designed to separate the desired frequency signals from the undesired frequency signals.

2. FILTER TYPES

Electronic Filters are many types and they are classified into many ways. The common most classification method is based on selectivity of filter frequency. Filters are mainly two types: Analog and Digital filters. Between the two, digital filters are most efficient. But to design digital filters, we need analog filters as basic building blocks. It plays an important role in development of electronics. Digital filters do not work well if we do not use analog filter

modules first. In other words, we can say analog filters are mandatory.

Passive Filters are made up of passive components like resistors, capacitors and inductors.

Active Filters are made up of operational amplifiers.

Passive Filters are built with (a) Resistor Capacitor and (b) Inductor Capacitor

(a) Resistive Capacitors are RC Filters. These are easier and cheaper. Therefore these are most used ones.

(b) Inductor Capacitors are LC Filters. The performance of these filters are better than other filters. There are some limitations which affect these filters. Inductors are more expensive, to tune the exact value is very difficult and electromagnetic shield may be required.

We obtain nth order filters by cascading both the passive and active filters. Depending on their functionality both passive and active filters are classified as (i) Low pass Filter, (ii) High pass Filter, (iii) Band pass Filter, (iv) Band stop Filter

These filters specifications are based on frequency range of the signals. The frequency range is classified into three regions.

PASS-BAND: Signals in this range of frequencies are passed with little attenuation. This region extends from zero frequency (dc) to pass band edge frequency f_{pass} .

STOP-BAND: Signals in this range of frequencies are attenuated by at least a specified amount. This region extends from stop band edge frequency (f_{stop}) to infinity.

TRANSITION BAND: Signals in this range of frequencies are present in the region between pass band and stop band. This region extends from f_{pass} to f_{stop} . The width of the transition band is determined by the response type chosen and the order of the filter.

These three regions determine the filter frequency range which is used for the filter specifications. Here f_c indicates cut-off frequency, A_{vs} indicates Attenuation in Stop band region, A_{vp} indicates attenuation in Pass band region and H_{pp} indicates High Power Point of value 0.707 volts.

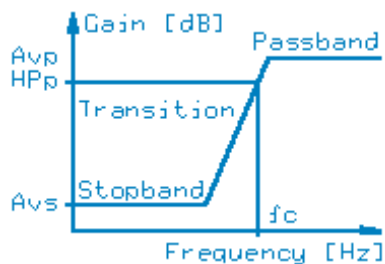


Fig 1: Lowpass Filter Circuit

(II) HIGHPASS FILTER: High pass Filters are required whenever low frequencies are needed to be eliminate from the signal. We can say high pass filter is the inverse of the low pass filter. In this filter, signals below the cut off frequency are attenuated and signals at higher frequencies are passed.

Below Figure 1.2 shows the High pass Filter Circuit with three regions

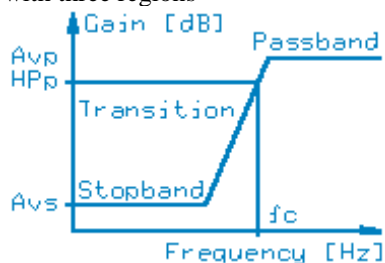


Figure 1.2: Highpass Filter Circuit

(III) BANDPASS FILTER: Band pass Filter pass the band of signal frequencies while attenuating the frequencies above or below that band. In general we can say signals between a lower cut off frequency and an upper cut off frequency are attenuated and signals at higher or lower frequencies are passed.

Below Figure 1.3 shows the Band pass Filter Circuit with three regions.

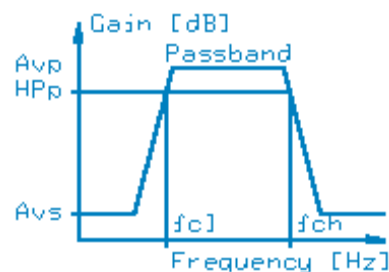


Figure 1.3: Band Pass Filter Circuit

(IV) BANDSTOP FILTER: In this type of filters, the rejected band frequencies present between the two pass bands is located. Simply we can say that the inverse of the band pass filter is known as band stop filter. Signals at the higher cut off frequencies or lower cut off frequencies are passed and signals between the higher and lower frequencies are attenuated.

Below Figure 1.4 shows the Band stop Filter Circuit with three regions.

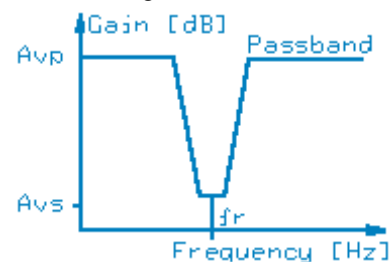


Figure 1.4: Bandstop Filter Circuit

3. Classification of Filters based on Filter Response

RESPONSE TYPE: Filters can be implemented in different ways. Each way of implementation has its own advantages and disadvantages. We have two kinds of transition bands are there, Narrow transition band and Wide transition band.

In Narrow transition band, the advantages are it is very frequency selective in frequency domain and it requires fewer components to achieve the desired specification. But the disadvantage is, it has undesirable overshoot is present and it will ring in their time domain responses.

When coming to the Wide band transitions, it has a little or no overshoot in their time domain responses. But it requires the maximum number of components to achieve the desired specifications.

In this filter literature, we come across a new concept called „Brick Wall Filter“. This is a theoretical concept which has zero transition band width and infinite order.

In this paper, we are going to discuss about some more common filter response types like Butterworth response, Chebyshev response, Bessel response, Elliptical response.

(a) BUTTERWORTH RESPONSE FILTER:

It is also known as Maximally Flat Response because it has smooth roll-off with no ripple. The width of the transition band is medium. The filter cutoff frequency is not too sharp and for the low order filters, the phase response is not too bad. To compute the pole and zero locations, it is the easiest filter type as it falls exactly on the circle whose radius is cutoff frequency in s-plane.

Below Figure 2, shows the Butterworth filter response which is most popular filter and it is a general purpose filter.

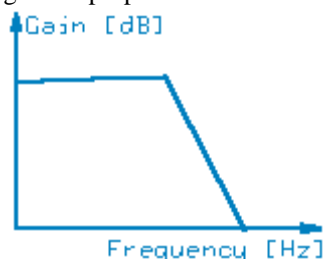


Figure 2: Butterworth Filter Response

(b) CHEBYSHEV FILTER RESPONSE:

It is based on Chebyshev polynomial which has equal ripple about the desired pass-band response. The desired pass-band response is more accurate and the width of the transition band is much narrower than the Butterworth response. The order of the filter is generally less than the Butterworth response for a given specification. The frequency that the magnitude response drops below the specified pass-band ripple is known as cut off frequency of the Chebyshev Filter. The range of the pass-band ripple is specified between 0.01dB to 1 dB. There is a significant overshoot and ringing to a step function. The phase-response is poor. Whenever the time domain response is not important, then the Chebyshev filter is useful.

Below Figure 2.1 shows the Chebyshev Filter response whose transition slope attenuation is steeper than the Butterworth filter response.

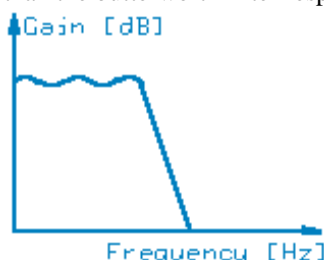


Figure 2.1: Chebyshev Filter Response

(c) BESSEL FILTER RESPONSE:

It is also known as Gaussian Response. It emphasises linear phase response which is known as constant time delay at the expense of magnitude response i.e., sharpness of cut-off frequency. It makes the filter very attractive for filtering pulse waveforms by causing the time-domain response to have a little or no overshoot to a step function. The transition band width is wide even when the order is high and it is very poor at the frequency selectivity.

Below Figure 2.2 shows the Bessel filter response which is an excellent filter for pulse generator circuits since it minimizes the ringing and overshooting responses.

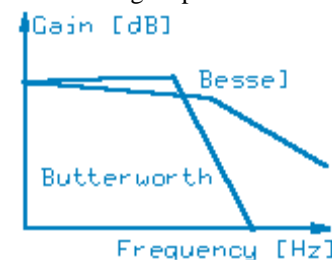


Figure 2.2: Bessel Filter Response

(d) ELLIPTICAL FILTER RESPONSE:

It is also known as Cauer response filter. It is the best response filter of any other response filters discussed so far. No other filter will be able to provide a low order filter for a specification provided. Elliptical overcomes this limitation by combining the ripple in the pass band and stop band. But the elliptical filter is so difficult to design when compared to any other response filters.

Below figure 2.3 shows the Elliptical Filter Response which is the best analog filter

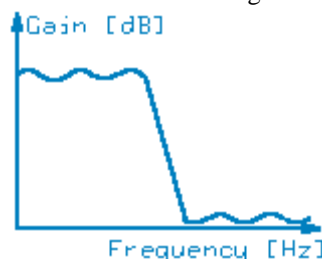


Figure 2.3: Elliptical Filter Response

4. IMPLEMENTATION OF ANALOG LOW-PASS AND BAND-PASS USING PSoC

4.1: PSoC: System-on-Chip is one which uses the configurable hardware surrounding a soft or hard process core. The Programmable-System-on-Chip is a mixed signal arrays that integrates microcontroller, configurable analog and digital components and programmable interconnections. PSoC is also known as **software configurable silicon**. It can integrate as many as peripheral functions with microcontroller

which is used to save the time to design board space and power consumption. The analogue peripherals like amplifiers, adc/dac, filters, comparators etc and the digital peripherals like timers, counters, PWM, SPI etc can be easily configured.

Below figure shows the logic diagram of PSoC architecture. It comprises of four main areas. They are PSoC Core, Digital System, Analog System and System Resources. It also contains the M8C CPU Core, memories like flash, sram. It has an inbuilt internal oscillator of 24MHZ. The PSoC CY8C29x66 family have five IO ports which connect to the global digital and analog interconnects and it provides access to 8 digital blocks and 12 analog blocks.

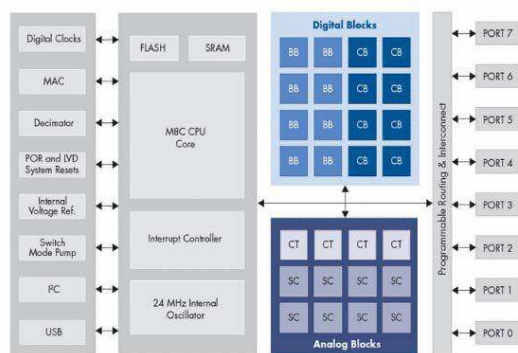


Figure 3: Basic Logic Block of PSoC Architecture

PSoC Core: It contains CPU, memory, clocks and configurable General Purpose IO (GPIO). The CPU core is a powerful processor with speed 24MHZ, providing four MIPS 8-bit Harvard architecture Memory provides 16K of Flash for storing the program, 256 bytes of SRAM for storing data, and up to 2K of EEPROM using the Flash. Program Flash contains four protection levels on blocks of 64 bytes, allowing customized software IP protection.

The PSoC device provides flexible internal clock generators which includes a 24 MHz IMO (internal main oscillator) accurate to 2.5% over temperature and voltage. The 24 MHz IMO will be doubled to 48 MHz by using the digital system.

PSoC GPIOs provides connection to the CPU, digital and analog resources of the device. Each pin drive mode will be selected from eight options, allowing great flexibility in external interfacing.

Digital System: The digital system contains 8 digital PSoC blocks. Digital peripheral contains 8 to 32 bits of PWMS, Dead band zone, Counters and Timers. Through series of global buses, the digital blocks can be connected to any of the GPIO that can route any signal to any pin.

Analog System: The analog system contains 12 configurable blocks. Each block allows complex analog signal flows by comprising an opamp circuit.

It contains upto 4 bit Analog-to-digital converters with 6- to 14-bit resolution as Incremental, Delta Sigma, and SAR), 2,4,6 and 8 pole band-pass, low-pass and notch filters, upto 4-bit amplifiers with gain of 48x, comparators of 4 bit with selectable thresholds, upto 2 bit instrumentation amplifiers with gain of 93x, DACs with 6 to 9 bit resolution.

4.1: Design Of Analogue Low-pass and Band-pass Filters:

Switched Capacitor technology is used in the PSoC with topology to build second order filters. To get 4th or higher order filters, we can cascade two or more order filters. The column frequency can control the cutoff frequency or resonant frequency as well as capacitor values in the switched capacitor technology. The filter coefficients can be calculated by using Filter Design Wizard in the PSoC Designer.

In this paper, we are designing the analog low pass and band pass circuits with butterworth response. The design of those filters is described in the following steps. The cutoff frequency of the low-pass filter is 14KHZ and the resonant frequency of the bandpass filter is 14KHZ with 1KHZ bandwidth frequency. We have to choose both the LPF2 and BPF2 from filters in user modules and we have to set the global resources as well as module parameters. Then select the input and output terminal pins and assign them to low-pass and band-pass filters accordingly.

As mentioned earlier, LPF2 and BPF2 are based on switched capacitor technology. Therefore column frequency and capacitor values are the key elements for the proper filter design. From global resources, a 4MHZ clock is sent to the first analogue column for LPF2 and 800KHZ is assigned to the 4th analogue column of the BPF2 to meet the desired filter requirements.

Below figure shows the block diagram of the Low-pass and Band-pass filters design using PSoC.

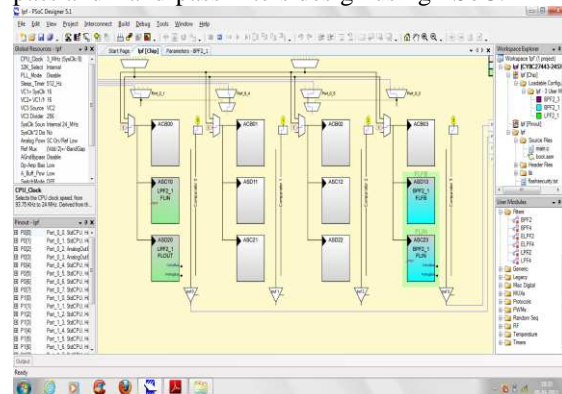


Figure 4.1: Design Of Low-Pass And Band-Pass Filters Using PsoC

4.2: Analogue Low-pass Filter:

The steps involved in designing an analogue low-pass filter are described below. The design wizard of the analogue low pass filter with 14KHZ cutoff frequency is shown below.

After placing the LPF2 from the user module, right click the mouse to pop up the design wizard. Fill the details of corner frequency, sample frequency, gain and type of response. Normally butterworth response type is chosen to get the maximally flat magnitude response.

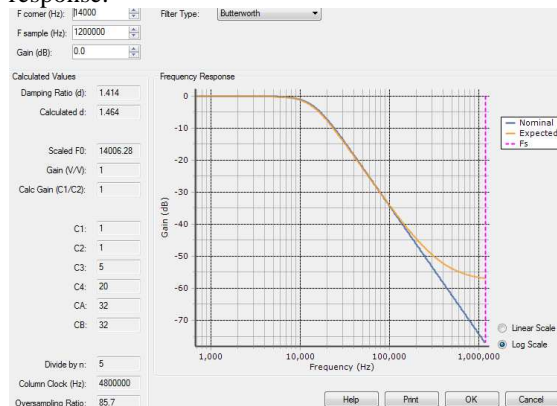


Figure 4.2: Design Wizard Of Analogue Low-Pass Filter

Check the Calculated Values to determine whether the calculated damping coefficient, gain are satisfied or not. Also, make sure that the calculated column frequency is feasible. Calculate the over again if any Calculated Values are not satisfied. After everything is satisfied, hit “Apply” bottom to obtain a set of coefficients to switched capacitors in the low-pass filter topology. The final step is to obtain a specified column frequency, 4 MHz in this case, in order to accomplish desired low-pass filter.

4.3: Analogue Band-pass Filter:

The step involved in designing the analogue band-pass filter is same as the designing low-pass filter. The design wizard of the band-pass filter is shown in figure below.

After placing the BPF2 from user modeule, right click the mouse to pop up the design wizard. Enter the filter Parameters with required centre frequency, gain and bandwidth. Then, apply a suitable sampling clock frequency and value of switched capacitor C2 to match green expected curve to the blue nominal curve.

Check Calculated Values column to check if calculated frequency selectivity and gain are satisfied or not. Also, make sure that the calculated column frequency is satisfied. Calculate over again if any item of Calculated Values are not satisfied. After all values are checked, hit “Apply” bottom to apply a set of coefficients to switched capacitors in the band-

pass filter topology. The final step is to obtain a specified column frequency, 800 kHz in this case, in order to meet the desired band-pass filter.

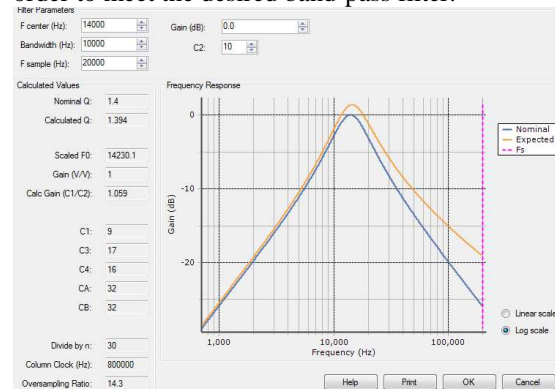


Figure 4.3: Design Wizard Of Analogue Band-Pass Filter

After completing the design wizard level, now the output should be verified. It can be done by programming the software in C language. The compiled software is then programmed into a PSoC chip to obtain the required low-pass and band-pass filter outputs.

5. RESULTS

5.1 Low pass Filter:

The output waveform of the Low-pass Filter is shown in the figure 5.1. The LPF2 shows the output with respect to 10KHz. All the high frequency inputs above the 10KHz are attenuated.



Fig 5.1: Lpf2 Waveform

5.2 Band pass Filter:

The output waveform of the Band pass filter is shown in the figure 5.2. The BPF2 shows the output with respect to 10 KHz. Only those inputs around the center frequency (10 kHz) are allowed to pass through.

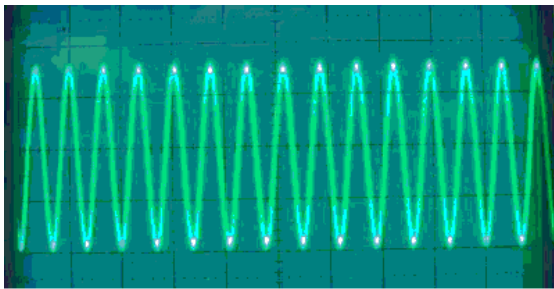


Fig 5.2:Bpf2 Waveform

CONCLUSION

In this paper, we can conclude that designing of Analogue Filters using PSoC is an easiest way instead of going for other software tools like Cadence, Mentor Graphics etc.. In other tools, we want to design the circuit, should apply the parameters values and then we need to write the code to implement the design.

But in Cypress PSoC designer everything is inbuilt. It contains both Low-pass and Band-pass filter designs. Notch filters cannot be designed in this software. For low-pass and band-pass filters, four design topologies are present. We can choose the required topology according to our requirement. The interconnections can be changed according to our requirement. We just need to connect the required IO pins. The code required for the desired filter can be obtained from the datasheet present in the properties of the filter. We need to modify the code according to our filter design.

Finally we can say that, by using the Cypress PSoC software, we can reduce- the time required to design the filter, space of the board, power consumption. Not only filters, we can design ADCs, DACs, Timers, counters, PWMs etc..

(I) LOWPASS FILTER: Whenever to limit the high-frequency content of a signal, we need lowpass filter. It will stop all the frequencies greater than the cut-off frequency. Simply we can say that signals from dc to upper cutoff frequency are passed and signals at higher frequencies are attenuated.

Below Figure 1 shows the low pass filter circuit with pass band, stop band and transition band

REFERENCES:

- [1] Chia-Chang Tong, Wu-Shun Jwo, Jhih-Yu Lin, Shih-Fan Li, Juin-Yi Li, "The Firmware Design Of Analogue and Digital Filters", Digital Signal Processing Workshop and IEEE Signal Processing Education Workshop (DSP/SPE), 2011 IEEE, 4-7 Jan. 2011, pg 523 – 528,
- [2] PSoC Mixed Signal Array Final Data Sheet, Document 38-12013 Rev. H, February 15, 2007, available at: <http://www.cypress.com/pso>.
- [3] "Practical Analog and Digital Filter Design", Textbook by Les Thede January 2005, November 1, 2004 | ISBN-10: 1580539157 | ISBN-13: 978-1580539159.
- [4] "Frequency Filters" Textbook by Kenneth A.Kuhn
- [5] "Handbook & Manual for Programmable System on Chip Lab" by Dr MK Deshmukh, Aalap Tripathy.
- [6] R.Dhanabal, V.Bharathi, G.Prithvi Jain, Ganeash Hariharan, P.Deepan Ramkumar, Sarat Kumar Sahoo", Gabor Filter Design for Fingerprint Application Using Matlab and Verilog HDL", International Journal of Engineering and Technology (IJET),2013.