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A 120 GHZ DOWN CONVERSION MIXER DESIGN FOR IMPROVED LINEARITY, HIGH CONVERSION-GAIN AND LOW NOISE-FIGURE IN 130 NM CMOS TECHNOLOGY

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ABSTRACT

Future mobile networks, like 6G, will use frequencies above 100 GHz. Mobile networks target higher radio frequencies because they provide more bandwidth and capacity. Higher frequencies increase power consumption. This could be a problem for 6G battery-powered phones. High linearity, high conversion gain, and low NF are also challenges. Although Gain, power, linearity, and noise figure are trade-offs. More attention should be paid to the linearity of mixers in the design of wireless receivers because their input signal level is above 100 GHz, which is much higher than any other amplifier in the receiver. This study proposes a Gilbert cell mixer using BALUN to increase linearity, CG, and NF. 120 GHz is the mixer's input frequency. This mixer was simulated using ADS 130 nm RF-CMOS. The RF and LO BALUNS in this Gilbert cell mixer convert 120 GHz to 1 GHz. and obtains 68.664 dB RF-LO isolation, 8.882 CG and 8.4 db NF. The suggested design has -12.2 dBm of 1-dB compression point in this RF bandwidth. At 3 V bias, this double-balanced Gilbert cell mixture dissipates 66.8 mW.

Keywords: *6G, Gilbert Cell Mixer, Conversion Gain (CG), Linearity, 1dB compression point, Noise Figure (NF), BALUN*

1. INTRODUCTION

Among the most intriguing research hubs in recent time is the Sixth-generation (6G) wireless network. The Wireless Communication network frequency is continuously increasing with increase in wireless generation standard and approaching the bands of millimeter-wave in order to gain broader bandwidth and higher communication rates [1]. As an example, 3G networks predominantly only use the 900 MHz and 2.1 GHz bands. 4G networks can use frequencies up to 2.5 GHz, whereas the 28GHz and 39 GHz bands are being increasingly used by 5G networks. Our need for bandwidth is still unquenchable. T S Rapaport et.al has offered a thorough and in-depth examination of the key prospects, difficulties, and strategies for developing future wireless application over 100 GHz, which are projected to be used in the 6G period between 2025 and 2035 [2]. Depending on the design's selection of components and the topology, the mixer's employed in the Radio Frequency receiver for the purpose of frequency conversion may be passive or active. Due to their greater conversion gain, active mixes are more appealing and are thus favored in the majority of wireless applications (relatively much higher than passive counterpart). Today, the majority of CMOS implements RF building blocks. It is as a result of the CMOS technology's low-cost implementation and ability to integrate with baseband chipsets. Because of their high adaptability and cost-effectiveness, CMOS technology and direct-conversion architecture are embraced. In a wireless communication system on the receiver side the primary linearity limiting components are mainly mixers, power amplifiers (PAs), and LNA (low-noise amplifiers) out of which linearity of mixers should get more consideration in their design because at the receiver front end RF input signal levels are considerably much higher at mixer. A high conversion gain mixer will have a higher noise figure. In recent time as the main focus of the researchers requires majority of communication systems, especially portable wireless systems, to be built with minimal power consumption in mind but low power consumption will also cause low conversion gain and high non linearity . So there is a Tradeoffs and compromise between performance requirements, such as improved linearity, strong conversion gain, low power consumption, improved noise figure etc. as indicated by the RF design hexagon in the figure1.

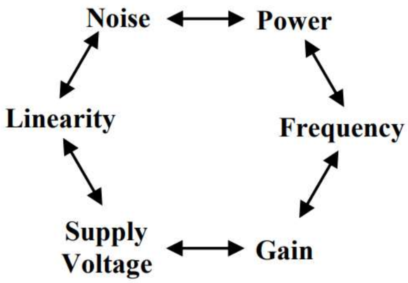


Figure 1: Tradeoffs in RFIC design [1]

2. METHOD

This research section discusses the basic aspects and topologies of RF mixer and challenges in the RF receiver architectures in the mixer. We explore the various research gap: a) achieving high conversion gain (CG) with CMOS implementation has always been a demanding property from RF-Mixers. Though lots of recent works have focused to obtain the same, a simultaneous low noise figure (NF) below 10-15 dB has been difficult to obtain. b) Linearity of Mixer is another aspect which greatly influences the harmonic distortion of the RF path and received signal quality. c) Achieving a higher IP1dB above -10 dBm is a new standard reference which has rarely been attempted with active Mixer topologies. d) Compatibility of the additional components like BALUNs to incorporate the balanced active Mixer architecture has been a challenging task in active mixer topologies employing current reuse property and compact chip size. Although some recent research works have attempted to work in this aspect, an optimum compatibility solution without significant degradation in the mixer properties is still expected. The first one has to do with the kind of electrical parts or gadgets that are within the mixer that is Passive mixers or Active mixers. There are many common passive mixer designs, most of which lack gain but instead improve isolation and implementation. Schottky diodes, which provide an extra low turn-on voltage advantage, are employed as the switching element in the majority of passive systems. Most high-performance designs need balanced transformers for this, which might restrict the frequency range over which they can function [3-5]. Passive mixers feature a number of important characteristics, one of which is the introduction of a conversion loss which might affect the Radio Frequency circuit design. In Active mixers we use transistors as a key component in electronic switching, which performs the necessary mixing function. A high gain with adequate isolation is active architecture's key benefit. Active mixers, in contrast to passive mixers, are capable of having a conversion gain, which will impact the item's RF design. The Gilbert cell appears to be a desirable active mixer circuit because it produces less even order distortion as a result, the half IF concern in heterodyne receivers is reduced, further gilbert cell mixer also offers excellent high IIP3 and improved linearity. Mainly we have Four active mixer design approach [6]. To be productive, one must perform at their optimum possible level, the RF-IF path must be linear, and the LO switching time must be maintained at a minimum. Furthermore, matching wide-band LO/RF oscillators with low-noise amplifiers to achieve the most efficient gain at the lowest power consumption ports is difficult. The passive mixer described in [7, 8] virtually consumes no DC power, making it an attractive component for technologies such as low-supply-voltage CMOS and submicron fabrication. Additionally, it has exceptional intermodulation qualities and linear behavior. The main disadvantages of the passive approach, as opposed to active mixers, are conversion losses and, occasionally, the requirement for a greater LO power. The mixer designs reported in [9, 10] characterized by a differential Local Oscillator signal, these types of transmitters are referred to as “single-balanced mixer”. Depending on the power dissipation, the single balanced architecture exhibits less noise at the input, but It is far more prone to noise in LO, this could result in LO-Intermediate Frequency feed-through. In a 65-nm CMOS, Fang Zhu et al. [11] demonstrated a mixer that can be switched between operating as a fundamental and dual-band subharmonic mixer. The suggested CMOS mixer is based on a modified Gilbert mixer design. It can work with a low voltage supply and a low LO power and still give good results in Subharmonic Mixer and Fundamental mixer configurations. The mixer may be repurposed for use in dual-band applications by having its bias adjusted so that it can operate in either the subharmonic or fundamental modes. The entire amount of dc power that is consumed by the mixer in either condition, including the output IF buffers, is seven milliwatts. The use of this circuit in a Millimeter Wave portable dual-band system which requires low level voltage and limited power, might make it an appealing option. B. R. Jackson et al. [12] demonstrate a mixer that is capable of achieving a CG of 5 dB across frequencies ranging from 5-6 GHz and 9.8-11.8 GHz, keeping the intermediate frequency output constant. The circuit has the potential to be employed as a component of an integrated multi standard system to minimize the required number of circuits parts. This might possibly result in lower power consumption as well as cost savings. This method might also be highly appealing at millimeter-wave frequencies, where it would be able to eliminate frequency double circuit usage that is coupled to output of a local oscillator, in addition to circumstances where using a broadband mixer circuit would be impossible.

3. BLOCK DIAGRAM OF THE PERPOSED MIXER

This section presents the sophisticated RF down-conversion mixers and the difficulties involved. Along with, the associated projects and publications are also listed. The next part will provide the ideal design to address these problems. In its simplest form, a Gilbert cell is a differential amplifier (also known as a variable gain amplifier) whose gain is managed by a control voltage. Because of their low conversion loss, high conversion gain, and small size, CMOS Gilbert-cell based mixers may operate at frequencies as high as 50 GHz when employing CMOS with a feature size of 0.13 micrometres [13]. Gilbert cell have a strong efficacy short chip size, which makes them ideal for applications with low frequencies. Above 100 GHz, Gilbert mixers also offer appealing characteristics, but in order to expand their bandwidth, they need an additional matching circuit. Although Gilbert cell mixer are completely differential circuits, connecting them to other components of the circuit may require a transition from single-ended to balanced. Mixers that are passively balanced and make use of Marchand baluns are quite common in the microwave and millimetre-wave frequency ranges. The sizes of the baluns in passive balanced mixers are wavelength-proportional and they frequently take up the majority of the chip surface. Alternately, we want a small design in the band with a frequency that is higher than 100 GHz that makes use of the passive baluns that were discussed before; this is a challenging task. The differential radio frequency and local oscillation signals are offered by a integrated 1800-balun that uses Marc-hand-type transformers [14]. The LC ladder matching networks [15] are added to this mixer architecture to increase bandwidth.

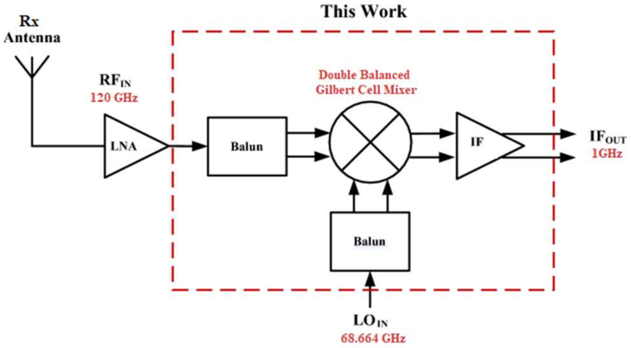


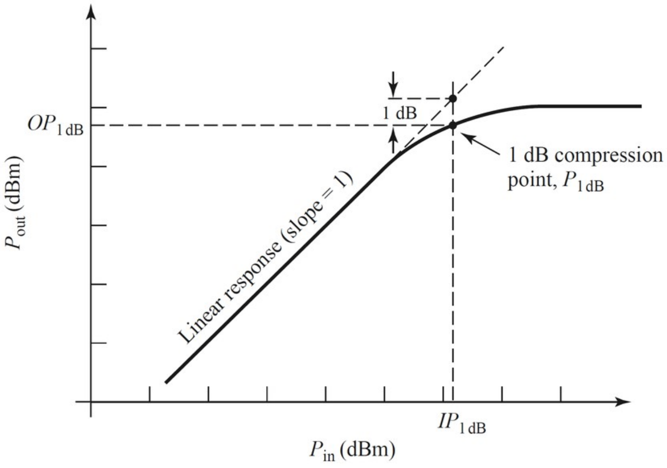
Figure 2: Block diagram of the perposed mixer with 2 BALUNS

Figure 2 depicts the planned 120 GHz down-conversion Gilbert cell mixer block diagram, which includes a Gilbert cell and two baluns (Marchand Type) for converting radiofrequency as well as Local Oscillator signals in to differential output signals. The flat conversion gains as well as radio frequency port return loss in monolithic microwave integrated circuit (MMIC) are more than broad bandwith with ladder matching networks. The operating frequency of CMOS technology is constrained by parasitic capacitances. In order to reduce conversion losses, which are primarily linked to a passive down-conversion mixer structure, a high LO voltage signal is typically sought after. However, this poses a challenging restriction on the LO structure's design and eventually reduces the mixer's performance. Additionally, this leads to high-power dissipation losses.

In addition to the high conversion gain, welcomes higher linearity and improved port isolation. If the application is moved to a higher frequency range, such as 120 GHz, these criteria become more demanding. On the other hand, it is challenging to achieve a high CG and improved isolation for 120 GHz. It is crucial to choose a mixer with LO drive level that provides the necessary compression point for the application since the compression point varies with LO drive level. We must remain much below the one dB compression point ((IP1 dB) if you want the mixer to behave linearly.

S. Krishnamurthy, et.al and L. Iotti, et.al respectively designs a Receivers with high linearity mixers for mm-wave digital mimo array by utilizing the overlapping square-wave drive [16]. This technology was used to increase mixer switch linearity particularly at mili meter wave frequencies; however, feedback linearization has restrictions that prevent it from being used for broadband operation, then a LNA raised final stage is necessary. Additionally, the works [17], [18], and [19] use Passive phase shifters based on transmission lines, which also employ vector interpolator-based active phase shifters and exhibits much worse linearity. The significance of this performance metric in evaluating dynamic range in terms of maximum input for different mixers is what makes it significant. The signal power range that a mixer can operate effectively is referred to as its dynamic range. The conversion compression point denotes the dynamic range's upper bound. IP1dB is one of the most important specifications for mixers, as it is up to this point that we consider a mixer to operate linearly. Fig.3 offers a graphical illustration of this1-dB Compression Point.

Figure 3: 1-dB Compression Point graphical



representation

For higher linearity the IP1dB point should also be higher. The LO drive level is connected directly to the mixer's 1-dB compression point. Mixers that require a higher LO drive level have a larger 1-dB compression point. With high transconductance differential pairs (with greater dimensions), strong linearity has also been investigated, as well as a larger 1-dB compression point is desired.

Our next investigation in this paper is Compatibility of the additional components like BALUNs to incorporate the balanced active Mixer architecture has been a challenging task in active mixer topologies employing current reuse property and compact chip size. The difficulty of connecting differential RF circuits to single-ended ones is overcome by the balun, a variant of a specialised RF [20]. A balun, which means "balanced to unbalanced," is a type of electrical interface that connects balanced and unbalanced lines without changing the impedance configuration of either line. The switch stage that receives its power from the differential architecture's RF signals. The input balun has previously acquired these LO signals in the balance mode. By increasing the size of the transistors that make up the switch stage, which Low overdrive gate voltages drive them, the necessary driving LO power is greatly lowered. It is designed to get a very high-quality factor while employing the inductors at 24 GHz. The cross-coupled pairs used provide a high conversion gain, which necessitates an active load stage with an extremely high corresponding load resistance. The balanced IF ports have inverter mode buffer amplifier stages added, which has significantly improved the mixer's isolation performance. The current reusable cross-coupled differential structure's explanation and detailing make it extremely easy to understand the topology and aid in the improvisation of the architecture [21, 22]. Two stages' independent bias between the trans conductance stage and switch stage using the transformer with harmonic suppression is used to increase linearity of the mixer [23]. Using the resonant circuit byincluding a inductor to adjust the path for current improvement significantly minimizes the linearity damage imposed by the pMOS switch cell's nonlinear capacitances [24]. The standard current bleeding circuit is replaced with a current-reused bleeding amplifier to increase conversion gain even more while consuming the same amount of current as before [25]. To improve the linearity of a current converter mixer, researchers are investigating static and dynamic current injection strategies [26]. This also clarified every significant restriction pertaining to crucial metrics like gain and linearity. A 65nm CMOS gain-boosted current bleeding D band mixer was created [27]. This suggested gain-boosted current-bleeding mixer outperformed all previously reported mixers when operated at D-band frequencies using the proposed gain-boosted current bleeding approach. Recently, many 80 GHz CMOS and SiGe BiCMOS mixers were disclosed [28, 29]. Its power consumption of 6 mill watts which is much low, while the conversion gains of 8 decibels, the low LO-RF isolation 21 decibels, and the low LO-IF isolation 32 decibels be all inadequate [28]. A double-balanced 75 to 110 GHz Gilbert mixer is shown in a 200 GHz fT SiGe process [29]. The system proved unsatisfactory despite its 14.4 dB CG, 30 dB LO-RF isolation, and 92.4 mW power consumption. Low isolation and excessive power consumption rendered the system unsuitable for practical applications. We describe a low power down-conversion mixer giving good CG, linearity, low noise figure, and strong isolation between ports with a thickness of 130 nano meter CMOS technology.

4. DOUBLE-BALANCED CURRENT REUSE MIXER TOPOLOGY

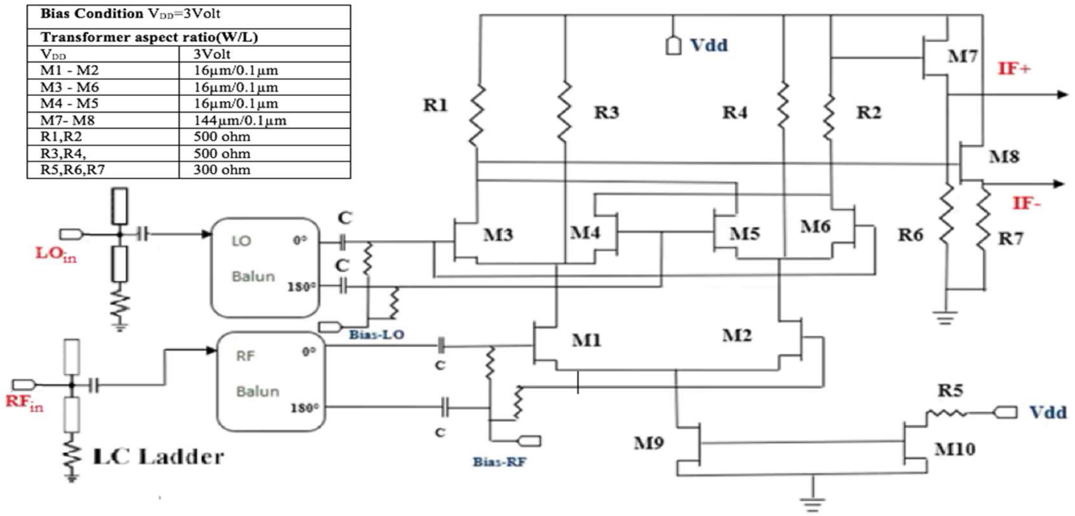
The suggested Gilbert-cell down conversion double balanced mixer architecture is shown in Figure 4. To produce the various Radio Frequency and local oscillation signals, a small 1800 balun utilizing transformers of the Marc-Hand type incorporated. The bias condition is mentioned with the component and its parameter at the top left corner of figure 4. By applying a bias during saturation zone to the transistor M1 and M2 terminals, the Radio Frequency input signal can be converted into current at output. The two parallel linked pairs, M3 and M6, which together form the LO switching quad, have their biases set so that they are somewhat close to the pinch-off area. It may be possible to enhance the functionality of a Gilbert-cell mixer using a method known as charge injection. A charge injection circuit is employed, and it consists of two resistors, R3 and R4, each of which has a value of 500 ohms. This circuit is used to allow the drain current to flow freely into M1 and M2. With the assistance of this charge-injection circuit, it is possible to lessen the amount of voltage that is lost all over the load resistors as well as the drain current that is carried by the switching quad transistors. It may be possible to achieve a higher gain in the voltage conversion if the value of these load resistors is increased. In order to ensure that the input and output impedances are compatible, we have included two source follower transistors (M7 and M8), which are nine times as thick as M3 and M6, as well as R6 and R7, which each have a resistance of 300 ohms. A current mirror source consisting of M9, M10, and R5 is responsible for regulating the overall bias current that is produced by the modified Gilbert-cell mixer (300 ohms). The monolithic transformer of the Marc-Hand type is responsible for providing the differential RF and LO signals. Utilizing designs for thin-film micro strips makes it possible to fold the coil of a Marchand-type transformer into an extremely compact size. Along with the two source follower transistors, this folded Marchand-type transformer offers a match to the overall input impedance, which is 50 ohms.

5. RESULT AND DISCUSSION

Figure 4 on next page shows a potential design for a mixer that has been put to the test using the ADS tool in order to accomplish the objective requisite Conversion Gain and Noise Figure using a 130-nm Radio Frequency CMOS Technology. To maintain the highest feasible conversion gain, the 130-nanometer CMOS technique has been chosen for the mixer, and a supply bias of 3 volts has been chosen. The supply's power consumption was 66.8 mW. Figure 5 shows Simulation of the conversion gain (CG) expressed in dB as a variation of the Local Oscillator power expressed in dBm. Figure 6 shows the Simulation of DSB noise figure (NF) as a direct result of the Local Oscillator power.

Figure 5: Simulation of the CG as a variation of LO power

Figure 6: Simulation of the DSB noise figure as a variation of the LO power



Bias Condition V_{DD}=3Volt	
Transformer aspect ratio(W/L)	
V_{DD}	3Volt
M1 - M2	16µm/0.1µm
M3 - M6	16µm/0.1µm
M4 - M5	16µm/0.1µm
M7- M8	144µm/0.1µm
R1,R2	500 ohm
R3,R4,	500 ohm
R5,R6,R7	300 ohm

Figure 4: Schematic diagram of Proposed double-balanced gilbert cell topology

Table 1. The Performance and comparison with earlier efforts with similar operation frequencies

References	CMOS Technology	Topology	RF Frequency (GHz)	Conversion gain (dB)	RF-LO Isolation(dB)	Linearity (1dB compression pt.)	Noise Figure(dB)	LO power (dBm)
This Work*	**130 nm CMOS**	**Double balanced Gilbert cell**	**120**	**8.882**	**68.664**	**-12.2**	**8.4**	**4**
[27]	65 nm	Gain-Boosted Current Bleeding	120	-11	-30	4	33.5	-9
[28]	65nm CMOS	Double-Balanced Gilbert-Cell with 2 Baluns	77	-8	21	-6.5	17.8	4
[29]	200 GHz f_T BiCMOS	Double-Balanced Gilbert-Cell with 2 Baluns	110	14.4	30	-15	19.5	3
[30]	0.13 µm	Subharmonic mixer (SHM)	122	5dB	-	-44	21	9
[31]	0.13 µm SiGe	passive SHM topology based on APDP	122	-8dB	-	-5	8.5	5
[32]	90nmCMOS	Double-Balanced Gilbert-Cell with 2 Marchand Baluns	80	1.5	49.2	-9	23.3	5
[33]	SiGe BICMOS	Gm-boosted active mixer	135	11.5	-31	-	-	10

The ideal RF power and Local Oscillator power values are kept at -30 dBm and 4 dBm, for all simulations respectively. For Conversion gain The simulation was made for Radio Frequency input powers varying from -50 dBm to 0 dBm, following figure represents conversion gain of the order of 8.82 dB. The Figure 7 shows the variation of the CG according to the RF power and Figure 8 shows the variation of the CG as a direct result of the radio frequency from 119 to 121 GHz.

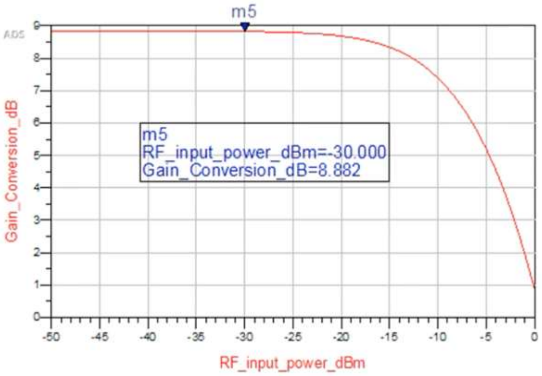


Figure 7: Simulation for the variation of the conversion gain according to the variation in RF input power

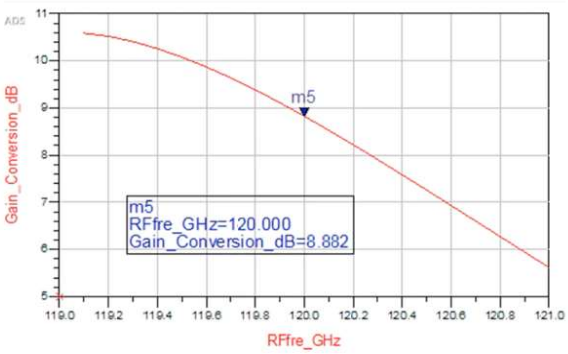


Figure 8: Simulation for Conversion gain while simulating it in the RF Frequency D-band from 119 to 121 GHz.

The 1 dB (IP1dB) compression point obtained is -12 dBm as shown in Figure 9 which characterizes the limit of the linear operation of the circuit. It measures the 1 dB deviation of the conversion gain as a function of the power applied to the mixer. Fig 10 shows the isolation in between the radio frequency and LO ports. In the down-conversion mixer, this isolation in between these ports is important as it reflects the device's ability to avoid LO signal leakage onto the RF port.

Figure 9: Simulation for the variation of the IF output power with the RF input power (IP1dB)

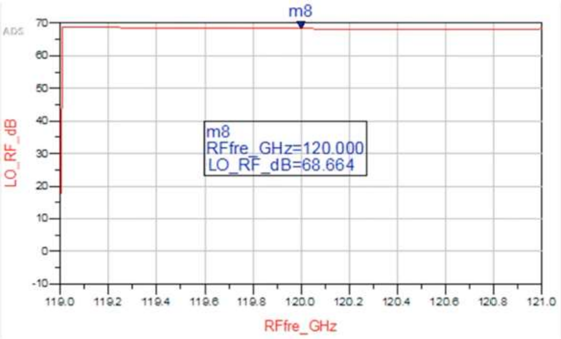


Figure 10: Simulation for LO-RF isolation with function of the RF frequency in GHz.

In order to demonstrate the suggested double balanced current reuse down-conversion mixer's evaluated performance against other popular and widely-published designs from earlier literature with similar operation frequencies of around 120 GHz, a thorough comparative table (Table 1) has been created. Linearity, Conversion gain (CG) and NF (Noise Figure), three of most crucial indicators, are provided to emphasize the innovative successes of the suggested work in this study.

The current reuse double balanced architecture has also led to the improved performance metrics even for K band in modern RF applications [34]. Also, in contemporary WSNs with multiple data-transmitting nodes, Mixer applications can increase data transmission efficiency and reliability [35]. Wireless networks have limited capacity, thus transferring all the data at once might cause interference and data loss. A mixer application combines signals from several nodes into a single signal for wireless transmission to solve this problem.

6. CONCLUSION

After qualitatively examining current Radio Frequency down conversion mixer, this research suggests a better architecture. This double balanced current reuse architecture has a few distinct advantages like high gain and linearity. The 120 GHz input RF was developed using the 130-nm CMOS process. The radio frequency and LO differential signals are given by mixer through Marc-hand-type transformers. In order to achieve uniformity of conversion gain across a broad bandwidth of 120 GHz, an LC ladder matching approach is used. We qualitatively analyze three key features of the down-conversion gilbert cell mixer architectures: noise figure, conversion gain and linearity. Numerous restrictions on topologies of conventional mixers and difficulties with RF receiver layouts have been reported. The proposed double balanced Gilbert cell tries to incorporate all of these components. High linearity with a -12.2 dBm compression point has been obtained. The suggested mixer architecture had a high CG performance (8.882 dB) compared with earlier efforts. Furthermore, the obtained noise figure of 8.4 dB is significantly lower than that of the other mixers compared in this paper. The work that is currently being presented is innovative due to its superior conversion gain, higher linearity, and low Noise Figure (NF), and measurement results indicate that this modified Gilbert cell is good for MMW 120 GHz RF scenarios.

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