The Double Balance Mixer Design with the Characteristics of Low Intermodulation Distortion, and Wide Dynamic Range with Low LO-power using InGaP/GaAs HBT Process

InGaP/GaAs HBT 공정을 이용하여 낮은 LO 파워로 동작하고 낮은 IMD와 광대역 특성을 갖는 이중평형 믹서설계

S. H. Lee · S. S. Choi · J. Y. Lee · J. C. Lee · B. Lee · J. H. Kim · N. Y. Kim · Y. H. Lee* · S. H. Jeon* · J. W. Park*

이상훈 · 최상신 · 이제영 · 이종철 · 이병제 · 김종헌 · 김남영 · 이영호* · 전상훈* · 박재우*

Abstract

In this paper, the double balance mixer(DBM) for Ku-band LNB using InGaP/GaAs HBT process is suggested for the characteristics of low DC power consumption, low noise figure, low intermodulation distortion and wide dynamic range. The 5 dB conversion gain, 14 dB NF, bandwidth 17.9 GHz and 50.34 dBc IMD are obtained under RF input power of −23 dBm, with bias condition as 3 V and 16 mA. The linearity of InGaP/GaAs HBT, the broad band input matching scheme and the optimization of bias point result in the low IMD, the broad bandwidth and the low power consumption characteristics.

요 약

본 논문에서는 InGaP/GaAs HBT 공정을 이용하여 낮은 DC 파워소모, 낮은 NF, 낮은 IMD 와 광대역 특성을 갖는 Ku-band LNB용 이중평형믹서를 설계하였다. 제작된 믹서는 3 V, 16 mA 의 DC 조건과 -23 dBm의 RF입력 조건하에서 5 dB의 변환이득, 14 dB의 NF, 17.9 GHz의 대역폭 그리고 50.34 dBc의 IMD특성을 얻었다. 낮은 IMD 특성, 광대역폭, 낮은 파워소모 특성은 InGaP/GaAs HBT의 선형성과 광대역 입력 정합기법과 바이어스 점의 최적화를 통해 얻을 수 있었다.

Key words : Mixer, Double Balance Mixer, DBM, Low IMD, Ku-band, InGaP, GaAs, HBT, Low LO-Power

Ⅰ. Introduction

Wireless communication system is rapidly growing in the demand of present electronics world that includes wireless local area network(WLAN), global positioning system(GPS), low noise block(LNB) and so on. Because of continuous development of such a radio communication system, a new technology is developed in which the various signal control techniques are included. So, the high RF frequency must be converted

「This work has been performed through the support Project of University Information Technology Research Center(ITRC) supported by the Ministry of Information & Communication of Korea.」

광운대학교 RFIC 센터(RFIC Center Kwangwoon University)

*(주)나리지*온(Knowledge*ON Inc.)

· 논 문 번 호 : 20030524-08S

· 수정완료일자 : 2003년 7월 30일

into intermediate frequency for channel selection. The frequency conversion process is necessary for the quality of the signal as well as the wider communication area using a small antenna. Therefore, the mixer is necessary for this process and it plays a key role in wireless communication[1]. Thus, the mixer should be designed with considering the several parameters such as conversion gain, intermodulation distortion, operational frequency, frequency bandwidth, noise figure, isolation and so on[2]. In this paper, the merits of this designed mixer have more linearity, lower power consumption, lower noise, lower distortion, better isolation, and broad bandwidth. This designed mixer is focused on the IMD and the noise figure, which make interference in a whole system, and they all have been improved and satisfied the various other parameters so that the mixer has the high performance by using the linearity of InGaP/GaAs HBT, broad-band input-matching and optimization of bias point.

Ⅱ. InGaP/GaAs HBT MMIC Process

The HBT offers a more efficient approach in many front-end signal-processing functions than advanced Si homojunction bipolar transistors and III-V compound field-effect transistor(MESFET and HEMT) technology. Although the GaAs HBT has higher white noise than III-V FETs, advantages include greater speeds with relaxed lithographic dimension, higher current per effective chip, better device matching, higher transconductance, lower output conductance, and reduced trapping effects accompanied by low 1/f and phase noise. 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. The nominal detailed values of HBT models are shown in Table 1[3].

Table 1. Characteristics of the InGaP/GaAs HBT Process.

Parameter	Unit	High Power	High Linearity	High Speed	Remark
Test Device		F2×2×20	F2×2×20	F1×1×10	
β		87	105	130	Gummel Plot (Jc=2.5 kA/㎠)
f_T	GHz	34*	50**	65***	
f_{MAX}	GHz	84*	80**	100***	Unilateral Gain
BV_{ceo}	V	20-23.5	13.8	10.4	IC=100 ㎂
BV_{cbo}	V	36.9	23.5	18.9	IC=100 ㎂
BV_{ebo}	V	7.61	7.2	6.4	IE=100 ㎂
V_{Turnon}	V	1.20	1.20	1.24	Gummel Plot (IC=100 ㎂)
V_{offset}	V	0.10	0.10	0.15	DCIV (Jc=2.5 kA/㎠)
η_c		1.02	1.02	1.07	Gummel
η_b		1.10	1.10	1.13	Gummel

Ⅲ. Design of Double Balance Mixer

This paper presents the design of DBM using the high linearity of InGaP/GaAs HBT fabrication. It is required that the output signal must be proportional to the input signal in analog signal process. The merits of double balanced mixer(DBM) are good IMD characteristics, high linearity and low current consumption. That is, DBM functions as active device with a good RF-IF isolation, RF-LO isolation, and conversion gain. Fig. 1 shows the photograph of the 2-finger active

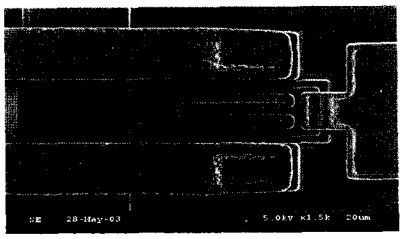


Fig. 1. Photograph of the active device.

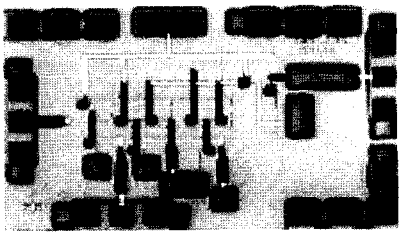


Fig. 2. Designed double balance mixer.

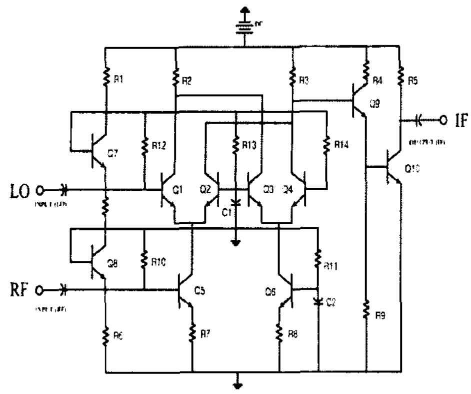


Fig. 3. Schematic of the double balance mixer.

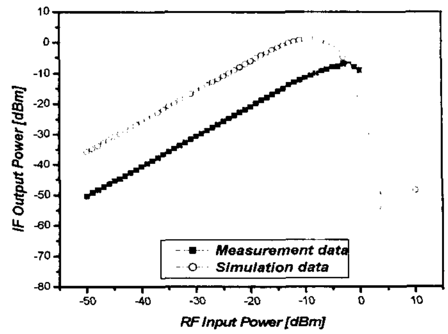


Fig. 4 One tone result at LO −10 dBm.

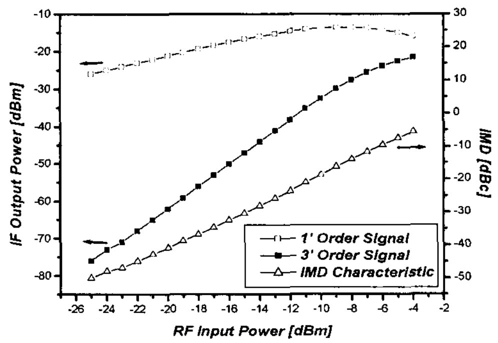


Fig. 5 Two tone result and IMD at LO −10 dBm.

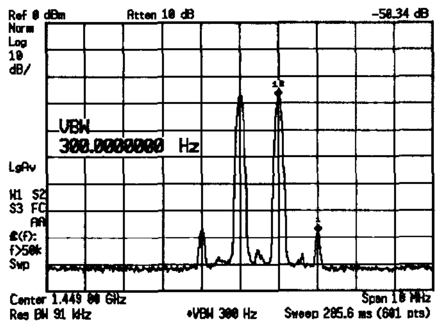


Fig. 6. Measurement IMD at RF −23 dBm, LO −10 dBm.

device and Fig. 2 shows the designed double balance mixer. Similarly, Fig. 3 shows the schematic of the designed double balance mixer. As the characteristics of DBM, fundamental products of RF and LO from output have been rejected. For this purpose, the input of RF and LO should be incident as a balanced pattern and the output port should be composed in the same way.

In this circuit, the design is focussed in parameters between RF input port and IF which includes isolation, IMD, conversion gain, noise figure and minimization of current consumption output port. A device is adopted for setting the maximum bias point in G_m of transistor which acts as a I-V converter in RF input part(Q5, Q6). The circuit is designed in such a way that the transistor in LO input part acts as a switch(Q1, Q2 Q3, Q4) and can be operated in cut off area by applying minimum bias. In course of designing, in the output part, the conversion gain is maximized. The buffer(Q9, Q10), which is designed, plays the role of level shifting as well as makes output impedance matching easily. The emitter bias consists of the current mirror(Q7, Q8), which is a way to increase the common-mode rejection ratio and IMD characteristics. Besides, C1 and C2 are signal path for the balanced input signal. Moreover, R4 and R9 are optimized for low current consumption and conversion gain.

Ⅳ. Simulated and Measured Performance of Double Balance Mixer

The fabricated DBM is provided 3 V and 16 mA having size of 1.7 mm×1.06 mm. The DBM is attached with die using Silver epoxy on the PCB. In this device, DC contact is bonded to the die PAD using an approximately 10 mil in length/1 mil diameter gold wire for the stable DC supply. The fabricated DBM is shown in Fig. 2. Furthermore, the measurement data of fabricated mixer are obtained which have 5 dB conversion gain by considering the cable loss of 5 dB; RF input of −30 dBm, LO input of −10 dBm. Next, the isolation between RF-IF and LO-IF port are −41.5 dB and −10 dB, respectively.

The reflection coefficient of the RF port is −14 dB and LO port is −8.5 dB. IF port is measured as 10.6 dB and Noise Figure as 14 dB. Fig. 3 and Fig. 4 shows the change of output power with change of input power.

The performance of mixer having characteristics of

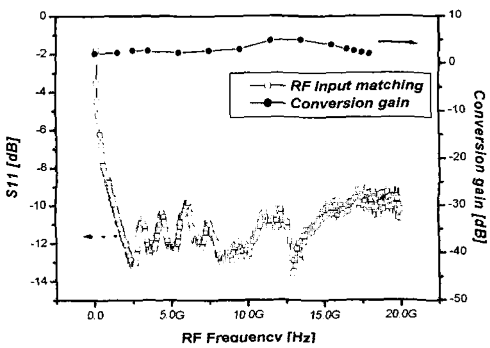


Fig. 7. RF input matching and bandwidth at RF −23 dBm, LO −10 dBm.

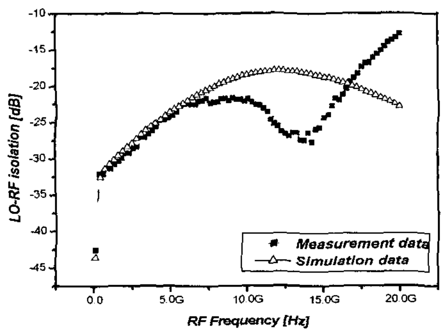


Fig. 8. Measurement LO-RF isolation at RF −23 dBm, LO −10 dBm.

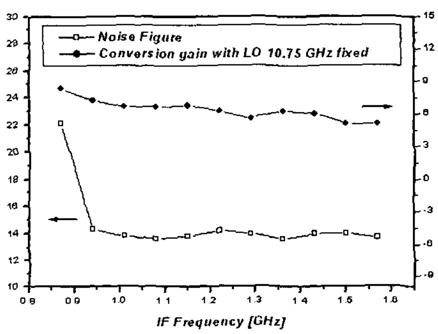


Fig. 9. Measurement noise figure at LO −10 dBm.

IMD at RF −23 dBm, which is decided the linearity of whole receiver terminal, has about 50.34 dBc as shown in Fig. 5 and Fig. 6. The measured wide-band down-conversion mixer performance which is shown in Fig. 7. The excellent broad-band characteristic is obtained as compared to the existing DBM circuit on the basis of f_T. With both RF and LO ports swept in frequency with a fixed IF frequency of 1.5 GHz, the Mixer achieved 5 dB conversion gain, and 3 dB bandwidth from 1 GHz to 17.9 GHz. Fig. 8 shows the

Table 2. Simulation and measurement result of the double balance mixer.

Requirement	Simulation	Measurement	Unit
RF frequency	11.7~12.75	11.7~12.75	GHz
LO frequency	10.75	10.75	GHz
Conversion Gain	8	5	dB
LO-IF return loss	−8.7	−8.4	dB
RF-LO return loss	−15	−25.9	dB
IMD	60	50.34	dBc
NF	20	14	dB
3 dB BW When both RF and LO ports swept with a fixed IF		17.9	GHz

Table 3. Low LO power performance of the double balance mixers.

Reference	RF Frequency	LO Drive	Conversion Gain
LiLi[4] (Sibipolar)	2.73 GHz	0 dBm	2.78 dB
T. Kashiwa[5] (InP HEMT)	55 GHz	−2 dBm	−7 dB
Kevin W. Kobayashi[6] (InP HBT)	0~20 GHz	10 dBm	15.3 dB
B. Matinpour[7] (GaAs MESFET)	5.2 GHz	5 dBm	5.5 dB
A. P. Freundorfer[8] (GaInP/GaAs HBT)	26 GHz	3 dBm	−4 dB
Charles J[9] (GaAs)	14~26 GHz	11 dBm	6 dB
P. J. Sullivan[10] (CMOS)	1.9 GHz	−8 dBm	5.5 dB
This Work	0~17.9 GHz	−10 dBm	5 dB

LO-RF isolation and the frequency from DC to 7.5 GHz which agree with the results of measurement data and simulation data. The phenomenon in which the fre--quency above 7.5 GHz is due to the coupling of each layout and its fabrication process mismatch.

Fig. 9 shows the measurement data of NF and conversion gain with LO 10.75 GHz by using the Agilent N8975A and 346C Noise Source. Table 3 shows that this LO power level is comparable with the best data ever reported microwave double balance mixers.

Ⅴ. Conclusion

In this paper, DBM is designed using InGaP/GaAs HBT for satellite communication applications. There are characterized the merits of high IMD characteristics, high linearity, and a good isolation between LO and IF frequencies. The measurement data are obtained such as IMD of 50.34 dBc at RF - 23 dBm, LO - 10 dBm, conversion gain, 5 dB, NF, 14 dB and 3 dB bandwidth from DC to 17.9 GHz when both RF and LO ports swept in frequency with a fixed IF frequency of 1.5 GHz.

Acknowledgements

The authors would like to thank Knowledge*ON Inc. for InGaP/GaAs HBT foundry service and Agilent eesof for donation of the ADS.

References

[1] Stephen A. Maas, *Microwave Mixers,* 2nd edition, Artech House, 1993.

[2] Burhan Bayraktaroglu, "GaAs HBT's for Microwave Integrated Circuits", *Proceeding of the IEEE*, vol. 81, no. 12, Dec. 1993.

[3] www.knowledge-on.com

[4] Li Li, Hannu Tenhunen, "Noise Analysis of Mono lithic RF Balanced Conversion Mixers", *IEEE*, 2001.

[5] T. Kashiwa, T. Katoh, T. Ishida, Y. Kojima, Y. Yamamoto, M. Komaru and Y. Mitusi, "A V-Band Monolithic InP HEMT Resistive Mixer with Low LO-Power Requirement", *IEEE*, 2001.

[6] Kevin W. Kobayashi, "A DC-20-GHz InP HBT Balanced Analog Multiplier for High-Data-Rate Direct-Digital Modulation and Fiber-Optic Receiver Applications", *IEEE Trans. On Microwave Theory and Techniques*, vol. 48, no. 2, Feb. 2000.

[7] B. Matinpour, J. Laskar, "A Compact Direct Conversion Receiver for C-band Wireless Applications", *IEEE Radio Frequency Integrated Circuits Symposium*, 1999.

[8] A. P. Freundorfer, C. Falt, "A Ka-band GaInP/GaAs HBT Double Balanced Upconvert Mixer using Lumped Element Balun", *IEEE MTT-S Digest*, 1996.

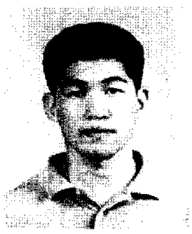
[9] Charles J. Trantanella, "Ultra-Small MMIC Mixers for K- and Ka-BAND Communications", *IEEE MTT-S Digest*, 2000.

[10] P. j. Sullivan, B. A. Xavier and W. K. Ku, "Low Voltage Performance of a Microwave CMOS Gilbert Cell Mixer", *IEEE Journal of Solid-State Circuits*, vol. 32, no. 7, Jul. 1997.

이 상 훈

2002년 2월: 광운대학교 전자공학부 (공학사)
2002년 3월~현재: 광운대학교 전자공학과 석사과정
[주 관심분야] RFIC/MMIC, RF/Analog System

최 상 신

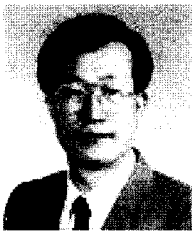


2002년 8월: 광운대학교 전자공학부 (공학사)
2002년 9월~현재: 광운대학교 전자 공학과 석사과정
[주 관심분야] RFIC/MMIC, Microstrip Antenna

이 제 영

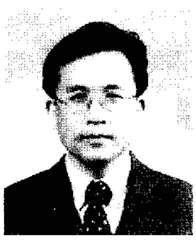
1998년 2월: 광운대학교 전자공학과 (공학사)
2001년 2월: 광운대학교 전자공학과 (공학석사)
2001년 3월~현재: 광운대학교 전자공학과 박사과정
[주 관심분야] RFIC/MMIC, Modeling 및 System design

이 종 철



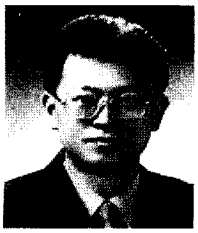
1983년 2월: 한양대학교 전자공학과 (공학사)
1985년 2월: 한양대학교 전자공학과(공학석사)
1989년 12월: 미국 Arizona State University 전자공학 (공학석사)
1994년 5월: 미국 Texas A&M University 전자공학 (공학박사)
1998년 4월~현재: 광운대학교 전파공학과 조교수
[주 관심분야] 초고주파 및 광전자 공학, RF MEMS

이 병 제



1983년 2월: 경북대학교 전자공학과 (공학사)
1993년 12월: 미국 Southern Illinois University 전자공학과 (공학석사)
1997년 5월: 미국 Southern Illinois University 전자공학과 (공학박사)
2000년 4월~현재: 광운대학교 전파공학과 조교수
[주 관심분야] 마이크로 스트립 안테나 및 전자파이론

김 종 헌



1984년 2월: 광운대학교 전자통신공학과 (공학사)
1990년 6월: 독일 Ruhr University Bochum 전자공학과 (공학석사)
1994년 8월: 독일 Dortmund University 전자공학과 (공학박사)
1995년 4월~현재: 광운대학교 전파공학과 조교수
[주 관심분야] RF, RF power Amplifier, EMC, SDR

김 남 영

1987년 2월: 광운대학교 전자공학과 (공학사)
1991년 2월: New York 주립대학교 전자공학과 (공학석사)
1994년 2월: New York 주립대학교 전자공학과 (공학박사)
1994년 9월~현재: 광운대학교 전자공학과 부교수, 미션텔레콤(주) 대표이사, RFIC센터장
[주 관심분야] RFIC, MMIC, ASIC 등

이 영 호

2002년 2월: 광운대학교 전자공학부 (공학사)
2002년 1월~현재: ㈜나리지*온
[주 관심분야] HBT Modeling 및 Noise 측정

전 상 훈

1993년 2월: KAIST 전자공학과 (공학사)
1995년 2월: KAIST 전자공학과 (공학석사)
2001년: KAIST 전자공학과 (공학박사)
2001년 11월~현재: ㈜나리지*온
[주 관심분야] MMIC 및 large signal modeling

박 재 우

1987년 2월: 광운대학교 전자재료공학과 (공학사)
1989년 2월: 광운대학교 전자재료공학 (공학석사)
2000년 1월: University of Michigan at Ann Arbor 전자공학과 (EECS) (공학박사)
1989년 2월~1994년 7월: 국방과학연구소 연구원
2000년 1월~2000년 10월: 미국 Anadigics사 책임연구원 (6인치 InGaP HBT라인 개발 및 GSM PA개발 담당)
2000년 11월~현재: ㈜나리지*온 이사 (6인치 InGaP HBT 파운드리 서비스 본부장)
[주 관심분야] InGaP & III-V HBT Device Physics & modeling, 공정 개발, MMIC, RF test