A 26-40 GHz Broadband Fixed IF Sub-harmonic mixer Based on Schottky Diode

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Abstract—This paper describes the design of a broadband, fixed-IF single balanced subharmonic mixer at entire Ka-band. The co-simulation between HFSS and ADS was applied to the modeling of the mixer. In order to improve the accuracy of simulation, an accurate diode nonlinear equivalent circuit is established and verified by testing data. The circuit of the presented mixer printed on the substrate of Rogers RT/Duroid 3003 with permittivity of 3 and thickness of 254 μm is mounted in a waveguide block. When the IF frequency is fixed at 1.5 GHz, the measured results show that the conversion loss of the mixer is less than 9 dB in most bandwidth from 25 GHz to 40 GHz. The minimum conversion loss of 6.9 dB is measured at 36 GHz. The measured isolation of LO to RF and LO to IF is more than 28 dB. The RF to IF isolation is more than 20 dB. The good isolation has been achieved.

Keywords*：*Ka band; subharmonic mixer; fixed IF; broadband

I. INTRODUCTION

Ka band is widely used in the field of satellite communications because of its wide bandwidth and fast communication speed[1]. The mixer is an important part of radar and microwave measurement systems. In the measurement systems, the frequency of IF signal is usually fixed, so that the back-end circuit can be processed. Differ from most mixers with fixed local oscillator and frequency of IF signals are changed with frequency of RF signals, this mixer has fixed IF frequency and broadband matching of LO and RF. The fixed low IF can be sampled directly by back-end circuit, avoiding second times of down-conversion, which reduce the volume of the systems.

Harbmonic mixers require LO signals of only 1/N the frequency of the RF(where N is the harmonic order) [2]. It can ensure good isolation between RF and LO. However, conversion loss increase compared with fundamental mixers. Considering the low fixed-IF frequency is set at 1.5 GHz, to obtain better isolation and low conversion loss, sub-harmonic mixers becomes a better choice. The local oscillator frequency of Ka-band sub harmonic mixer is located at Ku-band, and the waveguide size of this band is larger. To ensure good broadband matching and reduce module volume, substrate integrated waveguide (SIW) microstrip transition is adopted. SIW can realize the propagation characteristics of the traditional metal waveguide on the substrate. It has many advantages like low radiation, low insertion loss, high Q value, high power capacity and small volume for rectangular waveguide and microstrip. Through the good matching networks of RF and LO, the conversion loss is less than -9 dB over the bandwith from 26 GHz to 40 GHz. Therefore, characteristic of wide broadband and high efficiency can be achieved.

II. MIXER DESIGN

The anti-parallel balanced circuit is shown in Fig.1. These two diodes present anti-parallel as to input and output circuits which make the odd-harmonic mixing component exists in the internal circulation of the diode pair, while even-harmonic mixing component exists outside. The suppression to odd harmonics depends on the uniformity of the diodes and the symmetry of the circuit.

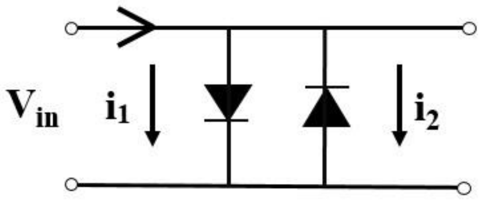


Fig. 1 The anti-parallel balanced circuit

Accurate diode nonlinear equivalent circuit is the key of mixer design. The diode chip used in this work is MA4E1310 produced by MACOM [3]. The series resistance Rs is 6 Ω and the zero voltage junction capacitance C_{j0} is 0.01pF. The size of the diode chip is 660 μm × 330 μm × 20 μm. In millimeter wave band, the geometry of the diode chip causes significant high frequency parasitic effect, and affects the performance of the mixer greatly. So parasitic capacitance and lead inductance must be introduced to describe high-frequency parasitic effect. By modifying some of the circuit model parameters through test data, an accurate diode equivalent circuit model is established with the parasitic capacitance C_P=0.03 pF and lead inductance L_P=0.1 nH. The diode nonlinear equivalent circuit is shown in Fig.2. The test results show that the test results are basically consistent with the simulation results.

The principle circuit of the subharmonic mixer is depicted in Fig.3. The mixing circuit consists of a RF probe [4], a LO SIW transition [5], an idle energy recovery network, an IF filter, the matching networks, a compensation solder pad and a pair of Schottky diodes.

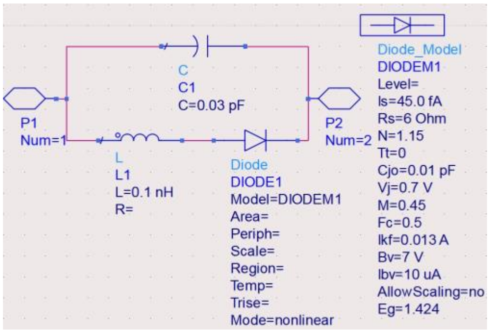


Fig. 2 The diode nonlinear equivalent circuit

To minimize the loss of the RF signal and achieve broadband matching in the entire Ka-band, the WR-28 waveguide and 1/4 wavelength microstrip line matching networks are adopted. The LO signal is fed by SIW transition because the seize of standard waveguide Ku-band is large 15.799mm × 7.899mm. By designing a reasonable idle frequency energy recovery circuit at the LO, the idle energy including the RF energy and the odd harmonic energy of the LO is recycled to decrease the conversion loss of the mixer. With the increase of working frequency, the influence of parasitic parameters introduced by pads on the performance of the whole circuit is also affected. In order to improve the design reliability and improve the performance of the mixer, a microstrip compensation pad structure is adopted to compensate the parasitic capacitance effect of diode pads [6]. By using ADS to extract the impedance of diodes at fundamental and second harmonic frequency, the broadband matching network of RF and LO can be reasonably designed.

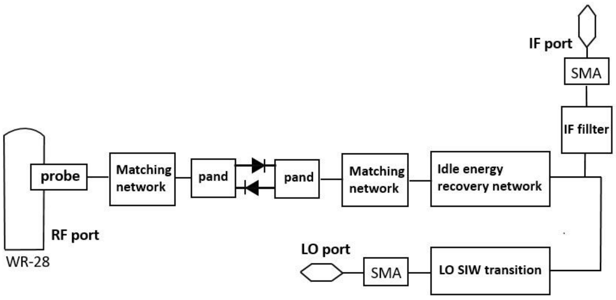


Fig.3 Structure of the mixer

The IF signal is extracted through a low pass filter in CMRC form. The output current of the mixing product generally consists of the following series of low frequency current components. The current components are:

$$\begin{aligned} i &= A\cos w_{LO}t + B\cos w_{S}t + C\cos 3w_{LO}t \\ &+ D\cos 5w_{LO}t + E\cos(2w_{LO}+w_{s})t + F\cos(2w_{LO}-w_{s})t \\ &+ G\cos(4w_{LO}+w_{s})t + H\cos(4w_{LO}-w_{s})t + \ldots\ldots \end{aligned} \tag{1}$$

The filter with BCMRC [7] is designed to get the IF signal from the mixer and ensure good isolation between IF and LO. It exhibits remarkable wide stopband and slow-wave characteristics. Simulated result of the filter is shown in the Fig.4.

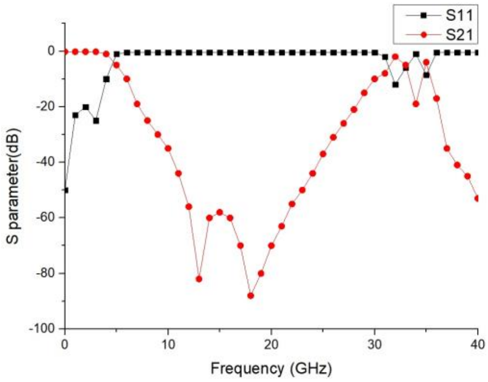


Fig.4 The simulated results of IF low pass filte for CMRC

III. FABRIACTION AND MEASUREMENT

The circuit of the presented mixer is patterned on the substrate of Rogers RT/Duroid 3003 with a permittivity of 3 and a thickness of 254 um, followed with a photolithography process. The E-Plane cut split-block waveguide is milled in aluminum and the LO and IF part connect to the SMA connector. The anti-parallel planar Schottky diodes chip is filp-chip mounted on the pand with silver epoxy. The mixer is fabricated and shown in Fig.5. Its overall dimension is 49 × 41 × 10mm^3.

In the conversion loss test, a coaxial-to-waveguide adapter is used with the RF waveguide. The RF signal is provided by Agilent E8257D signal generator from 26 GHz to 40 GHz. The LO signal is provided by R&S®SMB100A signal generator and IF signal is measured by Agilent 8257D spectrum analyzer. When the fixed IF frequency is 1.5 GHz, the comparison between simulated results and testing results are shown in the Fig.6 (a). The results show that the testing data and simulated data are basically consistent. The accuracy of the diode equivalent circuit has been verified.

The measured results are illustrated in Fig.6 (b) (c) with the LO power level of 12 dBm and the IF frequency fixed from 1.3 GHz to 2.5 GHz. The results show that the conversion loss are below 12 dB from 26 GHz to 40 GHz when the fixed IF frequency is 1.4 GHz, 1.5 GHz, 1.6 GHz, 1.7 GHz, 2.3 GHz, 2.4 GHz, 2.5 GHz .

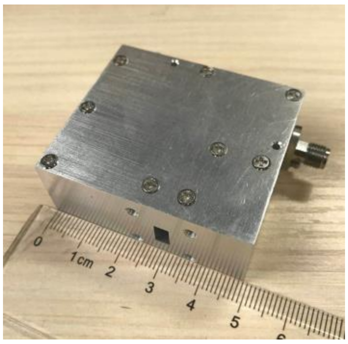
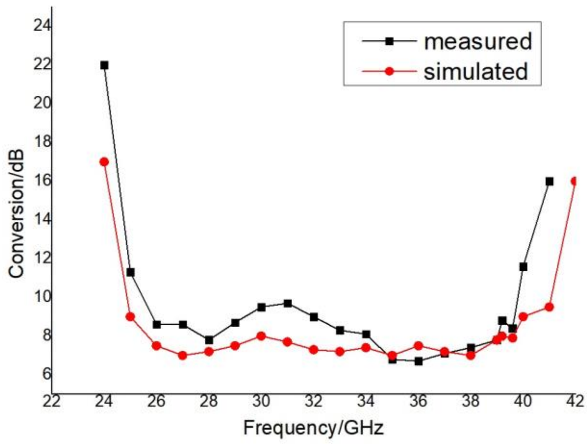
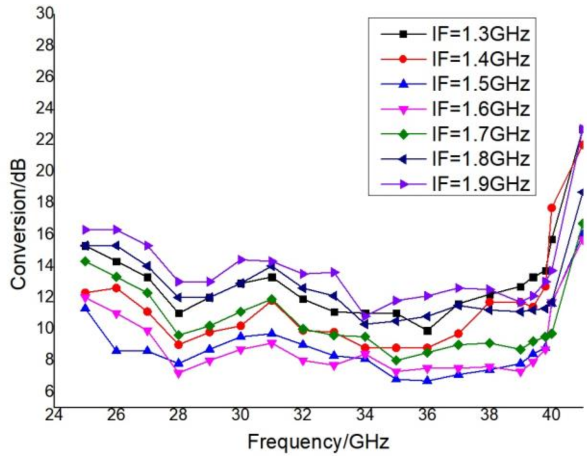


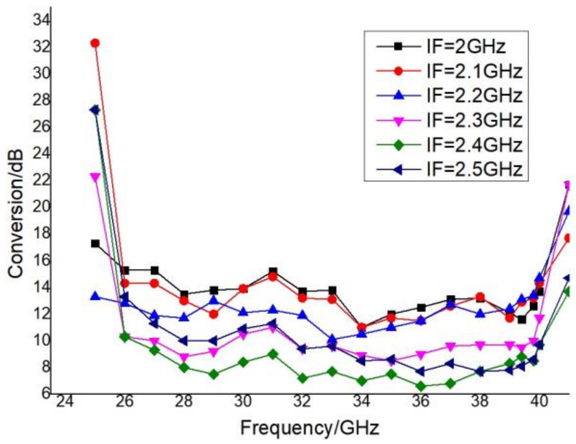
Fig.5 the photograph of the mixer



(a)



(b)



(c)

Fig.6 measured results of conversion loss (a) comparison of conversion loss between simulation result and measred result; (b)(c) measured result of conversion loss at diffierent IF frequency

The measured isolation is illustrated in Fig.7. The isolation of LO to RF and LO to IF are more than 28 dB. The RF to IF isolation is more than 20 dB.The good isolation has been achieved.

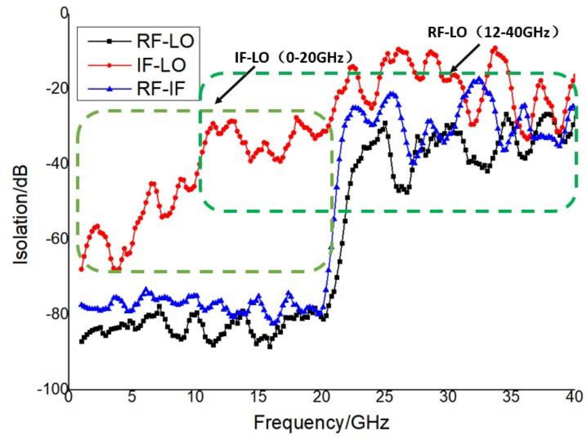


Fig.7 measured isolation of three port

IV. CONCLUTION

With the field-circuit co-simulation method, a broadband, high efficiency, fixed-IF subharmonic mixer at Ka-band is designed in this work, basing on the accurate diode nonlinear equivalent circuit. The mereasured results show that the conversion loss of the mixer is less than 9.3 dB over the bandwidth from 26 GHz to 40 GHz when the IF frequency is fixed at 1.5 GHz. The measured results are in accordance with the simulated results, which verifies the accuracy and feasibility of the nonlinear equivalent circuit discussed in this article. A reasonable matching network and idle energy recovery network are adopted to achieve good isolation between the three ports and prevent port power leakage.

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