Design and Simulation of CMOS Based Low Power Direct Conversion Receiver for Millimeter Wave Communication

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Abstract*-The paper presents the design of a direct conversion receiver (DCR) system for the millimeter wave communication based applications. The simulations results obtained have high gain and optimal noise characteristics with good stability. The proposed DCR is basically designed and analyzed for short range applications and all. An efficient DCR design system should manage trade-offs among the performance parameters like; gain, noise figure, power consumption, input-output loss device's stability etc. The ever increasing demand of portable wireless devices has motivated the development of CMOS radio frequency integrated circuits (RFIC).*

Keywords-DCR, Noise Figure, Gain, Stability, CMOS RFIC

I. INTRODUCTION

All these are limited to transfer of voice, images and data. The streaming of videos require much higher bandwidths and only communication standards were of capable of supporting the same. The WLAN systems are scalable and can be configured in various topologies to meet the needs of specific applications replacing the need for wired connections i.e. mobile WLAN users can access real-time information at high speed data rates of up to several MG/s downlink. A WLAN operates ubiquitously in the license free bands between 2.4 GHz and 5.8 GHz. The Bluetooth technology also enables data connections between electronic devices such as laptop computers and mobile phones in the 2.4 GHz range. The Zigbee specification provides a reliable and inexpensive solution for small devices such as wireless headsets offering low data rates and low power consumption [1].

The WLANs are not adequate for next generation multi-gigabit wireless communication devices due to their confined bandwidth. Therefore, the purpose of the research basically is to study the analysis and design of high speed direct conversion receivers and a novel broadband mixed signal demodulation with a fully integrated digital signal processing consisting of low power CMOS process technology circuitry. The system is integrated in the next generation millimeter wave CMOS receiver and come up with an innovative dual mode solution to demodulate multi-gigabit signals [2].

This very approach reduces the resolution needs of the high speed analog to digital converter leading to reduction in power consumption for any multi-gigabit communication system without performance degradation. A special feature of RF amplifiers where they are used in the earliest stages of a receiver is low noise performance. In wireless system Low Noise Amplifier (LNA) is the first stage of any RF Receiver design. Performance of RF receiver mainly depends on the effectiveness of LNA. Radio Frequency amplifiers are tuned amplifiers in which the frequency of operation is governed by a tuned circuit. This circuit may or may not, be adjustable depending on the purpose of the amplifier. Bandwidth also depends on use and may be relatively wide, or narrow. A short range based satellite technology also offers a cost-efficient solution for transmitter with fully integrated IQ receiver monolithic microwave integrated circuit (MMIC). The measurement of noise figure (NF) in low noise elements has become particularly important to the development of next-generation communication systems like satellites etc. [3].

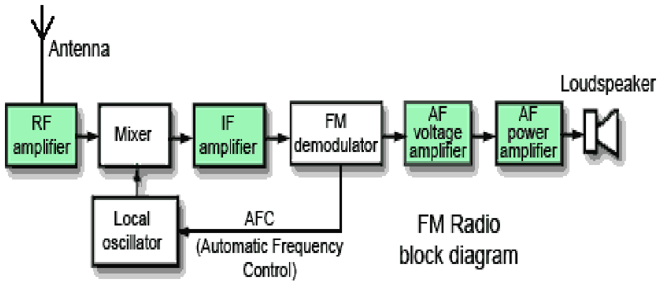

Fig. 1: Block diagram of a receiver system

II. DESIGN PARAMETERS

Design parameters of an electronic circuitry or device determine the behavior of the same. Some of the prominent design parameters of an electronic device are given below.

Noise Figure

Noise figure (NF) is a measures of degradation of the signal-to-noise ratio (SNR), caused by components in a radio frequency (RF) signal chain. The overall noise figure is mainly determined by the first amplification stage, provided that it has sufficient gain. It is the ratio between SNR at input to the SNR at output, and is expressed in decibels (dB). NF specifies the noise performance of a circuit or device. The noise factor is the ratio of the input SNR to the output SNR. The noise ratio is the difference between input and output SNR.

$$F = \frac{SNRin}{SNRout}$$

NF = 10 log (SNRin/ SNRout) dB

Gain

Gain is basically the ratio of output to input amplitude or power. It is generally denoted by G and measured in decibel (dB). The gain of an electronic device or circuit generally varies with the frequency of the applied signal.

$$G = 10 \log \left(\frac{Pout}{Pin}\right)$$

Linearity

Linearity is most of the crucial circuit design parameter along with gain, noise and impedance matching. The active RF devices can be non-linear while in operation due to intermodulation distortion, non-linearity and cross modulation in the circuit system. The output of the non-linear circuit system contains several harmonics of the input signal which are integral multiple of input frequency [4].

S-parameters

The S matrix accurately describes the properties of complicated networks. Some fraction of the signal bounces back out of that port, some scatters and exist other ports and some disappears as heat or even electromagnetic radiation for an RF signal incident. The S-parameters are complex because both the magnitude and phase of the input signal are changed by the network. They are defined for a given frequency andsystem impedance and vary as a function of frequency for any non-ideal network. They come in a matrix with the number of rows and columns equal to the number of ports.

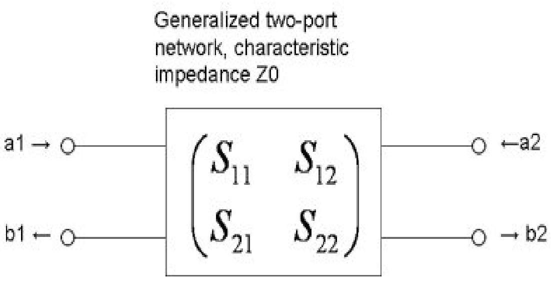

Fig. 2: Block diagram of generalized two-port network

Stability

Stability is an important issue in RF amplifiers. An LNA can as an oscillator if it is unstable in performance. The stability factor can measure the degree of an amplifier's stability. The stability of a circuit can be calculated by the stern stability factor.

$$K = \frac{1 + |\Delta|^2 - |s_{11}|^2 - |s_{22}|^2}{2|s_{11}||s_{22}|}$$

Δ = S11 S22 – S21 S12

Input-Output Matching

Importantly, the performance of the RF circuit systems depends on the input and output matching. The impedance matching is a crucial aspect in RF circuit design systems. Impedance matching is required in order to maximize power transfer from source to load. If the load impedance is ZL then for maximum power transfer, the source impedance ZS should be equal to the conjugate of load impedance [5].

ZS = ZL*

Reflection coefficient (Γ) is a normalized measure of the relationship between source impedance and load impedance.

$$\Gamma = \frac{Zl - Zo}{Zl + Zo}$$

20 log Γin = 20 log IS11I

20 log Γout = 20 log IS22I

III. PROPOSED LNA DESIGN

LNAs are generally used in many systems where low level signals must be sensed and amplified accordingly. LNAs are typically used in communication transceivers for the amplification of the weal electrical signals. Importantly, an LNA is capable of decreasing most of the incoming noise and amplifying a desired signal within a certain frequency range to increase the signal to noise ratio (SNR) of the communication system and improve the quality of received signal as well. An LNA is basically utilized in various aspects of wireless communications including cellular network communication, Local Area Networks (LANs) and satellite communications.

A critical building block in a radio receiver is the LNA. An LNA is a key component which is placed at the front-end of a radio receiver circuit which determine the performance of sensitivity, linearity and power consumption. The main function of LNA is to amplify the signal without adding extra noise to the received signal. The design consists of lumped DC components i.e. L, C, R with different value at input and output side of circuit. The design below uses common source topology of LNA which either grounded or common to both input and output side. LNA designing includes managing its parameters like noise figure, gain, linearity, stability, input and output matching. The main objective of the LNA design is to get good gain with minimum noise generation for the entire operating frequency range. With proper matching, Wideband LNA would be one with approximately or exactly the same operating characteristics over a very wide passband and would be used for multiple applications.

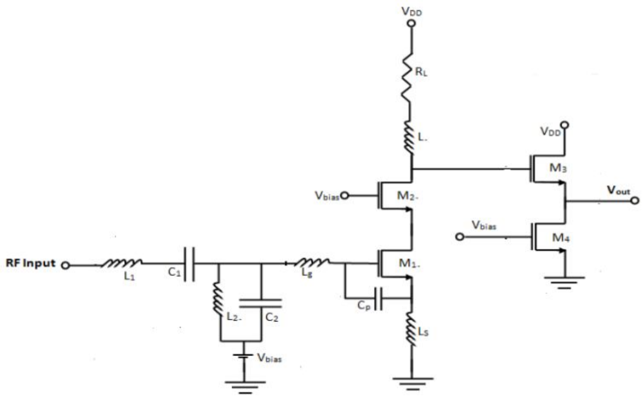

Fig 3: Diagram of an Inductive Source Degeneration LNA

These design parameters are interdependent thus managing trade-off between them is crucial. The LNA is designed on ADS as it is provides an integrated design environment for the circuit design at RF frequency. This technology gives low power consumption, strong reliability and supports multi-dimensional applications as well. The common source topology is used in the design of LNA as it requires low bandwidth of operation. Common source topology also provides high gain and corresponding low noise figure with moderate power consumption. It also has good impedance matching and linearity to lower the distortions [6].

IV. PROPOSED MIXER DESIGN

A mixer is basically a non-linear electrical circuit that generates new frequencies from the two or more signals applied to it. These are usually used to shift signals from one frequency to another which is known as heterodyning in transmission or signal processing. The passive mixers use one or more diodes and rely on non-linear relation between voltage and current to provide multiplying elements. Also, the desired signal is always of lower power than the input signals. The active mixers usually use an amplifying device like, transistor etc. to increase the strength of the desired signal. Theyimprove the isolation between the ports but may have higher noise and high power consumption. It can also be less tolerant of overload.

A mixer is one of the most important building block in today's radio frequency wireless communication systems. The performance of the mixer directly impacts the system's performance as a part of RF front-end circuits. DCR has the potential for reduced power consumption, multiband operation, reduced dependence on off-chip filters, higher levels of integration and reduced system complexity as compared to the traditional super heterodyne conversion architecture [7].

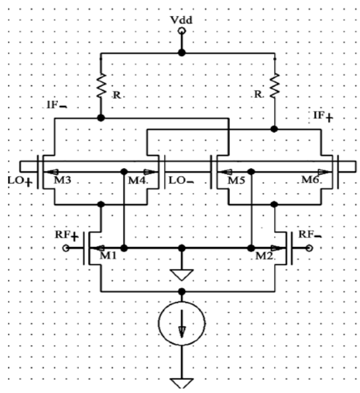

Fig. 4: Diagram of a mixer

V. PROPOSED VCO DESIGN

A VCO is the essential building block of modern day communication systems. The performance of the VCO in terms of tuning range, phase noise and power dissipation determines many of the basic performance characteristics of a transceiver. A VCO is basically an electronic oscillator whose oscillation frequency is basically controlled by a voltage input. The modulating signals applied to control input may cause frequency modulation (FM) or phase modulation (PM). The current trend to utilize multiband multi-standard receivers and also very wideband systems is driving the effort to create new VCO topologies with wide tuning range, low power consumption and low phase noise.

There is a growing interest to extend their tuning range because LC VCO has been successful in narrowband wireless transceivers. Recently, several wideband CMOS LC VCOs have been demonstrated using a variety of techniques. The high accumulation type MOS varactors support a very wide tuning range and their Q is sufficiently high that good phase noise performance can be maintained. The same can be considered as the extension of a cross-coupled oscillator by capacitive voltage dividers and alternatively more consistent with earlier implementation at lower frequencies. It can be seen as a differential oscillator. The transistors are used in a common source configuration in contrast to the common drain configuration inverts the signal. Hence, the output signal is fed back from the other half of the differential circuit where the drain voltage is available at inverted polarity due to odd mode operation [8].

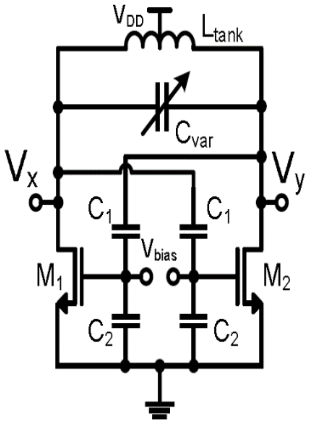

Fig. 5: Diagram of a common source VCO

VI. ANALYSIS OF SIMULATION RESULTS & DISCUSSIONS

LNA SYSTEM DESIGN

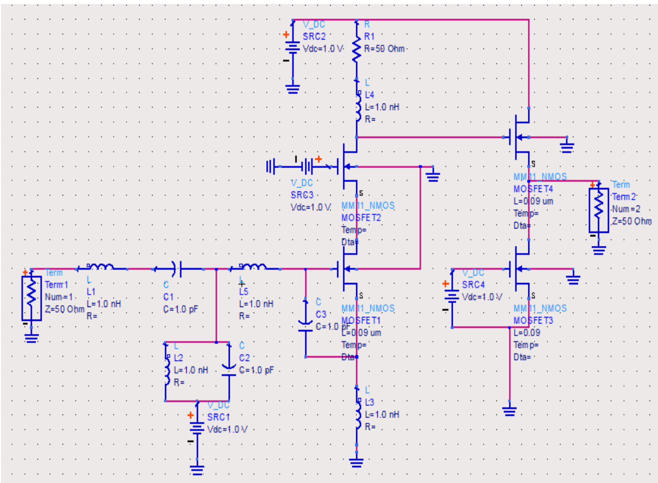

Fig. 6: System Design of LNA with inductive source degeneration

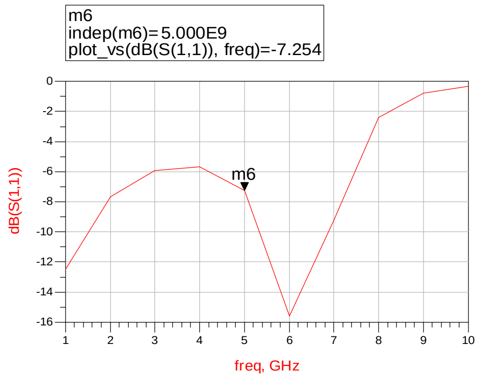

Fig.7: Input matching (S11) Vs. Frequency

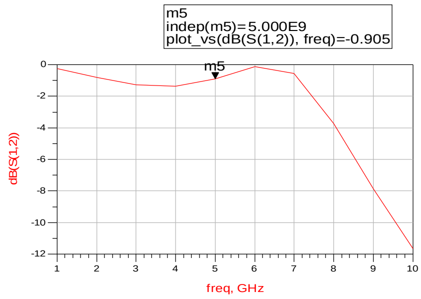

Fig. 8: Output matching (S12) Vs. Frequency

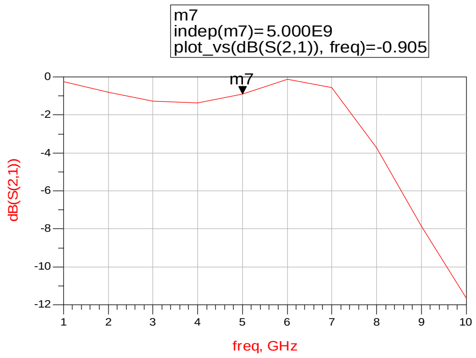

Fig.9: Forward transmission (S21) Vs. Frequency

MIXER SYSTEM DESIGN

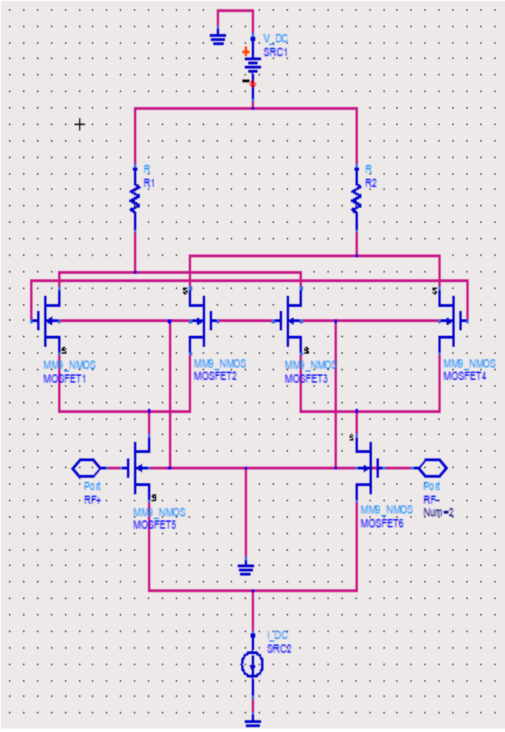

Fig. 10: Schematic diagram of a DB Mixer

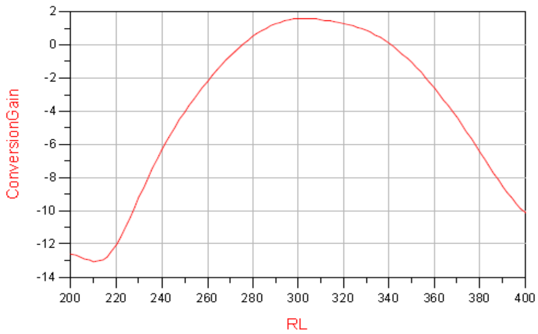

Fig. 11: Conversion Gain against load resistance

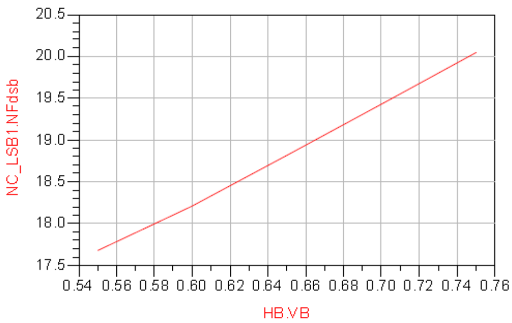

Fig. 12: Noise Figure against gate voltage

VCO SYSTEM DESIGN

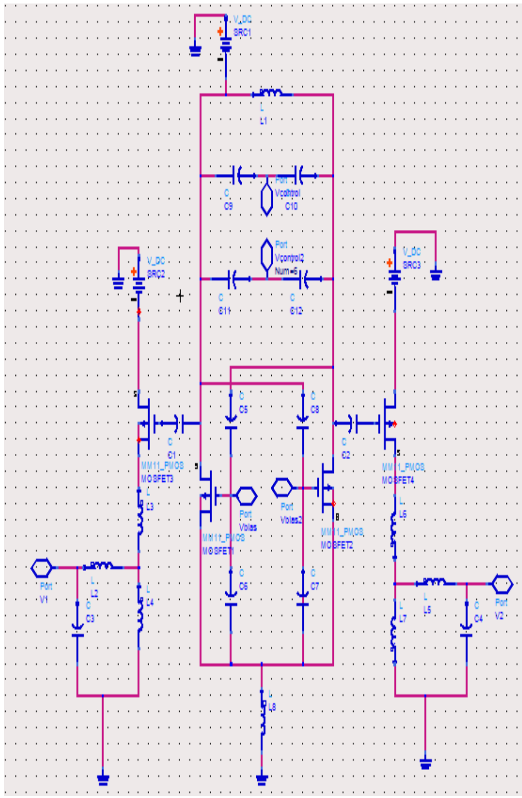

Fig. 13: Schematic diagram of differential common source VCO

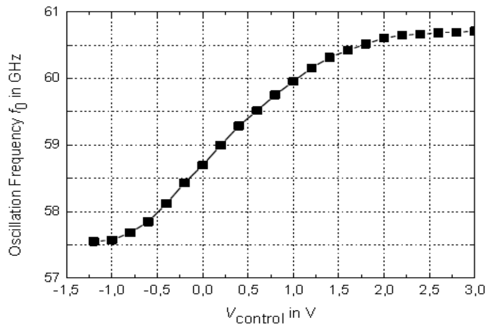

Fig. 14: Tuning curve of the VCO against voltage

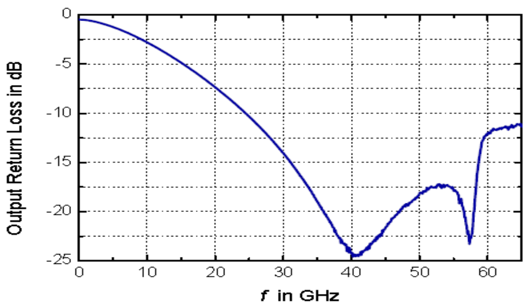

Fig. 15: Output return loss of the VCO against frequency

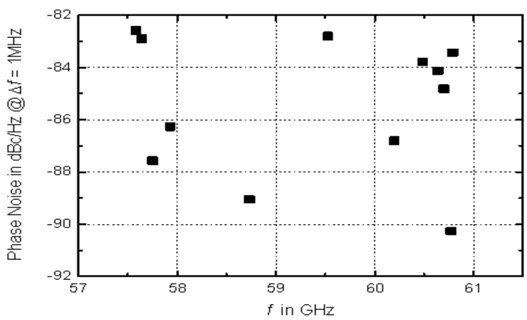

Fig. 16: Phase noise of the VCO against frequency

VII. CONCLUSION

This paper has described the concept and design of DCR which will help the implementation of a high data rate wireless communication system for various wireless applications. The proposed system provides a good trade-off between performance and complexity. The paper also gives the detailed information about the parameters affecting the DCR design system. The simulations results show high gain and low noise figure with good stability features. The DCR can be employed in RF receiver for good quality reception. The measurement results validate the architecture of the whole system. The demonstrator will be further enhanced to prove the feasibility of gigabit wireless communications in different configurations.

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