Design and Fabrication of the MMIC frequency doubler for 29 GHz local Oscillators

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Abstract : We demonstrate the MMIC(monolithic microwave integrated circuit) frequency doublers generating stable and low-cost 29 GHz local oscillator signals from 14.5 GHz input signals. These devices were designed and fabricated by using the MMIC integration process of 0.1 μm gate-length PHEMTs (pseudomorphic high electron mobility transistors). The measurements showed S_{11} of -9.2 dB at 14.5 GHz, S_{22} of -18.6 dB at 29 GHz and a minimum conversion loss of 18.2 dB at 14.5 GHz with an input power of 6 dBm. The fundamental signal of 14.5 GHz was suppressed below 15.2 dBc compared with the second harmonic signal at the output port, and the isolation characteristics of the fundamental signal between the input and the output port were maintained above 30 dB in the frequency range of 10.5 GHz to 18.5 GHz.

1. Introduction

Recently, the millimeter-wave communication systems such as 38 GHz PCN(personal communication network) and 60 GHz wireless LAN(local area network) are drawing strong attention, because of the shortage in the frequency resource by the rapid development of various telecommunication services. In order to apply millimeter-waves in these communication systems, the millimeter-wave LO(local oscillator) signal is obviously necessary to convert RF(radio frequency) signals to IF(intermediate frequency) signals. However, it is very difficult to obtain a stable oscillation or to fabricate PLL(phase locked loop) circuits at a high frequency. To solve these problems, frequency multipliers are commonly used. These days, much effort is being made on fabricating the frequency doublers and triplers, which are adopted by millimeter-wave application[1-2]. In this paper, we have designed and fabricated the MMIC(monolithic microwave integrated circuit) frequency doubler using CPW(coplanar wave-guide) structures. This frequency doubler generates 29 GHz signals from 14.5 GHz input signal.

2. GaAs PHEMT device technology

We designed the epi structure of AlGaAs/InGaAs/GaAs with double heterojunction to manufacture PHEMT and MIMIC frequency doubler for 29 GHz applications. The PHEMT's epitaxial structure used in this study was grown by molecular beam epitaxy(MBE) on a semi-insulating GaAs substrate. The structure of the device consisted of the following layers : 5000 Å GaAs buffer, 185/15 Å AlGaAs/GaAs × 10 super-lattice buffer, silicon planar doping layer(1×10^{12} cm^{-2}), 60 Å AlGaAs lower spacer layer, 120 Å InGaAs channel, 40 Å AlGaAs upper spacer layer, silicon planar doing layer (5×10^{12} cm^{-2}), 250 Å AlGaAs donor layer, and 300 Å n^+-GaAs cap layer. The unit process that was applied to manufacture PHEMT, is as follows: AuGe/Ni/Au metals were used for the drain/source to get low ohmic contact resistance. Prior to ohmic formation, mesa etching process was carried out to isolate the devices. The 0.1 μm Γ-shaped gates were patterned by the triple-layer resists using the 50 kV electron-beam lithography system. After the gate fabrication, the Si_3N_4 passivation process was made to protect channel of the device, and air-bridge metals of Ti/Au were then formed to interconnect the isolated electrodes. Figure 1 shows the SEM photograph of the fabricated PHEMT's with 2 fingers of 70 ㎛ unit gate width.

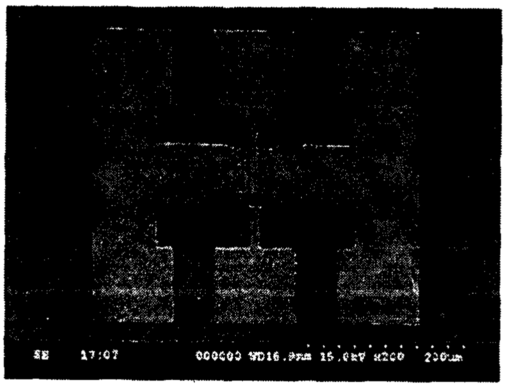

Figure 1. SEM photograph of 70 ㎛ × 2 PHEMT(0.1 ㎛)

From the fabricated device, we obtained the DC characteristics as follows; I_{dss} of 53.8 mA, transconductance(g_m) of 367.9 mS/㎜, and a pinch-off voltage of -1.5 V. In addition, we obtained f_T(current gain cut-off frequency) of 106 ㎓, f_{MAX}(maximum oscillation frequency) of 160 ㎓, and measured S_{21} gain of 3.9 dB at 50 ㎓. The large-signal modeling for the fabricated PHEMTs was performed using the IC-CAP of EEHEMT1 model.

3. MMIC design and fabrication

We used 70 ㎛ × 2 PHEMT device for the design of MMIC frequency doubler. To produce more harmonic components, the gate bias point is set near the pinch-off voltage(V_{gs} = -1 V, V_{ds} = 2 V). The input and the output ports were matched at 14.5 and 29 ㎓, respectively. In figure 2, we showed a schematic of the MMIC frequency doubler circuit used in this study. We produced the layouts using the ADS(advanced design system), and verified them by using the momentum simulation. The momentum simulation exhibited a different matching condition with the schematic simulation. Therefore, the layout was modified iteratively until the momentum simulation results satisfy the matching state at 14.5 and 29 ㎓.

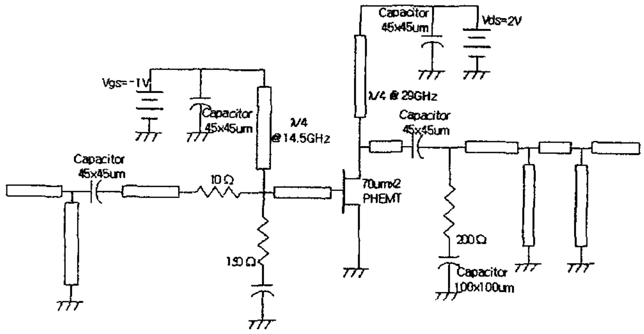

Figure 2. Schematic of MMIC frequency doubler

From the results of S-parameters simulation, S_{11} of -17.8 dB at 14.5 ㎓ and S_{22} of -11.7 dB at 29 ㎓ are obtained, respectively. When the input power is varied from -10 dBm to 10 dBm, a minimum conversion loss of 13.4 dB was obtained at a 4 dBm input power. The designed MMIC frequency doublers were fabricated using our standard integration process for the MMICs including the active and the passive components [3]. The fabricated chip size is 1.5 × 2.2 mm^2 and the photograph of fabricated doubler is shown in figure 3.

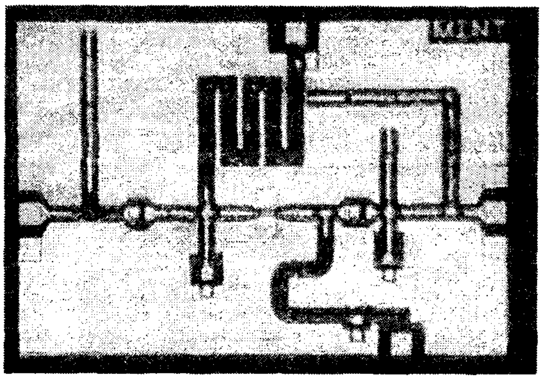

Figure 3. SEM photography of the MMIC frequency doubler

4. Measurements

The input and the output matching characteristics of the fabricated frequency doublers were measured by a on-wafer probing using the 8510C network analyzer and the MS2668C spectrum analyzer. From the measurement, we obtained S_{11} of -9.2 dB and S_{22} of -18.6 dB at 14.5 and 29 ㎓, respectively. Overall, the S-parameter measurement results were similar to the simulation results. However, the input matching peaks were shifted by 3 ㎓ toward higher frequency. The difference between the measurement and the simulation results was attributed to the degradation in PHEMT performance of the fabricated MMICs. In figure 4, we illustrated the S-parameter characterization of the measurement and the simulation results.

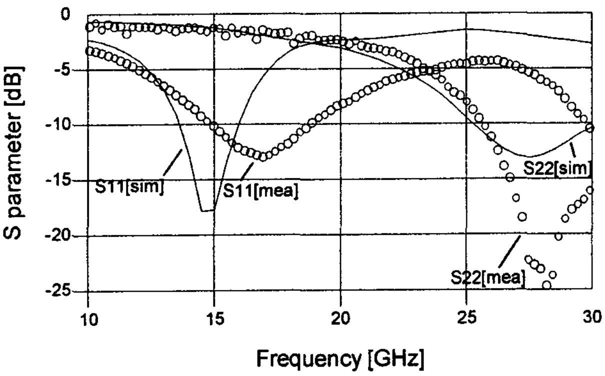

Figure 4. S-parameter measurement and simulation characteristics.

We also measured the conversion loss at various input powers and frequencies. For the measurements, 14.5 ㎓ input signal was generated by an Agilent 83623B signal generator. The output signal was detected by an Anritsu MS2668C spectrum analyzer. The measurements were performed by fixing the input power at a 6 dBm and by varying input signal frequency. A minimum conversion loss of -18.2 dB was obtained under an input power of 6 dBm at 14.5 ㎓. It is believed that, because the DC characteristics of PHEMTs in the MMIC were degraded compared with those of the library, the measured conversion loss was higher than expected in the simulation results. By using more reliable MMIC and PHEMT process, a comparable conversion loss with the simulation result is expected. Shown in figure 5 and figure 6 are the measured conversion loss versus the input frequency and the power, respectively.

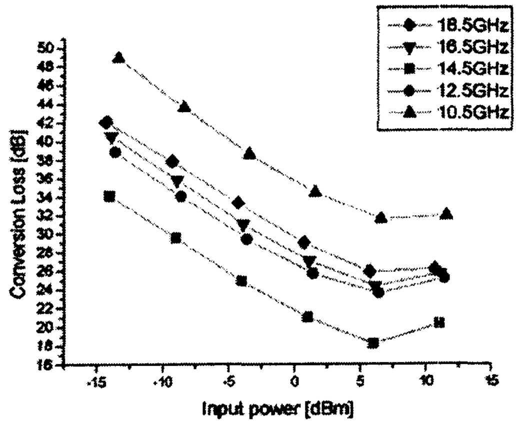

Figure 5. Conversion loss versus input power

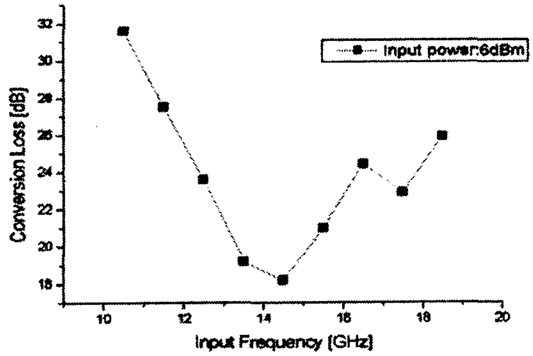

Figure 6. Conversion loss versus input frequency

The measurements also showed a maximum D/U (desired/undesired) ratio of 15.2 dBc at 14.5 ㎓. The examined isolation of the fundamental signal was greater than 30 dB in the frequency range from 10.5 to 18.5 ㎓. In figures 7 and 8, the measured output power spectra and isolation characteristics were presented, respectively.

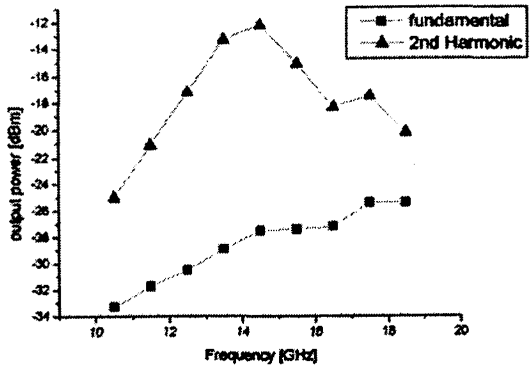

Figure 7. Output power spectra of the fundamental and second harmonic signal

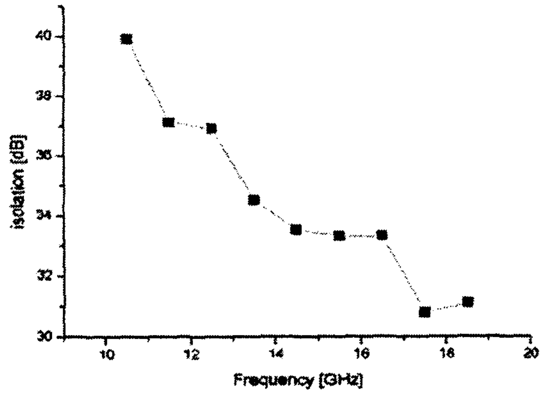

Figure 8. Isolation between input and output port versus frequency

We believe that the developed MMIC frequency doubler can used in the 29 GHz local oscillator application.

4. Conclusion

We demonstrated MMIC frequency doublers generating 29 GHz signals using the PHEMT-based technology. The fabricated devices showed the S_{11} of -9.2 dB at 14.5 GHz and S_{22} of -18.6 dB at 29 GHz. The matching was shifted by 3 GHz toward higher frequency region compared with the simulation result. The conversion loss was examined at various frequencies (from 10.5 to 18.5 GHz) and powers (from -10 dBm to 10 dBm). A minimum conversion loss of 18.2 dB was obtained under an input power of 6 dBm at 14.5 GHz. The measurement also showed a maximum D/U (desired/undesired) ratio of 15.2 dBc at 14.5 GHz. The examined isolation was greater than 30 dB, as measured from the fundamental signals in the frequency range from 10.5 to 18.5 GHz. It is believed that, because DC characteristics of PHEMTs in the MMIC were degraded compared with those of the library, the measured conversion loss was higher than expected in the simulation results.

Acknowledgements

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Reference

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