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Low Cost RF Transceiver Design For Signal Repeaters

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ABSTRACT

Trends in complementary metal-oxide-semiconductor (CMOS) technology and very large scale integration architectures are responsible for the increasing role in overall performance, power consumption, cost and size of the signal repeaters. The existing repeater design consists of duplexer or isolator along with the transmitter and receiver. The amount of passive components used in the transmitter and receiver is found out to be high which ultimately results in low performance and high cost. This paper presents a simple model of the transceiver which boosts the signal strength along with isolating the transmitting and receiving signals. Moreover, if we optimize the transmitter and receiver block as one signal block it will minimize the power-hungry components and thus improving the performance. Due to the presence of atmospheric and transmission losses the transmitting signal gets weak until it reaches the receiver. The received signal is amplified by using a low-noise amplifier. In the existing model of receiver, the low noise amplifier uses bipolar junction transistor (BJT). Overall performance will drastically decrease as BJT will not recognize a weak signals. Therefore, we use metal-oxide semiconductor field effect transistor (MOSFET) to amplify weak signals and overcome the disadvantage of using a BJT.

Keywords: CMOS Technology, improve performance, transceiver, low-noise amplifier, MOSFET.

1. INTRODUCTION

IN the modem RF wireless communications, small size, low cost and low power dissipation are indispensable. Therefore, the RF circuits with high integration level and low power consumption are needed. Recent researches demonstrated the capabilities of RF building blocks and transmission-receiving modules fabricated by the standard CMOS technologies [1, 2, 3].

In wireless communication system, every cellular telephone system desires to extend its coverage area for profitable purposes. Improvement in the signal coverage area fall into three general categories:

a) Holes - relatively small dead spots and zones of marginal operation within the system’s existing service coverage.

b) Fringe areas - areas at the edge of the existing coverage area where service would be desirable.

c) Corridors - long, narrow zones of high traffic potential extending outward from the main service area or tying together two service areas.

All three types of system enhancement can be accomplished by adding or relocating cell sites, but the high cost of these solutions makes it difficult to implement. Recently, however, evolving technology has made it possible to improve existing system coverage much more economically with low-power, broadband cellular boosters and high-power, narrow-band cellular repeaters. A repeater is an electronic device that boosts the signal strength of the received signal and transmits in a specific direction. A cellular repeater is a radio repeater for boosting cell phone reception in a limited area. The device functions like a small cellular base station, with a directional antenna to receive the signal from the nearest cell tower, an amplifier,

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and a local antenna to rebroadcast the signal to nearby cell phones. It is often used in downtown office building, rural areas, hilly areas or highly populated area.

The existing cellular repeaters are very expensive for the public.In this paper,an overview is presented in order to demonstrate the suitability of standard CMOS technology for the integration of high-quality low-power RF transceiver and reducing the cost of the repeater [4]. Also the use of MOSFET instead of BJT for low noise amplifier is proposed in this paper. Further, a cascode amplifier can be used to achieve a higher gain and a lower noise figure [5].

2. ARCHITECTURE OF REPEATER

A repeater receives a signal and re-transmits it, usually with higher power and from a better location, to provide a greater communications range. Often located on top of a tall building or high mountain, or rural area where the cellular service signal is weak, VHF and UHF repeaters greatly extend the operating range of amateurs using mobile and hand-held transceivers. A repeater receives a signal on one frequency and simultaneously retransmits (repeats) it on another frequency. The frequency it receives on is called the *input frequency*, and the frequency it transmits on iscalled the *output frequency*. To use a repeater, we must have a transceiver that can transmit on the repeater's input frequency andreceive on the repeater's output frequency. The input and output frequencies are separated by a predeterminedamount that is different for each band. This separation is called the *offset.* Repeater frequencies are often specified in terms of the output frequency (the frequency wesetour receiver to listen on) and the offset. The transmitter operates on a frequency that is different from thereceive frequency by the offset amount. In cellular repeaters, 900MHz frequency band is used, i.e. the uplink frequency is 890-915MHz and the downlink frequency is 935-960MHz with an offset frequency of 45 MHz. Based on the mode of operation the repeaters are classified into simplex and duplex repeaters. A simplex repeater records and retransmits at same frequency. A duplex repeater, in concept, is not really a complicated device. It's a '*duplexed*' two-way radio set that listens on one frequency, then re-transmits what it hears on another; and does it simultaneously. In general, a cellular booster or repeater is adual-path RF amplifier system which picks up thesignals from an existing cell site (the donor cell) andamplifies them [6]. Depending on the application being addressed, the booster then beams the amplifiedsignals into a hole, outward into a fringe area, ordown a corridor. Simultaneously, it picks up thesignals from mobiles in the boosted coverage area,amplifies those signals, and beams them back to the donor cell. A basic repeater consists of several individual pieces like the duplexer, transmitter, receiver and the control system that, when connected, form a functional system. This paper emphasizes on the reducing the cost of the transceiver block.

2.1. Duplexer

The duplexer separates and isolates the incoming signal from the outgoing and vice versa. Even though the repeater's input and output frequencies are different, the duplexer is still needed. As there is a lot of RF activity going on in the receiver, it goes deaf or gets desensitized from the strong RF signals ad get confused what to receive. The result is poor receive quality, or in extreme cases, complete lack of receive capability. The duplexer is used to prevent the receiver and transmitter from being mixed. A duplexer has the shape of tall canisters and is designed to pass a very narrow range of frequencies and to reject others. The components used in theRF circuits of the duplexerssuchas capacitors, coupling loops, connectors, and cable also haveto stand up to the amount ofpower going through the duplexer. This leads to heating problem.

2.2. Controller

This is the brain of the repeater. It handles station identification, activates the transmitter at the appropriate times, controls the auto patch, and sometimes does many other things. The controller is a little computer that's programmed and optimized to control a repeater. The various models of controllers have different

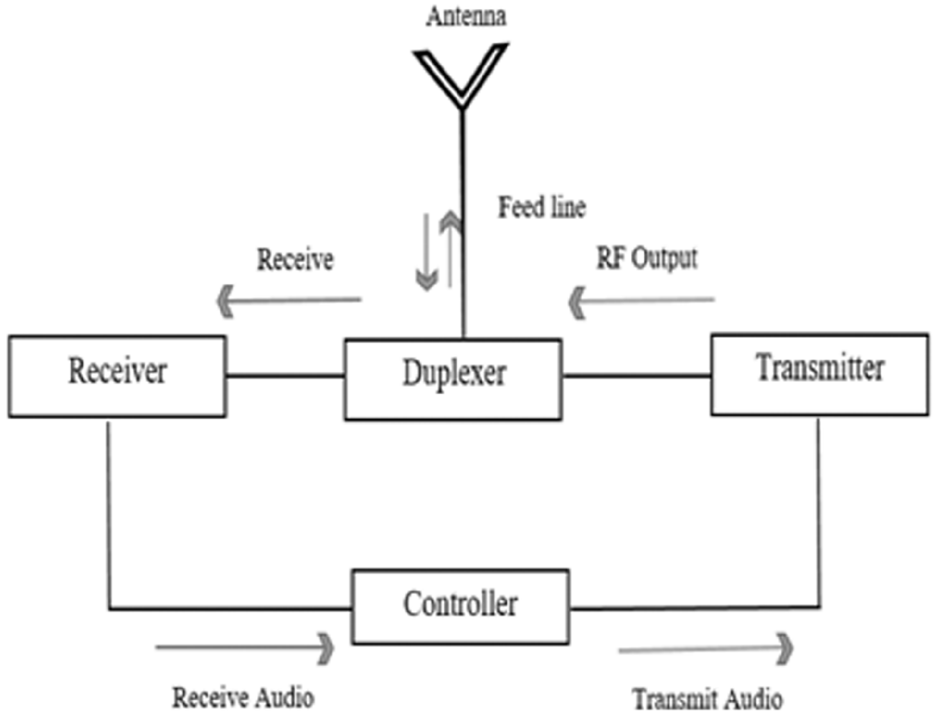

Figure 1: Block diagram of repeater

useful features like speed-dial for phone patches, a voice clock, facilities to control a remote base or linking, etc. The controller provides the repeater the ability to identify the type of signal and improve the performance of the signal.

3. RF TRANSCEIVER

Transceiver is the device which houses both transmitter and receiver in single module. Transceivers which operate at radio frequency range are known as RF Transceivers. It is mainly used for transmitting the data in the form of voice/data/video over the wireless medium. RF Transceiver is used to convert IF frequency to RF frequency and vice versa. It is used in satellite communication, for radio transmission and reception,for television signal transmission and reception, and in cellular networks. The block diagram of RF Transceiver to be implemented is represented in Fig. 2. A typical RF transceiver consists of LNA, filters, mixers and amplifiers [7]. The model eliminates the need for separate transmitter and receiver circuits, thereby reducing the cost. It also uses filters for selecting the transmitting and the receiving signal frequencies. The model also provides a significant gain at the receiver side.

3.1. Low-Noise Amplifier

Low-noise amplifier (LNA) is an electronic amplifier that amplifies a very low-power signal without significantly degrading its signal-to-noise ratio. An amplifier will increase the power of both the signal and the noise present at its input. Low-noise amplifiers are designed to minimize the additional noise.Low-noise amplifier (LNA) is a very first stage of receiver side which provides enough gain forsubsequent stages, by adding very less noise [8, 9]. LNA must present 50 ohm impedance to the input source to achieve a higher gain, stability and bandwidth [10]. At the same time LNA must consume very low power to perform all these tasks [11, 12]. At the “front end” of the receiver channel, it must capture and amplify a very low-power, low-voltage signal plus associated random noise which the antenna presents to it, within the bandwidth of interest. Gain is the main primary parameter for LNA. Typical gain of a LNA is between 10 and 20 dB for a single-stage.Some designs use cascaded amplifiers with a low-gain. To handle a wide dynamic range of input signals without any overload and saturation, gain control is included in the LNA.

3.2. Filter

A three section Butterworth Band Pass Filter (BPF) for high frequency is used to minimize insertion loss, produce a flat response across each band and maintain 50 ohm impedance [13]. Impedance match is very important with solid-state transceivers if maximum power is to be obtained from the transceiver.ABand Pass Filters passes signals within a certain "band" or "spread" of frequencies without distorting the input signal or introducing extra noise. This band of frequencies is the filter's Bandwidth.Bandwidth is the frequency range that exists between two specified frequency cut-off points (f_c), that are 3dB below the maximum center or resonant peak while attenuating or weakening the other frequencies outside of these two points.

3.3. Mixer

Radio frequency or RF mixer is a non-linear device that takes two signal frequencies as input and produces a single frequency as output. Mixer is of two types: up conversion mixer and down conversion mixer. A down conversion mixer takes RF and LO signals as inputs and produces an intermediate frequency (IF)

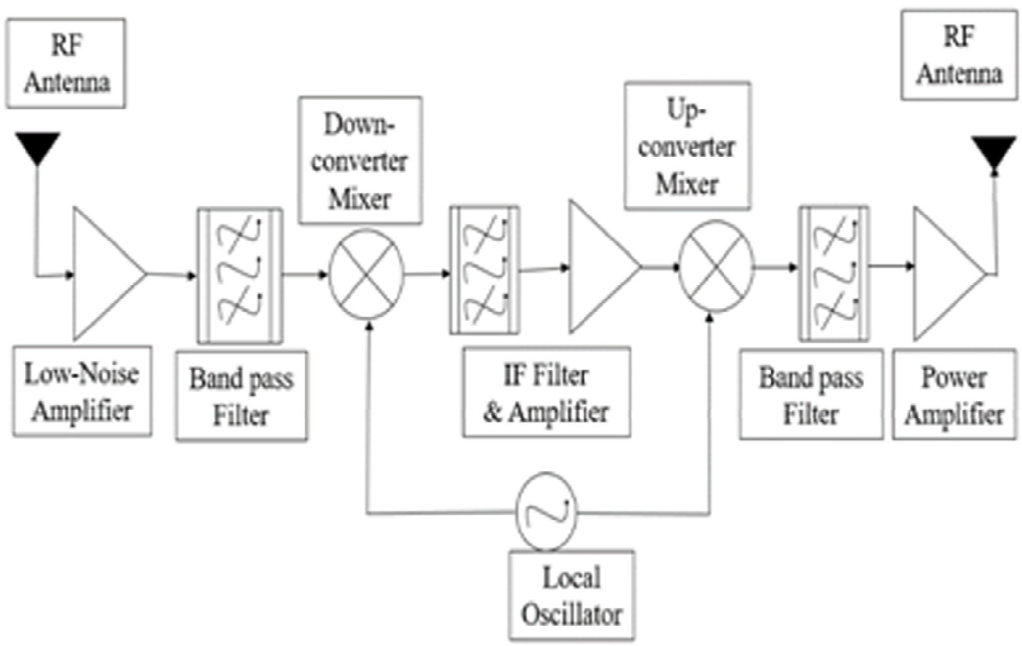

Figure 2: Block Diagram of RF transceiver

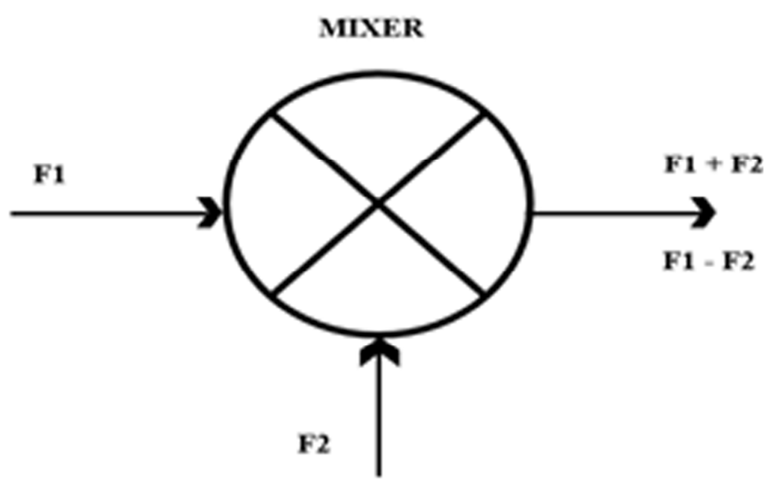

Figure 3: Block diagram of mixer

signal. This IF signal has a lower frequency as compared to the RF signal. Down conversion mixer is used at the receiver side. An up conversion mixer takes IF and LO signals as inputs and produces a RF signal. Up conversion mixer is used at the transmitter side [14].If the two input frequencies to the mixer are f1 and f2, then new signals are seen at frequencies of (f_1+f_2) and (f_1-f_2).

3.4. IF Filter

An ideal mixer produces the sum and difference frequency components but a real mixer produces many side frequency components which are undesirable. Therefore to select only the IF frequency component an IF filter is placed after the mixer stage.

3.5. IF Amplifier

IF amplifier is a selective high gain amplifier used in super-heterodyne receivers that amplifies signals after they have been converted to fixed intermediate-frequency value by the frequency converter. It processes and enhances the down converted or modulated signals.

3.6. Power Amplifier

Apower amplifier increases the power of the signal by taking energy from a power supply and controlling the output to match the input signal but with larger amplitude.Typically RF amplifier will consist of following stages/modules.

i. Input Matching network: Used to match the amplifier device with input 50 Ohm impedance line.

ii. Amplifiers one or more stages: Based on the requirement of the gain, one or more cascaded amplifier stages, such as voltage amplifier, driver amplifier and power amplifier are essential [15].

iii. Output matching network: Used to match the amplifier device with output 50 Ohm impedance line.

3.7. Local Oscillator

Local Oscillator (LO) is used with a mixer to change the frequency of a signal. This frequency conversion process, also called heterodyning, produces the sum and difference frequencies from the frequency of the local oscillator and frequency of the input signal. Processing a signal at a fixed frequency gives a radio receiver improved performance.

4. LNA SIMULATION RESULTS

The circuit of a low noise amplifier using the BFR740L3RH RF low noise BJT transistor is simulated. The simulations are carried out in NI Multisim 14.0 Circuit Design Suite. The simulated circuit diagram is shown in Fig. 4.

It is a wideband feedback LNA for 200 MHz to 6 GHz applications. The amplifier is stable over the entire 5 MHz to 6 GHz range. The circuit draws a current of 14.2 mA from a 3V power supply. The simulation result is viewed with the help of the network analyzer XNA1. The simulated forward gain S_{21} along with the other S-parameters (S_{11}, S_{12}, S_{22}) at 1 GHz and 901.225 MHz are depicted in Fig. 5 and Fig. 6 respectively.

The simulation results depict that a forward gain of 21.625 dB is achieved at 1 GHz and a forward gain of 21.652 dB is achieved at 901.225 MHz. In the proposed model of RF Transceiver as depicted in Fig.2, the low noise amplifier circuit is designed using MOSFET instead of BJT. The LNA implemented with MOSFET would consume low power and low voltage thereby reducing the power consumption of the overall RF transceiver. By suitable design techniques, the MOSFET LNA can provide a higher gain and

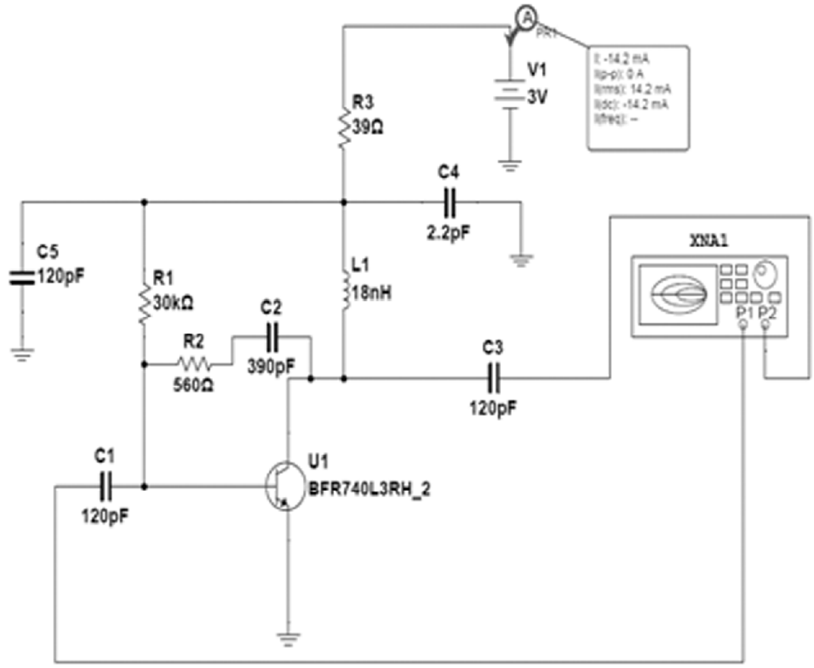

Figure 4: Simulated Circuit Diagram of LNA

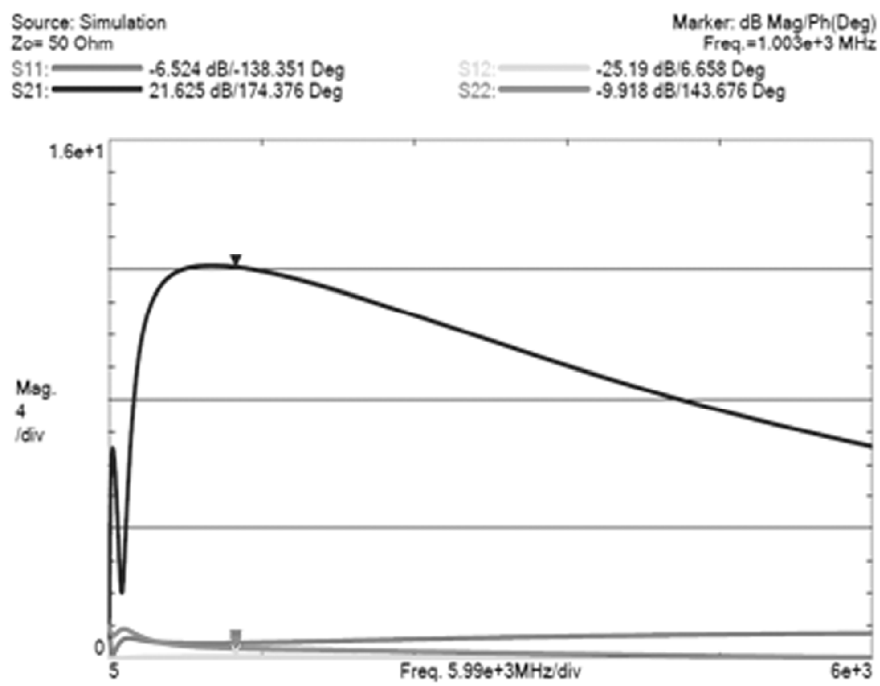

Figure 5: Simulation result at 1 GHz

hence, the gain of the overall RF transceiver can be increased. In addition to this, MOSFET LNA has a lesser loading effect as MOSFET has oxide in between which enables only the field to interact with the channel and so very small current is drawn.

Fabrication also becomes easier with MOSFET as MOSFET consumes less space and active resistors can be fabricated using same MOSFET fabrication, which is not possible in case of BJTs. LNA implemented using MOSFET has a lower noise level and MOSFET LNA can respond to low input signals while a BJT LNA cannot respond to low input signals as input current is high. The input impedance of a LNA realized using MOSFET is high in comparison to that realized using a BJT transistor. MOSFET also provides a greater thermal stability as compared to BJTs.

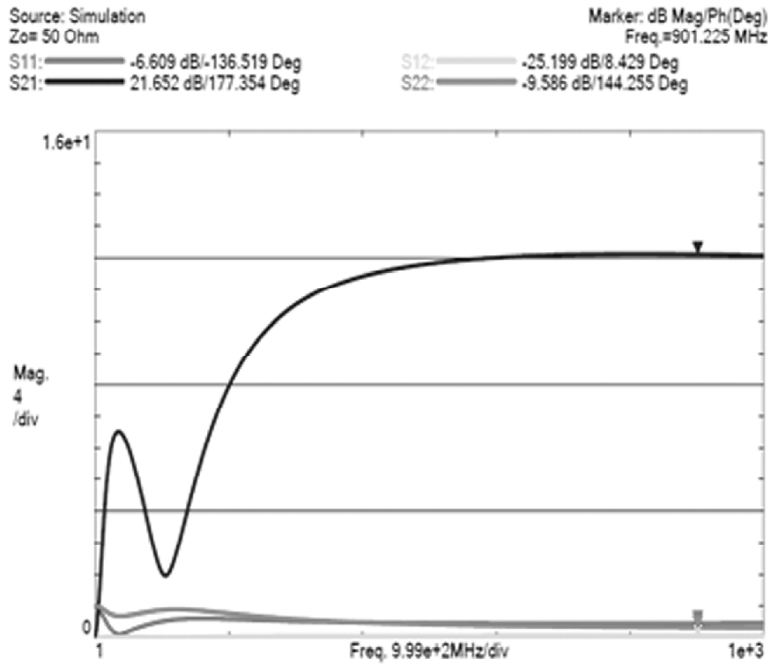

Figure 6: Simulation result at 901.225 MHz

5. CONCLUSION

An overview of the repeater and a low cost cellular RF transceiver has been presented. The circuit of low noise amplifier using a RF BJT transistor is simulated using NI Multisim 14.0 Circuit Design Suite. The LNA offers a gain of 21.625 dB at 1 GHz and a gain of 21.652 dB at 901.225 MHz. The circuit consumes 14.2 mA of current from a 3 V DC power supply. For lower power consumption, small size and a higher gain, use of MOSFET for LNA instead of BJT is proposed. The advantages offered by a MOSFET LNA over BJT LNA are discussed.

REFERENCES

[1] A. Ajikuttira, C. Leung, E. S. Khoo, M. Choke, R. Singh, T.H. Tea, B. C. Cheong, J. H. See, H. S. Yap, P. B. Lcong, C. T. Law, M. Itoh, A. Ykhida, Y. Yoshida, A. Tamura, and H.Nakamura "A Fully-Integrated CMOS RFIC for Bluetooth Applications", Proc. IEEE International Solid-State CircuitsConf., pp. 198-200, 2001.

[2] A. N. L. Chan, K. W. H. Ng, J. M. C. Wong, and H. C. Luong "A 1-V 2.4-GHz CMOS RF Receiver Front -End for Bluetooth Application", IEEE International Symposium on Circuits and Systems, pp. 454-457, 2001.

[3] Michiel S.J. Steyaert, Bram De Muer, Paul Leroux, Marc Borremans and Koen Mertens, "Low-Voltage Low-Power CMOS-RF Transceiver Design", IEEE Transactions on Microwave Theory and Techniques, Vol. 50, Issue 1, pp. 281-287, Jan. 2002.

[4] Trung-Kien Nguyen, Chung-Hwan Kim, Gook-Ju Ihm, Moon-Su Yang, Sang-Gug Lee, "CMOS Low-Noise Amplifier Deign Optimization Techniques", IEEE Transcactions on Microwave Theory and Techniques, Vol. 52, Issue 5, pp. 1433-1442, May 2004.

[5] Abdelhalim Slimane, Sid Ahmed Tedjini, Abdelkader Taibi, Mohand Tahar Belaroussi , "A 0.6-V/0.12-V Low Power Single Ended CMOS LNA for Multi-standard RF Front-Ends", 26th International Conference on Microelectronics (ICM), pp. 68-71, Dec. 2014.

[6] Ronald J. Jakubowski, "A New Generation of High-Power Cellular Repeaters", IEEE 40th Vehicular Techonology Conference, pp. 24-28, May 1990.

[7] Vasanthi M.S, Rama Rao T, "RF Transceiver Design and Simulation for Indoor Wireless Applications", Third International Conference on Computing Communication and Networking Technologies (ICCCNT), pp. 1-6, Jul. 2012.

[8] Ehsan Kargaran, Hojat Khosrowjerdi, Karim Ghaffarzadegan, Moosa Kenarroodi, " A Novel High Gain Two Stage Ultra-Wide Band CMOS LNA in 0.18um Technology", 5th European Conference on Circuits and Systems for Communications (ECCSC), pp. 90-92, Nov. 2010.

[9] Madiha Hajri, Dalenda Ben Issa, Hekmet Samet, "New design of 3-10 GHz low noise amplifier for UWB receivers", 12th International Multi-Conference on Systems, Signals & Devices (SSD), pp. 1-5, Mar.2015.

[10] Othman A.R, Ibrahim A.B, Husain M.N, Ahmad M.T, Senon M., "High Gain, Low Noise Cascode LNA Using T-Matching Network for Wireless Applications", IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE), pp. 383-387, Dec. 2012.

[11] Jack Li, S.M. Rezaul Hasan, "Design and Performance Analysis of a 866-MHz Low-Power Optimized CMOS LNA for UHF RFID", IEEE Transactions on Industrial Electronics, Vol. 60, Issue 5, pp.1840-1849, May 2013.

[12] Mohammad Rezvani, Shahab Ardalan, Kaamran Raahemifar, "High Gain, Low Power, CMOS Current Reused LNA with Noise Optimization", 26th Annual IEEE Canadian Conference on Electrical and Computer Engineering (CCECE), pp. 1-6, May 2013.

[13] Cristian Andriesei, Liviu Goras, Bruno Delacressoniere, "Active RF Bandpass Filter with Wide Frequency Tuning Range", International Semiconductor Conference, pp. 397-400, Oct. 2008.

[14] A.N. Karanicolas, "A 2, 7 V 900 MHZ CMOS LNA andmixer", ISSCC Dig Tech. Papers, Vol. 39, pp 50-51, 1996.

[15] H.S. Song, M. Ghregherehchi, S.H. Lee, T.V. Cong, J. H. Kim, J. S. Chai, "Development of an 83.2 MHz, Three-Stage RF Amplifier for SKKUCY-9 Cyclotron", IEEE Transactions on Nuclear Science, Vol. 61, No. 6, pp. 3579-3583, Dec. 2014.