

Voltage-Controlled Oscillator at 6 GHz for Doppler Radar in Heart Sensing Applications*

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Abstract: In this paper, the design of a low noise voltage controlled oscillator (VCO) for heart sensing applications is presented. It is designed using Ansoft Designer software to have a low level of phase noise, therefore a bipolar transistor is chosen. Many effects such as the behaviour of large signals, the parasitic effects of packages, etc., are taken into account. Hence, through a nonlinear analysis, quite accurate simulation results are provided.

Keywords: VCO, 6 GHz, Low phase noise, High output power, Microstrip technology.

1 Introduction

An oscillator is a system that converts the DC voltage from a source into an RF signal. There is no external excitation. The oscillations are the result of random noise (usually thermal noise in resistors). This noise enters a cumulative process and gets amplified. Part of the signal goes to the output and part is fed back (in a resonant circuit) to the input. The resonator has a selective function, hence some components of the returned signal are passed and some are severely attenuated. Establishing positive feedback, the amplified signal has the same phase as the original signal, which means that they add and the signal gets amplified. A similar action takes place in the next few cycles and the amplitude of the signal gets higher and higher at the frequencies which are passed by the resonant circuit. This process is terminated by the nonlinearity of the amplifier (transistor). When amplification in the loop becomes 1, the amplitude stabilizes.

Here, we present an oscillator which is part of a Doppler radar for heart sensing applications. Detection of heart activity is performed at 24 GHz but this oscillator operates at 6 GHz, hence the frequency of the signal at the output of the oscillator needs to be multiplied by four. This radar is based on the Doppler effect which is manifested when a signal of constant frequency encounters an object whose area has a periodic movement and the signal is reflected from the

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*Award for the best paper presented in Section *Microwave and Submillimeter Technique*, at Conference ETRAN 2009, June 15-19, Vrnjačka Banja, Serbia.

object at the same frequency, only the signal now has a time varying phase $\Phi(t)$. This time varying phase is equivalent to the shift, $x(t)$:

$$\Phi(t) = \frac{4\pi x(t)}{\lambda}, \tag{1}$$

where λ is the wavelength of the signal.

Now, we have phase modulated the reflected signal. If the shift is smaller than the wavelength of the signal, then the change of phase is small and the phase-modulated signal can be directly de-modulated by mixing it with the original signal. The de-modulated signal is proportional to the periodic shift of the object. If we consider that the object is a human's lungs, the de-modulated signal represents a shift caused by breathing or heart activity. Detection of breathing and heart activity is performed at various frequencies (2.4 GHz, 5.8 GHz and 24 GHz IMS band). By performing this kind of measurement, we can get quite accurate data on heart rhythm and its variation and run long-term statistics of heart activity.

2 Linear Analysis of Oscillators

Oscillators are highly nonlinear circuits. In order to analyze a nonlinear system, we need computers with lots of processing power. First, we want to gain insight into how an oscillator works, so we use a simplified linear model (linear analysis). The transistor model is replaced by a small signal model which is determined by the DC bias. The procedure of linear analysis gives a very good starting point for further oscillator analysis. There are many methods for linear analysis of oscillators (determination of basic conditions for oscillations). Here is described the method of negative resistance.

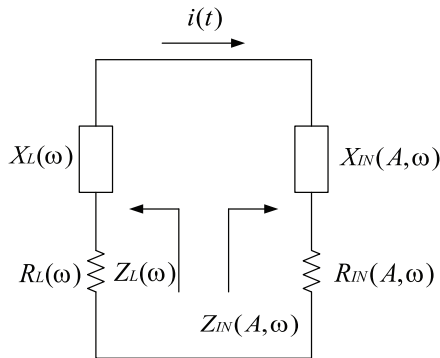


Fig. 1 – Schematic of the system with negative resistance.

Fig. 1 shows a schematic of the system with negative resistance.

The input impedance of a system with negative resistance depends on the amplitude and frequency of the signal:

$$Z_{IN}(A, \omega) = R_{IN}(A, \omega) + jX_{IN}(A, \omega), \quad (2)$$

where A is the amplitude of current $i(t)$ and

$$R_{IN}(A, \omega) < 0. \quad (3)$$

In order for oscillations to start, a condition must be satisfied:

$$R_{IN}(I, \omega) + R_L < 0. \quad (4)$$

Any kind of noise in the circuit will start oscillations. The amplitude of current will rise over every cycle and the resistance will become less negative (eventually converging to zero). This process lasts until some particular frequency when a nominal value of current is achieved and a stationary state is established. Equations that describe the stationary state are:

$$R_{IN}(I, \omega) + R_L = 0, \quad (5)$$

and

$$X_{IN}(I, \omega) + X_L = 0. \quad (6)$$

3 Phase Noise

In modern communication systems, it is very important that signals are stable. When we talk about oscillators, we talk about the stability of the frequency of oscillations. Stability of frequency is defined by two parameters: long-term stability and short-term stability. Long-term stability refers to slow changes in nominal frequency, while short-term stability refers to instantaneous variations of the nominal frequency. Deterministic variations of frequency are discrete signals which appear in the spectrum and are designated as spurious signals. Short-term random fluctuations of frequency are designated as phase noise. Sources of phase noise are thermal noise, quantum noise and flicker noise. Phase noise is very often the limiting factor in many applications. Phase noise is described in terms of the power level in a 1 Hz band at some frequency offset from the carrier, in dBc/Hz at x Hz from the carrier, where x could have values from 100 Hz to 10 MHz, depending on application.

Unlike an ideal signal whose phase and amplitude are constant in time, the real signal has a time varying amplitude and phase and can be represented as:

$$v(t) = [V + n(t)]\cos[2\pi ft + \phi(t)], \quad (7)$$

where:

$n(t)$ is amplitude noise, and

$\varphi(t)$ is phase noise.

Phase noise can be described in time and as a spectrum. As a spectrum, phase noise is usually presented as SSB (single sideband) with units of dBc/Hz.

In order to calculate phase noise, there is one very suitable formula which was defined by *Leeson*, and modified by *Scherer* and *Rohde* to take the form:

$$L(f_m) = 10 \log \left\{ \left[1 + \frac{f_0^2}{(2f_m Q_L)^2} \right] \left(1 + \frac{f_c}{f_m} \right) \frac{FkT}{2P_{sav} \left(1 - \frac{Q_L}{Q_0} \right)} + \frac{2kTRK_0^2}{f_m^2} \right\}, \quad (8)$$

where:

$L(f_m)$ is the ratio of SSB in a 1 Hz band at frequency f_m to total power in dB

f_m is the frequency at which the ratio $L(f_m)$ is calculated

f_0 is the central frequency

f_c is the flicker frequency

Q_L is the Q -factor of the loaded resonant circuit

Q_0 is the Q -factor of the unloaded resonant circuit

F is the noise figure

$kT = 4.1 \times 10^{-21}$ at room temperature (300K)

P_{sav} is the average output power of the oscillator

R is the equivalent resistance of the varicap diode from the point of view of noise (200 Ω – 10 k Ω)

K_0 is the gain of VCO.

4 Design of Oscillator

In this paper, the design of a voltage controlled oscillator (VCO) at 6 GHz with a low level of phase noise is presented. The Clapp configuration is chosen for the synthesis of this oscillator.

Starting from this schematic, values of elements in the resonant and transistor circuits are determined in order to establish oscillations at 6 GHz. For this oscillator, a bipolar transistor Infineon BFP420 is chosen. The reason is that

bipolar transistors have better phase noise characteristics and better wideband characteristics than FET transistors.

To change the frequency of oscillations, a varicap diode is used. Varicap diodes act as voltage-controlled capacitors. The relationship between the voltage of polarization of a varicap diode and its capacitance is defined as:

$$C_V(V_V) = C_{V0} \left(1 + \frac{V_V}{\phi} \right)^{-\gamma} \quad (9)$$

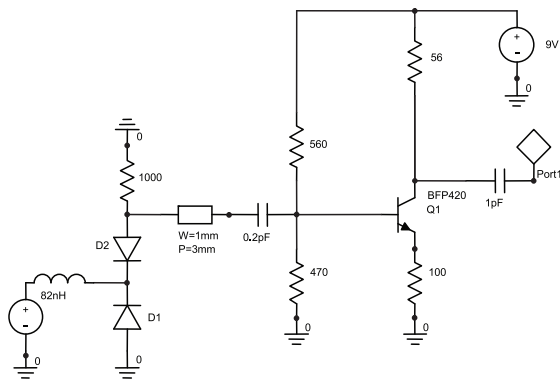


Fig. 2 – Schematic of the voltage controlled oscillator.

In this paper, a flip-chip GaAs hyperabrupt varicap diode MV39003 (by MDT) is used. This diode is polarized by voltages in the range of 2–9V.

From the basic model with discrete elements, we move to a more complex model implemented in microstrip technology. The substrate on which this oscillator is simulated is a Rogers RO 4003 with parameters: $h = 0.2\text{ mm}$, $t = 0.017\text{ mm}$, $\epsilon_r = 3.63$, $\tan \delta = 0.0027$.

5 Results

Here are shown results of simulations of the designed oscillator. We can conclude that the condition for oscillations at 6.38 GHz are obtained when a voltage of 2 V is applied to the varicap diodes.

Fig. 3 shows the negative resistance (line with lower starting value) and reactance (line with higher starting value) of the oscillator.

The linear analysis shows where oscillations may occur. This is a good starting point with which we can get a picture of how the system works. Next, a nonlinear analysis is performed in order to get information about the output power of the oscillator and phase noise.

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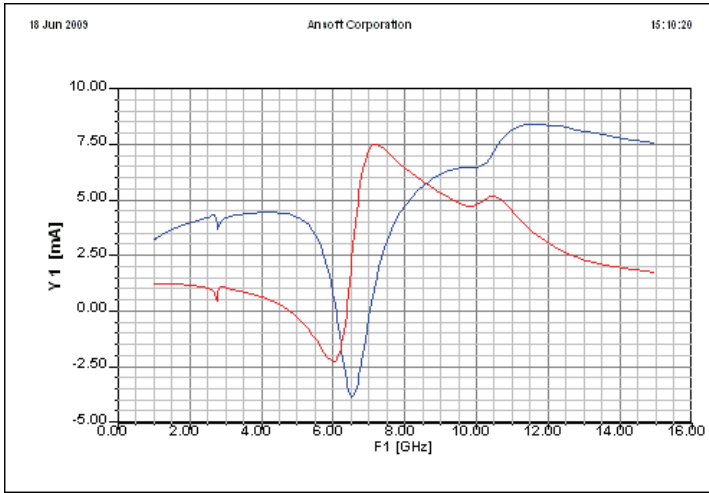


Fig. 3 – Linear analysis of oscillator.

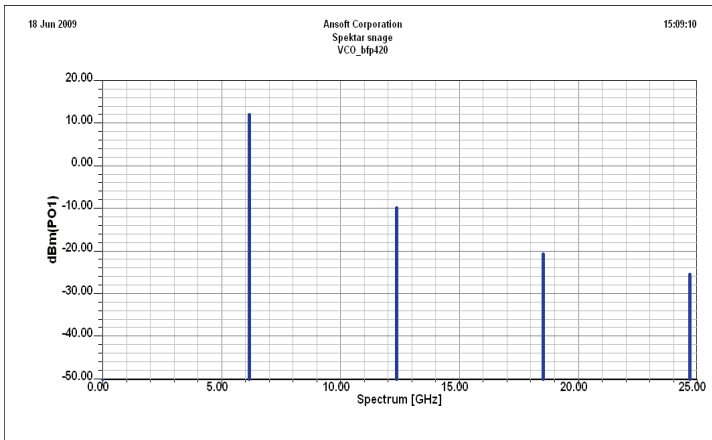


Fig. 4 – Output power of oscillator (spectrum).

Fig. 4 shows the output power spectrum of the oscillator.

Fig. 5 shows the level of phase noise in the oscillator.

From Figs. 5 and 6, it is easy to conclude that oscillations are established at 6.17 GHz, where the output power is about 12 dBm. The level of phase noise at 10 kHz in the carrier is -74 dBc. Results of simulations for a polarization voltage of 9 V applied to the varicap diodes are: level of phase noise is -73 dBc, oscillations occur at 6.36 GHz, and output power is about 12 dBm.

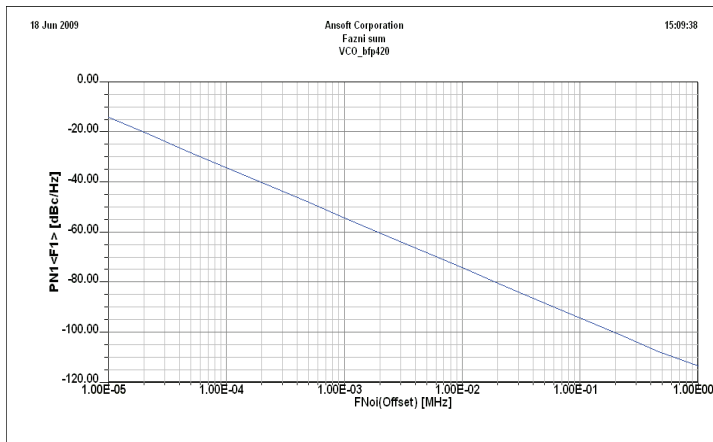


Fig. 5 – Level of phase noise.

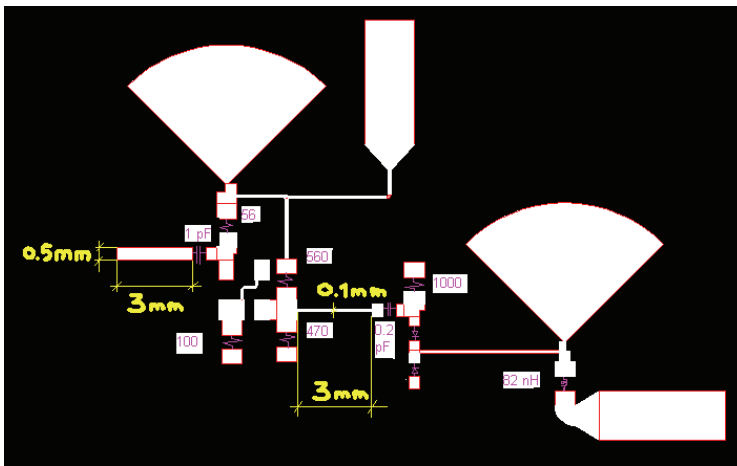


Fig. 6 – Layout of oscillator.

Fig. 6 shows layout with some characteristic dimensions.

Dimensions of layout of VCO are 20×15 mm.

6 Conclusion

In this paper, the design of a low noise voltage controlled oscillator at 6 GHz for heart sensing applications is presented. We started with a model with ideal discrete elements in order to build a final model with real elements in microstrip technology. By performing a linear then a nonlinear analysis, information about the frequency of oscillations, output power of the oscillator

and level of phase noise level is obtained. The designed oscillator oscillates at 6.17 GHz with an output power of 12 dBm. The level of phase noise at 100 kHz from the carrier is -74 dB. The advantage of using Doppler radar for wireless detection of heart activity and breathing is that the designed oscillator can be used for transmission and for reception. This means that the phase noise of both signals is correlated, so the use of a phase locked loop and reference crystal oscillator is avoided.

7 References

- [1] A. Grebennikov: RF and Microwave Transistor Oscillator Design, John Wiley & Sons, UK, 2007.
- [2] G. Gonzalez: Microwave Transistor Amplifiers – Analysis and Design, Prentice Hall, NJ, 1997.
- [3] A. Djordjevic, D. Tosic: Mikrotalasna tehnika, Akademska misao, Belgrade, 2006.