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Chapter 32

Oscillators

Circuit Analysis with Devices:
Theory and Practice

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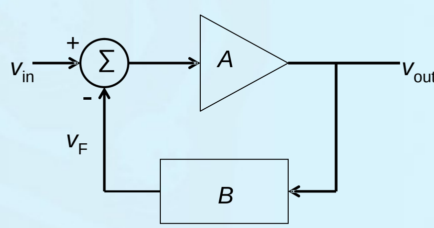
Basics of Feedback

- Block diagram of feedback amplifier
- Forward gain, *A*
- Feedback, *B*
- Summing junction, Σ
- Useful for oscillators



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Basics of Feedback

- Op-amps
  - Inverting & non-inverting
  - Negative feedback 180° out of phase w/input
  - High input impedance
  - Low output impedance
  - Wide bandwidth
  - Stable operation

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Basics of Feedback

- Oscillators
  - Positive feedback
  - In-phase with input
  - Unstable

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Basics of Feedback

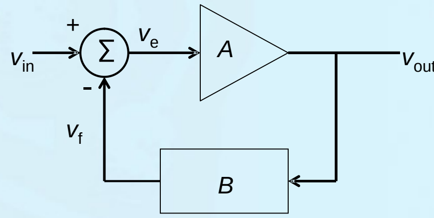
- Block diagram analysis

$$v_e = v_{in} - v_f$$

$$v_{out} = A(v_{in} - v_f)$$

$$v_f = Bv_{out}$$

$$\frac{v_{out}}{v_{in}} = \frac{A}{1+AB}$$



5

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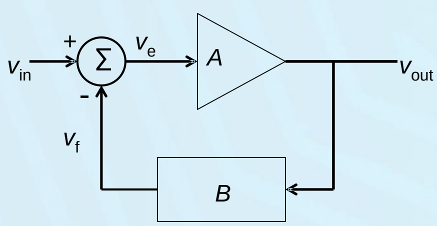
Basics of Feedback

- Inverting amplifier



$$v_e = -v_{in} - v_f$$

$$v_{out} = A(-v_{in} - v_f)$$

$$v_f = Bv_{out}$$

$$\frac{v_{out}}{v_{in}} = -\frac{A}{1+AB}$$

$$\frac{v_{out}}{v_{in}} = -\frac{1}{\frac{1}{A}+B} \approx \frac{1}{B}$$

$$B = \frac{R_1}{R_F}$$

6

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Relaxation Oscillator

- Square wave generator
- Composed of
  - Schmitt trigger comparator
  - Positive feedback
  - *RC* circuit to determine period

7

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Relaxation Oscillator

- Schmitt Trigger
  - R_1 and R_2 form a voltage divider
  - Portion of output applied at + input
  - Hysteresis: output dependent on input and previous value of input

8

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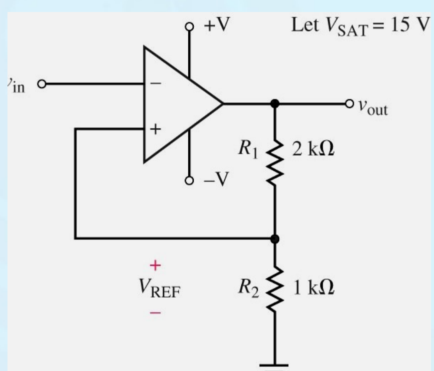
Relaxation Oscillator

- Schmitt Trigger
  - Hysteresis: upper and lower trip points
  - Can use a voltage follower for adjustable trip points

Relaxation Oscillator

- Schmitt trigger



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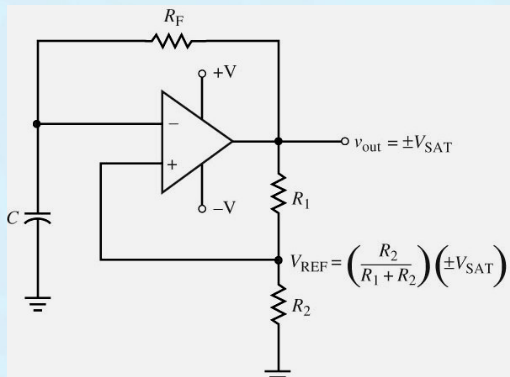
Relaxation Oscillator

- Schmitt Trigger Relaxation Oscillator



11

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Relaxation Oscillator

- R_1 and R_2 voltage divider

$$V_{REF} = \frac{R_2}{R_1 + R_2}(\pm V_{SAT})$$

- Capacitor charges through R_F
- $V_C < +V_{SAT}$ then C charges toward $+V_{SAT}$
- $V_C > -V_{SAT}$ then C charges toward $-V_{SAT}$

12

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Relaxation Oscillator

- Schmitt Trigger Relaxation Oscillator Equations

$$\tau = R_F C$$

$$v_C(t) = \left(V_F - V_O\right)\left(1 - e^{-\frac{t}{RC}}\right)$$

$$T = 2R_F C \ln\left(1 + \frac{2R_2}{R_1}\right)$$

13

Wien Bridge Oscillator

- For a sinusoidal oscillator output
  - Closed loop gain ≥ 1
  - Phase shift between input and output = 0° at frequency of oscillation
- With these conditions a circuit
  - Oscillates with no external input
- Positive feedback = regenerative feedback

14

Wien Bridge Oscillator

- Regenerative oscillator
  - Initial input is small noise voltage
  - Builds to steady state oscillation
- Wien Bridge oscillator
  - Positive feedback, *RC* network branch
  - Resistor branch establish amplifier gain

15

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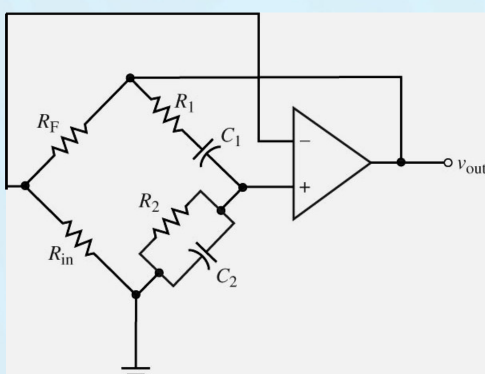
Wien Bridge Oscillator

- Circuit



16

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Wien Bridge Oscillator

- Equations

$$f_0 = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} = \text{ Output frequency}$$

$$B = \frac{R_2 C_1}{R_1 C_1 + R_2 C_2 + R_2 C_1}$$

$$\text{if } R_1 = R_2 \text{ and } C_1 = C_2 \text{ then}$$

$$f_0 = \frac{1}{2\pi RC} \text{ and } B = \frac{1}{3}$$

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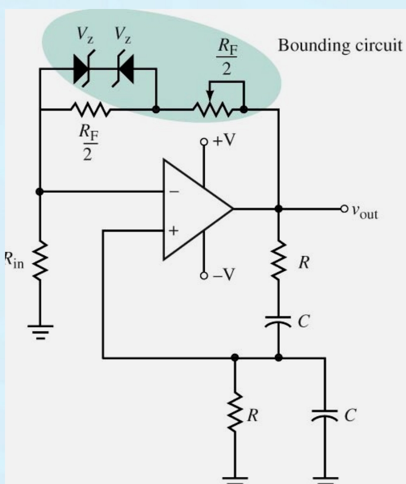
Wien Bridge Oscillator

- Another form of Wien Bridge



Wien Bridge Oscillator

- For a closed-loop gain, *AB* = 1
  - Op-amp gain ≥ 3
- Improved circuit
  - Separate R_F into 1 variable and 1 fixed resistor
  - Variable: minimize distortion
  - Zener Diodes: limit range of output voltage

Phase-Shift Oscillator

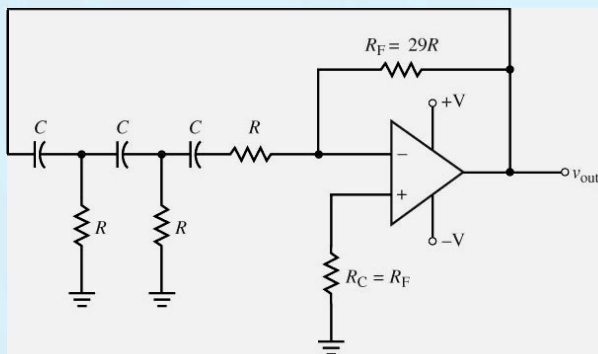
- Three-section *R-C* network
  - ≈ 60° per section
  - Negative FB = 180°
  - 180° + (60° + 60° + 60°) = 360° = Positive FB

$$f_0 = \frac{1}{2\pi\sqrt{6}RC} \text{ Output frequency}$$

$$A = 29 \text{ Required voltage gain}$$

Phase-Shift Oscillator

- Circuit



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LC Oscillators

- *LC* circuits can produce oscillations
- Used for
  - Test and measurement circuits
  - RF circuits

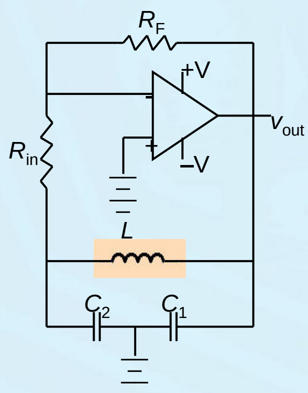
LC Oscillators

- Named after pioneer engineers
  - Colpitts
  - Hartley
  - Clapp
  - Armstrong

LC Oscillators

- Colpitts oscillator
  - f_s = series resonance
  - f_p = parallel resonance
  - *L-C* network → 180° phase shift at f_p

LC Oscillators



25

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LC Oscillators

- Equations

$$\text{Impedance: } Z(s) = \frac{1 + s^2 L C_2}{s(C_1 + C_2)\left(1 + \dfrac{s^2 L C_1 C_2}{C_1 + C_2}\right)}$$

$$\text{Oscillator frequency: } f_0 = \frac{1}{2\pi\sqrt{L\dfrac{C_1 C_2}{C_1 + C_2}}}$$

26

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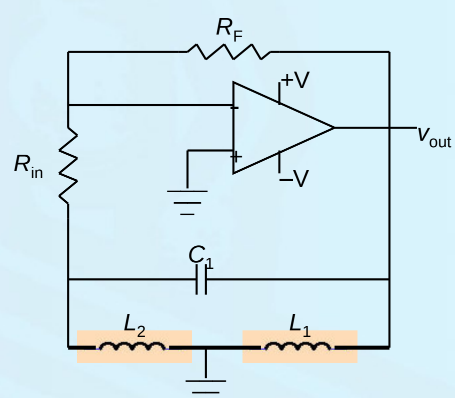
LC Oscillators

- Hartley oscillator
  - Similar to Colpitts
  - *L* and *C*'s interchanged
  - Also have f_s and f_p

LC Oscillators

$$Z(s) = \frac{sL_1\left(1+s^2L_2C\right)}{1+s^2\left(L_1+L_2\right)C}$$

$$f_0 = \frac{1}{2\pi\sqrt{\left(L_1+L_2\right)C}}$$



Crystal Oscillators

- Quartz crystals
- Mechanical device
- Higher frequencies (>1 MHz)
- Stability
- Accuracy
- Reliability
- Piezoelectric effect

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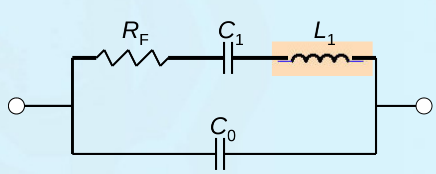
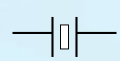
Crystal Oscillators

- Electrical model
  - Both have parallel and series resonance

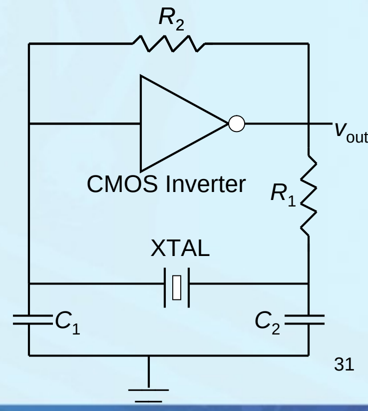


- Symbol
  - Quartz crystal
  - metal plates



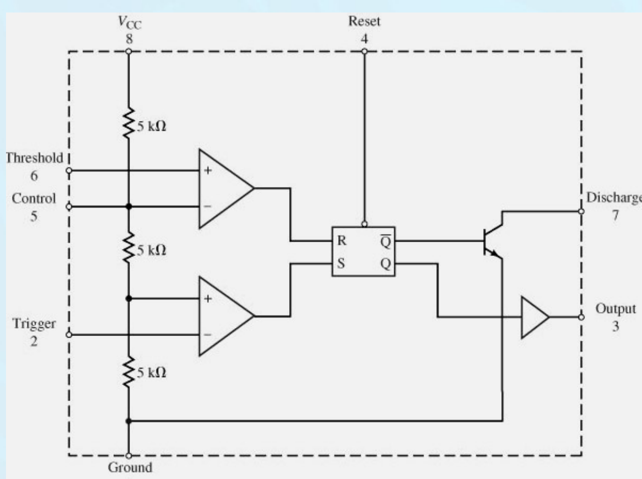
Crystal Oscillators

- Impedance varies with frequency
- Square wave crystal oscillator circuit
- Choose C_1 and C_2
  - Oscillation frequency between f_s and f_p



555 Timer

- IC
  - Internal circuit



555 Timer

- Usage
  - Monostable timing
  - Astable mode = relaxation oscillator
  - Trigger voltage
  - Control voltage
  - Threshold voltage
  - R-S flip-flop

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555 Timer

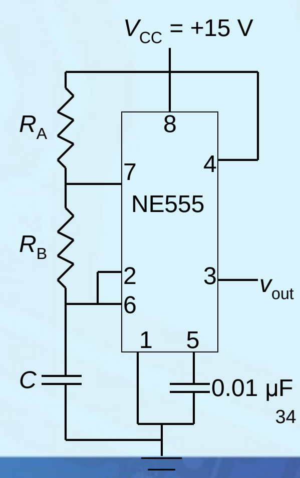
- Relaxation oscillator

$$T_1 = \ln(2) * (R_B C)$$

$$T_2 = \ln(2) * (R_A + R_B) C$$

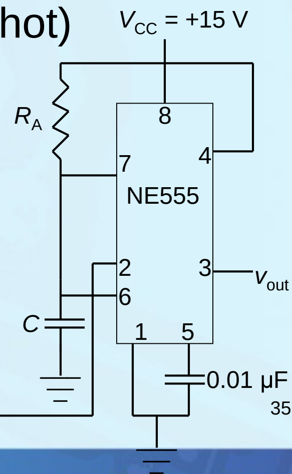
$$T = \ln(2) * (R_A + 2R_B) C$$

$$f = \frac{1}{T}$$



555 Timer

- Monostable Circuit (one-shot)
- Trigger high → v_{out} = low
- Trigger low → v_{out} = high



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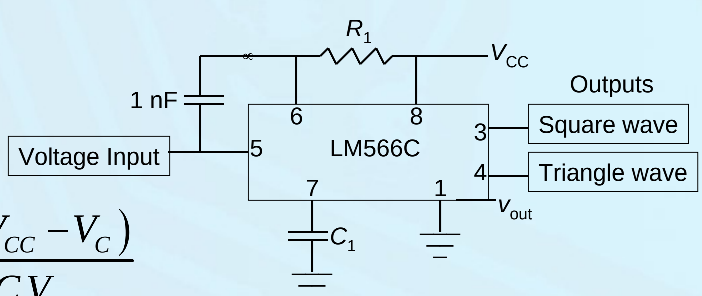
Voltage Controlled Oscillator-VCO

- $\Delta f_{out} \propto \Delta v_{in}$



$$f_O = \frac{2.4(V_{CC} - V_C)}{R_1 C_1 V_{CC}}$$