On-chip Active RF Tracking Filter with 60dB 3rd-order Harmonic Rejection for Digital TV tuners

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***Abstract*—a new structure of RF tracking filter to solve the linearity and harmonic mixing problem in DTV (digital TV) tuner is proposed in this paper. The proposed structure composed of two filters: harmonic rejection tracking filter (HRTF) and RF tracking filter (RFTF). They are activated / deactivated by complementary digital control switches. HRTF works in the frequency range 48~287MHz. It can reject not only 3rd-order harmonic by more than 60dB but also unwanted channel signal from 5 to 15dB. The RFTF can reject unwanted signal from 287~860MHz. The proposed structure can realize pre-band selection function in the tuner front-end and covers a wide frequency range from 48-860MHz. The center frequency and the bandwidth of both filters can be tuned by adopting the proposed tuning method. Also, the proposed structure can be implemented without any off-chip component. Simulation results show the tunable ability of the center frequency from 48 to 860MHz, and the bandwidth from 8~20MHz. These features are obtained drawing 19.8mA (7.2mA from RFTF, 12.6mA from HRTF) current from a 1.2-V supply in a standard 0.13um CMOS technology.**

Keywords-digital TV tuner, on chip, active RF tracking filter, harmonic mixing, harmonic rejection, bandpass filter.

I. INTRODUCTION

The use of digital TV (DTV) is expected to be rapidly increased as a requisite content in multi-function personal information terminal of next generation. Today's digital TV standards, such as ATSC and DVB (Digital Video Broadcasting), cover a wide frequency range from 48 to 860MHz. A key element to digital TV is a silicon tuner with a low-power and small-size required to be implemented as a single-chip. To design this broadband single-chip DTV tuner, there are many challenging technical issues including harmonic mixing, image rejection, dynamic range, and linearity [1]. The bottlenecks in selectivity and linearity performances of DTV tuner are mainly from the TV broadcasting environments with multiple strong interferers. Moreover, wideband DTV tuners are different from narrowband RF receivers, when receiving lower band channels, the harmonics of the local oscillator will occur in the same DTV band. Because of these phenomena, the linearity requirements to the RF front-end and baseband circuit components of tuner become very eminent and a complex gain control algorithm is needed, which make the cost of tuner development increase. Therefore, the rejection of unwanted channel signals and odd-harmonic is the main design concern of tuner. RF tracking filter (RTF) is always a desirable asset to the digital tuner design because it can achieve superior performance in the presence of unwanted channel signal and 3rd order harmonic [2, 3]. However, the tracking filter for DTV tuner has to be tuned from 48 to 860MHz with narrow bandwidth; therefore it is very challenge to implement on-chip and active.

In [1], the combination of a double conversion super heterodyne and a zero-IF tuner is implemented where the harmonic rejection is easily achieved but the structural complexity requires additional frequency conversion circuitry and many external components. In [2], the RF LC tracking filter used to protect the active RF circuits from saturation by rejecting strong unwanted band signals and to secure the linearity by rejecting the 3rd-order harmonic signals. However, the using of off-chip varactors and inductors increase the module size and process complexity. In [3], on-chip RF tunable band-pass filter and poly-phase mixer for harmonic rejection are implemented to achieve 60dB harmonic rejection which is required to alleviate possible SNR (signal-to-noise ratio) degradation. However the limited number of filters and the large bandwidth provide only harmonic rejection not unwanted channel signal rejection. Moreover, it is very challenge to generate the LO input signal to the poly-phase mixer because of bulky, complex and high power consumption ring oscillator and poly phase filter.

In order to achieve on chip active RF tracking filter with also 60dB 3rd-order harmonic rejection up to 287MHz, a new structure composed of HRTF (harmonic reject tracking filter) and RFTF (RF tracking filter) for integrated Digital TV tuners is proposed in this paper. Section II presents the design strategy of HRTF and RFTF. Section III shows simulation results. Finally, conclusion is given in section IV.

II. DESIGN STATEGY

A. New structure

The new RF tracking filter structure is proposed in this paper. Fig.1 shows the structure of tuner RFIC adopting the proposed filter, where the proposed filter is located between LNA and mixer in the DTV tuner. It composes of two filters: HRTF and RTF. They are activated / deactivated in different frequency range by complementary digital control switches. A higher order HRTF is needed to achieve 60dB 3rd-order

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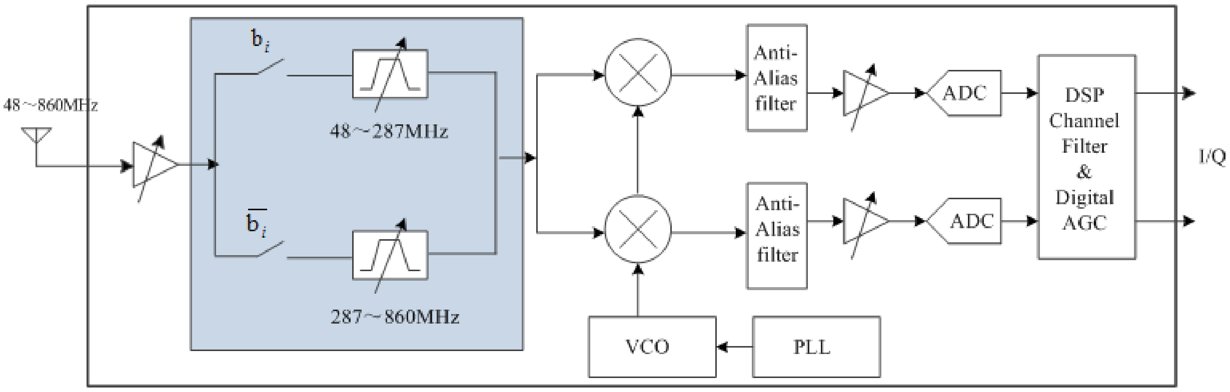

Figure 1. Direct Conversion TV tuner architecture

harmonic rejection ratio, at the same time reject unwanted channel signal. While the RTF works in the frequency range 287~860MHz to achieve only unwanted signal rejection. The proposed structure can achieve sufficient 3rd-order harmonic rejection and also can realize pre-band selection function in the tuner front-end.

B. *RFTF design*

The RFTF for DTV tuner in the proposed structure has to be tuned from 287 to 860MHz with narrow bandwidth to achieve sufficient rejection of unwanted signal. The center frequency of the RTF is set according to the desired channel frequency to pre-select channels. G_m-C type filter is adopted in our tracking filter because of their superior performance than other continuous-time methods, especially in the high frequency range [4]. The proposed compact tunable 2nd-order band pass RTF, as shown in Fig 2, can be readily cascaded to realize a high-order filter with enhanced rejection ability. The dc bias of each Gm output node is set to the desired value by a common-mode-feedback circuit. The transfer function of the tracking filter is:

$$\frac{V_2}{V_1}=-\frac{G_{m1}}{G_{m2}+sC_1+\frac{G_{m3}G_{m4}}{sC_2}}=-\frac{sC_2G_{m1}}{s^2+sw_0/Q+w_0^2}. \qquad (1)$$

Where the center frequency and quality factor are:

$$w_0=\sqrt{\frac{G_{m3}G_{m4}}{C_1C_2}},\ Q=\frac{1}{G_{m2}}\sqrt{\frac{G_{m3}G_{m4}C_1}{C_2}}. \qquad (2)$$

And the bandwidth is:

$$B=\frac{G_{m2}}{C_1}. \qquad (3)$$

There are two key factors for RFTF design: widely frequency tunable ability and narrow bandwidth. From (2), the widely tunable center frequency of the RTF can be achieved by programmable cap bank C_1 and C_2 and large transconductance value of G_{m3} and G_{m4}. From (3), the narrow and constant bandwidth can be achieved by fixed C_1 and small value transconductance of G_{m2}. But the constant bandwidth from (3) is not valid in the practical design; therefore a tunable C_1 is used in our RFTF to compensate the parasitic capacitance to achieve narrow bandwidth in whole frequency range. In order to decide the transconductance value of G_{m2}, G_{m3} and G_{m4}, an 860MHz RFTF with 20MHz 3dB bandwidth is design first. Then other frequency can be achieved by tunable cap banks. In our RFTF, the coarse gain tuning is performed by adjusting the tunable G_{m1}. As shown in Fig 3, by using tunable cap banks, wide frequency tuning range from 48 to 860MHz and about 4dB unwanted signal rejection at 16MHz offset can be achieved.

The G_m cell is main building block in the proposed RFTF. Parameters such as linearity, noise, and power dissipation, etc are considered in the design of a G_m. A wide tuning range G_m cell using source degeneration is proposed as shown in Fig 4. MOS based source degeneration can improve the linearity of G_m cell [5]. We use four cross-connected triode region transistors M3-6 connected to the gates of input saturated MOS stage, in a way similar to [6]. Qualitatively, when the amplitude of the input signal increases, the triode-region degeneration MOS resistors M3-6 will be more biased such that the synthesized resistance is reduce. The less degeneration results in more G_m of the differential pair which can compensate for the drop of G_m. And the cross connection trades transconductance for larger input linear range, the improved linearity of this G_m cell can be achieved. The common mode feedback circuit is used stabilize the DC operating point and bias the circuit properly. It has good linearity and enough phase margins by adopting a source degeneration resistor Rc. The transconductance plot is obtained by differentiating the simulated output V-I characteristics, as shown in Fig 5. We can see that the transconductance of proposed G_m cell is almost flat in the required input signal range which gives stable frequency and bandwidth performance.

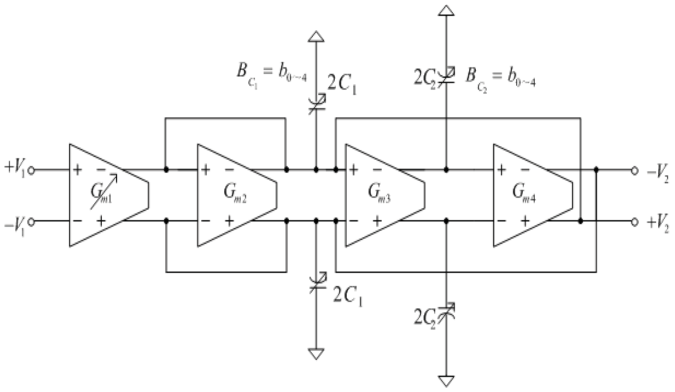

Figure 2. The Gm-C realization of the second-order RF tracking filter.

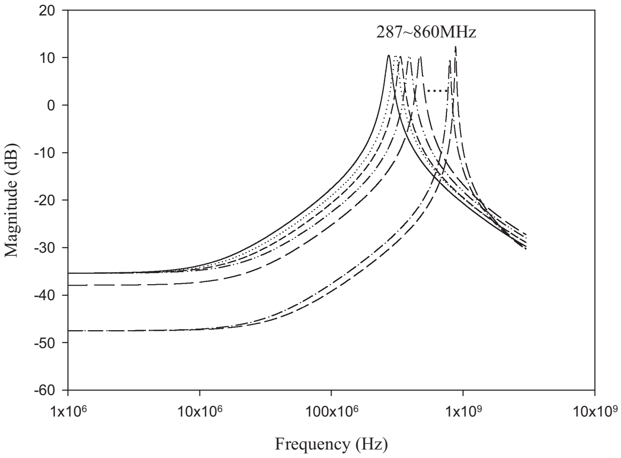

Figure 3. Characteristics of the RF tracking filter with gain adjustment.

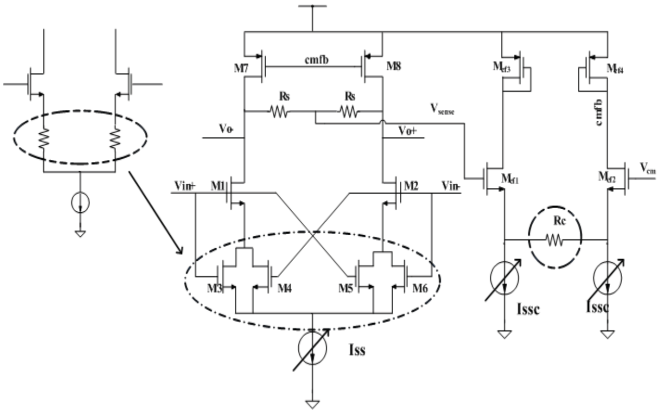

Figure 4. Fully differential linear Gm cell with CMFB.

C. HRTF design

As mentioned in part I, wideband DTV tuners are different from narrowband RF receivers, when receiving lower band channels, the odd-harmonics of the local oscillator will occur in the same DTV band. Therefore, in the frequency range 48~287MHz, the harmonic mixing problem exists. To solve this problem and at the same time achieve unwanted channel signal rejection, a 3rd–order harmonic rejection over 60dB is necessary at that frequency range. Therefore a higher-order band-pass tracking filter is required to provide sufficient harmonic rejection. The property of the HRTF is shown in Fig 6. As mentioned in RFTF design part, one of the advantages of the proposed biquad RFTF topology is that the realization of higher-order filter is straightforward, simply by cascading of the biquads. The proposed HRTF is 8th-order gm-c type band-pass filter cascaded by four biquads. The center frequency and quality (Q) factor of the HRTF is different from RTF because of different functions. The topology of G_m cell in the HRTF design is same as RFTF with different transconductance value, as shown in Fig 4. And the G_m cell in HRTF has same topology with RFTF but different transconductance value. Take an example of highest frequency (287MHz) HRTF design. The 1st biquad has 283MHz center frequency and 14MHz bandwidth, the 2nd biquad works at 291MHz center frequency and 19MHz bandwidth, the 3rd biquad has 278MHz center frequency, 7.5MHz bandwidth and the 4th biquad works at 296MHz center frequency with 7.5MHz bandwidth. The HRTF operates in other frequency can be gained by tunable cap bank Simulated AC response of HRTF is shown in Fig 7. The working frequency range of HRTF is 48~287MHz, with 20MHz bandwidth. It can reject 60dB 3rd-order harmonic and 5~15dB unwanted channel signal.

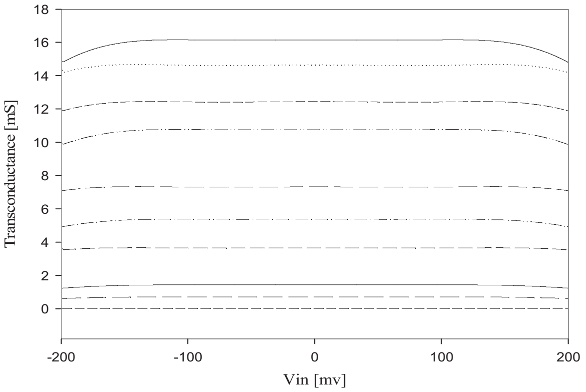

Figure 5. Transconductance of the Gm cell.

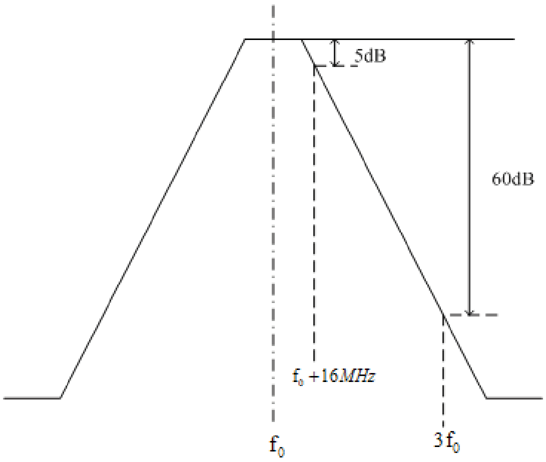

Figure 6. The property of HRTF.

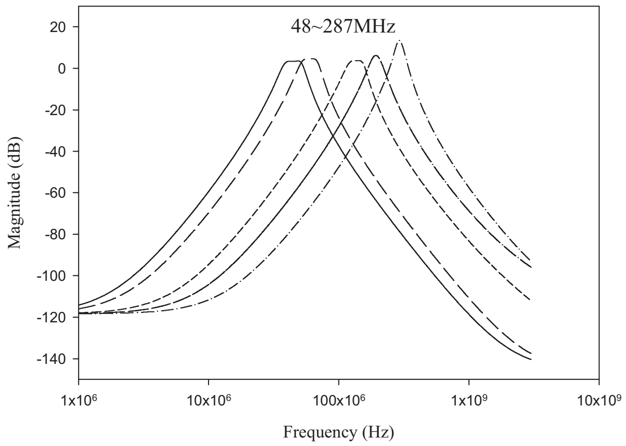

Figure 7. The property of HRTF without gain adjustment.

III. SIMULATION RESULTS

The proposed filter was designed in the TSMC 0.13-um CMOS process. Simulation results show the wide frequency tuning range from 48 to 860MHz, as shown in Fig 4. The bandwidth of both tracking filter is from 8~20MHz in whole band which is hardly the case for high frequency filter. The HRTF can achieve 5~15 dB N+2 channel (16MHz offset) rejection and 60dB 3^{rd}-order harmonic rejection. And the RFTF can reject around 4.2dB unwanted N+2 channel signal in the frequency range 287~860MHz. The summarized performance of both tracking filers is shown in table I.

IV. CONCLUSION

In this paper, a new on-chip RF tracking filter structure composed of HRTF and RFTF for integrated Digital TV tuners is presented. The proposed structure can realize pre-band selection function in the tuner front-end and solve harmonic mixing problem by the rejection of unwanted channel signal and 3^{rd}-order harmonics. It covers a wide frequency range from 48-860MHz while keeping narrow bandwidth. The proposed structure can be implemented without any off-chip component. These features are obtained drawing 19.8mA current from a 1.2-V supply in 0.13um CMOS technology.

TABLE I. SUMMARIZED PERFORMANCE OF RFTF AND HRTF

Parameter	RFTF	HRTF
Supply Voltage	1.2V	1.2V
Input Vpp	300mV	300mV
center frequency	287~860MHz	48~287MHz
bandwidth	10~20MHz	8~14MHz
3rd Harmonic rejection	/	60dB
Unwanted signal rejection@16MHz offset	4.2dB	5~15dB
Gain	10dB	3~10dB
Power dissipation	8.64mW	15.12mW

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