A Monolithic W-band High-gain LNA/Detector for Millimeter Wave Radiometric Imaging Applications

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ABSTRACT

We have demonstrated a monolithic W-band six-stage low noise amplifier/detector, using 0.1 µm passivated pseudomorphic $Al_{0.25}Ga_{0.75}As/In_{0.22}Ga_{0.78}As/GaAs$ HEMT technology. The front-end LNA, over the band from 85 to 96 GHz has achieved an average small signal gain of 40 dB which is the highest gain value ever reported for a MMIC operating in the W-band. The measured minimum resolvable temperature of the MMIC is about 1.6 ^{o}K, where the dominant noise source is attributed to be the 1/f noise of the monolithically integrated HEMT diode.

INTRODUCTION

Monolithic microwave/millimeter-wave integrated circuit (MMIC) technologies have advanced rapidly in the past years. MMIC components such as low noise amplifiers, mixers, voltage control oscillators, power amplifiers, preamplified detectors operating up to 100 GHz have been successfully demonstrated [1-4]. Advance of MMIC technology not only improves the existing microwave system performance but also enable several new system designs. One example is the direct-detection millimeter-wave (MMW) radiometric imaging system.

The interest of MMW imagining is primarily due to its capability of imaging through fog, cloud, smoke, sandstorms, and at dark [5-8]. Owing to lack of MMW components, existing MMW imaging arrays were typically based on heterodyne approach and relied on a front-end mixer to downconvert an incoming signal to low frequency for signal processing . Not only does this approach suffer from high conversion loss, high noise figure, but also it requires complicated local oscillator (LO) signal generation and distribution. The LO problem is aggravated with increasing imaging array size. An alternative approach is to employ a direct-detection architecture which requires a high gain, low noise amplifier (LNA) and a detector circuit [9]. This approach has the advantages of no LO requirement, low dc power consumption, fewer parts, and low cost. These advantages becomes even more pronounced in focal plane staring array systems. However, despite the advantages described, the direct detection architecture has been less popular than the heterodyne approach for lack of enabling circuit components, particularly the high gain LNA.

Owing to recent advance in the MMW MMIC LNAs [1], the simple direct detection approach has become feasible. We have demonstrated several direct detection receiver hybrid modules previously with Q- and W-band LNAs and diode detectors [10,11]. These modules have shown good results and proved the concept. However, due to insufficient gain of the single MMIC LNAs, these modules required several MMIC LNAs in series which increases circuit instability and assembly difficulty. For large imaging array applications, it would be preferred to have a single MMIC LNA/detector with sufficient high gain and broad bandwidth. Two major design considerations in a high gain LNA are circuit stability and chip size. Previous designed single-ended high gain LNA/detector has achieved a gain of 34 dB but with narrow bandwidth (2GHz), and its stability is sensitive to the input load [12]. In this paper, we present a monolithic W-band six-stage LNA/detector which has a gain of 40 dB with 10 GHz bandwidth. Due to balanced design in the input and out stages, the MMIC is stable and has high yield. The MMIC has achieve a minimum resolvable temperature (ΔT) of 1.6 ^{o}K which is a factor of 3 better than that of previous reported MMIC [12].

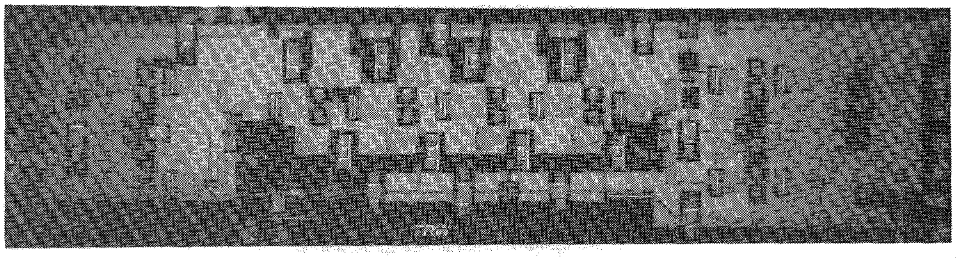

Fig.1. Photomicrograph of the complete monolithic seven-stage LNA/detector.

MMIC DESIGN

Figure 1 shows the photomicrograph of the complete monolithic six-stage LNA/detector with a die size of 6.5 mm X 1.7 mm. The LNA alone is also fabricated on the same wafer for circuit diagnosis. The MMICs were fabricated using the TRW 0.1 μm T-gate passivated pseudomorphic (PM) $Al_{0.25}Ga_{0.75}As/In_{0.22}Ga_{0.78}As$ HEMT production line process [13]. The LNA consists of a 4-stage single-ended LNA and two one-stage balanced LNAs at the LNA input and output, respectively, to improve overall circuit stability. A 40 μm HEMT is used at each LNA stage. Both drain and gate bias networks were low-pass topologies to stabilize the circuit and prevent any cross coupling between stages. All line-to-line coupling effects were investigated by full-wave electromagnetic analysis tools [14].

For process compatibility, the monolithically integrated detector employs a Schottky diode constructed from a HEMT device with the drain and source connected together. Typical zero bias cut-off frequency of a HEMT diode with two finger and total length of 16 μm is about 450 GHz [4]. In the MMIC, all the drain bias, gate bias, detector bias and output pads are placed in one side, opposite to the input of the MMIC, to simplify the bias interconnect of the array constructed in brick architecture.

MEASURED RESULTS

The completed MMICs were measured using an automated W-band on-wafer measurement system which shows significant advantages of repeatability, volume testing capability and low cost over conventional in-fixture testing procedure. Note that the MMIC testing results obtained from this on-wafer measurement system have shown good agreement with the in-fixture measured data [15]. Figure 2 shows the histogram of the measured gain of the six-stage LNA as a function of the input frequency for the device biased at V_d=2 V and I_d=80 mA. The amplifier has achieved an average gain of 40 dB over the band from 85 to 96 GHz This gain performance is the best result ever reported for a monolithic amplifier operating at this frequency range. The LNA typically shows a noise figure of 6.5 dB as indicated in the Fig. 3, which shows the histogram of the measured noise figure of the LNA for the device biased at V_d=2 V and I_d=50 mA. The monolithic LNA/detector was also tested on wafer with a W-band noise source [16] as the input signal. Figure 4 shows the histogram of the measured detector output voltage change between noise source on and off for the MMIC bias at Vd=2V, Id=60, 70, and 80 mA. Figure 5 shows the MMIC response as a function of input frequency with a power of -90, -70 and -65 dBm. The MMIC shows a detection bandwidth of about 10 GHz the same as that of front-end LNA. The MMIC is further assembled in a WR-10 wave guide text fixture with W-band horn antenna for hot- and cold- load test. The absorbers at room and liquid nitrogen temperatures are used as the hot and cold loads, respectively. The measured output voltage difference between the hot and cold loads was typically about 652 mV with root-mean-square noise voltage of 4.9 mV(10 ms integration time), corresponding to a signal to noise ratio of 42.5 dB and a ΔT of 1.6 °K. We found the MMIC ΔT performance is limited by the HEMT diode 1/f noise.

CONCLUSION

Advance of MMIC technology has enabled the next generation MMW radiometric imaging. A W-band high gain LNA/detector has been developed for this application. The MMIC has achieved a ΔT of 1.6 °K. We believe that the ΔT can be improved by increasing the gain of the front-end LNA, improving the diode 1/f noise with optimal diode device profile by selective epitaxial

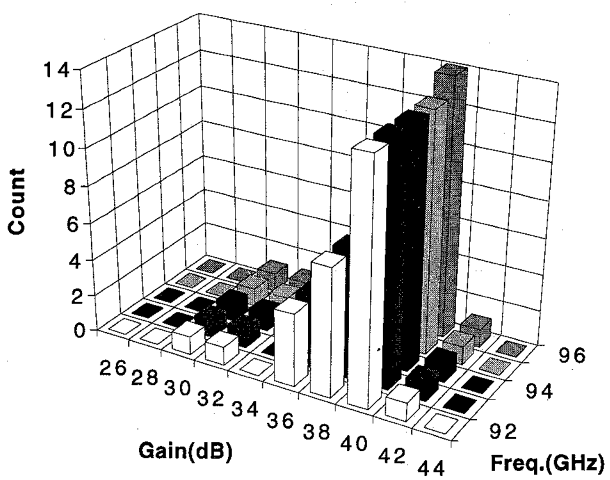

Fig.2. Histogram of the measured gain of the MMIC LNA biased at Vd=2V and Id=80 mA.

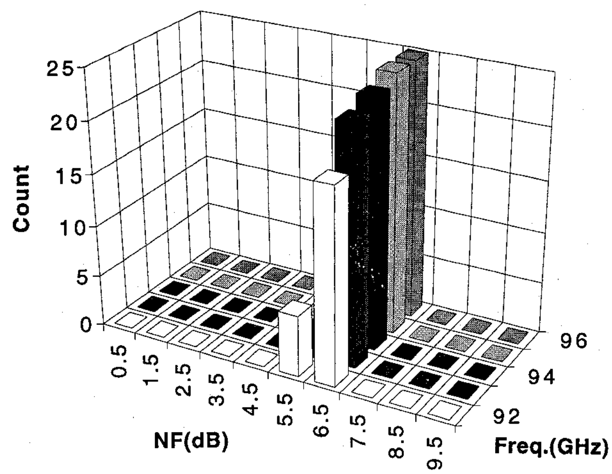

Fig.3. Histogram of the measured noise figure of the MMIC LNA biased at Vd=2V and Id=50 mA.

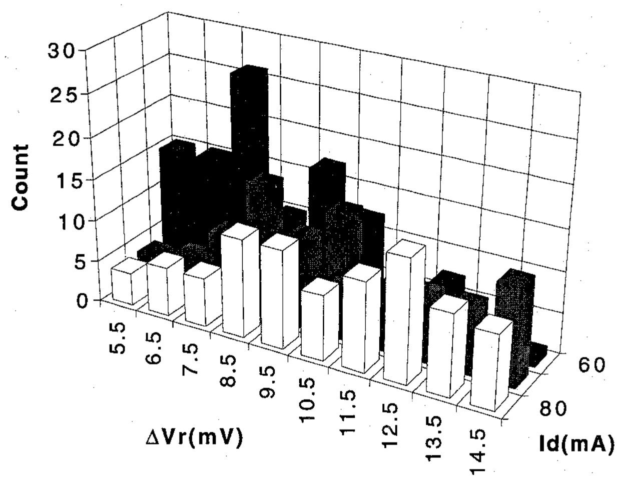

Fig. 4. Histogram of the measured detector output voltage change between noise source on and off for the MMIC LNA/detector.

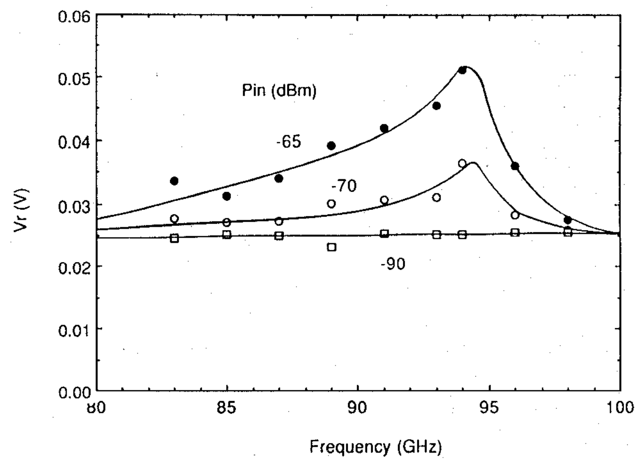

Fig. 5. Measured detection bandwidth of the MMIC LNA/detector for various input powers

technology, or operating the MMIC at Dicke mode with a switching rate where diode 1/f noise is less. Based on the MMIC, larger linear or two-dimensional direct-detection radiometric imaging staring array can be easily constructed with low cost, high reliability, and low maintainability. These imaging array can be applied in the future all weather aircraft landing, traffic sensing, and collision avoidance warning system.

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