WIDEBAND MMIC VOLTAGE CONTROLLED OSCILLATOR USING ACTIVE IMPEDANCE LOAD MATCHING

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ABSTRACT

A novel wideband MMIC voltage controlled oscillator (VCO) using an active impedance load matching composed of a common gate FET is proposed. The MMIC VCO achieves a bandwidth of 24.2 to 27.2 GHz and an output power of 9 dBm in size of 1 mm^2 with a fully integrated structure.

INTRODUCTION

High-frequency oscillation using a transistor often requires an output impedance matching network that provides a low impedance load, because the negative resistance of the transistor becomes relatively low in the high-frequency range. An impedance transformer composed of transmission lines is conventionally used for this purpose [1]-[3]. However, these transmission lines limit the operating frequency and degrade the pulling performance, as well as increasing the size of the MMIC.

This paper proposes a wideband MMIC voltage controlled oscillator (VCO) using a novel active impedance matching network composed of a common gate FET. Advantages of the active impedance load are high oscillation frequency and wide bandwidth, as well as reduction of the chip size. Furthermore, the pulling performance is improved due to the FET's buffering effect. These features come from the common gate FET which eliminates frequency dependent transmission lines from the impedance transform function.

CONFIGURATION

Figure 1 shows an equivalent circuit of the proposed MMIC VCO. The common gate FET Q_2 operates as the active impedance load Z_L, and the FET Q_1 generates a negative resistance Z_S. The FET Q_3 is a buffer amplifier. Since the parasitic capacitances of Q_1 degrade Z_S at high frequencies, and since Re$\{Z_L\}$ must be smaller than |Re$\{Z_S\}$| to satisfy the conditions for oscillation to begin, a lower Z_L is required at such high frequencies. When Q_2 is modeled with a current source ($-g_m v_1$), a gate-source capacitance (C_{gs}), and a gate-drain capacitance (C_{gd}) as shown in Fig. 2, the Y matrix of the common gate FET Q_2 is given by Equation (1):

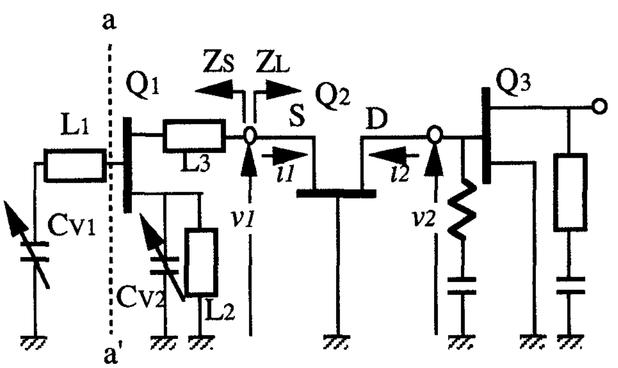

Fig. 1. Equivalent circuit of MMIC voltage-controlled oscillator using active load.

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$$\begin{pmatrix} i_1 \\ i_2 \end{pmatrix} = \begin{pmatrix} j\omega C_{gs} + g_m & 0 \\ -g_m & j\omega C_{gd} \end{pmatrix} \begin{pmatrix} v_1 \\ v_2 \end{pmatrix} \quad (1)$$

where g_m is the transconductance of Q2. Equation (1) gives Equation (2):

$$Z_L = \frac{v_1}{i_1} = \frac{1}{j\omega C_{gs} + g_m} \quad . \quad (2)$$

Since cut-off frequency f_T is given by

$$f_T = \frac{g_m}{2\pi C_{gs}} \quad , \quad (3),$$

the real and imaginary parts of Z_L become

$$\mathrm{Re}\{Z_L\} = \frac{1}{\left(\left(\frac{f}{f_T}\right)^2 + 1\right) g_m}$$

and
$$\mathrm{Im}\{Z_L\} = \frac{-\left(\frac{f}{f_T}\right)}{\left(\left(\frac{f}{f_T}\right)^2 + 1\right) g_m} \quad (4)$$

where f is frequency. When f is varied from dc to f_T and g_m is 0.1 S, $\mathrm{Re}\{Z_L\}$ is between 10 and 5 Ω and $\mathrm{Im}\{Z_L\}$ is between 0 and -5 Ω from Equation (4). These values are very stable and suitable for the low load.

Figure 3 shows the predicted frequency responses of Z_L including all parastics of Q_2. The predicted performance of a conventional quarter-wavelength transmission line impedance transformer is also shown. This figure shows that the active load achieves a wider bandwidth for low impedance of around 15 Ω than the conventional transformer. The f_T of Q_2 is 40 GHz in Fig. 3. The oscillation frequency is varied by the bias of varactor diodes C_{V1} and C_{V2} that are constructed from Schottky junctions of the FET gate. Figure 4 shows the frequency which provides $\mathrm{Im}\{Z_S\}=0$ and the magnitude of the reflection coefficient of negative resistance at 15 Ω of load impedance. Since the variable ratios of C_{V1} and C_{V2} are limited to around two, the variable bandwidth of oscillation will be 3 or 4 GHz. The gate widths of Q_1 and Q_2 are decided by the required Z_L and the saturation output power of Q_1, which should be in the linear region of Q_2.

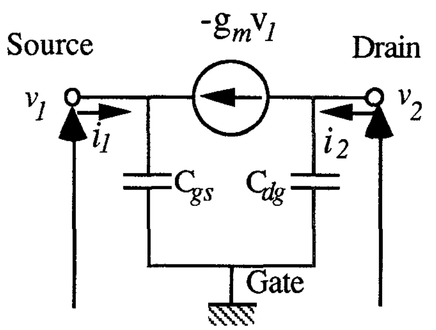

Fig. 2. Equivalent circuit of common gate FET.

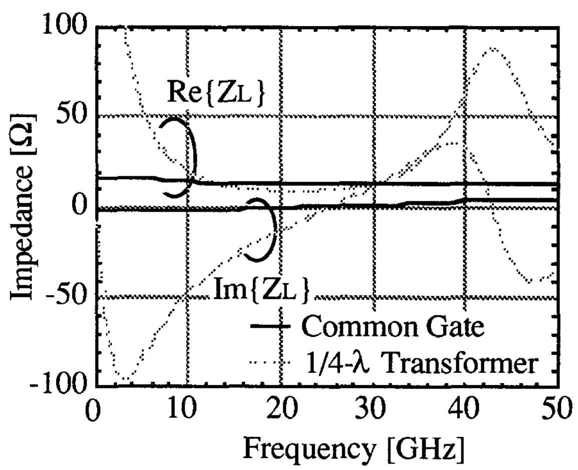

Fig. 3. Predicted impedance frequency responses of active load and conventional quarter-wavelength impedance transformer.

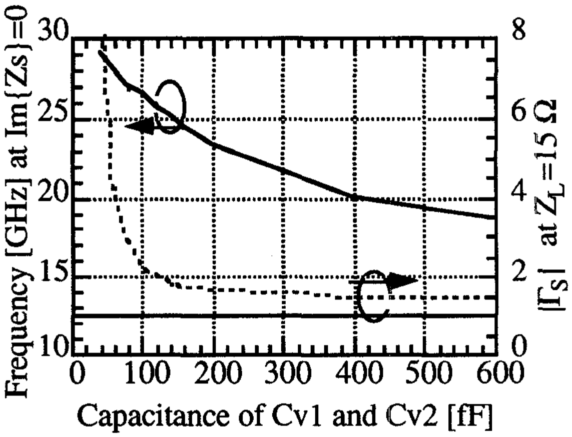

Fig. 4. Predicted frequency providing $Im\{Z_S\}=0$ and magnitude of reflection coefficient, $|\Gamma_S|$, at $Z_L=15\ \Omega$.

Figure 8 shows the oscillation frequencies with the proposed MMIC VCO and recently reported ones which are fully monolithic structures. The y-axis is normalized by the f_{max} of the transistor used. The proposed MMIC VCO shows excellent results for these criteria.

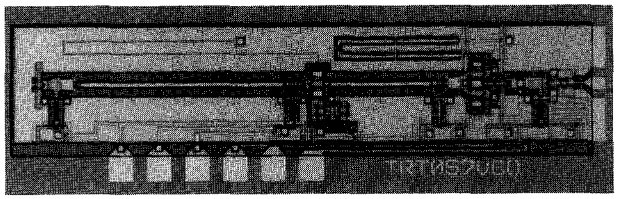

Fig. 5. Photomicrograph of fabricated MMIC VCO. Chip size is 2.33 mm x 0.45 mm.

EXPERIMENTAL RESULTS

Figure 5 shows a photomicrograph of the fabricated MMIC VCO. The chip is 2.33 mm x 0.45 mm, approximately 1 mm^2. The MMIC uses a semi-insulated GaAs substrate and quarter-micron-gate-length, hetero-junction FETs (nAlGaAs/nGaAs/InGaAs/GaAs, f_T= 40 GHz, f_{max}=70 GHz). The nGaAs layer improves large signal performance [4]. Co-planar waveguides are mainly used for the transmission lines because of their simple uni-planar metal structure and flexibility of line-width, but thin-film micro-striplines (TFMS lines) [5] are also used for line-cross-overs and bias distributions because of their narrow line-width and low cross-talk at the cross-over.

The measured frequency characteristics are shown in Fig. 6. Oscillation frequency is from 24.2 to 27.2 GHz with varactor bias of 0.8 to - 2 V. The flat output power response of 9.3 ± 0.9 dBm is obtained in this range. The oscillation frequency range is limited by the variable ratio of C_{V1} and C_{V2} that is about 2 (80 - 160 fF). Their Q factors are about 10. The measured frequency spectrum is shown in Fig. 7. The phase noise of - 94 dBc/Hz is measured at 1-MHz off carrier.

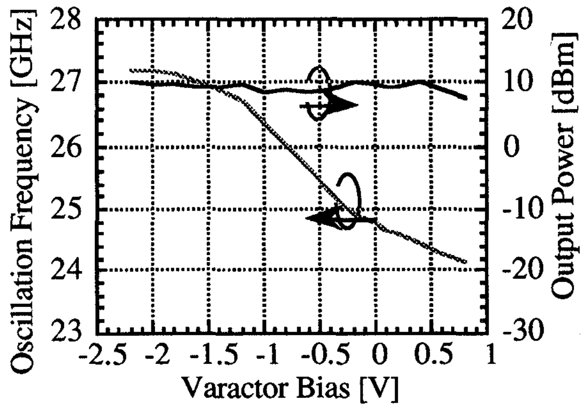

Fig. 6. Measured performances of oscillation frequency and output power.

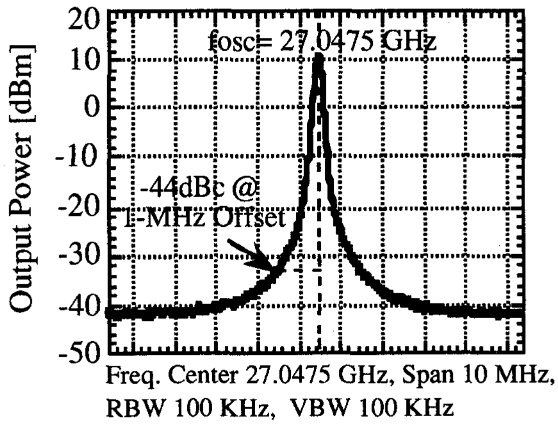

Fig. 7. Measured frequency spectrum of oscillation.

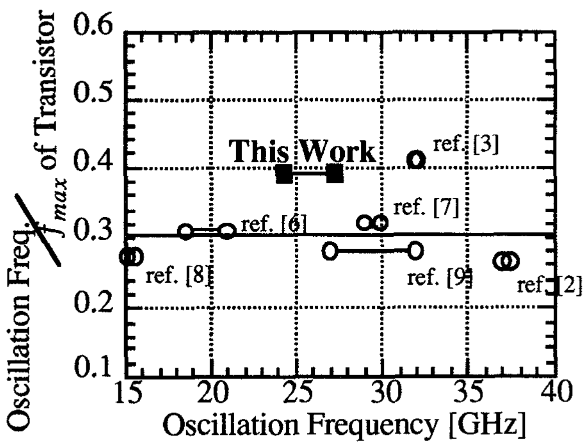

Fig. 8. Comparison of bandwidth and "ratio of oscillation frequency to f_{max} of transistor" between proposed MMIC VCO and recently reported MMIC VCOs.

CONCLUSION

A novel way of achieving wideband oscillation while reducing the size of an MMIC VCO has been proposed and demonstrated. By adapting an active impedance load matching network composed of a common gate FET, we have achieved oscillation from 24.2 to 27.2 GHz with 9 dBm output power in a 1-mm^2 chip. This approach will be very valuable for wideband applications such as measurement instruments if used with a wideband high-Q resonator such as a YIG device.

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