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Design of FET Ring Mixer using 180 nm CMOS Technology for Band #1 of WiMedia MB-OFDM UWB Systems

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Abstract

A double balanced down conversion FET ring mixer is proposed for band #1 of WiMedia multi band Orthogonal frequency division multiplexing (MB-OFDM) ultra wideband (UWB) system at RF frequency of 3.432 GHz and IF frequency of 264 MHz and LO frequency of 3.696 GHz. Differential LC matching is used at RF port to impedance match the RF signal with required matching bandwidth with low conversion loss. Proposed mixer is simulated using Keysight ADS software using 180nm CMOS process. The mixer achieves the minimum conversion loss of 5.38 dB, 1 dB compression point (P1dB)of 5.85 dBm, the third order input intercept point (IIP3) of 16.530 dBm, a SSB noise figure of 4.687 dB and S_{11} of -14.020 dB.

Keywords: *WiMedia, Down-conversion mixer, FET Ring Mixer, Differential Matching,*

1. Introduction

Wireless personal area networks (WPANs) standards provides a wireless solution for connecting computer peripherals smart phones and PDAs. The next-generation of WPANs standards are being developed with a primary objective of increasing data rates with high throughput, low power consumption. WiMedia ultra wideband (UWB) technology is a one of such a standard for WPANs. A system is referred as UWB when either it has a fractional bandwidth greater than 20% or it has absolute bandwidth greater than 500 MHz. There are currently two major competing UWB standards i.e. direct sequence-UWB (DS-UWB) and multi-band OFDM. In DS-UWB technology, a single pulse, is transmitted in any of the spectrum ie 3.1 GHz - 4.85 GHz, or at 6.2 GHz - 9.7 GHz. Whereas in MB-OFDM use multiple sub-bands of 528 MHz bandwidth. WiMedia Alliance [WiMedia] is WPAN standard based on MB-OFDM technology. Wimedia uses the spectrum from 3.168 GHz to 10.560 GHz, which is divided into 14 equally-sized sub-bands of 528 MHz each. Band 1 ranges from 3.168 GHz to 3.696 GHz with center frequency of 3.432 GHz [1-5].

Frequency plan of WiMedia MB-OFDM standard is given in figure 1[2].

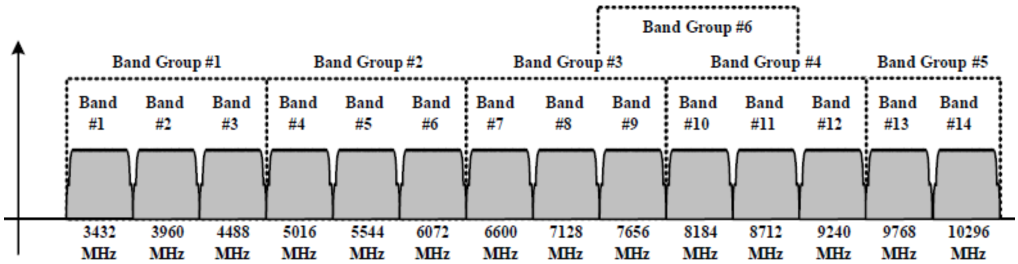

Figure 1. Frequency plan of WiMedia MB-OFDM standard

Mixer is an essential block of modern wireless transceiver systems. Mixer is a frequency translation device which can be classified as up converter mixer and down converter mixer. Up converter mixer converts low intermediate (IF) frequency to high radio frequency (RF) frequency with the help of local oscillator frequency (LO) frequency. Whereas down converter mixer coverts high value of RF frequency to Low value of IF frequency as shown in figure 2.

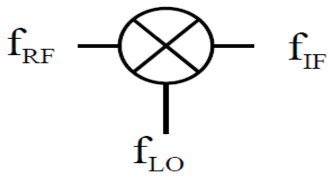

Figure 2. Function of down converter mixer

Mixer is fundamentally a multiplier in time domain. Multiplication in time domain results in frequency mixing.

Let RF signal is expressed as
And LO signal is expressed as
Mixer output (is given as

For downconversion
When output is passed through low pass filter then higher component is rejected and is filtered outas

Mixers can be classified as square law mixer and switching mixer. Square law mixer uses second order nonlinearity to implement multiplier (mixing) operation whereas switching mixer implement multiplication operation by switching RF signal with respect to o signal frequency. Square law mixers are unbalance in nature and produces lot of spurious signals including RF and LO feedthrough at the output. Switching mixers are inherently are passive mixer, which do not provide gain but switching mixers can be modified using some active stage to provide gain but on the expense of linearity. So when the linearity is a concern then passive mixers are the choice of the mixer. Passive ring mixer is one of the most widely used mixer topology. They require balun or transformer at RF and LO ports. Balanced LO and RF voltage drive results in rejection of even order spurious signals and reduced LO to RF and LO to IF leakage. Switching action in ring mixer can be implemented using diode or FET devices. The channel resistance shown by a large FET in triode region is low and not much dependent on current as the diode, so FET based switching mixer shows more linearity in the RF to IF path than diode based switching mixers and consequently FET based mixer shows higher values of 1 dB compression and third order input intercept point than diode based mixers. Basic FET ring Mixer circuit diagram is shown in figure 3.RFp and RFm, LOp and LOm and IFp and IFm denotes the differential positive and negative supply of RF, LO and IF signals respectively.

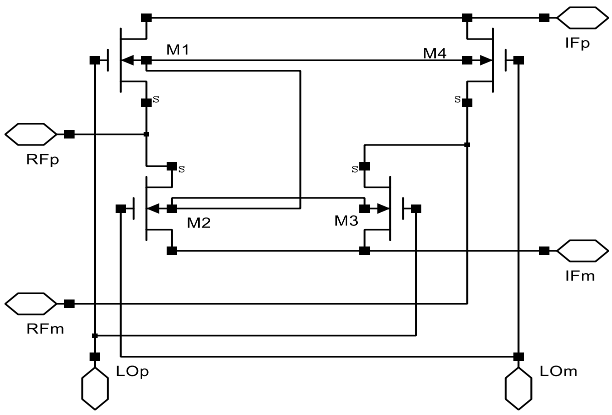

Figure 3. Basic MOS ring Mixer

The LO signal switches on M1, M3 and off M2, M4 during positive LO cycle and switches on M2, M4 and off M1, M3 during next LO cycle. Result of this that RF is switched on and off with respect LO signal frequency which results in mixing of RF and LO signal [6-17].

2. Proposed Design

Schematic circuit of proposed mixer design is shown in figure 4. Proposed mixer design is based on FET ring mixer design using 180 nm CMOS process technology. Basic FET Ring mixer require large LO to voltage to achieve superior intermodulation distortion rejection performance. To reduce the LO power requirement, a gate voltage Vgg of is applied through voltage divider bias circuit shown as R1 and R2 [17]. Capacitor C1 and C2 are used to couple LO voltage decouple the Vgg to LO signal.

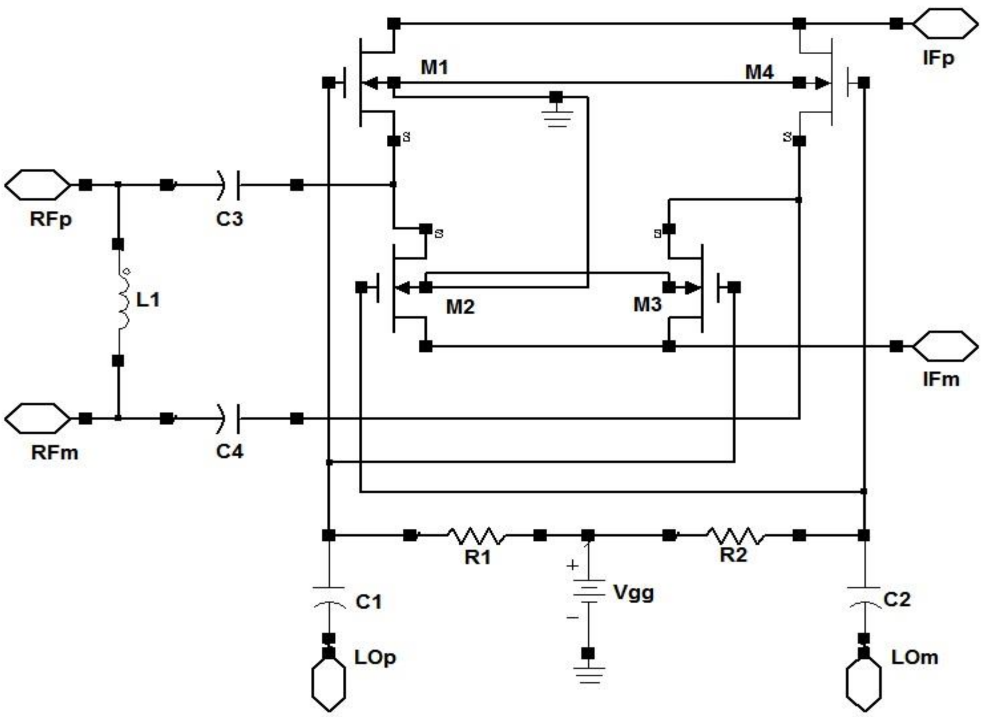

Figure 4. Proposed Mixer circuit design

Differential LC matching is applied at the RF port of the mixer to minimize return loss (input reflection coefficient).

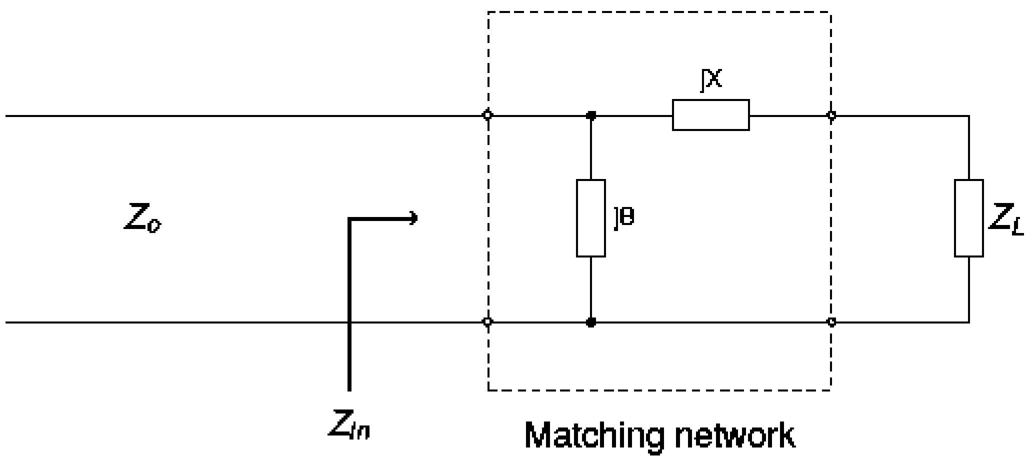

Figure 5. Schematic of matching network applied at RF port

Where Z_L is the input impedance of the RF port. X and Bare the series reactance and parallel admittance of the matching circuit respectively. In this proposed circuit, series and parallel elements are calculated as capacitor and inductor respectively.

3. Simulation Results and Discussions

In this proposed work, A FET ring mixer is designed for Band #1 of MB-OFDM UWB Systems for RF frequency of 3.432 GHz, IF frequency of 264 MHz with corresponding LO frequency of 3.696 GHz. The proposed mixer is simulated using ADS software with 180 nm CMOS process technology with 7 dBm LO power. As per MB-OFDM WiMedia recommendations, the minimum receiver sensitivity should be −63.5 dBm [2]. The average RF power for mixer simulation is chosen as -55.5 dBm, assuming overall gain of front end filters and LNA as 8 dB. For simulation of gain compression, RF power is varied (slightly higher than -55. dBm) from -60 dBm to higher values to observe 1 dB compression point. Table 1 summarizes the simulation parameters of the mixer.

Table 1.Simulations parameters

Parameters	**Value**
CMOS Technology	180 nm
RF Frequency	3.432GHz
IF Frequency	264 MHz
LO Frequency	3.696 GHz
Maximum order of RF frequency	11
Maximum order of LO frequency	3
Mean RF Power level	-55.5 dBm
LO Power level	7 dBm

Harmonic balance simulation is done to observe nonlinear effects in the mixer.Conversion gain versus increasingRF power level is shown in figure 6. Minimum value of conversion loss (maximum value of conversion gain)is noted as 5.38 dB. Value of P1dB (1 dB compression point) is observed as5.85 dBm. This large value of P1dB indicates the linear nature of mixer at large operating power levels.

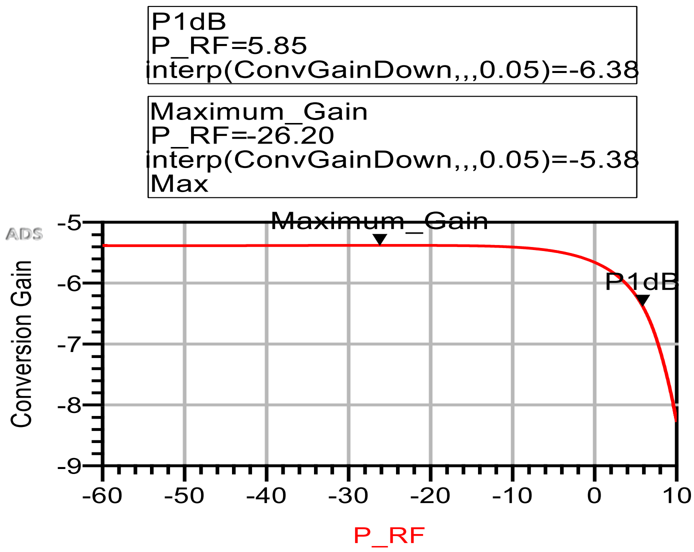

Figure 6. Conversion gain versus RF power

Results of IF power versus RF power is presented in figure 7. Straight line shows ideal behavior of If power and delivered IF power is shown as curved line. This result indicates that delivered amount of IF power level decreased from ideal one at high values of RF power, which confirms the gain compression phenomenon. At P1dB point of 5.85 dBm, the IF power level is reported as -0.531 dBm.

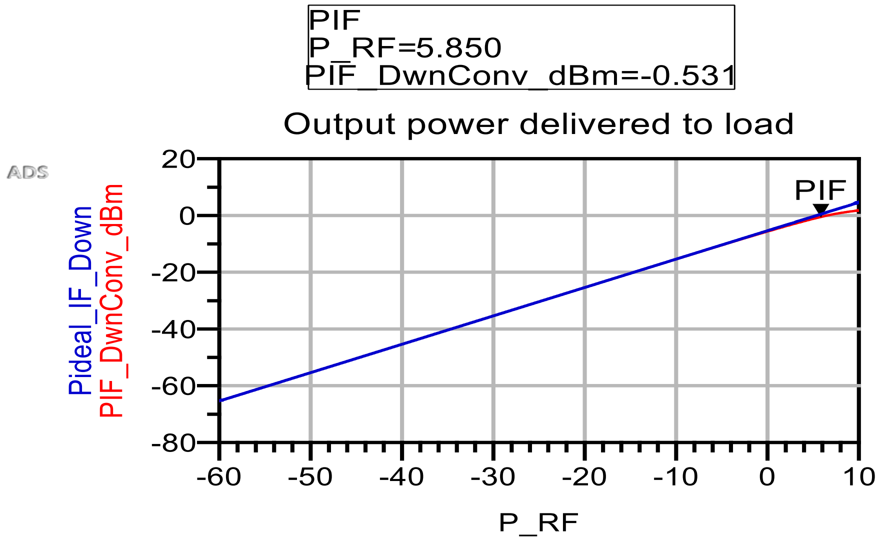

Figure 7. IF power versus RF power level

Conversion gain versus frequency is shown in figure 8, which indicates conversion loss of 5.384(conversion gain of -5.384 dB) at input RF frequency of 3.432 GHz. The values of conversion loss of 5.211 dB and 5.583 dB are noted at lower and higher frequencies of band # 1 respectively, which shows that conversion loss does not deviate much across whole spectrum of the required band.

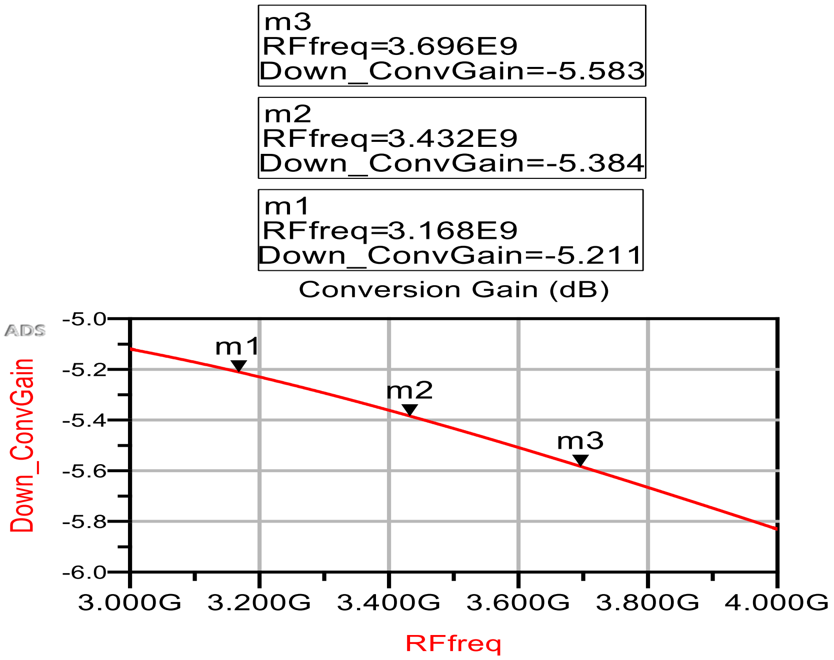

Figure 8. Conversion gain versus RF frequency

Results of S-parameter simulation is shown in figure 9. Return loss at input port (S_{11}) noted below -10 dB from 2.655 GHz to 4.467 GHz with minimum value of -14.020 dB at 3.432 GHz. This result shows that circuit is well tuned 3.432 GHz with sufficient matching bandwidth.

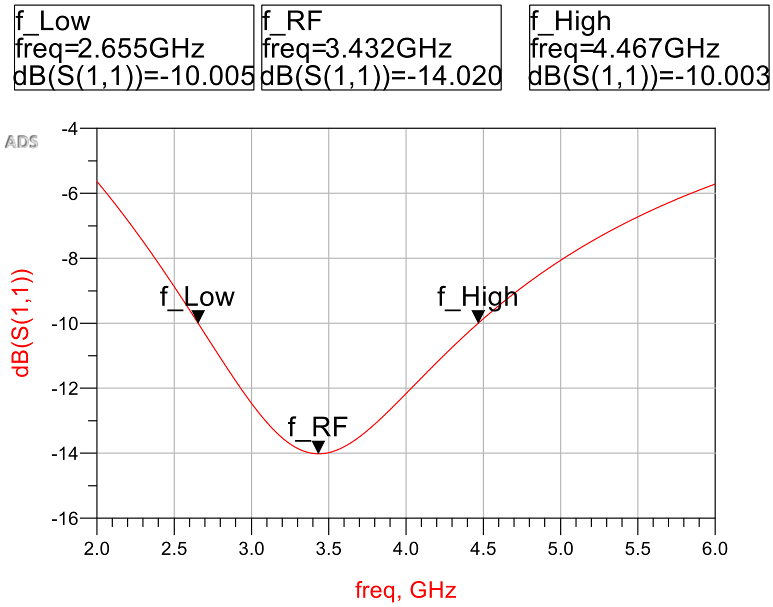

Figure 9. Return loss versus RF frequency

SSB noise figure versus RF frequency is shown in Figure 10. SSB noise figure is reported as 4.687 dB at 3.432 GHz RF frequency. These results justify the fact that noise figure of the lossy system is roughly equal to conversion loss

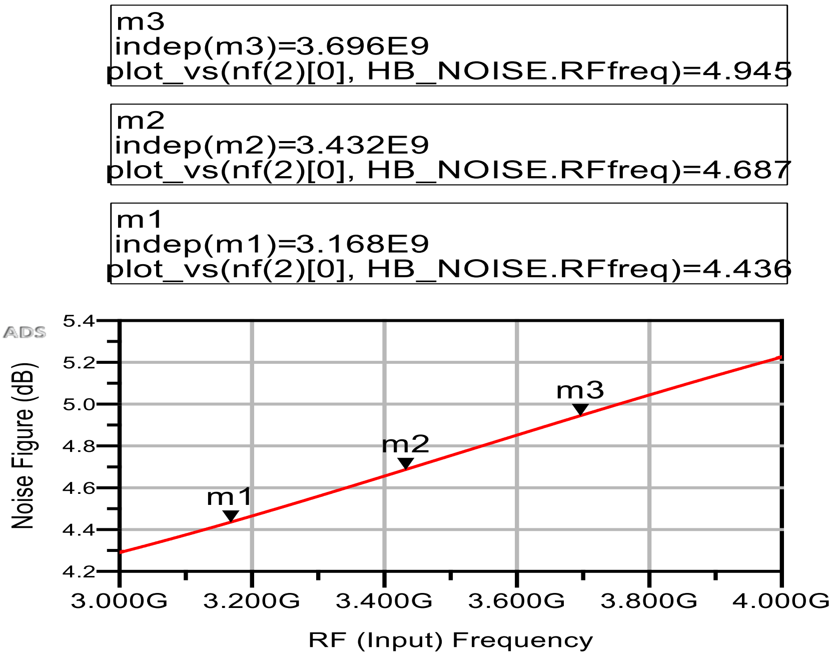

Figure 10. SSB noise figure versus RF frequency

Intermodulation distortion (IMD) simulation is performed to measure third order input intercept point (IIP3) parameter. Two RF frequencies are chosen with spacing as 4.125 MHz. Upper line shows upper side band IF power versus RF power whereas lower line shows corresponding third order intermodulation (IM) power versus with RF power. Intersection of extrapolated values of these lines gives the value of IIP3, which is noted as 16.530 dBm. This large value shows that mixer is quite resistant to IMD.

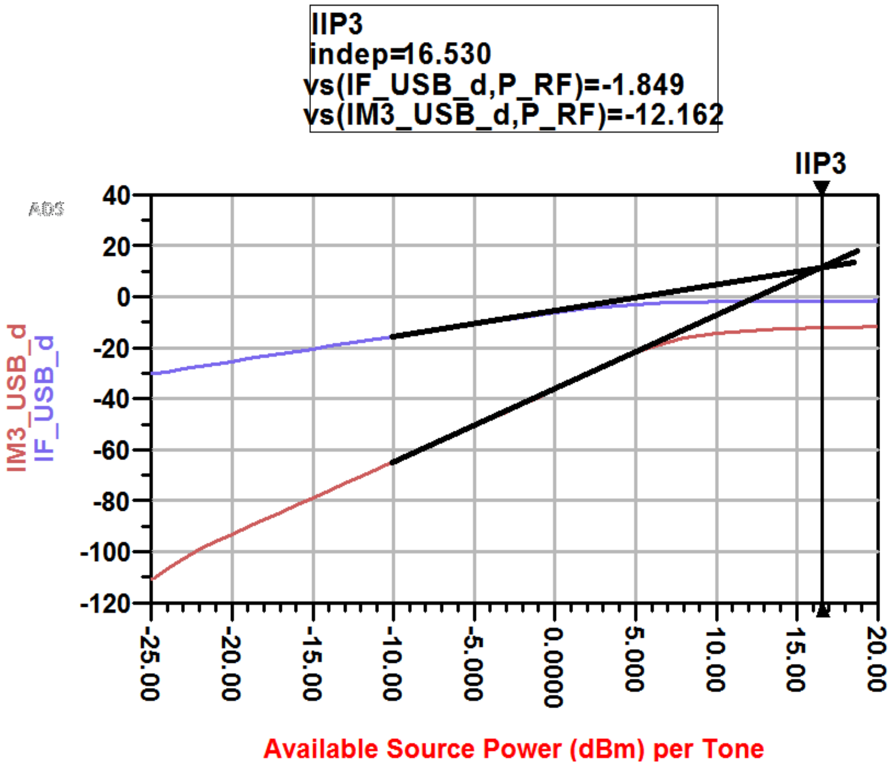

Figure 11. Results of IMD simulation

Output power spectrum is shown in Figure 12. Spectrum shows required IF Output with different spurious products. Fundamental IF power is observed as -62.18 dBm with second harmonic at -138.496 dB. Very low power of second harmonic shows that mixer effectively suppresses spurious products.

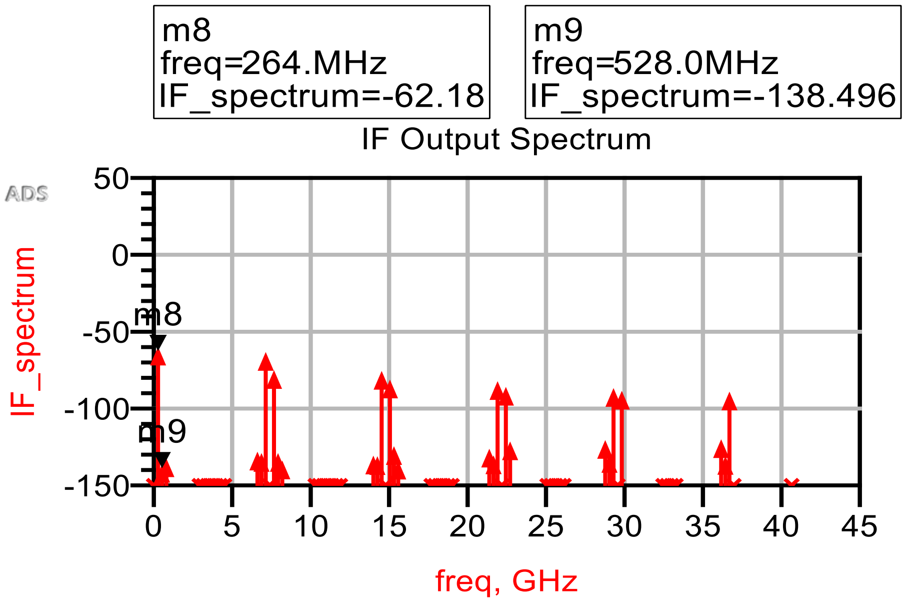

Figure 12. Output power spectrum

Transient simulation output load is shown in figure 13. Transient shows that load waveform is quite smooth with no clipping.

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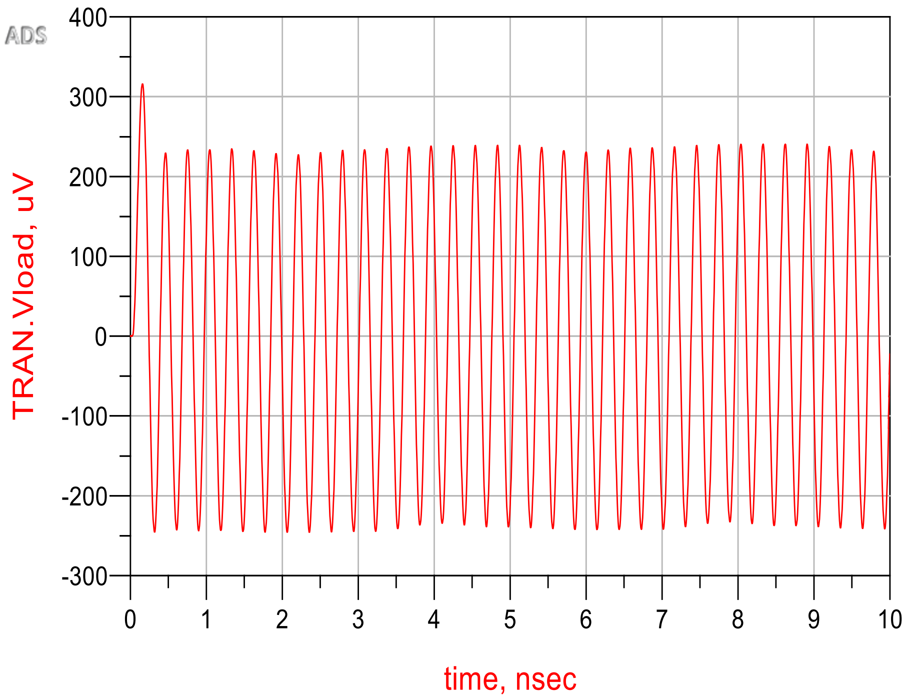

Figure 13. Transient analysis of output IF

Final component values of designed mixer are listed in table 2 and different performance metrics of designed mixer are summarized in table 3.

Table 2. Final component values of designed mixer

Component	Value
Vgg, R, C	0.5 V, 100 KΩ. 100 pF
Width of MOSFETs	0.90 µm
Legth of MOSFETs	0.18 µm
L1, C3, C4	11.15 nH, 24 pF, 24 pF

Table 3. Performance metrics of designed mixer

Performance metrics	Value
Minimum Conversion loss	5.38 dB
P1dB	5.85 dBm
Return loss (S_{11}) (min.)	-14.020 dB
Noise figure (SSB)	4.687 dB
IIP3	16.530 dBm

4. Conclusion

A low conversion loss with high linearity FET ring mixer is designed for RF, IF and LO frequency of 3.432 GHz, 264 MHz and 3.696 GHz respectively. Mixer is designed in 180 nm CMOS technology using Keysight ADS software. Mixer shows low value of conversion gain as 5.38 dB with value of P1dB as 5.85 dBm. At RF port, differential LC matching is used which shows minimum value of return loss (S_{11}) as -14.020 dB at RF frequency of 3.432 GHz with wide input matching bandwidth. Large value of IIP3 reported by the mixer as 16.530 dBm which indicates that mixer effectively suppress third order IM products. Mixer shows a low value of noise figure (SSB) as 4.687 dB. The designed mixer is useful for transceivers operating at band #1 of MB-OFDM UWB wireless standard.

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