LETTER

A five-octave broadband LNA MMIC using bandwidth enhancement and noise reduction technique

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Abstract This letter presents the design and fabrication of a five-octave broadband low noise amplifier (LNA) using 0.1- μm GaAs pseudomorphic high-electron mobility transistor (pHEMT) technology. The multi-peaking bandwidth enhancement and noise reduction technique is proposed for a cascode topology to significantly improve the performance of the LNA. The fabricated LNA achieves a -3 dB bandwidth of 1–32 GHz with an average gain of 12.2 dB, an excellent noise figure (NF) of 1.9–2.6 dB, and an output-referred 1 dB compression point ($OP_{1\text{dB}}$) of 10.2–12.7 dBm with good input/output matching over the entire bandwidth. To the best of the authors' knowledge, these results demonstrate the lowest room-temperature NF ever reported for fully integrated MMIC amplifiers with a bandwidth of 1 to more than 30 GHz.

Keywords: ultra-wideband, low noise amplifier (LNA), cascode, GaAs, pseudomorphic high electron mobility transistor (pHEMT)

Classification: Integrated circuits

1. Introduction

Advancements in wireless communication technology have prompted the demand for multi-octave broadband amplifiers for application in high data rate transmission, ultra-wideband (UWB) systems, high-resolution radars, and instrumentations where a broadband LNA is a crucial component [1, 2, 3, 4]. For designing UWB amplifiers, Darlington configurations [5, 6, 7], feedback techniques [8, 9, 10, 11, 12, 13], inductive-peaking techniques [14, 15, 16, 17], and distributed amplifiers (DAs) [18, 19, 20, 21, 22, 23, 24] are the most popular approaches. Researchers in [5] reported broadband feedback Darlington amplifiers with bandwidth enhancement. A broadband gallium-nitride (GaN) LNA using a modified resistive-feedback topology is reported in [8]. A 0.1–20 GHz UWB LNA with the combined techniques of shunt-resistive feedback, dual inductive-peaking techniques and an improved active load is reported in [15]. The study in [18] reported a tapered, distributed LNA that can provide a lower broadband average NF compared to a uniform DA by optimal tapering of the gate and drain transmission lines and transistors. A fully integrated distributed amplifier using the GaAs

HEMT–HBT cascode gain stage is explored in [19]. However, previously reported UWB amplifiers tend to have high NFs, therefore, they are not preferable in many applications as receivers. Furthermore, many reported UWB LNAs [5, 16, 17, 25] cannot realize full integration with the entire RF choke bias circuit or input/output blocking capacitors, which is inconvenient in practical applications.

In this letter, we report on a fully integrated UWB LNA with a low noise figure and flat gain over the full operation bandwidth of 1–32 GHz. We propose the multi-peaking bandwidth enhancement and noise reduction technique, which is used in input matching, inter-stage matching and the RF choke bias circuit of the LNA. The five-octave bandwidth LNA presented in this letter achieves the excellent NF, relatively high $OP_{1\text{dB}}$ and FOM, with comparable gain, power consumption and chip area. Meanwhile, the measured room-temperature NF is the lowest among fully integrated MMIC amplifiers ever reported with a bandwidth of 1 to more than 30 GHz.

2. Design and analysis of the UWB LNA

The LNA is implemented in the 0.1- μm AlGaAs/InGaAs pHEMT technology. The cascode topology was employed because it has wider gain bandwidth over the common-source configuration due to its suppression of the Miller effect [26, 27]. Transistors M_1 , M_2 have equal size of $8 \times 50 \mu\text{m}$. The LNA was biased with a drain-to-source voltage (V_{DS}) of 2 V and a gate-to-source voltage (V_{GS}) of -0.42 V, since simulations demonstrate that the transistor exhibits the lowest minimum noise figure (NF_{min}) in the full operation band under this bias condition, and the NF_{min} is 0.7 dB at 16 GHz.

The improved cascode configuration with the multi-peaking bandwidth enhancement and noise reduction technique, mainly including inductors L_A , L_X , L_Y , L_D and L_1 , is illustrated in Fig. 1. Fig. 2 shows the small-signal equivalent circuit of the proposed LNA. The inductor L_A is added in series with the total parasitic capacitance at node A, mainly including the gate-to-source parasitic capacitance of M_1 (C_{gs1}), as shown in Fig. 2. With careful selection of the inductor L_A , the high resonant frequency point with the capacitance at node A is introduced, thus expanding the gain bandwidth. The series inductor L_A was realized using a micro-strip line with a width of $35 \mu\text{m}$ to reduce the NF because the parasitic resistance of the input

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Fig. 1. Complete schematic of the proposed broadband LNA.

Fig. 2. The small-signal equivalent circuit of the LNA using the multi-peaking bandwidth enhancement and noise reduction technique.

matching circuit has a great influence on the NF of the total circuit. The noise introduced by M_2 at low frequencies of the operation band is much less. At high frequencies, the parasitic capacitance C_X at node X can increase the noise considerably, where C_X is the total parasitic capacitance and includes the parasitic capacitances of M_1 and M_2 at node X. Therefore, an 84 pH inductance L_X is intentionally added between M_1 and M_2 to eliminate the effect of C_X by resonating with it at the high operating frequency, as shown in Fig. 2. The NF of the cascode cell can be minimized accordingly [28]. Simulations show that the NF of the proposed LNA is reduced from 2.72 to 2.51 dB due to the impact of L_X at 32 GHz. The effect of L_X on the input is only a slight increase in the input impedance, since the inductance is small. Moreover, to meet the challenge of full integration with the broadband RF choke, the on-chip drain bias circuit (Z_L) including the series inductance network is employed, as shown in Fig. 1 enclosed by dash line. The large inductance L_D introduces low and high resonant frequency points, while the moderate inductance L_Y introduces a high resonant frequency point. The three optimized resonant frequency points help to achieve the desired RF choke performance in a wide band with the advantages of a lower NF and higher operation frequencies compared with the active load structure.

Furthermore, the inductor L_1 is used to compensate for the roll-off of the output impedance of the cascode topology, thus enhancing the gain in high operation frequency bands [15].

The resistors R_d and R_1 are employed to decrease the quality factor of the bias circuit and enhance the circuit stability, as shown in Fig. 1. The design employs an R-L-C feedback loop to achieve a flat gain response in a wide band and improve the stability of the LNA, as shown in Fig. 2.

Fig. 3. Die photograph of the proposed LNA.

Fig. 4. Measured and simulated S-parameters of the amplifier.

Fig. 5. Measured and simulated NF and OP_{1dB} of the amplifier.

3. Measurement and discussions

The die photograph of the LNA is shown in Fig. 3. The chip area is 1.3 mm × 1.4 mm including pads. The LNA RF performance was measured with a KEYSIGHT N5245A PNA-X at room temperature. The on-wafer measurement results are shown in Figs. 4–5. Fig. 4 shows the measured and simulated S-parameters including S_{21} , S_{11} , and S_{22} . The measured S_{21} reaches a peak value of 13.1 dB at 16 GHz and an average value of 12.2 dB over the 1 to 32 GHz band (−3 dB bandwidth). The measured $|S_{11}|$ is better than −8 dB between 1.5 and 32 GHz, and $|S_{22}|$ is better than −8 dB between 2 and 32 GHz. Fig. 5 shows the measured and simulated NF and OP_{1dB} . The measured NF is 1.9–2.6 dB throughout the band, and the average NF is 2.1 dB. The measured OP_{1dB} is from 10.2–12.7 dBm over the entire bandwidth, as shown in Fig. 5. The LNA is unconditionally stable for all frequencies ($K > 1$). The above

measurement results are obtained with a V_{GS} of -0.42 V and a total drain voltage (V_{DD}) of 4.0 V. The whole chip draws 44 mA from the power supply, resulting in a power consumption of 176 mW. A comparison between this work and the previously reported III–V compound-based broadband amplifiers with various technologies is summarized in Table I. The five-octave bandwidth LNA presented in this letter exhibits the lowest room-temperature NF ever reported for fully integrated MMIC amplifiers over the 1 – 32 GHz band. Meanwhile, it achieves higher OP_{1dB} and FOM with comparable small signal gain among the listed amplifiers in Table I.

Table I. Performance comparison.

Ref	Bandwidth (GHz)	Gain (dB)	NF (dB)	OP_{1dB} (dBm)	FOM
[6]	dc–25.3	13.2	7.8	–0.7	-
	1.8–26	11	8.6	–0.75	
	dc–29.8	10	10.2	1.46	
[8]	1–25	13	3.3–4.6	17.5	0.1
[15]	0.1–20	28.6	3.1–5.8	7.8–12.7	1.0
[19]	dc–40.4	8.2	4.2–16.5*	7	0.49
	dc–43.5	8.5	4.2–18.5*	8	0.32
[29]	1–13	13.1–18.2	>5.28	–15*	2.7
[30]	0.5–30	10.5	7.5 [#]	>–5	0.53
This work	1–32	12.2	1.9–2.6	10.2–12.7	1.3

*estimate value from figure; # average NF from 1 to 30 GHz; the figure-of-merit (FOM) is defined in [31].

4. Conclusion

A fully integrated LNA MMIC using a $0.1\text{-}\mu\text{m}$ GaAs pHEMT process has been successfully presented in this letter. The multi-peaking bandwidth enhancement and noise reduction technique is proposed and successfully used in a feedback cascode topology. The bandwidth and noise performance of the LNA are strongly improved. The 1 – 32 GHz LNA obtains a relatively flat gain of 12.2 dB, a noise figure of 1.9 – 2.6 dB, and a maximum OP_{1dB} of 12.7 dBm with good input/output matching. The proposed UWB LNA can be further applied to modern high-speed data communications due to its superior performance.

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