A Ka-Band High Power Monolithic HEMT VCO Using a Sub-resonator Circuit with Phase Control Architecture

Takuo KASHIWA, Takayuki KATOH, Takao ISHIDA, Hitoshi KURUSU, and Yasuo MITSUI

High Frequency & Optical Semiconductor Div.
Mitsubishi Electric Corporation
4 -1 Mizuhara, Itami, Hyogo 664, Japan
E-mail: kashiwa@oml.melco.co.jp

ABSTRACT

This paper reports on a high output performance of a Ka-band monolithic HEMT Voltage Controlled Oscillator(VCO). This VCO has a sub-resonator in order to avoid reduction in Q-factor of a resonator. Circuit elements of the sub-resonator are optimized to achieve a wide tuning range as well as high output power and low phase noise performances. In addition, an AlGaAs/InGaAs double-hetero structure High Electron Mobility Transistor(HEMT) is employed in the VCO to obtain a high output performance. A high output power of 19.4 dBm has been achieved at an oscillation frequency of 36.2 GHz. This performance has been achieved without any buffer amplifiers. A tuning range of more than 2.5 GHz is also obtained with a stable high output power. To our knowledge, this represents the highest output power of monolithic VCO without any buffer amplifiers.

INTRODUCTION

Recently, Ka-band is becoming attractive because this frequency band is to be utilized in many communication systems such as satellite communications and point-point communications, which are expected to be in high demand. A monolithic VCO integrated circuit is a promising candidate for making these systems small. The High Electron Mobility Transistor(HEMT) is a suitable device to realizing oscillators in the millimeter-wave range because of their high frequency performances(1-3). There have been many approaches proposed to improve oscillator phase noise. There have been several successfully developed circuits using dielectric resonators assembled on MMICs or off-chip(4-5). The problem in these oscillators is the difficulty in precisely placing a dielectric resonator in the designated position. Phase Locked Oscillators(PLOs) have good phase noise performances near carrier frequencies. However, PLOs need several additional ICs such as divider ICs, therefore these oscillators tend to be large in total size, raising manufacturing costs. Monolithic oscillators are desirable as a solution of achieving smaller size and lower cost. In fabrication of oscillators, high output performances are required as well as low phase noise characteristics because a higher output power characteristic leads to the smaller number of stages of the buffer amplifier, making the oscillator smaller. In this paper, we report on high output performance of a monolithic HEMT VCO using an AlGaAs/InGaAs pseudomorphic HEMT. A high output power of more than 18 dBm has been obtained with more than a 2.5 GHz-band tuning range.

DEVICE STRUCTURE

An AlGaAs/InGaAs pseudomorphic HEMT is used to in a monolithic VCO. Fig. 1 shows a cross sectional view of the HEMT. A double hetero structure with double Si-planar doped layers is applied to obtain high drain current density. The gate length and width are 0.2 μm and 160 μm, respectively. The gate electrode is defined by a photo/EB hybrid exposure system with double photo-resist layers(6). This process has an excellent wafer throughput because it allows the utilization of a step-and-repeat optical exposure technique instead of EB lithography in fabricating the head part of the T-shaped gate structure. The drain current density and maximum transconductance of the HEMT are 500 mA/mm and 480 mS/mm, respectively. A transient frequency and a maximum oscillation frequency of this HEMT with the gate periphery of 160 μm are 90 GHz and 160 GHz, respectively at a drain voltage of 4 V and a drain current of 30 mA.

CIRCUIT DESIGN

Fig. 2 shows a microphotograph and a circuit schematic of the fabricated monolithic VCO. The chip size is 2.0 mm X 1.4 mm X 0.1 mm. The oscillator circuit employs a series feedback network with source inductors constructed by microstrip lines. The resonance circuit consists of a microstrip line and a Metal-Insulator-Metal (MIM) capacitor. A quarter-wave-length high impedance line is used for a gate bias circuit. In addition, an RC-circuit is incorporated as a filter in order to avoid undesirable low-frequency oscillation. A varactor diode is connected to the gate electrode of the HEMT through a microstrip line and a MIM capacitor. These circuit elements act as a sub-resonator and control the phase of the resonator to vary the oscillation frequency. Γ_{in} and Γ_d shown in the figure are defined as in the following equations(7).

$$|\Gamma_{in}| > \left|\frac{1}{\Gamma_d}\right| \tag{1}$$

$$\mathrm{Ang}(\Gamma_{in}) = \mathrm{Ang}\left(\frac{1}{\Gamma_d}\right) \tag{2}$$

In Fig. 3, reflection coefficients are compared between two resonators. One is with a sub-resonator, the other is the one terminated with a varactor diode and a MIM capacitor. The magnitude of S_{11} of the resonator with the sub-resonator is much larger than that of the varactor-terminated resonator under a condition that satisfies the above phase equation. This indicates that a stable oscillation is possible over the tuning range of the varactor diode.

OSCILLATION PERFORMANCE

Figure 4 shows the oscillation frequency as a function of the varactor tuning voltage. A tuning range of more than 2.5 GHz with a center frequency around 38 GHz is obtained at a tuning voltage from 0 V to 1.5 V. Fig. 5 shows a output power and a DC-RF efficiency in this tuning range. High output power of more than 18 dBm and high efficiency of more than 22% are obtained at a drain voltage of 5 V. The highest output power of 19.4 dBm is obtained at a drain voltage of 5.5 V as shown in Fig. 6. In Fig. 7, measured phase noise is plotted as a function of the varactor tuning voltage. Fig. 7 shows an oscillation spectrum of the VCO at a drain voltage of 5 V. A phase noise of - 57 dBc/Hz at a 100 kHz offset and -87 dBc/Hz at a 1 MHz offset are obtained. To our knowledge, this is the highest output power among ever reported monolithic oscillators without any buffer amplifiers.

CONCLUSION

The Ka-band high output power monolithic HEMT VCO has been successfully developed for Ka-band applications. The VCO has a sub-resonator to avoid reduction in Q-factor of the resonator and to obtain a wider tuning range. An output power of more than 18 dBm has been achieved with a high DC-RF efficiency at a drain voltage of 5 V. This represents the highest output power of monolithic VCOs without any buffer amplifiers. Tuning range of more than 2.5 GHz has been also obtained over the tuning voltage of the varactor diode from 0 V to 1.5 V.

REFERENCES

(1) T. Saito et al., " 60-GHz HEMT-based MMIC receiver with On-Chip LO," *in proceeding of IEEE GaAs IC Symp.*, pp. 88-91, 1994.

(2) J. E. Muller et al., " A GaAs HEMT MMIC chipset for automotive radar systems fabricated by optical stepper lithography," *in Proceeding of IEEE GaAs IC symp.*, pp. 193-196, 1996.

(3) M. Funabashi et al., " A V-band AlGaAs/InGaAs heterojunction FET MMIC dielectric resonator oscillator," *in Proceeding of IEEE GaAs IC Symp.*, pp. 30-33, 1994.

(4) K. Hosogi et al.,"Photo/EB hybrid exposure process for T-shaped gate super low-noise HEMTs," *Electronics letters*, vol. 27, No. 22, pp. 2011-2012, October 1991.

(5) M. Funabashi et al., "A V-band AlGaAs/InGaAs heterojunction FET MMIC dielectric resonator oscillator," in *proceeding of IEEE GaAs IC Symp.*, pp. 30-33, 1994.

(6) P. G. Wilson, " Monolithic 38 GHz dielectric resonator oscillator," in *IEEE Int. Microwave Symp. Dig.*, pp. 831-834, 1991.

(7) P. G. Wilson and R. D. Caver, "An easy-to-use FET DRO design procedure suited to most CAD programs," in *IEEE Int. Microwave Symp. Dig.*, pp. 1033-1036, 1989.

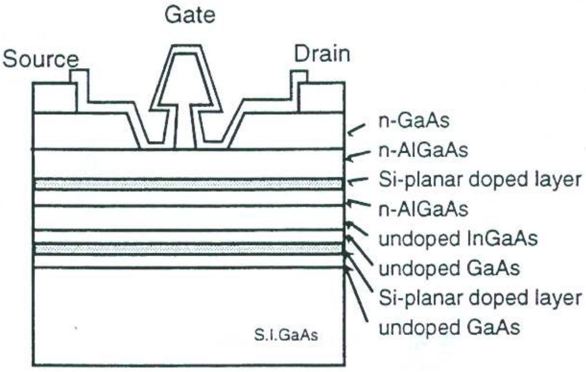
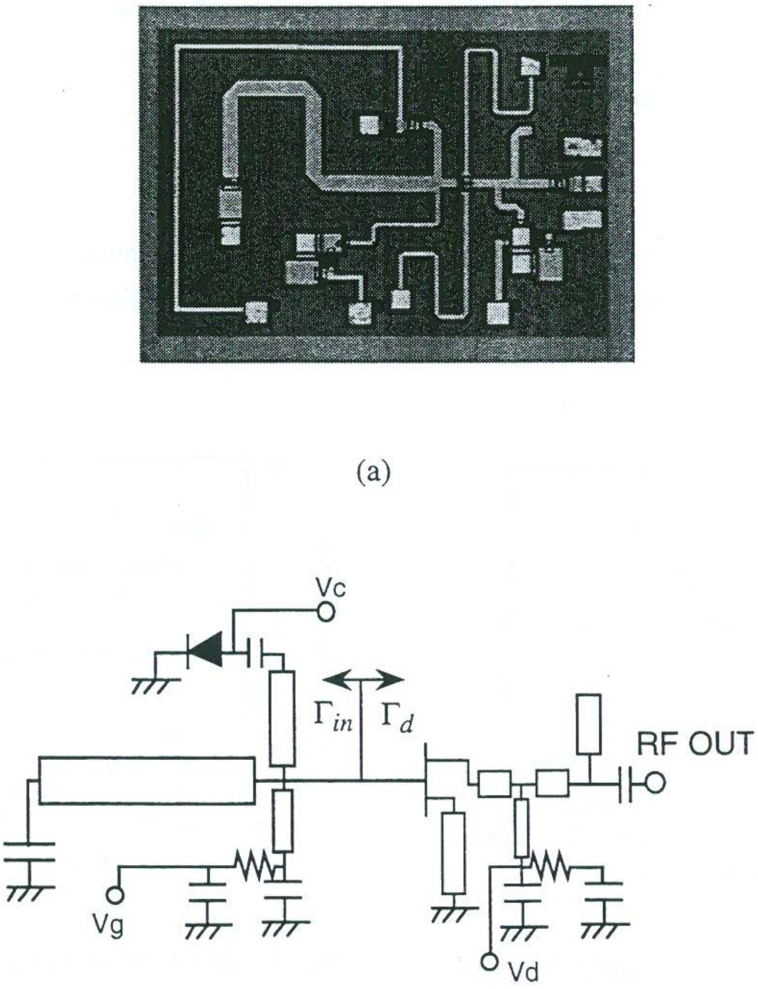


Fig.1. Cross sectional view of an AlGaAs/InGaAs Double hetero PHEMT.



(a)

(b)

Fig. 2. (a)Microphotograph of the monolithic VCO. (b) Circuit schematic diagram.

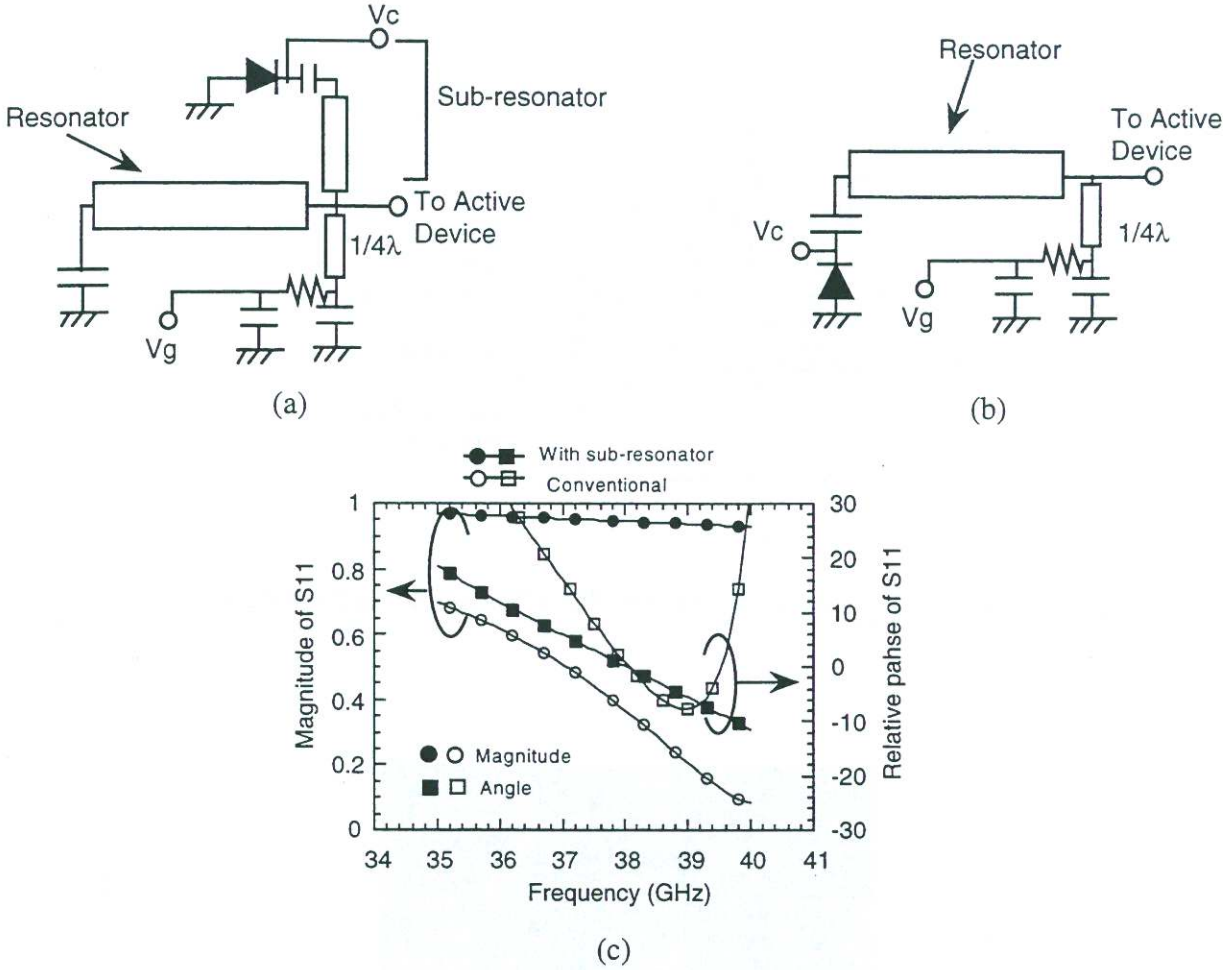


Fig. 3. Comparison of two resonatior circuit. (a) Equivalent circuit of resonator with the sub-resonator. (b) Equivalent circuit of resonator terminated with a varactor diode. (c) Comparison of S-parameters.

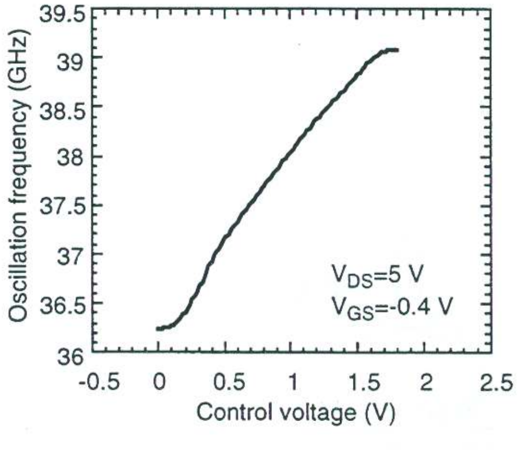


Fig. 4. Measured oscillation frequency as a function of the varactor tuning voltage.

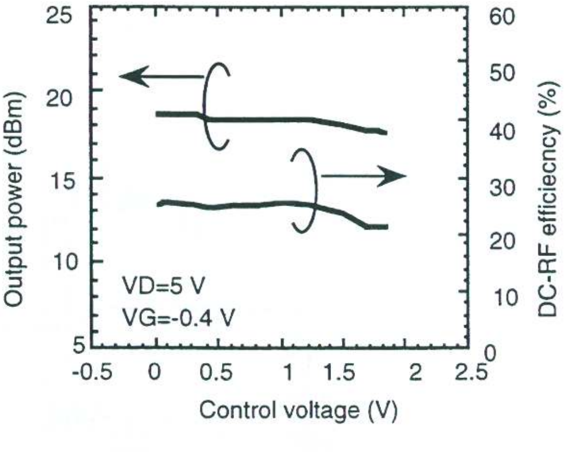


Fig. 5. Measured output power and DC-RF efficiency as a function of varactor tuning voltage.

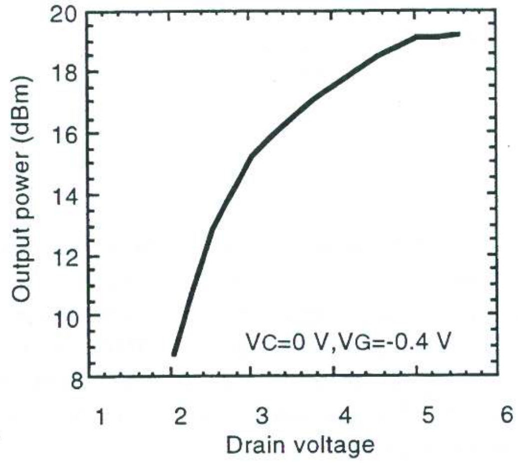


Fig. 6. Measured output power as a function of drain voltage.

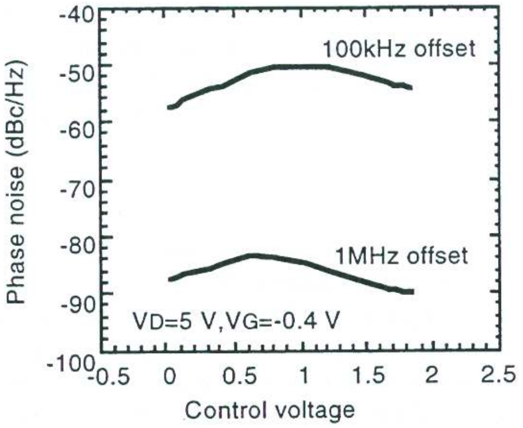


Fig. 7. Measured phase noise performance as a function of varactor tuning voltage.

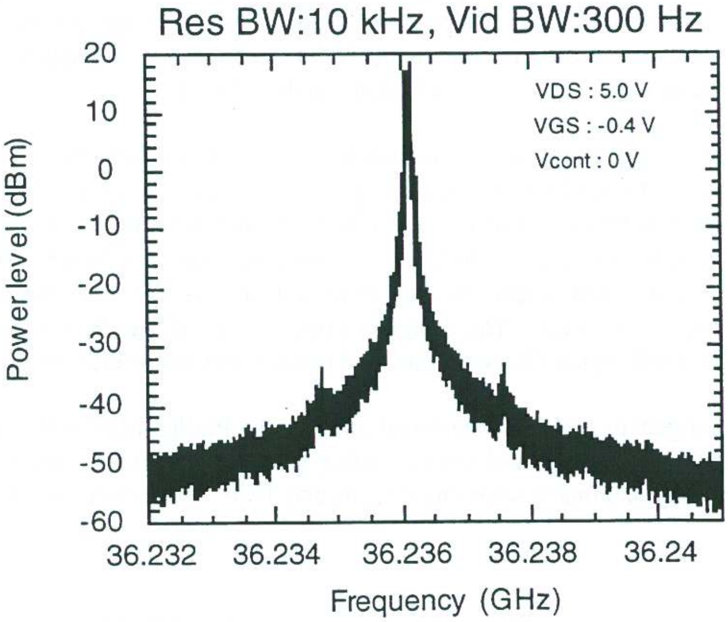


Fig. 8. Oscillation spectrum of the VCO.