BRIEF PAPER

A Low Power and Low Noise On-Chip Active RF Tracking Filter for Digital TV Tuner ICs

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SUMMARY In this paper, a highly linear and low noise CMOS active RF tracking filter for a digital TV tuner is presented. The G_m cell of the $G_m - C$ filter is based on a dynamic source degenerated differential pair with an optimized transistor size ratio, thereby providing good linearity and high-frequency operation. The proposed RF tracking filter architecture includes two complementary parallel paths, which provide harmonic rejection in the low band and unwanted signal rejection in the high band. The fabricated tracking filter based on a 0.13 μm CMOS process shows a 48∼860 MHz tracking range with 30–32 dB 3rd order harmonic rejection, a minimum input referred noise density of 2.4 nV/$\sqrt{\text{Hz}}$, and a maximum IIP3 of 0 dBm at 3 dB gain while drawing 39 mA from a 1.2-V supply. The total chip area is 1 mm × 0.9 mm.

key words: *CMOS, on-chip, DTV tuner, active RF tracking filter, transconductance-c filter (G_m-C filter), low-pass filter (LPF)*

1. Introduction

Various existing digital TV standards such as advanced television systems committee-terrestrial (ATSC-T) and digital video broadcasting terrestrial (DVB-T), cover a wide range of operating frequencies from 48 to 860 MHz. This broadband character presents many technical challenges in the design of DTV tuners, including harmonic mixing, image rejection, dynamic range, and linearity [1]. Different from narrowband receivers, for broadband DTV tuners, the local oscillator (LO) harmonic mixing problem is severe: when receiving lower-band channels (48∼288 MHz), signals of other channels exist at the harmonic frequencies of the wanted signal in the same DTV band. Those unwanted harmonic signals will degrade the RF sensitivity in the tuner. To secure down conversion of the lower-band channels, without degradation by the signals at the harmonic frequencies, harmonic rejection is an essential requirement of the DTV tuner. Use of an on-chip tunable RF tracking filter together with a harmonic rejection mixer (HRM) is a new technical trend to suppress the 3rd and higher order harmonics rejection in the DTV tuner [2], [3]. Figure 1 shows a typical front-end architecture for a silicon DTV tuner, where the proposed RF tracking filter is located between the LNA and the mixer.

This paper describes the design and implementation of a fully integrated on-chip active RF tracking filter with high linearity, low noise, and good harmonic rejection ratio. Section 2 describes the G_m-cell and the design details of the $G_m - C$ type tracking filter. Section 3 presents the measurement results. And Sect. 4 concludes.

Manuscript received March 22, 2011.
Manuscript revised May 23, 2011.
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DOI: 10.1587/transele.E94.C.1698

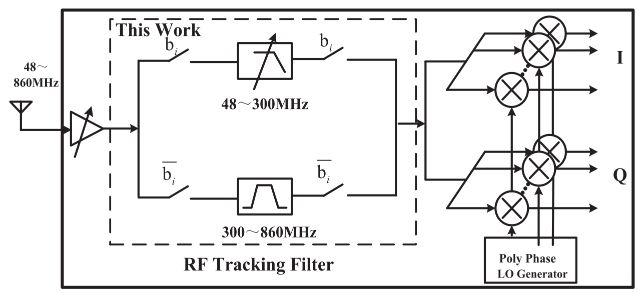

Fig. 1 Typical block diagram of RF front-end for silicon DTV tuner.

2. RF Tracking Filter Design

2.1 Unit G_m-Cell Design

A $G_m - C$ type filter has been adopted in the proposed RF tracking filter design owing to its superior high frequency performance with low power consumption. The G_m cell is the main building block in $G_m - C$ type filters, since it dominates the filter linearity, noise figure (NF), and power dissipation. Figure 2 shows a schematic of the unit G_m-cell used in this work, where the dynamic source degeneration technique is adopted to improve the linearity [4]. In Fig. 2, four cross-connected transistors, M_{3-6}, operate in linear mode and provide dynamically varying degeneration resistance to the differential pair, M_1-M_2, leading to nearly constant transconductance to input signal amplitude variation. In Fig. 2, as the input differential voltage v_{in} increases from zero, the channel resistance of one of the two degeneration transistors (M_3 or M_4, M_5 or M_6) is reduced, and the transconductance thereby stays constant.

In addition to good linearity, the G_m-cell shown in Fig. 2 also exhibits good high-frequency performance, as no additional internal nodes are created in the circuit. In addition, the input impedance of the G_m-cell is highly capacitive, and can easily be incorporated into the integrating capacitors of the filter.

2.2 Proposed RF Tracking Filter Design

Figure 3 shows the proposed RF tracking filter architecture.

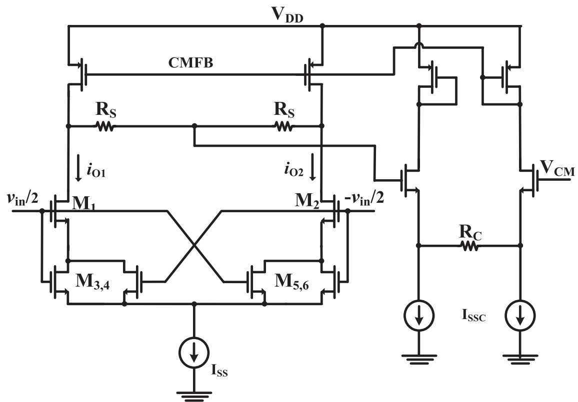

Fig. 2 Schematic of unit G_m-cell used in the proposed RF tracking filter.

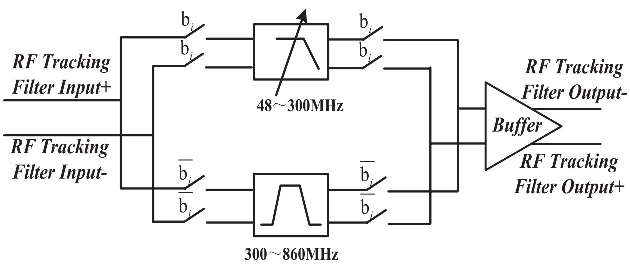

Fig. 3 Proposed RF tracking filter architecture.

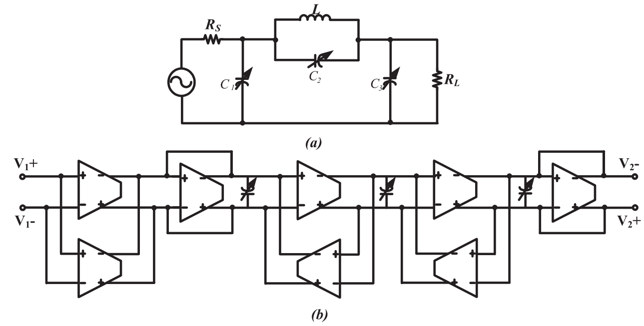

Fig. 4 Third-order elliptic low-pass filter. (a) Passive ladder filter. (b) $G_m - C$ filter.

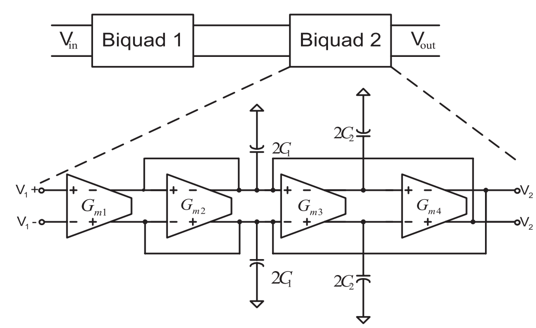

Fig. 5 Fourth-order $G_m - C$ bandpass filter.

As shown in Fig. 3, the full band from 48 to 860 MHz is split into two sub-bands. For the lower half band below 300 MHz, the 3rd-order tracking low pass filter is selected for harmonic rejection. For the upper band above 300 MHz, harmonic rejection is not required since all harmonics of the LO are already out of the TV band. However, in the proposed architecture, paralleling the bandpass filter in the band of 300~860 MHz is necessary for the following reason: for the case of cable TV, the large number of channel signals (up to 130) can saturate the tuner RF front-end and generate many 2nd-and 3rd-order mixed terms in the desired signal band after down mixing, which degrades system performance, i.e., the signal to noise distortion ratio (SNDR) performance. Therefore, above 300 MHz, a bandpass tracking filter is selected for the better system performance. In Fig. 3, *bi* and $\overline{bi}$ are complementary switches. A buffer is added for the purpose of measurement at the output.

Below 300 MHz, a third-order elliptic low-pass RF tracking filter is designed with the G_m-cell shown in Fig. 2. The filter is based on a passive ladder architecture, which shows good sensitivity and dynamic range. Figure 4(a) illustrates the third-order elliptic passive ladder schematic. Figure 4(b) shows the third-order elliptic $G_m - C$ filter, which is converted from the passive ladder filter.

As shown in Fig. 4(b), the 1st stage of the $G_m - C$ filter adopts two G_m cell in parallel to compensate the loss realized by the passive ladder. Moreover, in the proposed filter, the parallel G_m cell has large value to achieve good noise performance. 2nd stage G_m represents the resistor. The floating inductor shown in Fig. 4(a) is replaced by a capacitor between two gyrators shown in Fig. 4(b). The low pass RF tracking filter has a 4-bit capacitor array, which is switched by a digitally controlled signal. This capacitor array can compensate the process, supply voltage, and temperature variations. The cutoff frequency of the low-pass filter can be tuned in a frequency range from 50 to 300 MHz. Above 300 MHz, a 4th-order $G_m - C$ based bandpass filter is implemented by a cascade connection of two biquads. Figure 5 shows the architecture of the biquad, which can readily be cascaded for higher-order filters. The biquad consists of four G_m-cells ($G_{m1} \sim G_{m4}$) and four capacitors (C_1, C_2). Each biquad is designed to control the value of G_m and the capacitance (C_1 or C_2). The G_{m1} converts the input voltage to a current; G_{m2} represents the resistor; and the identical G_{m3}, G_{m4}, together with the capacitor C_2, implements the inductor. From Fig. 5, the transfer function of the $G_m - C$ bandpass filter is given by

$$\frac{v_2}{v_1} = -\frac{sC_2G_{\mathrm{m}1}}{s^2 + s\omega_0/Q + \omega_0^2} \tag{1}$$

where the center frequency ω_0, quality factor (Q), and the bandwidth (BW) are given as follows, respectively.

$$\omega_0 = \sqrt{G_{m3}G_{m4}/C_1C_2} \tag{2}$$

$$Q = (1/G_{m2})\sqrt{G_{m3}G_{m4}C_1/C_2} \tag{3}$$

$$BW = \omega_0/Q = G_{m2}/C_1 \tag{4}$$

From (2) and (3), by setting the ratio between G_{m2}, $G_{m3,4}$, C_1 and C_2, the proposed filter can be tuned to cover 300~860 MHz. Based on the proposed RF tracking filter architecture shown in Fig. 3, while adopting the unit G_m-cell shown in Fig. 2 with optimized transistor size ratio [5], the proposed filter shows high linearity, low noise, and high frequency performances.

3. Measurement Results

The proposed RF tracking filter shown in Fig. 3 is fabricated using a 0.13 μm CMOS process. The filter is designed to cover 48~860 MHz while drawing 39 mA from a 1.2 V supply, excluding a buffer that is added for the purpose of measurement at the output. Figure 6 shows the measured frequency characteristics of the filter for various cutoff frequencies. As can be seen from Fig. 6, the proposed RF tracking filter shows a tuning range of 48~300 MHz for harmonic rejection. At frequencies higher than 300 MHz, a bandpass filter response is shown for better system performance. Figure 7 shows the measured and simulated 3rd-order harmonic rejection ratio (HRR) versus the cutoff frequency. As can be seen in Fig. 7, over a tuning range of 48~300 MHz, 30~32 dB HRR is achieved. Figure 8 shows the measured and simulated IIP3 versus the cutoff frequency for the input signals with 10 MHz offset, where the filter IIP3 varies from −4.5 to 0 dBm. Figure 9 shows the measured and simulated NF, which varies from 12.5 to 16.2 dB. Figure 10 shows the chip micro-photograph, which has a size of 1 mm × 0.9 mm including pads and the output buffer. Table 1 compares the performance of the proposed RF tracking filter with that of other reported filters. In Table 1, a figure-of-merit (FOM), defined in [2], is adopted. As can

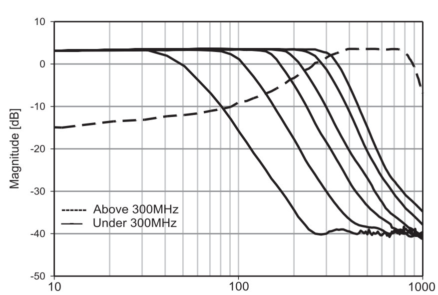

Fig. 6 Measured frequency response of the RF tracking filter.

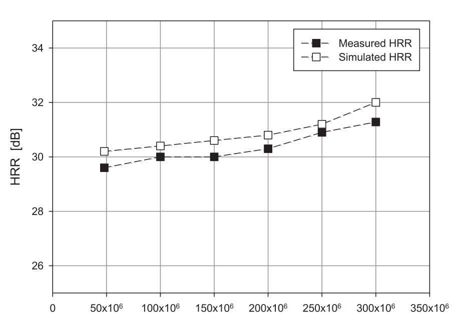

Fig. 7 Measured and simulated third order HRR versus channel frequency.

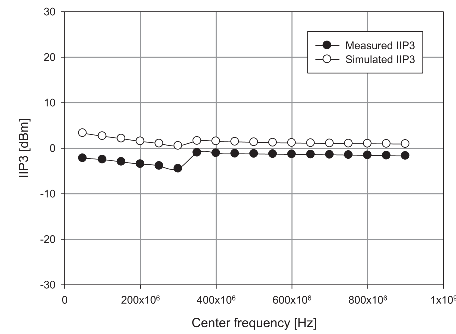

Fig. 8 Measured and simulated IIP3 versus channel frequency.

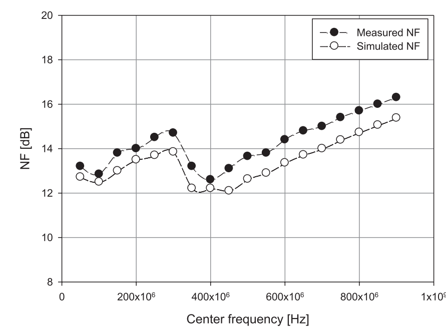

Fig. 9 Measured and simulated NF versus channel frequency.

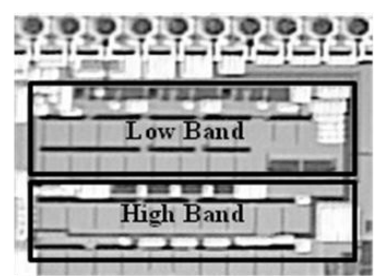

Fig. 10 Chip micro-photograph of the proposed RF tracking filter.

Table 1 Performance summary and comparison.

Parameter	This work		[2]	[6]	[7]	Units
Tech.	0.13		0.18	0.25	0.25	um
Filter type	LPF	BPF	LPF	LPF	LPF	-
HRR	30~32	/	30	/	/	dB
Freq range	48~300	300-860	50-300	80-200	30-120	MHz
OIP3	2.5	3	16.9	18	10	dBm
N	3	4	3	7	8	-
NF	13.7	14.4	14	-	-	dB
Power	46.8		72	210	120	mW
FOM	117		152	-	-	
FOM*	(2625)		(3675)	(1264)	(327)	

NF listed in this table is the average values for fair comparison.

$FOM = OIP3 \cdot f_{MAX} \cdot TR \cdot N / (F-1) Pdc$ [2]

FOM* (without NF)

be seen in Table 1, the proposed tracking filter shows good FOM with large tuning range, low NF under smallest power consumption.

4. Conclusion

In this paper, an on-chip active RF tracking filter was proposed and implemented in order to realize harmonic rejection and unwanted signal rejection for a DTV tuner. The proposed filter includes two paths: below 300 MHz, the tracking filter is implemented for harmonic rejection; above 300 MHz, the tracking filter is implemented for unwanted signal rejection to achieve better system performance. A third-order elliptic low-pass RF tracking filter based on a passive ladder architecture and a fourth-order G_m-C bandpass filter based on biquad architecture are implemented for low band and high band paths, respectively. The proposed RF tracking filter implemented with a 0.13 μm CMOS process requires no off-chip components. Measurement results show a wide frequency range (48~860 MHz) with low NF. The proposed RF tracking filter can suppress third-order harmonic mixing by 30~32 dB. The average NF, the maximum OIP3, and the power consumption (without buffer) are 13.5 dB, 3 dBm, and 46.8 mW (from a 1.2-V supply), respectively.

Acknowledgments

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) (No. R0A-2007-000-10050-0).

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