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UWB Mixer improvement with Regulated Voltage Source

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ABSTRACT

This paper presents a design of an UWB downconversion integrated CMOS resistive ring mixer with Linear Voltage Regulator (LVR), to supply required biasing voltages for the mixer section. The designed mixer circuit has been optimized for using in heart rate extraction system with microwave Doppler radar at 2.4GHz frequency. This mixer needs 2 DC bias voltages equal to 0.5 and 1 volts for its best operation. The designed LVR circuit would supply needed bias voltages. This mixer is called UWB and the changes in its necessary bias voltages would result in its weak operation. The design has been implemented in TSMC 0.18μm CMOS technology and simulated by Advanced Design System (ADS) software. Simulation results indicate good operation of regulator and mixer output during input changes.

1. Introduction

UWB has many potential applications to be researched. Some unique features of UWB make it very suitable for medical areas, such as medical monitoring, and medical imaging.

Designing a wide bandwidth RF component using traditional narrowband matching techniques on mixers would be difficult, so wideband matching techniques should be used [1]. Ultra-wideband (UWB) communications is fundamentally different from all other communication techniques because it uses very narrow RF pulses to communicate between transmitters and receivers. The design of wideband RF components using narrowband matching approaches on mixers is a completely complicated issue; thus it is needed to use other designs including distributed structures, negative feedback, or wideband techniques. Distributed structures using Gilbert cell structures have been reported in [2-3]. There are some bad traits in distributed architectures. The first one is high power consumption. The second one is large area due to the many lumped components needed in each stage of circuit. The next approach to achieve wideband operation is to use matching circuit in RF, IF, and LO ports in Gilbert cell mixer structure. Designs of these circuits can be seen in [4]-[8]. All of these mixers are Gilbert cell mixers. Another kind of mixer is resistive mixer. The previous reports can be found in relation to these kind of mixers in [9]-[13], and [14]. In spite of a resistive mixer has conversion loss, it has two advantages in comparison to active mixers. First, it doesn't have any power consumption that makes it suitable for low consumption circuit design. Second, it has a better linearity in comparison to active mixers.

One of the most attractive applications of UWB mixers is to use it in contactless heart rate monitoring by Doppler radar. The main part of the heart rate extraction system by using microwave Doppler radar is its mixer section, because all obtained data and their accuracy are achieved with respect to exact output of down-converted wave.

In this paper, for integrating mixer circuit with necessary voltage sources, two circuits has been used, one of them is used for the mixer and the other one is used for LVR. The reasons for selection of each circuit are described in its special section of that circuit.

This paper is organized as follow. At the first section, mixer and the reasons for its selection will be discussed. At second section, LVR choice, optimizations and circuit changes are explained. At the third section, the design of integrated circuit is covered. In each section, simulation results are presented and compared with other related works. In this paper, the circuit has been designed in CMOS 0.18µm technology, focused on 2.4GHz RF frequency.

2. MIXER

Resistive mixers employ the time-variant channel resistance of transistor for mixing process. When transistor is biased at linear region with channel resistance modulated by the LO signal, behaves like a variable resistor. When the gate voltage is below the turn-on voltage, the channel resistance is high. By increasing gate voltage, the channel resistance will be decreased. The mixing product of the RF signal and the LO signal generates the desired IF signal. The bandwidth of resistive mixer is basically controlled by turn-on resistance and its capacitor. Turn-on resistance is usually small for CMOS technology. For a NMOS transistor with 20µm/0.18µm dimension ratio, the turn-on resistance is about 10Ω [1].

It can be seen that the importance of receiver part especially mixer is one of the hot issues in recent research studies [8], [15], and [16]. Hence, in this paper the design and optimization of the mixer, for receiving part with the aim of more integrating circuits and to smaller the size of the system, due to the portable nature of the system has been discussed. By choosing a suitable mixer for the intended application, it designed in 0.18µm CMOS technology, and for required biasing of this circuit an LVR section designed and integrated with the mixer. The need of being smaller in this system is due to the portable nature in emergency cases. In recent researches, due to the benefits and obligations that exist e.g. in the security of body tissues exposed to radio waves [17], thus 2.4GHz frequency has been selected for optimization and simulation in this article as it was in more than 90% of projects and papers related to this subject.

Given the above, resistive ring mixer designed in [1] has been chosen for the mixer section of the integrated circuit in this article. This mixer downconverts RF signal to a fixed IF 500MHz, using LO signals. In the mentioned circuit, broadband compliance in RF port and source follower as output buffer in IF port have been used to achieve broadband frequency response. Output buffer stage uses 3mW which is much lower than previously published active mixers. Figure 1 shows a schematic of the resistive ring mixer [14]. In this mixer, due to better isolation between ports and elimination of even-order harmonics double-balance loop structure has been used.

In RF port, 1.4nH series inductors and 90fF parallel capacitors are used for matching. In addition, 250Ω parallel resistors are used for improving broadband matching. In IF output port, since required lumped elements for impedance matching (50Ω) may occupy much space on the chip at 500MHz IF, source followers are used for 50Ω impedance matching. Parallel capacitors to ground are used for short circuit of LO and RF signal to the ground and modifying the isolation of LO-to-IF, and RF-to-IF. DC blocking capacitors are embedded as series for blocking source follower biases from resistive mixer core.

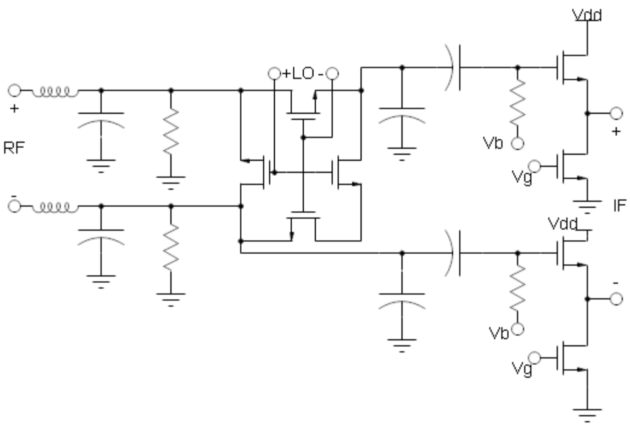


Figure1: Schematic of resistive ring mixer

The mixer with following values was used in this paper:

Three DC biases are required for the operation of this circuit that their preparation in fixed and regulated form is the main purpose of this paper. Optimum values for V_b, V_g, and V_{dd} are 0.5V, 0.5V and 1V respectively. Change in V_{dd} value less than this amount would increase the loss [1]. Figure 2, shows the effect of V_{dd} voltage change on the IF output which has been obtained through simulation with ADS software. Figure 3 shows simulation results of this mixer with the ideal bias resources.

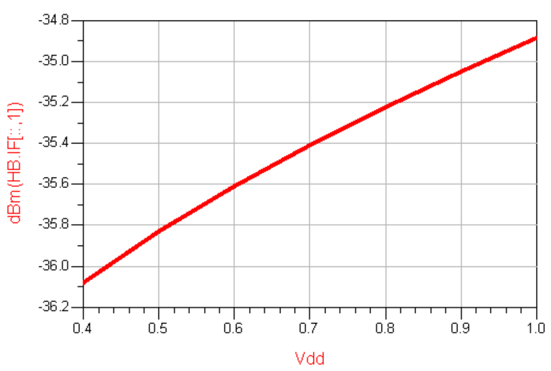


Figure 2: Variation of output power versus V_{dd}. LO-power = 5dBm at 2.9GHz and RF-power = -6dBm at 2.4GHz.

In the following sections, after introducing LVR and its simulation results, the fully simulated system including LVR and mixer was provided in integrated form and its results were compared to ideal bias condition. It can be seen that this mixer has successfully down converted RF wave to IF frequency. Then, LVR circuit designed to supply the required bias of this mixer will be introduced. It can be seen that by the mentioned design in this task, separate application of V_b, V_g and V_{dd} voltages to the mixer has been removed and only one 1.8V input voltage is sufficient for the circuit. With monolithic integration of voltage regulator and mixer, chip area decreases and the effects of feeding changes on circuit performance will be reduced and performance improvement will be achieved. Thus, it is made appropriate for portable and compact systems.

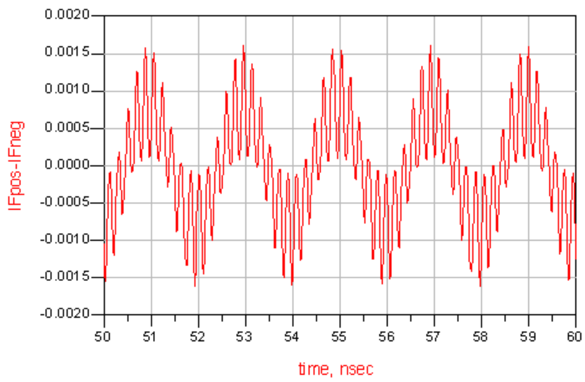


Figure 3: Mixer's simulation results with ideal bias sources in ADS simulation software; voltage ranges of IF output signal at 500 MHz frequency derived from local oscillator frequency at 2.9GHz and RF frequency at 2.4GHz.

3. Linear Voltage Regulator

The linear voltage regulator should provide voltage sources to bias different parts of circuit. Linear voltage regulators should withstands against differences in voltage input line and also load current fluctuations and delivers a constant output to circuit, because if these changes are transferred to the output regulator circuit, it may cause deviations from the optimal bias point of circuit and it may even endanger the linearity of circuit. Therefore, power providing system should have less impact on the linearity due to these differences.

Classical designed topologies for creating a stable voltage source is linear and is based on switching voltage regulators. Switching regulators offer a complex topology due to their control systems and generally require more power consumption and occupy larger silicon area which causes more noise in regulated output due to switching performance. Low-dropout linear voltage regulator (LDO) is one of the most popular power converters used in power management and it is much more suitable for the heart rate extraction system based on using microwave Doppler radar. In linear regulators, output voltage is monitored and compared with a voltage reference through an error amplifier. Amplified output directly acts on the pass element which no output voltage fluctuations should exist in its normal operation. Passed elements can be implemented using MOS transistors or bipolar ones. Since the MOS transistor is controlled by its gate voltage, thus, it benefits the lower power consumption, and consequently higher efficiency for voltage regulator. Since gate voltage is lower than source voltage, the appropriate selection for low voltage systems use a PMOS LDO. Mixer required voltages in this paper are 1V and 0.5V which should be made by the LVR in regulated form. Linear voltage regulator presented in reference [18] has a regulated output of 1V. This circuit has been designed and implemented in 0.35µm CMOS technology. In this paper, the mentioned circuit has been varied and optimized in order to provide 1V and 0.5V voltages in 0.18µm CMOS technology. Figure 4 (a) shows voltage references section, Figure 4(b) OTA, resistance sampler and output of voltage regulator specialized for the resistive ring mixer as described in the previous section.

LVR circuit requires two reference voltages, V1 and VREF. The V1 reference is necessary to bias source follower stage provided by MNFOL. The VREF reference is used to obtain the LVR output on closed-loop system.

$$V_{OUT} = \left(1 + {R_1}/{R_2}\right) V_{REF} \tag{1}$$

The core of this integrated circuit is the self-bias current mirror formed by MN1, MP1, MP2, and Q1. In the circuit of reference [18], three mirrors are used to achieve the 2V voltage for V1 , but in this study in a new design according to the used technology, the need of 2V voltage for V1 was eliminated and 1.4V voltage was obtained using two branches of current mirror. In this design, one 1.4V voltage is adequate for biasing the source follower stage (MNFOL). This reference voltage is obtained by equation (2):

$$V_1 = V_{EB}(Q_2) + V_{EB}(Q_3) = 2V_{EB} \cong 1.4V \tag{2}$$

VREF is concluded from Q2 transistor VEE which uses one composed structure of two MOSFET transistors, MN2 and MN3. Combined MOS transistor improves voltage reference PSRR. The topology is shown in Figure 5. Based on this structure, the relationships of currents are as follows [18]:

$$I_D(MN_2) = I_D(MN_3) \tag{3}$$

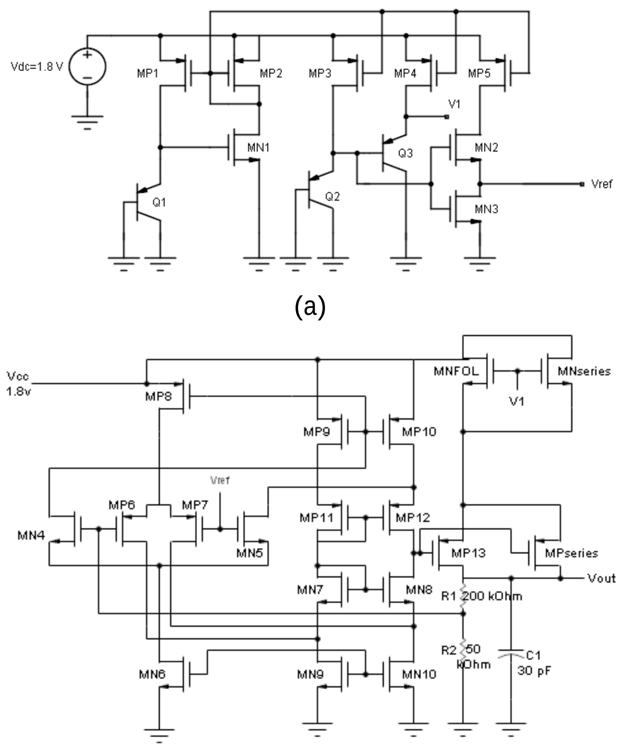
$$I_X\left(\frac{W}{L}\right)_1 exp\left[\frac{V_{EB}-V_{REF}-V_{THO(N)}}{nU_T}\right] = \beta_N\left(V_{EB}-V_{THO(N)}\right)^2(1+\lambda_N V_{REF})$$

Apart from the term $\lambda_N V_{REF}$, equation (3) can be written as follows:

$$V_{REF} = V_{EB} - V_{THO(N)} - nU_T ln\left[\frac{\beta_N\left(V_{EB}-V_{THO(N)}\right)^2}{I_X\left(\frac{W}{L}\right)_1}\right] \quad (4)$$

VREF accepted as 200mV and W/L of transistors was determined based on this voltage. Using equations (1) and (2), the sampler resistors values were calculated.

$$1V = \left(1+\frac{R_1}{R_2}\right)0.2 \rightarrow \frac{R_1}{R_2} \cong 4 \quad (5)$$



(a)

(b)

Figure 4: (a) Voltage references of specialized linear voltage regulators, (b) OTA and the resistive sampler and regulator output.

R_1=200 kΩ and R_2=50 kΩ were selected for sampler resistors. To supply enough current for output transistors, one transistor was paralleled with each of MN_{FOL} and MP_{13} transistors. The results of simulated circuit are shown in Figure 6. As it is shown in figure 6, the designed circuit provides the required outputs with high accuracy. The required 1V voltage has been made with the amount of 994.7mV along with 1000 volt changes, which caused by V_{REF} and V1 voltages with 200mV and 1.4V respectively which in this paper obtained at 199.3mV and 1.432V.

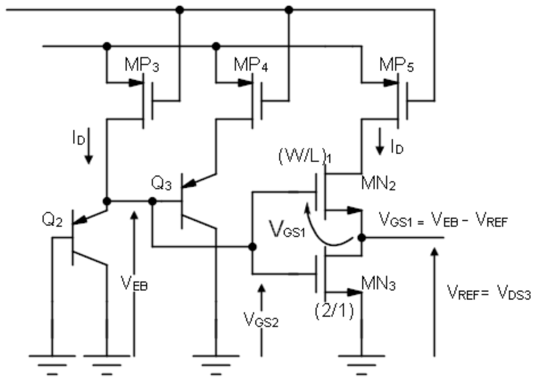
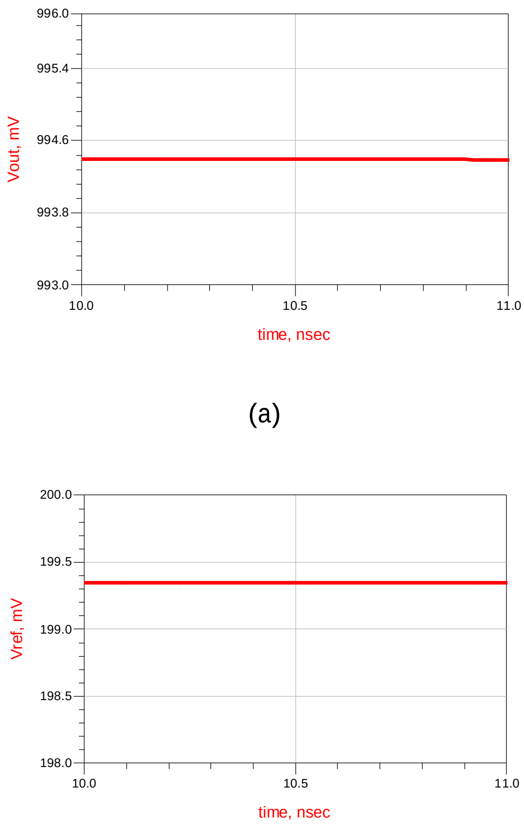


Figure 5: Composite structure of two NMOS transistors to produce VREF.



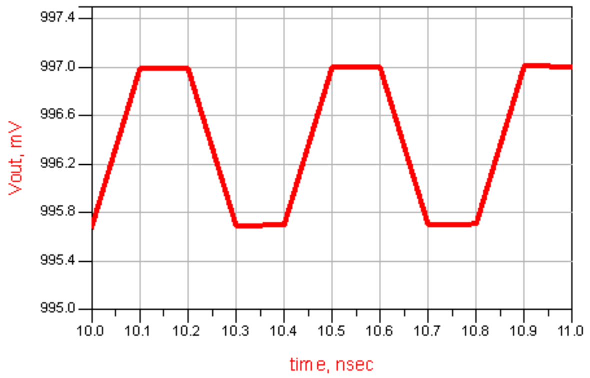
(a)

(b)

Figure 6: Simulation results of generated voltages by LVR

To be ensure about good regulation of generated voltages, by adding a pulsed voltage source of 0.3 V at 2.4GHz frequency to the input of LVR circuit, its insignificant impact on output (in the millivolt), was obtained. The simulation results are shown in Figure 7.

The obtained results of simulation shows that adding a pulsed source to feeding circuit with 0.3V amplitude can cause very little regulated output changes in the millivolt range. This feature gives us the confidence that in the case of any change caused by noise or other factors in the power supply, the output is stable and mixer performance is approximately unchanged.



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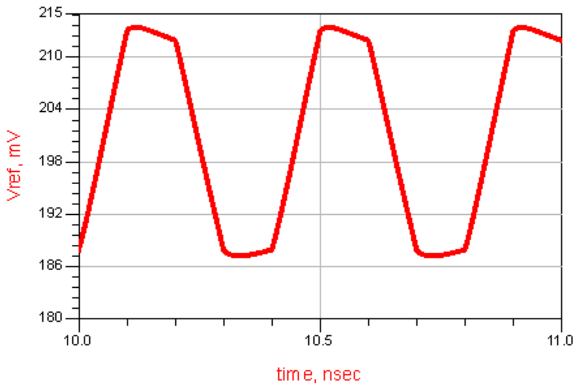


(b)

Figure 7: Simulation result of LVR voltages during changes at input as large as 0.3v.

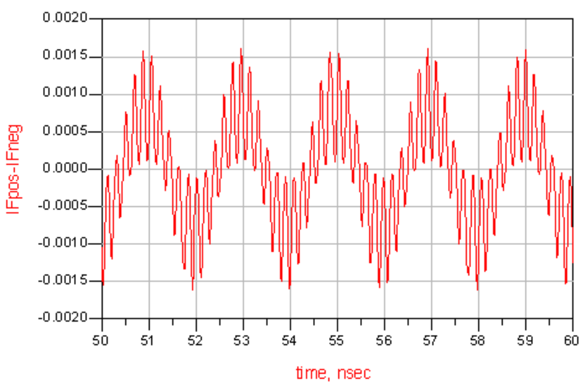
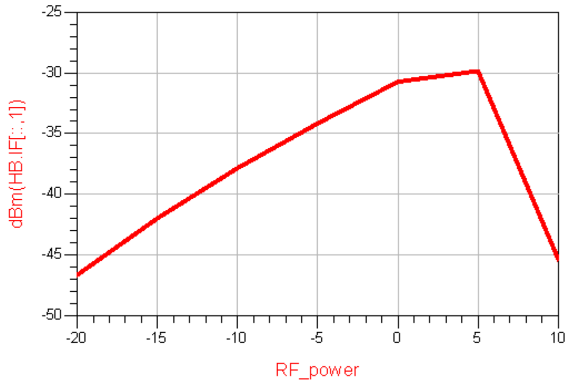
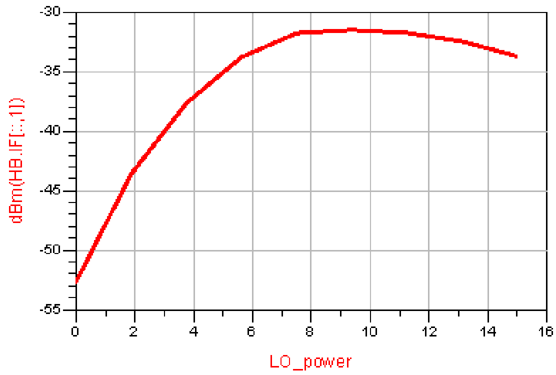


Figure 8: Simulation result of full output circuit of mixer with LVR

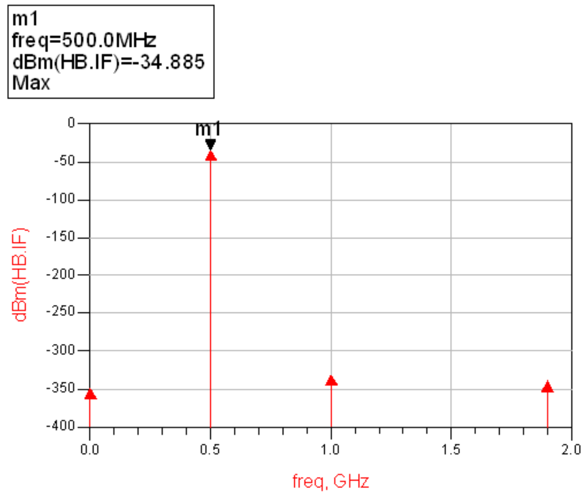
The full version of circuit (mixer plus LVR) is simulated with RF at 2.4GHz frequency and local oscillator at 2.9GHz frequency. The IF output circuit simulation results are given in Figure 8. It can be seen that the mixer output shows the 500 MHz frequency well. It can be seen that a resistor voltage divider has been used to have 0.5v mixer required voltage. To study the harmonics generated in the output, harmonic simulation were conducted. The results can be seen in Fig. 9. In Fig. 9, the input RF has -6dBm power at 2.4GHz frequency, and LO has 5dBm power at 2.9 GHz frequency and the IF output power is around -35dBm power at 500MHz frequency, which is good and acceptable power for output IF.



(a)



(b)



(c)

Figure 9: Simulation (a) Power changes in IF output port with changes in RF input power at LO fixed in 5dBm, (b) Power changes in IF output port with changes in LO power at RF fixed in -6dBm, (c) Harmonics in IF output port with LO fixed in 5dBm and RF fixed in -6dBm.

TABLE 1
IF POWER CHANGES WITH THE CHANGES IN VBIAS (VB AND VG)

Vbaias	dBm (HB.IF{::,1})
0.10	-45.395
0.20	-45.369
0.30	-44.117
0.40	-35.357
0.50	-34.699
0.60	-35.082
0.70	-35.284
0.80	-35.548
0.90	-35.874
1.00	-36.212

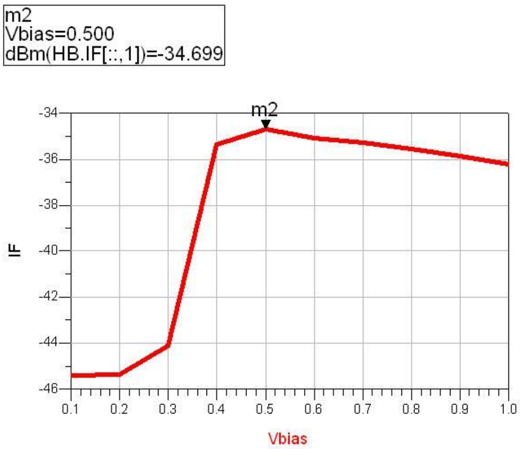


Figure 10: Simulation result of IF power when Vbias changes from 0.1V to 1V.

To have a comparison between the cases that Vbias (Vb and Vg) changes, a simulation has performed. The results are shown in Fig. 10 and table 1. These graphs show that the less conversion loss would be achieved in 0.5v and changes from this point; also would result in a larger conversion loss.

4. CONCLUSION

In this paper, design of an integrated CMOS resistive ring mixer has been done along with a linear voltage regulator, to supply the required biasing voltages. The design has been optimized for heart rate extraction system using Doppler radar microwaves at 2.4GHz frequency for down conversion of signal reflected from patient's chest. Simulation results asserted the stability of regulator and mixer output during input changes. Through this integration, a reduction has been occurred in the volume of mixer for using in portable systems and more specifically heart rate extraction system via Doppler radar. The advantages of this integrated design are lower volume and also the accuracy of mixer in the case of fixed required biasing voltages is ensured. Therefore, the separate application of two 0.5V and 1V voltages was canceled and the potential loss due to the extra metal in the IC reached the minimum.

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BIOGRAPHIES

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