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# A compact broadband MMIC sub-harmonic mixer using quasi-lumped transmission lines

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ABSTRACT

A compact broadband monolithic microwave integrated circuit (MMIC) sub-harmonic mixer using an OMMIC 70 nm GaAs mHEMT technology is demonstrated for 60 GHz down-converter applications. The present mixer employs an anti-parallel diode pair (APDP) to fulfill a sub-harmonic mixing mechanism. Quasi-lumped components are employed to broaden the operational bandwidth and minimize the chip size to $1.5\times0.77\ \text{mm}^2$. The conversion gain is optimized by a quasi-lumped 90° phase shift stub. Experimental results show that from 50 GHz to 70 GHz, the conversion gain varies between −12.1 dB and −15.2 dB with a LO power level of 10 dBm and 1 GHz IF. The LO-to-RF, LO-to-IF and RF-to-IF isolations are found to be greater than 19.5 dB, 21.3 dB and 25.8 dB, respectively. The second harmonic component of the LO signal is suppressed. The proposed mixer has an input 1 dB compression point of -2 dBm and exhibits outstanding figure-of-merits.



## 1. Introduction

In recent years, the V-band has gained an increasing academic and commercial interest for the wide unlicensed bandwidth. The representative application for 60 GHz is the high speed short-range point-to-point communication. The data link rates of the 60 GHz can reach multi-gigabit/s between different wireless personal area network (WPAN) and wireless local area network (WLAN) devices. One application is the full uncompressed High Definition (HD) video streaming between mobile electronics and HD-TVs or HD-projectors and high speed wireless links from terminals to wireless access point (AP) etc [1–3].

A high performance millimeter-wave local oscillator (LO) source is a major challenge for radio frequency (RF) circuit designers [4]. For many years, various sub-harmonic pumped (SHP) mixers have already been reported [5–13]. Previous studies have shown that the SHP mixer engaging a halved LO frequency is an attractive solution. Especially, the mixer based on anti-parallel diode pair (APDP) is most widely studied for no DC power consumption, superior LO-to-RF isolation and noise suppression [4,5]. A conventional configuration of the APDP-based SHP mixer is shown in Fig. 1 [6]. The mixers published in reference [7–9] with the quarter-wavelength stubs and other topologies occupy much chip area. Reference [7] manufactured a high performance V-band sub-harmonic mixer. It develops three pre-amplifiers for the LO, RF and IF ports respectively to reduce the requirement of LO power and enhance the conversion gain. It also adopts several quarter-wavelength stubs to improve port-to-port isolations. However, the amplifiers result in an extra DC power consumption and the stubs enlarge the chip area to $4.94\ \text{mm}^2$. And its 3 dB bandwidth is only 3 GHz. Reference [8] developed a V-band high isolation sub-harmonic mixer with a hairpin diplexer. Although the structure enhances the input 1 dB compression point to 8 dBm and blocks the LO signal to the RF port, the maximum conversion gain is only −15.2 dB and the minimum LO-to-IF isolation is 16.5 dB with the area of $1.5\ \text{mm}^2$. Reference [9] demonstrated a broadband sub-harmonic mixer with a compact band pass filter. The filter is applied to reduce line length and enlarge the bandwidth. The mixer also has an IF common-source amplifier to enhance the conversion gain and LO/RF-to-IF isolation. However, the amplifier leads to a DC power requirement of 146.44 mW and the worst LO-to-RF isolation is 11 dB. The area is $1.4\ \text{mm}^2$.

To solve the aforesaid problems, several approaches have been proposed in reference [10–13]. Reference [10] utilized a directional coupler to minimize the chip area. But, the sub-harmonic mixer needs an extra quarter-wavelength short-circuited stub to provide DC ground paths and the best LO-to-IF isolation is only 17 dB. Reference [11] employed a three-conductor coupler to trim down the fabrication cost and extend the bandwidth. Nevertheless, the applied optimal power level of the LO signal is around 15 dBm. Reference [12,13] used the quasi-lumped stubs to shorten the line

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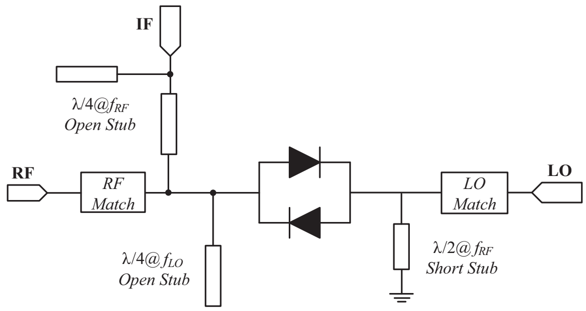


**Fig. 1.** Conventional configuration of the APDP-based SHP mixer.

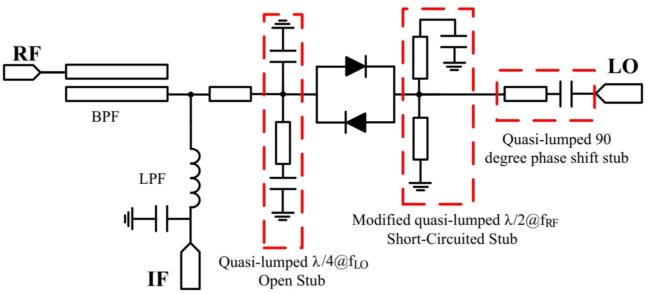


**Fig. 2.** Schematic of the SHP mixer.

length. The two aforementioned circuits are designed for Ka band applications and the 3 dB bandwidth is less than 10 GHz.

The motivation of the research is to demonstrate an available approach to cut down the area cost and widen the operational bandwidth for 60 GHz down-converter applications. Based on the typical mixers, we herein have designed a compact broadband monolithic microwave integrated circuit (MMIC) SHP mixer on an OMMIC 70 nm GaAs mHEMT process. A modified quasi-lumped short-circuited component and a 90° phase shift stub are developed to satisfy the target. The compact area is $1.5 \times 0.77$ mm$^2$. The measured results exhibit that the present mixer can operate with a good conversion gain and isolation characteristics in the RF frequency range from 50 GHz to 70 GHz.

## 2. Circuit design

### 2.1. The principles of the SHP mixer

The schematic of the designed APDP-based SHP mixer circuit is shown in Fig. 2. The mixer is composed of two quasi-lumped stubs, a quasi-lumped 90 degree phase shift stub, a coupler band-pass filter (BPF) and a low-pass filter (LPF). It adopts an anti-parallel diode pair (APDP) to fulfill the sub-harmonic mixing mechanism. Owing to its anti-symmetric current–voltage characteristics, the APDP configuration has extremely low even-order spurious components, such as $nf_{LO} \pm mf_{RF}$ ($n+m$=even, $m$ and $n$ are integers), where $f_{LO}$ and $f_{RF}$ are LO and RF frequency, respectively. Moreover, the odd-order components, such as $nf_{LO} \pm mf_{RF}$ ($n+m$=odd), are obtained at the output port. The second harmonic component of the LO signal is applied to mixing. Therefore, the IF frequency is described by Eq. (1):

$$f_{IF} = f_{RF} - 2f_{LO} \tag{1}$$

The BPF of parallel coupled line blocks the LO and IF signals to the RF port. The IF signal covering from DC to 5 GHz is extracted with the LPF which also rejects the LO, RF signal and all mixed frequencies to the IF port. In addition to mutually decoupling the LO and RF port, the quasi-lumped components have a function of impedance matching. Furthermore, the short-circuited stub provides DC grounding and is combined with the quasi-lumped phase shift stub to cause a phase inverter of the RF and IF signal and optimize the conversion gain.

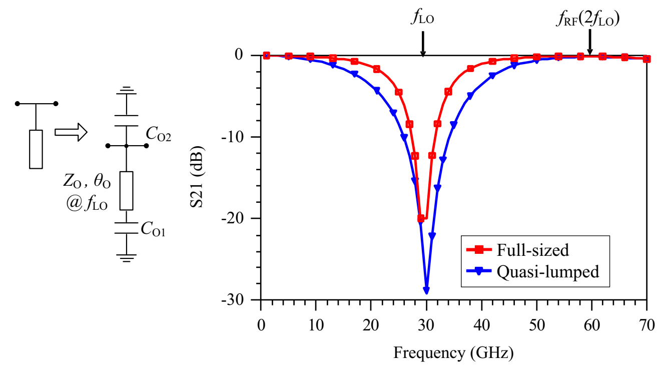


**Fig. 3.** Quasi-lumped LO quarter-wavelength open stub.

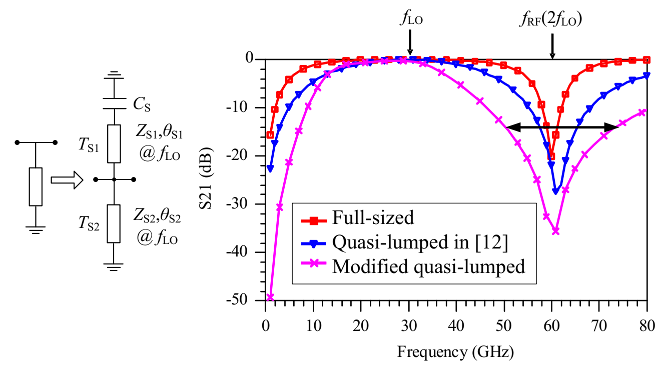


**Fig. 4.** Modified quasi-lumped RF half-wavelength short-circuited stub.

### 2.2. The quasi-lumped topology

Referring to Figs. 3 and 4, the quasi-lumped topology shortens stubs with shunt capacitors, making the circuit more compact and flexible. The employment of the quasi-lumped LO quarter-wavelength open stub is to suppress the LO signal with low insertion-loss at RF frequencies. The asymmetric shunt capacitors ($C_{O1}$ and $C_{O2}$) reduce the stub length. The capacitance $C_{O1}$, $C_{O2}$ and the electrical length $\theta_O$ are determined by Eq. (2) [12]:

$$C_{O1} = 1/(2\pi f_{LO} Z_O \tan \theta_O)$$
$$C_{O2} = C_{O1}/(3 + \tan^2 \theta_O), \tag{2}$$

where $Z_O$ represents the transmission line characteristic impedance and $\theta_O$ is the electrical length of the stub at LO frequency. The range of $\theta_O$ is $0 < \theta_O < \pi/2$. The simulated frequency response is shown in Fig. 3. The central frequency is 29 GHz.

The short-circuited stub suppresses the RF leakage and performs high impedance at LO frequencies. To achieve a broad operational bandwidth, a modified quasi-lumped RF half-wavelength short-circuited stub is proposed. As shown in Fig. 4, the stub consists of two asymmetric shunt short-circuited transmission lines ($T_{S1}$, $T_{S2}$) and $T_{S1}$ is in series with a capacitor ($C_S$). The function of suppressing the RF signal is realized by the resonance of $C_S$ and $T_{S1}$. The transmission line $T_{S2}$ is to minimize the insertion loss at LO frequencies and ground the IF signal. Since the RF frequency is double the LO frequency, the RF half-wavelength stub can be expressed as the LO quarter-wavelength stub and vice versa. For the short-circuited stub, the capacitance $C_S$, and the