Wideband sub-harmonic mixer incorporating short-circuited band-pass filter

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Abstract: A Q band sub-harmonic mixer with wideband radio frequency (RF) and high intermediate frequency (IF) is proposed. The mixer employs a short-circuited band-pass filter (BPF) and a RF-IF diplexer, which provide proper terminations for the IF, RF, and local-oscillator (LO) signals simultaneously, and reject the major unwanted mixing products. A Q-band sub-harmonic mixer is designed and fabricated. The measured results show that the proposed sub-harmonic mixer can operate from 40 to 50 GHz for RF and support up to 10 GHz for IF bandwidth. As a down-conversion mixer, the measured conversion-loss is less than than 10.5 dB over the available RF band, while the minimum conversion-loss is about 6.8 dB at an RF of 45 GHz and IF of 5 GHz. As an up-conversion mixer, the measured conversion-loss is less than 11 dB over the available IF band, while the minimum conversion-loss is about 7.5 dB at an RF of 45.5 GHz and IF of 5.5 GHz.

Keywords: wide band, high intermediate frequency (IF), short-circuited band-pass filter (BPF), low conversion-loss

Classification: Microwave and millimeter-wave devices, circuits, and modules

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1 Introduction

In millimeter-wave frequency band, sub-harmonic mixers play a key role in radar, communication and other systems. Compared with the fundamental mixer, sub-harmonic mixer needs a lower frequency of local-oscillator (LO) source, which is very important in millimeter-wave band. Additionally, the excellent RF-to-LO isolation and inherent LO noise suppression can be achieved by the use of anti-parallel diode pair (APDP) in the sub-harmonic mixer [1, 2].

In [3, 4, 5], the performance improvement of conversion loss is introduced. Those mixers achieve a low conversion loss, which is comparable with the conversion loss of fundamental mixers. Methods of enlarging the working bandwidth of the sub-harmonic mixers is reported in [6, 7, 8].

In this paper, a wideband sub-harmonic mixer exploiting standard microstrip hybrid microwave integrated circuit (MIC) technology for Q-band applications is proposed. The high frequency parasitic effects are taken into account by the EM analysis of the diode’s 3D geometric model. A short-circuited band-pass filter (BPF) and a novel diplexer are employed for the wideband design. Ansoft HFSS and Agilent ADS are used to simulate and optimize the performance of the mixer. The measured results show that the proposed mixer achieves a conversion loss of less than 11 dB over 40 to 50 GHz RF frequency band and the IF bandwidth can be up to 10 GHz. As a result, this proposed configuration provides a flexible and wideband design in sub-harmonic mixers.
2 Design of the short-circuited BPF

In this paper, a short-circuited BPF is used to pass the LO signal, and reject RF and IF signals. However, the conventional frequency bandwidth of the band-pass filter (BPF) with $\lambda g/4$ short stubs is too wide [9], while the bandwidth of BPF with flexible $\lambda g/4$ short stubs is too narrow [10]. To solve this problem, a BPF consisting of $\lambda g/4$ transmission lines, straight $\lambda g/4$ short stubs and flexible $\lambda g/4$ open stubs is proposed as shown in Fig. 1. The design equations about the characteristic admittances of each stub are described in [10].

A demonstration circuit of the short-circuited BPF was simulated on a Rogers RT/duroid substrate with a thickness of 0.254 mm and a relative permittivity of 2.2. The center frequency of the filter is about 20 GHz, which is chosen for the LO signal. Simulation was carried out by Ansoft HFSS 15.0. Fig. 2 depicts the simulation and measurement results with parameters of $w1 = 0.86$ mm, $l1 = 1.02$ mm, $w2 = 0.9$ mm, $l2 = 1.01$ mm, $w3 = 85$ mm, $l3 = 1.25$ mm, $w4 = 0.67$ mm, $l4 = 1$ mm, $wp = 0.75$ mm, $lp = 2.55$ mm. It shows that the insertion loss is less than 1.7 dB and the return loss is better than 10 dB with about 50% bandwidth.
3 Circuit design

The proposed sub-harmonic mixer circuit configuration is shown in Fig. 3. It consists of three parts, 1) the anti-parallel diode pair (APDP); 2) the RF-IF network; 3) the LO network. The APDP is the non-linear device for frequency conversion. The LO signal is applied from the left side of the APDP. The RF signal and IF signal are on the right side of the APDP. The diplexer is employed to separate the RF signal and IF signal from each other. The short-circuited BPF is adopted to provide a proper pass band for the LO signal and a stop band for suppressing the RF, IF and some other unneeded signals. Meanwhile, it creates a ground paths for the RF and IF signals by choosing a proper length of ML1. The \( \lambda_{LO}/4 \) long open stub on the right side of APDP is designed to isolate the RF port from LO and IF ports.

Fig. 3. Circuit configuration of the proposed sub-harmonic mixer.

Fig. 4 shows the simulation results of the diplexer by HFSS. The cut-off frequency of the low-pass filter is about 12 GHz, and the pass-band for RF is about 39 to 52 GHz. There is a sharp rejection at the lower band of the BPF, owning to the use of open stubs at the parallel coupled filters. The APDP used is
commercial GaAs Schottky diode DMK2308 from Skyworks, Inc. Table I lists the SPICE model parameters of the diode. Coaxial probe method [11] is used to determine the effect of the diode packaging. The complete mixer circuit is simulated by the harmonic balance analysis module of the Agilent ADS 2014. The frequency response of the passive elements is represented by S-parameters, which are calculated by HFSS and imported to ADS as a sNp file.

| Table I. | Spice model parameters of DMK2308 |
|----------|----------------------------------|
| Is (pA)  | 0.5 | Rs (Ω) | 4 | XTI1 | 2 |
| n        | 0.5 | TD (sec) | 1E-11 | FC | 0.5 |
| CJ0 (pF) | 0.05 | M | 0.26 | BV (V) | 4 |
| EG (eV)  | 1.43 | VJ (V) | 0.82 | IBV (uA) | 10 |

4 Mixer implementation and measurement

The sample mixer is fabricated using the Rogers RT/duroid 5880 substrate with substrate thickness of 0.254 mm. The mixer is mounted in a metal housing as shown in Fig. 5. The mixer includes a transition between microstrip line and rectangular waveguide, and two SMA connectors at LO and IF ports for the testament.

![Fig. 5. Photograph of the fabricated sub-harmonic mixer.](image)

The conversion loss of the proposed sub-harmonic mixer is measured using the Agilent PNA Network Analyzer E8364C with PSG Analog Signal Generator E8257D providing the LO signal. Fig. 6 illustrates the measured conversion loss as a function of RF frequency with different fixed LO frequencies and an LO power of 10 dBm. The conversion loss is less than 11 dB over the RF frequency band of 40–50 GHz, and the LO frequency is workable at 20 GHz, which means the IF bandwidth can be up to 10 GHz. The minimum conversion loss is about 6.8 dB at an RF of 45 GHz and IF of 5 GHz for the down conversion, and about 7.5 dB at an RF of 45.5 GHz and IF of 5.5 GHz for the up conversion.
Table II summarizes the performance (down conversion) of the proposed sub-harmonic mixer with other similar published works. The proposed sub-harmonic mixer has a low conversion loss and wide IF bandwidth. Moreover, owing to the use of common PCB technology and commercial schottky diode pair, the cost of the proposed sub-harmonic mixer is low.

Table II. Comparison of published sub-harmonic mixers

| Reference | RF frequency/ GHz | IF frequency/ GHz | Conversion loss/dB | Technology            |
|-----------|-------------------|-------------------|--------------------|-----------------------|
| [5]       | 71–86             | 10–16             | 12–16              | MMIC                  |
| [7]       | 43–50             | 7–8.5             | 9.5–14.5           | MMIC                  |
| [12]      | 90–100            | DC-4              | 8–11               | Microstrip hybrid MIC |
| This work | 40–50             | DC-10             | 6.8–10.5           | Microstrip hybrid MIC |

5 Conclusion

A sub-harmonic mixer has been realized for Q-band applications by using a short-circuited BPF. A wide RF and IF frequency band is achieved. Measurements show that the performance of the proposed sub-harmonic mixers is comparable to the best performance of the similar mixers published so far. Meanwhile, the proposed mixer maintains a low cost property by the using of microstrip hybrid MIC technology. Furthermore, the proposed sub-harmonic is a planar circuit, which makes it easy to be integrated with other planar circuits.

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