Chapter 29

Transistor Amplifiers

Use of Capacitors in Amplifier Circuits

- Capacitor review
  - Store electrical charge
  - Impedance:

$$X_C = \frac{1}{2\pi fC} \; [\Omega]$$

  - ∞ impedance at dc
  - Impedance decreases at higher frequencies

Use of Capacitors in Amplifier Circuits

- Capacitors
  - Block dc between stages
  - Can be designed to readily pass ac

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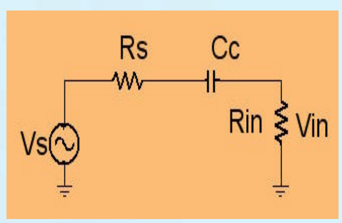
Use of Capacitors in Amplifier Circuits

- Coupling capacitors
  - At "high" frequencies

$$V_{in} = \left(\frac{R_{in}}{R_{in} + R_S} \right) V_S$$



  - For $R = R_{in} + R_S$, select capacitor so $X_C \leq 0.1\, R$
  - Referred to as "stiff coupling"

Use of Capacitors in Amplifier Circuits

- Bypass capacitors
  - Emitter resistor, R_e used for biasing
  - C_e is a short circuit at high frequencies
  - R_e has no effect on amplification when C_e is present
  - Select $X_C \leq 0.1R$

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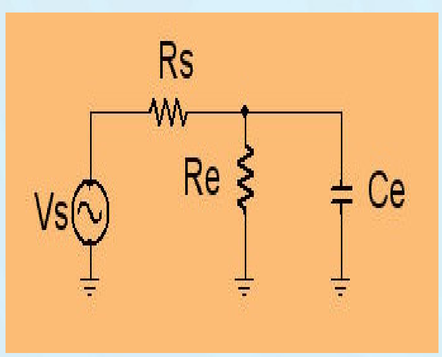
Use of Capacitors in Amplifier Circuits



Use of Capacitors in Amplifier Circuits

- Capacitors
  - Couple desired ac signals between stages
  - Bypass unwanted ac signals to ground

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Use of Capacitors in Amplifier Circuits

- Circuit analysis
  - If $X_C \leq 0.1R$
  - Replace *C* with O.C. to determine dc *I* and *V*
  - Replace *C* with S.C. to determine ac *i* and *v*

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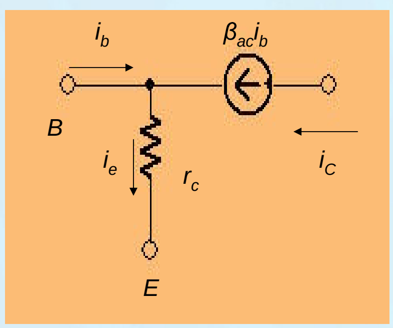
BJT Small-Signal Models

- *T*-Equivalent Model
  - $i_e = i_b + i_c$
  - $i_e = (\beta + 1)i_b$
  - $$r_e = \frac{26\,mv}{I_{EQ}}\ at\ 25^o\ C$$
  - Simple
  - Good enough for most applications

BJT Small-Signal Models



BJT Small-Signal Models

- Models
  - *T*-equivalent model simpler
  - *h*-parameter model more accurate
  - h_{fe} (*h*-model) = β_{ac} (*T*-model) [$\beta_{ac} \approx \beta_{dc}$]
  - *h*-parameters dependent on Q-point
  - BJT is a current amplifier (current source in both models)

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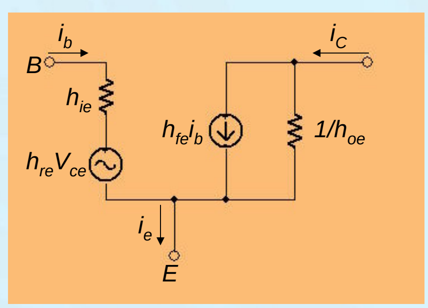
BJT Small-Signal Models

- *h*-parameter model
  - More complex
  - Better for ac operation
  - Common Emitter model
    - h_{ie} = input impedance (Ω)
    - h_{re} = reverse voltage transfer ratio (unitless)
    - h_{fe} = forward current transfer ratio (unitless)
    - h_{oe} = output admittance (S)



Calculating A_v, z_{in}, z_{out}, and A_i of a Transistor Amplifier

- Voltage Gain, A_v
  - Output voltage divided by input voltage

$$A_v = \frac{v_{out}}{v_{in}}$$

- Input Impedance, z_{in}
  - Input voltage divided by input current

$$z_{in} = \frac{v_{in}}{i_{in}}$$

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Calculating A_v, z_{in}, z_{out}, and A_i of a Transistor Amplifier

- Output Impedance, z_{out}

$$z_{out} = \frac{v_{out(OC)}}{i_{out(SC)}}$$

- Current Gain, A_i

$$A_i = \frac{i_{out}}{i_{in}}$$

- Power Gain, A_p

$$A_p = \frac{P_{out}}{P_{in}}$$

Common-Emitter Amplifier

- General BJT circuit analysis
  - Find operating point
  - Determine ac parameters (*T*- or *h*- models)
  - Remove dc *V* sources & replace with S.C.'s
  - Replace coupling & bypass *C's* with S.C.'s
  - Replace BJT with circuit model
  - Solve resulting circuit

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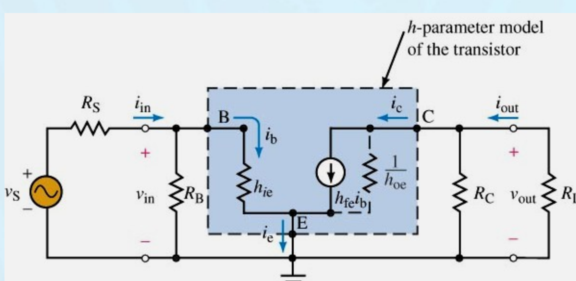
Common-Emitter Amplifier

- ac equivalent of fixed-bias CE amplifier using *h*-parameter model



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Common-Emitter Amplifier

- Equations for *h*-parameter model for fixed-bias CE amplifier
  - Circuit voltage gain a function of
    - Model forward current transfer ratio, h_{fe}
    - Model input impedance, h_{ie}
    - Circuit collector resistance, R_C
    - Circuit load resistance, R_L

$$A_v = -\frac{h_{fe}\left(R_C \| R_L\right)}{h_{ie}}$$

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Common-Emitter Amplifier

- Circuit current gain a function of
  - Same parameters, plus
  - Fixed bias resistance, R_B

$$A_i = \frac{h_{fe} R_B R_C}{\left(R_C + R_L\right)\left(R_B + h_{ie}\right)}$$

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Common-Emitter Amplifier

- Equations for *h*-parameter model for fixed-bias CE amplifier
  - Circuit input impedance a function of
    - Model forward current transfer ratio, h_{fe}
    - Model input impedance, h_{ie}

$$z_{\text{in}} = R_{\text{B}} \| h_{\text{ie}}$$

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Common-Emitter Amplifier

- Circuit output impedance a function of
  - Collector resistance (model output admittance), h_{oe} very low $z_{\text{out}} = R_{\text{C}}$

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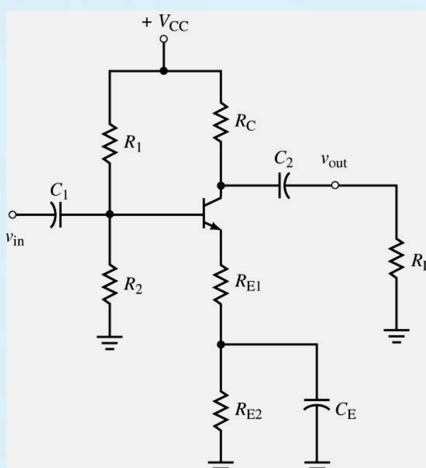
ac Load Line

- Q-point is on dc load line
- ac load line determines maximum undistorted output
- Can calculate maximum power
- Q-point also on ac load line
- ac load line has different slope

ac Load Line

- CE amplifier circuit



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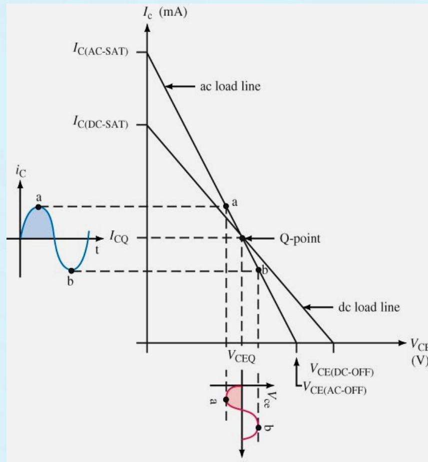
ac Load Line

- dc and ac load lines



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ac Load Line

- Equations of ac load line
- Consider
  - CE amplifier circuit
  - dc load line

$$v_{CE} = -i_C(r_C + r_E)$$

$$I_C = \frac{V_{CE}}{r_C + r_E}$$

$$i_C = O_{CQ} + i_c$$

$$v_{CE} = V_{CEQ} + v_{ce}$$

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Common-Collector Amplifier

- Important characteristics
  - High input impedance
  - Low output impedance
  - v_{out} in-phase with v_{in}
  - $V_{out} \approx V_{in}$

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Common-Collector Amplifier

- Important characteristics
  - Large current gain
  - Input voltage measured at base
  - Output voltage measured at emitter

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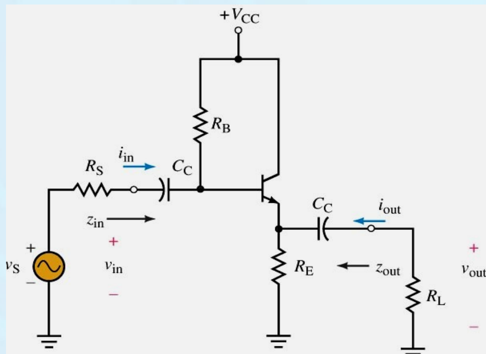
Common-Collector Amplifier

- Common-Collector circuit

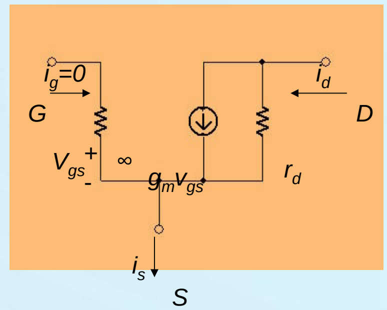


Common-Collector Amplifier

- Circuit gains and impedances
  - $A_v \approx 1$
  - $z_{in} = R_B || z_{in(Q)}$
  - $A_i = -\frac{A_V z_{in}}{R_L}$ close to h_{fe}
  - $z_{out(Q)} = \frac{R_S \| R_B}{h_{fe} + 1} = r_e$ very small

FET Small-Signal Model

- Voltage controlled amplifier
- Small-signal model same for JFETs & MOSFETs
- High input impedance
- $i_s = i_d$



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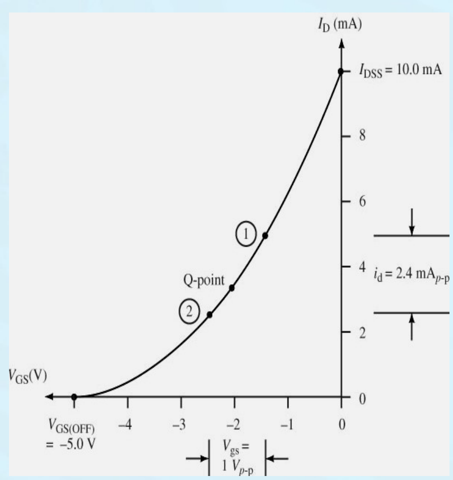
FET Small-Signal Model

- g_m is transconductance
- g_m is slope of transfer curve



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FET Small-Signal Model

- Equations
  - Definition $g_m = \dfrac{\Delta I_D}{\Delta V_{GS}}$
  - Maximum $g_{mo} = \left|\dfrac{2I_{DSS}}{V_{Gs(OFF)}}\right|$
  - Measured $g_m = g_{mo}\left(1 - \dfrac{V_{GSQ}}{V_{GS(OFF)}}\right)$

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Common-Source Amplifier

- Analysis
  - Similar to BJT using *h*-parameter model
  - First determine bias
  - Find dc operating point (Q-point)
  - Determine g_m

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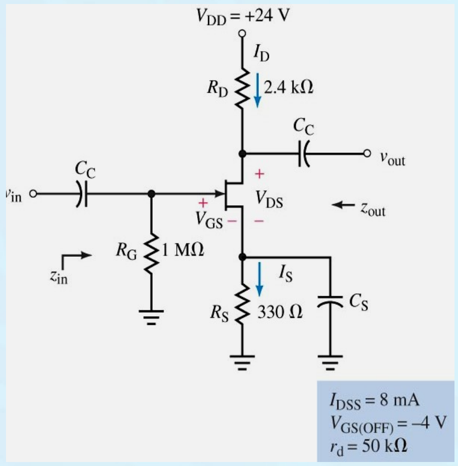
Common-Source Amplifier

- A common-source circuit



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Common-Source Amplifier

- Equations
  - No current input
  - Voltage gain dependent on g_m and R_D
  - Input impedance is $R_G \parallel \infty$
  - Output impedance approximately drain resistance

$$A_V \approx -g_m R_D$$

$$z_{in} = R_G$$

$$z_{out} \approx R_D$$

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Common-Source Amplifier

- D-MOSFETs
  - Analysis same as JFETs
  - Except operation in enhancement region

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Common-Source Amplifier

- E-MOSFETs
  - Find I_{DSQ}, V_{GSQ}, and V_{DSQ} at Q-point
  - Solve for g_m of amplifier
  - Sketch ac equivalent circuit
  - Determine A_v, z_{in}, and z_{out} of amplifier

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Common-Drain (Source Follower) Amplifier

- $A_v < 1$
- v_{out} in phase with v_{in}
- Input impedance very high
- Output impedance low
- Main application: Buffer

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Troubleshooting a Transistor Amplifier Circuit

- Incorrect placement of electrolytic capacitors
  - Noisy output signal
  - Capacitor as an antenna
  - Generally 60 Hz added

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Troubleshooting a Transistor Amplifier Circuit

- Correct placement
  - Check proper polarity
  - Replace faulty capacitors

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Troubleshooting a Transistor Amplifier Circuit

- Faulty or incorrectly placed capacitor
  - Measured A_v different from theoretical A_v
  - Faulty capacitor behaves like an open circuit
  - Faulty capacitor can develop internal short

Troubleshooting a Transistor Amplifier Circuit

- Troubleshooting steps
  - Remove ac signal sources from circuit
  - Calculate theoretical Q-point
  - Measure to determine actual Q-point
  - Verify capacitors are correctly placed
  - Ensure connections, especially ground wires, as short as possible

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Troubleshooting a Transistor Amplifier Circuit

- Distorted output signal usually the result of too large an input signal

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