

Microwave Triple Tuned Wideband VCO

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1. Introduction

In this paper a triple tuned voltage controlled oscillator (VCO) is proposed for small, low-cost transceiver applications. Analytical calculations showed that the proposed VCO enables a wider oscillation bandwidth than the conventional double tuned type⁽¹⁾. A fabricated prototype exhibited a wide oscillation bandwidth of 5.6 to 16.8 GHz (relative bandwidth: 100%) and confirmed the effectiveness of the proposed configuration.

2. Configuration

Figure 1 shows the basic equivalent circuit of the triple tuned VCO. The triple tuned VCO is a series feedback oscillator consisting of one active device and three tuned circuits. In our configuration, a hetero-junction bipolar transistor (HBT) having a low 1/f noise is used as the active device. The three tuned circuits consist of a series-connected variable capacitor and inductor.

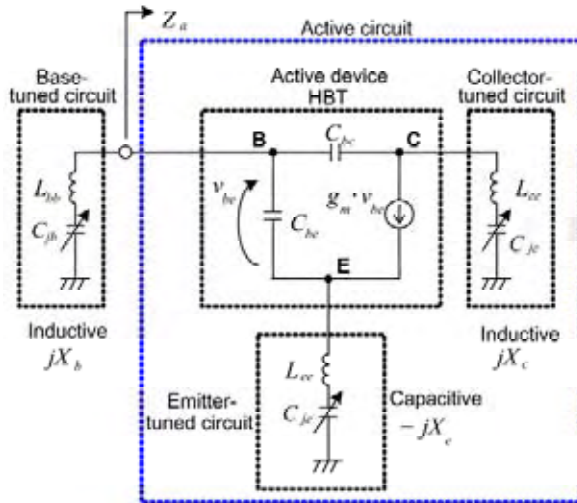


Fig. 1 Small signal equivalent circuit of the triple tuned VCO

In the basic configuration of series feedback oscillator, the tuned circuit connected either to the base or to the collector is inductive, whereas the one connected to the emitter is capacitive. A circuit consisting of an HBT and tuned circuits connected to either emitter or collector is considered to be an active circuit. Z_a is the input impedance of this active circuit when looking toward the HBT's base terminal.

3. Analysis

The following sections describe the conditions re-

quired to achieve a wide oscillation bandwidth and the relationship between the oscillation bandwidth and circuit parameters.

3.1 Conditions for wideband oscillation

If the tuned circuits are assumed to be lossless, the real and imaginary parts of Z_a are respectively expressed as the following equations:

$$\text{Re}(Z_a) = \frac{g_m \left(X_c + \frac{C_{be}}{C_{bc}} X_e \right) \cdot \left(X_c - \frac{1}{\omega C_{bc}} \right)}{\alpha^2 + \beta^2} \quad (1)$$

$$\text{Im}(Z_a) = \frac{\omega C_{be} \left(\frac{1}{\omega C_{be}} + X_e \right) \alpha - g_m X_e \beta}{\alpha^2 + \beta^2} \cdot \left(X_c - \frac{1}{\omega C_{bc}} \right) \quad (2)$$

where

$$\alpha = \omega C_{be} \left\{ \frac{1}{\omega C_{be}} + \frac{1}{\omega C_{bc}} - (X_c - X_e) \right\} \quad (3)$$

$$\beta = g_m (X_c - X_e) \quad (4)$$

The oscillation conditions are expressed as the following equations:

$$\text{Re}(Z_a) < 0 \quad (5)$$

$$\text{Im}(Z_a) + X_b = 0 \quad (6)$$

The conditions for negative resistance are derived from equations (1) and (5) and expressed as follows:

$$0 \leq X_c < \frac{1}{\omega C_{bc}} \quad (7)$$

In the case of the double tuned configuration, X_c is inductive and uncontrollable, and thus equation (7) is not satisfied at high frequencies. In the case of the triple tuned configuration, X_c can be controlled to be smaller than $1/\omega C_{bc}$. Consequently, the oscillation bandwidth of the proposed triple tuned VCO is wider than that of the double tuned VCO.

3.2 Oscillation bandwidth

Since the tuned circuit connected to the base is assumed to be lossless, $\text{Re}(Z_a)$ becomes zero in a stable oscillation state. Therefore, in a stable oscillation state, the value of g_m becomes zero and the oscillation angular frequency ω_0 is expressed by the following

equation derived from equation (6):

$$\frac{1}{X_b} = \frac{1}{\frac{1}{\omega_0 C_{be}} + X_e} + \frac{1}{\frac{1}{\omega_0 C_{bc}} - X_c} \quad (8)$$

Now, the following parameters are defined:

$$k_c \equiv \frac{C_{be}}{C_{bc}} \gg 1 \quad (9)$$

$$k_j \equiv \frac{C_{je \min}}{C_{be}} \quad (10)$$

$$n \equiv \frac{C_{je \max}}{C_{je \min}} \quad (11)$$

where $C_{j \min}$ is the minimum value of variable capacitance and $C_{j \max}$ is the maximum value of variable capacitance.

In order to control three varactor diodes using a single voltage supply, the following equations are assumed to hold:

$$C_{jc} = C_{jb} = C_{je} \quad (12)$$

In addition, since X_c and X_b are inductive and X_e is capacitive, the following equation is also assumed to hold:

$$k_l \equiv \frac{L_{cc}}{L_{ee}} = \frac{L_{bb}}{L_{ee}} > 1 \quad (13)$$

By solving equation (8), the oscillation frequency change ratio is obtained as follows:

$$\frac{\omega_{\max}}{\omega_{\min}} \approx \sqrt{n} \cdot \frac{\sqrt{2\left(1 + \frac{2}{k_l}\right) + k_j k_c \left(\frac{2}{k_c} + 1 + \frac{1}{k_l} - \sqrt{1 + \frac{2}{k_l}}\right)}}{\sqrt{2\left(1 + \frac{2}{k_l}\right) + n k_j k_c \left(\frac{2}{k_c} + 1 + \frac{1}{k_l} - \sqrt{1 + \frac{2}{k_l}}\right)}} \quad (14)$$

where the following approximation is used.

$$\chi \equiv \sqrt{\left\{2(k_l - 1) + \frac{(2k_l - k_c)C_{je}}{C_{be}}\right\}^2 + \frac{k_l(k_l + 2)k_c^2 C_{je}^2}{C_{be}^2}} \approx 2(k_l - 1) + \frac{k_c C_{je}}{C_{be}} \sqrt{k_l(k_l + 2)} \quad (15)$$

Figure 2 shows the calculation results of the oscillation bandwidth versus capacitance ratio. Equation (14) was used for the calculations. It is understood from Fig. 2 that an oscillation bandwidth of 100% is obtained when k_j is 0.05 and n is approx. 14. Figure 2 also indicates that a smaller k_j provides a wider oscillation bandwidth. Therefore, from equation (10), a transistor that has a large C_{bc} , and hence a larger emitter size, is better suited for a wideband VCO.

4. Prototype Fabrication Results

Figure 3 shows a configuration schematic of the fabricated triple tuned VCO. The active device is an InGaP/GaAs HBT with an emitter size of $120 \mu\text{m}^2$ and cut-off frequency of 31.6 GHz. The capacitance ratio of the varactor diode is approx. 13.6 with a reverse voltage between 0 and +16 V. All varactor diodes are controlled using a single voltage source.

Figure 4 shows a photograph of the fabricated triple tuned VCO. Because of high frequency operation and to prevent errors in fabricating the VCO, the HBT and varactor diodes are mounted on an alumina substrate using flip-chip technology. The size of the VCO is $8.6 \text{ mm} \times 6.8 \text{ mm}$.

Figure 5 shows the measured oscillation frequency of the fabricated VCO. Bias voltages of the HBT are $V_c = 3 \text{ V}$, $V_b = 0.3 \text{ V}$, and $V_e = -1 \text{ V}$.

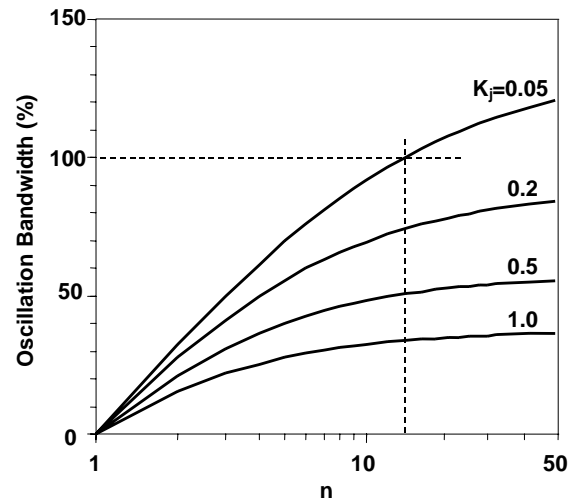


Fig. 2 Calculation results of the oscillation bandwidth versus capacitance ratio of the tuned capacitance: $k_c = 28$, $k_l = 6$

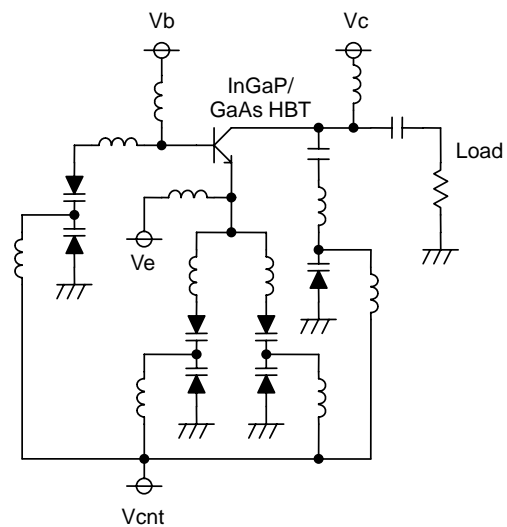


Fig. 3 Configuration of the fabricated triple tuned VCO

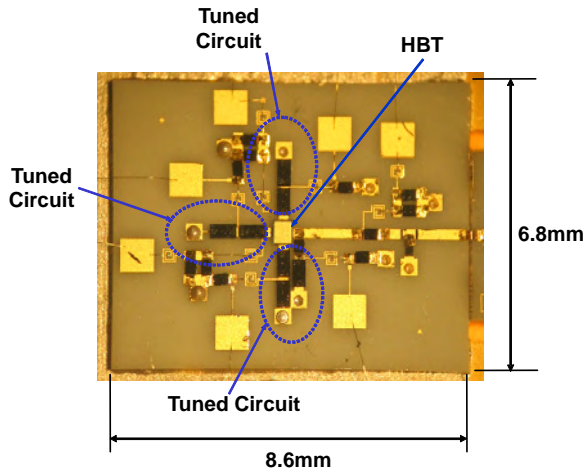


Fig. 4 Photograph of the fabricated triple tuned VCO

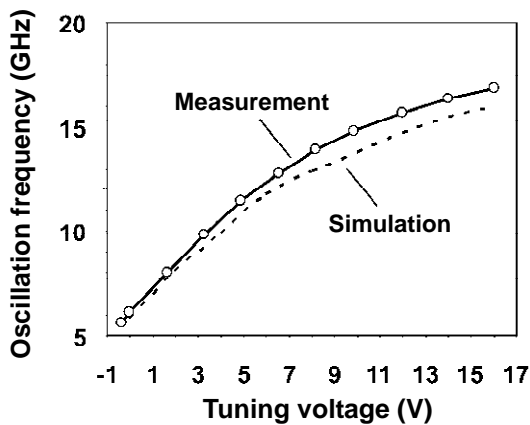


Fig. 5 Measurement results of the oscillation frequency of the fabricated VCO

Corresponding to the tuning voltage, V_{ctrl} , of -0.35 V to $+16$ V, the oscillation frequency varied from 5.6 GHz to 16.8 GHz (relative bandwidth: 100%), the phase noise was -112.0 dBc/Hz or lower at 1 MHz offset from the carrier, and the output power was 3.4 dBm \pm 2.0 dB. The current consumption was 76.1 mA or lower. The measurement results are in close agreement with the calculation result, confirming the effectiveness of this configuration.

VCOs incorporating our technology are expected to be used in a wide variety of applications.

Reference

- (1) K. Tajima, Y. Imai, Y. Kanagawa, and K. Itoh, "A 5 to 10 GHz Low Spurious Triple Tuned Type PLL Synthesizer Driven by Frequency Converted DDS Unit," IEEE MTT-S International Microwave Symposium Digest, vol. 3, pp. 1217-1220, Jun. 1997