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A COMPARATIVE STUDY OF DIFFERENT TYPES OF MIXER TOPOLOGIES

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Abstract

In this paper, a comparative study of different types of mixer topologies is presented. Gilbert cell is widely used as core of the mixer because it provides high conversion gain, good port-to-port isolation and low even-order distortion. It is found that the linearity of mixer is very good for Multi-Tanh technique by incorporating multiple differential trans-conductance stage but it reaches to very low conversion gain whereas, use of current bleeding technique increase linearity and conversion gain of the mixer by adding current source to increase the bias current at the expense of power consumption. A very low value of noise figure can be achieved with the switched biasing technique by replacing current source with parallel connected nMOS transistors but due to use of the transistor in place of tail current source, linearity is degraded and more power is consumed. Folded Cascode Technique is used to reduce DC supply voltage by folding the LO switching stage with pMOS transistors in switching stage but it degrades the noise figure. Bulk-driven technique can be employed to lower down the power consumption by providing the switching action via the gate of LO (RF) and amplification by the bulk of LO (RF) transistors, however it reduces the linearity. High linearity is obtained by using CCPD (Cross coupled post distortion) technique by cancelling of third order derivatives but it decreases the conversion gain and consume more power due to increase in the number of auxiliary transistors. MGTR enables to achieve high linearity by incorporating auxiliary transistor but it decreases the overall conversion gain and increases noise figure of the mixer. So it is observed that there is a trade-off among the performance metrics, i.e., conversion gain, noise figure linearity, and power consumption of the mixer.

Keywords:

Multi-Tanh, Current Bleeding Technique, Switched Biasing, Folded Cascode, Bulk-Driven, CCPD, MGTR

1. INTRODUCTION

RF mixer is an indispensable part of modern wireless communication system. Mixer is a three port active or passive device, designed to provide down-converted and up-converted version of input frequency. When the desired frequency at the output is lower than the input frequency it is called as down-conversion and if the signal at the output is at higher frequency than the input signal, it is known as up-conversion as shown in Fig.1.

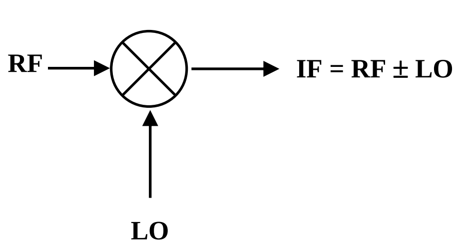

Fig.1. Mixer

On the basis of performance and structure, mixer can be single balanced mixer or double balanced mixer [14]. An active mixer provide conversion gain and requires low LO power but it has poor linearity, whereas, passive mixer provides high linearity and increased dynamic range but requires high LO drive [23]. Single balanced mixer requires differential form of local oscillator (LO) signal and single ended form of RF signal as shown in Fig.2 [12].

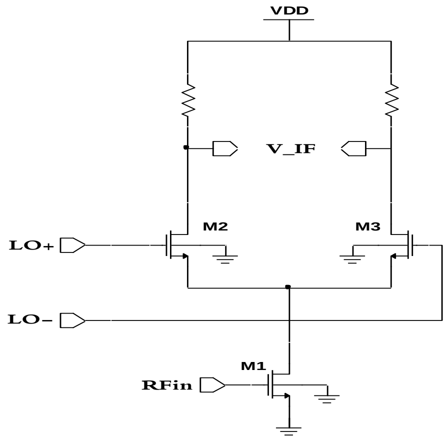

Fig.2. Single balanced mixer [12]

Double balanced mixer operates with differential LO as well as differential RF signal as shown in Fig.3. [20]. Single balanced mixer is simple in design and provide moderate gain and low noise figure but has poor port to port isolation between LO to RF and LO to IF and possesses low third order input intercept point (IIP_3). Double balanced mixer provide high port to port isolation and has output spurious product rejection capability [7].

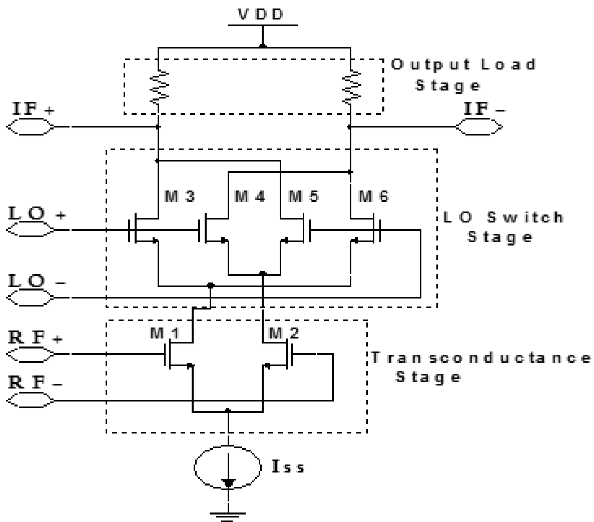

Fig.3. Schematic of conventional double balanced CMOS Gilbert cell mixer [12]

In mixer design, double-balanced Gilbert cell mixer is preferred as a core of many mixers due to benefits, such as higher linearity, low even order distortion and good port to port isolation [8]. The basic double-balanced CMOS Gilbert cell mixer consists of three stacked stages i.e., trans-conductance stage, LO switching stage and output load stage.

There exists trade-offs between the performance parameters of mixer like conversion gain, noise figure, linearity, power consumption and so on as shown in Fig.4 as RF design hexagon. [23].

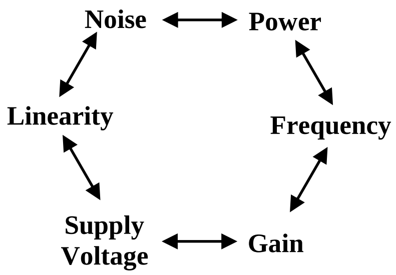

Fig.4. Tradeoffs in RFIC design [23]

The high linearity can be achieved at the expense of low conversion gain and high power consumption, while high conversion gain mixers suffer from increase in noise figure. The highly linear mixer can increase the dynamic range of the mixer. The linearity of mixer affects overall linearity of the system which can be expressed by Friss equation [20]:

$$\frac{1}{IIP_3} \approx \frac{1}{IIP_{3,1}} + \frac{G_1}{IIP_{3,2}} + \frac{G_1 G_2}{IIP_{3,3}} \cdots \quad (1)$$

In Eq.(1), G_i, i = 1,2,3,…,n are the power gains of each cascode stage, therefore, the designing of front-end transceivers require a highly linear mixer. Therefore, designing highly linear mixers has attracted a considerable amount of attention [14].

Linearity of mixer is measured by third order input intercept point ($IIIP_3$) as well as 1 dB compression point as shown in Fig.5 [25].

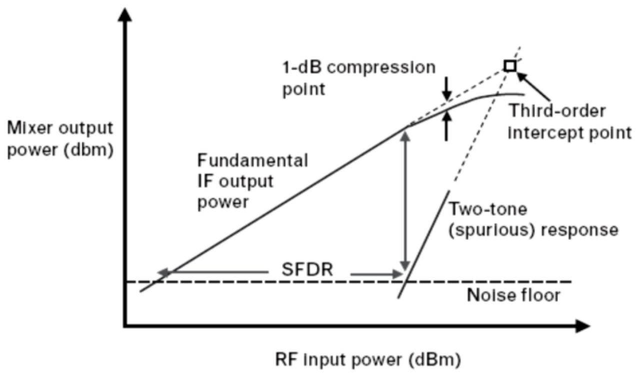

Fig.5. output power versus input power [25]

Third order input intercept point (IIP_3) can be estimated by Eq.(2) [20]:

$$A_{IP3} = \sqrt{\frac{4}{3}\left|\frac{\alpha_1}{\alpha_3}\right|} \quad (2)$$

where, α_1 and α_3 are the coefficients of non-linearity.

Linearity can also be measured through 1-dB compression as given by Eq.(3) [20]:

$$A_{1-dB} = \sqrt{0.145\left|\frac{\alpha_1}{\alpha_3}\right|}\ . \quad (3)$$

In this paper, the comparative study of different topologies of mixer such as Multi-Tanh [1], Current bleeding [8], Switched biasing [2], folded cascode [4], bulk driven [5], CCPD [6] and MGTR techniques [7] are discussed with their merits and demerits. These techniques can be used to improve mixer performance parameters in terms linearity, noise figure, supply voltage, power consumption and conversion gain.

2. LITERATURE SURVEY

This section summarizes the techniques that are used to enhance the performance of Gilbert cell mixer.

Barrie Gilbert proposed "Multi-Tanh" technique [1] in order to extend the voltage capacity of a trans-conductance (g_m) of mixer, by incorporating multiple differential pairs operating in parallel as shown in Fig.6 [28],

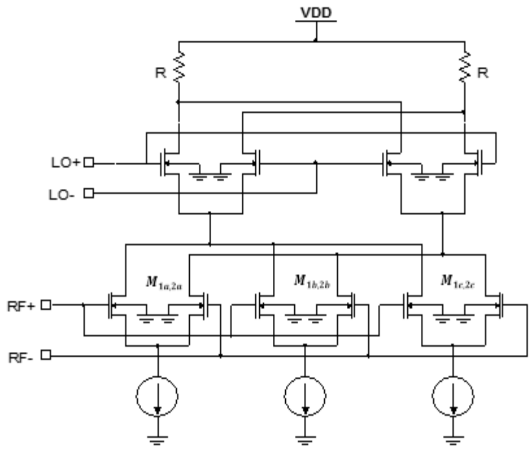

Fig.6. Schematic of Multi-Tanh technique [28]

In this technique, a constant g_m along a large range of input voltage is achieved by replacing single differential pair stage with a multiple differential pair stages. The individual g_m functions of each differential stage is distributed along the required larger input range, so that the resultant constant trans-conductance (g_m) can be achieved over a wider range of input voltage [25].

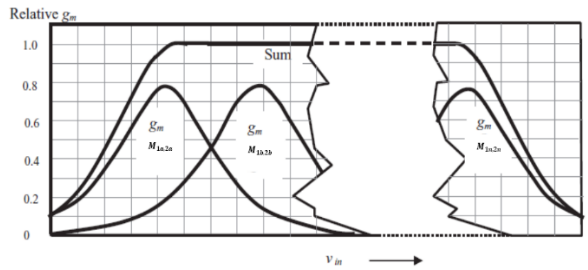

Fig.7. n-Multi - Tanh differential pairs [25]

Multi-Tanh technique allows the mixer to handle larger input voltage swings, as a result, performance of mixer can be enhanced in terms of wider range of constant trans-conductance with better linearity and low-distortion [1]. But power consumption is increased in this technique [28].

S. Douss, F. Touati and M. Loulou proposed current -bleeding technique with double-Balanced mixer [8]. This technique can be explained more clearly using a single-balanced mixer as shown in Fig.8 [8], in which a bleeding current source (*I_BLD*) is added between the supply voltage and the source of LO switching transistors, without this current source, the total bias current is $I_{Bias} = I_{D1} + I_{D2}$, but by using current bleeding technique I_{Bias} increases to $I_{Bias} = I_{D1} + I_{D2} + I\_BLD$. Therefore, the conversion gain as well as linearity can be improved simultaneously but this increases the total power dissipation of the mixer. The power dissipation of the mixer can be controlled by keeping the total bias current (I_{Bias}) constant. For this I_{D1} and I_{D2} can be decreased, by adding the current bleeding source but it requires to increase the load resistor R_L to ensure that the bias conditions of the switching pair should not be destroyed. Improvement of conversion gain in this technique can be shown as Eq.(4) [8].

$$CG \approx \frac{2}{\pi} R_L \sqrt{K_n I_{Bias}} \tag{4}$$

where, $K_n = \mu_n C_{ox} \dfrac{W}{L}$.

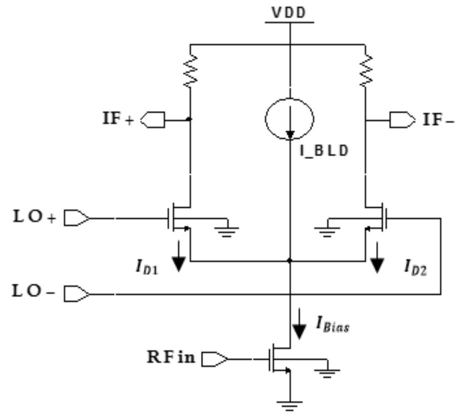

Fig.8. Single-balanced mixer with current bleeding source [8]

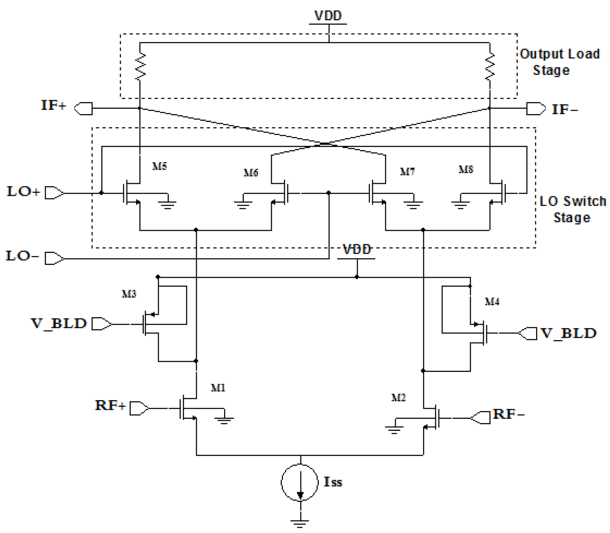

Fig.9. Double-balanced mixer with current-bleeding technique [8]

Whereas the voltage conversion gain of the basic Gilbert-cell without current bleeding technique can be expressed as:

$$A_V = \frac{2}{\pi} g_m R_L \,. \tag{5}$$

It is clear that conversion gain of double balanced Gilbert mixer depends on the trans-conductance (g_m) of RF stage transistors and output load stage resistor (R_L) as given by Eq.(5). Conversion gain is increased by increasing the current flow through RF differential pair but it also increases the power consumption. Besides this, voltage headroom problems also arises due to higher RF current through the switching transistor. Current-bleeding transistors are used to minimize this problem as they provide larger current at trans-conductance stage but do not increase the current flowing through the switching pair transistors as well.

Eric A.M. Klumperink, Sander L.J. Gierkink, Arnoud P. Van der Wel and Bram Nauta proposed a switched bias technique [2] for reducing flicker (1/*f*) as well as white noise. The principle of switched biasing technique with conventional constant bias is shown in Fig.10 [2].

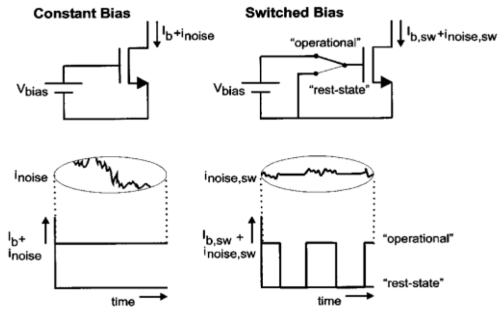

Fig.10. Basic principle of switched biasing technique [2]

In switched biasing technique MOS transistor is periodically switched between two states [2]:

1) "Active state" or "operational state", in which transistor is biased in strong inversion region to provide a bias current [2].
2) "Inactive state" or "rest state", in which transistor is biased in or near to accumulation region. In this region MOSFET does not remain in fully active state. This state of transistor is responsible of reducing flicker noise as well as power consumption [2], [3], [10].

In double-balanced Gilbert cell mixer, tail current source of the transistor is considered as a critical noise source. The switched biasing technique replaces the tail current source into two half size transistors by operating them alternatively using IF output signal [2]. This reduces the flicker noise generated by tail current source. The switching operation of switched bias tail current transistors are generally asymmetric because of large difference between the dc voltage of the output nodes and the threshold voltage of the tail current. To overcome this problem, dc level shifter can be used, as shown in Fig.11 [3], to provide efficient gate to source voltage (V_{GS}) for symmetric switching operation with a small output swing and to make the overdrive voltage as smaller as possible, but the overall conversion gain of the mixer is reduced [10].

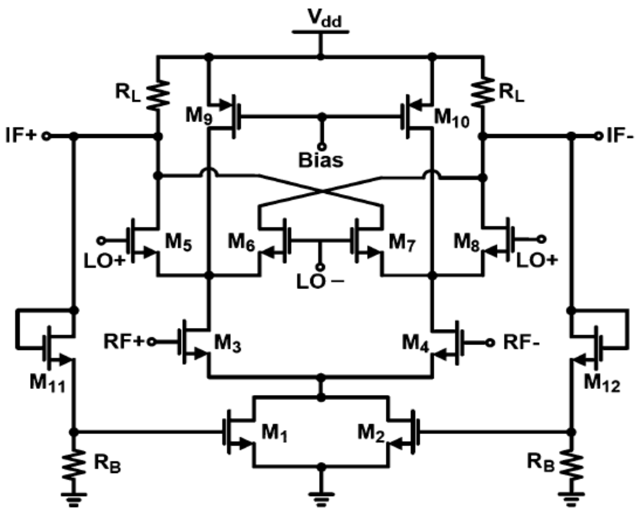

Fig.11. Schematic of switched biasing technique [3]

Pokuri Sravanthi and Aniruddha Chandra applied folded cascode technique [4] in Gilbert mixer for reducing the power consumption of the mixer while maintaining the values of all the parameters as of Gilbert mixer but the linearity of the mixer is degraded. Basic schematic of folded cascode is shown in Fig.12 [4].

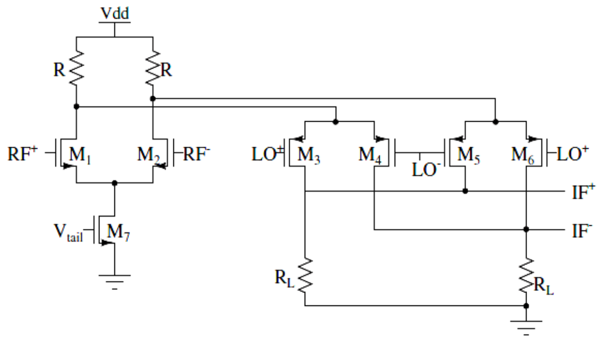

Fig.12. Folded cascode mixer [4]

Che-Yu Wang and Jeng-Han Tsai proposed a mixer with reduced supply voltage and low power consumption using Bulk driven technique [5]. This technique allows the RF trans-conductance and LO switching stages of the core of the basic Gilbert mixer to be merged to a single stage, consisting of only four transistors. Schematic of this technique is shown in Fig.13 [14].

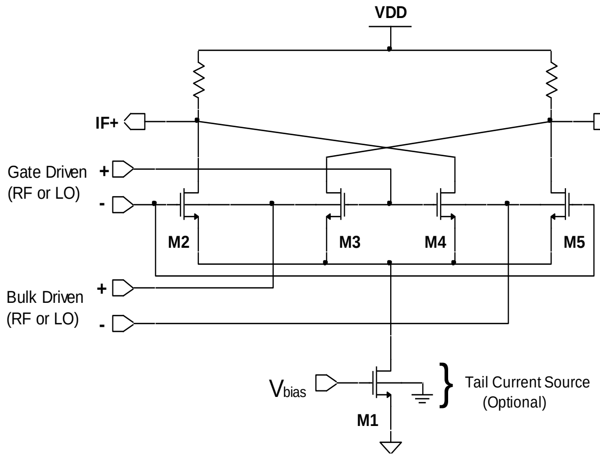

Fig.13. Schematic of Bulk driven mixer core [14]

The principle of the Bulk-driven method is that; the gate-source voltage (V_{GS}) of all the four transistors is set to a value sufficient to form an inversion layer, and an RF input signal is applied to the bulk terminal. Bulk-driven technique increases the threshold voltage, therefore, the condition of ($V_{GS} > V_{th}$) is relaxed [14]. Using Bulk driven technique number of transistors reduces, therefore, voltage supply is decreased. Transistors are biased in sub threshold region for decreasing current dissipation, therefore, power consumption is low, and drain current is estimated by [24]:

$$I_D = \frac{W}{L} I_{Do} \exp\left(\frac{V_{GS} - V_{th}}{nV_T}\right). \tag{6}$$

The relationship between threshold voltage (V_{th}) and source-bulk voltage (V_{SB}) is given by Eq.(7) [24]:

$$V_{th} = V_{tho} + \gamma\left[\sqrt{2\varphi_F + V_{SB}} - \sqrt{2\varphi_F}\right] \tag{7}$$

where, (V_{tho}) is the nominal zero bias threshold voltage, i.e., for (V_{SB}) = 0, γ is the process-dependent body effect factor, and (φ_F) is a substrate (Bulk) Fermi potential typically in the range of 0.2-0.4V [27, p. 258].

D. Selvathi, M. Pown, and S. Manjula presents a paper on CCPD technique [6], to improve the mixer performance in terms of linearity.

The expression using Taylor series expansion for the drain current (i_{ds}) versus gate to source voltage (v_{gs}) up to its third-order non-linearity can be expressed as [6]:

$$i_{ds} = i_{dc} + g_{m1}v_{gs} + g_{m2}v_{gs}^2 + g_{m3}v_{gs}^3. \tag{8}$$

In Eq.(8), g_{m1}, g_{m2}, g_{m3} are the first order, second order and third order of transconductance of the transistor. The coefficients for higher order terms are typically small and can be ignored.

The main objective of using CCPD is to improve the linearity of mixer by incorporating auxiliary transistors, operating in weak inversion region and main transistors, operating in strong saturation region, as shown in Fig.14 [6].

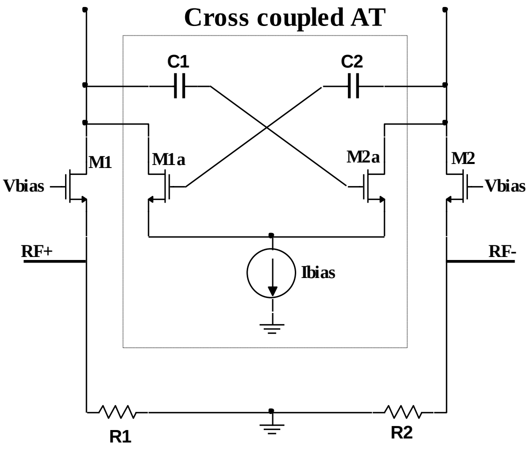

Fig.14. Schematic of CCPD technique trans-conductance stage [6]

Bonkee Kim, Jin-Su Ko, and Kwyro Lee proposed Multiple Gated Transistor (MGTR) [7] technique, as shown in Fig.15 [7]. The input signal is given to the gate of the RF trans-conductance transistors. The drains of differential main transistor are connected to the respective drains of the differential auxiliary transistor. The main transistors shown in Fig.16 [6] are operating in strong inversion region and the auxiliary transistors are operating in weak inversion region. The MGTR enables the cancellation of third order derivative due to the introduction of auxiliary transistors.

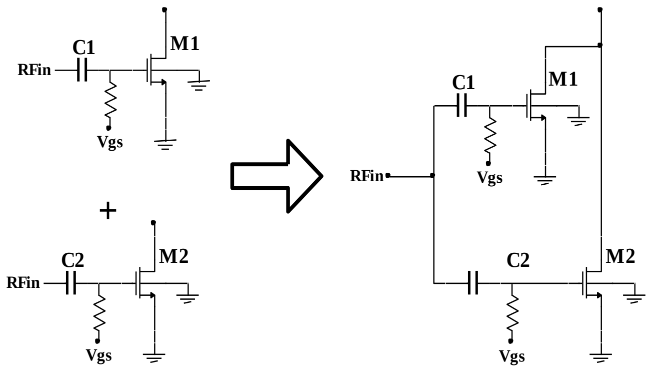

Fig.15. Single ended MGTR [7]

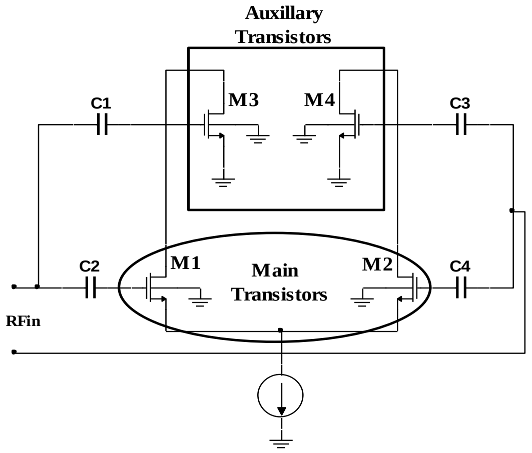

Fig.16. Differential multiple gated transistor (DMGTR) [6]

The advantages of the MGTR technique is that it provides high conversion gain, moderate noise figure and higher linearity under lower power dissipation but the DC overdriving voltage of the auxiliary transistors can degrades the overall linearity of the mixer. In order to overcome this limitation, careful design of the bias voltage of the auxiliary transistors is needed so that auxiliary transistors should operate in weak inversion region [29].

Comparison of the discussed proposed mixer techniques is shown in Table I. Comparative results show that there is trade-off among different parameters of mixer ,which is in agreement with RF design hexagon [12], [23].

3. CONCLUSION

In this paper, various mixer topologies such as Multi-Tanh, current bleeding, switched biasing, folded cascode, bulk-driven CCPD and MGTR techniques are discussed and compared. It can be concluded that there is a trade-off among the performance parameters of the mixer. If one of the parameters of the mixer is improved using some technique then the other mixer parameter may be degraded. Such as linearity can be improved by using Multi-Tanh technique but it suffers with a very low conversion gain. Similarly bulk driven technique is used to obtain low power consumption but it degrades linearity. So the overall comparative study shows that there must be some compromise among the values of the different performance parameters of the mixer. This work facilitates the selection of a particular topology of the mixer depending on the specific requirements of the mixer.

Table.1. Summary and Comparison of different types of mixer techniques

Techniques	**Multi-Tanh**	**Current Bleeding**	**Folded cascode**	**Bulk-driven**	**CCPD**	**MGTR**	**Switched biasing**
Linearity	High	High	Moderate	Low	High	Moderate	Low
Noise figure	Moderate	High	High	High	Moderate	Moderate	Low
Conversion gain	Low	Moderate	Moderate	Moderate	Moderate	Low	Moderate
Power consumption	High	High	Low	Low	High	High	High

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