Wrap Up

In this course, you have learned…

- Microelectronic devices that can provide gain (active)
  - Basic semiconductor physics
  - Operation principles, terminal I-V equations and circuit models of
    - PN-junction diode
    - BJT transistor
    - MOS transistor
- Special analysis techniques for microelectronic circuits
  - DC analysis (biasing)
  - Small signal analysis
- Diode circuits
  - Rectifiers
  - Regulators
  - DC-DC converters
  - Clipping & Clamping ckts
- BJT & MOS transistor circuits
  - Single transistor amplifiers
  - Differential amplifiers
  - Multi-vibrators
  - Logic circuits
- Feedback principles
  - Topologies
  - Stability analysis
  - Oscillators

PN Junction Diode

- Physical operation
  - Including the reverse-breakdown phenomenon
- Simplified circuit models
  - E.g., the 0.7V constant voltage drop model
- Zener-Diode and voltage regulator
- Half-wave, full-wave and bridge rectifiers
  - Advantages and disadvantages
- DC-DC converters
- Clipping and clamping circuits

Bipolar Junction Transistor

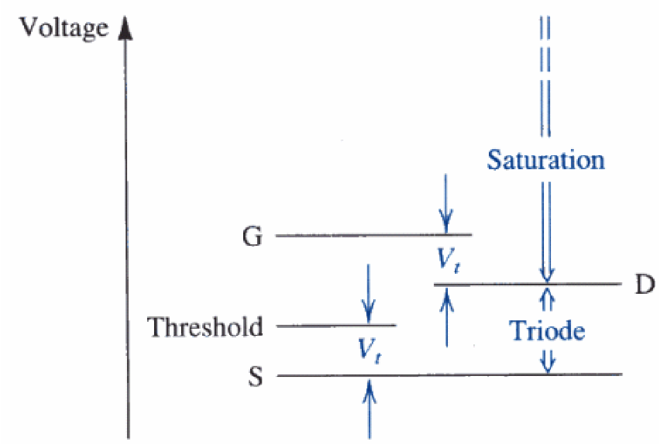
- Regions of operation: Cutoff, Saturation and Active
- I-V behaviors for the three regions:
  - Cutoff: $I_B=I_E=I_C=0$;
    Voltages depend on external circuit
  - Saturation: $V_{BE}=V_{ON}$, $V_{CE}=V_{CESat}$;
    Currents depends on external circuit
  - Active: $i_C=\beta i_B$, $i_C=\alpha i_E$,

$$\boxed{i_C = I_S \exp(\frac{v_{BE}}{V_T})}$$

- Non-ideal effects
  - Early Effect
  - Temperature dependence
  - Breakdown

MOSFET

- Three regions of operation:
  - Cutoff: $V_{GS}<V_{TN}$ (for nmos, same below)
  - Triode or Linear: $V_{GS}\geq V_{TN}$, $V_{GD}\geq V_{TN}$
  - Saturation: $V_{GS}>V_{TN}$, $V_{GD}<V_{TN}$



(for nmos)

- I-V equations in three regions
  - Square-law I-V behavior in saturation mode

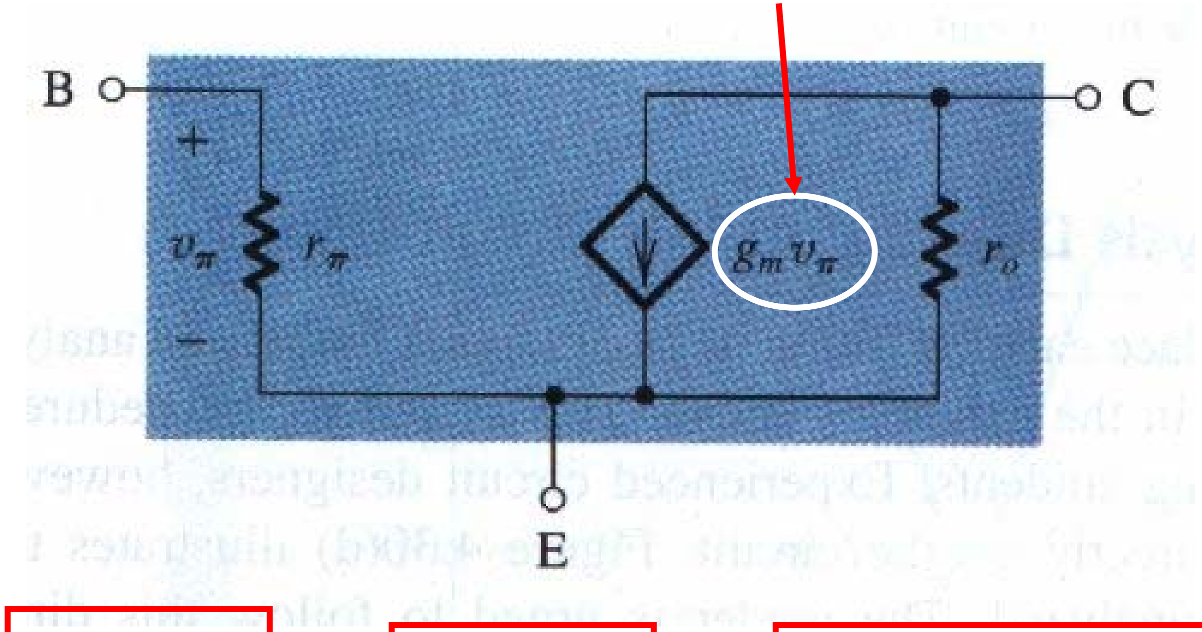
$$\boxed{i_D = \frac{1}{2}(\mu_n C_{ox})\frac{W}{L}(v_{GS} - V_{TN})^2}$$

$$K_n = \mu_n C_{ox}\frac{W}{L}$$

$$K'_n = \mu_n C_{ox}$$

- Non-ideal Effects
  - Channel length modulation
  - Body effect
  - Breakdowns and gate-breakdown protection

BJT Small Signal Model



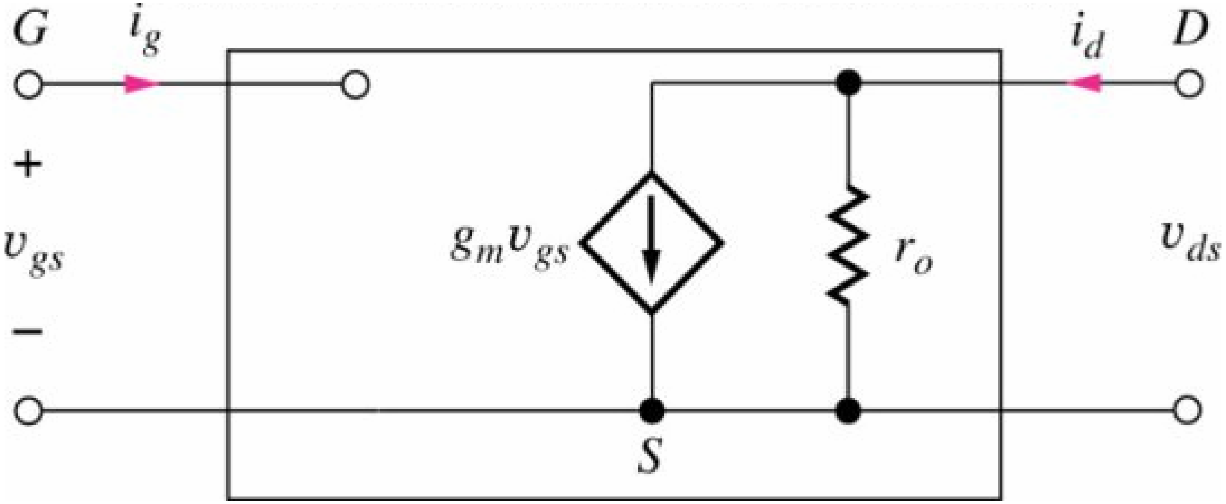
Can also be βi_b

$$\boxed{r_\pi = \frac{V_T}{I_B}}$$

$$\boxed{g_m = \frac{I_C}{V_T}}$$

$$\boxed{r_o = \frac{V_A + V_{CE}}{I_C} \approx \frac{V_A}{I_C}}$$

MOSFET Small Signal Model



$$g_m = k_n' \frac{W}{L}(V_{GS} - V_t) = \sqrt{2k_n'}\sqrt{\frac{W}{L}}\sqrt{I_D} = \frac{I_D}{(V_{GS} - V_t)/2}$$

$$r_0 = \frac{1 + \lambda V_{DS}}{\lambda I_D} \cong \frac{1}{\lambda I_D}$$

Single Stage Amplifiers

- For use as an amplifier
  - BJT operates in active region
  - MOSFET operates in saturation region
- Amplifiers need a stable biasing point
  - Four-resistor bias network
  - Current mirror
- Basic amplifier configurations and their properties
  - Common-emitter/Common-source
    - Effect of emitter/source resistor
  - Common-base/Common-gate
  - Emitter/Source follower

Multivibrators

- A multivibrator is used to implement simple **two-state systems** such as oscillators, timers and flip-flops.
- Three types:
  - **Astable** – neither state is stable.
    Applications: oscillator, etc.
  - **Monostable** - one of the states is stable, but the other is not;
    Applications: timer, etc.
  - **Bistable** – it remains in either state indefinitely.
    Applications: flip-flop, etc.

Differential Amplifier

- Purpose:
  - To amplify the difference between two input voltages
- Properties:
  - Effectively a single-stage CS/CE amplifier
  - No bypass capacitor is needed to produce emitter ac ground for differential mode inputs
  - Common-mode signal is not amplified
    - CMRR measures the ability to reject CM signals
- Half-circuit analysis technique
  - Common-mode and differential-mode equivalent half circuits

Output Stage

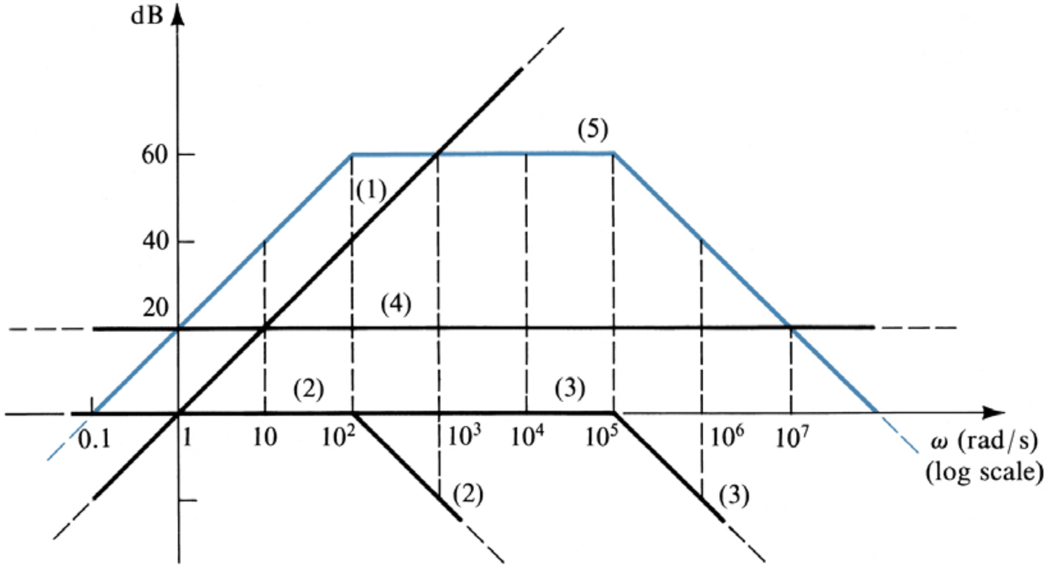
- Class A: highest linearity, lowest power efficiency
- Class B: lowest linearity, highest power efficiency
- Class AB: linearity better than that of Class B, power efficiency close to that of Class B, but lower.

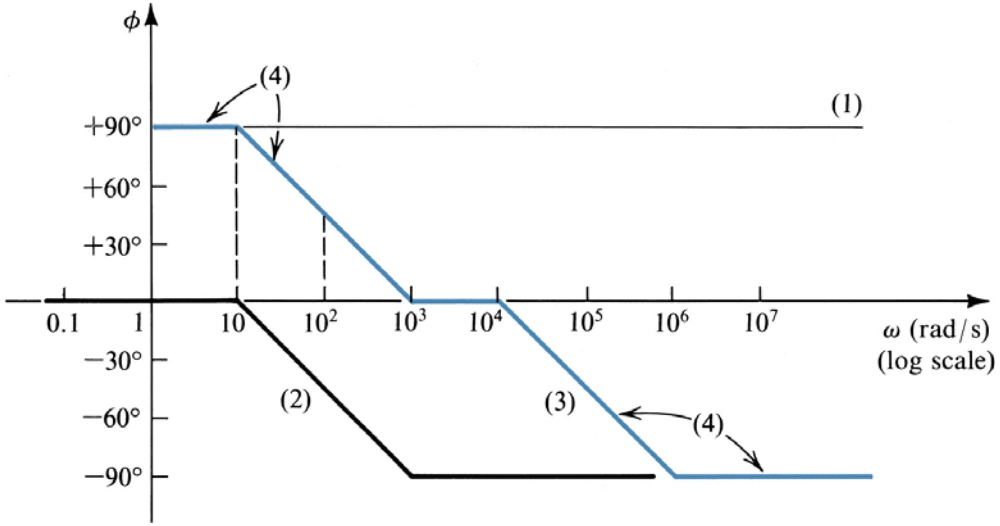
Frequency Response of Amplifiers

- Amplifiers' gain depends on frequency
  - b/c the impedance of capacitors depends on frequency
- High-frequency models for BJT and MOSFET
  - Device capacitors added
- Low frequency response
  - Determined by coupling and bypass capacitors
  - Can be estimated by SCTC method
- High frequency response
  - Determined by internal capacitors of transistors
  - Can be estimated by OCTC method
- Mid-band gain
  - Calculated with circuit capacitors short-circuited and device capacitors open-circuited

Bode Plot

$$T(s)=\frac{10s}{(1+s/10^2)(1+s/10^5)}$$





Feedback

- Feedback amplifiers combine the advantages of both active and passive circuits:
  - It can provide gain (advantage of active circuits)
  - The gain can be accurate (advantage of passive circuits)
- Properties of negative feedback amplifier
  - Gain variation is reduced
  - Bandwidth is extended
  - Non-linearity is reduced
- Four topologies
- Stability can be determined by
  - Nyquist plot
  - Root locus diagram
  - Bode plot (phase and gain margins)
- Positive feedback is used in oscillator circuits

Digital Circuits

- CMOS logic circuits (Inverter, NAND, NOR)
  - Transistor operates as a switch
    - Either in cutoff mode or triode mode
  - Performance parameters
    - Dynamic power consumption

$$P = fCV_{DD}^2$$

    - Propagation delay (speed)

$$t_p \propto \frac{1}{(\frac{W}{L})}$$

$$t_p \propto C_{load}$$

Final Examination:

25 April 2008, Friday
9:30am – 11:30am
Sir Run Run Shaw Hall

Closed-book, closed-notes.

Unlike last year, no equations sheet will be provided!

But you can expect the questions to be less complex.