

Development of An Improved Sub-harmonic Mixer Based on Planar Schottky Diodes at 94 Ghz

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Abstract: Accompany with the rapid development of millimeter-wave science and technology, sub-harmonically pumped mixers has received more and more attention. In this study, a balanced sub-harmonic fix-tuned mixer is designed based on combination of linear/nonlinear circuit simulation. It is realized based on rogers substrate process to minimize the cost and simplify the assembly. The mixer works in the 91-98 GHz band with SSB conversion loss 8~11 dB when pumped with 6 mW of local oscillator power and minimum SSB conversion loss of 8 dB is measured at 93 GHz. The measured performance of this mixer is sufficient and robust for the foreseen applications.

Key words: Fix-tuned, low conversion loss, planar schottky diodes, sub-harmonic mixer

INTRODUCTION

Millimeter-wave science and technology has made rapid development for past two decades, which is a new research area involving electromagnetism, optoelectronics, optics semiconductor physics, materials science, biology, medical and so on (Crowe *et al.*, 2005). Accompany with increased security need for point-to-point communications as well as covert battlefield communications systems, millimeter-wave communication technology has made tremendous progress. We know that most millimeter-wave communication systems, here we refer to space-borne receiver front-end, are based on high performance mixers (Zhang *et al.*, 2009), among which a type called Sub-Harmonically Pumped (SHP) mixers has received more and more attention. The application of SHP mixers has a number of attractive features from a system design point of view. First, RF and LO frequencies are well separated and can be isolated by simple filters within the waveguide cavity. Second, the local oscillator requirements are easier to meet because the LO frequency is about half of that in the corresponding fundamentally pumped mixers, and because SHP mixers have substantial AM local oscillator noise suppression (Cohn *et al.*, 1975; Carlson *et al.*, 1978; Henry *et al.*, 1976). And SHP mixers have become critical components in receivers and radiometers for millimeter-wave communication systems. Compared with the early SHP mixers, fixed tuned SHP mixers are cheaper to machine, assemble and require no post-tuning. Owing to the fixed tuned nature of these mixers, their

design must be precise and should guarantee good performance.

This study describes design, fabrication and measurement of the fixed-tuned sub-harmonically pumped mixers operating in the 91-98 GHz band for millimeter-wave communication using a discrete pair of planar Schottky diodes fabricated by Virginia diodes Inc. The mixer is designed by the use of co-simulation of HFSS and ADS. The sub-harmonic mixer is designed as a fix-tuned component with the least number of parts to minimize the cost and maximize its potential for volume manufacture.

MIXER ARCHITECTURE

The topology of the mixer circuit is presented in Fig. 1. The design is based on a traditional E-plane split-block waveguide architecture (Raisanen *et al.*, 1993) with fixed RF and LO backshorts. The microstrip circuit consists of a grounded microstrip, a probe crossing RF waveguide (WR-10), the antiparallel diode pair in series with the transmission line, a low-pass filter to block the RF signal, a probe crossing the LO waveguide (WR-19) and the low-pass IF filter. The mixer was designed as a split block with an antiparallel diode pair mounted on microstrip circuit (Hesler *et al.*, 1997; Thomas *et al.*, 2005). The circuit is precisely RF grounded at one end by directly silver-epoxy gluing the circuit to the bottom half of the block and avoiding the use of gold ribbons or bonding wires. Such structure also provides the return ground for DC current from any imbalance between the

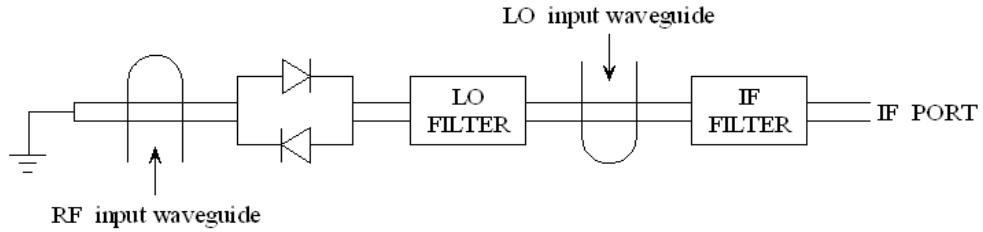


Fig. 1: The topology of the mixer circuit

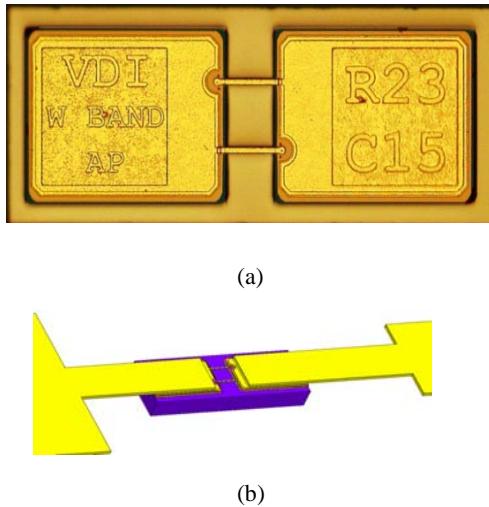


Fig. 2: (a) The actual photograph of the antiparallel Schottky diodes from VDI. (b) The electromagnetic model of the antiparallel schottky diodes

diode pair without biasing the diode pair asymmetrically (Marsh, 1988). At the other end, the microstrip circuit is silver-epoxy glued to a K-connector as the IF output port. Both RF and LO inputs are coupled to the microstrip using reduced height waveguides and E-plane probes for broadband operation.

DESIGN

Schottky diode modeling and harmonic balance simulation: The junction parameters of the antiparallel Schottky barrier diode fabricated by VDI chosen here are an anode diameter of $3.8 \mu\text{m}$, a pad to pad capacitance C_{pp} of 15 fF , a finger to pad C_{fp} capacitance of about 1 fF , zero biased junction capacitance for single anode C_{j0} of 22 fF , an ideality factor η of 1.176 , a series resistance R_s of 4 W , a saturation current I_{sat} of 71.9 fA and a built-in potential of 0.75 V . A combination of linear/nonlinear circuit simulation (Agilent ADS) and three dimensional electromagnetic simulations (Ansoft HFSS) are used to compute and optimize the performance of the circuit.

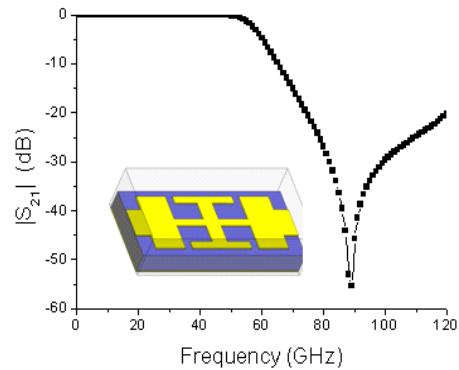


Fig. 3: The structure and simulated results of the LO filter

Electromagnetic modeling: Each part of the passive circuit elements corresponding to an impedance transition is modeled accurately using a 3D EM software tool. The embedding circuits were analyzed using co-simulation of ADS and HFSS.

Antiparallel schottky diodes electromagnetic model: The diode considered is an antiparallel GaAs Schottky diode version of Virginia Diode, as shown in Fig. 2(a). The diode structure was modeled using Ansoft HFSS FEM simulator. A SEM microscopy was used to obtain physical dimensions of the diode structure. The effect of the planar diode chip structure on the diode embedding impedance could be modeled by using HFSS to solve for the fields within the diode chip when mounted in the microstrip channel. Small coaxial ports were attached to probes on each anode so that the individual embedding impedances for each diode could be monitored directly (Fig. 2b) (Marsh *et al.*, 2007; Porterfield, 2007; Maestrini *et al.*, 2008).

LO filter: Compact Microstrip Resonant Cells (CMRC) filter is used to improve the performance of the mixer due to the shorter size and wider stop-band. The LO filter have ability to block the RF signal and pass the LO and IF signal with low loss. The structure and simulated results of the LO filter are presented in Fig. 3.

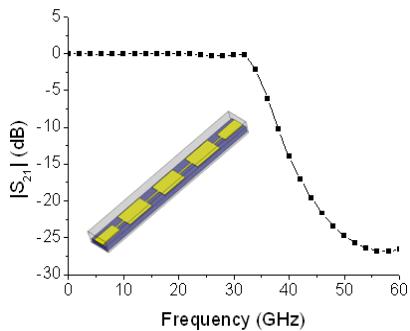


Fig. 4: The structure and simulated results of the IF filter

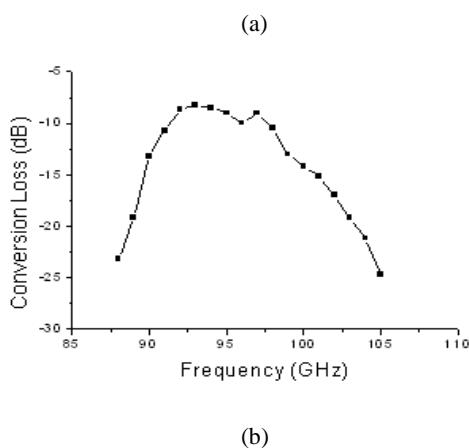


Fig. 5: (a) Photograph of mixer (b) Measured conversion loss

IF filter: Low-and-high-step-impedance filter is designed to realize the IF low pass characteristic. The IF filter has low pass characteristic to pass the IF frequency and block local oscillator frequencies, which is connected with LO input waveguide E-plane probe. The filter shows a good band rejection to LO frequency and low loss to IF frequency, the structure and simulated results of the IF filter are presented in Fig. 4.

Mixer measurement: The circuit was fabricated on 0.254-mm-thick rogers5880 substrate, and the photograph of the SHP mixers is shown in Fig. 5a. The mixer is

pumped with a widely tunable LO source, the calibration of the RF and LO power was performed using Erickson PM-4 power-meter, and the IF signal has been measured with the Agilent spectrum analyzer 8563EC (Zhang *et al.*, 2011). According to experiment report, our test errors include power meter about 5% and the spectrum analyzer about 0.5 dB. The test results in Fig. 5b are average values of three sets of test data to reduce the test error. It can be found that the conversion loss was obtained in the range of 8~11 dB from 91 to 98 GHz when the LO frequency was fixed at 47 GHz with 6 mW of power.

CONCLUSION

The design of a 94 GHz fixed-tuned sub-harmonically pumped mixer using commercially available GaAs flip-chip Schottky barrier diodes has been demonstrated in this study. The design procedure shows how millimeter-wave circuit engineers can optimize their use of current CAD tools for high performance sub-harmonic mixers. The measured performance of this mixer is sufficient and robust for the foreseen applications.

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