A High-Gain 50-GHz-Band Monolithic Balanced Gate Mixer With an External IF Balun

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***Abstract*—This paper presents a 50-GHz-band high-gain monolithic balanced gate mixer. IF impedance of the balanced gate mixer is approximated from a small-signal equivalent circuit, and conversion gain of the mixer is improved by using an external IF balun with high impedance–transforming ratio. The maximum conversion gain of 8.2 dB is achieved at LO power of 0 dBm. Effectiveness of the described mixer is confirmed experimentally.**

***Index Terms*— Baluns, impedance matching, millimeter-wave mixers, MMIC mixers.**

I. Introduction

In recent years, a millimeter-wave utilization has been studied for short-distance radar systems and high-speed data communication systems [1]. In the millimeter-wave region, it is difficult to obtain high-gain amplifiers. Hence, millimeter-wave mixers are required to improve gain, noise, and output-power characteristics. There are Schottky-barrier diode mixers [2], [3] and high electron-mobility transistor (HEMT) mixers [4]–[6] as millimeter-wave mixers. Among these mixers, HEMT mixers have the advantages that: 1) the HEMT mixer can be integrated with amplifiers on the same GaAs substrate and 2) conversion loss of the HEMT mixer is lower than that of the diode mixer; moreover, the HEMT mixer has conversion gain in some cases described below.

There is a gate mixer, drain mixer and resistive mixer as configurations of HEMT mixers. In these configurations, the gate mixer has the advantages of higher conversion gain and lower LO power [4]. To apply the gate mixer to down-converters, a balanced mixer topology is employed for combining the RF signal and LO without any filter circuits [6]. High gain for millimeter-wave mixer was obtained by conversion gain and amplification. In this balanced mixer topology, an impedance matching of the IF port is important to improve conversion gain because: 1) the output impedance of the balanced mixer is higher than that of amplifier because LO switches drain conductance of the HEMT and 2) IF impedance of the balanced mixer is two times larger than that of the unit mixer.

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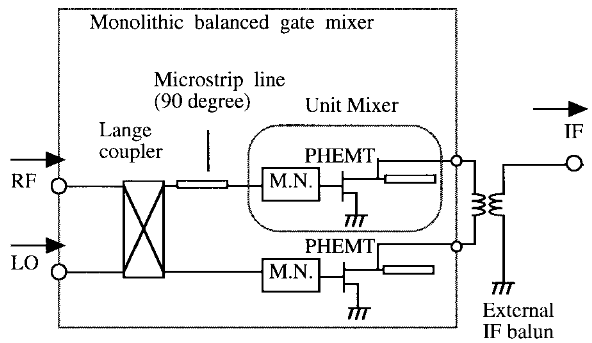

Fig. 1. Configuration of a developed 50-GHz-band monolithic balanced gate mixer. External IF balun is used for combining IF signals, and an impedance–transforming ratio of the balun is heighten to improve the conversion gain of the mixer. M.N.: matching network.

This paper presents a 50-GHz-band monolithic balanced gate mixer with an external IF balun. For high conversion gain, a pseudomorphic high electron-mobility transistor (pHEMT) is employed as the mixing device, and the external balun is designed to have a high impedance–transforming ratio.

In the following discussions, configuration of the balanced gate mixer is indicated. Furthermore, a design of the external IF balun is discussed for high conversion gain. Finally, experimental results of the developed 50-GHz-band monolithic balanced mixer are indicated.

II. Configuration

A configuration of a developed 50-GHz-band monolithic balanced gate mixer is shown in Fig. 1. This mixer consists of two unit mixers, a 180° hybrid circuit and an external IF balun. The 180° hybrid circuit consists of a Lange coupler and 90° microstrip line. The balun is used as a 180° combiner of IF signals. It is also used as an impedance transformer. Unit mixers employ the gate–mixer concept because of high conversion gain and low LO power. For down-conversion utilization, the RF signal and LO is fed to the gate. For combining the RF signal and LO without filter circuits, the 180° hybrid circuit is employed. By the hybrid circuit, the RF signal is divided in 0°, and the LO is divided in 180°. Thus, IF signals produced at each unit mixer are combined by the external IF balun with high impedance–transforming ratio. In the following section, the design concept of this impedance–transforming ratio is described in detail.

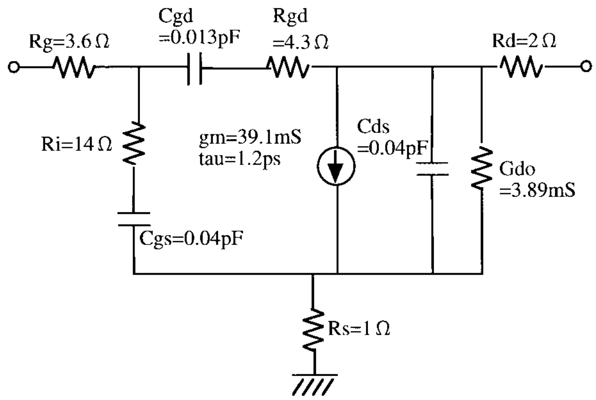

Fig. 2. An equivalent circuit and a parameter of the pHEMT in amplifier operation ($V_d = 2$ V, $V_g = -0.25$ V). G_{d0}: drain conductance in amplifier operation.

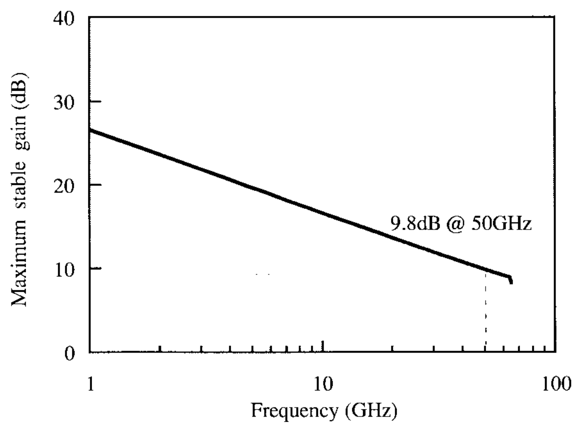

Fig. 3. Calculated MSG of the pHEMT. MSG of 9.8 dB is obtained at 50-GHz band.

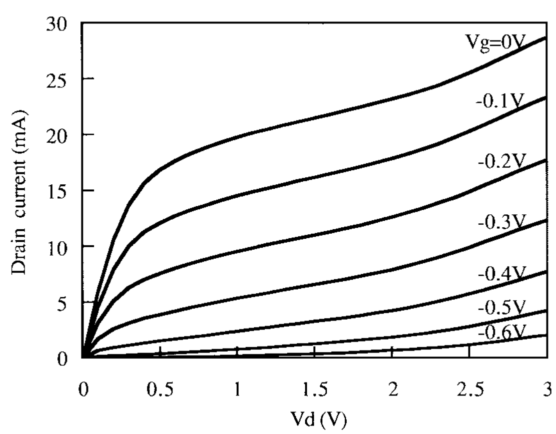

Fig. 4. Measured I–V characteristics of the pHEMT.

III. Design Results of a 50-GHz-Band Monolithic Balanced Gate Mixer

In this section, design results of a 50-GHz-band monolithic balanced gate mixer is presented.

For the mixer, AlGaAs/InGaAs/GaAs pHEMT [7] is employed to achieve high conversion gain. The gate length of the pHEMT is 0.15 μm and the gatewidth is 100 μm. An equivalent circuit of the pHEMT in amplifier operation

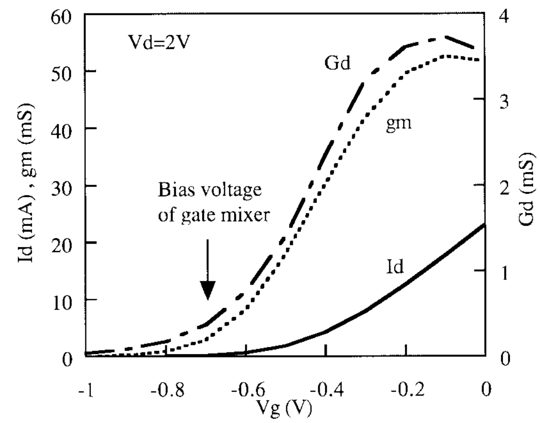

Fig. 5. Transconductance g_m and drain conductance G_d derived from measured I–V characteristics shown in Fig. 4. Bias voltage of the gate mixer is -0.7 V, which is pinchoff voltage.

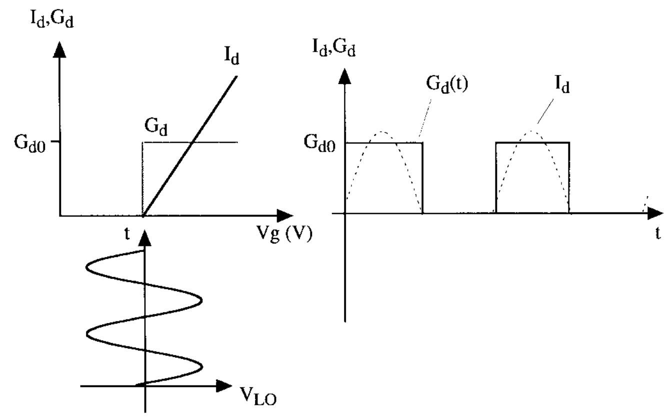

Fig. 6. Simplified G_d property on time domain. $Gd(t)$, which is swung by the LO, can be approximated by G_{d0} at positive half cycles of the LO and zero at negative half cycles.

is shown in Fig. 2. The bias conditions are drain voltage $V_d = 2$ V and gate voltage $V_g = -0.25$ V. In this figure, G_{d0} is a drain conductance in amplifier operation. In the operation, g_m and G_{d0} of the pHEMT have the values 39.1 and 3.89 mS, respectively. A calculated maximum stable gain (MSG) of the pHEMT is shown in Fig. 3. MSG of 9.8 dB is obtained at 50 GHz.

As a gate mixer, V_g is set at pinchoff voltage. Measured I–V characteristics of the pHEMT are shown in Fig. 4. Transconductance g_m and drain conductance G_d derived from I–V characteristics are shown in Fig. 5. Indicated g_m and G_d increase steeply above pinchoff voltage $V_{\rm poff}$ of -0.7 V. Noting this operation, simplified drain conductance in time domain is represented as $Gd(t)$ in Fig. 6. $Gd(t)$ can be approximated by G_{d0} at positive half cycles of the LO and zero at negative half cycles, and is represented by

$$Gd(t) = G_{\rm d0}\left(\frac{1}{2} - \frac{2}{\pi}\sum_{n=1}^{\infty}\frac{\sin(2n-1)\omega_p t}{2n-1}\right). \quad (1)$$

IF Impedance of the unit mixer $Z_{\rm if}$ can be approximated by the zeroth-order term of $Gd(t)$ as

$$Z_{\rm if} \cong \frac{2}{G_{\rm d0}}. \quad (2)$$

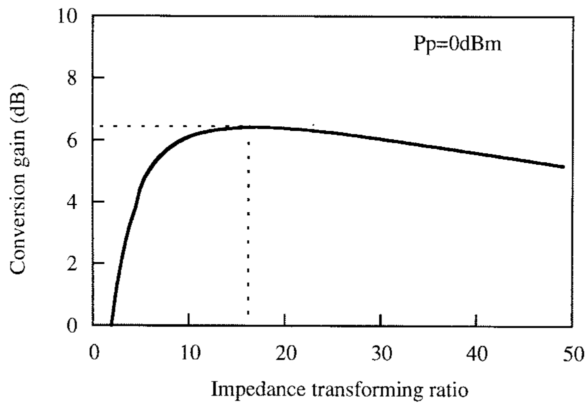

Fig. 7. Calculated conversion gain versus impedance–transforming ratio of the balun. The results are calculated by the harmonic-balance method. Maximum conversion gain is obtained for impedance–transforming ratio of 16. This value is the same as the predicted value.

TABLE I
THE PARAMETERS OF THE CURTICE CUBIC MODEL

Parameters	values
β	0.00044×10^{-12}
τ	1.2psec
γ	3.34
V^0_{out}	2V
A0	0.03
A1	0.054
A2	-0.014
A3	-0.038

Furthermore, IF impedance of the balanced mixer $Z_{\rm if2}$ is approximated as

$$Z_{\rm if2} \cong 2Z_{\rm if} \cong \frac{4}{G_{\rm d0}}. \tag{3}$$

From equations (1)–(3), IF impedance of the balanced gate mixer is given by drain conductance $G_{\rm d0}$ in amplifier operation.

For the pHEMT, $Z_{\rm if2}$ of 1028 Ω is derived from $G_{\rm d0}$ of 3.89 mS. To match between 50 and 1028 Ω, an impedance–transforming ratio of 20 is needed for the external balun.

Calculated conversion gain versus impedance–transforming ratio of the balun is indicated in Fig. 7. The results are calculated by the harmonic-balance method using the Curtice cubic model [8]. (The parameters of the model are indicated in Table I.) Maximum conversion gain is obtained at the impedance–transforming ratio of 16. This value almost coincides with the predicted value. The transforming ratio of 16 is selected as the designing value for the balun. Calculated conversion gain versus LO power is indicated in Fig. 8. The results are also calculated by the harmonic-balance method. The maximum conversion gain are obtained at LO power of 4 dBm for each condition.

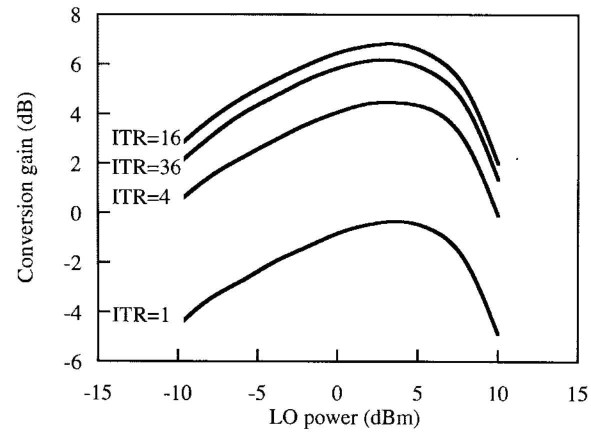

Fig. 8. Calculated conversion gain versus LO power. The results are calculated by the harmonic-balance method. The maximum conversion gain are obtained at LO power of 4 dBm for each condition. ITR: impedance–transforming ratio. ($P_{\rm in} = -10$ dBm, $f_{\rm in} = 51$ GHz, $f_{\rm if} = 10$ MHz).

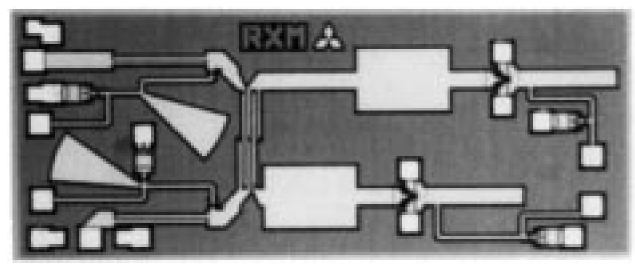

Fig. 9. A photograph of the developed 50-GHz-band monolithic balanced gate mixer. Chip size is 1.2 mm $\times$ 2.9 mm.

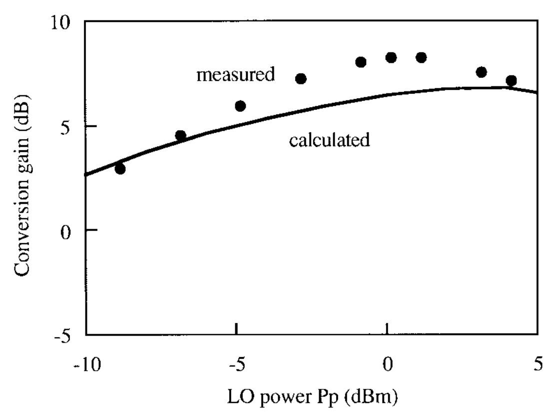

Fig. 10. Measured conversion gain of the 50-GHz-band balanced gate mixer. High conversion gain can be achieved by using the external balun with high impedance–transforming ratio ($P_{\rm in} = -10$ dBm, $f_{\rm in} = 51$ GHz, $f_{\rm if} = 10$ MHz).

IV. EXPERIMENTAL RESULTS

A photograph of the developed 50-GHz-band monolithic balanced gate mixer is shown in Fig. 9. The chip size of the MMIC is 1.2 mm $\times$ 2.9 mm. The thickness of the GaAs substrate is 100 μm.

Measured conversion gain of the mixer is shown in Fig. 10. The maximum conversion gain of 8.2 dB is obtained at LO

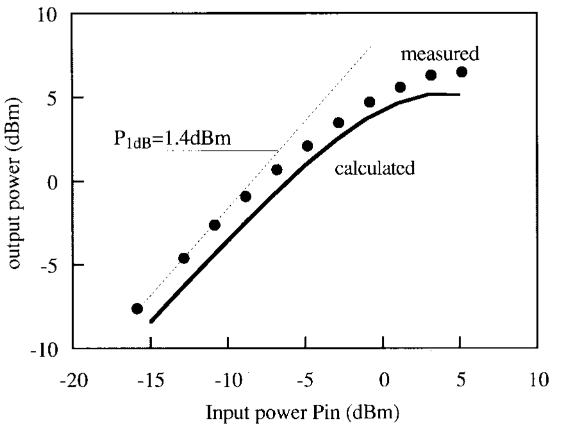

Fig. 11. Measured output power of the 50-GHz-band balanced gate mixer ($P_p = 0.5$ dBm, $f_{\rm in} = 51$ GHz, $f_{\rm if} = 10$ MHz).

power of 0 dBm. High conversion gain can be achieved by using the external balun with high impedance–transforming ratio of 16. As the external IF balun, we use an RF transformer that is a product of mini-circuits. This conversion gain of 8.2 dB is the highest one compared with [4] and [6].

Measured output power of the mixer is shown in Fig. 11. Output power of 1.4 dBm is obtained at 1-dB-gain compression. This value is higher than that of conventional diode mixers. Effectiveness of the described mixer is confirmed experimentally.

V. Conclusion

This paper presented a 50-GHz-band high-gain monolithic balanced gate mixer. High conversion gain was achieved by using the external IF balun with a high impedance–transforming ratio of 16. The maximum conversion gain of 8.2 dB was achieved at an LO power of 0 dBm. Effectiveness of the described mixer was confirmed experimentally.

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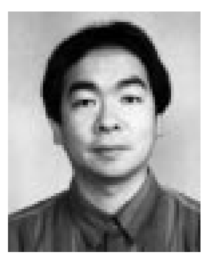

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