K-Band Low Noise Receiver Module Using MMIC Technology

Kyung-Wan Yu · Man-Seok Uhm · In-Bok Yom · Dong-Pil Chang · Jae-Hyun Lee

Abstract

A K-band GaAs MMIC receiver module has been developed using 0.15 μm HEMT technology process. It incorporates two front end low noise amplifiers, a double balanced diode mixer, and filters. The RF input frequency ranges 20.1 to 21 GHz and the IF output 1.1 to 2 GHz. Test results show an overall conversion gain of more than 27 dB, and less than a 2.2 dB noise figure. The image-rejection ratio greater than 21 dB has been obtained. The isolation between RF and IF ports is better than 27 dB, and between LO and IF is more than 50 dB.

I. Introduction

For wireless communication systems at K-Band and higher frequencies, receiver modules require not only high performance but also small size and light weight. In the past these were primarily hybrid MIC subsystems that integrate RF amplifiers and mixers based on hybrid planar circuit technology. At these frequencies, however, it is harder to realize such circuits due to difficulties in modeling parasitic effects. Replacing each hybrid circuit with monolithic microwave integrated circuit(MMIC) that have no tuning requirements can keep the resultant parasitics to a minimum. Full MMIC frequency converters provide great advantages of cost, size, weight and reliability[1]~[3]. However, most MMIC development in the frequency range over K-Band has remained on the basic functional circuit level of amplifiers and mixers. To realize a multichip MMIC module, it is necessary to develop tuning free circuits which can be directly connected to each other.

Our work, reported in this paper, shows that broadband low noise amplifier MMIC and double-balanced diode mixer MMIC can be integrated along with filters to obtain a complete low noise receiver module for K-band communication system.

All MMICs are fabricated with the 0.15 μm HEMT technology based on the 4 mil-thick GaAs process. The design, fabrication, and test results of the module to convert signals between 20 GHz-band and 1.5 GHz-band will also be described.

II. Receiver Configuration

Each component required for the receiver module as shown in Fig. 1 is first developed, fully characterized individually, and integrated within the module. Because of the extremely short interaction involved in MMICs, the resultant parasitics are kept to a minimum, resulting in a high performance module.

The RF amplifier at the front end receives the signal of 20 GHz and the double-balanced diode mixer down-converts the RF signal to an IF frequency of 1.5 GHz. The band-pass filter(BPF) is used to reject the image signal and prevent the LO signal from appearing at the antenna. The low-pass filter(LPF) is for eliminating RF and LO signals at the mixer output port.

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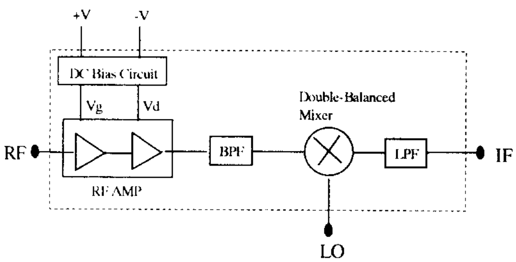

Fig. 1. Block diagram of MMIC receiver module.

III. RF Amplifier.

The RF amplifier, which consists of two low-noise amplifier MMICs, at K-Band and higher frequencies requires not only broadband performance but also small chip size since the MMIC package must be small enough to prevent waveguide-mode package resonance.

Fig. 2 represents the small signal model for 120 μm HEMT device and its circuit parameters. This model represents the average model over the process variation of wafers. With the bias conditions(Vds = 2 V and Ids = 15 mA), the minimum noise figure and the associated gain of a HEMT with a gate length of 0.15 μm are shown in Fig. 3.

The circuit topology of the low noise amplifier is shown in Fig. 4. It incorporated a balanced amplifier and is composed of two-stage HEMT with 4-fingers and 120 μm of gate length[4].

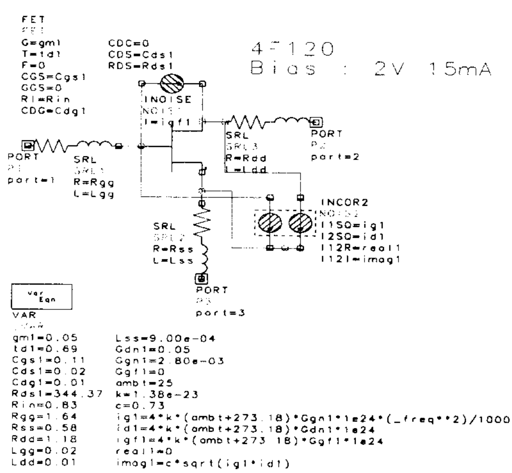

Fig. 2. Small signal equivalent circuit of a HEMT.

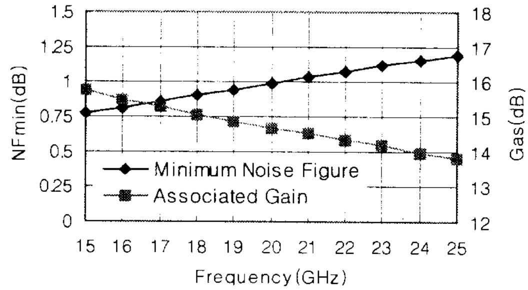

Fig. 3. Calculated minimum noise figure and associated gain.

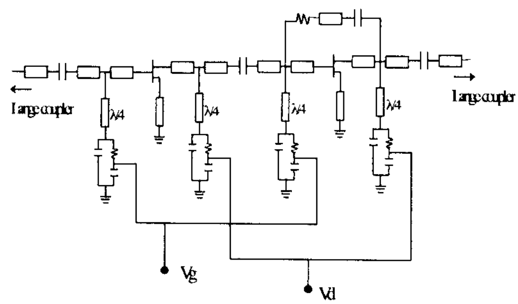

Fig. 4. Schematic of low noise amplifier.

The negative feedback topology cannot be used for input stage, because the additional noise generated by the feedback resistor would further degrade the cascaded noise figure. A solution to a compromise between low noise and input match is the introduction of stage's device source inductance as series feedback. Controlling inductive source feedback enables comparison of S^*_{11} and Γ_{opt}(the source reflection coefficient for minimum noise figure). It can be seen that as the source inductance increases, phase of S^*_{11} approaches that of Γ_{opt}. This series feedback is also selected to improve each stage's stability.

Matching is accomplished by distributed networks. The input stage is matched for low noise, while the second with negative feedback for moderate noise figure and flat gain over broadband ranges. The identical Lange couplers are placed at the input and output of the amplifier to achieve a good match and allow minimal effects Setween chips.

Stability analysis was done on both stages to ensure the amplifier's electrical stability and make sure there were sufficient margin over process variation. Out-of-band oscillation was suppressed by the stabilization R-C network loaded quarter-wave line. All two gates are connected and all two drains are connected thereby requiring only two external dc bias lines. The chip can be biased from either side for flexibility of insertion into different modules. The photograph of the fabricated chip is shown in Fig. 5. The chip size is 2.85 mm × 2.0 mm.

Fig. 6 shows the calculated and measured frequency responses of low noise amplifier under bias conditions of 2 V drain voltage and 60 mA drain current. This figure shows that a measured gain of 19 dB and a noise figure of 1.7 dB have been obtained over 19~23 GHz range and agree well with the calculated ones.

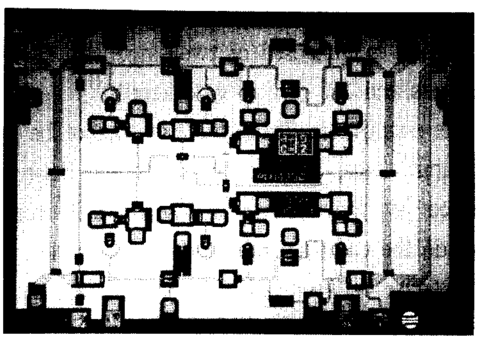

Fig. 5. Photograph of fabricated low noise amplifier.

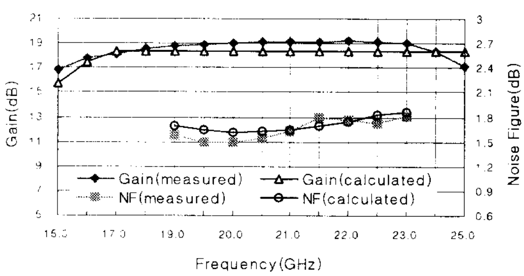

Fig. 6. Calculated and measured performance of low noise amplifier (on-wafer testing).

IV. Double-Balanced Mixer

Fig. 7 shows the configuration of a double-balanced diode mixer. It consists of four 0.15 μm × 32 μm HEMT schottky doides used as the mixing elements, 180 degree baluns, and matching networks.[5]

The RF and LO 180 degree baluns are realized using 90 degree Lange couplers with 90 degree offset lines. This provides better isolation between ports and less sensitivity to mismatches at RF/LO ports than baluns formed from high/low-pass filter networks. The isolation by each 3 dB port in phase of the baluns should be checked because it can greatly affect the level of spur products that come from the mixer. The center tap of the LO balun is grounded. The center tap of the RF balun serves as the IF output because the LO-to-IF isolation, which is more critical than the RF-to-IF isolation, would be worse. Matching networks between the diode ring and the baluns providesgreater isolation between ports and necessary dc returns for this

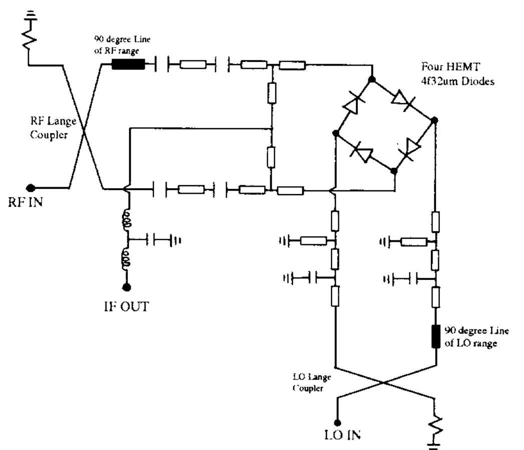

Fig. 7. Schematic of double-balanced diode mixer.

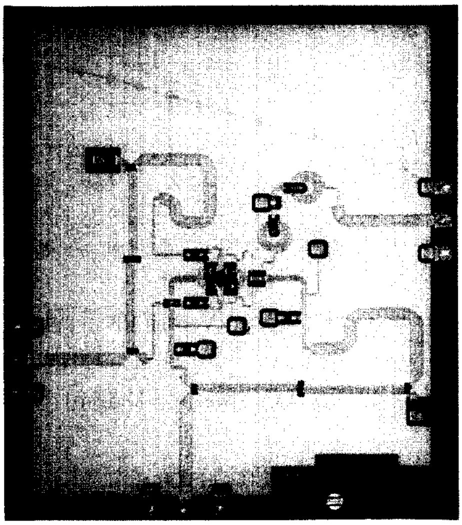

Fig. 8. Photograph of fabricated double-balanced diode mixer.

type mixer. The low pass matching at IF output was incorporated to suppress RF and LO signals by using MIM capacitors and spiral inductors. The fabricated mixer chip, shown in Fig. 8, measures 2.6 mm × 3.15 mm.

Fig. 9 shows the calculated and measured performance of the mixer. The mixer has a RF frequency range of 20 to 23 GHz and uses LO from 18.5 to 21.5 GHz to produce 1.5 ± 0.5 GHz IF signals. The LO power applied was 13 dBm, while the RF level was maintained at -15 dBm. The typical conversion loss is around 6.8 dB ahich is better than the calculated one. Both LO-to-IF and RF-to-IF isolations are lower than 50 dB.

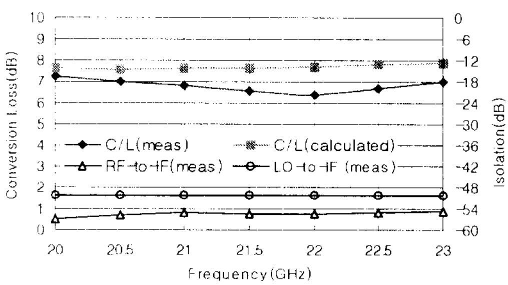

Fig. 9. Calculated and measured performance of double-balanced mixer(on-wafer testing).

V. Receiver Module

The receiver module as shown in Fig. 10 has been developed using above-mentioned MMICs, band-pass filter, and low-pass filter. Each filter was fabricated on the 10-mil alumina substrate(ε_r = 9.9).

The module was designed to be small enough to prevent waveguide-mode package resonance[6].

Bonding ribbons directly connect the input and output ports of each MMIC chip to adjoining chips or MIC circuits. The distance between them is kept approximately 0.1 mm, which is determined to give easy assembly. A pair of +5V and -5V is supplied to the bias circuits from power supply. The module was powered at the biases with a total current of 120 mA.

The measured conversion gain of the module is

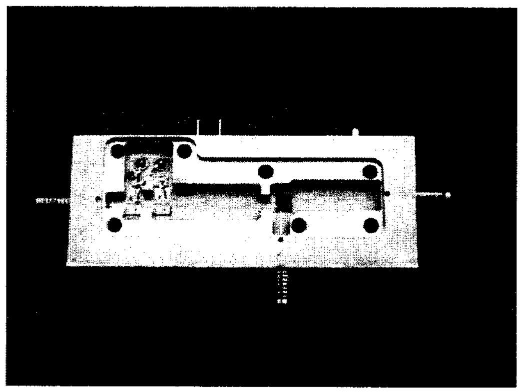

Fig. 10. Developed low noise receiver module.

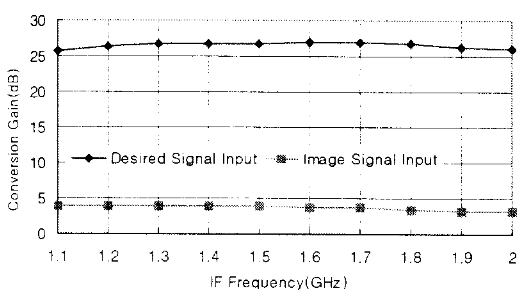

Fig. 11. Conversion gain of the receiver module.

shown in Fig. 11. The receiving RF frequency, which is determined by image-rejection band-pass filter, ranges 20.1 to 21 GHz. The typical gain of 27 dB and the image rejection ratio greater than 21 dB have been obtained. LO drive of +11 dBm is sufficient to drive the module.

The measured noise figure is less than 2.2 dB as shown in Fig. 12. The measured RF and LO input return losses are shown in Fig. 13. Both ports have better than 12 dB.

Fig. 14 shows the IF output power versus the RF input power. At 1-dB compression point the output IF power is about -6dBm. The third-order intercept point of the receiver is measured at 8dBm. The isolation between RF and IF ports is better than 27 dB, and between LO and IF is more than 50 dB.

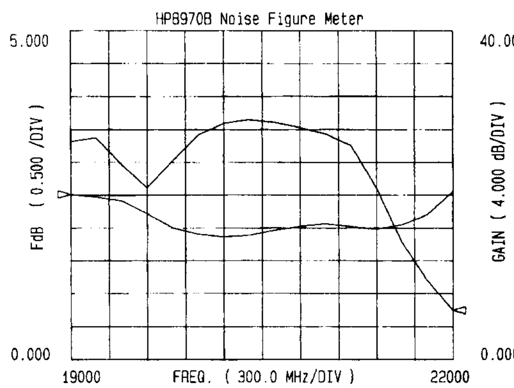

Fig. 12. Noise figure of the receiver module.

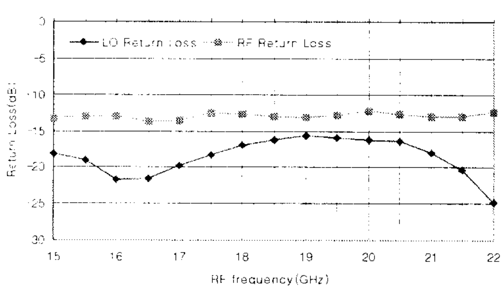

Fig. 13. Measured RF and LO return losses(RF power = -42 dBm, LO power = +11 dBm).

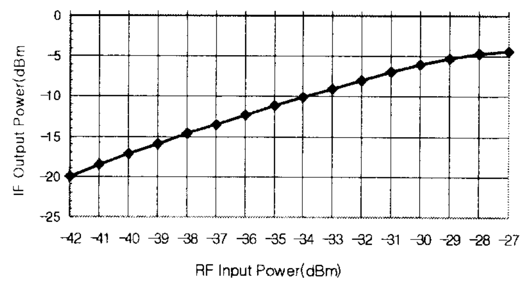

Fig. 14. IF Output Power Versus RF Input Power (RF frequency = 20.5 GHz, LO frequency = 19 GHz, LO power = +11 dBm)

Ⅵ. Conclusion

The development of a low noise 20 GHz-band MMIC receiver module has been reported. The module exhibits an overall conversion gain of more than 27 dB, and less than a 2.2 dB noise figure. The image-rejection ratio greater than 21 dB. The isolation between LO-to-IF and RF-to-IF of greater than 50 dB and 27 dB have been obtained, respectively. This module is suitable for satellite and commercial receiving system applications.

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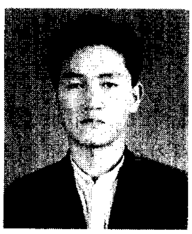

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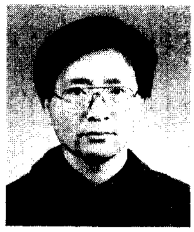

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