A 19 GHz Low Phase Noise HFET VCO MMIC

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Abstract — **A 19 GHz extremely low phase noise voltage controlled oscillator (VCO) MMIC is presented. To reduce the phase noise of the VCO, a heterostructure field effect transistor (HFET) is used as the active device, because its property of low frequency noise is superior to that of high electron mobility transistor (HEMT). This VCO showed the typical phase noise of -120 dBc/Hz at 1 MHz offset from carrier. This performance is better than other VCOs operating above 10 GHz. Measured tuning range is 400 MHz and output power is 2 dBm. The fabricated MMIC chip size is 2.7 mm x 1.4 mm.**

I. Introduction

Oscillators are key components for microwave and millimeter-wave communication systems requiring low phase noise characteristics. In particular, voltage controlled oscillators (VCOs) for automotive radars have been studied in recent years [1, 2, 3]. Fundamental VCOs are preferred for automotive radars in view of cost. Because fundamental VCO chip size is small and there is no need to use multipliers. However it is well known that as the oscillation frequency increases, the phase noise of VCO rises. The phase noise is one of the parameters that cannot be traded-off, so one solution employs lower frequency VCOs followed by one or two multipliers [1, 4]. To reduce the phase noise of the VCO, it is effective to reduce low frequency noise (LFN) because phase noise near the carrier is caused by LFN such as 1/f noise, thermal noise, and so on. Heterostructure field effect transistors (HFETs) have better LFN characteristics than high electron mobility transistors (HEMTs) have, although HEMTs have relatively good high frequency performance. Therefore, we adopted HFET for the active device of the VCO.

In this paper, we present a 19 GHz VCO MMIC using HFET.

II. Device Structure

Figure 1 shows the schematic cross section of HFET. The gate length and width of the active device used in VCO are 0.6 um and 75 um x 4, respectively. The varactor diode is implemented by connecting the source to the drain. The anode length and width are 0.6 um and 75 um x 4, respectively.

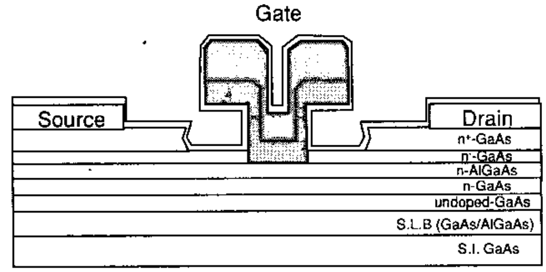

Fig. 1. Schematic cross section of HFET.

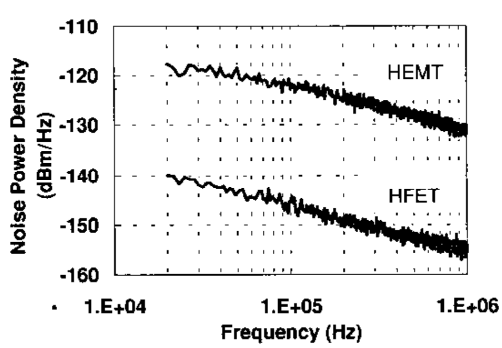

Fig. 2. LFN characteristics of HFET and HEMT.

Figure 2 shows the LFN characteristics of common source HFET and HEMT, which were measured with spectrum analyzer on wafer. The gate width of both devices is 40 um x 4. The drain voltage and current are 3.0 V and 50% of Idss, respectively. HFET noise spectrum is 25 dB lower than that of HEMT. Therefore, HFET is suitable for the active device of the VCO, which requires low phase noise. We adopted HFET for the active device of this VCO.

Figure 3 shows gate length dependence of LFN at 100 kHz and MSG at 19 GHz of HFET. The gate width of devices is 75 um x 4. As gate length increases, the noise power density decreases. Thus, a longer gate length is effective for lowering the phase noise. On the other hand, as gate length increases, the gain of the FET decreases. We considered the LFN and the gain for stable oscillation of VCO and adopted a 0.6 um gate length.

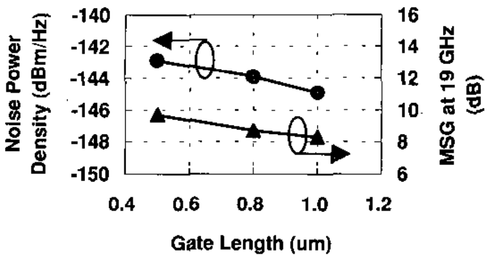

Fig. 3. Gate length dependence of LFN at 100 kHz and MSG at 19 GHz of HFET.

III. CIRCUIT DESIGN

To reduce the phase noise of the VCO, it is effective to use a high Q resonator as the main resonator. Because the phase fluctuation is measured as frequency fluctuation, it is important to make the slope of the loop phase sharp. Figure 4 shows the schematics of conventional shorted stub and coupled line stub. They both have quarter wavelength at oscillation frequency, and their widths are 20 um. The slopes of reflection phase of shorted and coupled line stub are 6.2 and 20.7 degree/GHz at oscillation frequency, respectively. Figure 5 shows the calculated comparison between them. The coupled line stub slope of the reflection phase is sharp. It is suitable for the main resonator of the VCO, which requires low phase noise [5]. It is important to note that a main resonator with excessively high Q value, has a disadvantage in frequency tuning range. Therefore, dielectric resonators may not be used in the VCO.

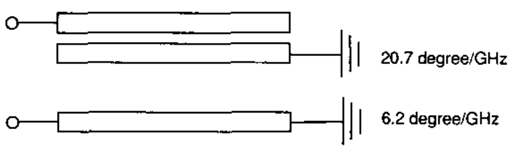

Fig. 4. Schematics of two resonators.

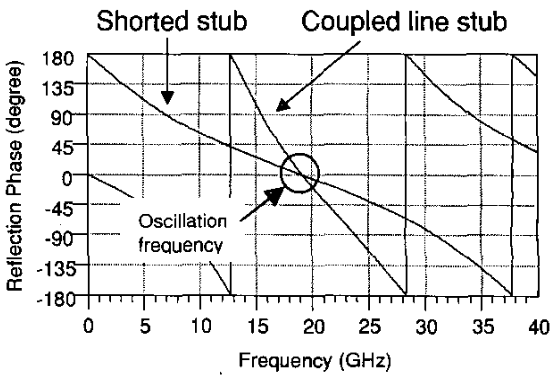

Fig. 5. Calculated comparison of two resonators. The coupled line stub reflection phase has a sharp slope.

The open stub, which is placed near the drain terminal of the FET, is used as the reflection circuit at oscillation frequency so that the FET obtains sufficient reflection gain. When its length is set exactly to a quarter wavelength, the reflection gain is maximal. But then the output power is minimal. After considering these points, we set its length at not exact quarter wavelength but near quarter wavelength.

The gate and drain bias circuits consist of quarter wavelength transmission lines and metal insulator metal (MIM) capacitors. The impedance of these bias circuits is near open at oscillation frequency. They do not substantially affect the oscillation circuit.

Figure 6 shows the circuit schematic of the VCO. The conditions of starting up oscillation are described by the following equations.

$$|\Gamma_{RES}| \times |\Gamma_{FET}| > 1 \quad (1)$$

$$\mathrm{Ang}(\Gamma_{RES}) + \mathrm{Ang}(\Gamma_{FET}) = 0 \quad (2)$$

To satisfy equation (2) at the desired frequency, the length of transmission line (A) is adjusted.

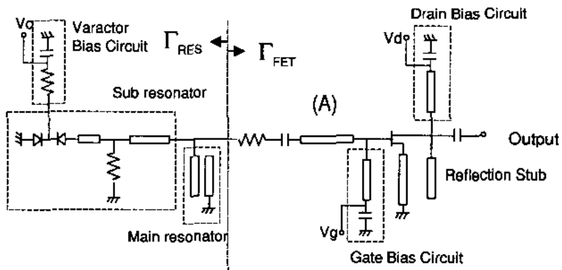

Fig. 6. Circuit schematic of the VCO. Vc means varactor bias voltage for frequency tuning.

IV. Measurements

The HFET VCO MMIC was fabricated. Figure 7 is a photograph of the VCO MMIC. The chip size is 2.7 mm x 1.4 mm. The thickness of the GaAs substrate is 100 um. Figure 8 shows the measured oscillation spectrum. Figure 9 shows the oscillation frequency and output power. Figure 10 shows phase noise at 100 kHz and 1 MHz offset of the fabricated VCO MMIC. The VCO MMIC was measured on wafer, and a 10 dB attenuator was used in order to stabilize load impedance of the VCO. The phase noise was measured with spectrum analyzer. The drain and gate voltage are 3.0 V and –1.2 V, respectively. The drain current is 50% of Idss. The control voltage means varactor bias voltage for frequency tuning. The measured tuning range is 400 MHz. No oscillation frequency discontinuity was observed over the range from 0 V to 5 V. The typical output power is 2 dBm. The power variation for control voltage is 1.2 dB and the control voltage property of output power is smooth. The typical phase noise is –120 dBc/Hz and –90 dBc/Hz at 1 MHz and 100 kHz offset, respectively. This result includes the effect of difference of phase slope between shorted stub and coupled line stub. Because of the effect of their loss, the difference of phase noise is not 10 dB but 3 dB.

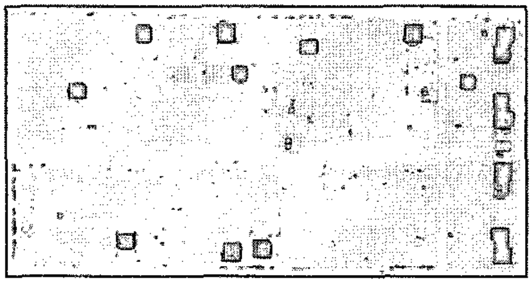

Fig. 7. Photograph of the 19 GHz VCO MMIC. The chip size is 2.7 mm x 1.4 mm.

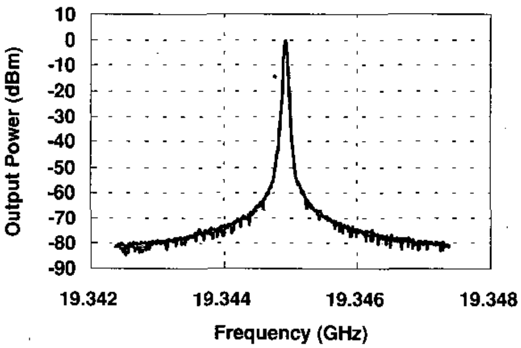

Fig. 8. The measured oscillation spectrum. Resolution bandwidth is 30 kHz.

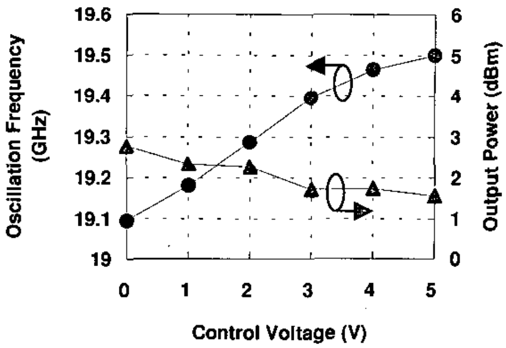

Fig. 9. The measured oscillation frequency and output power.

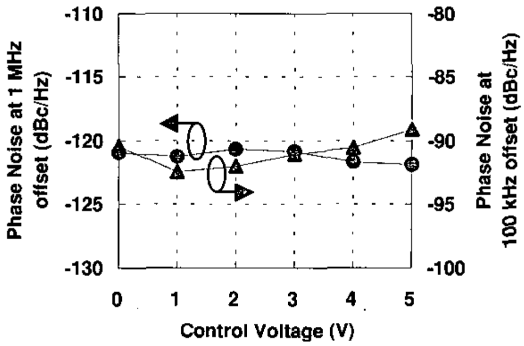

Fig. 10. The phase noise at 1 MHz offset measured by spectrum analyzer. The phase noise is typically –120 dBc/Hz.

Figure 11 shows a summary of previously reported phase noise at 1 MHz offset of various VCOs. Our VCO has lower phase noise than HEMT VCOs have. This result indicates that the low LFN device is advantageous as a lower phase noise VCO. Compared with InGaP HBT VCOs operating above 10 GHz, our VCO has coordinate phase noise performance at 1 MHz offset.

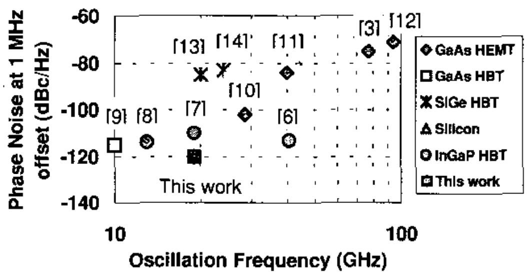

Fig. 11. Summary of previously reported phase noise of various VCOs.

Figures 12 and 13 show the ambient temperature characteristics of measured oscillation frequency and output power, respectively. The six lines in the figures each show a control voltage. The oscillation frequency typically changes 210 MHz over the temperature range from –35 to 85 degree C. The temperature stability is –92 ppm/degree C. The output power typically changes 2.0 dB over the same temperature range. The oscillation frequency and output power have no temperature discontinuity. Thus, this VCO is relatively easy to handle.

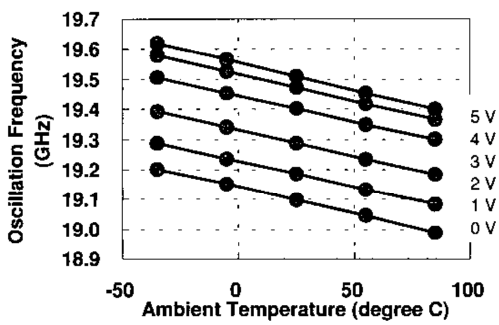

Fig. 12. The ambient temperature dependence of oscillation frequency. The temperature stability is –92 ppm/degree C.

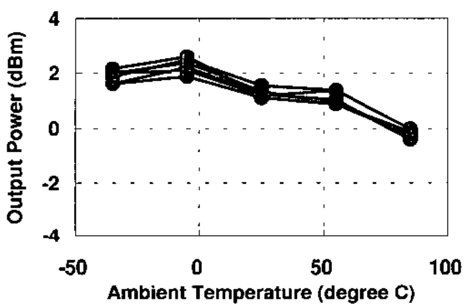

Fig. 13. The ambient temperature dependence of output power.

V. Conclusion

We have designed and fabricated the HFET VCO MMIC. For the reduction of phase noise, we adopted HFET as the active device of the VCO, because of its good low frequency noise characteristics compared with HEMT. Furthermore, a coupled line resonator was used as the main resonator to provide a sharply sloped reflection phase. The developed VCO showed typical phase noise of –120 dBc/Hz at 1 MHz offset, tuning range of 400 MHz, and output power of 2 dBm. This result is good performance compared with other VCOs operating above 10 GHz. The fabricated MMIC chip size is 2.7 mm x 1.4 mm.

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