A W-band Ultra Low Noise Amplifier MMIC Using GaAs pHEMT

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***Abstract* — This paper presents a newly developed 76 GHz three-stage LNA for automotive radar systems. The LNA utilizes multi band rejection filter type stabilizing circuits to achieve good noise figure together with good stability. The operating bias condition was carefully chosen to obtain low temperature dependence of gain. As a result, the LNA delivers a noise figure of 3.5 dB typically, small temperature dependence of gain of -0.016 dB/deg.C and high return loss using highly conventional 0.19 μm T-shaped gate AlGaAs/InGaAs/GaAs pHEMT process.**

I. Introduction

In recent years, automotive radar systems have progressed from the development stage to mass production. Almost all automotive radar systems use a homodyne frequency modulation continuous wave (homodyne FMCW) radar system because of its simple architecture [1]-[6]. In this system, an LNA MMIC plays an important role in improving the noise figure of the receiver circuit. As a result, demand for an LNA MMIC is increasing. An LNA for automotive radar systems requires a low noise figure across a wide temperature range and low temperature dependence of gain because it is used in severe ambiance of temperature. Many MMIC chips for automotive radar systems have been developed, however, no temperature dependence characteristics have been reported on the developed MMICs.

This paper demonstrates a 76 GHz LNA MMIC which has low noise figure across a wide temperature range and low temperature coefficient of gain using the productive 0.19 μm T-shaped gate AlGaAs/InGaAs /GaAs pHEMT process.

II. Circuit Design

In designing an LNA for automotive radar systems, the main objectives were to:

- achieve necessary RF performance characteristics using a conventional wafer process
- reduce temperature coefficient of gain
- obtain sufficient circuit stability without a chip capacitor
- enable using an LNA in a package which is small enough to suppress waveguide mode transmission at 76 GHz
- suppress gain in the lower frequencies

The LNA was fabricated using an electron beam defined 0.19 μm T-shaped gate AlGaAs/InGaAs/GaAs pHEMT device structure because this process has been used for many other applications and is productive.

Figure 1 shows the circuit diagram of the three stage LNA. Each stage utilizes a 40x2 μm gate width pHEMT. An LNA for automotive radar systems must have low

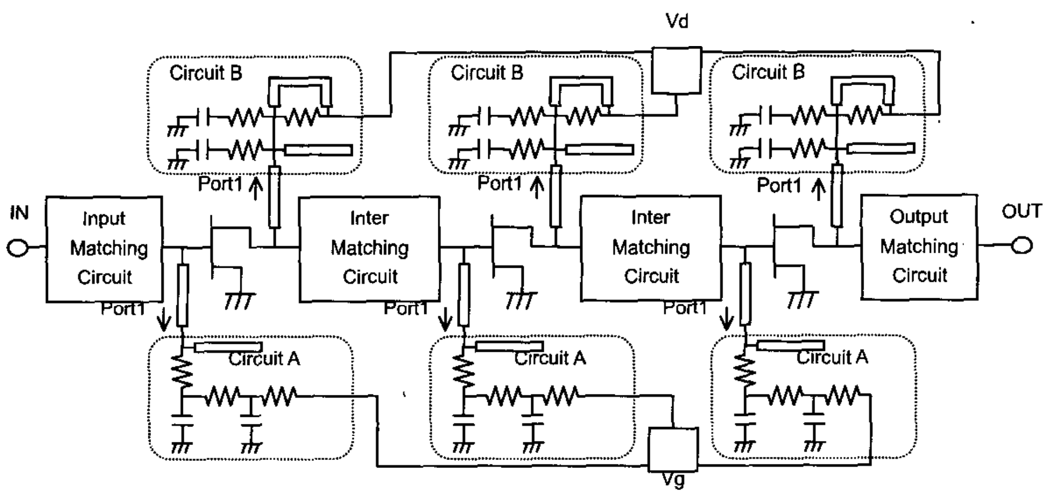

Figure 1. Circuit diagram of LNA

temperature dependence of gain because it is used in a

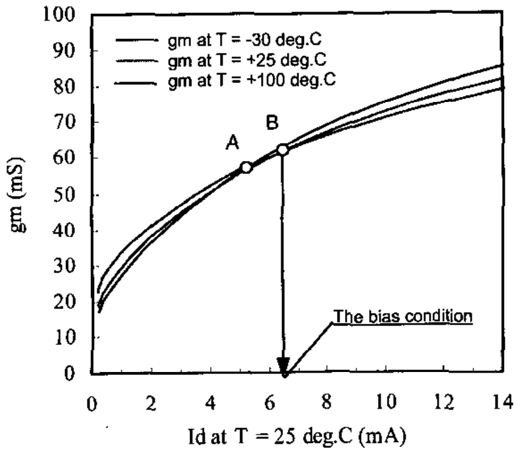

Figure 2. Traces of gm vs. Id at different temperatures

wide range of temperatures. Thus, its bias condition was carefully selected to balance the gain and its temperature dependence. Figure 2 shows traces of gm vs. Id at Vd = 2 V, which was measured in different temperatures. In Figure 2, the X-axis is the Id at T = 25 deg.C, which is associated with the same Vg at different temperatures. Curves of gm vs. Id at different temperatures cross at a certain Id, because Vp and Ids decreases steadily subject to temperature rise. In this case, these traces cross at point A and gm is constant at various temperatures at this bias point. It is difficult, however, to achieve sufficient gain at this bias condition. Thus, to obtain higher gain without substantially increasing temperature dependence of gm, the bias condition was determined at the point B (Id = 6.4 mA at T = 25 deg.C) near the point A. The Vg defined by this Id at T = 25 deg.C is fixed for all measured temperatures.

Small signal equivalent circuit parameters of GaAs pHEMT at this bias condition were extracted from S-parameters, measured in the frequency range from 0.5 GHz to 40 GHz using the hot and cold model. Noise parameters were calculated using the equivalent circuit and minimum noise figure at 12 GHz [7]. This pHEMT is unstable for frequencies below 65 GHz in this bias condition (shown in Figure 3). To obtain good stability, multi-band rejection filter type stabilizing circuits (circuit A and B in Figure 1) were employed. Both circuits were designed so that the impedance at port1 is short at 76 GHz, and sufficiently low below 65 GHz (shown in Figure 4). As a result, these circuits enable an improved K factor of over 1 for frequencies below 65 GHz (shown in Figure 3) without degrading the noise figure and gain performance at 76 GHz. These circuits, which also work as a loop gain filter, permit unifying gate bias pads and drain bias pads.

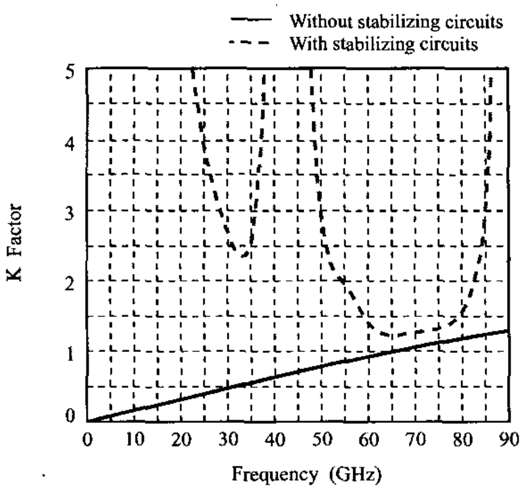

Figure 3. Calculated K factor of the pHEMT

Usually some chip capacitors are used to stabilize an MMIC amplifier. Consequently, it was difficult to mount both an MMIC amplifier and chip capacitors in a package which is small enough to suppress the waveguide mode transmission of the RF signal at 76 GHz. This three-stage LNA does not require any chip capacitors near the MMIC because of the stabilizing circuits. The length of the LNA perpendicular to the signal path was designed to enable assembling the LNA in a small package whose length perpendicular to signal path is less than 1.5 mm.

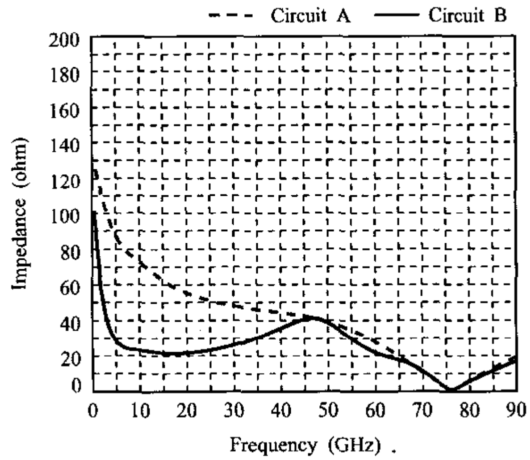

Figure 4. Simulated impedances of stabilizing circuits

The input matching circuit was designed to balance noise figure and input return loss. For inter matching circuits, the conjugate matching technique was adopted to minimize insertion loss of matching circuits and to reduce chip size. To suppress gain in the frequency range below 65 GHz, these matching circuits employ a band pass filter structure using two open stubs, a short stub, and a series capacitor with MIM structure. The output matching circuit was designed to achieve good return loss broadly to allow for variations in the wafer process. To ensure accuracy of design of these matching circuits, 2.5-D electromagnetic field simulator was utilized.

III. Measured Results

Figure 5 shows a photograph of the LNA. The chip size is 1.88 mm x 1.20 mm. The length of the LNA perpendicular to signal path is short enough to mount it in a package that suppresses the waveguide mode transmission in the frequency range from 76 GHz to 77 GHz. The S-parameter and noise figure were stably measured because of multi-band rejection filter type

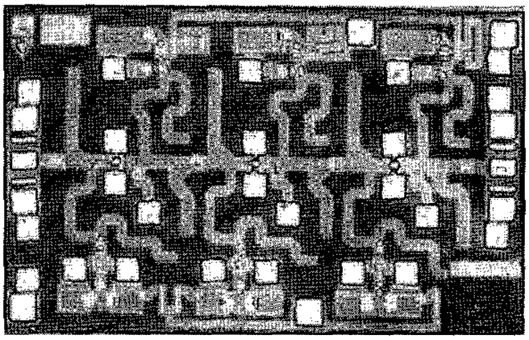

Figure 5. Photograph of the LNA

stabilizing circuits. Figure 6 shows the measured S-parameter results of the LNA compared with the design data. The bias condition for the LNA was Vd = 2 V, Id = 19.2 mA. The LNA typically has small signal gain of over 15 dB, input return loss (RLin) of over 10 dB and output return loss (RLout) of over 15 dB in the frequency range from 76 GHz to 77 GHz. The gain in the frequency range below 65 GHz was suppressed below 0 dB because of band pass type inter matching circuits. These results show good agreement with simulated data even at the lower frequencies. Figure 7 shows the measured noise figure of the LNA coupled with

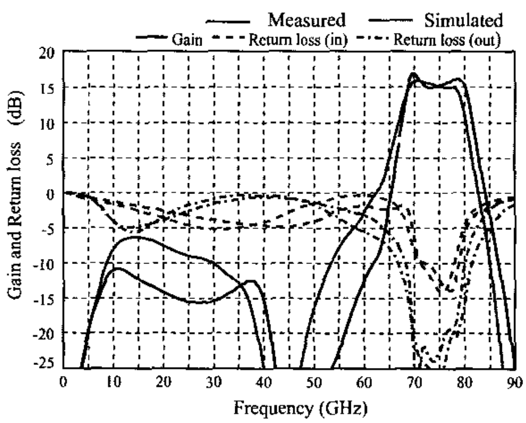

Figure 6. Measured S-parameters with simulated data

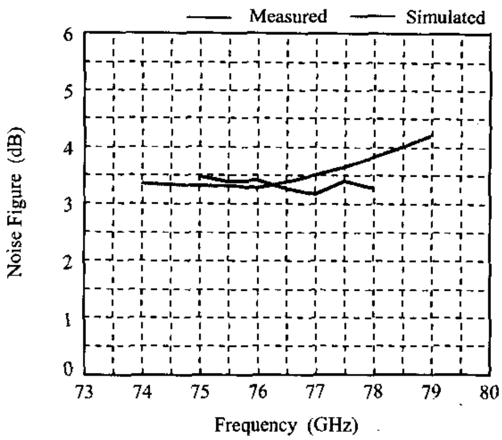

Figure 7. Measured NF performance with simulated data

simulated data. The measured noise figure is typically less than 3.5 dB in the frequency range from 76 GHz to 77 GHz, and it shows good agreement with the simulated data.

Figure 8 shows temperature dependence of gain and noise figure at 76.5 GHz. Generally, MAG of pHEMT is degraded at the ratio of about –0.015 dB/deg.C. This LNA consists of a three-stage amplifier, but its temperature coefficient of gain is only –0.016 dB/deg.C. This small ratio was a result of careful bias condition consideration. The temperature coefficient of noise figure is 0.013 dB/deg.C and the noise figure in the measured temperature range is less than 4.5 dB. An LNA for automotive radar systems must maintain a low noise figure across a wide temperature range, so this achievement is very significant.

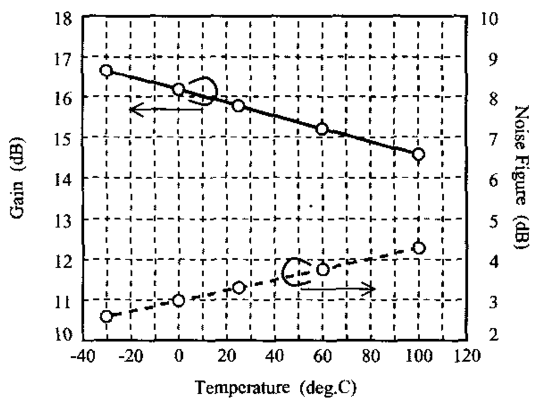

Figure 8. Temperature dependence of gain and noise figure at 76 GHz

IV. Conclusion

A W-band three stage low noise amplifier MMIC has been developed, which typically has gain of over 15 dB with small temperature dependence, RLin of over 10 dB, RLout of over 15 dB and noise figure of under 3.5 dB in the frequency range from 76 GHz to 77 GHz, using the highly productive 0.19 μm T-shaped gate AlGaAs/In GaAs/GaAs pHEMT process. This achievement enables mass production of an LNA for 76 GHz automotive radar systems.

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