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Single Balanced Monolithic Diode Mixer using Marchand Balun for Millimeter-wave Applications

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Abstract

In this paper, we reported on a single balanced monolithic diode mixer using Marchand balun for millimeter-wave applications. The single balanced monolithic mixer was fabricated using drain-source-connected pseudomorphic high electron mobility transistor (PHEMT) diodes considering the PHEMT MMIC full process. The average conversion loss is 16 dB in the RF frequency range of 81 ~ 86 GHz at LO frequency of 75 GHz with LO power of 10 dBm. The RF-to-LO isolation characteristics are greater than -30 dB and the total chip size is 1.0 mm × 1.35 mm.

Key words : diode mixer, marchand balun, single balanced mixer, millimeter-wave, PHEMT

I. Introduction

Mixer is one of the fundamental blocks in order to realize various systems in millimeter-wave applications. Although millimeter-wave mixer techniques are well developed, the high performance monolithic mixer is still popular research topic. Especially, diode mixers with the single balanced configuration have been developed continuously[1-4]. Even though the single balanced diode mixers have several serious limitations, they are used in many millimeter-wave systems due to their advantages such as simplicity of circuit structure compared with double balanced configuration and good RF-to-LO isolation characteristics. One of the major disadvantages of single balanced mixer is difficulty in injecting LO while still able to isolate the IF signals in the network due to their circuit geometry. This isolation can be achieved by using filters.

In the single balanced diode mixers, the RF and the LO signals are mutually isolated due to their circuit geometry including 90° hybrid or 180° hybrid structure. Among the various hybrid structures, Marchand baluns are very useful in millimeter-wave applications because they have a wide bandwidth characteristic.

In this paper, we presented the high performance monolithic single balanced diode mixer which can be used as an up-converter as well as down-converter in the RF and LO frequency range of 70 ~ 90 GHz with IF bandwidth of 15 GHz. For this, we used two diodes, three-coupled line Marchand balun, and IF low pass filter. Diodes are conventionally implemented by drain-source-connected pseudomorphic high electron mobility transistor (PHEMT) diodes considering the PHEMT MMIC full process on 2 mil thick GaAs substrate. A lot of core circuits used various millimeter-wave applications are microwave monolithic integrated circuits (MMICs) with microstrip topology on 2 or 4 mil thick GaAs substrate. Besides, PHEMTs are very attractive for MMICs and widely used in development of MMIC for millimeter-wave applications.

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II. Circuit Design

The circuit diagram of the developed single balanced monolithic diode mixer in this work is shown in Fig. 1. The single balanced diode mixer consists of anti-parallel diode pair, three-coupled line Marchand balun, coupled capacitor, and low pass filter. The design requires no external bias and can be used as an up-converter and as a down-converter in the frequency range of 70 ~ 90 GHz.

Conventional Marchand balun with two quarter-wavelength edge-coupled lines has leakage electric field along the outer sides and it causes the performance degradation of the balun. Therefore three-coupled line Marchand balun was used to obtain good RF-to-LO isolation characteristic as well as low loss characteristics compared with conventional Marchand balun[5]. In the simulation, the three-coupled line Marchand balun was designed on the GaAs substrate with a thickness of 50 ㎛ and a permittivity of 12.9. The widths of the inner and the outer strip are 20 ㎛ and 10 ㎛, respectively. A spacing of 12 ㎛ between coupled lines is chosen to achieve correct odd-mode impedance. The length of the balun is adjusted to achieve the desired center frequency of 80 GHz. Fig. 2 shows simulated insertion loss and phase difference of the balanced ports.

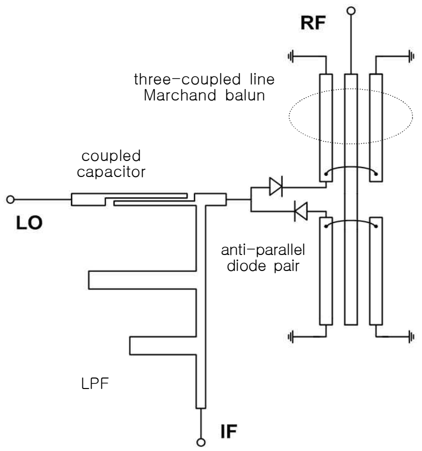

Fig. 1. The circuit diagram of the single balanced diode mixer

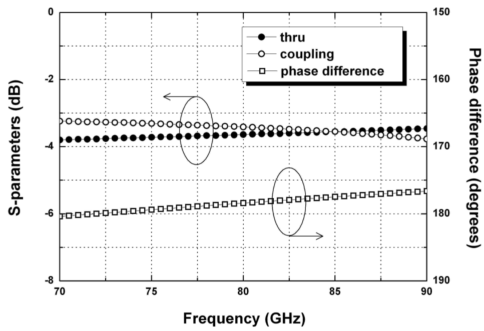

Fig. 2. Simulated results of insertion loss and phase difference characteristics of the Marchand balun

All 2 diodes are connected to together by anti-parallel structure. The diodes have one end connected to the three-coupled Marchand balun and the other terminals connected to the LO and IF ports. At LO port, the coupled capacitor is employed as high pass filter to block broad IF signal. Thus it adequately provides the selectivity for LO frequency and increases the IF-to-LO isolation characteristic.

At IF port, low pass filter is used to obtain good LO-to-IF and RF-to-IF isolation characteristics. RF-to-LO isolation characteristic is achieved due to the circuit geometry of the three-coupled Marchand balun.

After the circuit simulation with Agilent advanced design system (ADS), Momentum for electromagnetic (EM) simulation was also used in the design of the single balanced diode mixer. The conversion loss is better than 12 dB over the frequency range of 70 ~ 90 GHz with 15 GHz of IF bandwidth. The isolation characteristics among each port are greater than 30 dB.

III. Fabrication and measurement results

The designed single balanced diode mixer was fabricated using the foundry based on a 100 nm gate GaAs PHEMT of NGST. To ensure reliable operation, diodes are fully passivated. Both bond pad and backside metallization are Ti/Au, which is compatible with conventional die attach, thermocompression, and thermosonic wire bonding assembly techniques. Fig. 3 shows the fabricated source-drain-connected PHEMT diode and Fig. 4 shows the SEM photography of the fabricated mixer. The total chip size is 1.0 mm × 1.35 mm.

The fabricated single balanced monolithic diode mixer was measured using a Cascade on-wafer probing system. For measurements, a RF and LO input signal was generated by connecting Quinstar 94 GHz VCO and Millitech W-band variable attenuator for varying the power of input signals.

Fig. 5 shows the measured down-conversion loss of the fabricated mixer. The measured conversion loss is worse than the simulated result by 6-7 dB. The major cause is believed in the difference of the supplied LO power level. Generally, the better conversion loss is observed, the higher LO power level is supplied.

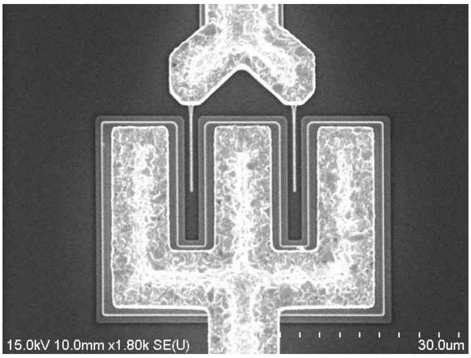

Fig. 3. The source-drain-connected PHEMT diode

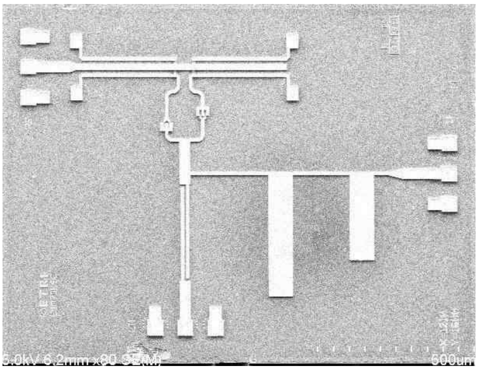
Fig. 4. The chip photograph of the fabricated mixer

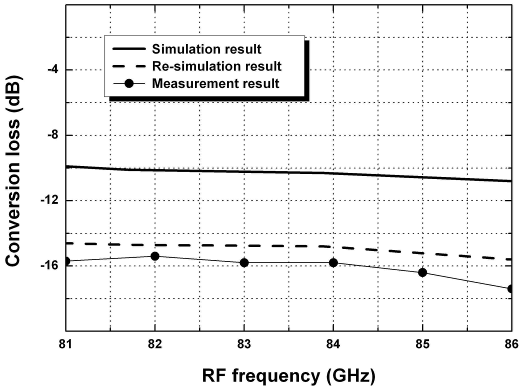

Fig. 5. The conversion loss of the fabricated mixer

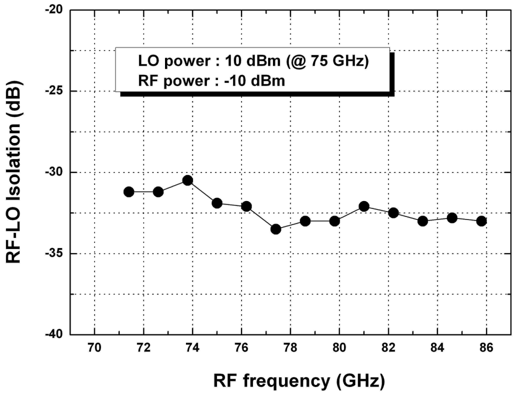

Fig. 6. The isolation characteristics of the fabricated mixer

The simulation was performed with the LO power of 14 dBm. However the measurement was performed with low LO power of 10 dBm due to power shortage of our VCO. Using the modified LO power level, the conversion loss was re-simulated. As a result, we can verify that the measured result is in agreement with the simulated result. The average conversion loss is 16 dB in the RF frequency range of 81 GHz to 86 GHz at LO frequency of 75 GHz with low LO power of 10 dBm.

Fig. 6 shows isolation characteristics. The isolation characteristics are greater than -30 dB over the frequency range of 71 ~ 86 GHz at LO frequency of 75 GHz with low LO power of 10 dBm and RF power of -10 dBm.

Ⅳ. Conclusion

In this paper, we successfully demonstrated the single balanced monolithic diode mixer using Marchand balun for millimeter-wave applications. The single balanced monolithic diode mixer was fabricated using drain-source-connected pseudomorphic high electron mobility transistor (PHEMT) diodes considering the 100 nm GaAs PHEMT MMIC full process of NGST. The average conversion loss is 16 dB in the RF frequency range of 81 ~ 86 GHz at LO frequency of 75 GHz with LO power of 10 dBm. The RF-to-LO isolation characteristics are greater than -30 dB and the total chip size is 1.0 mm × 1.35 mm.

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