BROADBAND AND COMPACT SIBJT BALANCED UP-CONVERTER MMIC USING SI 3-D MMIC TECHNOLOGY

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Abstract — **This paper presents a broadband and compact SiBJT balanced up-converter MMIC using Si 3-D MMIC technology. The balanced up-converter consists of newly designed Marchand-type balun, and two unit mixers that have stacked matching circuits. The fabricated balanced up-converter MMIC occupies just 1 mm^2 but achieves a conversion gain of 2.5 dB ± 2.5 dB and LO signal suppression of more than 30 dB at an RF port from 12 GHz to 27 GHz. The power consumption is 9.8 mW with 1 V supply voltage. The broadband performance factor of the fabricated MMIC is twice those of previously reported balanced up-converter MMICs.**

I. INTRODUCTION

Wireless communication systems operating at frequencies up to the X-band are becoming important as demand is growing for high speed data transmission. These systems require compact and low cost components; one essential component is a balanced up-converter. The balanced up-converter with high LO leakage suppression at the RF port eliminates the need to use RF filters at the RF output, resulting in low cost systems. In addition, the broadband balanced up-converter MMIC that covers those frequencies offers very low cost RF equipment. To meet the requirement of broadband operation, many up-converter MMICs, such as distributed mixers and diode mixers with wideband baluns have been reported[1]-[5]. However, these mixers are large, have high conversion loss, and require additional amplifiers to obtain adequate conversion gain, resulting in high cost.

This paper presents a broadband and compact Si BJT balanced up-converter MMIC that offers sufficient conversion gain without additional amplifiers. In addition, the fabricated MMIC can be operated with a collector supply voltage of under 1 V because of the reactive matching design method employed and the nonlinearity of Si BJT transconductance. An up-converter MMIC is fabricated on low resistivity Si wafers (ρ = 20 Ωcm) from NTT Electronics Corp. using Si 3-D MMIC technology[6] and commercially available 0.25-µm Si bipolar technology[7]. The Si 3-D MMIC technology offers highly integrated, broadband, and lower-cost MMICs. Use of this up-converter in the above wireless systems will significantly reduce RF component cost.

II. FABRICATION TECHNOLOGY

We used the Si 3-D MMIC technology[6] to realize the high performance and low cost up-converter MMIC. The Si 3-D MMIC consists of four layers of 2.5-µm thick polyimide film and 1-µm thick gold metal (top-level metal on the 3-D structure is 2-µm thick), formed on the top level metal of the Si wafer fabricated by a standard 0.25-µm Si bipolar IC process. BJTs, resistors, MIM capacitors, and two layers of aluminum metals are fabricated on the Si wafer. The second-level aluminum layer operates as a ground plane. This structure effectively isolates the microwave passive circuits on the 3-D structure from the low resistive Si wafer, resulting in low-loss passive circuits; transmission lines loss is reduced by 75 %. The key parameters of the 0.25-µm SiBJT are r_b = 65.6 Ω, C_{jeo} =8.6 fF, C_{jco} = 6.2 fF, C_{jso} = 6.9 fF, h_{FE} = 44, f_T = 40 GHz, f_{max} = 62 GHz, BV_{CEO} (I_c = 4 mA) = 3 V, and BV_{CBO} = 9.3 V at the emitter size of 0.3 µm x 5 µm and 1 V collector bias voltage. The MIM capacitor is composed of a 0.08-µm thick silicon-nitride film to obtain high capacitance (0.74 fF/mm^2).

III. CIRCUIT DESIGN

The design target was a broadband and compact up-converter with low-voltage operation for wireless applications. Figure 1 shows an equivalent circuit of the fabricated broadband up-converter. The up-converter consists of a newly designed Marchand-type balun and two unit up-converted mixers. The Marchand-type balun consists of two broadside couplers and the transmission line, T1, as shown in Fig. 1[8]. The transmission line connecting the couplers effectively compensates the amplitude and phase differences created within the balun

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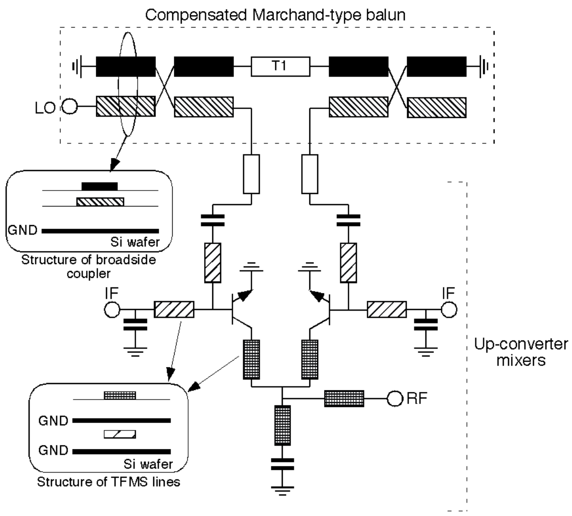

Fig. 1. Equivalent circuit of balanced up-converter.

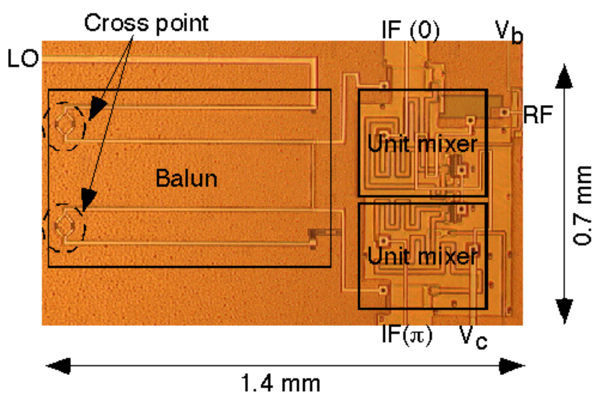

Fig. 2. Microphotograph of fabricated balanced up-converter MMIC.

by the difference in coupler phase velocities. The upper line and the lower line of the coupler shown in Fig. 1 cross over at the mid-point of the coupler to eliminate the difference in the losses of the coupler's upper and lower lines, resulting in better amplitude balance of the balun. The compensated Marchand-type balun is connected to the unit mixers through feed lines. A base active mixer configuration is employed for up-conversion to obtain sufficient conversion gain. IF and LO signals are applied to a base of the BJT. Generated RF signals from the collectors are directly combined with an associated short stub for output matching. The matching circuit for the LO input port (base side) is designed to match the output impedance of the balun. The emitter size of the unit mixer

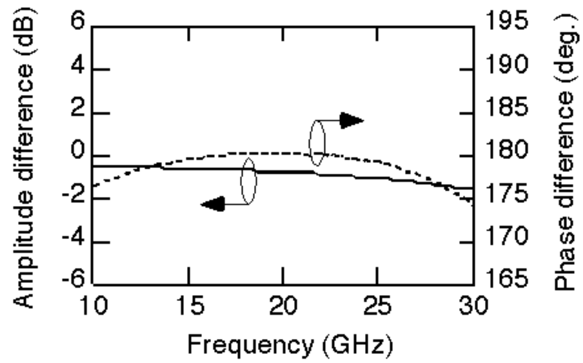

Fig. 3. Measured performance of compensated Marchand-type balun.

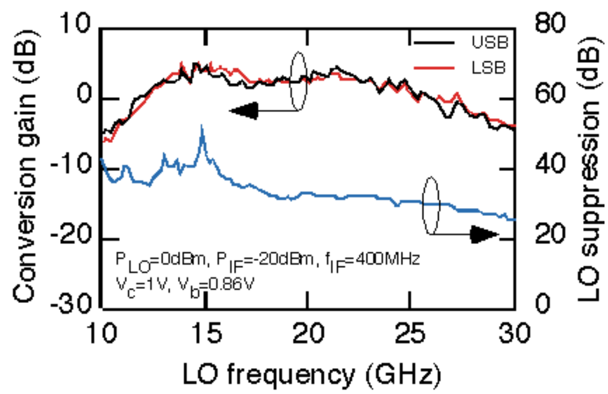

Fig. 4. Measured performance of fabricated balanced up-converter MMIC.

was determined so that the mixer achieves broadband matching performance. The emitter size of the BJT used is 0.3 µm x 40 µm and its base impedance slightly changes from the Ku-band to Ka-band. This means that simple matching circuits can be used to realize broadband operation. The matching circuits of the LO port and the RF ports are stacked above and below a middle ground plane formed on the polyimide films. This configuration greatly reduces mixer area. The fabricated balanced up-converter MMIC is shown in Fig. 2. The circuit area is just 1.4 mm x 0.7 mm.

IV. Measured Performance

Figure 3 shows the measured performance of the compensated Marchand-type balun. The solid and dotted lines plot amplitude and phase differences, respectively.

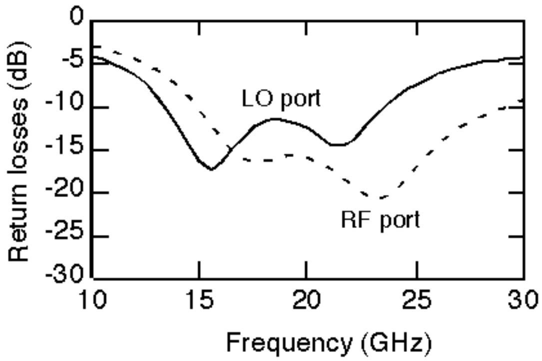

Fig. 5. Measured return losses at LO and RF ports of fabricated balanced up-converter MMIC.

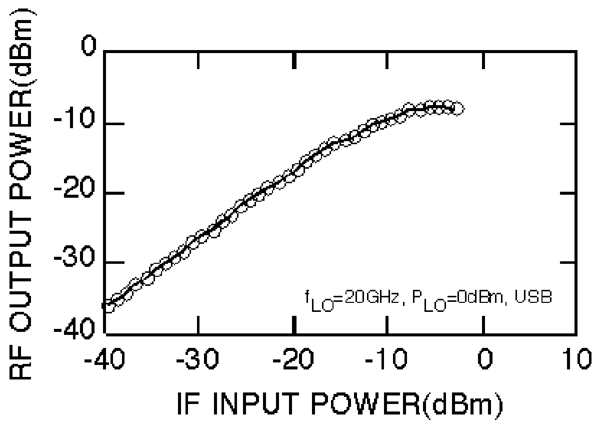

Fig. 6. Measured output power of fabricated balanced up-converter MMIC.

The balun achieves an amplitude difference of less than 1.5 dB and a phase difference from 180 degrees of less than 5 degrees from 10 GHz to 30 GHz. The measured results of the fabricated balanced up-converter MMIC are shown in Fig. 4. Conversion gains of upper- and lower-sideband signals are 2.5 dB ± 2.5 dB from 12 GHz to 27 GHz, respectively. The LO signal suppression of more than 30 dB (compared to LO input power) is achieved over this frequency range. The collector bias is 1 V while the base bias of 0.86 V is optimized to achieve the highest gain, its value is near the pinch off region. The power consumption is a mere 9.8 mW. The input LO power, the input IF power, and the IF frequency are 0 dBm, -20 dBm, and 400 MHz, respectively. Figure 5 shows the measured return losses at the LO and RF ports. The return losses are better than 10 dB from 15 GHz to 24 GHz (better than 5 dB from 12 GHz to 27 GHz). The measured RF output power of the upper-sideband signal at 20GHz is shown in

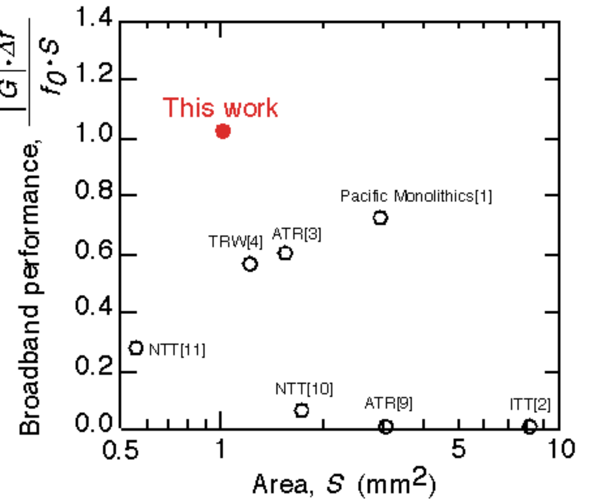

Fig. 7. Comparison of broadband performance of fabricated balanced up-converter MMIC and reported balanced up-converter MMICs.

Fig. 6. The saturated RF output power of the fabricated balanced up-converter MMIC is -7 dBm at a LO frequency of 20 GHz and a LO input power of 0 dBm. The output third-order intermodulation intercept point (OIP3) is 0 dBm at 20 GHz.

Figure 7 compares the broadband performance factor of previously reported balanced up-converter MMICs[1]-[4],[9]-[11]. The broadband performance factor is defined as conversion gain ($|G|$ in MAG)-bandwidth ($\Delta f / f_0$) product per area (S in mm^2). The fabricated balanced up-converter achieves the highest broadband performance of any balanced up-converter MMIC reported and its value is more than 1, which is twice that of the balanced up-converter MMIC in the same area. These results indicate that the balanced up-converter reported here achieves both compact and broadband operation with 1 V supply voltage, resulting in significant cost reductions.

V. Conclusion

A broadband and compact balanced up-converter Si 3-D MMIC was demonstrated in this paper. The balanced up-converter consists of a newly developed Marchand-type balun and Si BJT active base mixers. The balun achieved well-balanced performance and offered higher LO signal suppression level in a fabricated balanced up-converter MMIC. Use of Si BJT with low base impedance provides simple matching circuits even for broadband operation. The balanced up-converter MMIC occupied just 1 mm^2 but achieves a conversion gain of 2.5 dB ± 2.5 dB and LO signal suppression of more than 30 dB from 12 GHz to 27 GHz. The power consumption is 9.8 mW with 1 V supply voltage. This up-converter is easy to integrate into single-chip transmitters or transceivers.

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