Sharp-Rejection Technique in High Frequency Active-RC LPF for UWB Applications

Anh Tuan Phan, Ronan Farrell, and Sang- Gug Lee

***Abstract*—This paper describes a sharp-rejection technique in designing active-RC LPF for MB-OFDM UWB applications. Sharp rejection is attributed to the combination of different AC characteristic of three Biquads in series. A simple operational amplifier (Op-amp) is adopted to ensure high frequency and high linear performance for the designed filter. The cutoff frequency is 264MHz, with 13dB rejection at 290MHz and about 50dB at twice bandwidth. The LPF is designed in 0.13µm IBM CMOS process with pass-band ripple of less than 1dB, IIP3 is 23dBm while consuming 8.4mA from 1.5V supply.**

***Index Terms*—Continuous-time filters, High frequency filters, Op-amp, UWB, LPF, Sharp rejection, CMOS**.

I. Introduction

LOW Pass Filter (LPF) is a key building block in the transceivers, mostly designed for channel selection and anti-alias [1]. Especially in the MB-OFDM UWB, the interference from adjacent channel is severe. In MB-OFDM UWB [2], the whole UWB spectrum is divided into several sub-channels. Each of these channels can easily cause the interference on its both side adjacent one or in an opposite way, therefore the accumulated interferences from other channels can overlap on one given channel. Because of that severe inherent characteristics of MB-OFDM, high performance LPF is needed. The LPF is required to have high rejection ratio, so that it can suppress the interference from adjacent channels. Moreover, it should have high linearity and wide bandwidth to meet the requirement of UWB.

II. LPF Design

Rejection ratio or attenuation ratio is defined as the different level of signal in the pass-band compared to that at a given frequency. In this design, the requirements for rejection at 290MHz and at twice the channel bandwidth, 528MHz, are -12dBr and -30dB, respectively. The sharp slope rejection from 264MH to 290MHz is the most challenging. High linearity feature is also demanded, hence, out of band interferences do not create inter-modulations which fall in the pass-band. The order of the filter is determined based on the type of filter, cutoff frequency and signal attenuation ratio requirement. Classical configurations are Bessel, Chebysheve, Elliptical and Butterworth filters. Among them, Butterworth give the high rejection ratio with the same order while requires a reasonable Q factor. To achieve high rejection ratio as required, the number of order for Butterworth LPF (n_{Bu}) calculated from (1) should be larger than 20 based on the theory analysis in [3], resulting to a very complex, large chip size and high power circuit.

$$n_{Bu} = \frac{\log\left[\left(10^{0.1\alpha_{\min}} - 1\right) / \left(10^{0.1\alpha_{\max}} - 1\right)\right]}{2\log(\omega_s / \omega_p)} \qquad (1)$$

where ω_s and ω_p is the stop-band and pass-band frequency, α_{max} is the ripple at the pass-band and α_{min} is the attenuation at the stop-band. In order to satisfy the sharp rejection ratio, a new technique is proposed which employs the steep slope around the peaking point. In this design, 6th order LPF topology is chosen as a compromise of those constraints, shown in Fig.1.

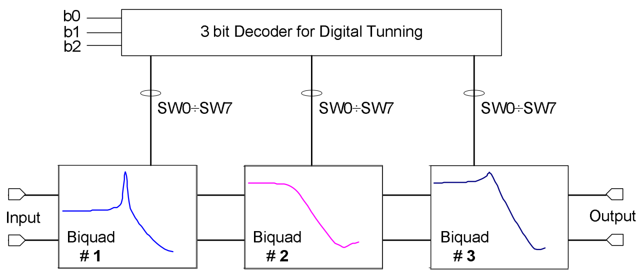

Fig. 1. 6th order LPF structure

III. Proposed Sharp Rejection Technique

The main idea is to make use of the steep slope at the peaking point which has high Q factor. In order to have high rejection ratio, the three different AC characteristics of the

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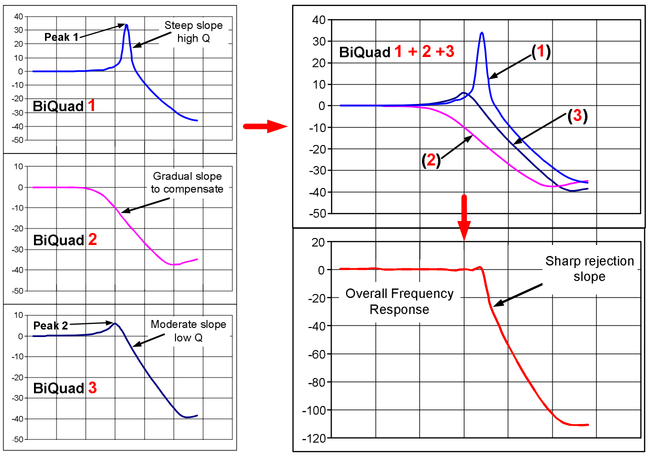

Fig. 2. Combination of three different biquad's AC characteristic

three biquads are combined as in Fig. 1. Each Biquad has the peaking at different frequencies with different Q factors. These peaking frequencies in each biquad are determined and optimized during the simulation. When cascading them, the frequency responses are combined, at the cut-off frequency, sharpest slope is obtained while at other frequencies in the pass-band, flat AC response is achieved by compensation of different frequency responses.

From Fig. 2, Biquad 1 has highest peaking at the cutoff frequency (at 260MHz), leading to a sharp slope. Biquad 2 has high attenuation at the cutoff frequency to compensate with the frequency response of Biquad 1. Hence, Biquad 3 should have moderate peaking at lower frequencies (at 150MHz) to compensate with the attenuation of Biquad 1 at these low frequencies. As a result, when the three frequency responses of biquads are combined, flat frequency response in the pass-band is achieved with very sharp attenuation at the corner frequency with. The order arrangement of three Biquads also helps reduce the noise figure (NF). Because the NF depends mostly on the first stage, thus, the first stage should have higher gain or high peaking.

IV. LPF Design

Operational amplifier (Op-amp) is the core circuit in designing the RC LPF. It determines the frequency characteristics, linearity and voltage swing of the whole LPF.

The Op-amp has two stages, transconductance stage (g_m) and the output buffer, shown in Fig. 3. The buffer stage has the unit gain and its main function is for the output impedance matching. A cross connection at the PMOS load transistors $M_{5,6}$ is adopted. This cross connection creates the negative transconductance ($-g_{mc}$) which compensate positive g_{mp} of the diode connected PMOS. Thus the load (R_L) in (2) is increased leading to the improvement of the gain as specified in (3).

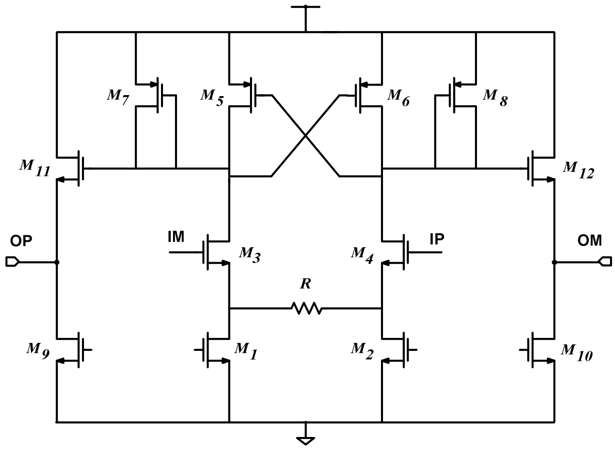

Fig. 3. Op-Amp topology

$$R_L = \left(-\frac{1}{g_{mc}}\right) // \frac{1}{g_{mp}} = \frac{-\frac{1}{g_{mc}} \times \frac{1}{g_{mp}}}{\frac{1}{g_{mp}} - \frac{1}{g_{mc}}} = \frac{\frac{1}{g_{mc}} \times \frac{1}{g_{mp}}}{\frac{1}{g_{mc}} - \frac{1}{g_{mp}}} \quad (2)$$

$$G_V = \frac{g_m \times R_L}{1 + g_m \times R_{degeneration}} \quad (3)$$

The Op-amp has two poles, the dominant one is at the output node and the other one is at the drain of PMOS load transistors. Those transistor sizes are selected with small channel length to put the pole far away from the dominant one. Thus, the Op-amp has very high frequency characteristic. Degeneration resistor R is used to increase the linearity of the Op-amp as well as of overall LPF.

V. Experiment Results

The UWB LPF is designed using IBM 0.13-μm CMOS technology in Cadence with the voltage supply of 1.5 V.

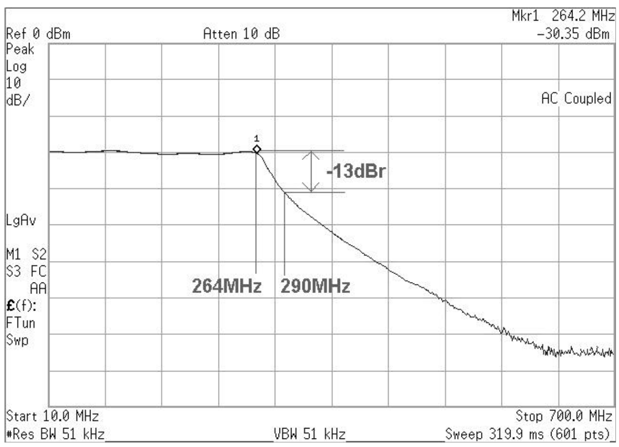

Fig. 4. AC characteristic of the designed UWB LPF.

The frequency characteristic of the designed LPF is shown in Fig. 4. The cutoff frequency at 1dB is 264MHz. The ripple is less than 1dB resulting to almost constant group delay along the pass-band. At 290MHz the attenuation is 13dBr, at twice the channel bandwidth, 528MHz, the attenuation is about 50dBr. This filter shows very sharp slope in the range from 264MHz to 290MHz, compared to other filters with the same order designed in conventional way by cascading a number of small order same-Q filter stages. Digital tuning is applied to deal with process variation and the tuning range is from 190MHz to 310MHz, about 40%. In Fig. 5, two-tones test at 30MHz and 40MHz shows high linearity performance with 23dBm of IIP3 and P1dB is 3dBm. The total current consumption of the LPF is 8.4mA or 12.6mW. This LPF has the smallest power consumption compared with state of the art published works for wideband applications.

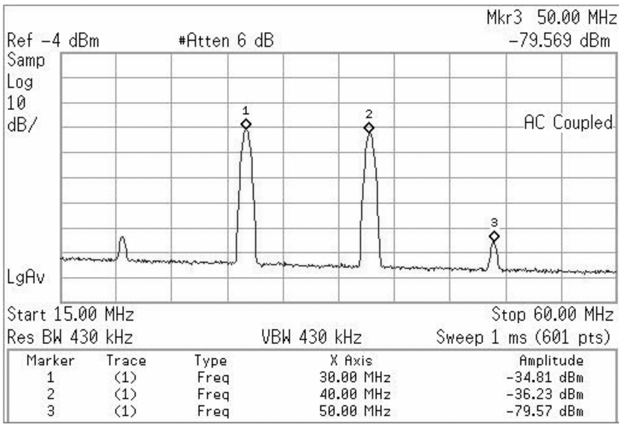

Fig. 5. Two-tone in-band IM3 test at 30 MHz and 40 MHz.

VI. Conclusion

A wide-band, high linear sharp-rejection LPF for MB-OFDM UWB was designed in 0.13μm IBM CMOS process. Experiment results have proved the effectiveness of the proposed technique. The designed LPF has very sharp rejection ratio, -13dB rejection at 290MHz while cutoff frequency is 264MHz. It consumes 8.4mA from 1.5V, and the chip size of 400μm x 640μm. The designed filter, among the first few designs of wide-band active-RC LPF, shows very good performance making it really suitable for multi-band and wide-band applications like UWB.

References

[1] Z. Hui, L. Shuzuo, L. Dongtian, S. Cheng, C. Tatfu, and H. C. Luong, "A 3.1-8.0 GHz MB-OFDM UWB Transceiver in 0.18μm CMOS," *IEEE Custom Integrated Circuits Conf.* (*CICC*), Sept. 2007, pp. 651–654.

[2] "Multi-band OFDM Physical Layer Proposal for IEEE 802.15.3a Task Group," IEEE P802.15 Working Group for Wireless Personal Area Networks, March, 2004.

[3] Rolf Schaumann and Mac E. Van Valkenburg, "Design of Analog filter", New York, Oxford Press, 2001.

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