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Design and Performance analysis of 60 GHz GaAs Mixer

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ABSTRACT

This paper presents a mixer using the GaAs FET technology. The proposed Mixer employs a Distributed Amplifier follow by the LPF. The T-network acts as a LPF for the RF/LO-to-IF isolation and extracts the IF signal.Using the distributed amplifier technique, the proposed Mixer offers significant advantages, such as high port-to-port isolation, minimum noise figure and good conversion Gain. The mixer has the Conversion Gain at 3 GHz is 28.915, good local oscillation LO-to-RF isolation, RF-to-IF isolation is less than -40 dB and achieve minimum noise figure of 3.283 at 60 GHz frequency.

Keywords: GaAs FET Technology, Mixer, Distributed Amplifier, LPF, Local Oscillator (LO).

1. INTRODUCTION

In order to the high-performance low-cost low power millimeter-wave technology, many state-of-the-art 60-GHz transceivers focused on wireless personal area network(WPAN),short-range communication has been reported [1]–[5]. The mixer is an important component of the transceiver because it converts signals from one frequency to another. RF mixing permits signals to be converted into different frequencies and thereby allow signals to be processed more effectively. An idealized mixer is shown in Figure 1.

Form Input side we provide RF Signal f_{RF}, mixes with a LO signals at a frequency f_{LO}, and at output side produces IF signal that consists of the sum and difference frequencies, $f_{RF} \pm f_{LO}$. When the sum frequency is used at the IF, the mixer is called an up-converter; basically it is used in Transmitter. When the difference is used at IF, the mixer is called a down-converter, which is used in Receiver. In a receiver, when the LO frequency is below to the RF frequency, it is called low-side injection and the mixer is a low-side down-

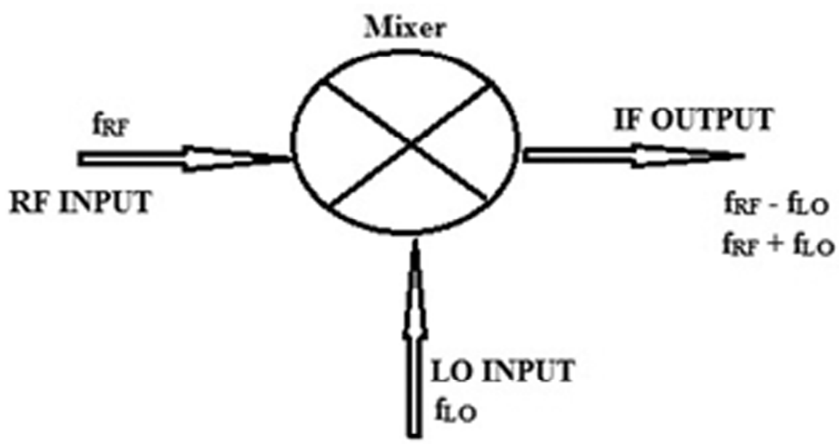

Figure 1: Mixing Process

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converter; when the LO frequency is above the RF frequency, it is called high-side injection, and the mixer a high-side down-converter.

The passive mixers and active mixers provide high conversion gain, small chip area, and minimum noise figure [6]-[7]. However, active mixers also have some disadvantages, namely, high dc power consumption and low linearity. Using anit-parallel diode pair (APDP) with passive SHMs provides several advantages, such as suppressing any even harmonics of RF signals and eliminate dc power [8]–[10], but they occupies a large chip area. Many topologies have been proposed to achieve broadband operation [9]–[11], but these topologies do not provide high isolation levels between ports. If the isolation between the LO and RF ports isn't huge enough, then some connection is created between the LO and RF port and LO signal will leak through the RF port, thereby its reduces the dynamic range of the pre-stage amplifier in the receiver. Therefore, it is important to maintain the good LO-to-RF isolation and low leakage between LO and RF port.

The active distributed amplifiers [12]–[17] possess several benefits, such as broadband, good gain flatness, and good insertion gain, which are very suitable for broadband and good port-to-port isolation. The two-stage distributed mixer has wide bandwidthoperation, but it has demerit of high conversion gain or loss [13].

In this paper, a novel Mixer using a distributed amplifier implemented by the GaAs FET technology for RF front-end application is presented. In a common source FET distributed amplifier, an artificial transmission line is constructed out of the gate - source side the gate line. Another artificial transmission structure is drain - source side – the drain line. If the artificial transmission structures are identical, a wave are often launched on the gate line and be coherently amplified onto the drain line.

The GaAs FET is used mainly for high performance in microwave applications. The GaAs FET semiconductor technology provides higher electron mobility, and the semi-insulating substrate provides lower levels of stray capacitance. This combination makes the GaAs FET ideal for an RF amplifier. Thus GaAs FET technology can be used for amplification in RF front-end which can operate between 50 to 60GHz.[19]

This paper is organized as follows: Section II cover the design issue for gain and Bandwidth of proposed Design, Section III show the proposed design of Mixer. Section IV Result and Discussion and Finally, Section IV has the conclusion of this paper.

2. DESIGN CONSIDERATIONS FOR GAIN AND BANDWIDTH

From the RF point of view, one of the major problems in broadband amplifier design is parasitic Capacitance. The design is limited by the gate–source and drain–source capacitances of the FETs. The distributed amplifiers

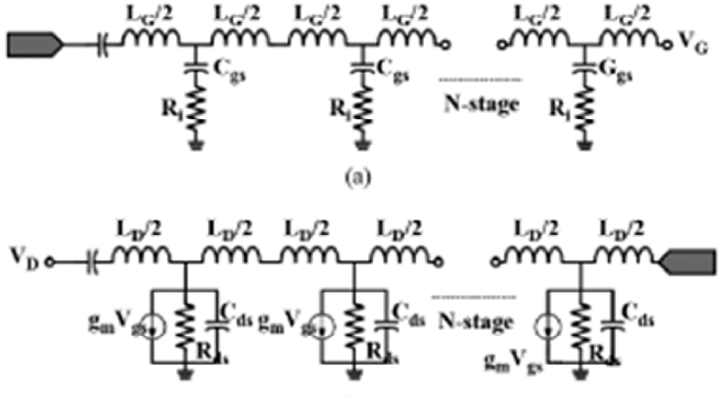

Figure 2: Simplified small-signal model of distributed amplifier. (a) Input, (b) Output.[18]

will simply overcome the matter of parasitic and achieves a broadband. The series inductor Lg/2 (gate line) and Ld/2 (drain line) combine with parasitic capacitance (Cgs & Cds) and create artificial transmission line in gate side and drain side. Small signal circuit of distributed FET is shown in Fig. 2(a) and (b), respectively [18].

In order to match the phase shift of the gate line and drain line while the impedance of 50 ohms, we must have gate source parasitic capacitance Cgs and drain source parasitic capacitance Cds should be equal, Basically the Cds is much smaller as compare to Cgs. In order to achieve this assumption the distributed amplifier must be designed to equalize the phase of the gate line and drain line to increase the signal amplitude at the output side. In this paper, 3- stages cascade GaAs FET distributed amplifier is followed by LPF to achieve good conversion Gain and good port-to-port isolation. The T-network (combination of inductor and capacitor) acts as a low-pass filter for the RF/LO-to-IF isolations and extracts the IF signal.

In the ideal case, adding a more stages should increase the gain, but in practice adding more stages will decrease the gain of amplifier due to increase the gate and drain line losses. The input source Resistance Ri decreases the amplitude of the signal whose transport through gate line, and drain-source resistance R_{ds} decreases the amplitude of the signal transport through the drain line. Therefore, adding more stages to the input signal makes it weak also it decreases thegain and amplitude of the signal.

The analysis presented in the term of the gate and drain line angular frequency. ω_g and ω_d are intrinsic cutoff frequencies of gate and drain side, respectively. ω_c is cutoff frequency of circuit. The Gate line loss Ag is[17].

$$A_g = \frac{(\omega_c/\omega_g)(\omega/\omega_c)^2}{\sqrt{1-\left[1-(\omega_c/\omega_g)^2(\omega/\omega_c)^2\right]}} \tag{1}$$

And the loss in drain-line, A_d, is given by

$$A_d = \frac{\omega_d/\omega_c}{\sqrt{-(\omega/\omega_c)^2}} \tag{2}$$

$\omega c = 2/\sqrt{(LgCgs)} = 2/\sqrt{(LdCds)}$, now if we increase the stage of distributed amplifier, amplitude will be decreased. The input and drain line losses generally decrease the gain. The gain of the distributed amplifier is found to be [16]

$$G = \frac{gm^2 Z_0^2\left[\exp(-A_g N) - \exp(-A_d N)\right]^2}{4(A_g - A_d)^2} \tag{3}$$

3. PROPOSED DESIGN

The mixing is performed between the RF signal and the LO signal. Consequently, it is difficult to combine the RF signal to LO signal. Maintaining a good LO-to-RF isolation is important to reduce high-power level leakage from the LO port to the RF port. The propose circuit consist 3 stage cascaded distributed amplifier, low-pass filter. The schematic of distributed amplifier is shows in Fig 3.

The distributed amplifier is used to enhance the RF signal amplitude for the proposed Mixer. The LO signal is not transferred from the LO port to the RF port because the unidirectional property of the distributed

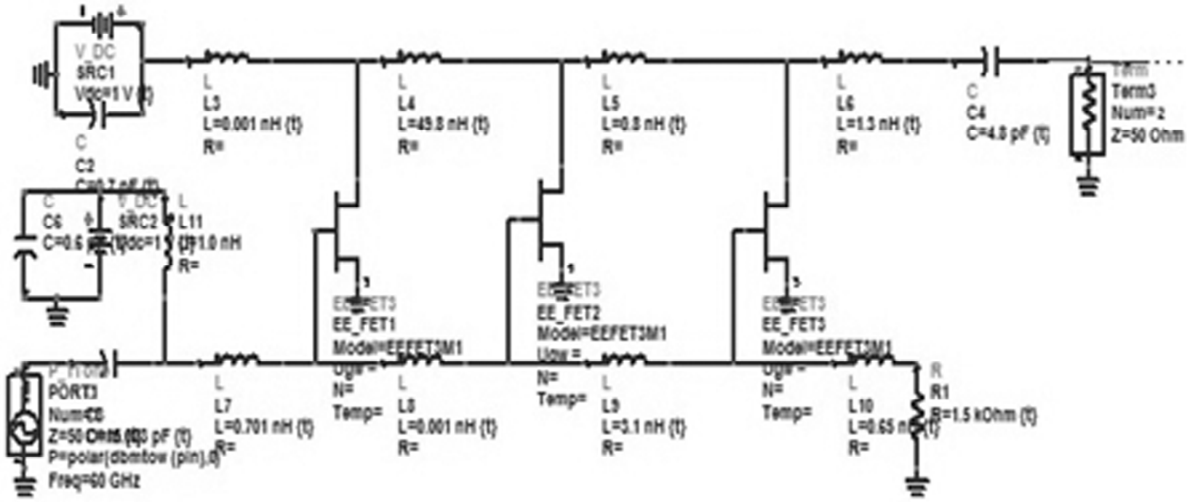

Figure 3: Schematic of Distributed amplifier

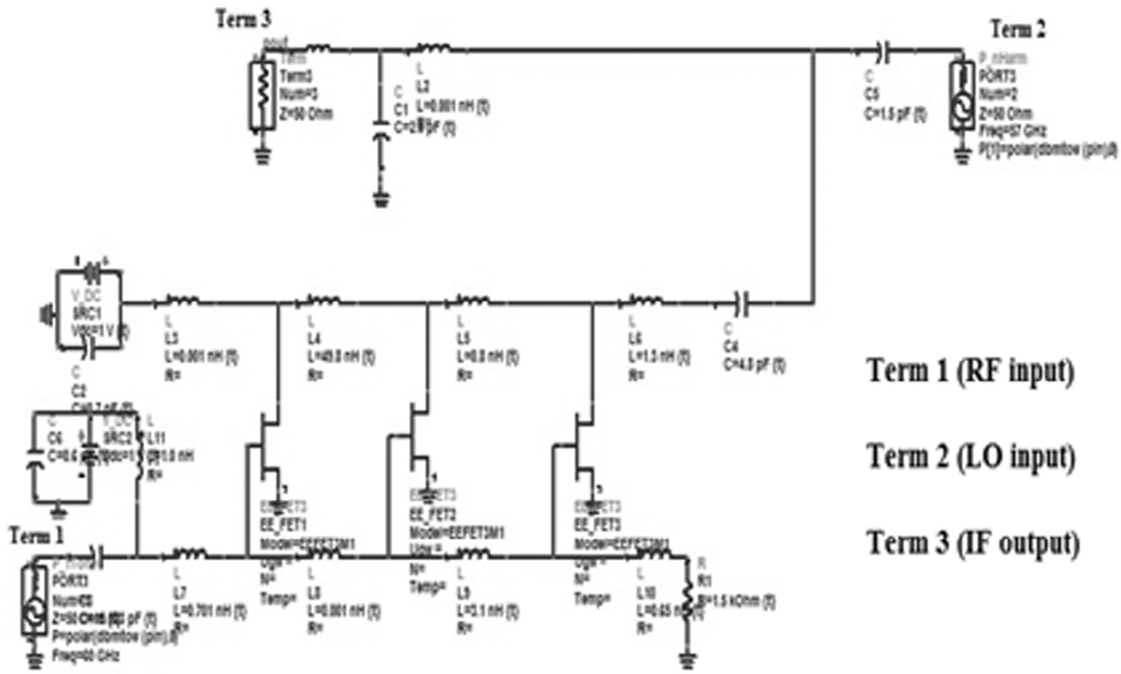

Figure 4: schematic of Mixer

amplifier. Therefore, the distributed amplifier not only provides the Good bandwidth, but also good conversion loss and good port-to-port isolation. Fig 4 show the full schematic of Mixer, distributed amplifier follow low pass filter.

4. SIMULATION RESULT

The designed circuit's schematic of Fig 3 and 4 is simulated and analyzed using ADS software.

4.1. Distributed Amplifier

Figure 3 represent the schematic of distributed amplifier, whose response can be seen in Fig. 5 where we can see Input reflection coefficient or return loss S_{11} is less than -10dB for better input impedance matching and the figure 6 shows the forward transfer gain S_{21} of Distributed Amplifier which is above 10dB. The S_{11} measured has a -13.510 dB & Transfer Gain (S_{21}) measured has an 11.536 at 60GHz.

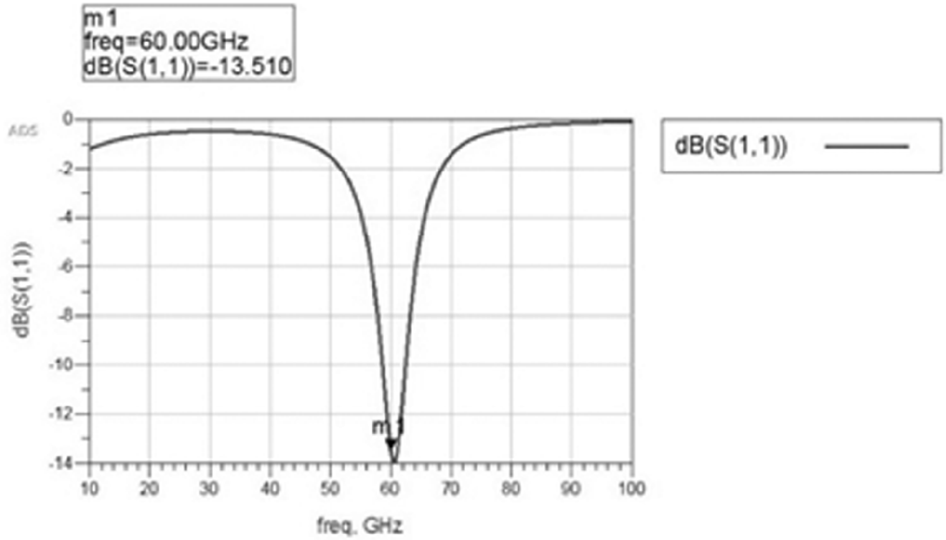

Figure 5: Distributed Amplifier Response (S_{11})

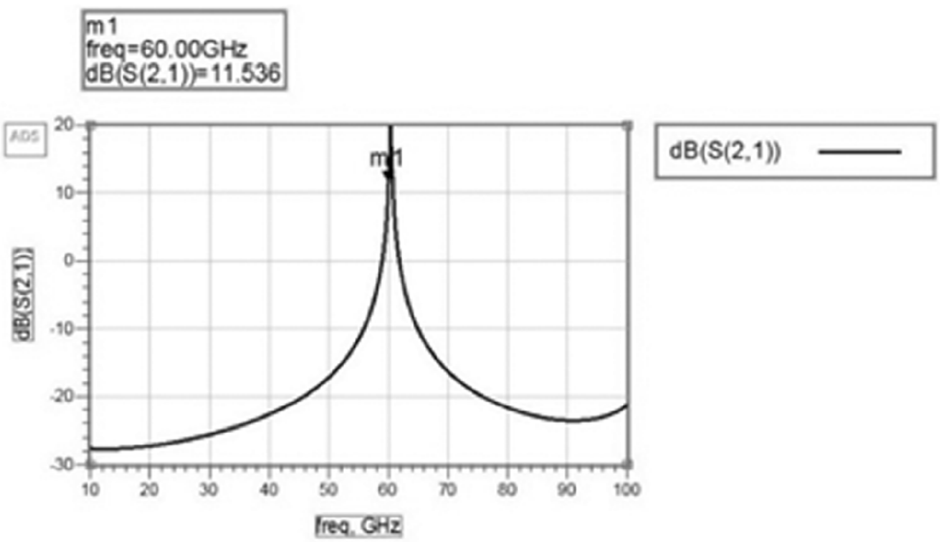

Figure 6: Distributed Amplifier Response (S_{21})

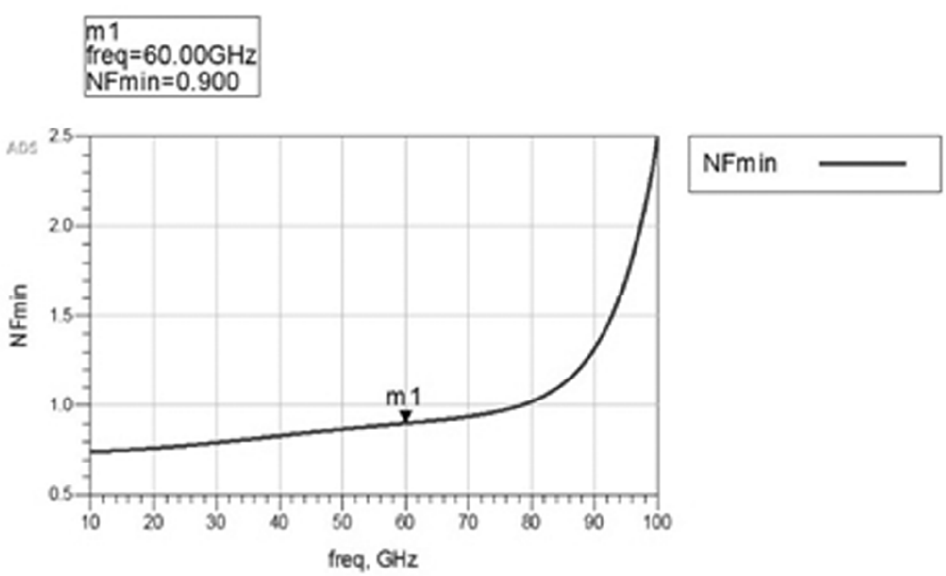

Figure 7: Noise Figure of Distributed Amplifier

Noise figure of the proposed Distributed Amplifier can be illustrated in the below Fig 7. It shows a minimum Noise Figure of 0.900dB at 60 GHz frequency.

4.2. Mixer

In the Proposed Mixer RF frequency is given as 60 GHz, LO provide frequency of 57 GHz at port 2 and IF frequency is calculated in port 3 at 3 GHz of frequency.

The schematic of Proposed Mixer is shown in Fig. 4. The harmonic response of the Mixer can be seen in the below Fig.8 where the fundamental harmonic can be observed at 60GHz, 2nd& 3rdobserved in 120GHz and 180GHz respectively. Figure 9 show the harmonic Response at 3 GHzin IF Port. 2nd& 3rdobserved in 4GHz and 5GHz respectively.

4.2.1. Conversion Gain or loss

Conversion Gain: Ratio of voltage (power) at output frequency to input voltage (power) at input frequency (IF power / RF power) S_{31-}. The response of Conversion Gain is illustrated in fig 10 @ 3 GHz frequency.

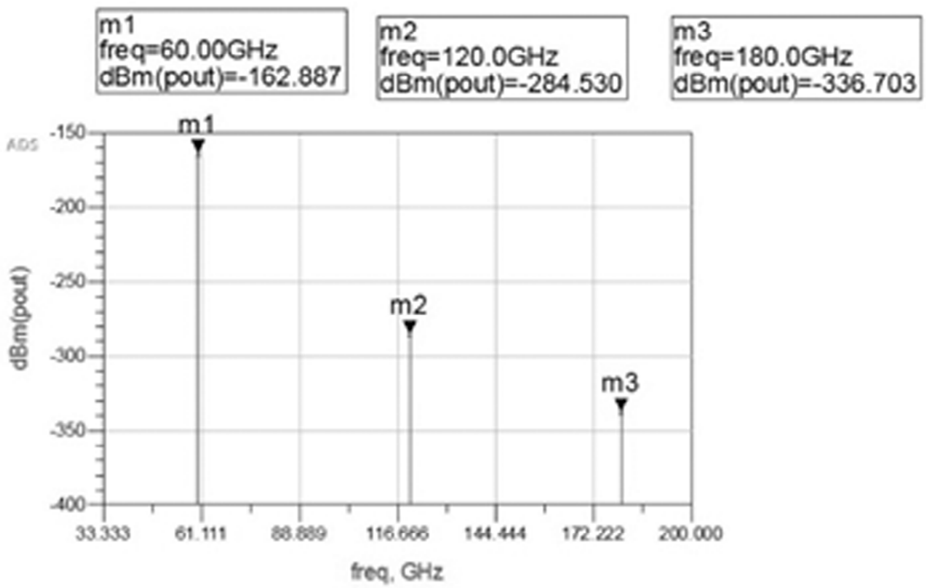

Figure 8: Harmonic Response of Mixer (@ 60 GHz)

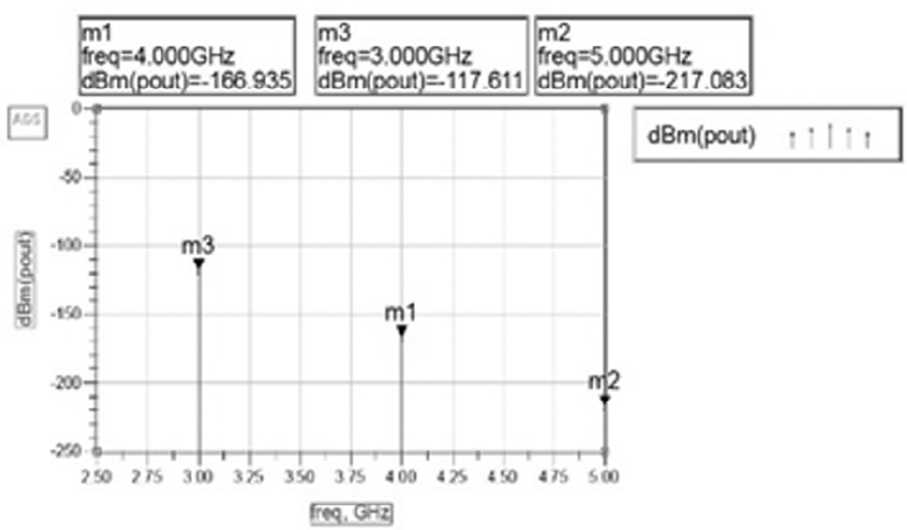

Figure 9: Harmonic Response of Mixer (@ 3 GHz)

Transient Response of IF of Mixer at 3 GHz shown in Fig 11. Using time period of the peak to peak value we calculate the frequency of the Mixer. Time period T is:

$$T = 1/f$$

$$F = 1/536.3\text{-}199.4 = 3\ \text{GHz}$$

4.2.2. Port-to-Port Isolation

In a mixer, the RF and LO signals would not be present at the IF port, and no back flow occur between RF and LO port In this paper we choose RF as port 1, LO as Port 2 and IF as port 3, by using S parameter method I calculated required port-to-port isolation. There are two important isolations to consider: RF to IF (S13) & RF to LO (S12)

The Response of RF to IF and RF to LO isolation has been shown in Fig 12 and 13, respectively.

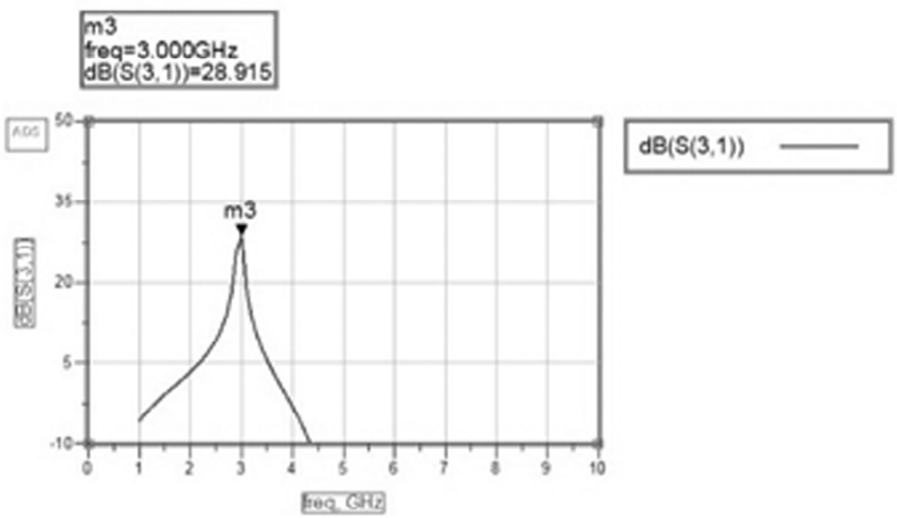

Figure 10: Conversion Gain (S_{31})

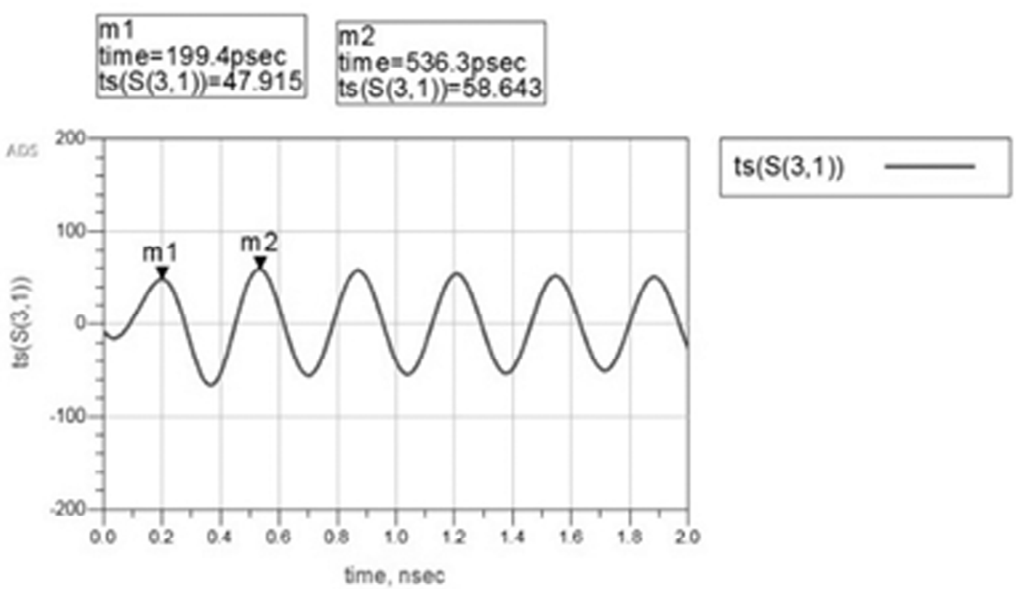

Figure 11: Transient Response of S31(Conversion Gain)

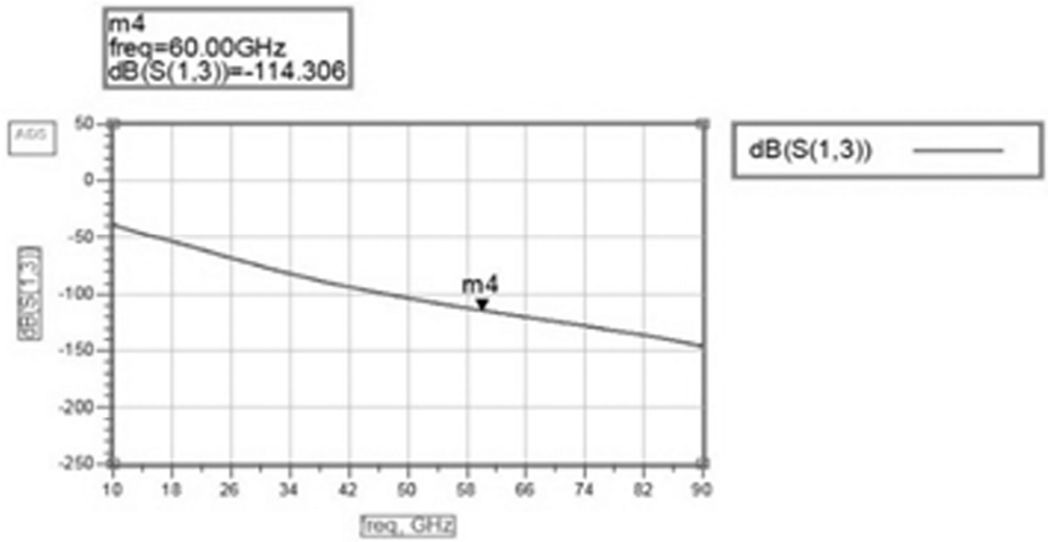

Figure 12: RF-to-IF isolation

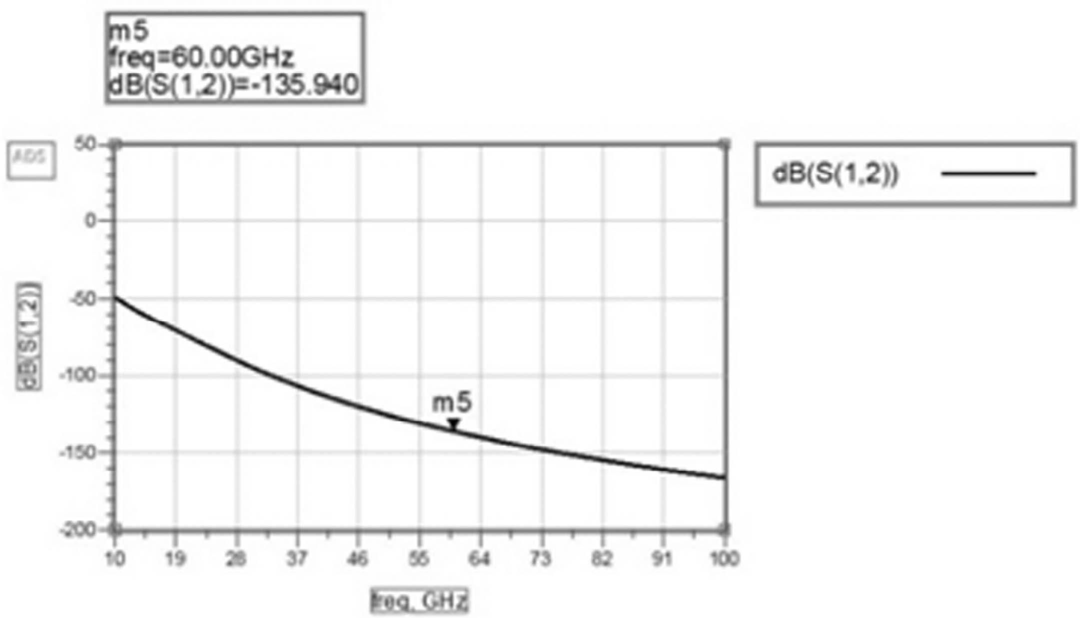

Figure 13: RF-to-LO isolation

Noise Figure

In the Proposed Mixer RF frequency is given as 60 GHz and LO frequency is 57 GHz and IF frequency is calculated at 3 GHz. Noise figure of the proposed Mixer can be illustrated in the below Fig 14. It shows a minimum Noise Figure of 3.283 at 60 GHz RF frequency & 2.291 at 3 GHz IF frequencies.

4.2.3. Linearity

The linearity of the Proposed Cascaded mixer can be illustrated in the below Fig.15, where the 1dB output power and 3db output power meets at the Intercept Point (IP3).

4.2.4. Performance Parameter of Mixer

The parameters such as Conversion gain S_{31}, RF-to-LO isolation S_{12}, RF-to-IF isolation S_{13}, linearity and noise figure of proposed Mixer is shown with the standard simulated value of Mixer i.e in reference [5] is given in Table 1.

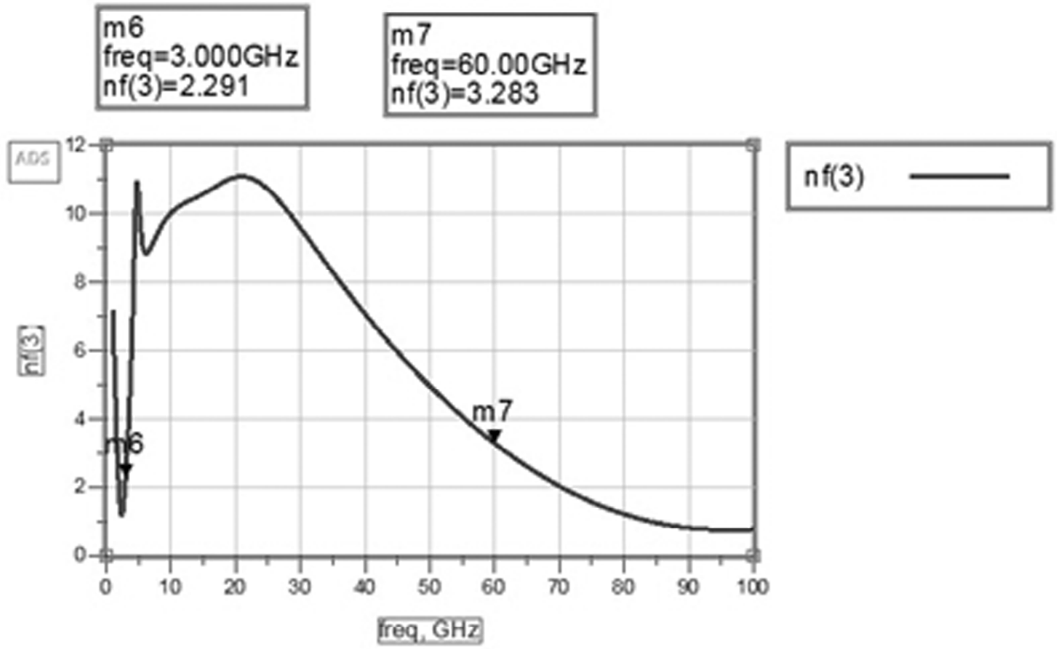

Figure 14: Noise Figure of Mixer

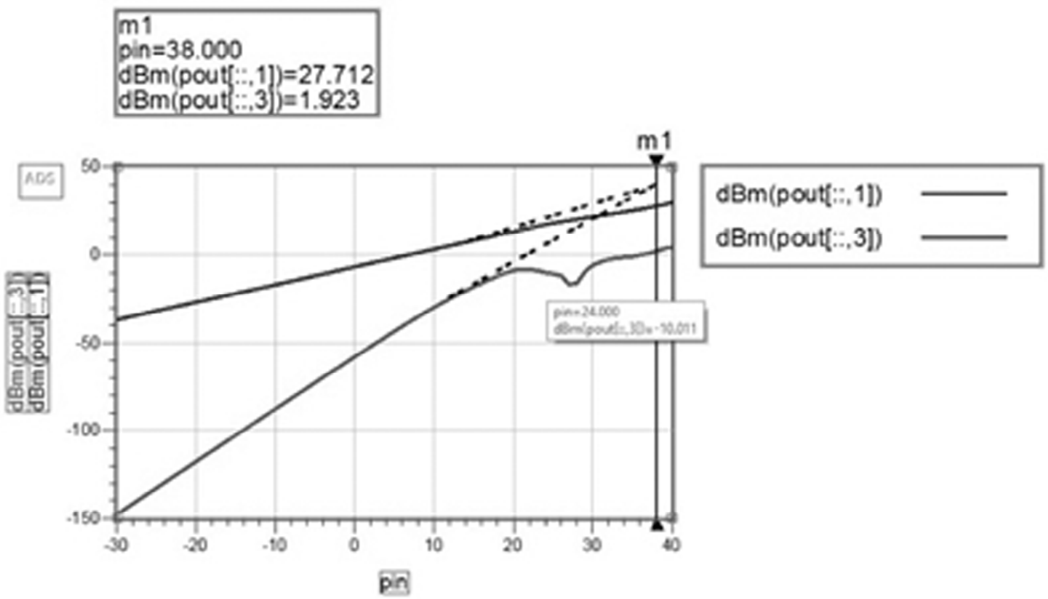

Figure 15: 3-dB compression Point (IIP3) of proposed Mixer

Table 1
Measured performance outline of the Mixer

Parameter	*Proposed Mixer*	*Reference [5]*
S_{31}(Conversion Gain)	28.915dB	7-10 dB
S_{12}(RF-to-LO isolation)	-135.94dB	< -35 dB
S_{13}(RF-to-IF isolation)	-114.30dB	< -30 dB
Min. Noise Fig	3.283dB	< 12 dB
linearity	~38	-
Technology	GaAs_FET	SiGe BiCMOS

5. CONCLUSION

A compact 60 GHz Mixerdemonstrated in GaAs Based EE_FET Technology. The chosen GaAs based EE_FET Distributed Amplifier gives wide bandwidth performance, good port-to-port isolation and high conversion gain. Based on Measured Result Mixer provide high conversion gain as 28.915 at 3 GHz, excellent RF-to-LO isolation as -135.940 and RF-to-IF isolation -114.306 with minimum noise figure of 3.283 at 60GHz.Therefore, the proposed Mixer with distributed amplifier is very suitable for RF front-end applications.

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