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Design of Crossbar Mixer at 94 GHz

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Abstract

This paper presents the design and performance of a 94 GHz crossbar mixer using chip diodes in crossbar configuration. The mixer has been designed in suspended stripline configuration on 2 mil fused quartz substrate. Co-simulation between Agilent Advance Design System (ADS) and CST Microwave studio is used to simulate and optimize the mixer circuit. The conversion loss of this crossbar mixer with ~10 dBm of LO power over RF bandwidth (89 to 93.8 GHz) with LO frequency at 94 GHz has been measured. Measurement results show minimum conversion loss of the order of 8 dB and achieved LO to RF isolation was greater than 26 dB.

Keywords

Crossbar Mixer, Waveguide, Suspended Stripline

1. Introduction

Mixer is an essential component of almost all receivers used in communication, radar and radio applications. The mixer generates an output spectrum, consisting of sum, difference and harmonics of the individual frequencies present at its input. The desired frequency can be filtered at output.

Millimeter wave mixers are generally designed in waveguide, suspended stripline, fin-line or combination of these lines. After going through many literatures, it has been found that suspended stripline has been successfully used to design mixer at 94 GHz [1]-[3]. Crossbar configuration of the mixer is well proven technology at this frequency.

Many researchers have designed crossbar mixer at 94 GHz with excellent results. Although cross-bar mixers have been described in many literatures, actual cross bar mixer modeling, simulation and optimization using commercial CAD software are not available. The aim of this paper is to describe the simulation technique which simplifies the design and reduces the time as well as cost for production.

2. Mixer Description

The configuration of cross bar mixer is shown in **Figure 1**. The mixer is realized in suspended stripline. The

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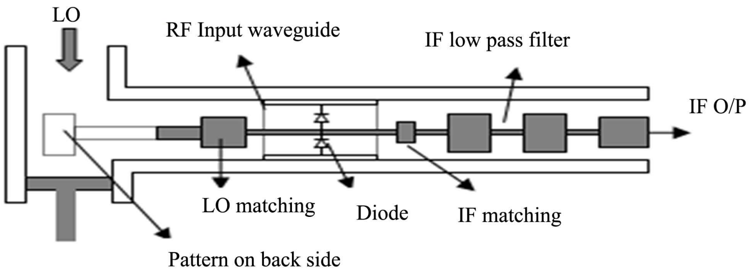


Figure 1. Configuration of crossbar mixer.

stripline circuit consists of two schottky barrier chip diodes, a suspended stripline to waveguide transition, an IF low pass filter and LO, IF & RF matching sections [4].

The LO power is coupled to the diode through a broadside coupler. The RF signal is incident perpendicular to the circuit.

Two diodes with opposite polarity are mounted in series across broad wall of the waveguide WR-10.

3. Analysis and Design

Cut-off frequency of the channel is also function of width of transmission line; hence channel dimension should ensure that cut-off frequency is beyond operating frequency band for the widest dimension of the transmission line used in the design. Cut-off frequency for the stripline channel can be calculated from standard formula [5] but they are not accurate at such a high frequency of operation. Hence complete port structure is simulated in CST microwave studio and port solution is obtained for different widths of transmission lines.

Analysis and design of crossbar mixer is carried out with the help of CST microwave studio and Agilent's ADS circuit simulator. In this method the basic structure of crossbar mixer without any matching, coupling and filter circuits is created and multiport (5 × 5) scattering parameter data is obtained. The LO port is labeled as port 1, IF as port 2, RF as port 3 port 4. Port 4 and 5 are used as internal ports where diode are placed in ADS circuit simulation. CST simulation of the above structure results in 5 × 5 S-matrix file. This S-matrix is renormalized with respect to distributed waveguide (WR-6) impedance and imported into the ADS circuit simulator in "Touchstone" (.SnP) format. The 2 × 2 S-matrix of LO coupler (along with suspended stripline to waveguide transition) and low pass filter is simulated separately and exported to ADS. All S-Parameters blocks are integrated in the ADS circuit simulator and harmonic balance analysis is done. The block diagram of the circuit used in ADS circuit simulation is shown in **Figure 2**.

The schematic circuit in ADS circuit simulator for harmonic balance simulation and optimization of the mixer is shown in **Figure 3**.

4. Simulation Steps

Mixer simulation has been done under following steps.

1) Basic crossbar mixer unit which consisting RF and LO waveguide and a small transmission line in LO-IF circuit is simulated in CST microwave studio and 5 × 5 scattering matrix file is exported to ADS circuit simulator.

2) Design and simulation of LO side broadside coupler is done in CST microwave studio and 2 × 2 scattering matrix file is exported to ADS circuit simulator. Broadside coupler can be replaced by band pass filter.

3) A 7 element Chebyshev low pass filter with 0.2 dB ripples in pass band is designed and simulated and resulting 2 × 2 S-matrix file is exported to ADS circuit simulator.

4) Complete harmonic balance simulation of crossbar mixer is done in ADS circuit simulator by integrating all S-Parameter blocks.

5) Finally equivalent matching circuit dimension is used from CST, which takes into account electromagnetic simulation of matching elements.

Harmonic balance is a frequency-domain analysis technique for simulating nonlinear circuits and systems. It is well-suited for simulating analog RF and microwave circuits.

Harmonic Balance Simulation calculates the magnitude and phase of voltages or currents in a potentially non-

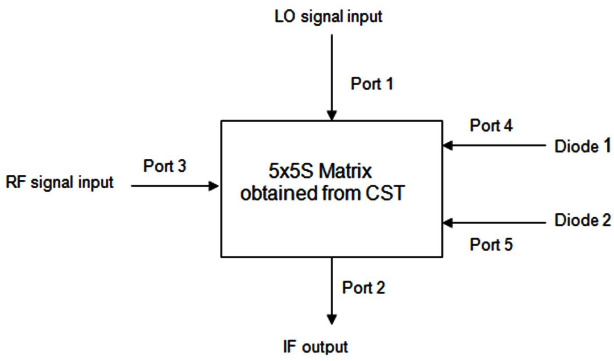


Figure 2. Block diagram of mixer circuit used in ADS.

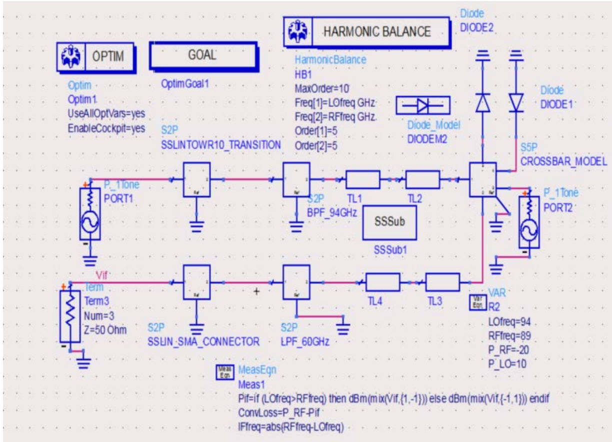


Figure 3. Schematic of the mixer in ADS.

linear circuit. In contrast, S-Parameter or AC simulation modes do not provide any information on nonlinearities of circuits.

Harmonic balance simulation makes possible the simulation of circuits with multiple input frequencies. This includes intermediation frequencies, harmonics, and frequency conversion between harmonics.

The HB method depends on calculating currents and voltages at many harmonically related frequencies for each fundamental signal under consideration.

5. Simulation Results

A) *Waveguide to SSLIN Transition*

The suspended stripline to waveguide transition consists of an electric probe inserted into the broad wall of the waveguide. The probe is an extension of a suspended stripline into the waveguide. When a probe is inserted into the waveguide it radiates and in certain position desired mode is excited or vice versa fields set up in the waveguide can be picked up. At one end of waveguide input is given and at other end tuning short is provided to provide optimum matching. Most critical parameters for the transition are probe shape and insertion distance of suspended stripline into the waveguide.

The A dimension of the channel is chosen as 1.27 mm to facilitate the waveguide (WR-10) transition. For WR-10 the dimension is a = 2.54 mm and b = 1.27 mm. The electric probe transition was chosen because it can be fabricated as an integral part of the stripline and difficulty of making variable contacts is avoided. The transition model and its simulated response are shown **Figure 4**.

B) *Band Pass Filter Simulation*

The end coupled suspended stripline band pass filters are most promising due to its compact size, lightweight, low cost and ease of fabrication. In E plane circuit supporting dielectric (e.g. Fin line) causes additional losses [6] [7].

The 94 GHz band pass filter exhibits an insertion loss of 1 dB with 3 dB relative bandwidth at a center frequency of 94 GHz and the return loss is better than −18 dB at a center frequency. The designed and fabricated 94 GHz band pass filter shows the good performance for planar integrated millimeter-wave circuits. The 3D view and simulated results of band pass filter are shown **Figure 5**.

C) *Low Pass Filter Simulation*

A 7 element Chebyshev low pass prototype has been designed using standard low pass filter design formulae given in Matthaei [8] for a cut-off frequency of 60 GHz and minimum of 30 dB rejection at 94 GHz. The 3D view and simulated results of low pass filter are shown **Figure 6**.

D) *Harmonic Balance Simulation Results*

Harmonic balance simulation results of the mixer after optimization are shown **Figure 7**.

6. Hardware and Results

The complete assembly of realized Quartz MIC card and mixer hardware is shown below in **Figure 8**. K-Type Connector is used to Extract IF output. To test the performance of the mixer, the conversion loss over the band is shown in **Figure 9**. With RF Frequency of 92 GHz, LO Frequency of 94 GHz and 10 dBm of LO power, LO leakage at RF port was found to be –18.3 dBm. Hence LO to RF isolation was 28.3 dB. For optimum conversion loss a LO power of 10 dBm is required. A conversion loss of the order of 8 dB was achieved.

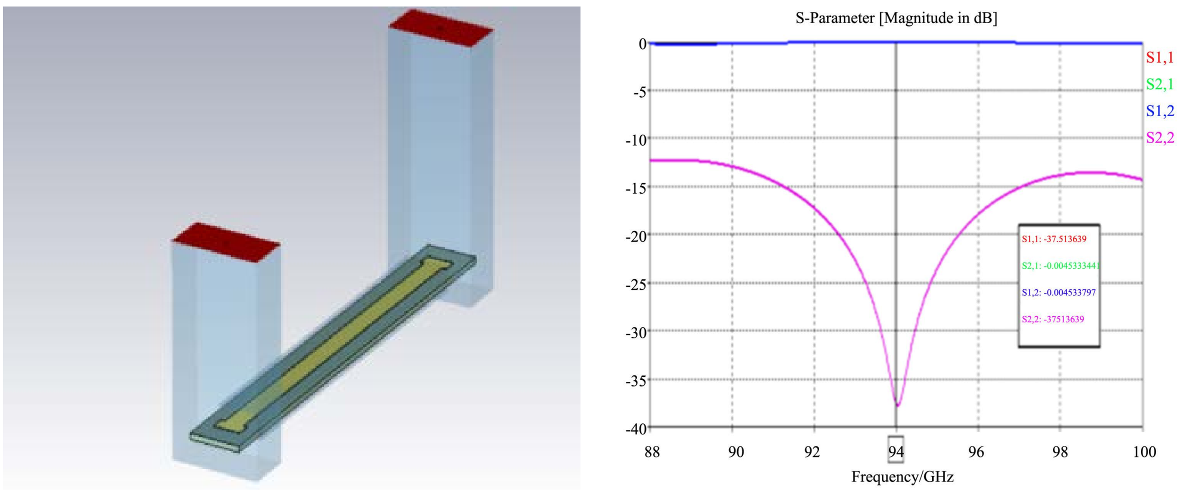


Figure 4. Waveguide to SSLIN Transition and simulation results.

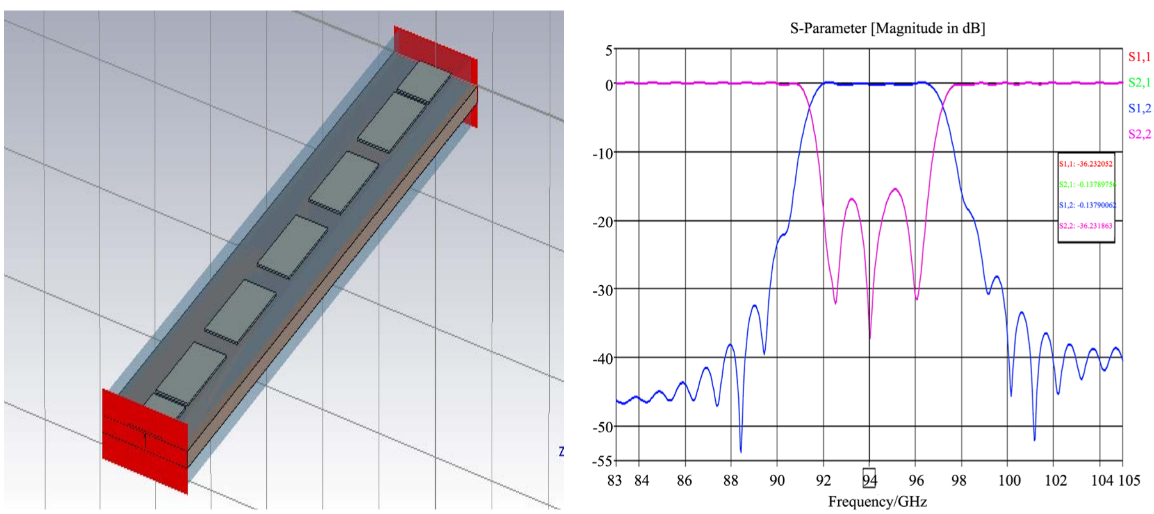


Figure 5. Band pass filter 3D view and simulation results.

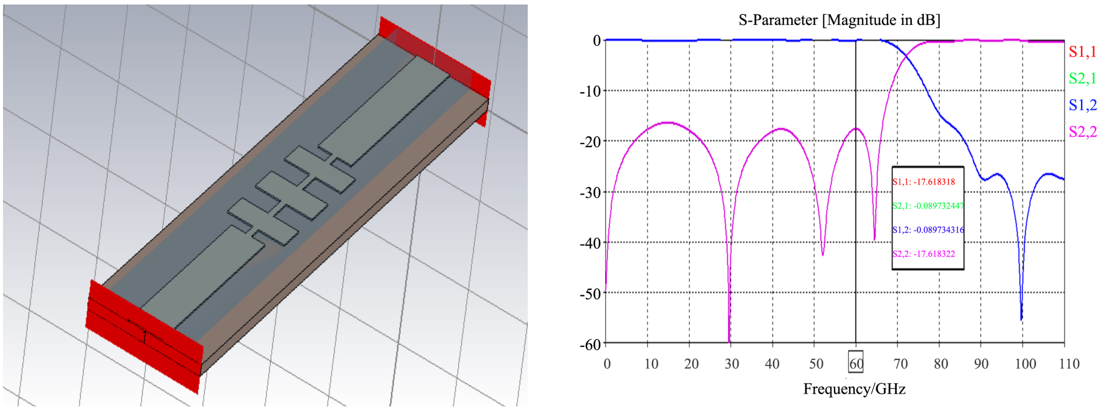
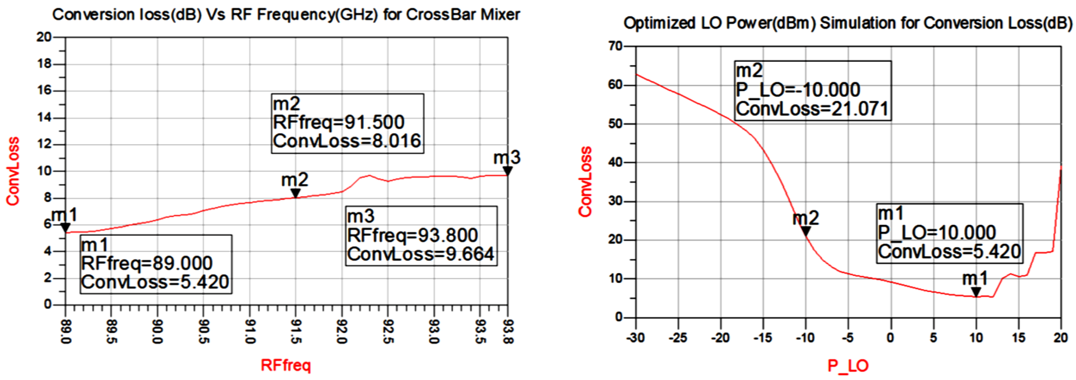


Figure 6. Low pass filter 3D view and simulation results.



(a) (b)

Figure 7. (a) Simulated results for conversion loss (dB) vs RF Frequency (GHz) LO Frequency = 94 GHz, LO power = 10 dBm; (b) Simulated results for conversion loss (dB) vs LO power (dBm) RF Frequency = 92 GHz, LO Frequency = 94 GHz.

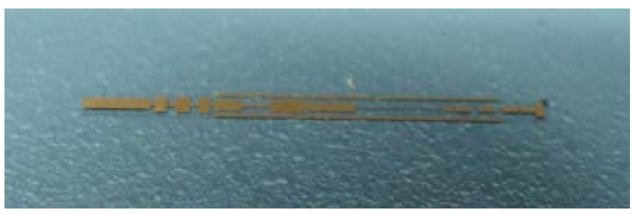


Figure 8. MIC card of mixer on 2 mil quartz substrate.

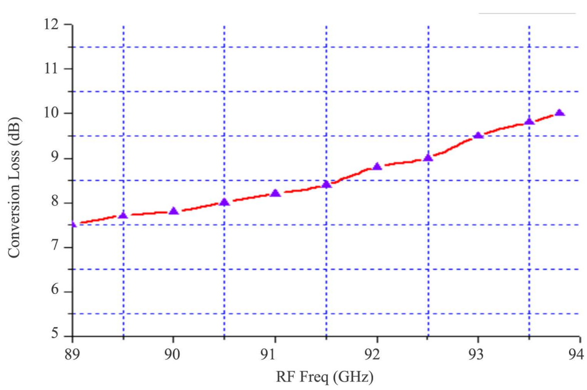


Figure 9. Conversion loss of realized mixer.

7. Conclusion

A simplified low conversion loss mixer at 94 GHz was developed using co-simulation techniques and optimization procedure. Deviation between simulation and measured results was mainly attributed to mechanical tolerances in the mixer cavity and bonding techniques. The realized mixer using chip diode meets the design objective and compares well at other crossbar mixer operating at W-Band.

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