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Low Power CMOS LNA and Mixer Design

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ABSTRACT: *A CMOS LNA design and Gilbert double balanced mixer design for indoor wireless application are presented in this paper. The LNA is designed with current reused technology for lowering the dc power consumption, and the current-bleeding approach is adopted in mixer design for boosting its conversion gain, respectively. The Narrow band LNA achieves the gain of 20dB with noise figure of 1.5dB at 787MHz. The power consumption of LNA is 21.793µW. The proposed Gilbert double balanced mixer achieves the conversion gain of 13.365dB with Noise Figure of 2.12db and IIP_3 as -2.8634dB for intermediate frequency of 100 KHz to 100MHz.*

I. INTRODUCTION

The rapid evolution of the wireless communication world has resulted in a tremendous amount of research on building high-performance RF circuits in various technologies. Comparatively, CMOS is particularly attractive for its low cost and high level of integration. The purpose of this work is to develop a CMOS receiver front-end operating in the frequency band in the range of 787MHz-887MHz for radio communication; International Mobile Telecommunications-2000 (IMT-2000) systems are third generation mobile Systems. In this paper, we propose a 0.1µm wide band, narrow band LNA and mixer, employing no external component and targeting the IMT standard. This poses a requirement of a low power CMOS receiver especially for the front-end LNA, which has to provide high gain with reasonable noise figure (NF) and impedance matching. The wideband amplifiers were implemented with balanced or distributed architectures that were originally used in microwave circuit design. However, large area and high power dissipation of the travelling-wave amplifier make it infeasible for low-power single-chip integration. So, a distributed amplifier has been designed, which achieves comparable performance with lumped design in terms of power and area consumption. The narrow band LNA uses an inductively degenerated input stage and an LC load. The inductive degeneration is used to enhance the transit time effects. The mixer follows the LNA directly on-chip and is based on a Gilbert cell. The power reduction technique consists of the use of PMOS and NMOS transistors, in parallel configuration, as the input stage of the mixer. The mixer is a critical building block which set the receiving linearity of the overall system. As a three-port device, Mixer multiplies two signals in time domain. It assumes that both sinusoidal type signals input to a multiplier, and then the output of the multiplier can get sum frequency component and difference frequency component. The nominal voltage supply, in the design, is set to 1.1V.

II. DESIGN OF A LOW NOISE AMPLIFIER

A low noise amplifier (LNA) is the first stage of any RF receiver. The signal received at the antenna of the receiver is comparatively weak so good gain and noise performances are necessary requirements for LNA. Its main function is to provide enough gain to overcome the noise of the subsequent stages. The noise factor of receiver front end is given by Friis' formula.
[Reference: A Novel Approach for Radio Frequency Front End as Part of System-On-Chip in Digital MOS Technologies, Gilles Petit, Richard Kielbasa, and Vincent Petit, IEEE journal, 2004].

$$NF_{rec\_front}=(1/G_{LNA})\,(NF_{subsequent}-1)+NF_{LNA} \qquad (1)$$

Where, NF_{rec_front}= Noise factor of receiver front end, G_{LNA}= Gain of LNA, $NF_{subsequent}$= Noise factor of components following LNA, and NF_{LNA}= Noise factor of LNA. From equation (1), we can infer that if the gain of LNA is very high then the noise factor of subsequent stages can be made negligible. The noise factor of receiver front end depends only on the noise factor of the LNA. Hence a trade-off between the gain and noise of the amplifier should be considered.

LNA Design: The issues to be considered for LNA design are:

i. The frequency response should be flat over the entire tolerance bandwidth.
ii. Low noise characteristics over the bandwidth.
iii. Matching networks at input and output for maximum power transfer.
iv. Stability, over the bandwidth.

Circuit description: Two types of LNA circuits are presented here

i. Wide band LNA
ii. Narrow band LNA

i. Wide band LNA

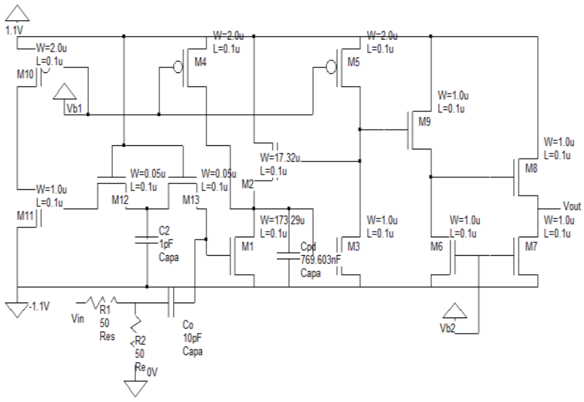

Fig 1: Wide band LNA design

Fig 1 shows schematic of Wide band LNA circuit, here: M1 transistor is a simple common source transconductance structure. To reduce the miller effect of M_1 we use M_2, M_4, and M_5 which form a shunt-shunt feedback and also improve the impedance. M_{12} and M_{13} are made to operate in triode region and they act as the resistors. M_{10}, M_{11}, M_{12} and M_{13} form an input bias circuit, whereas M_1, M_2, M_3, M_4 and M_5 form an amplifier core, and M_6, M_7, M_8 and M_9 form output buffer circuit.

ii. Narrow band LNA

Fig 2 shows circuit designed for Narrow band LNA, here: M_1, M_2, M_3 and M_4 form differential cascade pair. LC tuning circuits are used at the input and output for improving the circuit performance such as Noise Figure and Gain. The inductance values are calculated from the given unity gain frequency and Noise Figure.

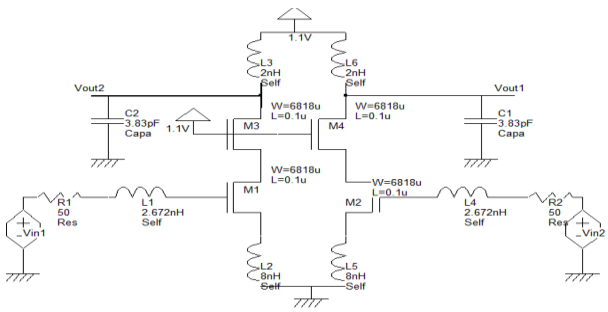

Fig 2: Narrow band LNA

III. DESIGN OF A MIXER

Definition: A mixer is a frequency converter with certain gain. We have designed Gilbert double balanced mixer as it has required gain.

Advantages over single ended mixer:

i. The feedthrough from V_{lo} and V_{rf} will not get propagated to the output.
ii. The mixer's gain is doubled compared to that of single balanced case.

Mixer Specifications:

1. Conversion Gain: The ratio of the output signal amplitude at w_{if} to the input signal amplitude at $w_{rf.}$.

$$G_c = 4/\prod (g_m * R_l)$$

2. Distortion: This is specified by the IIP_3 and NF of a mixer. It is defined for two cases:

1. Low frequency case: The capacitance and inductance effects can be neglected, then the quad switching pair transistors are either completely turned on or off so they do not contribute distortion. The source coupled pair which performs the V-I conversion contributes for distortion because it is dominated by the nonlinear square law I-V characteristics of the MOS transistors biased in saturation.

$$I_{rf} = 0.5k\,(V_{GS} - V_t)^2$$

1. Third order Harmonic Distortion (HD_3): It is defined as the ratio of the third order term to that of the fundamental term.

$$HD_3 = (I_{rf}|3^{rd}\text{ order term})/(I_{rf}|\text{fundamental term})$$

$$HD_3 = 0.03125A_{rf}^2/(V_{GS}-V_t)^2$$

2. Third order Inter Modulation product (IM_3): Intermodulation arises when more than one input is present at the input. It is the ratio of the amplitude of third order term to the amplitude of fundamental term of the output current.

$$IM_3 = I_{D3}/I_{D1}$$

$$IM_3 = 3HD_3$$

$$IM_3 = 0.09375A_{rf}^2/(V_{GS}-V_t)^2$$

3. Third order Intercept point (IP_3): The intersection point of the third order product curve to that of the desired signal line.The amplitude of the input interferer at the third order intercept point A_{IP3} is:

$$A_{IP3} = \sqrt{(1.33|\alpha_1/\alpha_3|)}$$

$$(IIP_3 = P_i-(IM_3/2))\text{ dB}$$

2. High frequency case: The capacitance and inductance effects cannot be neglected. The nonlinear (C_{sb} and C_{db}) and linear (C_{gs} and C_{gd}) capacitors are used for the calculation of distortion due to nonlinear components.

$$HD_3 = 0.03125A_{rf}^2\ (k/I_{ss})$$

$$IM_3 = 0.09375\ (A_{rf}^2/(V_{GS}-V_t)^2)*[|1-0.333(jw_1C_d/(k(V_{GS}-V_t)))|]$$

1. Noise Figure (NF): The ratio of SNR at input to that of the output.

$$NF = 1+(N_{dev}/N_{Rs})$$

$$N_{Rs} = 4KTR_s$$

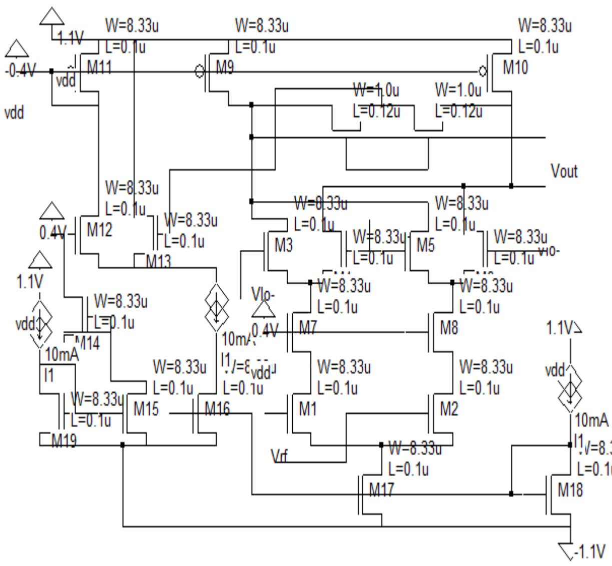

Fig 3: Gilbert Double Balanced Mixer

Circuit description: Fig 3 shows the circuit designed for Gilbert double balanced mixer, here: The transistors M_1, M_2, M_{17}, and M_3-M_6 form the basic quad pair of the Gilbert Mixer. M_7 and M_8 transistors are used between M_1-M_2 and M_3-M_6 transistor pairs for providing isolation between the RF and LO ports. M_9-M_{10} transistors act as the current sources which operate in saturation region for a given bias voltage respectively. M_{20}-M_{21} transistors are biased in triode region and used as loads. The resistance of these transistors is small than the resistance of current source transistors. M_9, M_{10}, M_{11}, M_{12}, M_{13} form Common Mode Feedback Loop (CMFL) to control the variations in the level of V_{center} of V_{out+} and V_{out-}. Current sources are used for proper biasing of the transistors.

IV. Results:

1. Wide band LNA: In the above Fig 1 v_{in} (input RF signal) is applied to M_1 through the R-C network and output v_{out} taken at the buffer circuit through drain of M_7. From Fig 4 the v_{in} peak voltage is 2V and the resultant v_{out} peak voltage is 5V. The Wide band LNA is designed for 787MHz centre frequency, with NF of 2dB, gain of 26.02dB, power consumption of 1mW for 173.29µm/0.1µm aspect ratio.

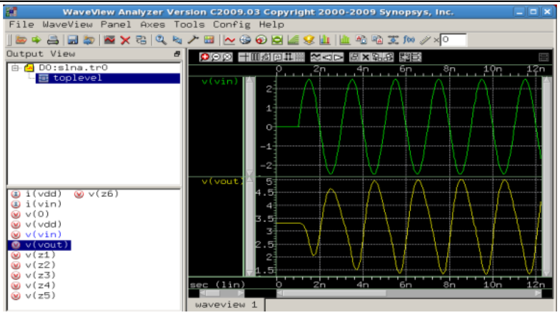

Fig 4: Wide band LNA

2. Narrow band LNA: In Fig 2 the input (RF signal) v_{in1} and v_{in2} are applied to M_1 and M_2 respectively and output is taken at drains of M_3, M_4. The Narrow band LNA is designed for 1GHz unity gain frequency, with NF of 1.5dB, power consumption of 21.793µW for 6818µm/0.1µm. From Fig 5 the differential peak-peak input voltages of v_{in1} and v_{in2} is -1V to 1V and the resultant peak-peak voltage is from -1V to 4V.

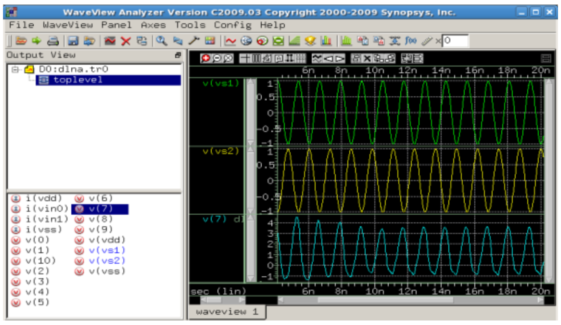

Fig 5: Narrow band LNA design

3. Mixer: In Fig 3 the RF output from LNA is given to M_1 and M_2 and the local oscillator (LO) input is applied to the switching transistor pair M_3, M_4, M_5 and M_6. The IF output is taken at the drain of M_9 and M_{10}. The Double Balanced Gilbert Mixer has been designed for local oscillator frequency of 787MHz and different radio frequencies in a band resulting in different intermediate frequencies of 100KHz to 100MHZ with NF of 2.12dB, third order harmonic distortion of -15.2644dB and conversion gain of 13.65dB for 8.33µm/0.1µm aspect ratio. The waveforms of the mixer are shown in Fig 6, Fig 7, and Fig 8 for 100MHz, 500KHz, and 100KHz respectively.

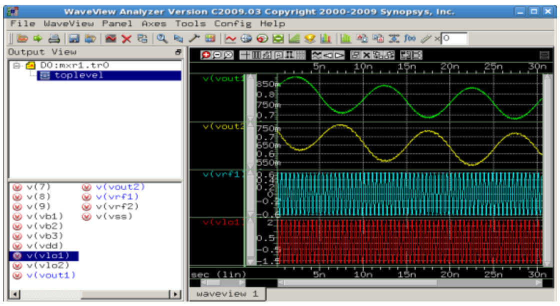

Fig 6: Mixer with intermediate frequency of 100MHz

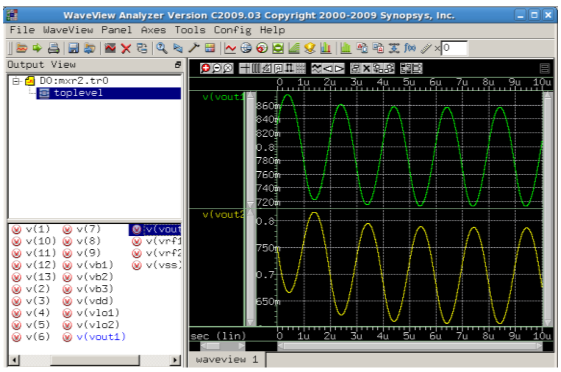

Fig 7: Mixer with intermediate frequency of 500KHz

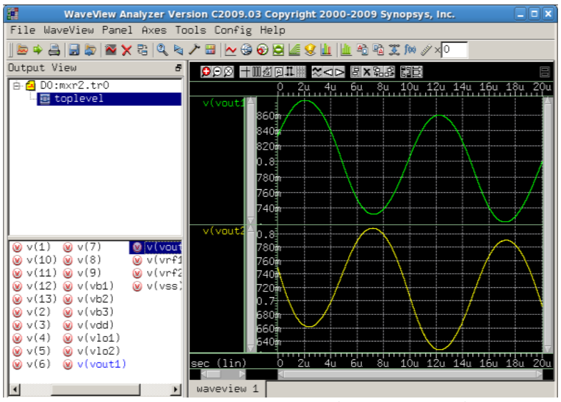

Fig 8: Mixer with Intermediate frequency of 100KHz

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