CMOS on-chip active RF tracking filter for digital TV tuner ICs

Y. Sun, C.J. Jeong, S.K. Han and S.G. Lee

A full frequency band active RF tracking filter design for a digital TV tuner is implemented for the first time. By combined control of the G_m and C values in the biquad of the G_m-C filter, the proposed tracking bandpass filter satisfies full frequency band tuning while maintaining narrow bandwidth. The G_m cell of the tracking filter is based on a dynamic source degenerated differential pair with optimised transistor size ratio, which provides good linearity and high-frequency operation. The fabricated tracking filter based on a 0.13 μm CMOS process shows 48–780 MHz tracking range with 15–60 MHz bandwidth, more than 50 dB of third-order harmonic rejection, 14 dB unwanted signal rejection at N + 6 channel offset, and a maximum IIP3 of 3.8 dBm at 4.7 dB gain while drawing 30 mA from a 1.2 V supply.

Introduction: Today's digital TV (DTV) standards cover a wide range of operating frequencies, from 48 to 860MHz. To develop a broadband DTV tuner, many challenging technical issues should be confronted, including harmonic mixing, image rejection, dynamic range, and linearity [1]. Unlike narrowband receivers, in broadband tuners, when receiving lower-band channels (48–288 MHz), the harmonics of the LO signal downconvert the higher-band channels (288–860 MHz). Harmonic rejection is thus an important feature of DTV tuners to secure downconversion of the lower-band channel signals [2]. Moreover, DTV tuners have high standards for selectivity and linearity. The bottlenecks in selectivity and linearity performances of DTV tuners arise mainly from TV broadcasting environments with a wide range signal strength. Therefore, the rejection of unwanted channel signals and harmonics is the main design concern of tuners. This problem has been resolved by the adoption of an RF tracking filter [1, 3, 4]. In typical silicon tuner architecture, the tracking filter is located between the LNA and a mixer. This Letter reports on the first implemented fully integrated active RF tracking bandpass filter that covers the full DTV frequency band with high linearity, wide frequency tuning range, and good harmonic and unwanted signal rejection ratio.

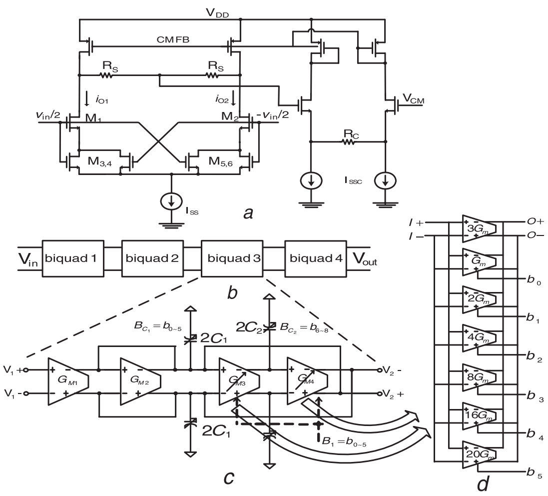

Fig. 1 *Proposed RF tracking filter design*

a Schematic of unit G_m-cell used in proposed RF tracking filter
b RF tracking filter architecture
c Biquad architecture
d G_M-cell in biquad

RF tracking filter 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. Fig. 1*a* 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 [5]. In Fig. 1*a*, 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. 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, this G_m-cell also exhibits good high-frequency performance, as no additional internal nodes are created in the circuit.

Fig. 1*b* shows the architecture of the proposed RF tracking filter, an eighth-order G_m-C based RF tracking filter that is implemented by a cascade connection of four biquads. The biquad based filter architecture is chosen considering the tunability and simplicity in analysis and control. Fig. 1*c* shows the architecture of the biquad, which can readily be cascaded for higher-order filters. As can be seen from Fig. 1*c*, the biquad consists of four G_M-cells ($G_{M1}-G_{M4}$) and four variable capacitors (C_1, C_2). In Fig. 1*c*, each biquad is designed to control the value of G_M (see Fig. 1*d*) and the capacitance (C_1 or C_2). From Fig, 1*c*, the transfer function of the biquad is given by:

$$\frac{v_2}{v_1} = -\frac{sC_2G_{M1}}{s^2 + s\omega_0 Q + \omega_0^2} \quad (1)$$

where the centre frequency, quality factor, and bandwidth are, respectively, given as follows:

$$\omega_0 = (G_{M3}G_{M4}/C_1/C_2)^{1/2} \quad (2)$$

$$Q = (1/G_{M2})[(G_{M3}G_{M4}C_1/C_2)^{1/2}] \quad (3)$$

$$BW = \omega_0/Q = G_{M2}/C_1 \quad (4)$$

From (2), the centre frequency of the filter can be tuned by controlling G_{M3}, G_{M4}, C_1, and C_2 of each biquad. In Fig. 1*d*, G_{M3} and G_{M4} can be varied in a binary weighted manner, where each G_m unit is based on the G_m-cell shown in Fig. 1*a*. From (2), a large value of G_M is required for high centre frequency. In the proposed tracking filter, considering the limited number of control bits (6 bits), variation of G_M is used for coarse tuning. For fine tuning, the value of C_2 is controlled by adopting a binary weighted capacitor array. Therefore, by a combination of G_M (active) and C_2 (passive) variation, the tracking filter can be tuned to cover the full frequency band (50–860 MHz) of a DTV tuner with sufficient frequency resolution. For the purpose of channel selection, the tracking filter not only requires a wide range of frequency tuning but also a constant bandwidth. From (4), in order to achieve a constant bandwidth, the quality factor of the filter has to be proportional to the centre frequency. In the proposed filter, from (4), a constant bandwidth can be achieved by maintaining a constant ratio between G_{M2} and C_1. In Fig. 1*c*, the value of C_1 is binary weighted with the same weightings as that of G_{M3} and G_{M4}, and controlled by the same control bits as that of G_{M3} and G_{M4} so that a constant G_{M2}/C_1 ratio can be maintained. However, in a real implementation, the filter bandwidth tends to vary, but mostly increases towards high frequencies, owing to the parasitic capacitances of the G_M-cell at the input and output nodes. In Fig. 1*c*, the input and output parasitic capacitances of the G_M-cell increase as more unit G_m-cells are turned on. The PVT variation is another cause of bandwidth variation. The linearity and noise performances of the filter tend to become poor with an increase in centre frequency owing to the higher Q-factor at high frequency. Based on the G_M-cell shown in Fig. 1*d* while adopting the unit G_m-cell shown in Fig. 1*a* with an optimised transistor size ratio, the proposed filter shows high linearity, high Q, and high frequency performances.

Measurement results: The proposed RF tracking filter shown in Fig. 1 was fabricated using a 0.13 μm CMOS process. The filter was designed to cover 48–860 MHz while drawing 30 mA from a 1.2 V supply, excluding a buffer that is added for the purpose of measurement only at the output. Fig. 2 shows the measured frequency and rejection characteristics of the filter for various centre frequencies. The proposed filter shows a tuning range of 48–780 MHz. At frequencies higher than 780 MHz, measurement shows oscillatory behaviour, which was not predicted by the simulation. This is attributed to the phase shift caused by the parasitic capacitances, which were not predicted owing to the inaccurate post-layout simulation. The 52–56 dB third-order harmonic rejection ratio (HRR) and 14–39 dB unwanted signal rejection ratio (URR) at N + 6 channel offset against the centre frequency are achieved. Fig. 3 shows the IIP3 and NF against the centre frequency. Owing to a higher Q-factor at high frequency, the linearity and noise performance of the filter are degraded at high frequency. Table 1 compares the performance of the proposed filter with that of other reported filters. The proposed RF tracking filter, which is implemented for the first time, shows good FOM with highest rejection ratio, and highest FOM* under lowest power consumption.

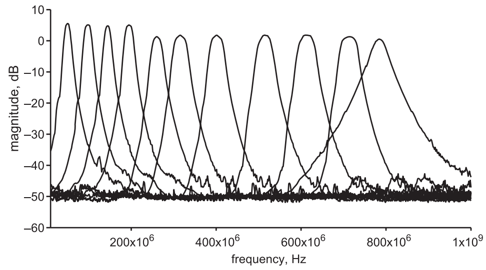

Fig. 2 *Measured frequency tuning and rejection performance*

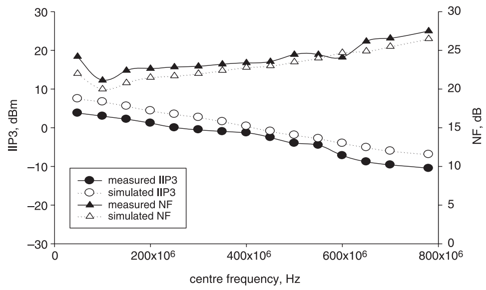

Fig. 3 *Linearity and noise performance against centre frequency*

Table 1: Performance summary and comparisons

Ref.	This work	[1]	[2]	[3]	Units
Tech.	0.13	0.18	0.18	0.18	μm
Filter type	BPF	BPF	LPF	BPF	–
HRR	50–56	30	30	32.9–40.8	dB
URR	14–39	No	No	No	dB
Freq. range	48–780	48–300	50–300	125–1060	MHz
OIP3	8.5	14	16.9	14	dBm
N	8	4	3	2	–
NF	24	17	14	18.2	dB
Power	36	–	72	138.6	mW
FOM (FOM*)	79.7 (19940)	–	152 (3675)	50 (3258)	–

NF listed in Table are average values for fair comparison
FOM = OIP3*f_{MAX}*(freq. range)*N/(F − 1)P_{dc} [2] (N is filter order)
FOM* (without NF)

Conclusion: An on-chip active RF tracking filter has been proposed and implemented for the first time to realise harmonic rejection and unwanted signal rejection for a DTV tuner. Based on the proposed active and passive tuning scheme with optimised unit G_m-cell design, the proposed filter shows a wide tuning range and high Q-factor with good linearity. The proposed RF tracking filter implemented with a 0.13 μm CMOS process requires no off-chip components. Measurement results show a wide frequency tuning range (48–780 MHz) with narrow bandwidth (15–60 MHz). The proposed RF tracking filter can suppress third-order harmonic mixing by 52–56 dB and unwanted signals by 14–39 dB, constituting the best rejection ability among all reported works. The average NF, the maximum OIP3, and the power consumption (without buffer) are 24 dB, 8.5 dBm, and 36 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).

18 December 2010
doi: 10.1049/el.2010.3552

Y. Sun, C.J. Jeong, S.K. Han and S.G. Lee (*Department of Information and Communication Engineering, Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Republic of Korea*)

E-mail: yixiusky@kaist.ac.kr

References

1 Lerstaveesin, S., Gupta, M., Kang, D., and Song, B.-S.: 'A 48-to-860 MHz CMOS low-IF direct-conversion DTV tuner', *IEEE J. Solid-State Circuits*, 2008, **43**, (9)
2 Kwon, K., Kim, H.T., and Lee, K.: 'A 50–300-MHz highly linear and low-noise CMOS filter adopting multiple gated transistors for digital TV tuner ICs', *IEEE Trans. Microw. Theory Tech.*, 2009, **57**, (2), pp. 306–313
3 Kanazawa, Y., *et al.*: 'A 130 M to 1 GHz digitally tunable RF LC-tracking filter for CMOS RF receivers'. IEEE Asian ASSCC, 2008, pp. 469–472
4 Sun, Y., Lee, J.S., and Lee, S.G.: 'On-chip active RF tracking filter with 60 dB 3rd-order harmonic rejection for digital TV tuners'. Int. SoC Design Conf., Busan, Republic of Korea, November 2008, pp. 406–409
5 Prodanov, V., *et al.*: 'A CMOS AGC-less IF strip for Bluetooth'. Proc. IEEE 27th European Solid-State Circuits Conf., Villach, Austria, September 2001, pp. 488–491