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Voltage–Controlled Oscillator (VCO)

Recommended Text: Gray, P.R. & Meyer. R.G., Analysis and Design of Analog Integrated Circuits
(3rd Edition), Wiley (1992) pp. 695-707

Introduction

- ***Voltage-Controlled Oscillator*** **–** is a principal part of the PLL.
- It determines the overall performance of PLL system, i.e.
  - The operating frequency range,
  - FM distortion,
  - center-frequency drift, and
  - center-frequency,
  - supply-voltage sensitivity are all determined by of the VCO.
- Integrated-circuit VCOs most often are simply R-C multivibrators in which the charging current in the capacitor is varied in response to the control input

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Emitter-Coupled Multivibrator as VCO

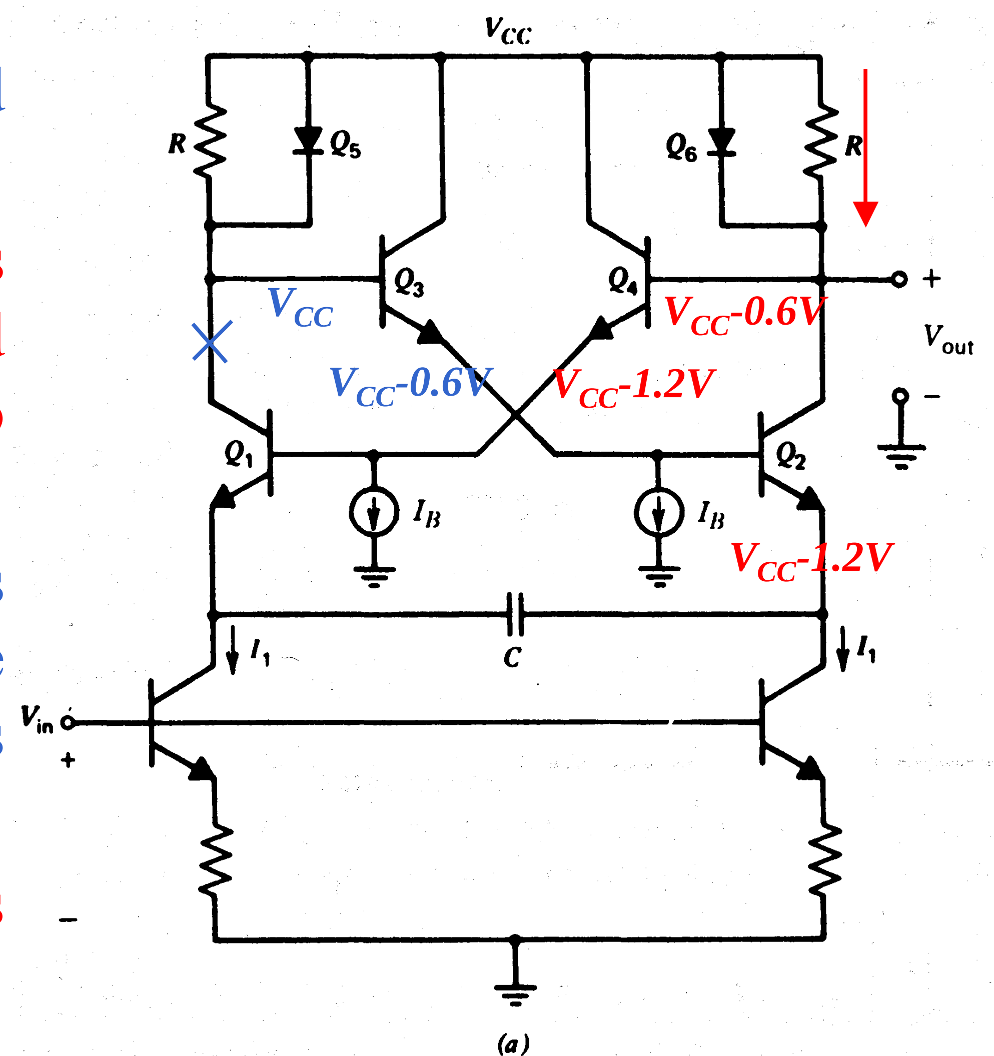
- Consider the emitter-coupled multivibrator, which is typical in this application

Assuming that *Q1* is turned off and *Q2* is turned on

The Q4 base voltage (V_{B4}) is one diodes drop (0.6V) and emitter voltage (V_{E4}) is two diodes drops below V_{CC}

Base voltage of Q3 (V_{B3}) is V_{CC} and emitter voltage (V_{E3}) is one diodes drops below V_{CC}

Thus the emitter of *Q2* is two diode drops below *Vcc*.

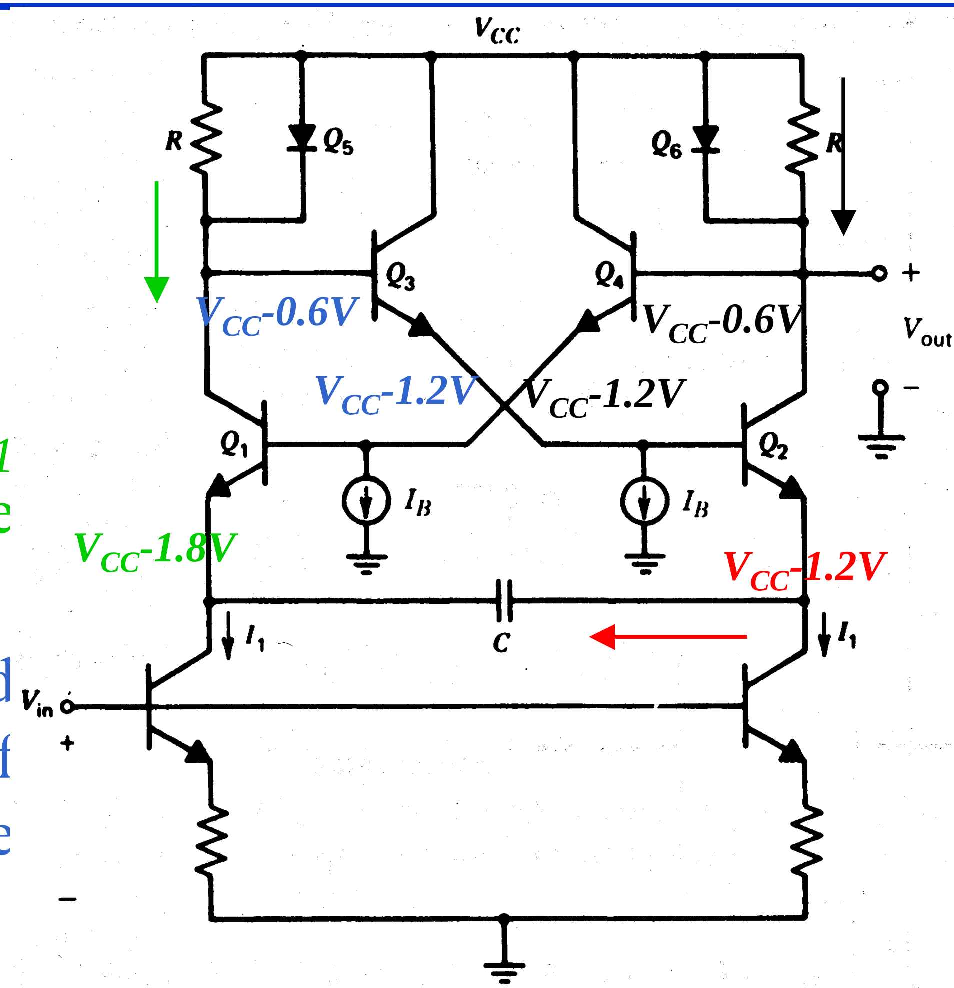


VCO Analysis

Since *Q1* is off, the current I_1 is charging the capacitor so that the emitter of *Q1* is becoming more negative.

Q1 will turn on when V_{E1} becomes equal to three diode drops below *Vcc'*

As a result, the base and emitter of *Q3* (and the base of *Q2)* moves in the negative direction by one diode drop

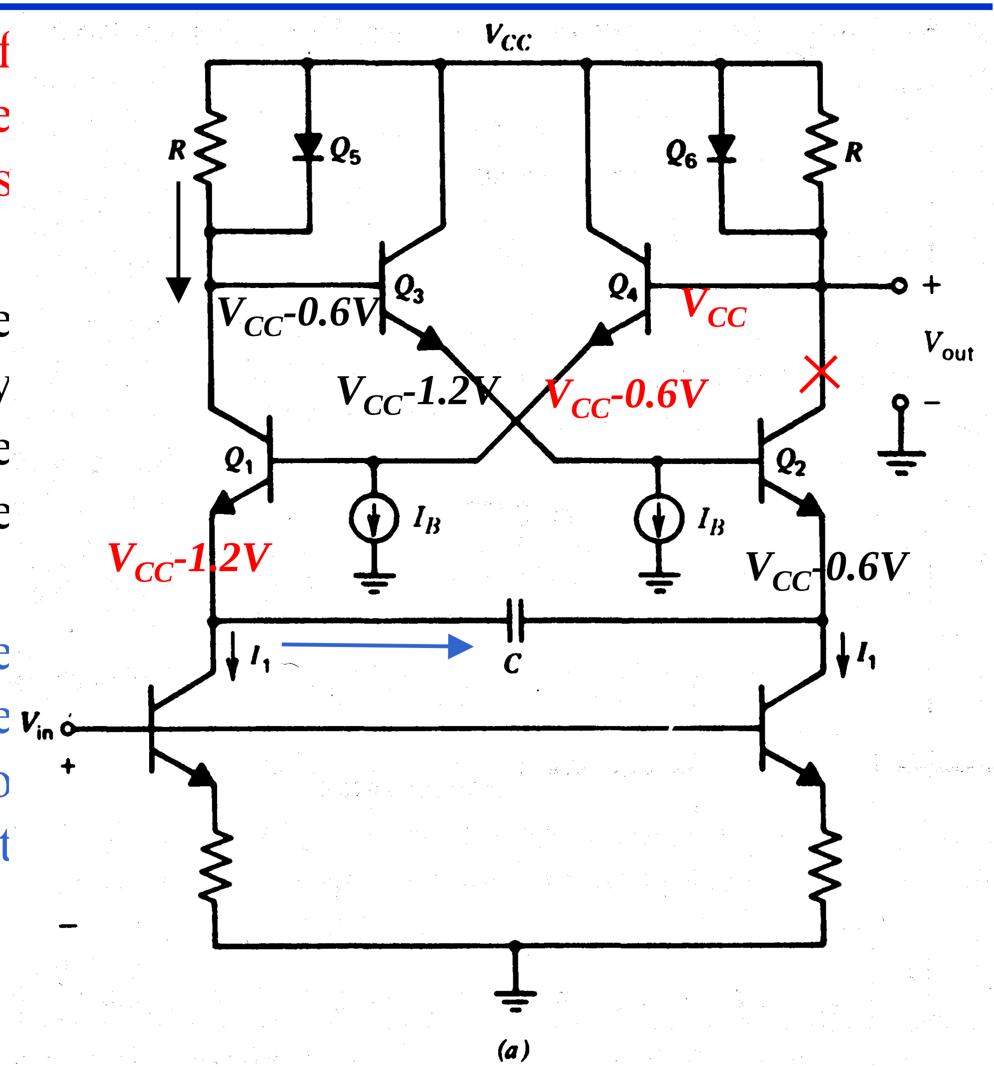


(a)

Q2 will turn off causing the base of *Q4* and *Q1* to move positive by one diode drop because *Q6* will turns off.

As a result, the emitter-base junction of *Q2* is reverse biased by one diode drop because the voltage on C cannot change instantaneously.

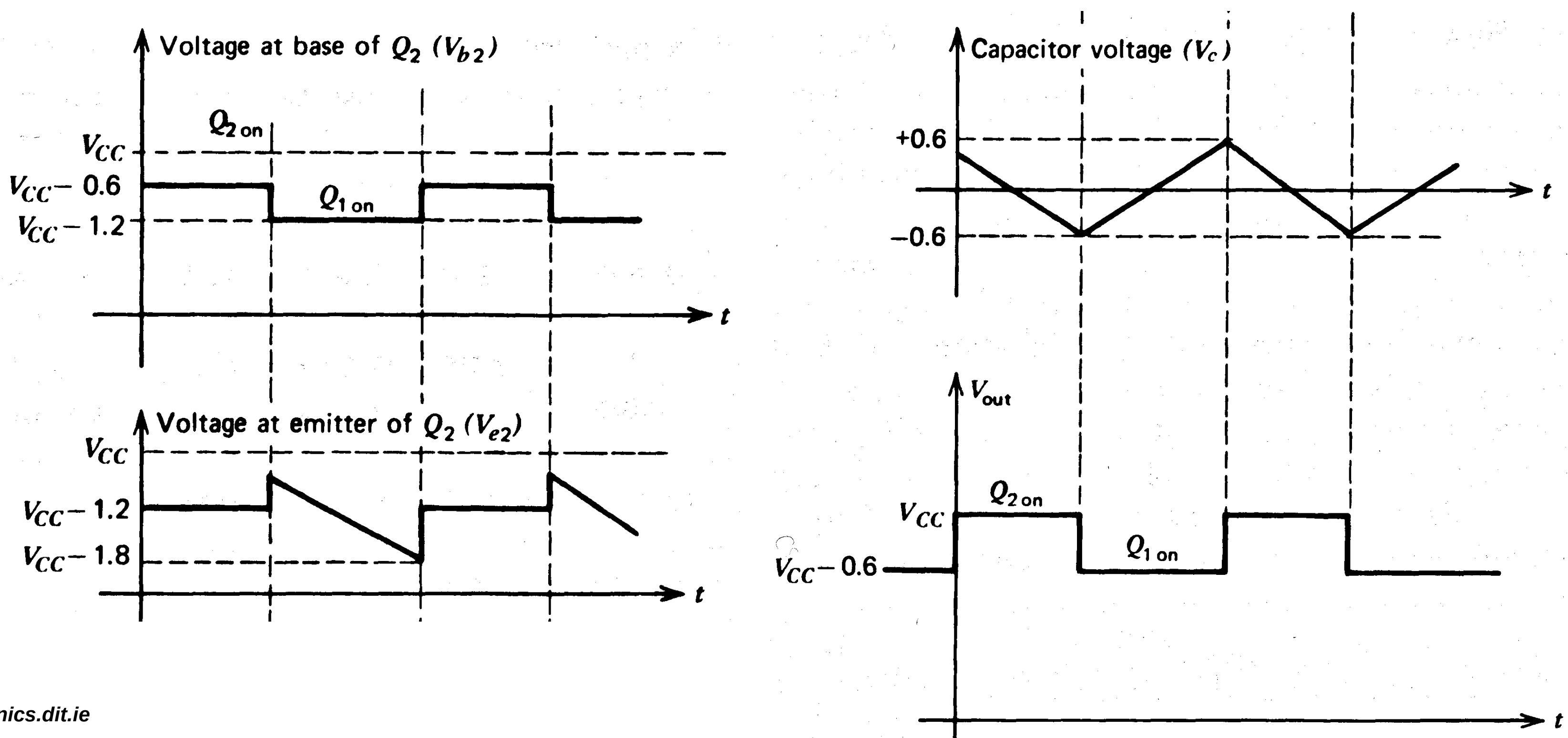
Current I_1 must now charge the capacitor voltage in the negative direction by an amount equal to two diode drops before the circuit will switch back again.



Since the circuit is symmetrical, the half period is given by the time required to charge the capacitor and is $T/2=Q/I_1$,

where $Q = C{\cdot}\Delta V = 2{\cdot}C{\cdot}V_{BE(on)}$ is the charge on the capacitor.

- The frequency of the oscillator is thus $f=1/T = I_1/4CV_{BE(on)}$



- The emitter-coupled configuration is capable of high operating speed, up to approximately 100 MHz .
- It displays considerable sensitivity of center frequency to temperature even at low frequencies, since the period is dependent on $V_{BE(on)}$
- The temperature coefficient of the period can be calculated as:

$$\frac{1}{\omega_{osc}}\frac{d\omega_{osc}}{dT} = -\frac{1}{V_{BE(on)}}\frac{dV_{BE(on)}}{dT} = \frac{2\, mV/^{o}C}{600\, mV} = 3300\, ppm/C$$

- This temperature sensitivity of center frequency can be compensated by causing current I_1 to be temperature sensitive in opposite way

Typical Problem

- A typical structure for a PLL voltage-controlled oscillator (VCO) is shown in Fig. 1.

The VCO contains matched transistors with $V_{BE(ON)}$ values of 0.6 V and is operated at a supply voltage (Vcc) of 12 V and a free-running quiescent current (I_1) of 1 mA.

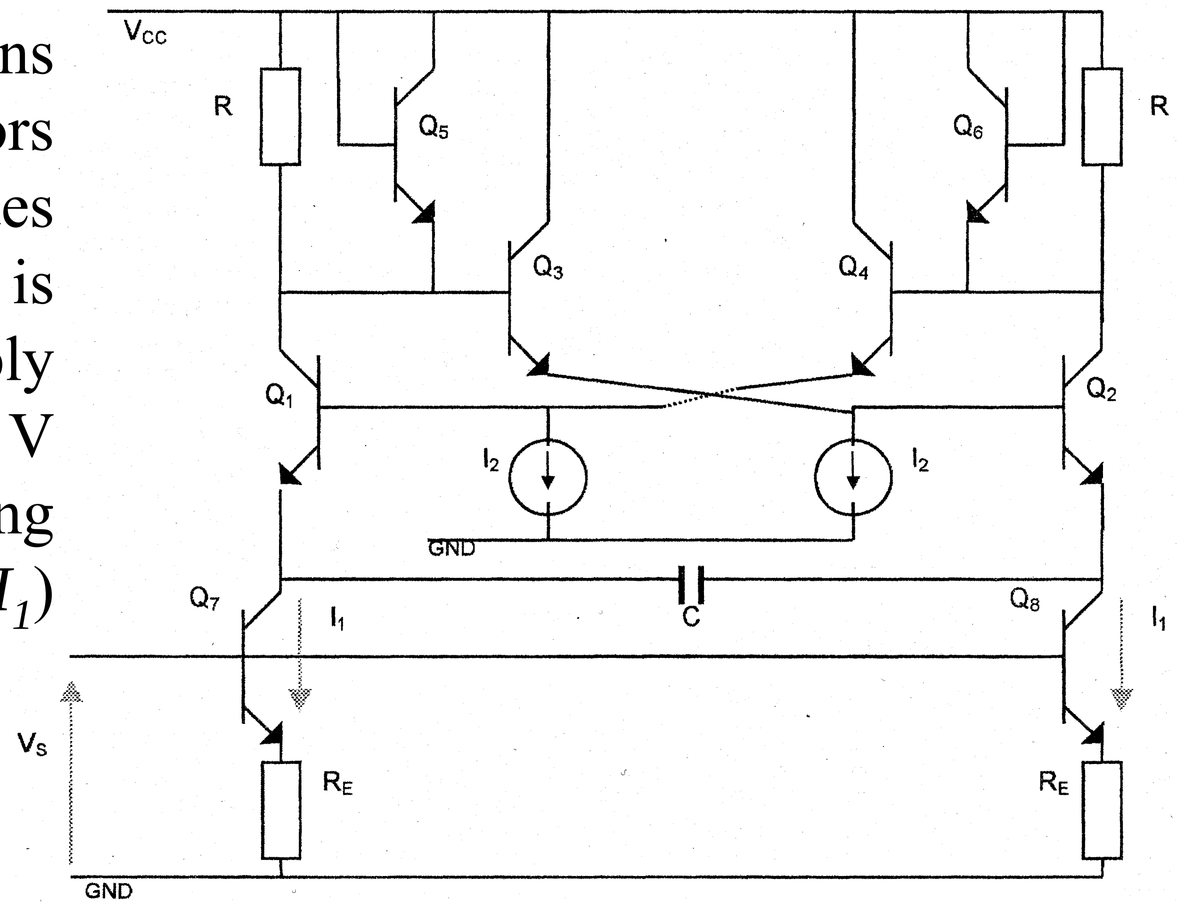


Fig. 1

- Sketch, to a common time-scale, the anticipated voltage waveforms at the emitter of *Q2* (V_{E2}) and of the capacitor voltage ($V_C = V_{E1} - V_{E2}$) over one cycle of oscillation.
- Assuming a base-emitter temperature coefficient of -2 mV/°C and a symmetrical input voltage range of 1.0 V < V_S < 1.4 V, determine :

(i) The value of capacitance required to attain a free-running oscillation frequency of 1 MHz.

(ii) The upper and lower limits of the oscillation frequency range;

(ii) The oscillation frequency temperature coefficient in ppm/°C.

- Assume that $2 \cdot I_1 \cdot R > V_{BE(on)}$ and that I_1 is temperature invariant.