Transistor Circuits X

Cascaded Amplifiers
Cascaded Amplifier Circuit

- $R_{1a} = 330 \, \text{kΩ}$
- $R_{2a} = 39 \, \text{kΩ}$
- $R_{C1} = 22 \, \text{kΩ}$
- $R_{E1} = 3.9 \, \text{kΩ}$
- $R_{1b} = 220 \, \text{kΩ}$
- $R_{2b} = 22 \, \text{kΩ}$
- $R_{C2} = 12 \, \text{kΩ}$
- $R_{E2} = 2.2 \, \text{kΩ}$
- $R_{L2} = 33 \, \text{kΩ}$

Input: $V_s$

Output: $v_{o2}$

Power Supply: $V_{CC} = 20 \, \text{V}$
AC equivalent of load “seen” by $Q_1$
Gain expectations

\[ A_v \cong A_{v1}A_{v2}A_{v3} \ldots A_{vn} \]
Circuit with partial bypass

\[ \text{vs} \]

\[ \text{C1} \]

\[ \text{Q1} \]

\[ \text{C2} \]

\[ \text{Q2} \]

\[ \text{C5} \]

\[ \text{C3} \]

\[ \text{C4} \]

\[ \text{VCC} \]

\[ 20 \text{ V} \]

\[ \text{vo2} \]

\[ 330\Omega \]

\[ 39k\Omega \]

\[ 22k\Omega \]

\[ 3.6k\Omega \]

\[ 220k\Omega \]

\[ 22k\Omega \]

\[ 12k\Omega \]

\[ 1.8k\Omega \]

\[ 33k\Omega \]
First example problem

• In the circuit of Slide 5, each BJT has an $h_{fe} = 80$ and a $V_{BE} = 0.6$ V. Find (a) the voltage gain of the second stage, (b) the voltage gain of the first stage, and (c) the total voltage gain $v_{o2}/v_s$. 
Example solution

• $A_v \cong \frac{-r_L}{r'_e + r_E}$ and $r'_b \cong \beta (r'_e + r_E)$

• $r_{L2} = \frac{R_{C2}R_{L2}}{R_{C2} + R_{L2}} = \frac{(12k)(33k)}{12k + 33k} = \frac{396 \times 10^6}{45 \times 10^3} = 8.8k\Omega$

• $V_{B2} = V_{CC} \frac{R_{2b}}{R_{1b} + R_{2b}} = 20 \frac{22k}{220k + 22k} = 20 \frac{22k}{242k} = 20(0.091) = 1.818\text{ V}$

• $V_{E2} = V_{B2} - V_{BE} = 1.818 - 0.6 = 1.218\text{ V}$
\( I_{E2} = \frac{V_{E2}}{R_{E2}} = \frac{1.218\text{V}}{1.8\text{k}\Omega + 330\Omega} = \frac{1.218\text{V}}{2.13\text{k}\Omega} = 571.916\mu\text{A} \)

\[ r'_{e2} = \frac{25\text{mV}}{I_{E2}} = \frac{25\text{mV}}{571.916\mu\text{A}} = 43.713\Omega \text{ (Using 26mV instead, } r'_{e2} = 45.461\Omega ) \]

\[ A_{v2} \approx \frac{-r_{L2}}{r'_{e2} + r_{E2}} = \frac{-8.8\text{k}\Omega}{43.713\Omega + 330\Omega} = \frac{-8.8\text{k}\Omega}{373.713\Omega} = -23.548 \text{ (Using 26mV instead, } A_{v2} = -23.438) \]
• \( r'_{b2} \approx \beta (r'_{e2} + r_{E2}) = 80(373.713\,\Omega) = 29.897\,k\Omega \) (Using 26mV instead, \( r'_{b2} = 30.037\,k\Omega \))

• \( r_{L1} = R_{C1} \parallel R_{1b} \parallel R_{2b} \parallel r'_{b2} = 22\,k\Omega \parallel 220\,k\Omega \parallel 22\,k\Omega \parallel 29.897\,k\Omega = 7.758\,k\Omega \) (Using 26mV instead, \( r_{L1} = 7.767\,k\Omega \))
\[ V_{B1} = V_{CC} \frac{R_{2a}}{R_{1a} + R_{2a}} = 20 \frac{39k}{330k + 39k} = 20 \frac{39k}{369k} = 20(0.106) = 2.114 \, \text{V} \]

\[ V_{E1} = V_{B1} - V_{BE} = 2.114 - 0.6 = 1.514 \, \text{V} \]

\[ I_{E1} = \frac{V_{E1}}{R_{E1}} = \frac{1.514V}{3.6k\Omega + 270\Omega} = \frac{1.514V}{3.87k\Omega} = 391.168 \mu\text{A} \]

\[ r'e_1 = \frac{25\text{mV}}{I_{E1}} = \frac{25\text{mV}}{391.168 \mu\text{A}} = 63.911 \Omega \] (Using 26mV instead, \( r'e_1 = 66.468 \Omega \))
\[ A_{v1} \approx \frac{-r_{L1}}{r_{e1} + r_{E1}} = \frac{-7.758k\Omega}{63.911\Omega + 270\Omega} = \frac{-7.758k\Omega}{333.911\Omega} = -23.233 \] (Using 26mV instead, \( A_{v2} = -23.084 \))

\[ A_{v(Total)} = A_{v1}A_{v2} = (-23.233)(-23.548) = 547.093 \] (Using 26mV instead, \( A_{v(Total)} = 541.042 \))
Second example problem

• In the circuit of Slide 5, each BJT has an $h_{fe} = 80$ and a $V_{BE} = 0.6$ V. Replace the 330 Ω with 100 Ω. Then find (a) the voltage gain of the second stage, (b) the voltage gain of the first stage, and (c) the total voltage gain $v_{o2}/v_s$. 
Example solution

- \( r_{L2} = \frac{R_{C2}R_{L2}}{R_{C2}+R_{L2}} = \frac{(12k)(33k)}{12k+33k} = \frac{396 \times 10^6}{45 \times 10^3} = 8.8 \text{k}\Omega \)

- \( V_{B2} = V_{CC} \frac{R_{2b}}{R_{1b}+R_{2b}} = 20 \frac{22k}{220k+22k} = 20 \frac{22k}{242k} = 20(0.091) = 1.818 \text{ V} \)

- \( V_{E2} = V_{B2} - V_{BE} = 1.818 - 0.6 = 1.218 \text{ V} \)

- \( I_{E2} = \frac{V_{E2}}{R_{E2}} = \frac{1.218 \text{ V}}{1.8 \text{k}\Omega + 100 \Omega} = \frac{1.218 \text{ V}}{1.9 \text{k}\Omega} = 641.053 \mu\text{A} \)
• \( r'_{e2} = \frac{25 \text{mV}}{I_{E2}} = \frac{25 \text{mV}}{641.053 \mu \text{A}} = 38.998 \Omega \) (Using 26mV instead, \( r'_{e2} = 40.558 \Omega \))

• \( A_{v2} \approx \frac{-r_{L2}}{r'_{e2} + r_{E2}} = \frac{-8.8 \text{k} \Omega}{38.998 \Omega + 100 \Omega} = \frac{-8.8 \text{k} \Omega}{138.998 \Omega} = -63.31 \) (Using 26mV instead, \( A_{v2} = -62.607 \))

• \( r'_{b2} \approx \beta (r'_{e2} + r_{E2}) = 80(138.998 \Omega) = 11.12 \text{k} \Omega \) (Using 26mV instead, \( r'_{b2} = 11.245 \text{k} \Omega \))
• \( r_{L1} = R_{C1} \parallel R_{1b} \parallel R_{2b} \parallel r'_{b2} = 22k\Omega \parallel 220k\Omega \parallel 22k\Omega \parallel 11.12k\Omega = 5.394k\Omega \) (Using 26mV instead, \( r_{L1} = 5.423k\Omega \))

• \( V_{B1} = V_{CC} \frac{R_{2a}}{R_{1a}+R_{2a}} = 20 \frac{39k}{330k+39k} = 20 \frac{39k}{369k} = 20(0.106) = 2.114 \text{ V} \)

• \( V_{E1} = V_{B1} - V_{BE} = 2.114 - 0.6 = 1.514 \text{ V} \)
\( I_{E1} = \frac{V_{E1}}{R_{E1}} = \frac{1.514V}{3.6k\Omega + 270\Omega} = \frac{1.514V}{3.87k\Omega} = 391.168\mu A \)

\( r_e'_{1} = \frac{25mV}{I_{E1}} = \frac{25mV}{391.168\mu A} = 63.911\Omega \) (Using 26mV instead, \( r_e'_{1} = 66.468\Omega \))

\( A_{v1} \approx \frac{-r_{L1}}{r_{e1}'+r_{E1}} = \frac{-5.394k\Omega}{63.911\Omega + 270\Omega} = \frac{-5.394k\Omega}{333.911\Omega} = -16.155 \) (Using 26mV instead, \( A_{v2} = -16.109 \))

\( A_{v(\text{Total})} = A_{v1}A_{v2} = (-16.155)(-63.31) = 1023 \) (Using 26mV instead, \( A_{v(\text{Total})} = 1009 \))
Third example circuit

• Show the normal dc collector-to-ground voltages on the circuit shown on Slide 5. Call them $V_{C1}$ and $V_{C2}$. What are these voltages with each one of the following faults? (a) $C_2$ is open. (b) The 39-kΩ is open. (c) The 22-kΩ resistor that is connected to the base of $Q_2$ is open. (d) $Q_2$ acts like an open.
Example solution

Normal conditions:

- $V_{E2} = 1.218\text{V} \text{ and } I_{E2} = 571.916\mu\text{A} \therefore I_{C2} = 571.916\mu\text{A}$
- $V_{C2} = V_{CC} - I_{C2}R_{C2} = 20 - (571.916\mu\text{A})(12\text{k}\Omega) = 20 - 6.863 = 13.137\text{V}$
- $V_{E1} = 1.514\text{V} \text{ and } I_{E1} = 391.168\mu\text{A} \therefore I_{C1} = 391.168\mu\text{A}$
- $V_{C1} = V_{CC} - I_{C1}R_{C1} = 20 - (391.168\mu\text{A})(22\text{k}\Omega) = 20 - 8.606 = 11.394\text{V}$
Condition (a):

- If $C_2$ opens, no ac can pass from $Q_1$ to $Q_2$, but to DC nothing has changed. Therefore, $V_{C1} = 11.394V$ and $V_{C2} = 13.137V$
Condition (b):

- If $R_{2a}$ (the 39-kΩ) opens, then $Q_1$ becomes a base-biased configuration. Since an open $R_2$ will cause the transistor to saturate, we calculate $V_{c1}$ thusly:

  \[ I_{C1(sat)} = \frac{V_{CC}}{R_{C1} + R_{E1}} = \frac{20\text{V}}{22\text{kΩ} + 3.87\text{kΩ}} = \frac{20\text{V}}{25.87\text{kΩ}} = 773.096\mu\text{A} \]

  \[ V_{C1} = V_{CC} - I_{C1}R_{C1} = 20\text{V} - (773.096\mu\text{A})(22\text{kΩ}) = 20\text{V} - 17.008\text{V} = 2.992\text{V} \]

- $Q_2$ is unaffected (due to $C_2$ blocking DC normally), so $V_{C2} = 13.137\text{V}$
Condition (c):

- Same thought as (b), but now Q2 is the one affected. Since this means that Q1 does not change, $V_{C1} = 11.394V$. However, we need to calculate $V_{C2}$ this way:

  \[ I_{C2(sat)} = \frac{V_{CC}}{R_{C2} + R_{E2}} = \frac{20V}{12k\Omega + 2.13k\Omega} = \frac{20V}{14.13k\Omega} = 1.415mA \]

  \[ V_{C2} = V_{CC} - I_{C2}R_{C2} = 20V - (1.415mA)(12k\Omega) = 20V - 16.985V = 3.015V \]
Condition (d):

- $V_{c1}$ is unaffected (isolated by coupling caps); $V_{c2}$ is at cutoff.
- Therefore, $V_{c1} = 11.394V$ and $V_{c2} = 20V$
Any questions?

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