Miniaturized LNB Downconverter MMIC for Ku-band Satellite Communication System using InGaP/GaAs HBT Process

Jei-Young Lee · Sang-Hun Lee · Jong-Chul Lee · Jong-Heon Kim · Byungje Lee · Chan-Hyeong Park · Nam-Young Kim

Abstract

In this paper, LNB(low noise block) downconverter MMIC is designed for Ku-band satellite communication system using InGaP/GaAs HBT high linear process. Designed MMIC consists of low noise amplifier, double balanced mixer, and IF amplifier with a total chip area of 2.6×1.1 mm^2. Designed MMIC has the characteristics of over 37.5 dB conversion gain, 14 dB noise figure, ripple of 3 dB, and output-referred P_{1dB}(1 dB compression power) of 2.5 dBm with total power dissipation of 3 V, 50 mA.

Key words : InGaP/GaAs HBT, Ku-band, LNB Downconverter, MMIC.

Ⅰ. Introduction

The satellite broadcast service has spread to over 140 million worldwide households, and is expected to serve more than 220 million households in 2005. Demand for satellite broadcast receiving systems is increasing as the satellite broadcast industry grows. Receiving antenna, LNB, and tuner(set-top box) are needed to receive and process high quality audio and video signals. The LNB downconverts satellite signal received from the antenna to an intermediate frequency.

The LNB consists of low noise amplifier(LNA), mixer, local oscillator(LO), intermediate frequency(IF) amplifier, and image rejection filter. The LNA receives the satellite signal from the antenna, and it amplifies the signal sufficiently to drive mixer with minimum noise added. Mixer as a frequency converting element makes the output signal from the LNA output signal and oscillator output. The oscillator generates the reference frequency output for the RF to IF down-conversion[1]. The frequency-converted output signal is amplified by IF amplifier sufficiently enough to drive the set-top box converter.

Ku-band downconverter MMIC has been designed in many ways[2]~[7]. In this paper, LNB MMIC is designed and optimized for small size and low power characteristics. This LNB downconverter is fabricated using commercially available 6 inch InGaP/GaAs HBT MMIC process by Knowledge*on Inc. Ku-band MMIC LNB downconverter block diagram is proposed as shown in Fig. 1.

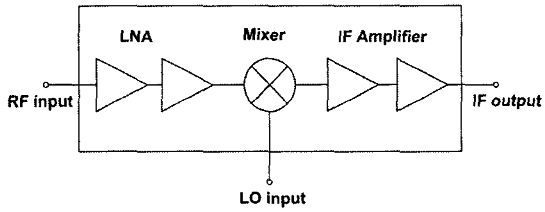

Fig. 1. Block diagram of MMIC LNB downconverter.

Ⅱ. Device Technology

The MMIC downconverter is fabricated using InGaP /GaAs HBT high linear process. GaAs-based HBTs offer excellent high frequency gain, efficiency, linearity, and single-supply operation in a compact structure with potential manufacturability at very low cost. GaAs HBTs benefit from high electron mobility and the availability of semi-insulating substrates[8]. The HBT offers a more efficient approach in many front-end signal-processing functions than advanced Si homo-junction bipolar transistors and Ⅲ-Ⅴ compound field-effect transistor(MESFET and HEMT) technology do. Although the GaAs HBT has higher white noise than Ⅲ-Ⅴ FET does, its advantages including faster speed with relaxed lithographic dimension, higher current per effective chip, better device matching, higher trans-

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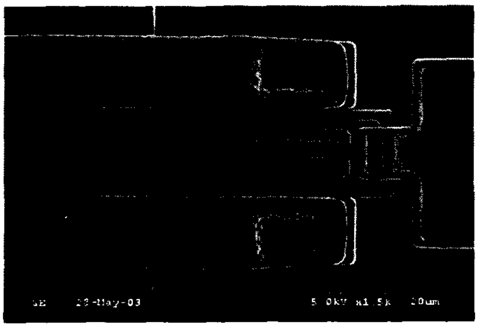

Fig. 2. SEM photograph of InGaP/GaAs HBT(two emitter fingers, emitter width of 2 μm, and emitter length of 20 μm).

conductance, lower output conductance, and reduced trapping effects accompanied by low $1/f$ and phase noise lead us to choose the GaAs HBT technology. As compared to advanced Si BJT technologies, the GaAs HBT is limited to integration complexity, but offers advantages of higher speeds with relaxed lithographic dimensions, lower output conductance, effectively no parasitic substrate capacitance, and greater radiation hardness. Table 1 describes the HBT parameters of the process including current gain, BV_{ceo}, f_T, and f_{MAX}[9]~[11]. Fig. 2 shows the SEM photograph of InGaP/GaAs HBT which has two fingers, emitter width of 2 μm, and emitter length of 20 μm.

The 6 inch InGaP/GaAs HBT process offers NPN HBT(two emitter fingers, emitter width of 2 μm, and emitter length of 20 μm: F2×2×20) with f_T of 50 GHz and f_{MAX} of 80 GHz, 600 pF/mm^2 metal-insulator-metal(MIM) capacitor, spiral inductor, 50 Ω/□NiCr thin film resistor, and backside via. Two metal layers are used for interconnection and their thicknesses are 1.3 μm and 4 μm.

The VBIC model is used for InGaP HBT large signal model, which compensates important deficiencies in Gummel-Poon model such as the Early effect modeling, quasi-saturation modeling, parasitic substrate transistor modeling, avalanche multiplication modeling, self-heating modeling, and temperature modeling[12].

Ⅲ. Downconverter Design

Designed MMIC downconverter includes LNA, mixer, and IF amplifier. RF frequency of 11.7~12.75 GHz is mixed with the local oscillator frequency of 10.75 GHz, which is downconverted to IF frequency of 0.95~2 GHz. MMIC downconverter is designed using single operation voltage of 3 V, and the total current

Table 1. Characteristics of the InGaP/GaAs HBT.

Parameter	Unit	F2×2×20	Remark
β		115	Gummel Plot (J_c=25 KA/cm^2)
f_T	GHz	50	
f_{Max}	GHz	80	Unilateral Gain
BV_{ceo}	V	13.8	IC=100 μA
BV_{cbo}	V	23.5	IC=100 μA
BV_{ebo}	V	7.2	IE=100 μA
V_{TurnOn}	V	1.20	Gummel Plot (IC=100 μA)
V_{offset}	V	0.10	DCIV (J_c=25 KA/cm^2)
η_{hc}		1.02	Gummel Plot
η_{hb}		1.10	Gummel Plot

consumption is 50 mA.

LNA is designed to increase the weakly received signal from the antenna. Two finger 2×20 μm^2 NPN HBT is used in each stage, as shown in Fig. 3. The active device size and the operation bias point of 8 mA is selected in consideration of small signal gain, noise figure and DC power dissipation. The large NiCr resistors are used in bias networks instead of large spiral inductors for minimization of the circuit area. The microstrip short stub matching is applied in the matching networks. Designed LNA has the characteristics of small signal gain of 10 dB, noise figure of 4.7 dB at the total current of 16 mA.

The merits of double balanced mixer are good intermodulation distortion(IMD) characteristics, high linearity and low current consumption. Fig. 4 shows the double balanced mixer with two finger 2×20 μm^2 NPN transistors, which is designed for the characteristics of low DC power consumption, low noise figure, high linearity and broadband operation[13]~[15]. The RF, LO, and IF ports should be designed as a balanced structure to reject the fundamental products of RF and LO signals. Designed mixer has the characteristics of 5 dB conversion gain, 14 dB noise figure,

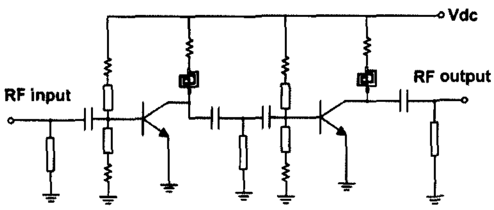

Fig. 3. Schematic of the low noise amplifier.

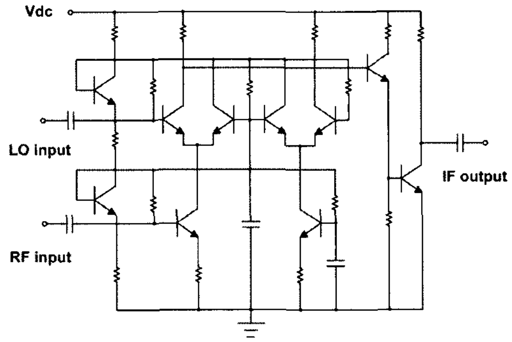

Fig. 4. Schematic of the double balance mixer.

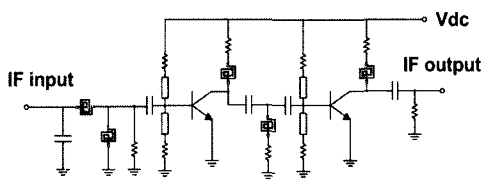

Fig. 5. Schematic of the IF amplifier.

RF-IF isolation of 41.5 dB and RF-LO isolation of 10 dB, 3 dB bandwidth of 17.9 GHz and 50 dBc IMD with bias condition of 3 V and 14 mA.

The schematic of IF amplifier is shown in Fig. 5. Two finger 2×20 μm^2 transistors are used in the active device. This IF amplifier is designed for broadband flat gain characteristics with low current consumption. The lossy matching technique is employed in the matching networks for broadband matching to achieve the flat gain. The common topology is to use resistors in series with high impedance stubs or inductors at both input and output of matching circuit[16]. Designed IF amplifier has the broadband characteristics of input return loss of 15 dB, output return loss of 13 dB, and ripple of 1.2 dB over the IF frequency(0.95~2 GHz), which result from lossy matching network. This amplifier generates over 28 dB gain, output-referred P_{1dB} of 3 dBm at the bias condition of 3.3 V, 20 mA. Also, broadband IF amplifier provides adjustable gain from 10 to 30 dB according to the voltage control from 2.6 V to 3.5 V over the IF frequency(0.95~2 GHz) by maintaining both the input and output return loss.

LNA, mixer, and IF amplifier are integrated in InGaP/GaAs HBT process with a total chip area of 2.6 $\times$1.1 mm^2 as shown in Fig. 6.

Ⅳ. Measurements

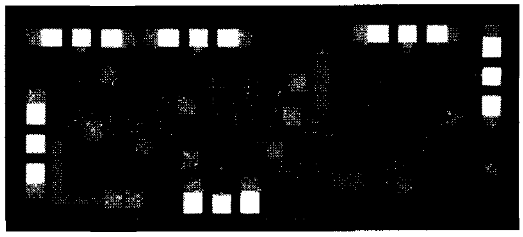

Fig. 6. Chip photograph of the fabricated Ku-band LNB MMIC downconverter. The chip size is 2.6×1.1 mm^2.

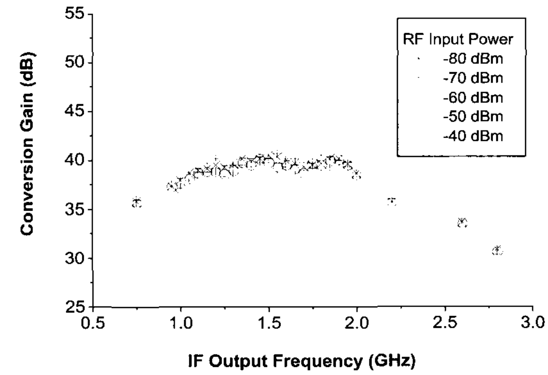

Fig. 7. Measured conversion gain of the downconverter MMIC as a function of the RF input power.

RF frequency is downconverted to IF frequency of 0.95~2 GHz, mixed with the local oscillator frequency of 10.75 GHz. All the measurements are performed by on-wafer test. Fig. 7 shows the conversion gain as a function of the RF input power(− 80 ~ − 40 dBm) with the LO power of − 10 dBm. The conversion gain of over 37.5 dB is measured in the desired frequency band. The output return loss is measured 10 dB. RF output power versus input power is shown in Fig. 8.

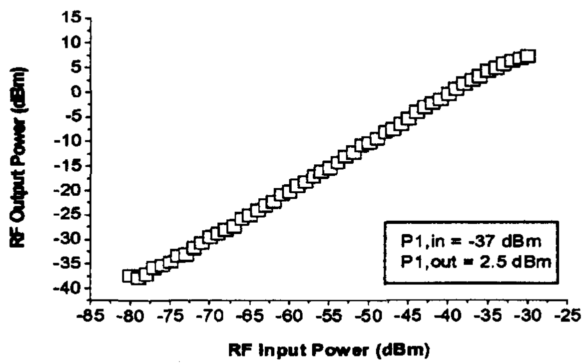

Fig. 8. Measured input and output power response of the downconverter MMIC.

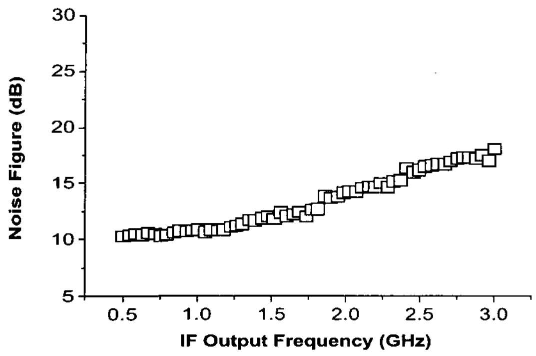

Fig. 9. Measured noise figure of the downconverter MMIC.

Table 2. Simulation and measurement results.

Parameter	Unit	Simulation	Measurement
Input Frequency	GHz	11.7~12.75	11.7~12.75
Output Frequency	GHz	0.95~2	0.95~2
Conversion Gain	dB	43	37.5
Gain Flatness	dB	1.5	3
Output Return Loss	dB	13	10
Noise Figure	dB	14	≤14
Current Consumption	mA	52	50
$P_{1dB,OUT}$	dBm	4	2.5
Chip Size	mm^2	2.6×1.1	2.6×1.1

The input-referred P_{1dB} of −37 dBm and the output-referred P_{1dB} of 2.5 dBm are measured. Noise figure of 10~14 dB is measured as shown in the Fig. 9. Total power dissipation for the MMIC chip operation is 3 V, 50 mA. Table 2 summarizes simulation results and measurement data.

V. Conclusion

Low power and miniaturized Ku-band MMIC down-converter is designed and fabricated using InGaP/GaAs HBT high linear process with a total chip area of 2.6×1.1 mm^2. Designed MMIC yields conversion gain of over 37.5 dB, noise figure of less than 14 dB, ripple of 3 dB, and the output-referred P_{1dB} of 2.5 dBm over the desired frequency range(11.7~12.75 GHz) with total power dissipation of 3 V, 50 mA. In Table 3, conversion gain, noise figure, power consumption, and chip size are compared with previously published Ku-band downconverters. MMIC LNB system can be achieved by adding additional LNA for the purpose of noise figure compensation.

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Table 3. Summary of previously published Ku-band downconverter MMIC performance.

Published Works	Device	Bandwidth [GHz]	Conversion Gain [dB]	Noise Figure [dB]	Power Dissipation	Chip Size	Remark
P. Bacon et al.[3]	0.5 μm GaAs MESFET	12.2~12.7	32	8.5	8 V, 210 mA	2×2 mm^2	Dual channel downconverter
K. Hubbard et al.[4]	HEMT	11.7~12.7	38	3.5	6 V, 125 mA	1.58×1.46 mm^2	Self bias topology
T. Sekiguchi et al.[5]	0.5 μm GaAs MESFET	11.7~12	52	2.1	·	4.5×2.2 mm^2 (LNA) 2.9×2.4 mm^2 (Mixer) 1.9×1.6 mm^2 (Osc) 1.9×1.2 mm^2 (IFA)	Individual MMICs
T. Kaneko et al.[6]	0.5 μm GaAs MESFET	11.7~12.5	10	8	10 V, 97 mA 5 V, 43 mA	1.2×2.8 mm^2	LNA, Mixer, IF amp, VCO, Prescaler
T. Yoshimasu et al.[7]	0.3 μm GaAs MESFET	11.7~12.2	37	3.5	4 V, 40 mA	2.8×2.8 mm^2	Included image rejection filter
This Work	InGaP/GaAs HBT	11.7~12.75	37.5	14	3 V, 50 mA	2.6×1.1 mm^2	Oscillator is excluded

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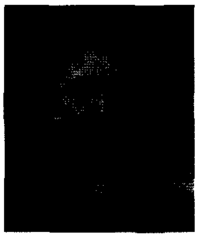

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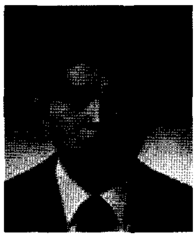

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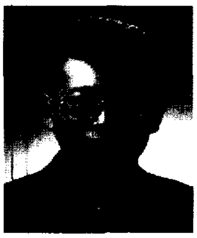

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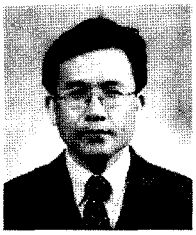

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