5 GHz Voltage Controlled Oscillations for Frequency Agile RADAR, with Initial Frequency Tuning Capacitor

Zar Khitab, Farooq Ahmed Bhatti

Abstract*—*This Paper presents voltage controlled oscillator at 5GHz, 300 MHz bandwidth, and up to 50 kHz wide pulse repetition frequency, for pulse to pulse frequency agile radar. Negative-resistance method with initial frequency tuning capacitor is used in design. The frequency tuning is based on resonant capacitance for varying controlled voltage. The oscillator peak out power is 7.7 dBm, minimum output power in 300 MHz range is 6.997 dBm. First harmonic have power -7.793 dBm. Peak voltage deviation of 12249mV occurs for 34.025 MHz band. The proposed oscillator satisfies standard requirements to generate oscillation frequency for wide band radar systems. Suppressed harmonics and lesser variation in output power throughout 300MHz chip enhances the receive sensitivity of RADAR.

Index Terms*—, *frequency agile radar, Harmonics, output power variation, Voltage Controlled Oscillator.

I. Introduction

Voltage controlled oscillator (VCO) plays an important role in communication systems, phase locked loops and especially in radars. The demand of high data rate, more channels in a unit bandwidth higher oscillator frequency lower power requirement and phase immunity makes oscillator design critical. Systems overall performance is limited by controlling parameters of VCO. Good VCO design is trade-offs among the several design parameters like power consumption, phase noise, and size on chip [7]. Good oscillator design heavily depends on LC components used in circuit for radiofrequency based systems [2]. The effect of these matching circuit components are investigated in a [3] and references therein. Parameters in design process of oscillators are frequency, power, phase noise, DC current requirement, residual FM, tuning sensitivity, harmonic powers and frequency push pulls [1]. VCO output frequency in respect to tuning voltage can further derivate tuning sensitivity as initial point to decide for the quality design. This can also be affected by power supply (also called as frequency pushing). Output RF signal power also depends on frequency and power supply power [1] [7] [8]. Post tuning drift calculations shows how much time the VCO will take to stabilize on frequency f_2 after initial frequency f_1 by changing voltage.

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This is demonstrated in fig. 1. The parameters of concern are post tuning drift in frequency, settling time and frequency overshoot. These parameters changes and these changes depend on switching period of VCO. Very high *Quality* factor Q impedance matching networks are characteristics for negative resistance design [4]. [7] Compares several recently developed oscillators. This Paper presents voltage controlled oscillator at 5GHz, 300 MHz bandwidth, and up to 50 kHz wide pulse repetition frequency, for pulse to pulse frequency agile radar. Negative-resistance method with initial frequency tuning capacitor is used in design. This Oscillator is proposed for pulse to pulse frequency agile radar at 5GHz frequency, 300 MHz bandwidth, and up to 50 kHz wide pulse repetition frequency. Wide band frequency diversity waveforms are required on radar transmitter to achieve adequate sensitivity at receiving side [5]. The receive sensitivity is directly proportional to receiver BW (bandwidth). Receive sensitivity is also inversely related to the product of PW (pulse width) and peak power.

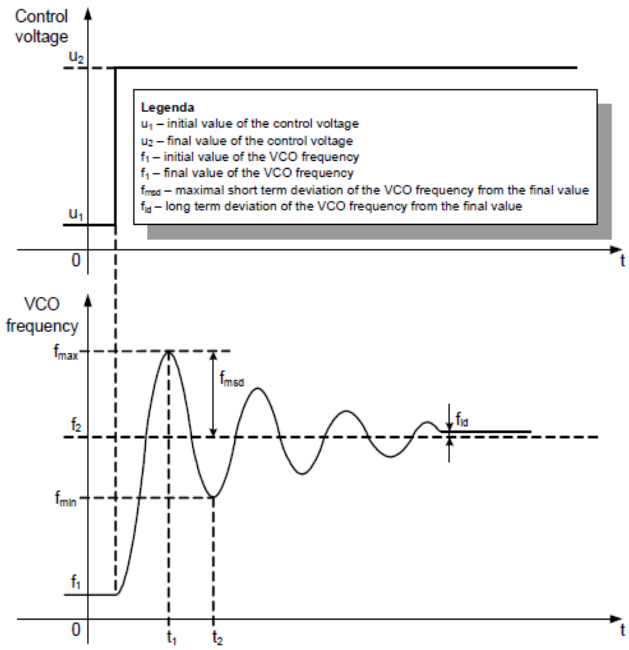

Fig. 1. Post Frequency Tuning Drift of VCO [1]

The oscillator achieves temperature and supply voltage independent tunable at 5GHz. The proposed oscillator satisfies standard requirements to generate oscillation frequency. The initial frequency tuning is achieved by resonant capacitor. Capacitor mismatch effects are not discussed here and the reader may find them in [3]. With capacitor mismatch [3], the amplitude of oscillation frequency decreases. [3] Also quotes the decrease in locking frequency with increase in percent capacitor mismatch [6].

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II. VCO CIRCUIT

A. Equations

Most Microwave Oscillators are negative resistance. From [4] port impedance must have negative real part and positive feedback should give reflection co-efficient $T_a > 1$, for the active device. For stable oscillations $S_{11} < 0$, for resonating port of circuit Fig.3 (a) below shows that S_{11} magnitude is less than 1, which makes $T_{res} < 1$ and equation (2) satisfied. Further

$$T_a \, T_{res} = 1$$
$$R_a + R_{res} = 0 \qquad (2)$$
$$X_a + X_{res} = 0$$

For oscillation to be get started [4].

$$T_a \, T_{res} > 1$$
$$R_a + R_{res} < 0 \qquad (3)$$
$$X_a + X_{res} = 0$$

The resonant circuit inductance is adjusted to constant value as per equation.

$$L = 1/(\omega_o^2 C) \qquad (4)$$

Considering the damping factor in Fig. 1.,ω_o is adjusted as[1].

$$\omega o = \frac{\pi}{(t2-t1)P} \qquad (5)$$

Where

$$P = \sqrt{1-\zeta^2} \qquad (6)$$

ζ is damping factor as shown in Fig. 1. [1]

$$\zeta = \left| \frac{\ln M}{\sqrt{\pi^2 - \ln^2 M}} \right| \qquad (7)$$

And

$$M = \frac{\text{fmax} - \text{fmin}}{\text{fmax}} \qquad (8)$$

The Quality factor Q is

$$Q = \pi * freq * (delay\ (2,1)) \qquad (9)$$

Using graph in Fig.3 (b)

The settling time for VCO at given frequency can indicate for short and long term tuning drift. The time domain analysis model for settling time is presented in [4].

B. Circuit Diagram

The frequency tune based on initial resonant capacitance with varactor diode's biasing VCO is shown in Fig. 2. The Oscillator is designed for pulse to pulse frequency agile radar at 5GHz frequency. Specifications for substrate and other components as expressed in Fig.2 are based on equations presented in section II-A. The matching networks are designed using smith chart tool available in ADS. Collector current rating is given in table 1. The difference in maximum collector current and minimum collector current is only 0.3mA.

t

min(ICC_dc)	mean(ICC_dc)	max(ICC_dc)
-10.37 m	-10.34 m	-10.07 m

Table. 1 Collector Current

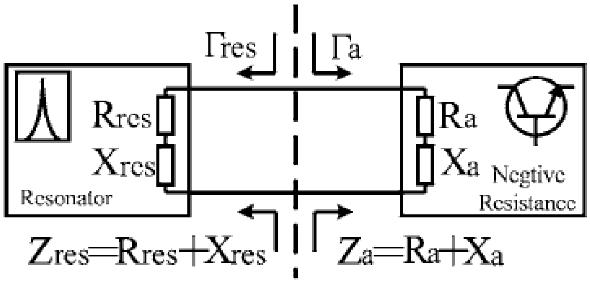

Fig. 2 (a) Block Diagram of Neg-Resistance VCO

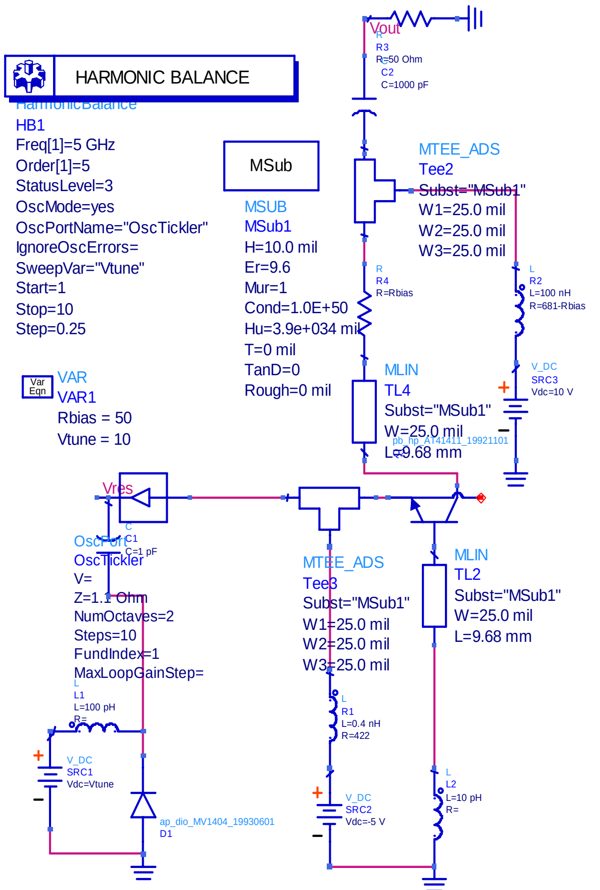

Fig. 2 (b) Proposed VCO Schematics with Description

III. SIMULATIONS

Simulations for varactor diode's bias voltage and VCO tuning characteristic are performed. Simulation results of resonance network for the oscillator in terms of S_{11} are shown in Fig.3. Since real S_{11} is less than 1, making T_{res}<1. It is obvious that real S_{11} is not equal to zero in 300MHz band. To calculate Q factor Fig.4 is used. Using equation (9) and Fig.4. Quality factor for the circuit.

$Q = 3.1416 * 5*109*8.200*10^{-10} = 13.2$

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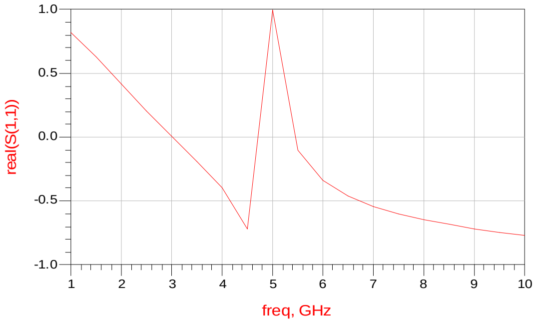

Fig. 3 S11 Magnitude Against Resonance Frequency

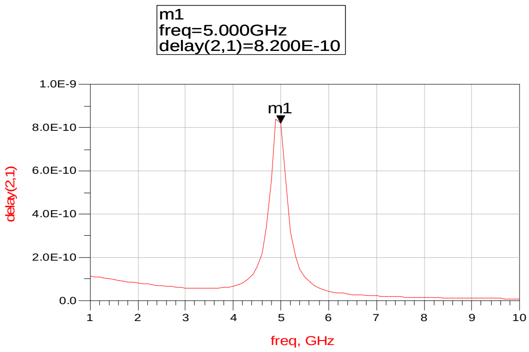

Fig. 4 Delay (2,1) vs Frequency

Results for output power at the fundamental frequency, two harmonics, harmonics power and their frequency and power flatness against fundamental frequency are shown in Fig.5 (a), Fig.5 (b) and Fig 5. (c) respectively. This figure indicates that harmonics are very weak. First harmonic have 15.6 dB lesser power then fundamental frequency. While second harmonic have 23 dB lesser power in comparison to fundamental frequency.

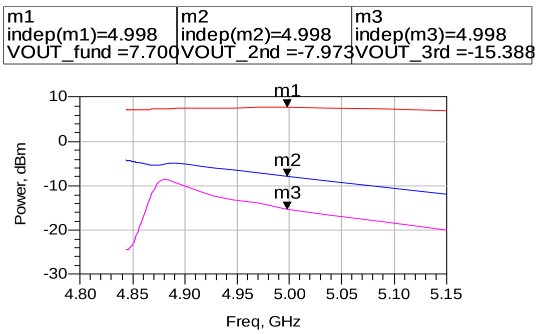

Fig. 5 (a) VCO Output Power & Harmonics vs. Tuning Voltage

Fig. 5 (c) shows that the variation in power when fundamental frequency is swept across 300 MHz bandwidth. At frequency 4.85GHz the output power is 7.12 dBm, at 5.15 GHz the output power is 6.997 dBm, while at centre frequency (5 GHz) the output power is 7.7 dBm. This shows flat and smooth response of oscillator for power. This is important in radar applications because radar sensitivity and target cross section depends on back wave's received power.

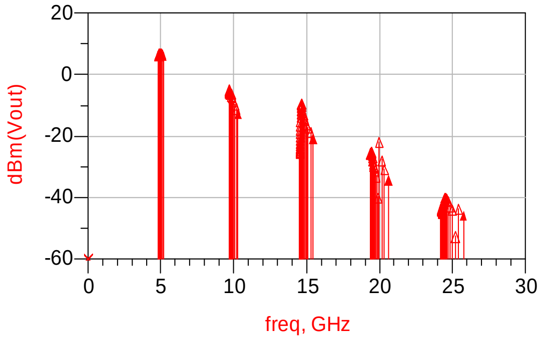

Fig. 5 (b) VCO Output Power vs Harmonics

Different parts of target scatter different amount of power from incoming wave. Uniform power throughout radar's transmitted band can make detection more accurate.

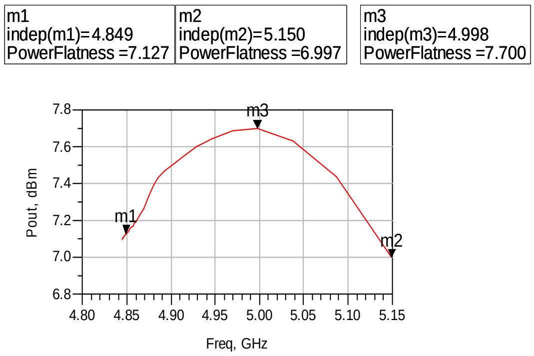

Fig. 5 (c) Power Flatness vs Frequency of Oscillation

Further tuning characteristic of VCO, tuning linearity deviation, and KVCO (MHz/V) are investigated in Fig. 6 (a) and Fig. 6 (b). Fig. 7. Show the time domain analysis for the device. The graph show the response time for the device as frequency is swept across 300MHz. This also shows the time the device will take to settle on frequencies it generates.

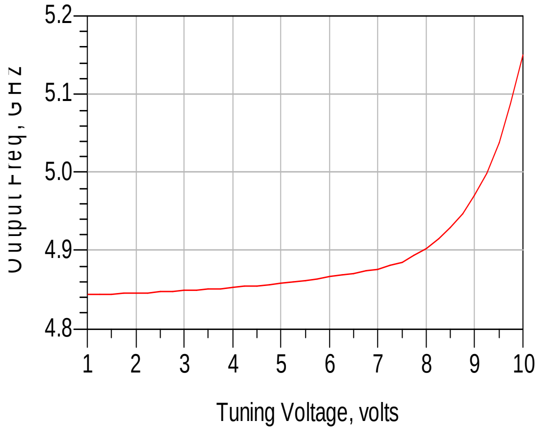

Fig. 6 (a) VCO Tuning Characteristic

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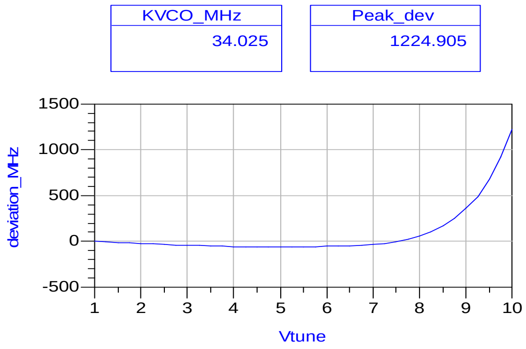

Fig. 6 (b) Deviation from Linear Tuning, MHz

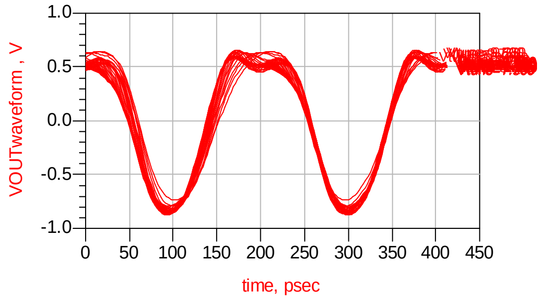

Fig. 7 Time Domain Analysis of Output Signal

IV. Results

The oscillator shows good flat output power response throughout 300MHz bandwidth. The oscillator peak out power is 7.7 dBm, minimum output power in 300 MHz range is 6.997 dBm. First harmonic have power -7.793 dBm. While second harmonic power is -15.388 dBm. Such low value of harmonics power can easily be ignored in wireless communication environment. Highest tuning deviation of 12249mV occurs for 34.025 MHz band.

V. Conclusion

This paper investigates oscillation frequency and tuning range VCO at 5GHz. The device design agrees with standard specification and provides large band width for transmitted signal. Uniform power throughout 300MHz transmitted band makes the device suitable for wide band radars. The settling provides enough time for the system to generate pulses with pulse repetition frequency up to 50 KHz. The device tuning voltage is almost independent of supply power. The difference in maximum collector current and minimum collector current is only 0.3mA.

References

[1] *Branislav LOJKO, Peter FUCH.,* "A Contribution to the VCO modeling and simulation." 2009 IEEE.

[2] Craninckx, J. and Steyaert, M., "Low-noise voltage controlled oscillators using enhanced LC-tanks," *IEEE Transactions on Circuits and Systems II: Analog and Digital Signal Processing.* vol.42, no.12, pp.794-804. 1995

[3] Antonio Buonomo, Alessandro Lo Schiavo. "The Effect of Parameter Mismatches in RF VCO." 2008 IEEE.

[4] Wang Xiantaiy, Shen Huajun, Jin Zhi, Chen Yanhu, and Liu Xinyu, "A 6 GHz high power and low phase noise VCO using an InGaP/GaAs HBT," Vol.30, No.2 Journal of Semiconductors, 2008 IEEE.

[5] Bharadwaj, kumar vijay mishra and v. chandrasekar, "waveform considerations for dual-polarization doppler weather radar with solid-state transmitters", 2009 IEEE.

[6] S.Y Lee, S. Amakawa, N. Ishihara, K. Masu, "Low-Phase-Noise Wide-Frequency-Range Differential Ring-VCO with Non-Integral Subharmonic Locking in 0.18 μm CMOS." Proceedings of the 40th European Microwave Conference. 2010 EuMA.

[7] M. R. Basar, F. Malek, Khairudi M. Juni, M. I. M. Saleh, M. Shaharom Idris. "A Low Power 2.4-GHz Current Reuse VCO for Low Power Miniaturized Transceiver System." 2012 IEEE International Conference on Electronics Design, Systems and Applications (ICEDSA)

[8] S. L. Jang, S. S. Lin, C. W. Chang, and S. H. Hsu, "Quadrature VCO Formed with Two Colpitts VCO Coupled via an LC-Ring Resonator," *Progress In Electromagnetics Research C*, vol. 24, pp. 185-196, 2011.

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