Figure 3 Processed moiré deflection interferogram of Figure 2(b)

to record the moiré deflection interferograms. Figure 2 shows two of the captured moiré deflection interferograms of the combustion field. The edge of the combustion is very clear to see in the figure. The distance Δ between the two gratings is 1.66 cm in our experiment, and the reference temperature is $T = 500$ K. Figure 3 is the processed moiré deflection interferogram of Figure 2(b). Based on the interferograms, temperature distribution of the cross-section 4 cm over the orifice of the round tube is reconstructed, as shown in Figure 4. The peak value of the temperature at the center of the flame is 2970°C .

4. CONCLUSIONS

Moiré deviation tomography is adopted successfully in our research to measure the infrared radiation temperature field generated by the burning pyrotechnic compositions with the sampling method of high-speed photography. The temperature distribution of the combustion field is given. Because of its unique merits of noncontact, strong antiinterference, and large range, moiré deviation

Figure 4 Reconstructed temperature distribution of a cross-section

tomography provides a new way for the measurement of high-temperature, high-brightness, and transient field.

ACKNOWLEDGMENT

This work was supported by the talent fund of Juangsu University (1283000118).

REFERENCES

1. H. Yao and A. He, Application of optical computerized tomography in the heat elimination of an aeroengine blade, *Microwave Opt Technol Lett* 38 (2003), 117–119.
2. D.T. Li, R. Xiong, and H. Xue, Temperature measurement in the swirl chamber of an idi engine using moire deflectometry, *Appl Therm Eng* 19 (1999), 543–554.
3. W. Ming, M. Li, Z. Jingang, and L. Dacheng, Subfringe integration method for automatic analysis of moire deflection tomography, *Opt Eng* 39 (2000), 2726–2733.
4. M. Ota, T. Koga, K. Toyoda, and K. Maeno, A measurement of 3-d flow field induced by shock waves using interferometric ct method and numerical analysis, *Int Soc Opt Eng* (2005), 384–392.
5. Z. Bin, S. Yang, S. Yizhong, and H. Anzhi, New reconstruction algorithm for moire tomography in flow field measurements, *Opt Eng* 45 (2006), 117002–117001.
6. D. Giri, M. Jouaneh, and B. Stucker, Error sources in a 3-d reverse engineering process, *Precision Eng* 28 (2004), 242–251.

© 2007 Wiley Periodicals, Inc.

A FULLY INTEGRATED CONCURRENT DUAL-BAND LOW-NOISE AMPLIFIER USING InGaP/GaAs HBT TECHNOLOGY

Yu-Tso Lin and Shey-Shi Lu

Graduate Institute of Electronics Engineering, National Taiwan University, Taipei 10617, Taiwan, Republic of China; Corresponding author: d92943018@ntu.edu.tw

Received 6 April 2007

ABSTRACT: A fully integrated concurrent dual-band low noise amplifier using InGaP/GaAs HBT technology is demonstrated for the first time. A new methodology is proposed so as to achieve simultaneous narrow-band gain and impedance matching at multiple frequencies. The experimental results showed that input return losses of -16.2 and -12.1 dB, voltage gains of 16.8 and 20.1 dB, and noise figures of 2.72 and 2.88 dB were obtained at 2 and 4.6 GHz, respectively with power consumption of 12 mW. © 2007 Wiley Periodicals, Inc. *Microwave Opt Technol Lett* 49: 2763–2765, 2007; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22868

Key words: concurrent; dual-band; LNA; HBT; wireless

1. INTRODUCTION

The diverse range of modern wireless applications necessitates the need to develop a wireless transceiver that can integrate multi-standards in a single chip [1]. While dual-band transceivers by switching between two different bands and receive one band at a time have been introduced [2, 3], they are not sufficient as multifunctionality transceivers [4]. To solve the inevitable increase in cost, footprint, and power dissipation brought by the conventional receiver architectures with multiple independent signal paths for the simultaneous operation at different frequencies, recently Hashemi and Hajimiri have introduced a new concurrent dual-band receiver architecture and the concurrent dual band low-noise

amplifier (LNA) for the new architecture [4]. The oscillation frequency of voltage-controlled oscillator is required to be carefully designed in the concurrent dual-band receiver. As in Figure 1, F_A (2.4 GHz) and F_B (5.2 GHz) are concurrent bands, LO is VCO oscillation frequency, and F_{IA} and F_{IB} are image frequencies. When LO is toward to F_A , F_{IA} is becoming closer to F_A . When LO is toward to F_B , F_{IA} and F_{IB} are becoming closer to F_B and F_A , respectively. Thus image-rejection filter is hard to suppress image signals, and therefore LO frequency design is critical for the concurrent dual-band receiver. Moreover, although excellent performance of this kind of LNA has been reported, one off-chip capacitor and two off-chip inductors are required [4]. In this work, a fully integrated concurrent dual-band InGaP/GaAs LNA without any off-chip component is reported. The experimental results showed that voltage gains of 16.8 and 20.1 dB, input return losses of -16.2 and -12.1 dB, and noise figures of 2.72 and 2.88 dB were obtained at 2 and 4.6 GHz, respectively with power consumption of 12 mW.

2. PRINCIPLES OF CIRCUIT DESIGN

The schematic of our dual-band image rejection LNA, which is recently presented in [5], is depicted in Figure 2. In this circuit, both $Q1$ and $Q2$ operate as common-emitter stages, but they share the same bias current. The signal amplified by $Q1$ is coupled to the base of $Q2$ by $C1$ while the emitter of $Q2$ is bypassed by $C3$ to ground. Power dissipation is reduced through the reuse of the bias current. Traditionally an emitter degenerative inductor is used to generate the 50 Ω for input matching [6]. The concurrent multi-band LNA based on this input matching method requires a parallel LC network in series with one inductor [4], which amounts to one off-chip capacitor and two off-chip inductors. Instead of using inductive feedback technique, the concurrent multi-band LNA presented here adopts the recently developed capacitive feedback technique for multi-band input matching [7]. Namely, the input impedance of the second stage amplifier in parallel with load resistance $R1$ of the first stage provides the necessary parallel RC load of the capacitive feedback amplifier composed of transistor $Q1$, inductor $L1$, and capacitor CF for input matching. For the new concurrent dual-band receiver architecture [4], image rejection is necessary. The LC tank consisting of $L2$ and $C2$ connected at the emitter of $Q2$ resonates at image frequency and hence reduces the gain of the image signal. A series LC branch ($L4-C4$) in parallel with the parallel LC tank composed of $L3$ and $C5$ introduces a zero in the gain transfer function of the LNA at its series resonant frequency, which determines the frequency of the notch in the transfer function. This notch also contributes to the enhancement of the image rejection.

Figure 1 Image frequencies related to LO frequency

Figure 2 The schematic of the InGaP/GaAs dual-band image rejection LNA

3. MEASURED RESULTS AND DISCUSSION

The concurrent dual-band image rejection LNA shown in Figure 2 was implemented in a standard InGaP/GaAs process by the commercial foundry GCTC. The circuit parameters are: $L1 = 0.18$ nH, $R1 = 220$ Ω , $R2 = 1200$ Ω , $C1 = 3$ pF, $C2 = 2.3$ pF, $C3 = 2$ pF, $C4 = 2.24$ pF, $C5 = 2.48$ pF, $CF = 0.11$ pF, $L2 = 1.16$ nH, $L3 =$

Figure 3 The die photograph of the monolithic dual-band image rejection LNA. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

Figure 4 The measured input return loss S_{11} and voltage gain A_v

0.73 nH, and $L_4 = 1.16$ nH. Both transistors Q_1 and Q_2 have the same emitter size of $3 \mu\text{m} \times 12 \mu\text{m} \times 1$ emitter finger. The die photo of the finished circuit is shown in Figure 3. Note that the core circuit (excluding the pads for testing) only occupies a very small area of $380 \mu\text{m} \times 560 \mu\text{m}$. The noise and scattering parameters were measured on wafer using an automated NP5 measurement system from ATN Microwave Inc.

The measured input return loss S_{11} and voltage gain A_v of the dual-band image rejection LNA when biased with $V_{CC} = 3.3$ V and $I_C = 3.5$ mA are shown in Figure 4. The S_{11} is below -10 dB from 1 to 6 GHz, indicating a very broadband matching characteristic of this new input matching technique. Since this LNA is intended for integrated front-end circuits, the voltage gain (A_v) instead of S_{21} is reported here [4]. The narrow-band voltage gains of 16.8 and 20.1 dB at 2 and 4.6 GHz are achieved, respectively. The notch is about 31.6 dB deeper than the peaks, which is translated to the same amount of improvement in image rejection. The measured noise figures are shown in Figure 5. Noise figures (NF) of 2.72 and 2.88 dB are obtained at 2 and 4.6 GHz, respectively. From the experimental results, it is clear that a miniaturized, fully monolithic 2 and 4.6 GHz concurrent dual-band image rejection LNA is realized. The comparison with the prior art of LNA [4] is shown in Table 1.

Figure 5 The measured noise figure NF

TABLE 1 Comparison with the Prior Art of LNA

	This work		[4]	
Frequency band (GHz)	2	4.6	2.45	5.25
Technology	InGaP $2 \mu\text{m}$		CMOS $0.35 \mu\text{m}$	
Voltage gain (dB)	16.8	20	14	15.5
S_{11} (dB)	-16.2	-12.1	-25	-15
Noise figure (dB)	2.72	2.88	2.3	4.5
Supply voltage (V)	3.3		2.5	
DC current (mA)	3.5		4	
Power consumption (mW)	12		10	

4. CONCLUSION

The first concurrent dual-band image rejection LNA using InGaP/GaAs technology is reported. This fully integrated LNA does not need any off-chip component for multi-band input matching and is very small ($380 \mu\text{m} \times 560 \mu\text{m}$). Shunt-shunt capacitive feedback instead of traditional series-series inductive feedback technique is adopted for input multi-band matching. This concurrent dual band LNA achieves voltage gains of 16.8 and 20.1 dB, input return losses of -16.2 and -12.1 dB, and NF of 2.72 and 2.88 dB at 2 and 4.6 GHz, respectively with power consumption of 12 mW. Image rejection ratio greater than 31.6 dB is also obtained.

ACKNOWLEDGMENT

Financial supports from national science council under contract no. NSC94-2212-E-002-067 is appreciated.

REFERENCES

1. T. Schwanenberger, M. Ipek, S. Roth, H. Schemmann, A multi standard single-chip transceiver covering 5.15 to 5.85 GHz, ISSCC Dig Tech Pap (2003), 350-351.
2. S. Wu and B. Razavi, A 900-MHz/1.8-GHz CMOS receiver for dual-band applications, IEEE JSSC 33 (1998), 2178-2185.
3. J. Ryyanen, K. Kivekas, J. Jussila, A. Parssinen, and K. Halonen, A dual-band RF front-end for WCDMA and GSM applications, CICC Dig. of Tech. Papers, Helsinki University of Technology, Helsinki, Finland, 2000, pp. 175-178.
4. H. Hashemi and A. Hajimiri, Concurrent dual-band CMOS low noise amplifiers and receiver architectures, Dig. Symp VLSI Circuits (2001), 247-250.
5. Y.-T. Lin and S.-S. Lu, A fully integrated concurrent dual-band low-noise amplifier using InGaP/GaAs HBT technology, 5th WSEAS International Conference on Electronics Hardware, Wireless and Optical Communications, 2006.
6. R.G. Meyer and W.D. Mack, A 1-GHz BiCMOS RF front-end integrated circuit, IEEE J Solid State Circuits 29 (1994), 350-355.
7. P.-W. Lee, H.-W. Chiu, T.-L. Hsieh, C.-H. Shen, G.-W. Huang, and S.-S. Lu, A SiGe low noise amplifier for 2.4/5.2/5.7 GHz WLAN applications, ISSCC Dig Tech Pap (2003), 364-465.

© 2007 Wiley Periodicals, Inc.