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A balanced sub-harmonic mixer for EHF satellite communications

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Abstract: In this letter, a balanced sub-harmonic mixer based on a dual-mode ring coupler is proposed for EHF satellite communications. Theoretical analysis is given to show that the proposed balanced sub-harmonic mixer has the ability to suppress the odd harmonics of LO and its mixed products. It can improve the poor spurious suppression performance commonly encountered with traditional sub-harmonic mixer. A balanced sub-harmonic mixer based on the proposed structure is designed and fabricated. Measurement results show the mixer achieves good performance in terms of conversion loss and spurious suppression.

Keywords: balanced sub-harmonic mixer, spurious suppression, EHF satellite communication

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

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1 Introduction

In recent years, satellite communications play more and more important role in both military and civil fields. With rapidly growing demand for achievable link capacity, the spectrum resources of C (6/4 GHz), Ku (14/12 GHz) and Ka (30/20 GHz) bands currently used for satellite communications are no longer sufficient. This requirement pushes the satellite communication to EHF band (44/20 GHz) [1], which has the benefits of large capacity, small antenna dish size, and strong anti-jamming ability.

Mixer is one of the most important components of the EHF band transmitter. In order to convert IF signal to RF signal, a LO signal of approximately 41 GHz is required. However, it is well known that building a high performance millimetre-wave frequency source is either difficult or expensive. In this case, sub-harmonic mixers (SHMs) are preferred to fundamental mixers because they reduce the LO frequency by half. Many types of SHM have been proposed in the past decades, but the most widely used SHM topology is the anti-parallel diode pair (APDP) proposed in [2]. Theoretical analysis shows that the output current of the APDP only contains frequency components of $mf_{\mathrm{LO}} \pm nf_{\mathrm{IF}}$, where $n = 0$ or 1, $m + n$ is an odd integer, f_{LO} and f_{IF} are frequencies of LO and IF signals. However, due to the asymmetry of the APDP and embedding networks, other spurious signals are generated as well. Unfortunately, some of them fall within the RF band, for example, $3f_{\mathrm{LO}}$ (20.5 GHz) $- 4f_{\mathrm{IF}}$ (4.2 GHz) $=$ 44.7 GHz. Therefore, the spurious suppression performance of the mixer may fail to meet the requirement ($\geqslant$60 dBc) of the EHF satellite communication. To overcome this problem, many balanced SHMs were proposed [3, 4, 5, 6]. Most of them are based on Marchand balun, whose structure is only suitable for MMIC circuit design because some of its dimensions are too small to be implemented by other processes. However, to the authors' knowledge, there is no commercial balanced SHM MMIC so far. Hybrid planar/NRD-guide balanced SHM has been proposed for millimetre-wave application [7], but the 3-D structure prevents a compact design. Balanced SHMs based on uniplanar structure can be fabricated by hybrid MIC process and have achieved a good performance [8, 9]. The downside is that CPW lines are not easily integrated with the most widely used microstrip MMICs.

In this letter, a single balanced SHM based on microstrip structure is presented for EHF satellite communications. Measurement results show that low conversion loss and high spurious suppression performance are achieved in the frequency band of interest.

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2 Circuit analysis and design

The proposed balanced SHM is shown in Fig. 1. It consists of a dual-mode ring coupler [10], two APDPs, and a low-pass filter. In order to reduce the area of the proposed mixer, two ports of the dual-mode ring coupler and the APDPs are located inside of the ring structure. A portion of the low-pass filter is also placed within the ring and the stubs of the low-pass filter are curved to further reduce the size of the mixer. The low-pass filter crosses over the ring coupler through a small bonding wire, as shown in Fig. 1. The RF and LO radial stubs are used to provide grounding for RF and LO signals, respectively. In order to achieve a high performance of the low-pass filter, the capacitance introduced by the radial stubs is absorbed into the low-pass filter.

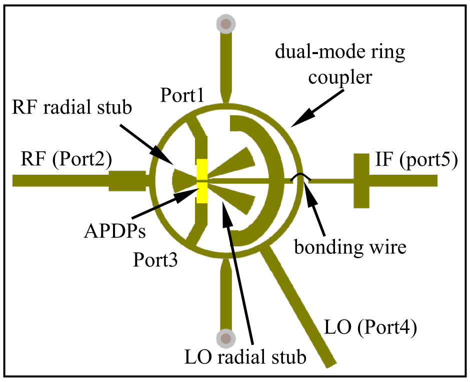

Fig. 1. The layout of the proposed balanced SHM

The LO signal is driven at Port 4 and split into two components of equal amplitude but 180° out-of-phase at Ports 1 and 3. According to the characteristics of a dual-mode ring coupler given in [10], it is known that Ports 2 and 4 are isolated from each other in both LO and RF bands. The IF signal is fed into the APDP through a low-pass filter, which are used to prevent RF and LO signals from leaking to the IF port. The short-circuited stubs of the dual-mode ring coupler provide a return pass for the IF signal and ensure that the IF signal is isolated from the LO and RF ports. The RF signal is extracted from Port 2 of the dual-mode ring coupler.

When both LO and IF signals are applied to the APDPs, the desired RF signal will be generated along with spurious signals. Denote two APDPs as APDP1 and ADPD2, respectively. The current through APDP1 and ADPD2 is

$$i_1 = \sum_{m=0}^{\infty}\sum_{n=0}^{\infty} A_{1mn}\cos[(m\omega_{LO} \pm n\omega_{IF})t + m\theta_{1LO} \pm n\theta_{1IF}] \tag{1}$$

$$i_2 = \sum_{m=0}^{\infty}\sum_{n=0}^{\infty} A_{2mn}\cos[(m\omega_{LO} \pm n\omega_{IF})t + m\theta_{2LO} \pm n\theta_{2IF}] \tag{2}$$

where A_{1mn} and A_{2mn} are the amplitudes of the mixing products generated by APDP1 and APDP2, respectively; ω_{LO} and ω_{IF} are the angular frequency of the LO and IF signals, respectively; θ_{1LO}, θ_{2LO}, θ_{1IF} and θ_{2IF} are the phase of the LO and IF signals arriving at APDP1 and APDP2, respectively.

Based on the analysis given above, it can be conclude that $A_{1mn} = A_{2mn}$, $\theta_{1LO} = \theta_{2LO} + \pi$ and $\theta_{1IF} = \theta_{2IF}$ if the dual-mode ring coupler is an ideal compo-

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nent. In this case, $i_1 = -i_2$ when m is an odd integer. Therefore, these spurious signals cannot be produced from the RF port. In other words, the proposed balanced SHM exhibits an ability to suppress odd harmonics of LO and their mixing products.

In order to validate the concept, a balanced SHM based on the proposed structure has been designed for EHF satellite communications. The circuit substrate used here is Rogers 5-mil-thick RT/duroid 5880 ($\varepsilon r = 2.2$). The APDP adopted for the circuit design is DMK-2308 from Skyworks Inc. The low-pass filter and dual-mode coupler are simulated by ANSYS HFSS. Then, the simulated S-parameters are imported to Agilent ADS, and the harmonic balance (HB) method is used to simulate and optimise the balanced SHM.

3 Experimental results

The designed mixer is fabricated by common PCB process and measured as an up-converter. The photograph of the balanced SHM module is shown in Fig. 2. In our application, the IF is in the frequency range of 3 to 5 GHz, and a LO of 20.5 GHz is used to pump the IF signal up to the RF band corresponding a frequency range of 44 to 46 GHz.

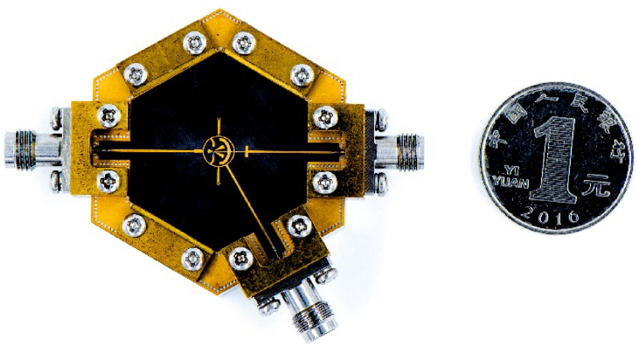

Fig. 2. Photograph of the EHF balanced SHM module.

Fig. 3(a) demonstrates the measured conversion loss against IF frequency with LO power of 12 dBm and fixed LO frequency of 20.5 GHz. The loss introduced by the microstrip line and coaxial connectors is removed by calibration. As shown in Fig. 3(a), the conversion loss is 9.5–11.5 dB over the IF frequency range of 0.1 to 5 GHz. Fig. 3(b) shows the curve of the output RF power versus the input IF power with LO power of 12 dBm and IF frequency of 4 GHz. It can be seen that the input P_{1dB} is about 8 dBm. In order to investigate how the LO power will affect the performance of the balanced SHM, curves with different LO power levels are also displayed in Fig. 3. It can be seen that the conversion loss increases as the LO drive power increases. Therefore, if only the conversion loss performance is of concern, the LO power should be as low as possible. However, a lower LO power will result in a lower input P_{1dB} of the mixer, as shown in Fig. 3(b). Consequently, the trade-off between conversion loss and P_{1dB} is necessary to achieve optimal system performance by varying the LO power.

As the spurious rejection is one of the important specifications of the mixer for satellite communication applications, the spurious outputs of the designed mixer

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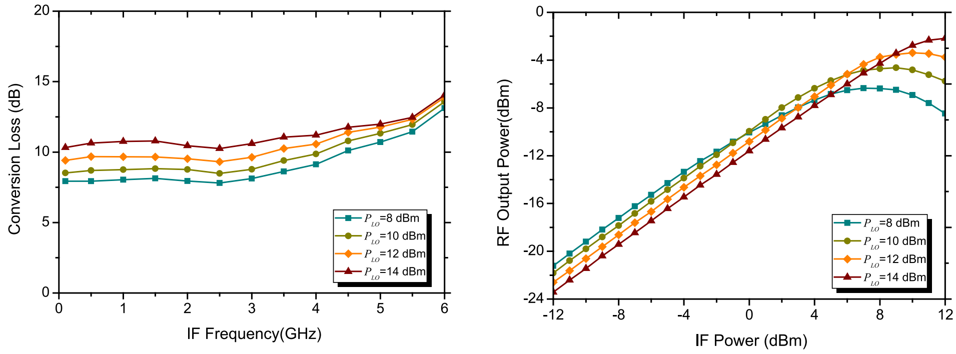

(a) (b)

Fig. 3. (a) Measured conversion loss against IF frequency and (b) measured output RF power versus the input IF power with IF frequency of 4 GHz

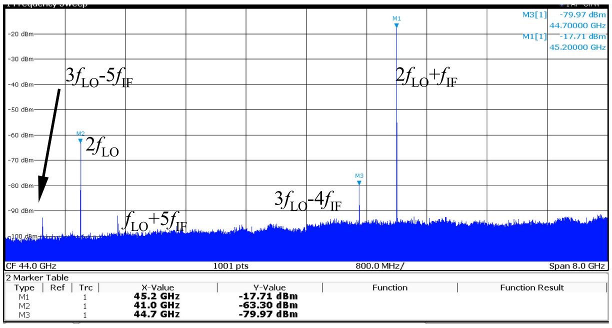

Fig. 4. Output spectrum of the balanced SHM (LO power: 12 dBm, LO frequency: 20.5 GHz; IF frequency: 4.2 GHz; IF power: 3 dBm)

are carefully measured with the LO power frequency of 12 dBm and frequency of 20.5 GHz. The spurious generated by the mixing of $3f_{LO}$-$4f_{IF}$ is observed in the RF band and its rejection is greater than 62 dBc when the input power of the IF signal is less than 3 dBm. Fig. 4 depicts the output spectrum of the balanced SHM with IF frequency of 4.2 GHz and power of 3 dBm. It can be seen that the spurious of $3f_{LO}$-$4f_{IF}$ is about 62 dB lower than the RF signal, and the rejection of $2f_{LO}$ is about 45 dBc. Although the rejection of $2f_{LO}$ is not larger enough for most satellite communication applications, it can easily be improved by an additional filter. Other spurious signals can also be observed. However, their power levels are small and have little effect on the system performance.

4 Conclusion

A single balanced SHM based on microstrip structure has been proposed. A prototype of the balanced SHM for EHF satellite communications has been fabricated and measured as an up-converter. Measurements have shown that the conversion loss is 9.5–11.5 dB over the IF frequency range of 0.1 to 5 GHz. In-band spurious has been observed, and its rejection is over 62 dBc when the input power of the IF signal is less than 3 dBm. Furthermore, the fabricated balanced SHM features a simple structure, low cost, and compact layout.

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