High Conversion Gain V-band Quadruple Subharmonic Mixer Using Cascode Structure

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Abstract — **In this paper, we present V-band high conversion gain quadruple subharmonic mixers adopting the cascode structure. The subharmonic mixers were successfully integrated by using 0.1 μm GaAs PHEMTs and the coplanar waveguide structures. We show that the highest conversion gain of 3.4 dB thus far at a LO power of 13 dBm from the fabricated mixers. The millimeter-wave subharmonic mixer also ensure a high degree of isolation showing -53.6 dB in the LO-to-IF and -46.2 dB in the LO-to-RF, respectively, at a frequency of 14.5 GHz. The high conversion gain achieved in this work is the first report among the millimeter-wave monolithic IC subharmonic mixers.**

I. INTROUCTION

As the demand for wireless data transmission of high speed and wide capacity is increased, research effort on highly integrated microwave monolithic integrated circuits (MMIC's) for millimeter-wave applications is strongly driven. Especially, a millimeter-wave frequency of 60 GHz in V-band (50~75 GHz) is the frequency of choice for the high speed, broad-band and wireless indoor local area networks (LANs). To realize such millimeter-wave wireless LAN system, a mixer is one of essential parts. It is however difficult to develop the oscillators satisfying the power requirements for the system at millimeter-wave frequency. Subharmonic mixers offer an alternative to the fundamental mixers. The advantage of this approach is that it allows the use of a local oscillator at a relatively low frequency because an LO frequency is located at some integer fraction (1/n) of the fundamental LO frequency. Moreover, the subharmonic mixer has a higher LO to RF isolation than that of the fundamental mixer. For this reason, the subharmonic mixers with anti-parallel diode (APD) structure were evaluated at millimeter-wave frequencies [1]. However, this type of mixer has a high conversion loss with the requisite of additional signal amplification.

In this paper, we report the V-band quadruple subharmonic mixers of a high conversion gain designed using the cascode structure. The V-band quadruple subharmonic mixers were designed using the library of 0.1 μm GaAs pseudomorphic high electron mobility transistors (PHEMTs) and the coplanar waveguide (CPW). The designed subharmonic mixers were fabricated, measured and analyzed.

II. DESIGN OF V-BAND QUADRUPLE SUBHARMONIC MIXER

In order to achieve high conversion gain of the subharmonic mixers, high order *n-th* harmonic power of the LO signal is required. The power at a desired *n- th* harmonic, P_n, can be described by equation (1) [2].

$$P_n = (1 - A_n)[P_o MG + P_n A_n G_n + (P_{n-1}A_{n-1} + P_{n+1}A_{n+1})CG] + \cdots\cdots \quad (1)$$

where;

P_n: Output power at *n-th* harmonic.

P_o: Output power at a fundamental frequency of f_o.

P_{n-1}, P_{n+1}: Powers at harmonics of (n-1) and (n+1).

A_{n-1}, A_{n+1}: Power couplings at harmonics of (n-1) and (n+1).

This equation includes three important mechanisms contributing to the global multiplication efficiency [2].

(1) Frequency multiplication from a fundamental frequency of the *n-th* harmonic. This power gain is defined as MG.
(2) Large signal amplification in the part of the *n-th* harmonic which was fed back to the input at a power gain of G_n.
(3) Frequency conversion due to the mixing of the fundamental frequency with the harmonics of (n-1) and (n+1) fed back at a conversion gain of *CG*.

Fig. 1 shows a cascode structure evaluated in this study. When an input signal f_o is divided into $f_{o(1)}$ and $f_{o(2)}$, the *n-th* harmonic power of the field effect transistors (FETs) at each divided signal can be given by equations (2) and (3), respectively.

$$P_{(FET1)} = P_{f_{o(1)}} + P_{2f_{o(1)}} + P_{3f_{o(1)}} + P_{4f_{o(1)}} + \cdots \quad (2)$$

$$P_{(FET2)} = P_{f_{o(2)}} + P_{2f_{o(2)}} + P_{3f_{o(2)}} + P_{4f_{o(2)}} + \cdots \quad (3)$$

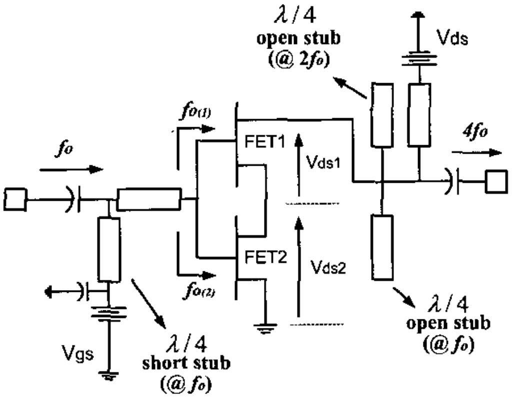

Fig. 1. The cascode structure used in this study.

In this cascode structure, $f_{o(2)}$ signal of the FET2 drives the FET1 due to the difference in voltage level between the transistors. Therefore, the total 4-th harmonic power is given by:

$$P_{4f_o} = P_{4f_{o(1)}} + P_{4f_{o(1)}}(P_{4f_{o(2)}}) + P_{4f_{o(1)}}(P_{2f_{o(2)}}) + P_{4f_{o(1)}}(P_{f_{o(2)}}) + \cdots \quad (4)$$

where;

$P_{4f_{o(1)}}$: f_o 4th harmonic of FET1 by $f_{o(1)}$.

$P_{4f_{o(1)}}(P_{4f_{o(2)}})$: f_o 4th harmonic of FET1 by 4th harmonic of $f_{o(2)}$.

$P_{4f_{o(1)}}(P_{2f_{o(2)}})$: f_o 4th harmonic of FET1 by 2nd harmonic of $f_{o(2)}$.

$P_{4f_{o(1)}}(P_{f_{o(2)}})$: f_o 4th harmonic of FET1 by $f_{o(2)}$.

As shown in equation (4), the cascode structure exhibits a higher 4-th harmonic power than that of the case that only FET1 was used because of additional harmonic power supplied by FET2. Moreover, a $\lambda/4$ short stub for the input port was included to pass the f_o (LO) signal. In contrast, the $\lambda/4$ open stubs for f_o and $2f_o$ pass $4f_o$ signal by suppressing the f_o and $2f_o$ signals. Fig. 2 shows the simulation results of output spectrum for the designed cascode structure, and exhibit the highest 4-th harmonic power at 58 GHz. We also obtained a good conversion loss of 9.98 dB at an input power of 15 dBm and an input frequency of 14.5 GHz. Fig. 3 shows the circuit schematic of the V-band subharmonic mixer used in this study. The RF, LO and IF frequencies were designed to have 60.4, 14.5 and 2.4 GHz, respectively. The CPW transmission lines were used for matching circuits of the RF and LO ports, whereas the lumped elements were adopted for the IF ports because of their relatively low IF frequencies.

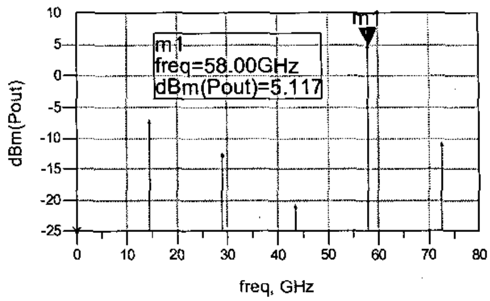

Fig. 2. Simulation result of the output spectrum for the cascode structure.
(Input frequency : 14.5 GHz, Input power : 15 dBm)

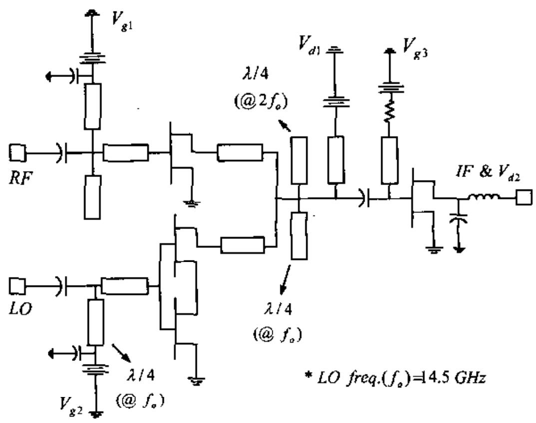

Fig. 3. Designed circuit schematic of the V-band subharmonic mixer.

III. FABRICATION AND MEASUREMENT

The V-band subharmonic mixers were fabricated by using the MMIC standard process established in our research group [3]. The integration process includes the fabrications of GaAs PEHMTs, CPW transmission lines, Ti resistors and metal-insulator-metal (MIM) capacitors.

Fig. 4 is a top-view photograph of the fabricated V-band subharmonic mixer. The total chip size is 1.9 mm × 1.8 mm. Shown in Fig. 5 are the measurement results of the conversion gain and the IF output power versus the RF input power at 60.4 GHz. For this measurement, we used an LO input power of 13 dBm at a 14.5 GHz. Measurement results demonstrated a high conversion gain of 3.4 dB and 1 dB compression point of -9.0 dBm. Fig. 6 also shows the conversion gain versus the LO input power at an LO frequency of 14.5 GHz. The conversion gain is saturated at LO input power level higher than 13 dBm. The measured conversion gain versus RF frequency is shown in Fig. 7 at an RF power of −15 dBm and an LO power of 13 dBm. The conversion gain was 2.5~3.4 dB in the RF frequency range of 59.4~60.9 GHz.

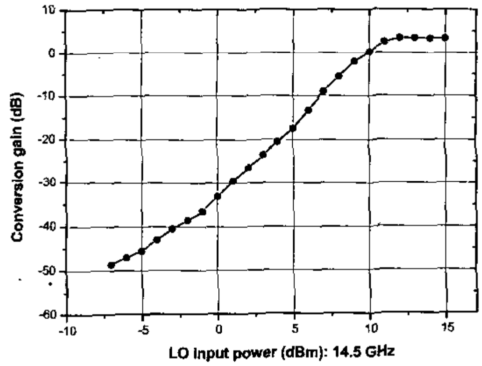

Fig. 6. Conversion gain vs. LO input power.
(RF frequency : 60.4 GHz, RF power : -15 dBm)

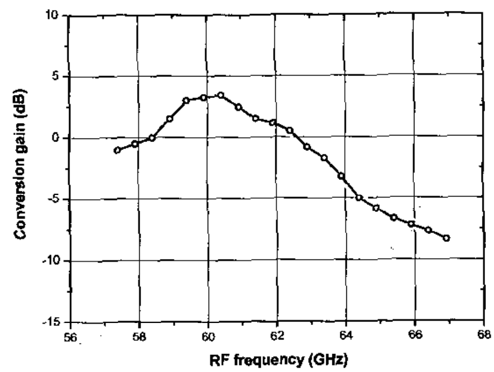

Fig. 7. Conversion gain vs. RF frequency.
(LO power: 13 dBm, RF power : -15 dBm)

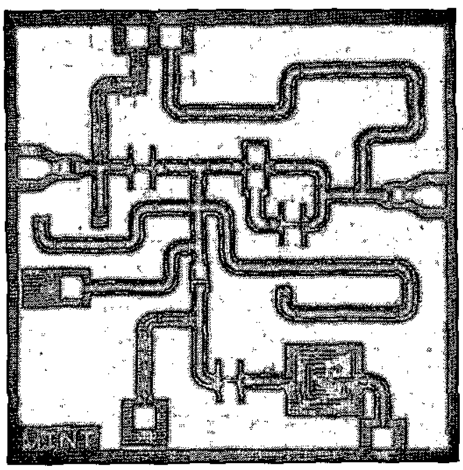

Fig. 4. Top-view micrograph of the fabricated V-band subharmonic mixer.

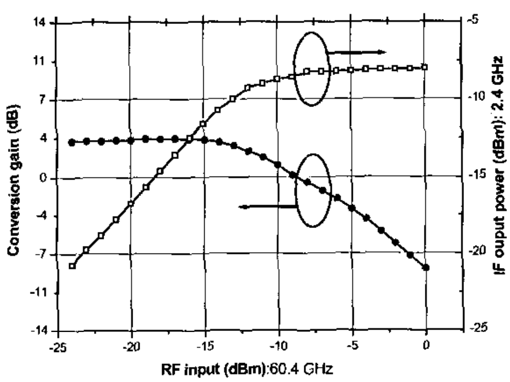

Fig. 5. Conversion gain and IF output vs. RF input.
(LO frequency : 14.5 GHz, LO power : 13 dBm)

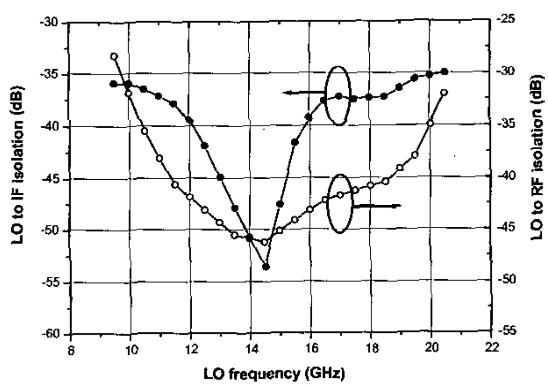

Fig. 8. The measured results of isolation characteristics.

As shown in Fig. 8, the fabricated subharmonic mixers show a good LO-to-IF isolation of -53.6 dB and LO-to-RF isolation of -46.2 dB at 14.5 GHz, respectively. This good LO-to-RF isolation is due to the greater difference in frequency between LO and RF than that of a fundamental mixer. In Fig. 9, the conversion gain performance of our subharmonic mixers is compared with those of the millimeter-wave subharmonic mixers reported earlier [4-9]. While the reported millimeter-wave subharmonic mixers exhibited conversion gains of -13.2 ~ -7 dB, an excellent gain of 3.4 dB was obtained in this work, as shown in Fig. 9.

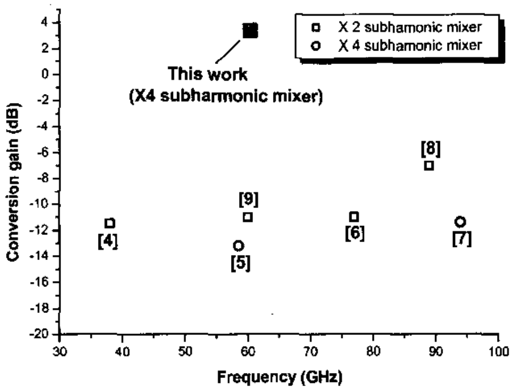

Fig. 9. Comparison of the reported millimeter-wave subharmonic mixers.

Ⅳ. CONCLUSION

We designed and fabricated the high conversion gain V-band quadruple subharmonic mixers operating at a millimeter-wave frequency of 60 GHz by using the cascode structure. The fabricated V-band subharmonic mixers showed the performances as follows. A high conversion gain of 3.4 dB at LO input power of 13 dBm was measured. The conversion gain was saturated at LO input power level higher than 13 dBm. We also observed good isolation properties of -53.6 dB for the LO-to-IF and -46.2 dB for the LO-to-RF, respectively, at 14.5 GHz. The high conversion gain achieved in this work is the first report among the millimeter-wave subharmonic mixers thus far.

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