Novel Sub-Harmonically Pumped Mixers Incorporating Dual-Band Quarter-Wave and In-Line Stub

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Abstract — **Sub-harmonically pumped (SHP) mixers with very low conversion loss are developed. These mixers entail the use of novel dual-band quarter-wave stubs and in-line stub simultaneously providing return paths for the IF, LO and RF frequencies and terminating unwanted frequency mixing products. These stubs are realized in the form of compact microstrip resonant cells with spiral patterns. The measured 4.1dB conversion loss at 11.8GHz RF signal of our new 2nd SHP mixer outperforms typical designs of 8-10dB. The 8th SHP mixer designed at 44GHz RF signal achieves a simulated minimum conversion loss of 9.5dB. These novel designs provide viable solutions to low-cost high-performance wireless communications subsystems.**

I. Introduction

Sub-harmonically pumped (SHP) mixers using anti-parallel Schottky diode pair pumped by 2, 4 or more even multiple of the lower frequency local oscillators (LO) are very attractive for low-cost microwave and millimeter-wave systems. However, the conversion loss of SHP mixers is usually much higher than that of the fundamental pumped ones and many papers have been devoted to their performance improvement, e.g., [1]-[5] to name a few. The basic principles of SHP mixer were presented in an excellent paper by Madjar [5] in which suitable terminations for different signals and their mixing products were emphasized. However, it is very difficult to satisfy these conditions with conventional circuit implementation. Therefore, only an 8.5dB conversion loss was obtained for a 2nd sub-harmonic mixer [5]. Design of harmonic mixers with low conversion loss thus remains a great challenge.

Recently, we have proposed a new approach for terminating the mixing products in the 4th SHP mixer based on our novel compact microstrip resonant cell (CMRC) structures [6]-[7], yielding a conversion loss of 6.1dB at 35GHz [8]. Quarter-wave stubs provided return paths for the signals. The CMRC's acted as a band-stop filter to eliminate unwanted frequencies. Reactive terminations were achieved by placing the CMRC's in proper locations. In this paper, CMRC's with spiral patterns are proposed leading to more compact CMRC's. These CRMC's are employed in the construction of dual-frequency quarter-wave stubs. Incorporating these dual-frequency quarter-wave stubs and improved in-line stub, we can provide proper terminations for the IF, LO, RF and unwanted frequency mixing products in additional to those eliminated in [8], leading to very low conversion loss SHP mixer designs.

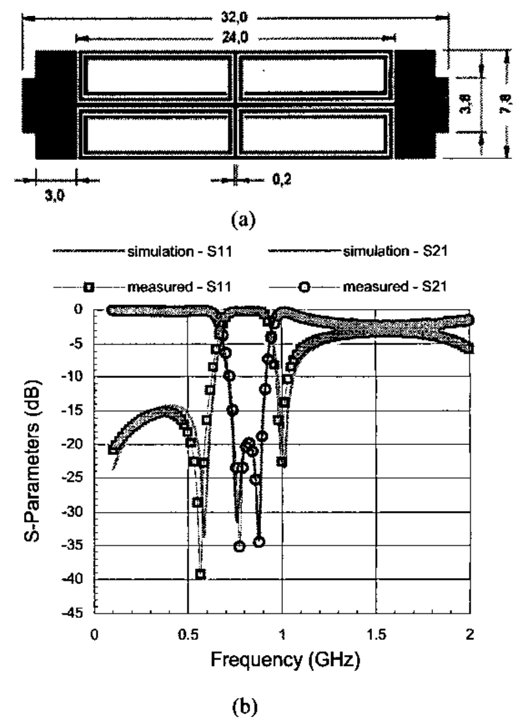

Fig. 1. (a) The spiral CMRC structure. (b) Simulated and measured S-parameters.

II. Spiral CMRC and Dual-Band Stub

The compact microstrip resonant cell (CMRC) is a section of microstrip line with some suitable pattern etched on the conducting trace. It exhibits slow-wave and band-stop characteristics [6]. Fig. 1 shows the new CMRC structure with a spiral pattern and its frequency response. The substrate is Duroid 5870 with ε_r = 2.94 and a

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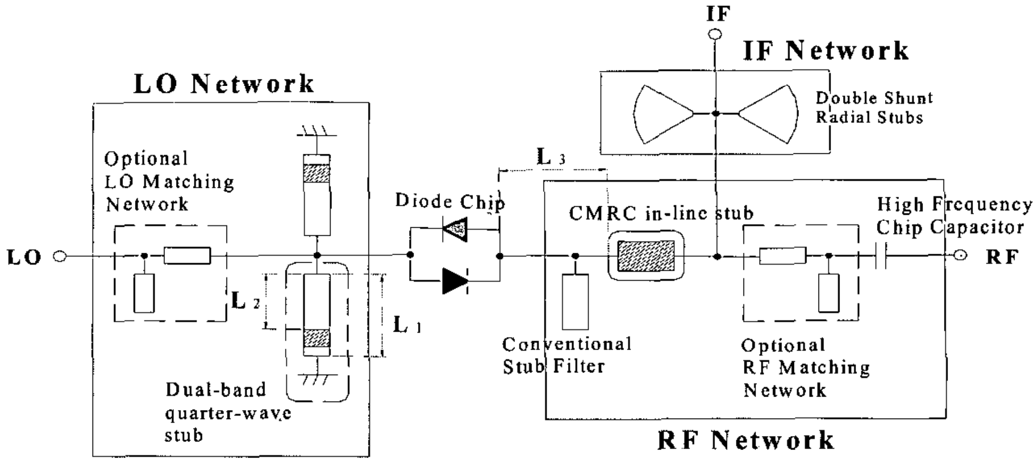


Fig. 2. The 2nd SHP mixer schematic

thickness of 1.524mm. Results show that a distinctive stop band of the spiral CMRC is centered at 0.8GHz and have about 35% -10dB bandwidth. The response in the low-pass region has an insertion loss of 0.2dB and a return loss lower than -15dB. The return loss in the stop-band region is close to 0dB, indicating an excellent band-stop filter. For the same cell length, the center frequency of stop-band using the pattern in [6] is 3GHz implying that the spiral pattern is more compact and flexible in circuitry application. This spiral pattern CMRC is then attached to a section of microstrip line to form a dual-band quarter-wave stub. The regular microstrip line is a quarter wavelength long at the higher-frequency band. Due to the band-stop characteristic of the CMRC, this microstrip line is practically terminated by an open circuit at the higher frequency. In contrast, at the lower-frequency band, the CMRC acts as a regular transmission line. Another piece of microstrip line can then be added to the opposite end of the CMRC so that the total length is also a quarter-wave stub at the lower frequency. Due to the slow-wave effect of the CMRC, the total length of the dual-band stub is only half that of the regular quarter-wave stub at the lower frequency. By altering the length of the two different microstrip sections, we can achieve different open/short circuit combinations for the two frequencies.

III. Mixer Design

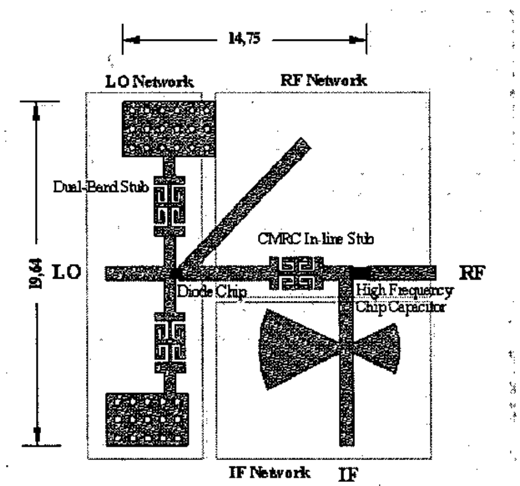
Fig. 2 shows our 2nd SHP mixer schematic. It consists of four parts: the anti-parallel diode pair, and the three networks for the LO, RF and IF ports. The LO network provides the return paths for the RF (11.2GHz) and IF (0.2GHz) signals by CMRC structures and the RF network provides the return path for the LO (5.5GHz) signal. In addition, both the RF and LO networks terminate the idlers (**For down conversion,** $2f_{LO}+f_{RF}$ = 22.2GHz, $4f_{LO}+f_{RF}$ = 33.2GHz, $6f_{LO}-f_{RF}$ = 21.8GHz and $8f_{LO}-f_{RF}$ = 32.8GHz. **For up conversion,** $4f_{LO}\pm f_{IF}$ = 21.8/22.2GHz and $6f_{LO}\pm f_{IF}$ = 32.8/33.2GHz) reactively so as to suppress them and dramatically improve the conversion loss. Finally, the IF network gives path to the IF signal and rejects the RF (11.2GHz) and the LO (5.5GHz) frequency.

LO Network: In the LO network, the spiral CMRC is added into a short-shunt stub such that it can serve as a novel tunable dual-frequency termination network. The whole stub, L_1, is electrically tuned as half wavelength long here to ground the RF frequency (11.2GHz). On the other hand, due to the stop-band of the CMRC at one of the idler signal (21.8/22.2GHz), the upper section, L_2, serves like an open-circuited quarter-wave shunt stub to terminate this idler reactively. Moreover, at the IF frequency (0.2GHz), the length of the stub is negligibly short that the DC/IF signal is grounded directly. To enhance the operating bandwidth, two of this dual-band stub are used in this LO network.

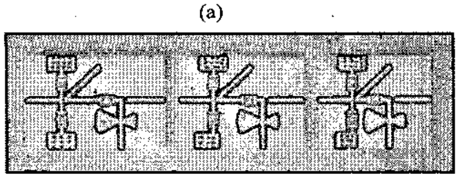
RF Network: In the RF network, a conventional open-circuit quarter-wave stub presents a short termination and a return path for the LO frequency (5.5GHz). On the other hand, the in-line CMRC is a wide band-stop (80% bandgap) structure with a tunable reflection phases. The stop-band covers the image and idler frequencies (**For down conversion**, the image: $2f_{LO}+f_{RF}$ = 22.2GHz, the idle frequencies: $4f_{LO}+f_{RF}$ = 33.2GHz, $6f_{LO}-f_{RF}$ = 21.8GHz and $8f_{LO}-f_{RF}$ = 32.8GHz; and **for up conversion,** the idle frequencies: $4f_{LO}\pm f_{IF}$ = 21.8/22.2GHz and $6f_{LO}\pm f_{IF}$ =

32.8/33.2GHz). By tuning the length L_3, the CMRC then presents different reflection phases on the right terminal of the diode pair. As such, the RF network with the in-line CMRC provides an optimal reactive termination for the major idlers and image, and suppresses them. In addition, it provides an open path for the IF and RF signal to pass through and gives a return path for the LO signal.

IF Network: In the IF network, two open radial stubs (a $\lambda_{RF}/4$ and a $\lambda_{LO}/4$ radial stub) reflect short terminations for the RF and LO frequency, respectively. The radial stub is chosen because wideband rejection of RF and LO signals can be obtained in this network.



(a)



(b)

Fig. 3. (a) Structure of the CMRC SHP mixer. (b) Three microstrip layouts with different reflection phases (135°, 90° and 45°) at the right terminal of the diode.

IV. Experimental Results

The SHP mixer was built on Duroid 5880 with $\varepsilon_r = 2.2$, h = 0.254mm according to the design mentioned above. In this paper, *Microwave Office 2000* [9] was used to calculate and optimize the mixer performance through a harmonic balance analysis routine (HBA). A commercial GaAs flip chip Schottky diode pair (Alpha DMK2308) was used and bonded to the circuit using silver epoxy. Three circuits with different phases (45°, 90° and 135°) at the right terminal of the diode pair for terminations of the idlers were then fabricated. Fig. 3 shows the microstrip

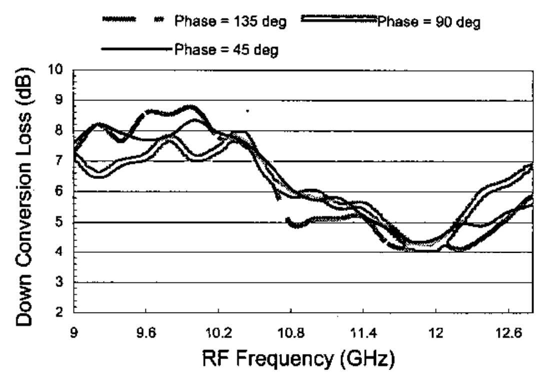


Fig. 4. The measured SSB down conversion loss versus RF frequency at LO power corresponding to the minimum conversion loss.

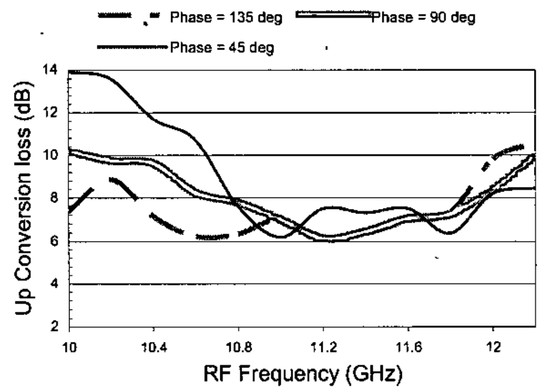


Fig. 5. The measured SSB up conversion loss versus RF frequency at LO power corresponding to the minimum conversion loss.

implementation of the CMRC 2^{nd} SHP mixer. Fig. 4 shows the measured SSB down-conversion loss versus RF frequency at the LO power corresponding to the minimum down-conversion loss. The results are obtained with the IF frequency fixed at 0.2GHz. At an RF of 12GHz and with a LO power of 6.5dBm, the measured minimum SSB conversion loss is 4.1dB. To the authors' knowledge, this is the best result of a 2^{nd} SHP mixer with state-of-the-art performance in X-band. Furthermore, it can be seen that when $\theta = 135^{\circ}$, the mixer is tuned to have a better bandwidth with the SSB conversion loss of 4.5-5.5dB from 10.6-12.6GHz and less than 8.8dB for the whole measurement range.

The mixer circuit was also measured as an up-converter. With the IF signal fixed at 0.2GHz, the measured SSB up-conversion loss for the USB ($f_{RF} = 2f_{LO} + f_{IF}$) versus RF frequency at the LO power (7dBm) corresponding to the minimum up-conversion loss is shown in Fig. 5. The minimum up-conversion loss is 6dB at 11.2GHz, and remains below 8.8dB from 10.3-11.8GHz. Both the minimum conversion loss and a better bandwidth can be optimized by setting $\theta = 135^{\circ}$. Fig. 6 shows the measured port-to-port (LO-RF, 2LO-RF, LO-IF and IF-RF) isolations for $\theta = 135^{\circ}$. It is found that the isolations between port-to-port do not vary too much with the reflection phase angle.

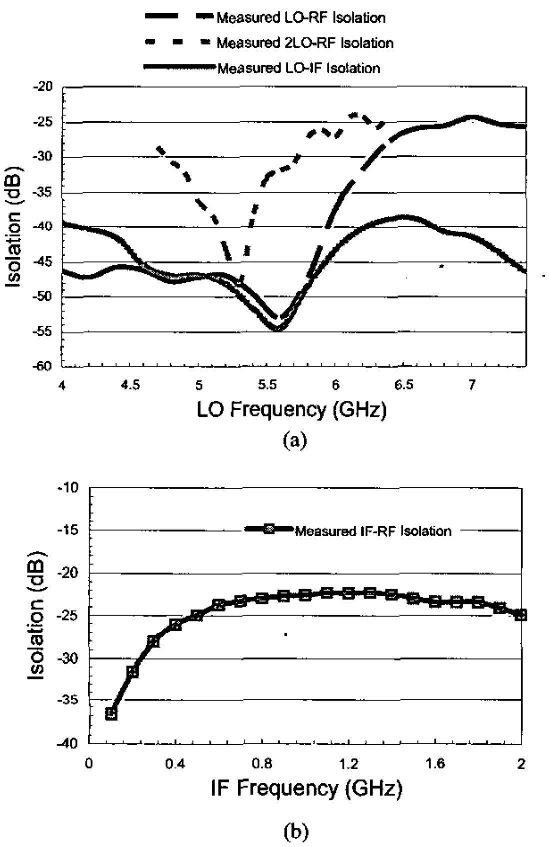


Fig. 6. Measured port-to-port isolation at optimum LO drives level (6.5dBm) (a) LO-RF, 2LO-RF, LO-IF. (b) IF-RF.

IV. Conclusion And Future Work

A low-cost high-performance X-band SHP mixer has been realized in planar microstrip structure utilizing our novel CMRC structures. The total circuit size excluding the SMA connectors is less than 19.65mm x 14.75mm. The measured minimum SSB conversion loss of 4.1dB at an RF of 11.8GHz and an IF of 0.2GHz represents the state-of-the-art performance for a planar X-band SHP mixer. The mixer is broadband with a SSB conversion loss of less than 8dB over 9-12.8GHz measurement ranges. The measured LO-RF isolation is better than -50dB for the LO frequency at 5.8GHz and is under -30dB over the LO frequencies range of 4-6.2GHz, which is extremely important in receiver applications to minimize the leakage of LO power from the RF network.

To exemplify the efficacy of our new CMRC for designing higher order SHP mixers, an 8th SHP up-converter which is designed at 44GHz (Q-band) RF frequency with 0.5GHz IF signal. Simulation results show that a minimum USB up-conversion-loss is 9.5dB, comparing to 30dB loss of commercial products. Fabrication of such mixer is in progress. All of the design presented can readily be extended to a fully monolithic implementation.

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