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PAPERS

Wideband ring mixer for band #1 of MB-OFDM systems in 180 nm CMOS technology

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A wideband down conversion ring mixer is proposed for multi band orthogonal frequency division multiplexing (MB-OFDM) system in 180 nm CMOS technology. The mixer is essentially used in a heterodyne wireless receiver to enhance the selectivity of the system. Being a nonlinear system, the mixer dominates the overall performance of the system. The design of down conversion mixer is the most challenging part of a receive chain. Wideband impedance matching always remains a challenge in any radio frequency integrated circuit design. This paper presents the design of a ring mixer with high linearity, wideband impedance matching using differential resistive impedance matching and without using any DC bias. The proposed mixer is tuned for a frequency of 3.432 GHz of band 1 of the MB-OFDM system. Mixer core is based on the FET ring mixer topology. The mixer is implemented in 180 nm CMOS technology. The mixer achieves the minimum conversion loss of 10.49 dB, 1 dB compression point (P1) of 12.40 dBm, third order input intercept point (IIP3) of 12.01 dBm, a minimum SSB noise figure of 8.99 dB, and S_{11} of less than -10 dB over the frequency range of 0 to 13.61 GHz . The layout of the mixer records an active area of 183.75 μm^2.

K e y w o r d s: MB-OFDM, mixer, ring topology, wideband, CMOS

1 Introduction

MB-OFDM is a next-generation wideband wireless standard with high throughput, high data rate, low power consumption and less interference. MB-OFDM consists of 14 sub-bands in the 3.168 GHz to 10.56 GHz range. Each sub-band has 528 MHz bandwidth [1-5]. MB-OFDM spectrum is shown in Fig. 1, [2].

Down conversion mixer converts radio frequency (RF) to intermediate frequency (IF) with the help of local oscillator (LO) frequency. Let RF and LO signals are expressed as

$$v_{\rm RF}(t) = A_{\rm RF}\cos\omega_{RF}t\,, \qquad v_{\rm LO}(t) = A_{\rm LO}\cos\omega_{LO}t. \tag{1}$$

Mixer output $v_{\rm IF}(t)$ is expressed as

$$v_{\rm IF}(t) = A_{\rm RF}A_{\rm LO}\cos(\omega_{RF}t)\cos(\omega_{LO}t)\,, \tag{2}$$

$$v_{\rm IF}(t) = \frac{1}{2}A_{\rm RF}A_{\rm LO}\left[\cos\left(\omega_{\rm RF}-\omega_{\rm LO}\right)t + {} + \cos\left(\omega_{\rm RF}+\omega_{\rm LO}\right)t\right]\,. \tag{3}$$

If output $|\omega_{\rm RF}-\omega_{\rm LO}| = \omega_{\rm IF}$ delivered at output after passing through low pass filter

$$v_{\rm IF}(t) = \frac{1}{2}A_{RF}A_{LO}\cos\omega_{\rm IF}t. \tag{4}$$

2 Design and simulation of MOS ring mixer without matching

Band #1 of MB-OFDM ranges from 3.168 GHz to 3.696 GHz with a center frequency of 3.432 GHz. The proposed mixer is tuned for band 1 of the MB-OFDM system with 3.432 GHz RF frequency, 264 MHz IF frequency and 3.696 GHz LO frequency. Active mixers provide gain [6-9] whereas passive mixers [10-22] suffer from

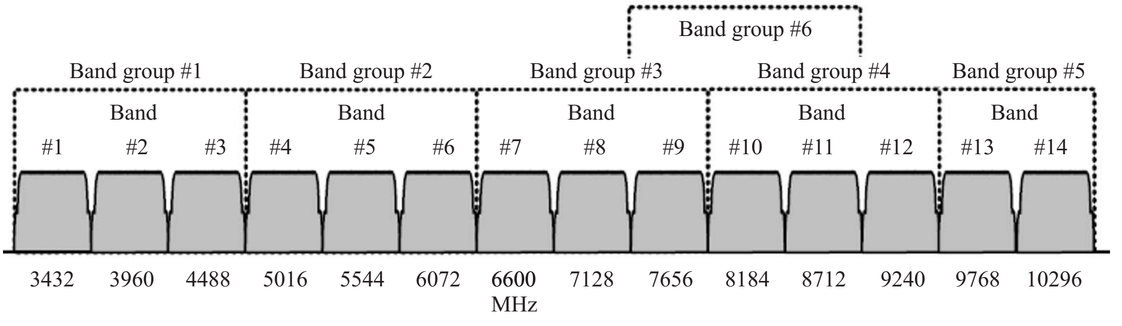

Fig. 1. Spectrum of MB-OFDM

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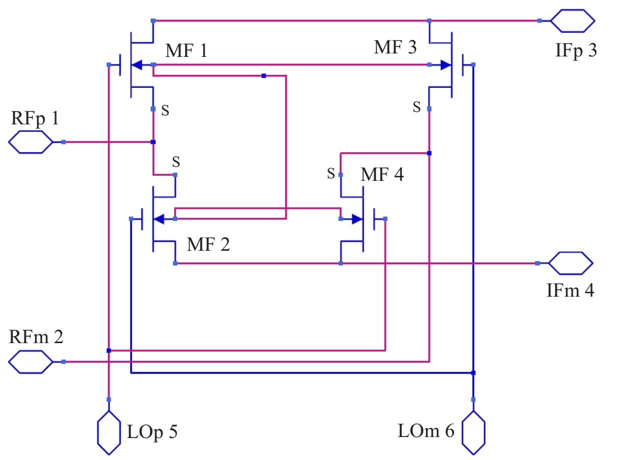

Fig. 2. MOSFET ring mixer without input impedance matching: MFET model-cmosn018, length = 0.18 μm, width = W_1, $\mathrm{A_{drain}}$ = $W_1 \times 10^{-6}$, $\mathrm{P_{drain}} = W_1 + 2 \times 10^{-6}$

conversion loss. But designing an active mixer wideband in nature is challenging due to the high degree of nonlinearity. Passive ring mixer topology is chosen for mixer implementation due to its wideband characteristics. The ring mixer is double balanced in nature so it suppresses effectively RF and LO signals at its output. Ring mixer implements mixing of RF and LO signals by switching of RF signal with respect to LO frequency. MOSFET is chosen in place of diode as a switching device. MOSFET shows higher linearity due to the low value of resistance in the ohmic region. MOSFET ring mixer circuit diagram is shown in Fig. 2. RFp and RFm, LOp and LOm and IFp and IFm represent RF, LO and IF ports respectively, [10-22]. Narrowband ring mixer is reported with dc bias and LC matching circuit. Use of LC matching results in a large area of mixer and use of dc bias leads to higher power dissipation. The wideband response cannot be achieved with pure LC matching due to the high quality factor and narrow bandwidth of the LC tank circuit [22].

In this paper, a mixer is designed in 180 nm CMOS technology using ADS software without the use of any DC bias. Further, the mixer is optimized for the minimum reactance value of input impedance so that a single resistor can be used in differential configuration to achieve wideband matching.

Mixer nonlinearity can be expressed for third order nonlinearity as

$$y(t) = \alpha_1 x(t) + \alpha_2 x^2(t) + \alpha_3 x^3(t), \qquad (5)$$

where α_1, α_2 and α_3 are coefficients of linear, second and third order nonlinearity, respectively. Mixer produces harmonics due to nonlinear characteristics. Harmonics can be filtered out easily. But the main issue is that the gain of the mixer reduces with an increase in amplitude or power of the RF signal due to nonlinearity, this phenomenon is known as gain compression. Gain of the mixer with respect to fundamental term is given by $\left(\alpha_1 + \frac{3}{4}\alpha_3 A^2\right)$, where A is the amplitude of RF signal. The coefficient of α_3 is negative in nature, which results in a decrease in the gain of the mixer with an increase in the amplitude of RF signal. The setup for gain compression and S-parameter simulation is shown in Fig. 3. For harmonic balance simulation, maximum harmonic order of LO is chosen as 11 and maximum harmonic order of RF frequency is chosen as 3.

In the first step, the mixer is designed and optimized for low loss without any input impedance matching. The optimized mixer has LO power of 10 dBm. The length and width of all the MOSFETs are 180 nm and 18000 nm, respectively.

The gain compression result of the mixer without a match is shown in Fig. 4. As the mixer is passive in nature

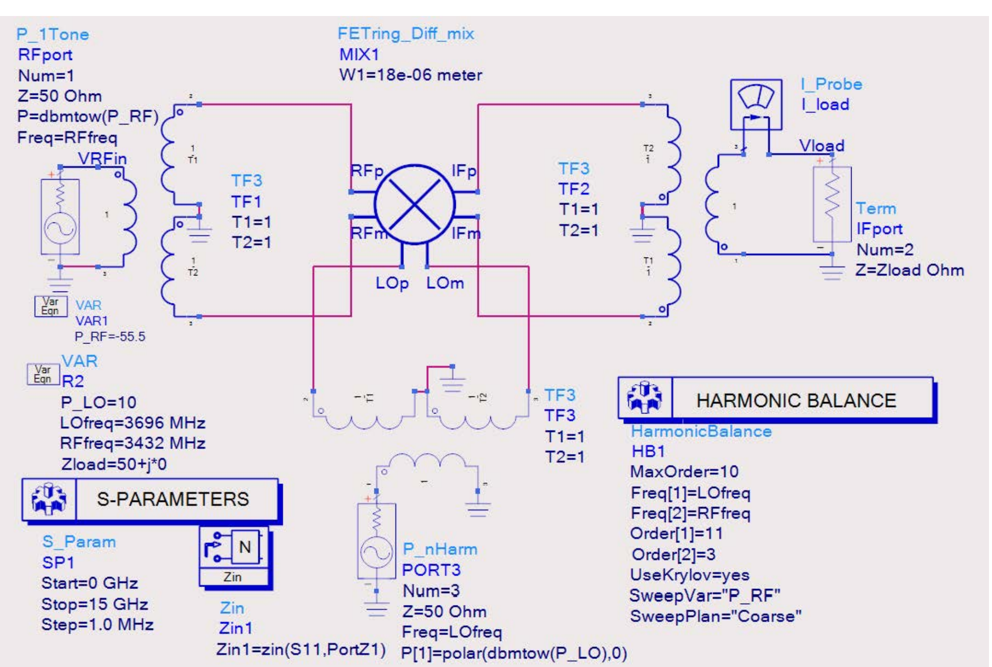

Fig. 3. Setup for gain compression and S-parameter simulation

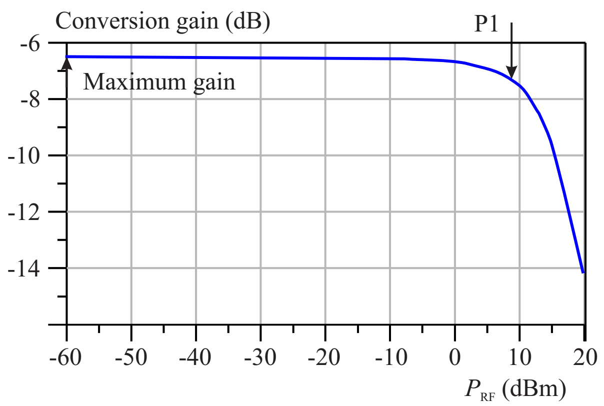

Fig. 4. Conversion gain versus RF power: P1 – (9.3 dBm; -7.51 dB), Maximum gain – (-60 dBm; -6.51 dB)

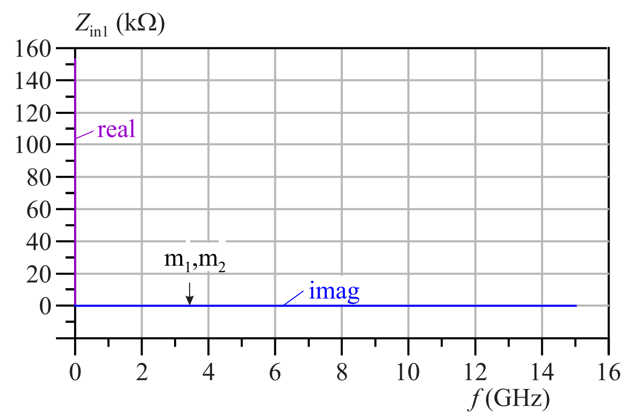

Fig. 5. Input impedance versus RF frequency at 3.432 GHz: m1 – Re$\{\mathcal{Z}_{in1}\} = 1.65\,\Omega$, m2 – Im$\{\mathcal{Z}_{in1}\} = -299.6\,\Omega$

so conversion loss is expected as observed in the results of conversion gain. The minimum value of conversion loss is observed as -6.51 dB and the value of P1 is observed as 9.30 dBm, which reflects that the mixer possesses a sufficient amount of linearity.

Now as a second step of designing, it is required to match the input impedance of the mixer. The input impedance of the mixer is measured as shown in Fig. 5. It is observed that the real part of input impedance has a very low value of $1.65\,\Omega$ and the imaginary part of input impedance as capacitive reactance has a high value of $-299.62\,\Omega$, which is justified as input is applied at source of the MOSFET which shows low value resistance but the high value of capacitive reactance due to parasitic capacitance. Further, this result shows that input impedance value remains flat for a wide frequency range, which is in agreement with the fact that passive type switching mixers offer wider bandwidth in comparison to active mixers.

3 Design and simulation of MOS ring mixer with matching

To match the RF Port, a differential resistive impedance matching circuit (R) is applied at the RF port as shown in Fig. 6.

Input impedance before matching is

$$\mathcal{Z}_{\text{in}1} = R_{\text{in}} - jX_{\text{in}}, \tag{6}$$

where, R_{in} and X_{in} are real and imaginary part of $\mathcal{Z}_{\text{in}1}$, respectively. Here $R_{\text{in}} = 1.65\,\Omega$ and $X_{\text{in}} = 299.62\,\Omega$.

Input impedance, after resistive matching is

$$\mathcal{Z}_{\text{in}2} = R||\mathcal{Z}_{\text{in}1}. \tag{7}$$

Rationalizing this, we get real and imaginary part as

$$Re\{\mathcal{Z}_{\text{in}2}\} = R\frac{(R+R_{\text{in}})R_{\text{in}} + X_{\text{in}}^2}{(R+R_{\text{in}})^2 + X_{\text{in}}^2}, \tag{8}$$

$$Im\{\mathcal{Z}_{\text{in}2}\} = \frac{-R^2X_{\text{in}}}{(R+R_{\text{in}})^2 + X_{\text{in}}^2}. \tag{9}$$

Now optimizing real part near to $50\,\Omega$ and the imaginary part near to zero, the matching resistor $R = 206\,\Omega$ is obtained, which gives $Re(\mathcal{Z}_{\text{in}2}) = 49.98\,\Omega$ and $Im(\mathcal{Z}_{\text{in}2}) = -8.58\,\Omega$ as shown in the simulated result of Fig. 7.

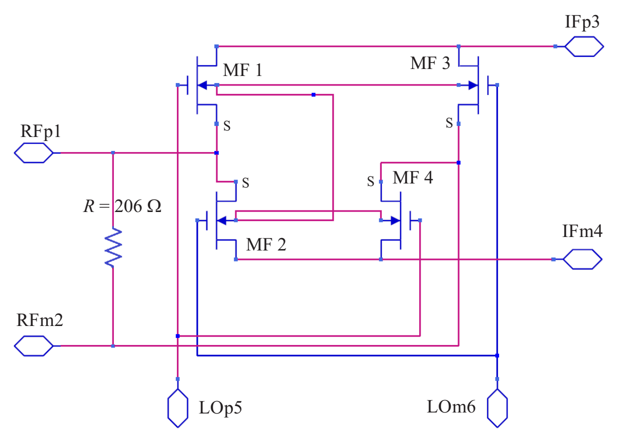

Fig. 6. MOSFET ring mixer with impedance matching

Gain compression simulation as shown in Fig. 8. It is performed again to observe the conversion loss with respect to RF power. Minimum loss is observed as -10.49 dB, with P1 value as 12.40 dBm. Conversion loss of mixer after matching is observed at a higher value compared to the mixer without match. It is expected due to the loss introduced by the resistor of the matching circuit.

Results of conversion gain versus down converted IF power is shown in Fig. 9. From these results, it is evident that conversion gain decreases at higher values of IF power. These results further justify the gain compression phenomenon.

Variation of ideal and down converted IF power with respect to RF power is shown in Fig. 10. Variation of IF power in ideal conditions is shown as a straight line. Ideal condition corresponds to a perfect linear system in which no gain compression phenomenon is observed. IF Power delivered in the real condition is shown as a curved line.

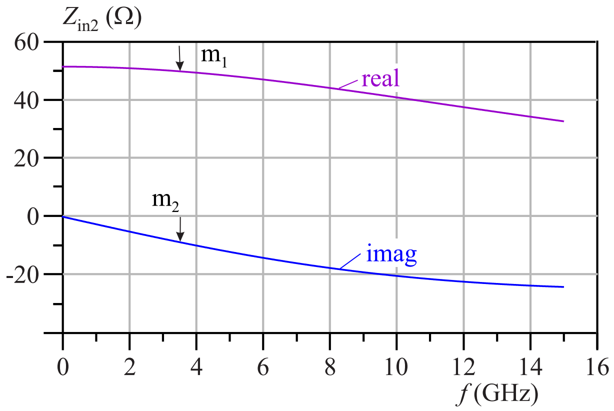

Fig. 7. Input impedance versus RF frequency at 3.432 GHz: m1 – $\mathrm{Re}\{\mathcal{Z}_{in2}\} = 49.98\,\Omega$, m2 - $\mathrm{Im}\{\mathcal{Z}_{in2}\} = -8.58\,\Omega$

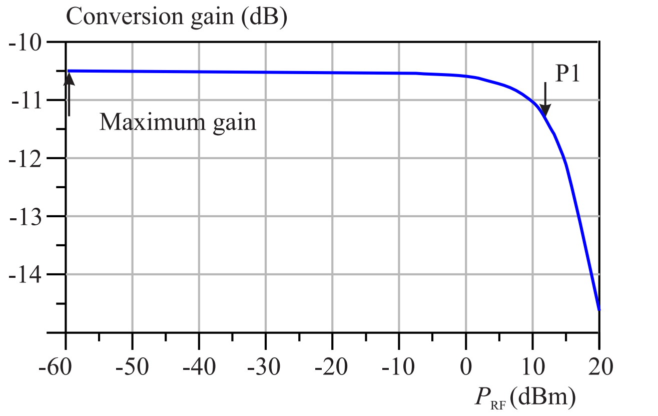

Fig. 8. Gain compression result versus RF power: P1 – (12.4 dBm; -11.49 dB), maximum gain – (-60 dBm; -10.49 dB)

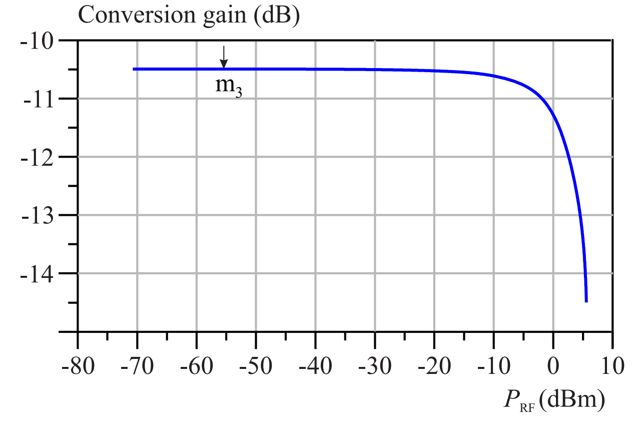

Fig. 9. Conversion gain versus IF power: m3 – (-55.5 dBm; -10.5 dB)

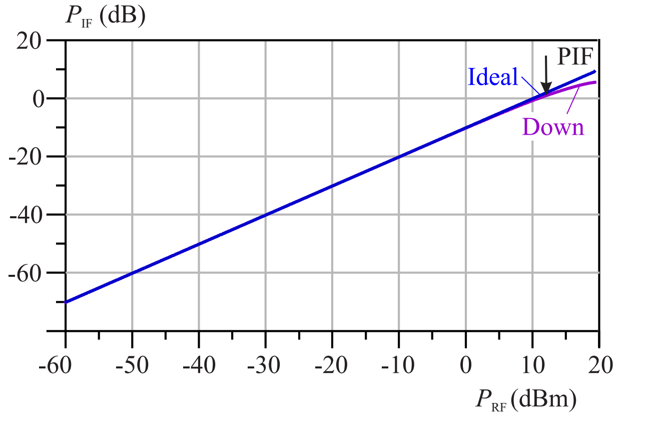

Fig. 10. Ideal and down converted IF power versus RF power: PIF – (12.4 dBm; 0.91 dBm)

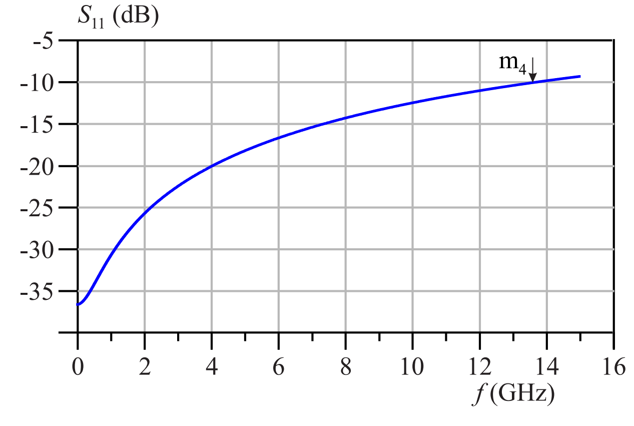

Fig. 11. S_{11} versus frequency: m4 – (13.6 GHz; -10 dB)

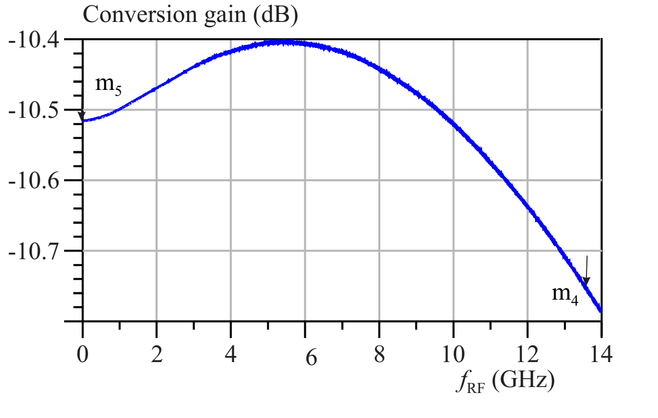

Fig. 12. Conversion gain versus RF frequency: m5 – (0 GHz,-10.52 dB), m4 – (13.61 GHz; -10.75 dB)

Table 1. Performance summary and comparison with other state of art works

Ref.	Technology	RF (GHz)	Conversion loss (dB)	IIP3 (dBm)	P1 (dBm)	NF (dB)	S_{11} (dB)
(13)	0.18 μm BiCMOS	2-6	7.8	13.4	6	-	$<$ -10
(16)	0.7 μm GaAs MESFET	2-8	10	18	11	-	-
(19)	0.35 μm MOSFET	2-3	6	16	7	6.5*	-
(22)	0.18 μm CMOS	3.168-3696	5.38	16.53	5.85	4.687*	$<$-14.02
This work	0.18μm CMOS	DC to 13.61	10.49	12.10	12.40	8.99*	$<$ -10

*(SSB)

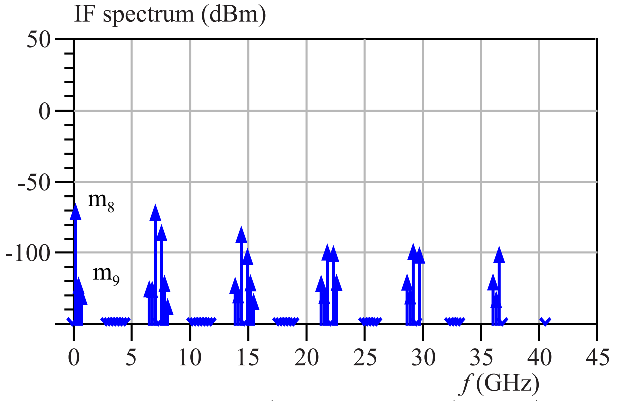

Fig. 13. IF Spectrum: m8 – (264 MHz, -67.3 dB), m9 – (528 MHz, -118.9 dB)

Delivered IF power level decreases at higher values of RF power, which validates the gain compression. At the P1 value of 12.40dBm, the IF power is 0.91dBm.

The graph of return loss (S_{11}) as a result of the S-parameter simulation is shown in Fig. 11. The value of S_{11} remains below from -10dB from DC to 13.61GHz range. This shows mixer possesses wideband characteristics. This indicates that the mixer can be easily tuned for wide band operation.

Variation of conversion gain versus frequency is shown in Fig. 12. Conversion loss varies from 10.52dB to 10.75dB from DC to 13.61GHz frequency. Variation of conversion loss is of low value across the whole band which indicates that this mixer possesses a sufficient amount of linearity

IF spectrum is shown in Fig. 13. Fundamental IF component of 264 MHz is observed with power as -67.3 dBm and a second harmonic of 528 MHz is observed with a power of -118.9 dBm. The second harmonic is 51.65 dB below the fundamental component which indicates that the mixer suppresses very effectively the harmonics and this characteristic further indicates that the mixer possesses sufficient degree of linearity.

The noise simulation setup is shown in Fig. 14. Setup for intermodulation distortion (IMD) simulation is shown in Fig. 15. IMD simulation requires two RF frequencies. For this purpose, two RF frequencies f_2 and f_3 are chosen with a spacing of 4.125 MHz.

Simulation results of single side band (SSB) noise figure versus RF frequency are shown in Fig. 16. SSB noise figure remains below the value of 9.51 dB from DC to 13.61 GHz band. The minimum value of the SSB noise figure is reported as 8.99 dB.

Results of the IMD simulation are shown in Fig. 17. The upper graph shows down converted power corresponds to the upper side band (USB) of the third order of IMD whereas the lower graph corresponds to the power of the fundamental IF component. The intersection of extrapolation of these graphs gives the value of IIP3 as 12.01 dBm and third order output intercept point (OIP3) as 1.52 dBm. A large value of IIP3 shows that the mixer possesses a sufficient amount of linearity and effectively suppresses IMD products.

The layout of the proposed mixer is drawn and shown in Fig. 18. The layout of the mixer records an active area of 183.75 μm^2. Performance summary and comparison with other state of art works are shown in Tab. 1. It is evident that the proposed mixer shows large bandwidth with a high degree of linearity in terms of a large value of P1.

4 Conclusion

This paper presents the design of a passive down conversion ring mixer with a high degree of linearity, wide band impedance matching and without any DC Bias. Differential resistive impedance matching is used at the

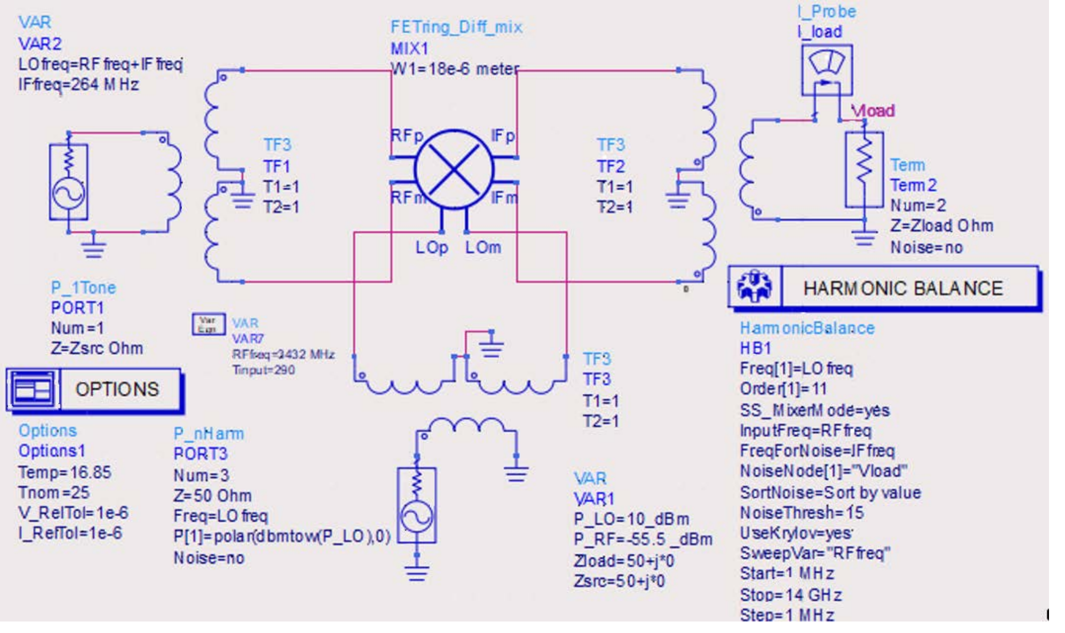

Fig. 14. Noise figure simulation setup

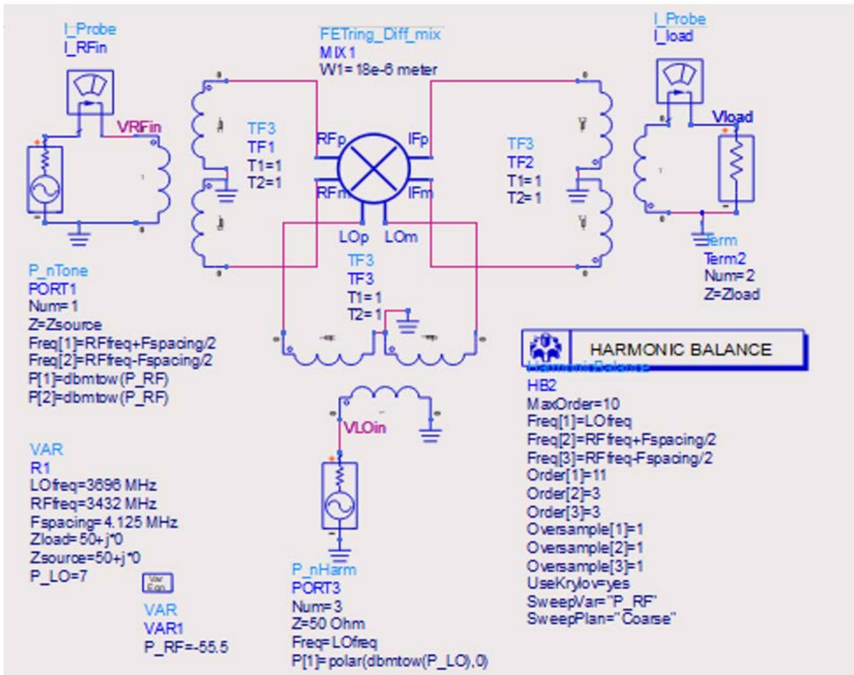

Fig. 15. Setup for IMD simulation

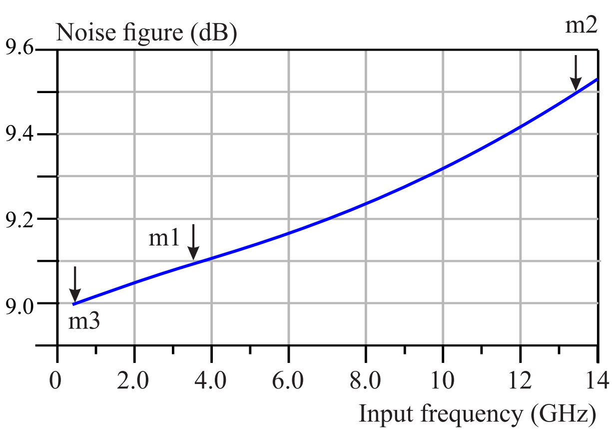

Fig. 16. Noise figure versus RF frequency: m2 – (13.6 GHz; 9.51 dB), m1 – (3.43 GHz; 9.09 dB), m3 – (0.27 GHz; 8.99 dB)

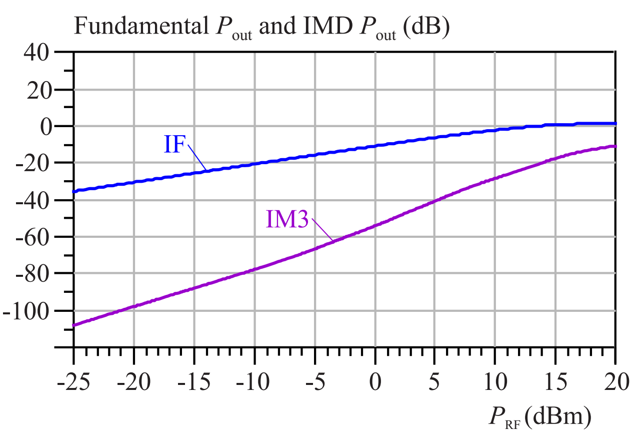

Fig. 17. Results of IMD simulation: OIP3 = 1.52 dBm, IIP3 = 12.01 dBm, carier to IMD ratio = 74.04 dB, LO power = 10 dBm

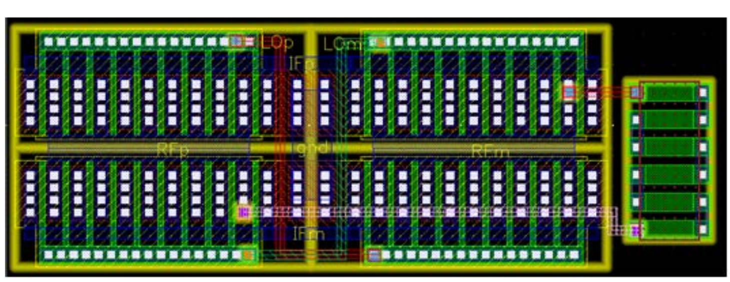

Fig. 18. Layout of the proposed mixer

RF port. This mixer is specifically tuned for band 1 of MB-OFDM system with a center frequency of 3.432 GHz. Mixer core is based on the FET Ring mixer topology. The mixer is simulated using ADS software in 180 nm CMOS technology. Mixer achieves the minimum conversion loss of 10.49 dB, P1 of 12.40 dBm, IIP3 of 12.10 dBm, minimum SSB noise figure of 8.99 dB and S_{11} less than -10 dB over a spectrum ranging from DC to 13.61 GHz. The layout of the mixer records an active area of 183.75 μm^2. Although this mixer is designed for band 1 of the MB-OFDM system but it can also be tuned for other bands of MB-OFDM and other wireless standards due to its wide-band characteristics. It also possesses excellent linearity across a wide range of frequency up to 13.61 GHz as S_{11}, conversion gain and noise figure show very less variation across the whole band of MB-OFDM.

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