Note: The main focus of the Test Seven will be on Op-Amps configured as Comparators, Schmitt Triggers, Active Filters, and Differential Mode and Common Mode Operation (hilited in green). However, in order to answer op-amp questions and to solve op-amp problems, it is still necessary to be familiar with op-amp properties and characteristics.

Transistor Amplifiers and Oscillators

Amplifiers require *negative feedback* (180º out-of-phase) for circuit stability, high fidelity, wide bandwidth
Oscillators require *positive feedback* (in-phase) in order to sustain operation
Oscillators convert DC supply voltages to AC signals
  Piezoelectric Effect (Crystal Control)
Common Emitter (BJT) Amplifiers
  Low frequency cut-off due to coupling capacitors and by-pass capacitors
  High frequency cut-off due internal junction capacitance and frequency dependence of β
Amplifier Gain (Generally expressed as Gain = Output / Input)
  Gain Factors are defined for Voltage, Current, and Power
  Voltage Gain is often expressed using slightly different symbology (α, A, A_0, A_v).
  Current Gain A_i
  Power Gain A_p

Operational Amplifiers (Op-Amps)

Series of cascaded amplifiers:
  differential amplifier, high gain voltage amplifier, low impedance output amplifier.
Characteristics of input and output impedance, voltage gain, bandwidth for an ideal op-amp:
  high input impedance, low output impedance, high gain, wide bandwidth.
$V_{sat} = V_{CC} \pm 2$ volts $+V_{sat}$ (Max V_{out}) = +Vcc - 2 V $-V_{sat}$ (Max V_{out}) = -Vcc + 2 V
Basic Rule for Input Currents: $i^- = i^+ = 0$

Open Loop (no feedback): $V_{out} = A(v^+ - v^-)$ such that $V_{out} = V_{sat}$
  Comparators: Protects against inadvertent output switching due to noisy input signals.

Closed Loop (positive feedback)
  Schmitt Triggers: Bi-reference level comparator with positive feedback.

Closed Loop (negative feedback)
  Basic Rule for Input Voltages: $v^- = v^+$
  Gain:
    Inverting (input to v- terminal) = $-Z_f / Z_i$
    Non-Inverting (input to v+ terminal) = $1 + Z_f / Z_i$
  Commonly used as summers, multipliers, differentiators, integrators; hence the name *operational amplifiers* (analog computers). Can also be configured as log and anti-log (exponentiation) amplifiers, active filters, unity buffers, comparators, Schmitt triggers, oscillators.

Differential Mode and Common Mode Operation

Differential Voltage $V_{DV} = v^+ - v^-$
Differential Gain $DG = |V_{out} / V_{DV}|$
Common Mode Voltage $V_{CMV} = (v^+ + v^-) / 2$
Common Mode Gain $CMG = |V_{out} / V_{CMV}|$
Common Mode Rejection Ratio CMRR = DG / CMG   CMRR dB = 20 log(DG/CMG)
Ideal CMG = 0 CMRR = ∞ Typical Values CMRR = 80dB = 10^4
Signal Noise Ratio
$SNR_{in} = V_{signal} / V_{noise}$
$SNR_{out} = CMRR * SNR_{in}$

Operational Amplifiers Handouts and Op-Amp Problems

Operational Amplifier Active Filters
  Calculate band pass gain and cut-off frequencies for low and high pass active filters with either non-inverting input or inverting inputs.
Comparators and Schmitt Triggers - Calculate V_{ref} voltages and describe the operation.