A New Method to Design Multi-Standard Analog Baseband Low-Pass Filter

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***Abstract*—Multi-standard transceivers allow to process different protocols in a single chip. These type transceivers need reconfigurable analog elements. In this work reconfigurable Analog Baseband low-pass filter is designed to support the application of Bluetooth, CDMA2000, Wideband CDMA, and IEEE 802.11a/b/g/n wireless LANs and 2G/3G/4G. The designed filter operates between 20kHz-40MHz. The filter is designed with cell-based variable transconductance amplifier. The minimum value of the designed filter's third order intersection point is 17.8dBm. The performance of the designed circuit is tested with TSMC 0.18µm technology in CADENCE environment.**

Keywords—ABB (Analog Baseband), cell-based Variable Gain Amplifier, Variable Transconductance Amplifier, cell-based Variable Transconductance Amplifier, Multi-standard Transceivers

I. INTRODUCTION

Many kinds of communication such as Wi-Fi, Bluetooth, Global Positioning Systems and so on require capability of transceivers to these communication standards. Generally, the commercial items must be compatible to the standards listed above. For example, cell phone transceivers must process all GSM, GPS, WCDMA, Wi-Fi (IEEE 802.11a/b/g/n), WiMAX, Bluetooth, Zee Bee, Ultra Wideband (UWB) and so on for more convenience. Such a transceiver named as multi standard transceivers can process all standards with a single chip by changing only software codes. This type chip production decreases cost and area. Software Defined Radio (SDR) transceivers provides these requirements [1].

The general aspect of conventional transceiver is given in Fig. 1. To design multi standard transceiver, LNA, local oscillators, mixers, filters and such architectures must be reconfigurable. For example, there exists a trade-off in IF selection due to the restricted IF choice of 10.7 or 71 MHz for commercial filters, a super heterodyne RX for multi-standard design normally constitutes a high cost for filtering at different IFs [2].

New trend to design transceivers is Zero-IF receiver which the incoming signal from the antenna is transferred directly to baseband without IF and channel selection. The input specifications for a flexible baseband low pass filter intended for a multi-standard zero-IF receiver are given in Table I.

Furthermore, analog baseband (ABB) [3, 4] has two main parts as low pass filter and programmable gain amplifier (PGA). Specially, low pass filter must provide different standard requirements to realize SDR transceivers. Because each standard has different channel bandwidth [5-8].

Some specifications of the ABB low pass filter for some technologies are given in Tab. 1. The main problem for designing reconfigurable ABB filter bring together the selection of the very low frequencies and the high frequencies. There are some designs in the literature to collect all these standards in a single filter, [10, 11].

Variable gain amplifier keeps constant the output power for different input signals. Analog signal controls VGAs, despite digital signal controls PGAs. As an extended summary of applications, variable gain amplifiers can be widely used in: WCDMA systems, Audio/Video analog signal processing circuits, Portable communication drivers, Hard disk drives, Medical equipment's, hearing aids, Imaging and wireless communications, Digital cable TV, satellite television, Wireless communication systems, wireless LAN, broadband residential communications, radio communicated system. There are some different methods to design VGAs, for example "cell-based" and "dB-linear" [7].

In this work, a new OTA realization method and its voltage mode reconfigurable ABB low pass filter is proposed for the application of Bluetooth, CDMA2000, Wideband CDMA, IEEE 802.11a/b/g/n wireless LANs and, also is suitable for other wireless applications as 2G/3G/4G. The recommended OTA circuit is based on cell-based variable transconductance amplifier (VTA). There are different examples of the variable transconductance amplifier are given those in [8, 9]. Cell-based VTA is inspired from cell-based VGAs [7]. The recommended circuit is very suitable for wide operation range, low power consumption and low occupation area.

Table I Input Specifications for a Flexible Baseband Low-Pass Filter Intended for a Multi-Standard Zero-If Receiver [4]

Standard	BW_{tot} [MHz]	Min. Attenuation [dB]	$V_{n,in}$ [μV_{rms}]	IIP3 [dBm]
Bluetooth	1	30 @ 1.5MHz	96-183	17.3
UMTS TDD	1.28	63 @ 3.84MHz	52-104	18.4
UMTS FDD	3.84	58 @ 11.92MHz	51-106	20.42
DVB-H	7.6	49.8 @ 19.8MHz	62-127	17.9
WLAN 802.11a	16.66	49.8 @ 48.6MHz	53-105	21.5
WLAN 802.11b	33.2	49.8 @ 96.6MHz	75-149	21.5

The key analyses (transient analysis for very low frequency, third order intersection point, noise analysis and harmonic distortion according to the input voltage swing) of the designed filter and comparison table with conventional designs are given in Fig. 10, 11, 12 and Table III, respectively. The performance of the designed filter is verified with TSMC 0.18µm in CADENCE.

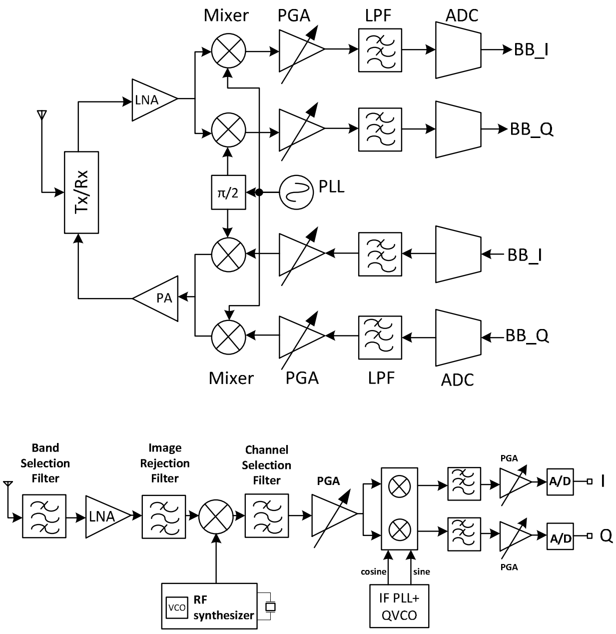

Fig. 1 The general structure of the transceiver and receiver.

II. Reconfigurable ABB Low-Pass Filter

The realization method of the cell-based variable gain amplifier is given Fig. 2. The very basic fully differential pair consists each unit cell. The different gain is obtained by activating different cell digitally. The gain of unique cell can be defined as "$g_m.r_o$". In this structure r_o is relatively constant according to the change of g_m. g_m is changed with V_{bias} and V_{CTRL} voltages.

VTAs can be considered as current mode version of the VGA. This cell based design can be applicable to cell based VTA. The overall cell based VTA CMOS structure is given in Fig. 3. The size of the transistors for Fig. 3 is given in Table II. Symmetrical OTA given in Fig 4 is used to implement each cells of cell-based VTA. Actually, there are some differences between cell-based VGAs and cell-based VTAs.

Firstly, OPAMP equation matrix gives $V_o= A(V_{in+}-V_{in-})$ and OTA equation matrix gives $I_o=g_m(V_{in+}-V_{in-})$. Because of the much higher input impedances of OTAs, the output current of OTA can not drive another input of OTA. Because of this reason, the cell output currents of the cell-based VTA must convert to voltage. R_1, R_2, R_3 and R_4 (10kΩ) are used to convert output current of each cells to voltage. MOS resistor can be applicable instead of these resistors.

Second, each cells in the cell-based VGAs can be randomly selected. But, each cells in the cell-based VTA can be respectively selected. As a result, the first cell is always activated.

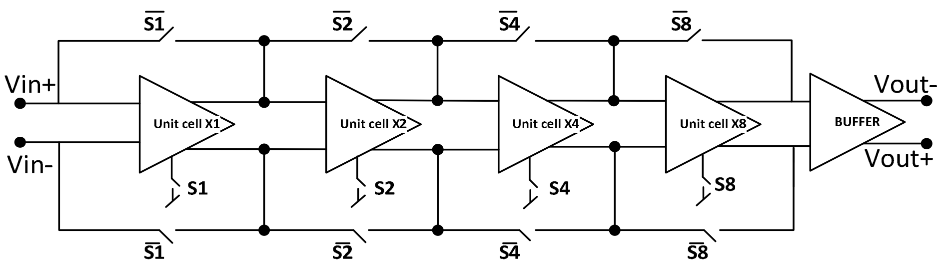

Fig. 2 The overall design "cell-based variable gain amplifier".

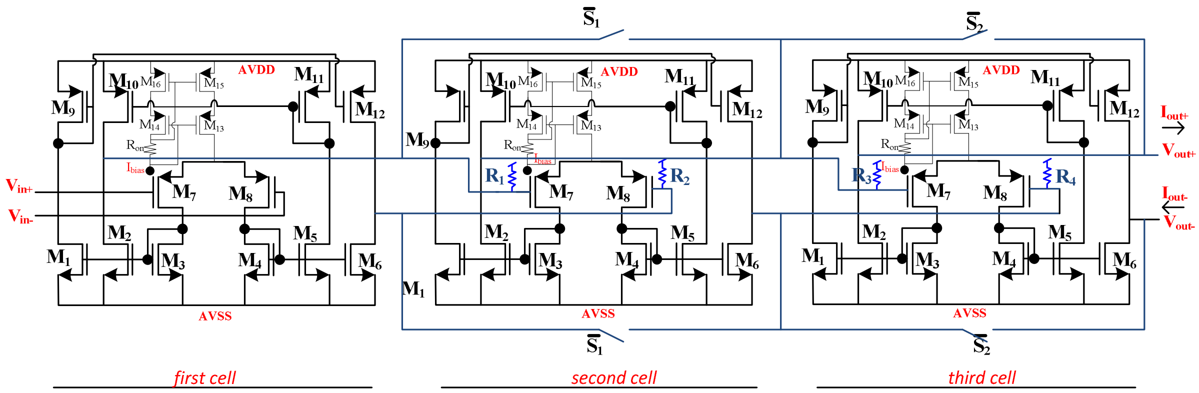

Fig. 3 The overall cascaded structure of cell-based VTA

The implementation of cell-based VTA structure is very appropriate to design reconfigurable g_m-C filter. First of all, the main purpose of multi-standard ABB low pass filter is "put together the very low frequency operations and high frequency operations 20kHz-40MHz. A single symmetric OTA can not reach this frequency range. There are lots of example, which has different techniques to realize multi-standard ABB low pass filter in literature [10, 11]. The proposed circuit has some good advantages as less die occupation, low power consumption and widen occupation frequencies for the application of Bluetooth, CDMA2000, Wideband CDMA, and IEEE 802.11a/b/g/n wireless LANs and, also is suitable for other wireless applications as 2G/3G/4G.

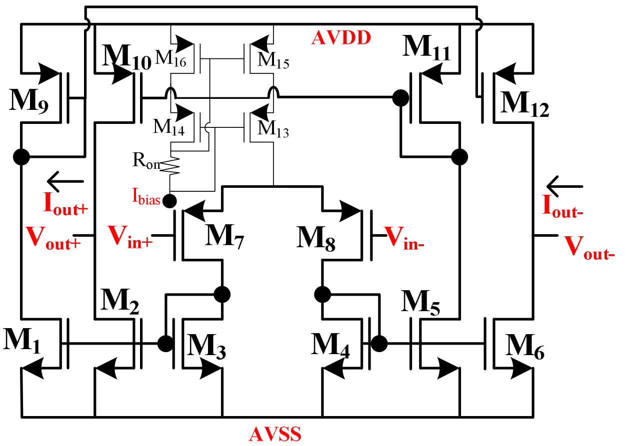

Fig. 4 The symmetrical OTA.

Second order low pass filter structure to design reconfigurable ABB filter is given in Fig. 5. This filter is voltage mode and has two grounded capacitors and two g_m blocks [12]. Low-pass filter transfer function, center frequency and quality factor are given in Equations 2, 3 and 4, respectively. C_1, C_2 are 5pF.

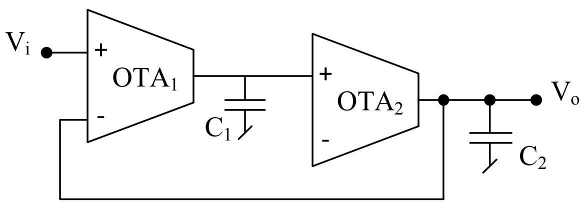

Fig. 5 Second order OTA based low pass filter

$$\frac{V_{LP}}{V_{in}} = \frac{g_{m1}g_{m2}}{s^2C_1C_2 + sC_1g_{m1} + g_{m1}g_{m2}} \quad (2)$$

$$\omega_0 = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}} \quad (3)$$

$$Q = \sqrt{\frac{C_2g_{m2}}{C_1g_{m1}}} \quad (4)$$

Table II The size of the transistors

TRANSISTORS	FIRST CELL	SECOND CELL	THIRD CELL
M1, M2, M5, M6	220nm/220nm	3µm/0.36µm	9µm/0.36µm
M3, M4	220nm/220nm	1µm/0.36µm	3µm/0.36µm
M7, M8	220nm/220nm	90µm/0.36µm	90µm/0.36µm
M9	220nm/220nm	10µm/0.36µm	10µm/0.36µm
M10, M11, M12, M13	660nm/220nm	9µm/0.36µm	27µm/0.36µm

Fig. 6 gives the results of the low pass filter's ac analysis for only first cell is active. f_{-3dB} frequency given in Fig. 6 changes between 20kHz – 800kHz. Fig. 7 gives the results of the low pass filter's ac analysis for double cell is active. f_{-3dB} frequency given in Fig. 7 changes between 1MHz – 10MHz.

Fig. 8 gives the results of the low pass filter's ac analysis for triple cell is active. f_{-3dB} frequency given in Fig. 8 changes between 10MHz – 40MHz. As a result, the low pass filter f_{-3dB} frequency range is 20kHz- 40MHz. The overall design of the designed filter's AC analysis is given in Fig. 9. The transient analysis for 10kHz is given in Fig. 10. The transconductance values of the designed cell-based variable transconductance amplifier change between 416nA/V-569µA/V.

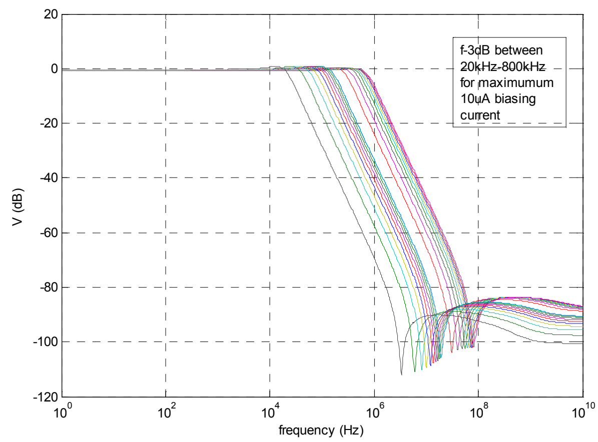

Fig. 6 AC analysis in the condition of unit cell is active

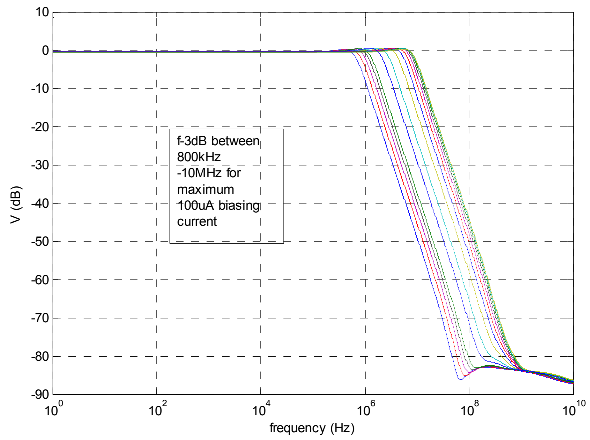

Fig. 7 AC analysis in the condition of double cell are active

The third-order input intercept point is shown in Fig. 11. The input 2-tone signal frequencies are 2MHz and 2.1MHz. The filter is operated in the second-order Butterworth. The IIP3 of 17.8dBm for in band is obtained with ±0.9V supply.

The input referred noise is given in Fig. 12. The total input referred integrated noise is calculated 44µVrms between 1kHz-40MHz.

The maximum output voltage harmonic distortion is measured as 3.2 % for 100mV input voltage amplitude at 2MHz center frequency. The total harmonic distortion according to the input level is given in Fig. 13. All simulations are performed in CADENCE environment with 0.18µm TSMC parameters. Table III shows the comparison of the designed filter with conventional designs. It can be easily seen that the designed filter has good advantages. The conventional design given in [4] has very benefits contrary to very huge die area occupation 1.56mm^2. The maximum expected chip area of the designed filter is only 0.2mm^2.

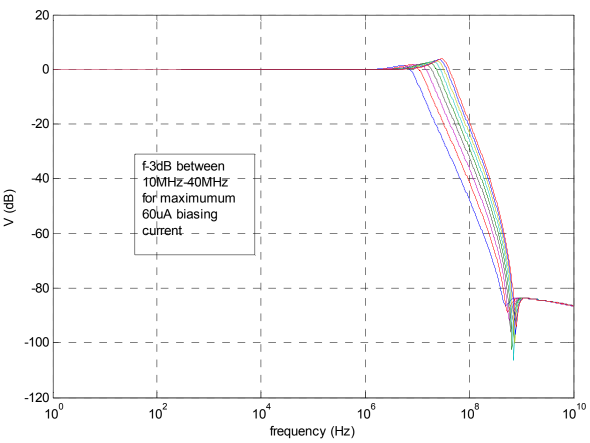

Fig. 8 AC analysis in the condition of triple cell are active

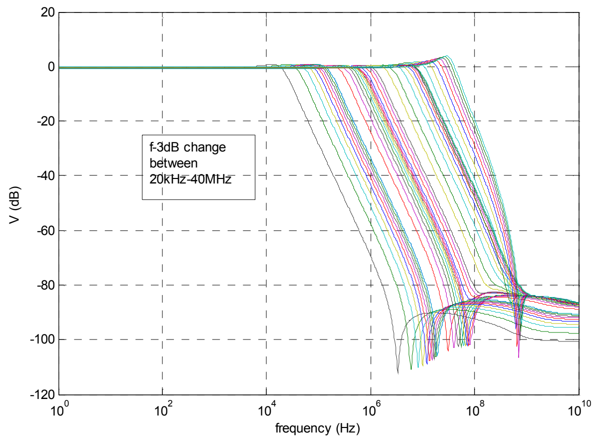

Fig. 9 The AC analysis of overall design

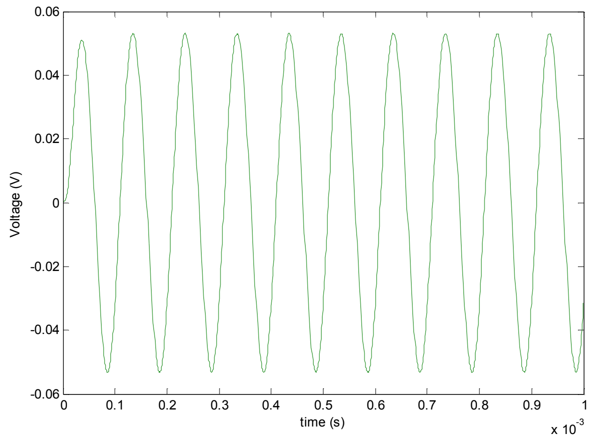

Fig. 10 Transient analysis for 10kHz

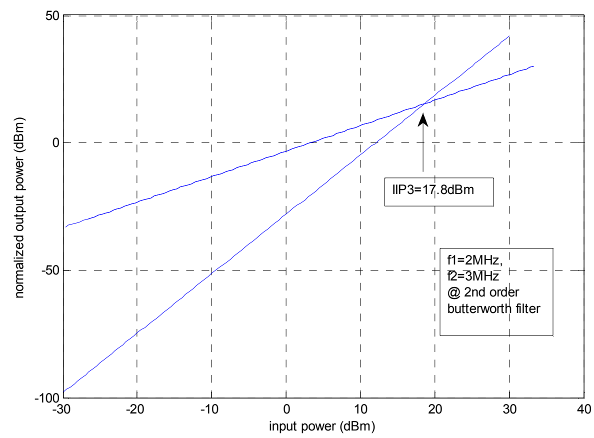

Fig. 11 The third-order input intercept point

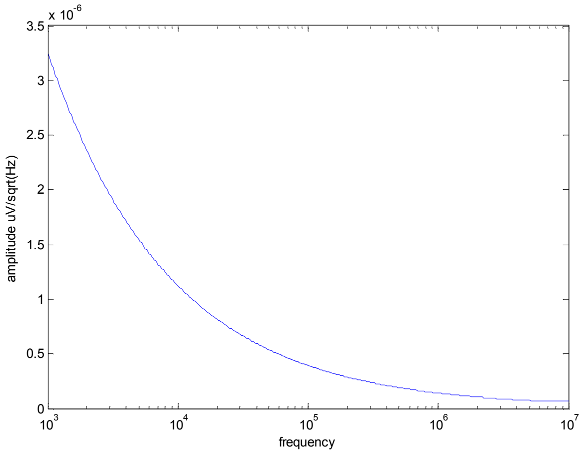

Fig. 12 The input referred noise

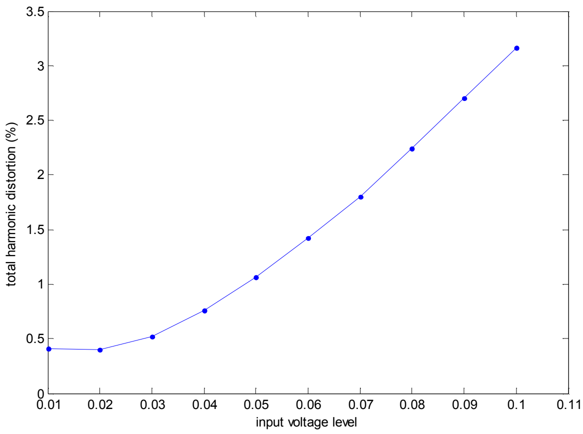

Fig. 13 Total harmonic distortion at 2MHz for maximum 100mV input voltage

Table III The Comparison Of The Designed Filter With Conventional Designs

	Technology	Power-Supply Voltage	$f_{co,min}$-$f_{co,max}$	Noise	IIP3(dBm)
This Work	0.18µm	4.75µW to 3.09mW @ 1.8V	20kHz-40MHz	44µV_{rms}	17.8
[4]	0.13µm	0.36mW to 13.5mW @1.2V	0.18MHz-200MHz	$12nV/\sqrt{Hz}$ to $40nV/\sqrt{Hz}$	9.96
[13]	0.25µm	70mW @3.3V	60MHz-350MHz	257µV_{rms}	n.r.
[14]	0.18µm	10-15mW @ 1.8V	1.5MHz-12MHz	150µV_{rms}	7.2-9.3
[15]	0.13µm	3.4 -14.2mW @1.2V	2.1MHz-11MHz	57µV_{rms}	21

CONCLUSION

In this work, second-order butter-worth low-pass filter is designed. Instead of conventional operational transconductance amplifier cell-based variable transconductance amplifier is used for CMOS implementation. The total input referred integrated noise is calculated as 44µV_{rms} between 1kHz-40MHz. The total harmonic distortion at 2MHz for maximum 100mV peak value is %3.2. The designed reconfigurable filter supports the operating frequencies of the applications {Bluetooth (650 kHz), CDMA2000 (700 kHz), Wideband CDMA (2.2 MHz), IEEE 802.11a/g (10 MHz), IEEE 802.11b (12 MHz), IEEE 802.11n (20 MHz) wireless LANs, 2G (93kHz-340kHz), 3G(HSPA SC/DC 1.92MHz-4.42MHz) and 4G(LTE 1.4M~20MHz)}. The expected layout of the designed filter is 0.02mm^2. The designed second order filter can easily improve for sixth order filter implementation. The simulations are realized with TSMC 0.18µm CMOS technologies.

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