EE112 - Fall 2016
Analog Integrated Circuits I

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5210 Research Bldg.

Transistor Operating Mode in Amplifiers

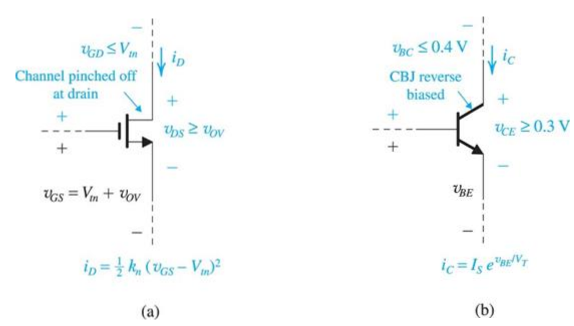


Figure 6.1 Operating (a) an NMOS transistor and (b) an npn transistor in the active mode. Note that $v_{GS} = V_{tn} + v_{OV}$ and $v_{DS} \ge v_{OV}$; thus $v_{GD} \le V_{tn}$, which ensures channel pinch-off at the drain end. Similarly, $v_{BE} \approx 0.7$ V, and $v_{CE} \ge 0.3$ V results in $v_{BC} \le 0.4$ V, which is sufficient to keep the CBJ from conducting

- Transistors are biased in flat part of the I-V curves
  - » Saturation mode for MOSFET, and active mode for BJT
    - – MOSFET: Channel pinched off at drain
    - – BJT: base-collector junction reverse-biased
  - » Drain (collector) voltage can vary without changing current

Voltage Transfer Curves

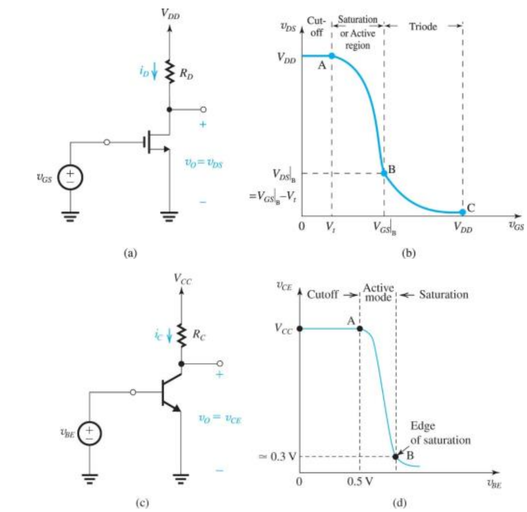


Figure 6.2 (**a**) An NMOS amplifier and (**b**) its VTC; and (**c**) an *npn* amplifier and (**d**) its VTC.

- Transistors are transimpedance amplifiers
  - » MOSFET: v_{GS} controls i_D
  - » BJT: v_{BE} controls i_C
- Adding load resistors converts current to voltage -> voltage amplifiers
  - » Drain (collector) voltage free to change in saturation (active) mode

Voltage Amplifier

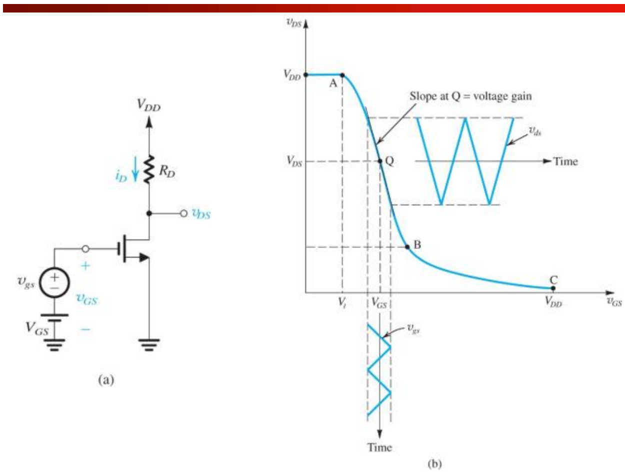


Figure 6.4 The MOSFET amplifier with a small time-varying signal $v_{gs}(t)$ superimposed on the dc bias voltage V_{GS}. The MOSFET operates on a short almost-linear segment of the VTC around the bias point Q and provides an output voltage $v_{ds} = A_v v_{gs}$

Maximum Input Signal Amplitude

To keep the MOSFET in saturation region:

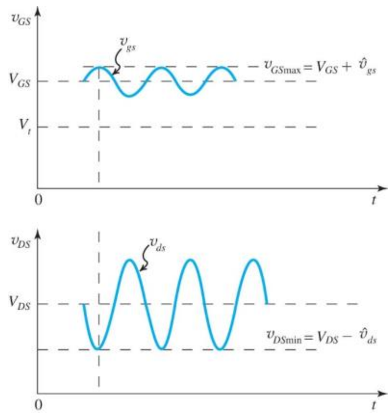


Figure 6.5 Signal waveforms at gate and drain for the amplifier in Example 6.1. Note that to ensure operation in the saturation at all times, $v_{DSmin} \geq v_{GSmax} - V_t$

BJT Amplifier

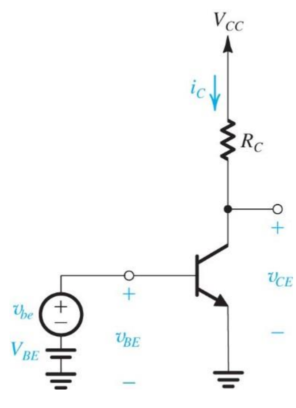


Figure 6.6 BJT amplifier biased at a point Q, with a small voltage v_{be} superimposed on the dc bias voltage V_{BE}. The resulting output signal v_{CE} appears superimposed on the dc collector voltage V_{CE}. The amplitude of v_{CE} is larger than that of the v_{be} by the voltage gain A_v.

Graphical Analysis with Load Line

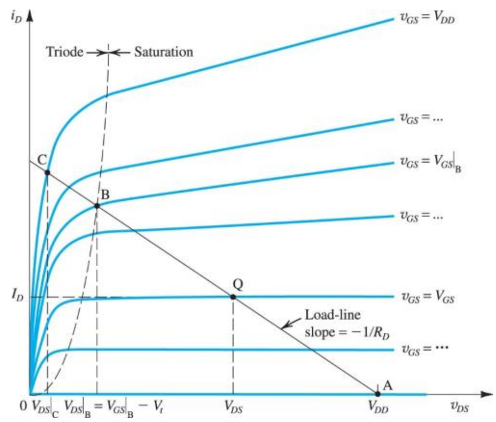
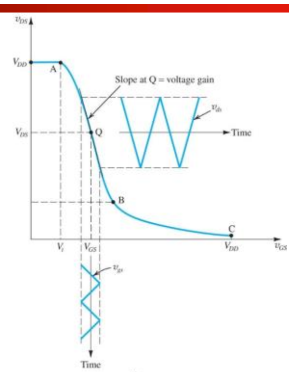


Figure 6.7 Graphical construction to determine the voltage-transfer characteristic of the amplifier in Fig. 6.4(a).

Consideration for Bias Point



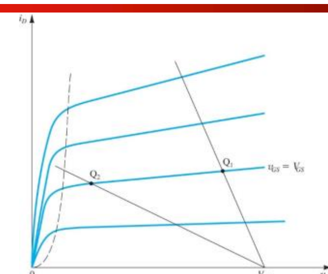
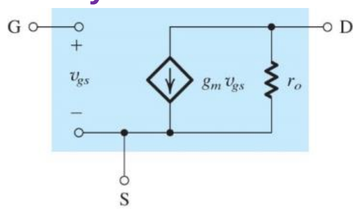


Figure 6.9 Two load lines and corresponding bias points. Bias point Q_1 does not leave sufficient room for positive signal swing at the drain (too close to V_{DD}). Bias point Q_2 is too close to the boundary of the triode region and might not allow for sufficient negative signal swing.

Small signal model for MOSFET

Hybrid-π Model

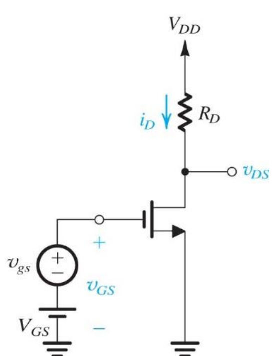


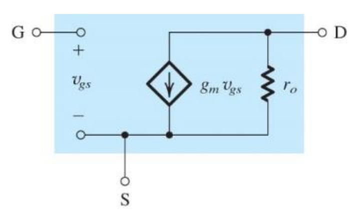
(b)

Figure 6.13 Small-signal models for the MOSFET: (b) including the effect of channel-length modulation, modeled by output resistance $r_o = |V_A|/I_D$. These models apply equally well for both NMOS and PMOS transistors.

- The equivalent circuit is valid for both NMOS and PMOS
- In PMOS, use absolute sign for all parameters: $|V_{GS}|$, $|V_t|$, $|V_{OV}|$, $|V_A|$, and replace k_n with k_p

Applying small-signal model





(b)

Figure 6.10 Conceptual circuit utilized to study the operation of the MOSFET as a small-signal amplifier.

Small signal model for BJT

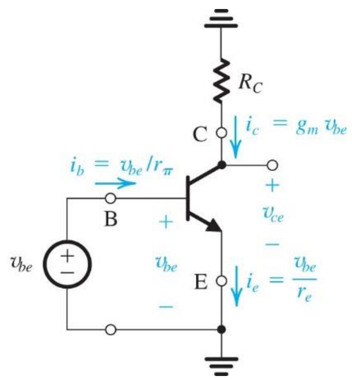


Figure 6.23 The amplifier circuit of Fig. 6.20(a) with the dc sources (V_{BE} and V_{CC}) eliminated (short-circuited). Thus only the signal components are present. Note that this is a representation of the signal operation of the BJT and not an actual amplifier circuit.

Hybrid-π model for BJT

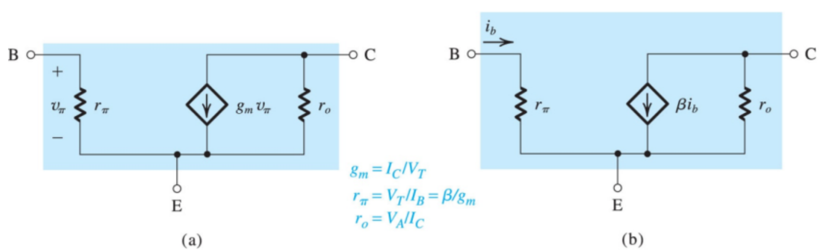
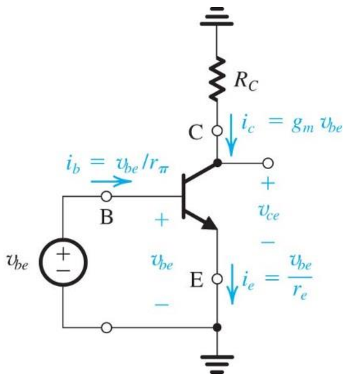
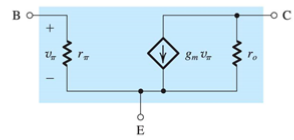


Figure 6.25 The hybrid-π small-signal model, in its two versions, with the resistance r_o included.

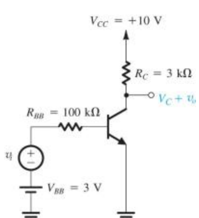
Applying Small-Signal Model



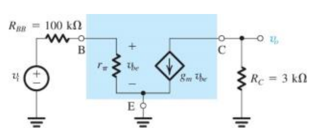


(a)

BJT Amplifier Example



(a)



(d)

Figure 6.28 Example 6.5: (**a**) amplifier circuit; (**d**) amplifier circuit with transistor replaced by its hybrid-π, small-signal model.

Systematic Procedure for Transistor Amplifier Analysis

- 1. Perform DC analysis (ignore small signal source)
- 2. Calculate small-signal parameters (g_m, r_π, r_o, etc)
- 3. Generate AC small-signal equivalent circuit
  - » Replace DC voltage source by short circuit
  - » Replace DC current source by open circuit
  - » Replace transistor by hybrid-π model (or other model)
- 4. Perform circuit analysis to determine voltage gain or other amplifier performance parameters

MOSFE Amplifier Example

(1) Solve DC Bias Point

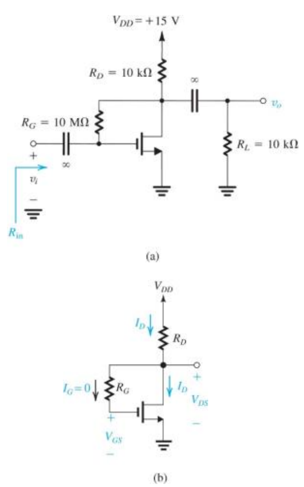


Figure 6.15 Example 6.3: **(a)** amplifier circuit; **(b)** circuit for determining the dc operating point;

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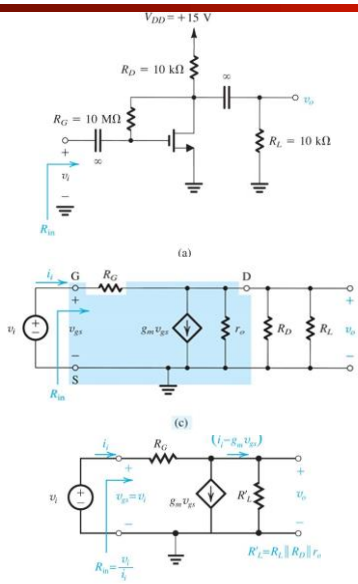
(2) Solve AC Small Signal Circuit



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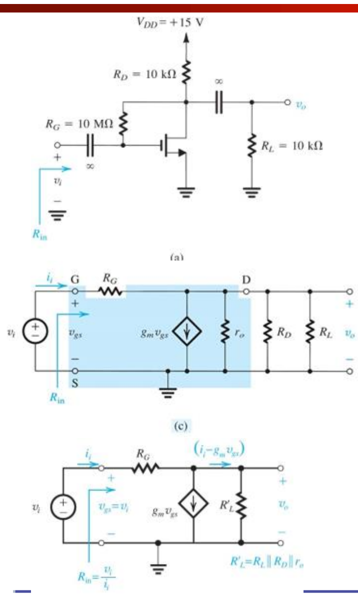
(3) Additional Parameters of Interest



BJT Amplifier Example

(1) Solve DC Bias Point

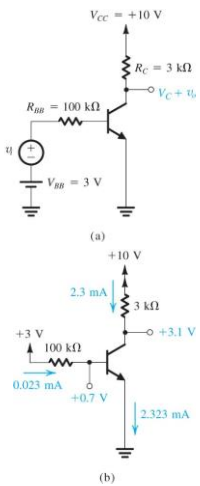


Figure 6.28 Example 6.5: (**a**) amplifier circuit; (**c**) amplifier circuit with dc sources replaced by short circuits;

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(2) AC Equivalent Circuit