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A broadband millimeter-wave sub-harmonic mixer using microstrip passive circuits

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Abstract: This paper presents a millimeter-wave microstrip-based sub-harmonic mixer with a wide operation band. In this design, frequency suppression circuits including a wideband bandpass short-circuited filter and a diplexer are employed not only to provide proper terminations for the intermediate frequency (IF), radio frequency (RF), and local oscillator (LO) signals simultaneously, but also to reject the major idle mixing products. The measured results show that the proposed sub-harmonic mixer can support the operations in RF band from 27 to 48 GHz, and in IF band up to 6 GHz. Meanwhile, the conversion loss is less than 12. 5 dB for both up- and down-conversion throughout the bandwidth, in which, the minimum conversion loss is about 7. 5 dB and 8. 2 dB for the down-conversion and up-conversion, respectively, at an RF of 33 GHz and IF of 1 GHz.

Key words: millimeter-wave, sub-harmonic mixer, microstrip, broadband
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基于微带无源电路的宽带毫米波分谐波混频器

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摘要:设计了一款基于微带结构的宽带毫米波分谐波混频器。混频器中引入了短路结构的宽带射频滤波器以及一个高性能本振-中频双工器,这些无源电路能够抑制空闲组合频率,同时为中频、射频以及本振信号提供合适的回路。测试结果表明,本文设计的毫米波分谐波混频器射频工作频率为27~48 GHz,中频工作频率宽至6 GHz. 在整个工作频段内上、下变频损耗均小于12.5 dB。当射频为33 GHz,中频为1 GHz时,上变频、下变频达到最小变频损耗分别为8.2 dB和7.5 dB。

关 键 词:毫米波;分谐波混频器;微带;宽带

中图分类号:TN773.2 **文献标识码**:A

Introduction

The sub-harmonic mixer is a common solution in the millimeter-wave system because it only requires a relatively low frequency of local-oscillator (LO) signal, which provides lots of merits, such as high reliability, low phase noise and low cost. Anti-parallel diode pair (APDP) was proved to have several advantages in the design of sub-harmonic mixers[1, 2], such as good radio frequency (RF)-to-LO isolation and suppression of any even harmonics of LO signals.

Many studies have been devoted to the performance improvement of conversion loss of sub-harmonic mixers[3-6]. Recently, the conversion losses of sub-harmonic mixers achieved similar low level as the fundamental mix-

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ers. Meanwhile, different methods are used to improve the operation bandwidth of the sub-harmonic mixers[7-14], and the RF bandwidth can be more than one octave. However, it is still difficult to achieve a wide IF bandwidth in design of sub-harmonic mixer.

In this paper, a millimeter-wave sub-harmonic mixer with a wide IF bandwidth is presented based on standard microstrip hybrid microwave integrated circuit (MIC) technology. Meanwhile, a novel frequency suppression circuit is employed to broaden the bandwidth and decreases the conversion loss. Hence, the proposed sub-harmonic mixer has features of wide operating frequency band, low conversion loss, the ease of fabrication and convenience of integration with microwave and millimeter wave circuits.

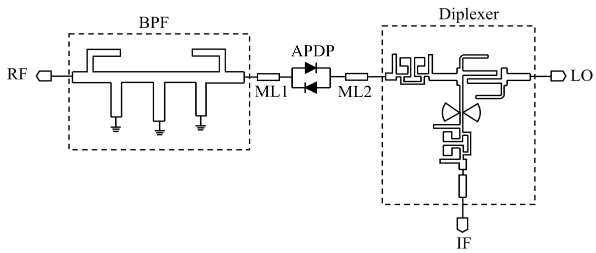


Fig. 1 The circuit topology of the proposed sub-harmonic mixer
图1 提出的分谐波混频器电路拓扑图

1 Circuit Design

To achieve broad band, a scheme of APDP sub-harmonic mixer including a short-circuited band pass filter (BPF) and a diplexer is proposed, as shown in Fig. 1. Among them, the BPF can provide a pass band for RF signal and a stop band for LO, IF and some other idle signals of mixing products of IF and LO, located on the left side of APDP. In addition, a diplexer is used to separate the LO and IF signals placed on the right side of APDP.

To design such a mixer with low conversion loss and broad band, the key factor is to achieve broad band and low insertion loss of the diplexer, the matching circuits, and the RF filter while maintaining enough isolation between LO and RF.

Firstly, the diplexer of this work adopts a compact low pass filter (LPF)[15] and an improved wideband edge coupled BPF. The wideband edge coupled BPF includes two high impedance open stubs, which are added at both ends of a single section coupled line to reduce the requirement of the lines' width and the gap between the coupled lines. Meanwhile, the diplexer also includes a compact LPF at the common port, which rejects the RF signal and passes the LO and IF signals. The simulation results of the diplexer in HFSS are shown in Fig. 2, in which the common, LO and IF ports are marked as Port 1, 2 and 3, respectively. As shown in this figure, the cut-off frequency for the IF is about 6 GHz and the passband bandwidth for the LO is about 12 GHz with a center frequency of 18 GHz. The simulation results also show that the diplexer has a sharp rejection level at the stopband.

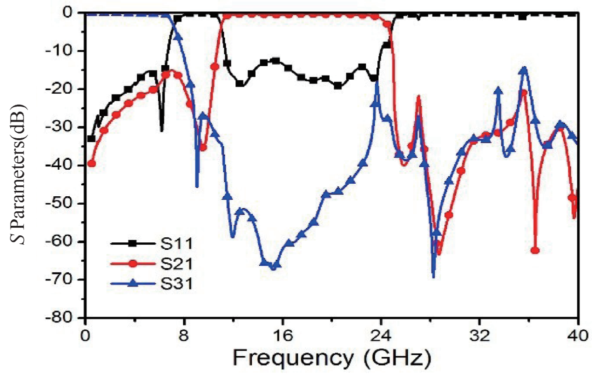


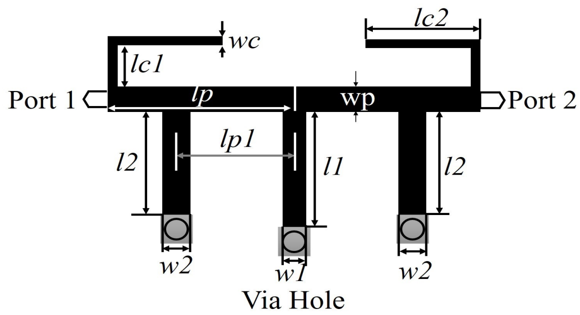
Fig. 2 Simulated S parameters of the proposed diplexer
图2 采用的双工器S参数仿真曲线

Secondly, considering to the RF BPF requires high rejection of LO/IF, and low insertion loss at RF port, a broadband BPF using short stubs is chosen for this purpose. Higher-order filter is necessary to achieve higher nearby LO rejection, however higher-order usually leads to higher insertion loss. To overcome this difficulty, a wideband short-circuited BPF shown in Fig. 3(a) is proposed, which consists of a pair of open stubs and three $\lambda/4$ shunt shorted stubs that are separated from each other by $\lambda/4$ connecting lines. The specific parameters of the filter are optimized by Ansoft HFSS to obtain a transmission zero at lower frequency band to reject the nearby LO signal using the equations in Ref. [16]. Finally, the geometrical parameters is chosen as $w1$ = 0.65 mm, $l1$ = 0.6 mm, $w2$ = 0.54 mm, $l2$ = 0.9 mm, wp = 0.8 mm, lp = 1.25 mm, wc = 0.15 mm, $lc1$ = 0.6 mm, $lc2$ = 2 mm. As shown in Fig. 3(b), the simulated result shown that the pass band is from 26 to 49 GHz, and a sharp rejection level of more than 30 dBc is at around 20 GHz.

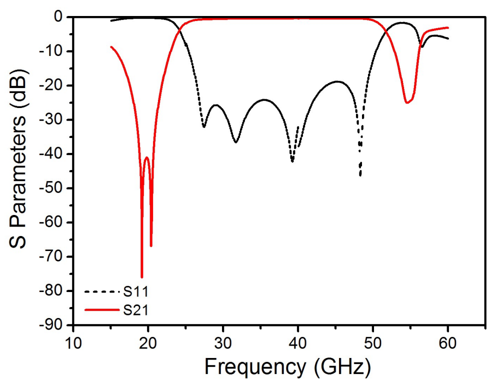
Finally, the APDP used is commercial GaAs Schottky diode DMK2308 from Skyworks, Inc. This diode chip structure can be modeled in HFSS[12] to determine the effect of the diode packaging. The input and output matching is achieved by tuning the line width and length of ML1 and ML2. These simple matching circuits help to achieve impedance matching and reduce the overall conversion loss. Hence, the whole completed mixer circuit can be simulated by the harmonic balance analysis module of the Agilent Advanced Design System (ADS). The S-parameters, which represent the frequency response of the passive elements discussed above, are calculated by HFSS and imported to ADS as a "sNp" file. Microstrip lines ML1 and ML2 are added to the circuit to connect those "sNp" modules. And the performance of the mixer is optimized by tuning the lengths of the microstrip lines.

2 Mixer implementation and performance

According to the optimized parameters, a demonstration circuit was fabricated on a Duriod RT/5880 substrate with a thickness of 0.254 mm and a relative permittivity of 2.2. And finally the whole mixer is mounted in a



(a)



(b)

Fig.3　The proposed RF band pass filter (a) Geometry view, (b) Simulated S parameters
图3　采用的射频带通滤波器 (a)结构图, (b)仿真S参数

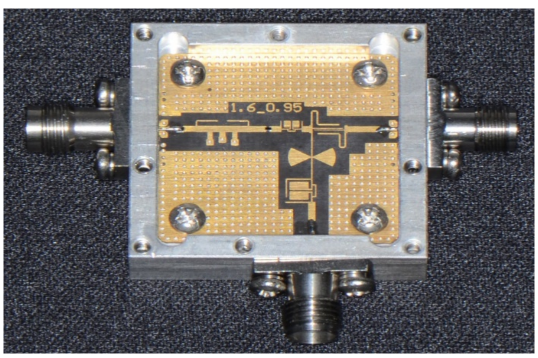
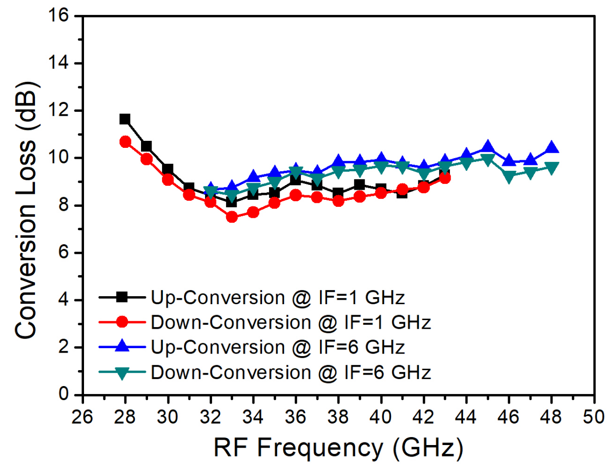
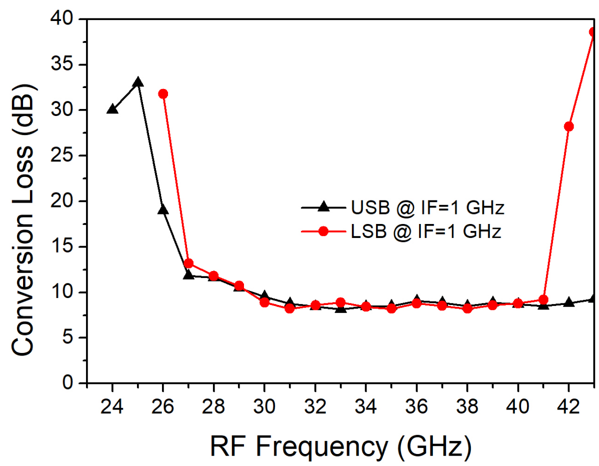


Fig. 4　Photograph of the fabricated sub-harmonic mixer
图4　分谐波混频器实物照片



(a)



(b)

Fig.5　Measured conversion loss versus RF frequency at different IF frequencies (a) USB at IF of 1 GHz and 6 GHz (b) USB and LSB at IF of 1 GHz
图5　不同中频频率下混频器变频损耗关于射频频率变化的测试曲线 (a) 中频为1 GHz和6 GHz时上边带曲线,(b)中频为1 GHz时上边带和下边带曲线

metal housing to shield from outside interference, as shown in Fig. 4. Agilent Analog Signal Generator E8257D was used to provide LO signal, and Network Analyzer E8364C was used to measure the frequency response of the mixer.

Figure 5 (a) illustrates the measured up side band (USB) conversion loss as a function of RF frequency with IF frequency at 1 GHz and 6 GHz, respectively. And all the measurement was implemented with the LO power level at 12 dBm. The minimum conversion loss is about 7.5 dB and 8.2 dB for down-conversion and up-conversion, respectively, at RF of 33 GHz and IF of 1 GHz, and the conversion loss is less than 11.2 dB with IF fixed at 6 GHz for both up-conversion and down-conversion. Meanwhile, Figure 5 (b) shows the measured USB and low side band (LSB) conversion loss as a function of RF frequency with IF frequency of 1 GHz. The measured LSB conversion loss presents a sharp rise at the RF frequency of 42 GHz, while the USB conversion loss has little change, which is led by the fact that LO signal is out of range. As the below cut-off frequency of the RF band pass filter is above 26 GHz, both USB and LSB conversion loss increased while the RF frequency below 26 GHz. Measured USB conversion loss versus IF frequency with different LO frequencies is shown in Fig. 6. Down-conversion loss (Fig. 6(a)) has a limited difference with the up-conversion loss (Fig. 6(b)). With the increase of IF frequency, the conversion loss increases, especially beyond 6 GHz, that agrees with the performance of the diplexer. In addition, Fig. 7 shows the measurement results of LO-to-RF and LO-to-IF isolations as a function of LO frequency. The LO-to-RF and LO-to-IF isolations are better than 15 and 38 dB for the LO frequency from 13 to 21 GHz, respectively. Hence, the carefully design of pass-band of the BPF and diplexer make it possible to provide a wider IF bandwidth than traditional method.

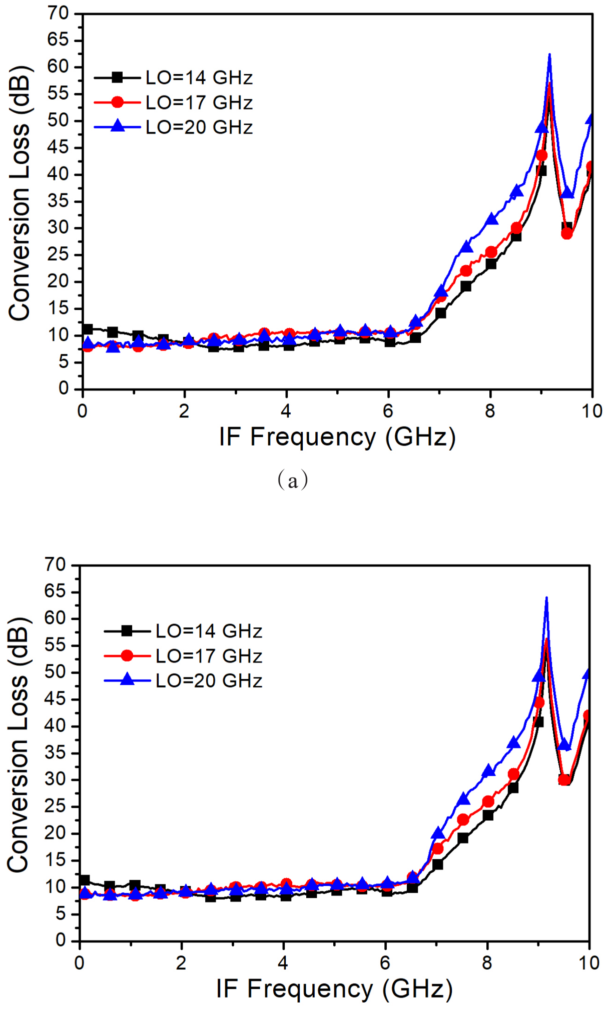


Fig.6 Measured USB conversion loss versus IF frequency at different LO frequencies (a) Down-conversion (b) Up-conversion
图6 不同本振频率下,变频损耗关于中频频率变化的测试曲线 (a) 下变频,(b) 上变频

Comparisons between the proposed sub-harmonic mixer and similar published works[8-9, 12-13] are summarized in Table 1. It shows that the performance of the proposed sub-harmonic mixer is comparable with that of the similar mixers. Moreover, the proposed mixer has a wide IF bandwidth and the microstrip hybrid MIC technology used in this paper has a low cost.

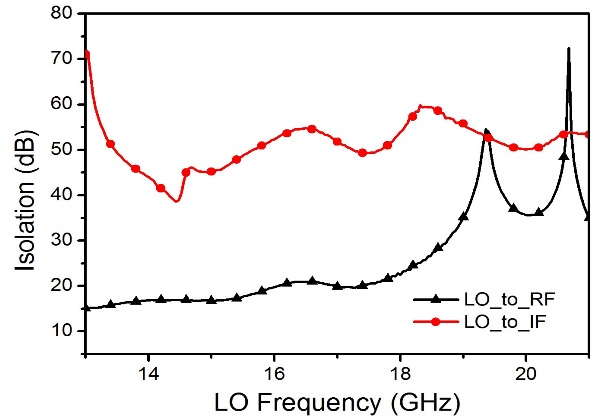


Fig. 7 Measurement results of LO-to-RF and LO-to-IF isolations as a function of LO frequency
图7 本振-射频以及本振-中频的隔离度随本振频率变化的测试结果曲线

Table 1 Comparison of reported similar sub-harmonic mixers
表1 与已报道的类似分谐波混频器性能比较

Reference	RF frequency /GHz	IF frequency /GHz	Conversion gain/dB	Technology
#[8]	35 to 42	DC to 0.5	<-7.2	MMIC
*[9]	28 to 50	DC to 1	-11 to -6.6	MMIC
*[12]	90 to 100	DC to 4	-11 to -8	hybrid MIC
#[13]	24 to 44	1 (fixed)	6 to 10.5	MMIC
#*This work	27 to 48	DC to 6	-11.2 to -7.5	hybrid MIC

Up-conversion mode, *Down-conversion mode

3 Conclusions

A microstrip-based millimeter-wave broadband sub-harmonic mixer employing an open stubs loaded short-circuited wideband BPF and a novel diplexer has been proposed. The measured results reveal a conversion loss of 7.5 to 12.5 dB over a wide RF frequency range of 27 to 48 GHz for both up-conversion and down-conversion. This proposed configuration provides a flexible and low-cost design in sub-harmonic mixers, which are relatively efficient for integration of millimeter-wave systems.

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