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Mixer Circuits Design and Performance Analysis using Planar Schottky Diodes – Simulation with MWO

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ABSTRACT

Three mixer circuits were designed: a single mixer, a balanced single mixer, and a double-balanced mixer, all utilizing planar Schottky diodes (Au/GaAs) for microwave frequencies. The design and simulation were conducted using the Microwave Office program. The performance of these designs was compared with a previous reference circuit by Rohyed, which also employed a planar Schottky diode. The comparison revealed that the conversion loss (CL) was lower in the single-diode mixer compared to the single-balanced mixer at fixe frequency 6GHz; the double-balanced mixer exhibited the best performance overall, and the single-balanced mixer showed slightly higher conversion loss. The noise figure remained relatively constant across the designs at operating frequencies for each circuit. Overall, the design effectively balanced conversion loss and Noise Figure.

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1. INTRODUCTION

Semiconductor devices such as the Schottky diode and double junction are crucial in microelectronics and microwave applications. The Schottky diode, which uses metal-semiconductor contacts, is especially known for its efficient modeling at submillimeter wavelengths. The integration of mixer and multiplier circuits into single units has been made possible by recent advancements in computing power, streamlining traditional separate designs. One important application of Schottky diodes is generating the difference frequency from mixing two input frequencies. Schottky diodes are known for their low forward voltage drop[1]. This characteristic is crucial in mixer circuits to minimize signal loss and maintain efficiency during frequency translation. Schottky diodes are valued for their low forward voltage drop and fast switching times, which are critical for high-frequency mixer operations. Planar Schottky diodes, known for their low noise and fast switching speeds, are essential in microwave and millimeter-wave mixer circuits. Shur and Anderson explored the performance of Schottky diodes at millimeter-wave frequencies, highlighting their fast switching capabilities and low noise properties, which are critical for efficient mixer performance[2]. Planar Schottky diodes are indeed integral to high-frequency applications like mixers. Their suitability for demanding tasks in microwave and millimeter-wave circuits, due to their low noise figure and fast switching speed, instills confidence in their performance[3]. Wang and Zhang presents a detail of simulation of planar Schottky diodes using Microwave Office (MWO) software to optimize their performance in microwave mixers. The authors analyze various device parameters and their impact on mixer performance, including conversion gain and Noise Figure NF[4]. Lee, and Kim gives an explore of the design and simulation of microwave mixers incorporating planar Schottky diodes. It provides insights into the simulation of device parameters and their influence on mixer performance using MWO software[5]. Recent studies by Thomas *et al*. [6] and Liu *et al*. [7] demonstrate advancements, including a sub-millimeter wave mixer/doubler and a sub-harmonic mixer, respectively. Understanding their merit, cutoff frequency, and Noise Figure is vital for optimizing performance in electronic applications [8]. We conducted simulations using MWO software to analyze the performance of a device with specific parameters in various microwave mixer circuits. This included assessing noise levels and conversion loss and comparing our findings with practical results from prior studies.

2. THEORITICAL PART

2.1. MIXER CONCEPTS

Mixers are nonlinear devices essential for generating various frequencies by combining Redio Frquency (RF) signal inputs with Local Oscillator (LO) frequencies. They convert high-frequency such as RF signals into lower Intermediate Frequencies (IF) by nonlinear mixing, where the LO frequency is altered to produce the IF signal [9]. The output frequency in mixers depends on internal signal additions and subtractions. Efficient mixer design minimizes conversion loss from input to output IF, often employing semiconductor diodes due to their appropriate impedance ratios [10].

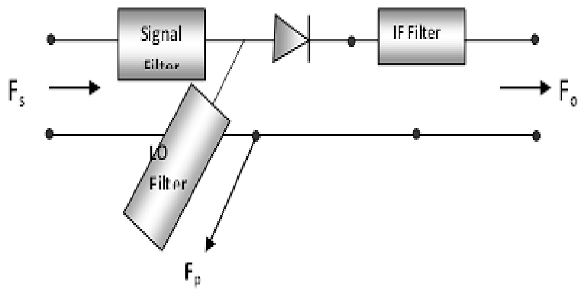


Figure 1: Schematic diagram of a simple mixer [11]

Different mixer types are tailored for specific applications, such as single-diode or double-balanced configurations [11]:

i. *Single-diode mixers* are suited for scenarios prioritizing signal strength over noise concerns [8]. They directly apply RF and LO signals to the diode without isolation, allowing the RF signal to pass selectively at the LO frequency. The fast switching capabilities of Schottky diodes are essential for handling high-frequency signals with minimal delay [12].

ii. *Single-balanced mixers* face challenges like inadequate isolation between RF and LO sources and generate noise and spurious signals in the IF. Double-balanced mixers address these issues with two diodes configured for improved balance and performance [13].

iii. *Double-balanced mixers* employ four diodes in a bridge network to achieve better isolation between RF, LO, and IF sources, reducing spurious signals at the IF output. They match even harmonics and minimize inter-modulation distortion, though their design complexity increases at microwave frequencies [12]. Several parameters may impact the mixer performer, such as mixing diode loss [14], transformer loss [15], harmonic generation loss [16], impact on system design [17], measurement techniques [17], temperature effects, and advanced Mixer designs [18]. This work focuses on the main factors of CL and NF, which will be discussed later.

2.2 MIXER PARAMETERS

a. Conversion Loss is a critical parameter in mixer design, defined as the ratio of the output power at the intermediate frequency (IF) to the input power at the RF signal frequency. It influences the mixer's performance and guides impedance circuit design. The fundamental aspect of mixer performance is its ability to balance conversion loss with other parameters such as noise figure and linearity, which are pivotal for achieving optimal performance in communication systems [18]. The total loss in a mixing diode can be calculated using the formula:

Loss (dB)=Conversion loss+Transformer loss+Loss due to harmonic generation +Diode loss

b. Noise Figure (NF) represents the difference between the input signal-to-noise ratio and the output signal-to-noise ratio, measured in dB. The noise figure closely correlates with the conversion loss in decibels. A higher conversion loss typically results in a higher noise figure, which can degrade the quality of the received signal [19].

The relationship between noise figure and conversion loss is explored in various texts on RF design, highlighting the trade-offs and optimization strategies for system designers.

2.3 MIXER ARCHITECTURE

The Microwave Office (MWO) program was used to build the design of the mixers to study their performance at Microwave frequencies and compare them with the results of [20]. A circuit for a single mixer, a balanced single mixer as well as a double balanced mixer has been selected. Using planar Schottky diodes of Au/GaAs with recipes extracted from the reference [21] in each mixer, as in Table (1):

Table 1: Characteristics of Schottky diode Au/GaAs

R_s Ω	$C_j \times 10^{-15}$ F	L µm	W µm	A µm^2	f_c GHz
7.3713	6	1.5	1	4.7143	3597.1

From this, it is possible to obtain better performance for the planar Schottky diode within the frequency range, which has good advantages that enable it to work within a wide range of frequencies. This proposal of the reference [21] is consistent with the results of [20], who showed that it is possible to obtain a high f_c when both (R_s) and (C_j) are very necessary, as they both remove the diode contact and the need for a low concentration semiconductor. Note that using a low concentration may lead to an increase in series resistance.

3. RESULTS AND DISCUSSIONS

The output results from the circuit used were represented (conversion loss, coupled noise shape) and the results were divided under the headings of the type of diodes used as follows:

A. Single diode mixer circuit.

The electronic circuit results from Rohade, [13] were compared with those obtained in our study in machine mixer measuring devices from the reference above. Variation in Figure (2) to represent the mixer circuit for a Rohade using a single-type diode (BAT14-099), according to the specifications manufactured by SIEMENS, which gave the results below.

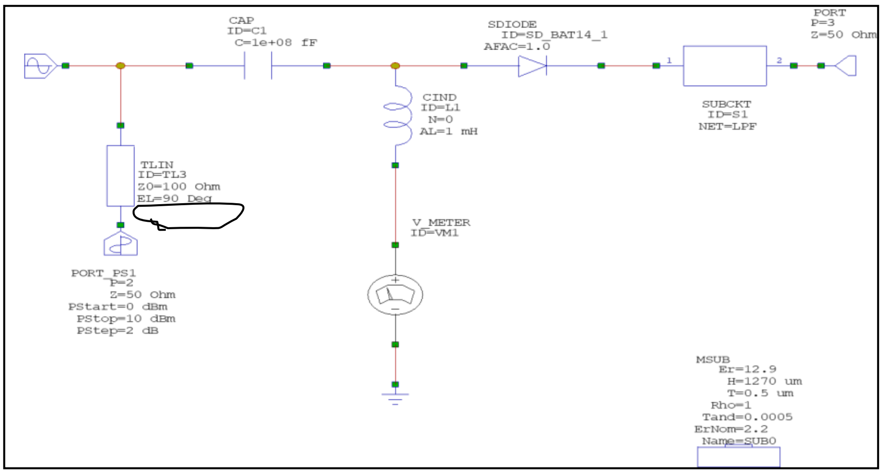
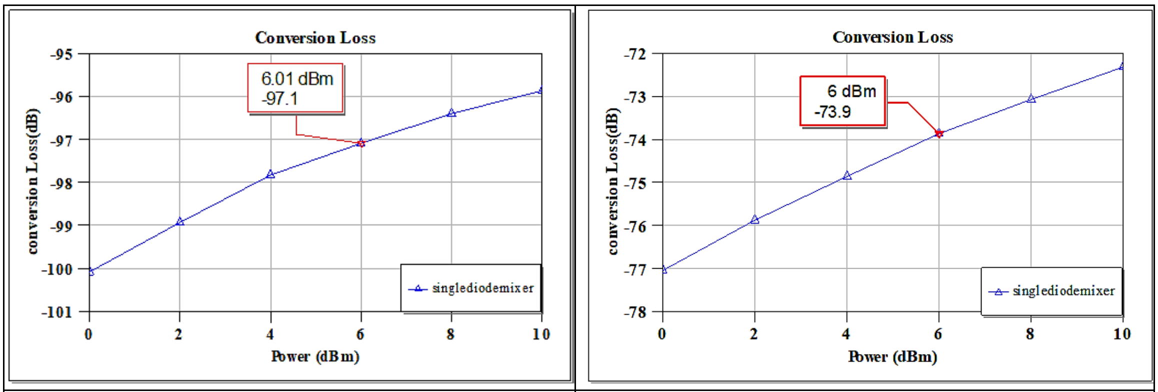


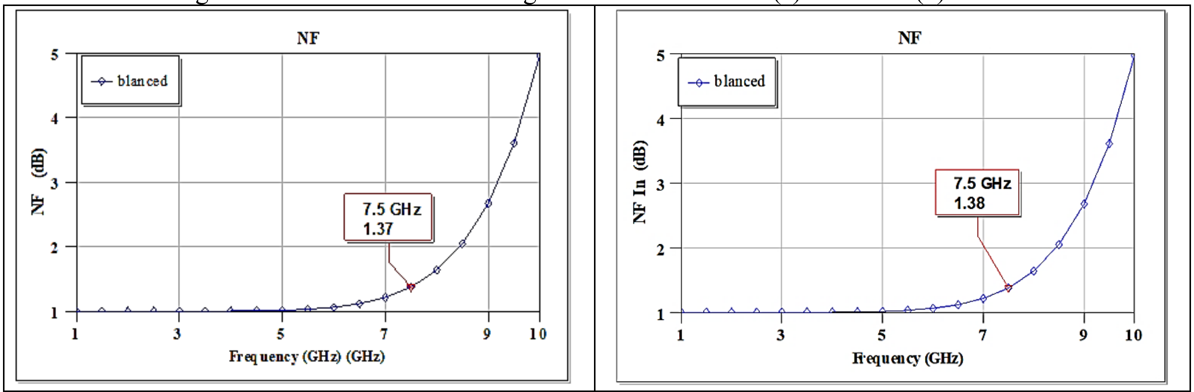
Figure 2: Single diode mixer circuit

Using the characteristics of planar Schottky diode in mixer circuits, the results of conversion loss, and noise figure are given in the following figure:



(a) (b)

Figure 3: Conversion loss for single diode mixer circuit (a) this work (b) Rohade



(a) (b)

Figure 4: Noise Figure for Single diode mixer circuit (a) this work (b) Rohade

Figures 3 and 4 show that the conversion loss CL for the chosen diode has decreased compared to that for the Rohade reference circuit, where NF has a similar value at the working frequency.

B. Single Balanced Mixer

The circuit in Figure (5) represents circuit of single balanced mixer for reference Rohade using a diode type (BAT14-099) with specifications manufactured by SIEMENS, and it gives the output results shown below.

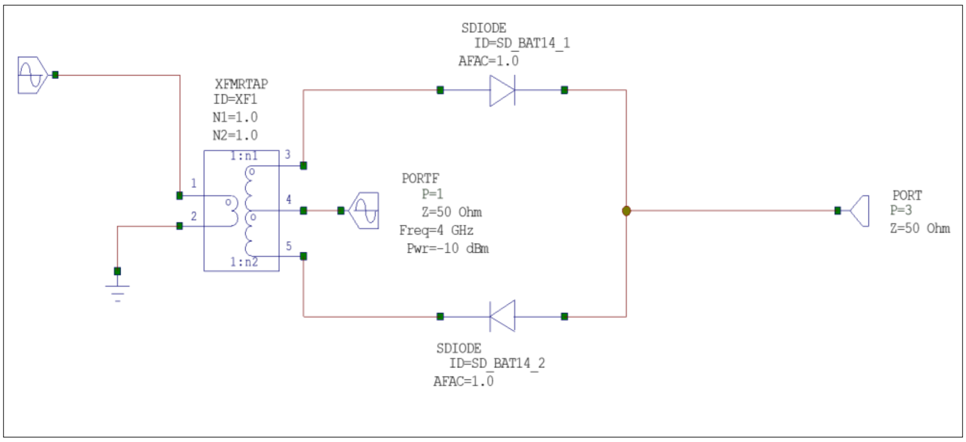
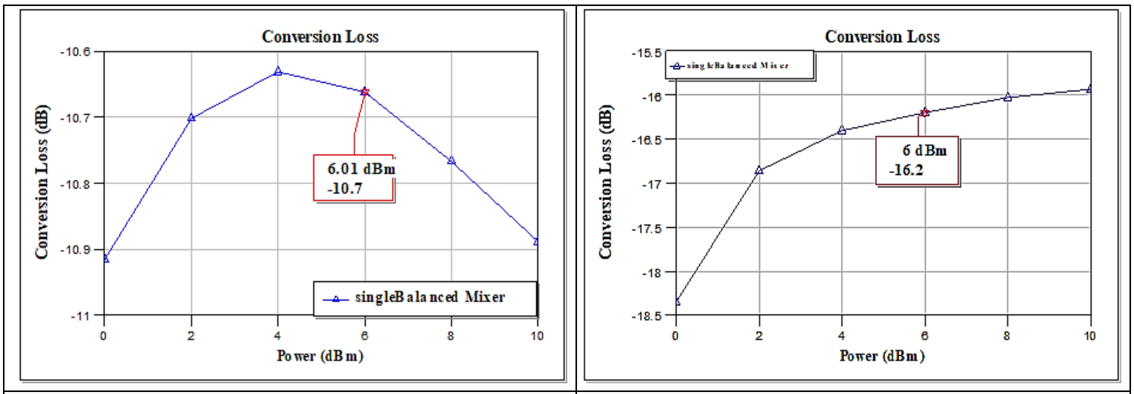


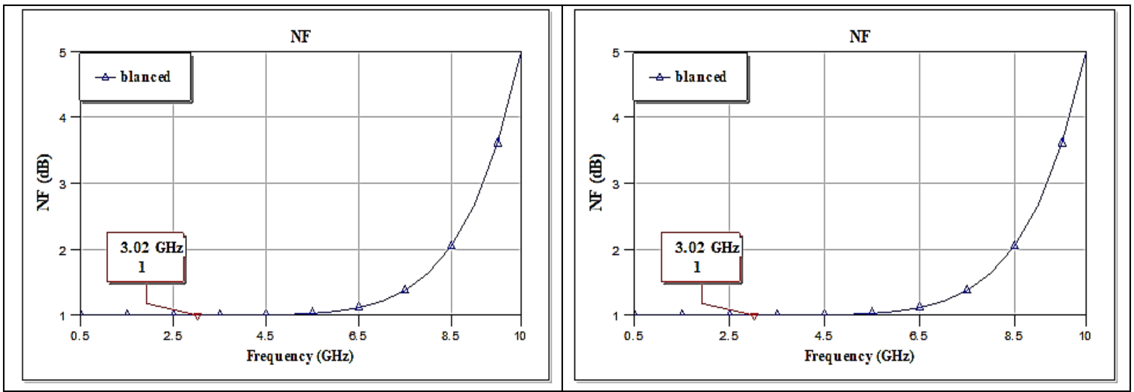
Figure 5: Single Balanced mixer circuit

The results of conversion loss, and noise figure for ingle balance mixer are given in the following figures:



(a) (b)

Figure 6: Conversion loss for Single Balanced mixer circuit (a) this work (b) Rohade



(a) **(b)**

Figure 7: Noise Figure for Single balanced mixer circuit (a) this work (b) Rohade

The two-Schottky diode mixer circuit was adjusted to minimize scattering coefficients, creating an appropriate working area, as shown in Figures 7 and 8. This resulted in an increased CL compared to the Rohade reference circuit, with NF maintaining a similar value at the working frequency.

C. Double balanced Mixer circuit

A circle in Figure (8) represents a Rohade mixer using four diodes, type (BAT14-099) and manufactured by SIEMENS, and the output results were shown below:

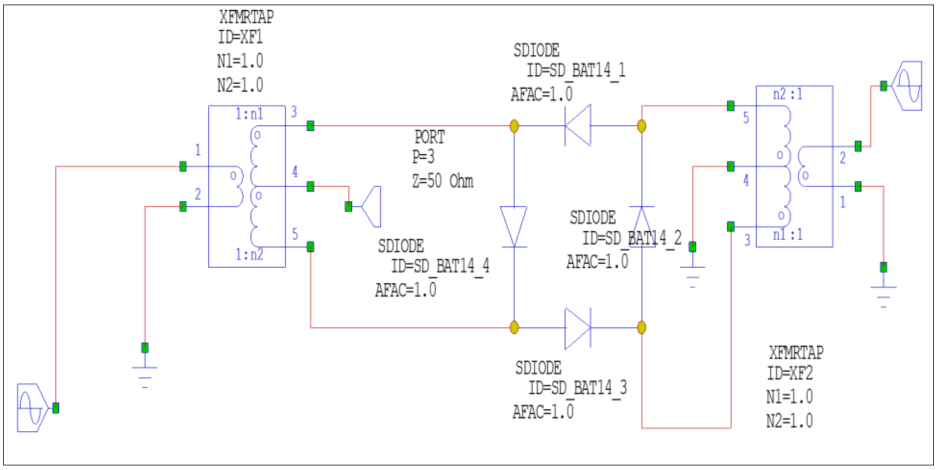
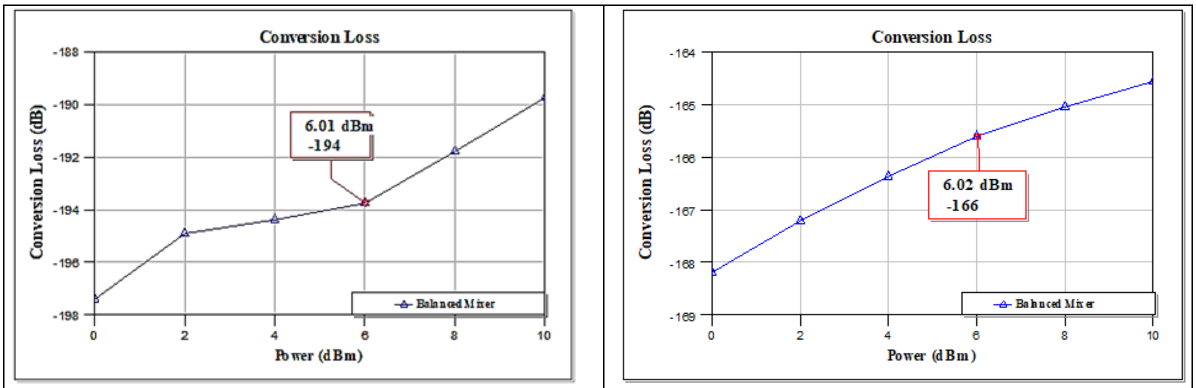
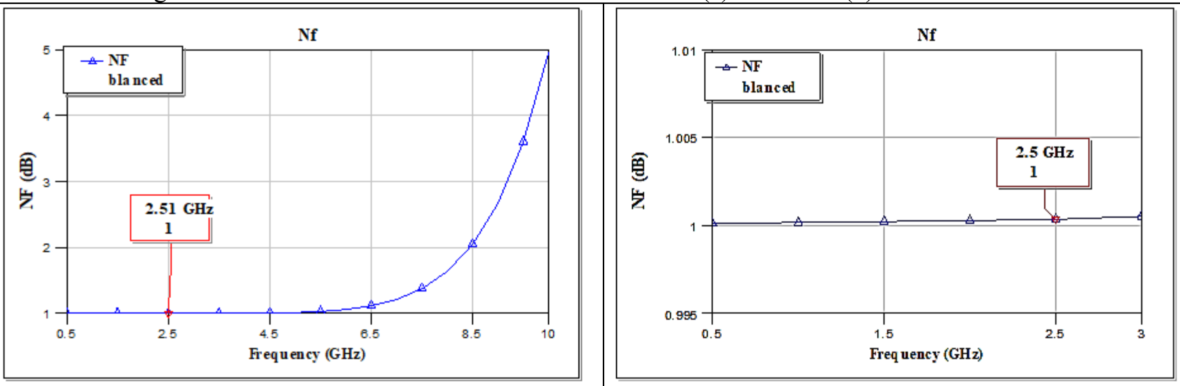


Figure 8: Double balanced Mixer circuit



a b

Figure 9: Conversion loss for double balanced mixer (a) this work (b) Rohade



a b

Figure 10: Noise Figure for double balanced mixer (a) this work (b) Rohade

The double-balanced mixer circuit was adjusted to minimize scattering coefficients. Figures (9) and (10) show that the conversion loss CL decreases compared to the Rohade reference circuit, and NF has a similar value at the working frequency.
The results of the mixer types are summarized in Table (2) within the operating frequencies. The comparisons were the Rohade reference circuit with the single-diode mixer, single-balanced mixer, and double-balanced mixer.

Table 2: Results for types of mixers at operating frequencies

Type	This work mixer		Rohade mixer[9]	
	CL	NF	CL	NF
Single Diode	-97.1@6dBm	1.37@7.5GHz	-73.9@6dBm	1.38@7.5GHz
Single Balanced	-10.7@6dBm	1@3GHz	-16.2 @6dBm	1@3GHz
Double Balanced	-194@6dBm	1@2.5 GHz	-166@6dBm	1@2.5GHz

The above table shows that the Schottky diode's operation is stable for each type of mixer circuit, as the noise figure NF was close to the Rohade value at each type's working frequencies. The conversion loss CL was indicated lower in the single-diode mixer circuit compared to the Rohade reference circuit and the single-balanced mixer. Still, it increased slightly in the double-balanced mixer circuit. Meanwhile, the noise figure remained approximately the same.
The simulation process sequence in this work is shown in the flowchart, as depicted in Figure (11).

4. CONCLUSION

The above simulation shows that the planar Schottky diode's operation is stable for each type of mixer circuit, as the NF was close and slightly different from the Rohade reference at the working frequencies of each type. The CL was indicated lower in the single-diode mixer circuit compared to the Rohade reference circuit and the single-balanced mixer. Still, it increased slightly in the double-balanced mixer circuit. Meanwhile, the Noise Figure remained approximately the same. The double-balanced mixer circuit performed best. Overall schottky diodes generally offer lower noise figures than traditional PN-junction diodes. New materials and optimized designs are pushing the limits of noise performance, making Schottky diodes even more effective in sensitive communication applications. This is consistent with the reference. However these designs achieve the fundamental aspect of mixer performance which is its ability to balance conversion loss with noise figure and linearity, which are pivotal for achieving optimal performance in communication systems which consist with Patel [21] and Lee,[23].

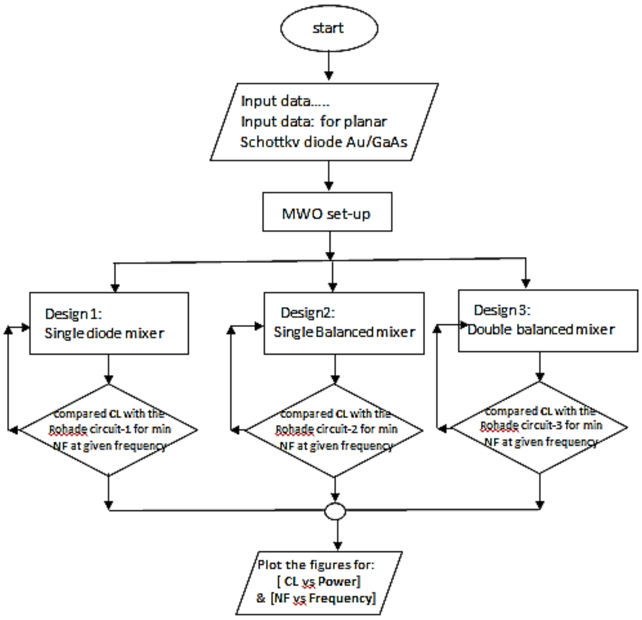


Figure 11 : Flowchrte for this work simulation

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