Compact 28-GHz Subharmonically Pumped Resistive Mixer MMIC Using a Lumped-Element High-Pass/Band-Pass Balun

Ping-Chun Yeh, Wei-Cheng Liu, and Hwann-Kaeo Chiou

***Abstract*—This work reports a novel lump-element balun for use in a miniature monolithic subharmonically pumped resistive mixer (SPRM) microwave monolithic integrated circuit. The proposed balun is simply analogous to the traditional Marchand balun. The coupled transmission lines are replaced by lump elements, significantly reducing the size of the balun. This balun requires no complicated three-dimensional electromagnetic simulations, multilayers or suspended substrate techniques; therefore, the design parameters are easily calculated. A 2.4-GHz balun is demonstrated using printed circuit board technology. The measurements show that the outputs of balun with high-pass and band-pass responses, a 1-dB gain balance, and a 5° phase balance from 1.7 to 2.45 GHz. The balun was then applied in the design of a 28-GHz monolithic SPRM. The measured conversion loss of the mixer was less than 11 dB at a radio frequency (RF) bandwidth of 27.5–28.5 GHz at a fixed 1 GHz IF, a local oscillator (LO)–RF isolation of over 35 dB, and a 1-dB compression point higher than 9 dBm. The chip area of the mixer is less than 2.0 mm^2.**

***Index Terms*—Baluns, microwave monolithic integrated circuit (MMIC) mixers, pHEMT, subharmonically pumped resistive mixer (SPRM).**

I. Introduction

LOCAL oscillator (LO) power is hard to achieve and expensive in the millimeter wave range, so a subharmonically pumped mixer (SPM) is commonly used [1]. This type of mixer requires only half of the normal LO-frequency. It also takes advantage of inherent LO rejection at the output since the LO-signals are cancelled at the drain. The antiparallel diode mixer and the resistive field effect transistor (FET)-mixer are the most used in SPM designs. The resistive mixer [2], [3] has been demonstrated to exhibit high linearity and favorable intermodulation characteristics, low dc power consumption, and a natural separation between LO and radio frequency/intermediate frequency (RF/IF) ports. The channel resistance of the FET acts as the mixing element. Therefore, resistive mixers have excellent intermodulation characteristics because their channel resistance is more linear than the nonlinear barrier resistance of a diode [4].

The SPRM circuit consists of two-pHEMT mixers in parallel which are pumped in antiphase at half of the LO-frequency without drain bias. The operation of the harmonic mixer depends on the generation of accurately antiphase LO signals. The microwave baluns are realized in either distributed or lump circuits. The capability of the former has been shown in many hybrid circuit designs. However, they are bulky and have a nonplanar structure, and so, a few have been used in monolithic microwave integrated circuit (MMIC) designs. In contrast, the lump circuit balun is compact and plays the important role in MMIC design [5]. Table I compares recently reported data concerning subharmonically pumped resistive mixer (SPRM) designs [6]–[9].

TABLE I
SPRM and SPM Comparison

Paper	Conversion loss	Size	Mixer Type
[6]	14 dB	6.09 mm^2	SPRM
[7]	12 dB	2.31 mm^2	SPRM
[8]	14.5 dB	3.48 mm^2	SPM
[9]	12.5 dB	5.47 mm^2	SPM
This Work	**11dB**	**2.0 mm^2**	**SPRM**

II. Balun Design

Fig. 1(a) is the schematic diagram of a Marchand balun. The Marchand balun [10] consists of two coupled-line sections, which is realized using coaxial lines, a microstrip couple-line, Lange couplers, multilayer coupled structures or a spiral coil. Fig. 1(b) is the schematic diagram of the proposed balun. The couple-line is modeled by the lump inductor L, and the capacitor C modeled the coupling capacitor effect which is produced from the couple-line. The unbalance LO port is port P_1, and the balance ports LO^+ and LO^- are P_2 and P_3, respectively. Unlike the coupled-line baluns, the balance ports are coupling ports instead of isolation ports. From the network point of view, this lump-element balun is taken as an out-of-phase power splitter which includes one high-pass filter and one band-pass filter connected in parallel. The signals through the output ports of the ideal balun have equal power but are 180° out of phase; all ports have an input impedance of 50 Ω. Additionally, the balun also acts like an impedance transformer. The relationships between L, C, and ω are described in

$$\omega \mathrm{L} = \frac{1}{\omega C}, \quad \omega L = 70.7\,\Omega. \tag{1}$$

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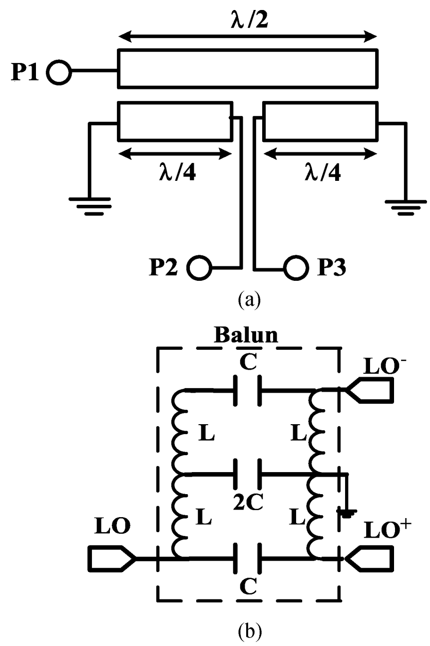


Fig. 1. (a) Marchand balun structure and (b) the lump-element balun equivalent circuit. L and C are lump elements. LO is input port and LO^+ and LO^- are output antiphase ports.

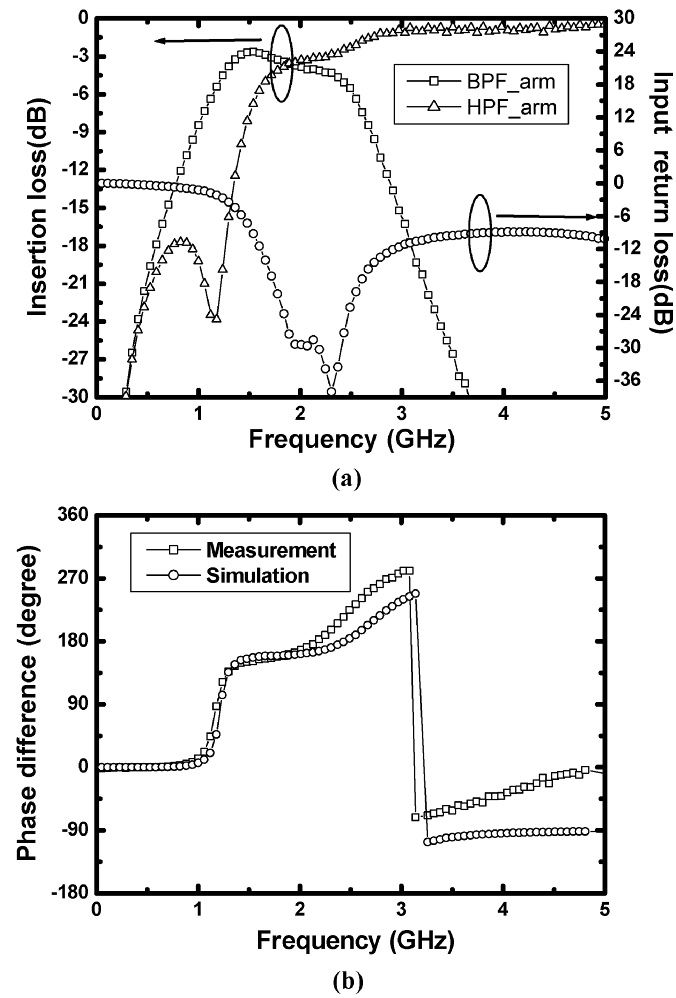


Fig. 2. Measurement and simulation of high-pass/band-pass balun. (a) Measured amplitude balance. (b) Measured and simulated phase balance.

Then, we can solve the results in

$$\frac{V_{LO+}}{V_{LO}} = \frac{1}{\sqrt{2}}\angle 90^\circ, \quad \frac{V_{LO-}}{V_{LO}} = \frac{1}{\sqrt{2}}\angle -90^\circ \tag{2}$$

where ω is the central frequency of the balun.

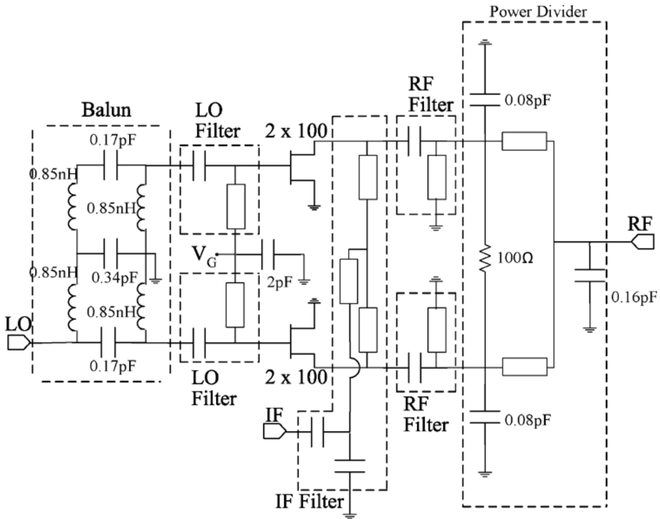
The balun outputs have exactly equal power with antiphase at the central frequency.

III. Experiment and Results

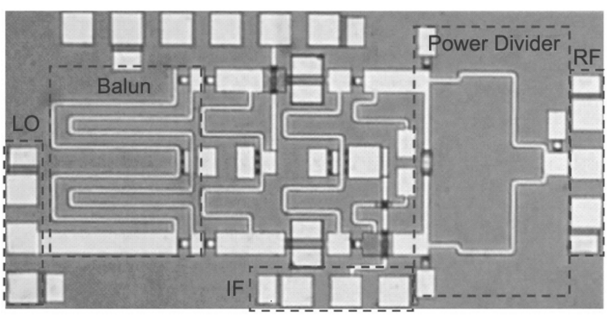
A high/band-pass balun is fabricated in a printed circuit board (PCB) circuit to demonstrate the design concept. The values of capacitors and inductors of the filters are obtained in (1) and (2). The balun is centered at 2.4 GHz. One high-pass filter has a 4.7-nH inductor and one 0.9-pF capacitor; the band-pass filter has inductors with an inductance of 4.7 nH and two capacitors with capacitances of 0.9 pF and 1.8 pF. Each filter has a characteristic impedance of 70.7 Ω, which transforms a 50-Ω unbalance impedance into a 100 Ω balance impedance. Since the parasitic effects of the multilayer chip inductors (MLCIs) are not exactly estimated, the performance of the balun is slightly degraded. However, the balun still retains good amplitude and phase-balanced responses. Fig. 2(a) shows the amplitude responses of the balun. The insertion loss of the HPF and the BPF arms is $-3.5 + / - 1$ dB from 1.7 to 2.45 GHz. The input return loss is better than -20 dB. Fig. 2(b) shows the out-of-phase property and the measurements well agree with the simulated results.

IV. MMIC SPRM Design

The schematic diagram and photograph of the SPRM are shown in Fig. 3(a) and (b). The SPRM includes two InGaAs pHEMTs with gates of length 0.15 μm, two fingers with width of 100 μm in a common-source configuration, a single balance balun for LO input, a Wilkinson power divider for RF input, and an RF/IF diplexing circuit. The LO-frequency is applied to the gates of the two devices through the balun and matching network, with an 180° phase shift. The RF is applied in phase at the drains through a Wilkinson power divider and an RF high-pass filter to prevent IF leakage into the RF port. Time-variable channel resistance causes frequency mixing and the resistance waveform has only the even harmonic LO frequency. The IF signal is extracted from the drain through the IF low pass filter to provide RF filtering. The LO leakage through the gate-drain feedback capacitance is drastically reduced due to their antiphase LO relationship. In Fig. 4, the conversion loss is measured at a fixed 1-GHz IF frequency under a 13-dBm LO drives. The obtained conversion loss is less than 11 dB within an RF bandwidth from 27.5 to 28.5 GHz. Fig. 5 depicts the measured LO-to-RF and LO-to-IF isolations. The LO/RF and LO/IF isolations exceed 30 dB as the LO frequency varies from 12.5–14 GHz. The observed 1-dB compression point is as high as 9 dBm under the 13-dBm LO drive. Table II presents a summary of the mixer characteristics.



(a)



(b)

Fig. 3. (a) Circuit schematic diagram and (b) photograph of the SPRM MMIC.

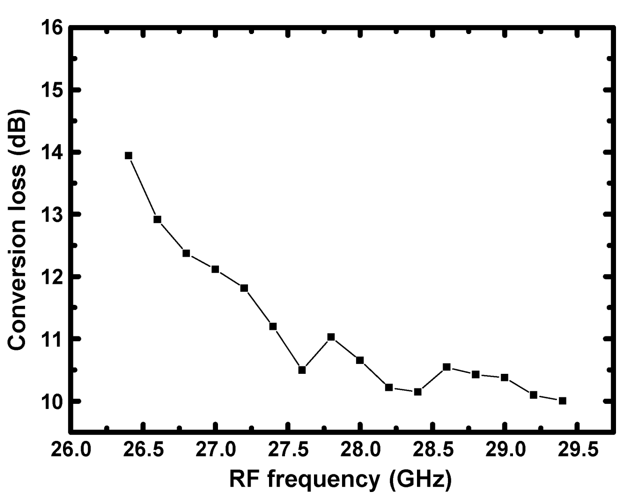


Fig. 4. Conversion loss of the SPRM with a fixed IF frequency of a 1 GHz.

V. Conclusion

This work presents a miniature monolithic SPRM that incorporates a simple single-balance balun. The measured conversion loss of the mixer is below 11 dB; its LO–RF isolation higher exceeds 35 dB, and its 1-dB compression point exceeds 9 dBm.

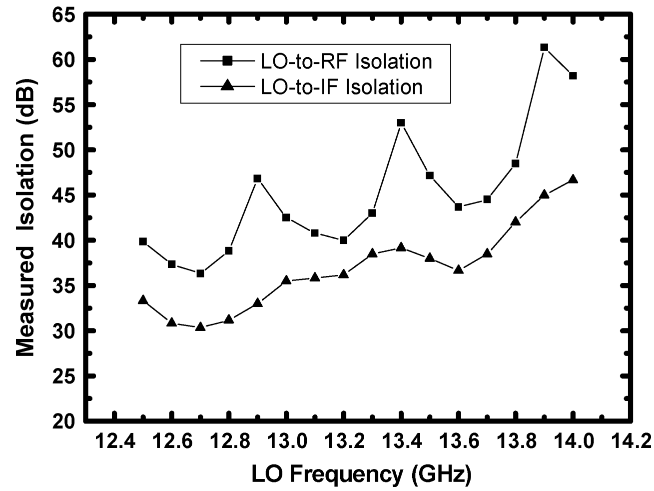


Fig. 5. Measured LO-to-RF and LO-to-IF isolations.

TABLE II
MMIC Performance Summary

Parameter	Range
Conversion Loss	11 dB
LO to RF Isolation	35 dB
LO to IF Isolation	30 dB
2LO to RF Isolation	25 dB
2LO to IF Isolation	35 dB
RF to IF Isolation	23 dB
RF 1-dB compression point	9 dBm

The single-balance balun is suitable for MMIC, PCB, and LTCC designs. The chip area of the mixer is under 1.0×2.0 mm^2.

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