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To cite to this article: Kazancı, Ö., Oral, O., (2023). TUNABLE RADIO FREQUENCY (RF) RECEIVER (RX) INTEGRATED CIRCUIT (IC). International Journal of Engineering and Innovative Research , 5(2), p:90-94 . DOI: 10.47933/ijeir.1156769

DOI: 10.47933/ijeir.1156769

To link to this artice: https://dergipark.org.tr/tr/pub/ijeir/archive

International Journal of Engineering and Innovative Research

http://dergipark.gov.tr/ijeir

TUNABLE RADIO FREQUENCY (RF) RECEIVER (RX) INTEGRATED CIRCUIT (IC)

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(**Received:** 05.08.2022; **Accepted:** 07.02.2023)

https://doi.org/10.47933/ijeir.1156769

ABSTRACT: In this work tunable radio frequency (RF) receiver (Rx) integrated circuit (IC) was demonstrated. TSMC 65 nm technology node was selected to implement IC. RF technique has some advantages over biomedical optic molecule investigation methods since it is easy to design, implement. Experimental measurement on live tissue is much easier than optic methods. Nanoscopic creatures have specific binding structures. Their elements construct their shapes and neighborhood conformation between their own atoms. Based on this work differential RF waves will be used to investigate the nanoscopic creatures. Since the investigation of nanoscopic creatures will require to use electromagnetic wave phase shift and scan of different RF frequencies, ultra-wide band (UWB) tunable receiver circuit topology was designed and simulated. For this purpose, Rx block was designed, and simulation work was demonstrated here. In the circuit simulations, off-chip antenna was connected to the low-noise amplifier (LNA) circuit. Specific frequency was around 30 GHz. Frequency tuning was adjusted by changing the source and bias voltages at the active inductor voltage-controlled oscillator (VCO) circuit block. The same VCO block was also used at the Tx circuit before. Antenna signal was modeled by using 33 GHz alternative sinusoidal signal. Antenna signal and 30 GHz active-inductor VCO voltage output were mixed at the mixer circuit block, 3 GHz envelope signal was extracted in this work. Layout implementation of Rx receiver IC was demonstrated.

Keywords: Biomedical diagnosis, Tunable RF Receiver (Rx), Integrated Circuit (IC), Transceiver.

1. INTRODUCTION

Novel inventions are necessary to scan and investigate possible virus threats such as Co-Vid19 virus by using non-invasive methods. Existing biomedical optic and photonic methods require to syringe blood samples from live organism and then scan process is taking long time. It has also high spread risk to the environment. Emerging non-invasive technological tools are necessary. Radio frequency (RF) method might be easy to setup and measure device tool since the emerging microelectronic technology can give us design, implement, apply, and observe opportunity very quickly. For this purpose, new tunable RF receiver integrated circuit (IC) was designed, and simulation waveform output was shown. Since RF receiver is tunable, it has novelty over traditional receiver RF circuits. The circuit gives us an opportunity to be able to scan different frequencies. Researchers demonstrated us one possible RF application methodology to detect some well-known microbial instances at around 10 GHz source signal frequency [1]. They used waveguide and applied around 10 GHz frequency source signal, they observed frequency versus temperature change depend on the virus existence. They show us RF signals can interact and depend on the nanoscopic creatures` atomic shape back reflected or transmitted RF signal intensity, frequency and phase might be shifted. Based on this knowledge, emerging microelectronic RF integrated circuit (IC) technologies can be used. With the help of emerging microelectronic RF IC technology, ICs would be designed and develope. Transmitter (Tx) and receiver (Rx) circuit blocks are thought to be applied to live-tissue non-invasively. For this purpose, receiver (Rx) RF IC circuit schematic block was designed and simulated at this work. Different virus and bacterial identification and destruction studies were done by using RF and terahertz (THz) techniques [2-7]. RF resonance method was used to destroy the virus [2]. THz technique was used to detect virus [3]. SARS-CoV-2 virus inactivation by using electromagnetic waves at the resonance frequencies was tested [4]. THz metamaterials were used to detect viruses [5]. 95 GHz millimeter wave exposure was used to kill coronavirus 229E, and poliovirus [6]. DNA and RNA viruses' resonance with millimeter waves was summarized in review article [7]. The philosophy like on differential photon waves imaging philosophy [2] will also be applied for RF signals. Differential photon waves imaging relies based on the sequential wave interactions with the interested nanoscopic creature. Nanoscopic creatures' atomic sizes and binding distances with each other neighbor atom can be linked with the sequential waves. Nanometric wave differences can be linked with the nanoscopic creatures' physical shape and binding distances. This natural relation can help to investigate the interested nanoscopic creature by sending time resolved sequential waves into live tissue. According to the paper [2] which explains the differential photon waves imaging philosophy, 26 nanometers (nm) phase shift can be realized by generating almost 14 attoseconds time delay. For example, let us say in a homogeneous environment, if 2 sequential waves were sent through live tissue from source position with the 14 attosecond (as) delay, and then if non-of them can reach to the detector position, it would be said that there exists specific creature. In the future, instead of using differential photon waves, it is aimed to use differential RF waves. For this purpose, receiver Rx RF IC block was designed and simulated in this work. Ka electromagnetic wave band spectrum was selected which mostly focused on 30 GHz and around it.

2. METHODS

The whole Rx circuit consists of off-chip antenna, impedance matching network (IMN) I, low-noise amplifier (LNA), IMN II, active inductor voltage-controlled oscillator (VCO), Mixer, IMN III, and output stage. The active inductor was studied [9]. The active inductor schematic was designed and simulated based on the literature work [10]. components and their values were selected appropriately. In the literature, there are also other active inductor analyses and design studies [11-14]. Low noise amplifier (LNA) designs were demonstrated for TSMC 65 nm technology node in the literature [15, 16]. 24-30 GHz band LNA schematic was also proposed in the literature [17]. LNA was designed according to the single stage common source double nMOS transistor structure like in the literature work [18] except transformer and separately second nMOS driver transistor was diode connected. The mixer designed according to the balanced Gilbert mixer cell topology [19].

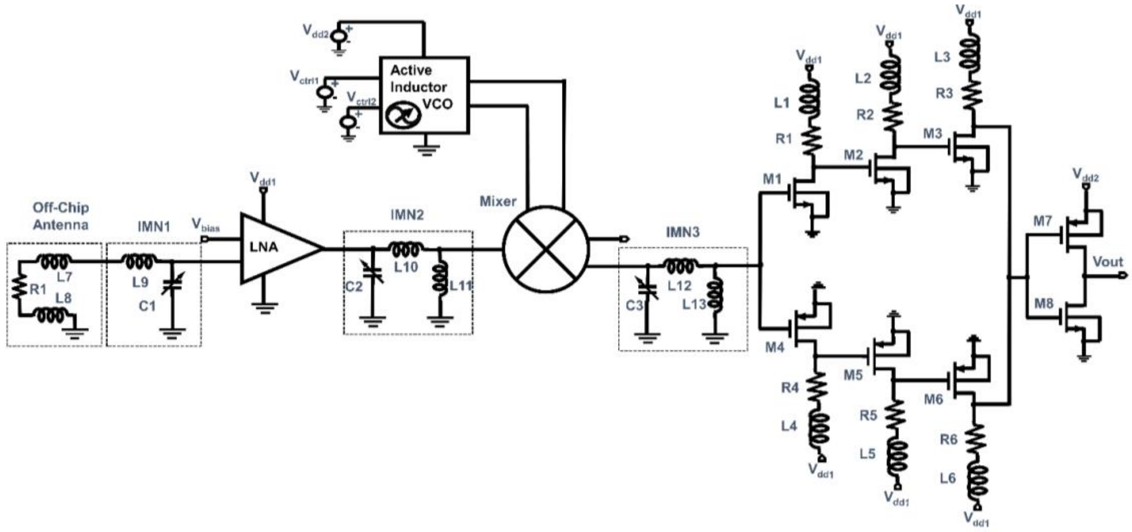

Figure 1. The receiver (Rx) circuit topology.

The whole Rx schematic circuit is shown in Figure 1. Impedance matching networks (IMNs) were added between each block. Totally 3 IMNs were added to the Rx circuit. 30 GHz Active inductor voltage output signals were generated by adjusting the control bias voltages. 33 GHz antenna signal was applied. Both antenna and active inductor VCO signal were mixed at the mixer circuit and 3 GHz envelope signal was extracted.

2. DISCUSSION AND RESULT

Simulation result was shown in Figure 2. Envelope signal is demonstrated in the Figure 2. Different control bias voltages were applied to the active inductor, by this way different VCO frequencies were generated and applied to the mixer circuit then envelope signals were extracted correctly.

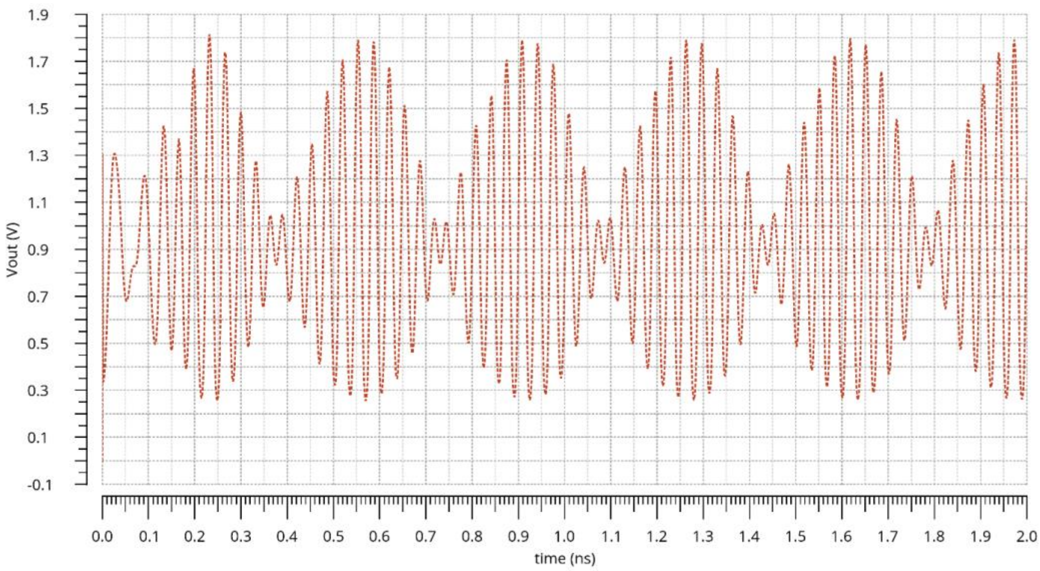

Figure 2. Extracted 3 GHz envelope signal voltage output.

In this work, Ka-band RF integrated receiver Rx circuit was designed, analyzed, and implemented at the TSMC 65 nm technology node. All processes include simulation, design rule check (DRC), electrical rule check (ERC), and layout-versus-schematic (LVS) were done successfully. Antenna signal was modeled as 33 GHz RF signal. It was simulated that there is off-chip antenna, and this off-chip antenna is receiving 33 GHz RF signal. At the receiving side 30 GHz active inductor voltage-controlled oscillator (VCO) circuit is generating mixer input signal. This active inductor has tunable oscillator input control voltages: vctrl1, vctrl2, vdd1. By changing the oscillator control voltages, it is possible to change the 30 GHz frequency output. In this work, for the simplicity 30 GHz signal frequency was generated and connected to Gilbert-cell mixer input. The other mixer cell input is the 33 GHz antenna signal. On the mixer circuit, these two different signals were mixed then finally 3 GHz envelope signal as an output waveform was extracted successfully. In the test and measurement setup it is aimed to tune 30 GHz active inductor signal frequency. By changing the 30 GHz signal frequency, mixer output envelope signal frequencies are changed. By using this method, it will be possible to detect the nanoscopic or microscopic creatures on transmission through geometry. On one side of the tissue specimen, 33 GHz transmitting source signal will be placed, on the other side of specimen receiving circuit will be placed. Similar studies were done in the literature. A 30–40 GHz CMOS receiver circuit which has high conversion gain was designed and implemented [20]. A 60 GHz CMOS receiver circuit was designed and implemented [21]. There is no tunable RF receiver in literature as in our study. We can change oscillator output frequency which is around 30 GHz. By changing the control voltages, we generate different oscillator frequencies than 30 GHz. By mixing the received signal with tunable oscillator frequency, different output envelope signal can be extracted.

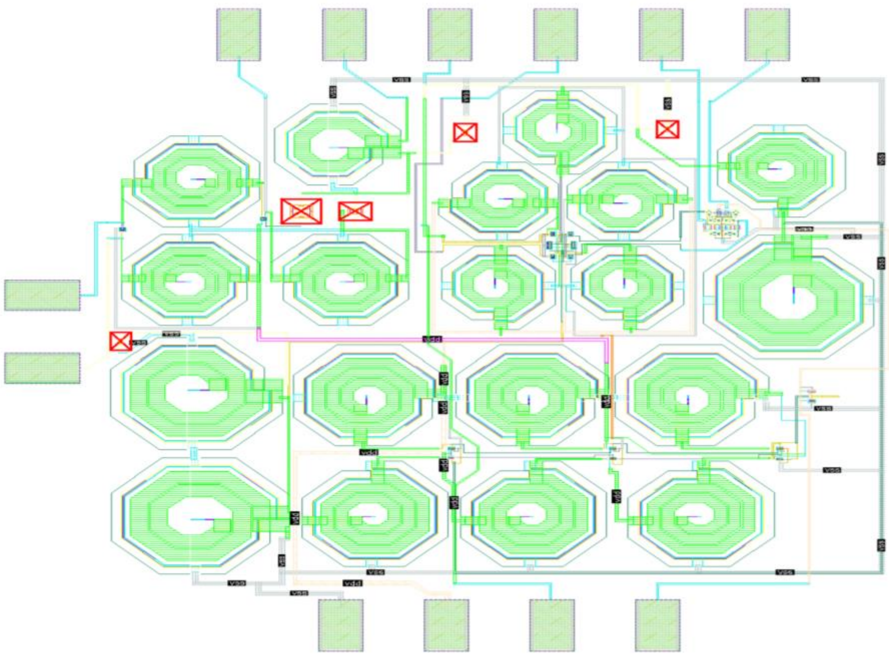

Figure 3. Layout implementation of Rx receiver IC.

4. CONCLUSIONS

Rx RF IC circuit was designed and simulated at this work for future differential wave imaging usage. Required circuit blocks were designed and connected appropriately. Off-chip antenna and wire bonding were modeled. Off-chip antenna was connected to the LNA circuit. Active inductor voltage-controlled oscillator (VCO) circuit generated 30 GHz frequency signal for demonstration purpose. Frequency tuning was adjusted by changing the source and bias voltages at the active inductor voltage-controlled oscillator (VCO) circuit block. The same VCO block was also used at the Tx circuit. Antenna signal was modeled by using 33 GHz alternative sinusoidal signal. Antenna signal and 30 GHz active-inductor VCO signal were mixed at the mixer circuit block and 3 GHz envelope signal was extracted and demonstrated in this work. The layout implementation of Rx Ic was demonstrated in Figure 3. The receiver circuit was implemented based on to realize the 3 GHz envelope signal which was demonstrated in the Figure 2. 30 GHz, active-inductor VCO signal was generated. The mixer circuit was designed according to the balanced Gilbert mixer cell topology. Extracted 3 GHz envelope signal is demonstrating important signal output. On layout, 12 I/O pads were placed around circuit borders. These signals are: vdd1, vdd2, vctrl1, vctrl2, vbias, vout. GDSII file format circuit layout was demonstrated in Figure 3. Inductors are spiral inductors and capacitors are mimCap capacitors. PADs were designed from metal1 to metal9.

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