8 The Role of the Varactor

1 Fundamentals

Over the oscillation cycle, the varactor capacitance spans a portion of their *C-V* curve that depends on the bias and control voltages as well as the signal amplitude. If the active device nonlinearity is memoryless, the oscillation frequency is determined by the balance of reactive currents in the tank capacitance and inductance [10]. In a differential oscillator, if the parasitic capacitances, other than those across the tank inductance, are negligible, the active negative resistance is nonlinear but memory-free. Furthermore, in an LC oscillator, it is reasonable to assume the oscillation waveform to be quasi-sinusoidal even in the presence of circuit and varactor nonlinearities. This allows the approximation of the frequency of oscillation by

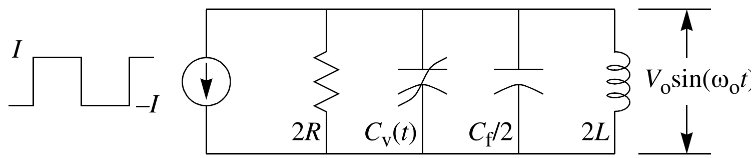
$$\omega_o = \frac{1}{\sqrt{LC_{avg}}}, \tag{1}$$

where L is the effective inductance and C_{avg} is the effective capacitance at balance.

To find the effective capacitance, we resort to basic principles. The oscillator is modeled as a lossy parallel LC tank. The loss is compensated by a negative resistance current that switches from $-I$ to I at the zero crossing of the voltage across the tank. This model captures all nonlinearities of the oscillator while assuming the nonlinear negative resistance is memoryless.

The fundamental component of the negative resistance current flows through the tank loss resistor because the inductor and the capacitor are at resonance at that frequency and so present an open circuit to the fundamental. As such, the amplitude of oscillation is

FIGURE 1 *Parallel resonance tank with switched current drive*



$$V_o = i_o \frac{4}{\pi} Q \omega_o L . \tag{2}$$

Harmonics of the negative resistance current elect to flow in the capacitor rather than the inductor because it provides a lower impedance path. With quasi-sinusoidal operation, harmonics of the negative resistance current cannot flow in the tank resistor which provides a higher impedance path. Note in Figure 2 that current switching affects only the current in the capacitor within a narrow time window around the oscillation voltage-zero-crossings causing more harmonics to flow into the capacitor. For moderate quality factors, 8 or above, the impact of these harmonics on the oscillation frequency can be neglected, in part because the current in the capacitor is Q times the resistor current at resonance and because the switching event occurs in a narrow time window depending on the oscillation amplitude and the switching transistors transconductance.

Having neglected the harmonics of the negative resistance current, the inductor current must balance the capacitor current at all times. Figure 2 shows the inductor and capacitor currents to be equal at all times except at the zero crossing of the oscillation voltage. This moment is when the current is diverted from one side to the other. The sharp transition in current can go through the capacitor but not through the inductor. Under large oscillation amplitude, this transition time is very short and the following applies:

$$i_C + i_L = 0 . \tag{3}$$

The oscillation voltage can be represented in general by its Fourier series expansion as follows

$$V(t) = \sum_n a_n \cos(n\omega t) , \tag{4}$$