Spring 2019 Purdue University

ECE 255: L26

Multi-stage Amplifiers

School of ECE
Purdue University
West Lafayette, IN USA

Purdue University

Announcements

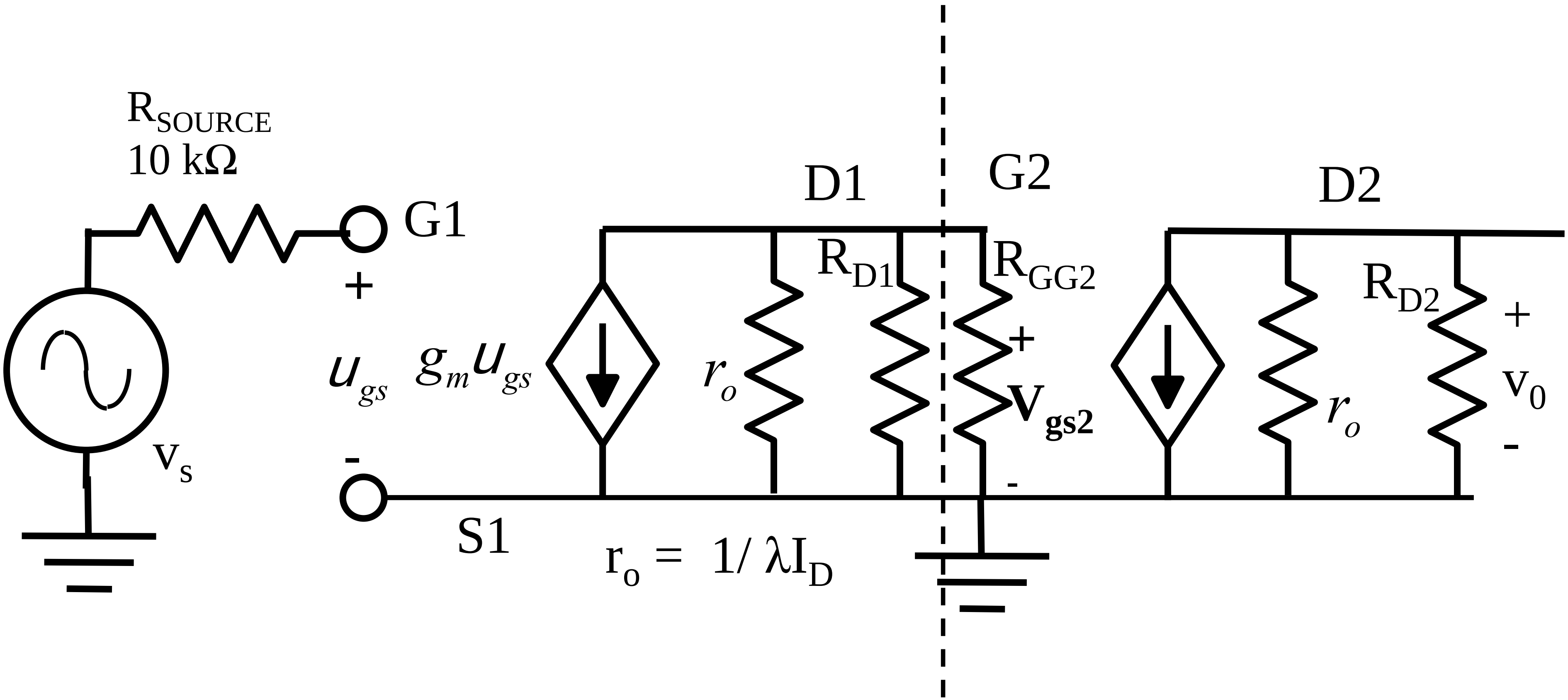
A1:

Outline

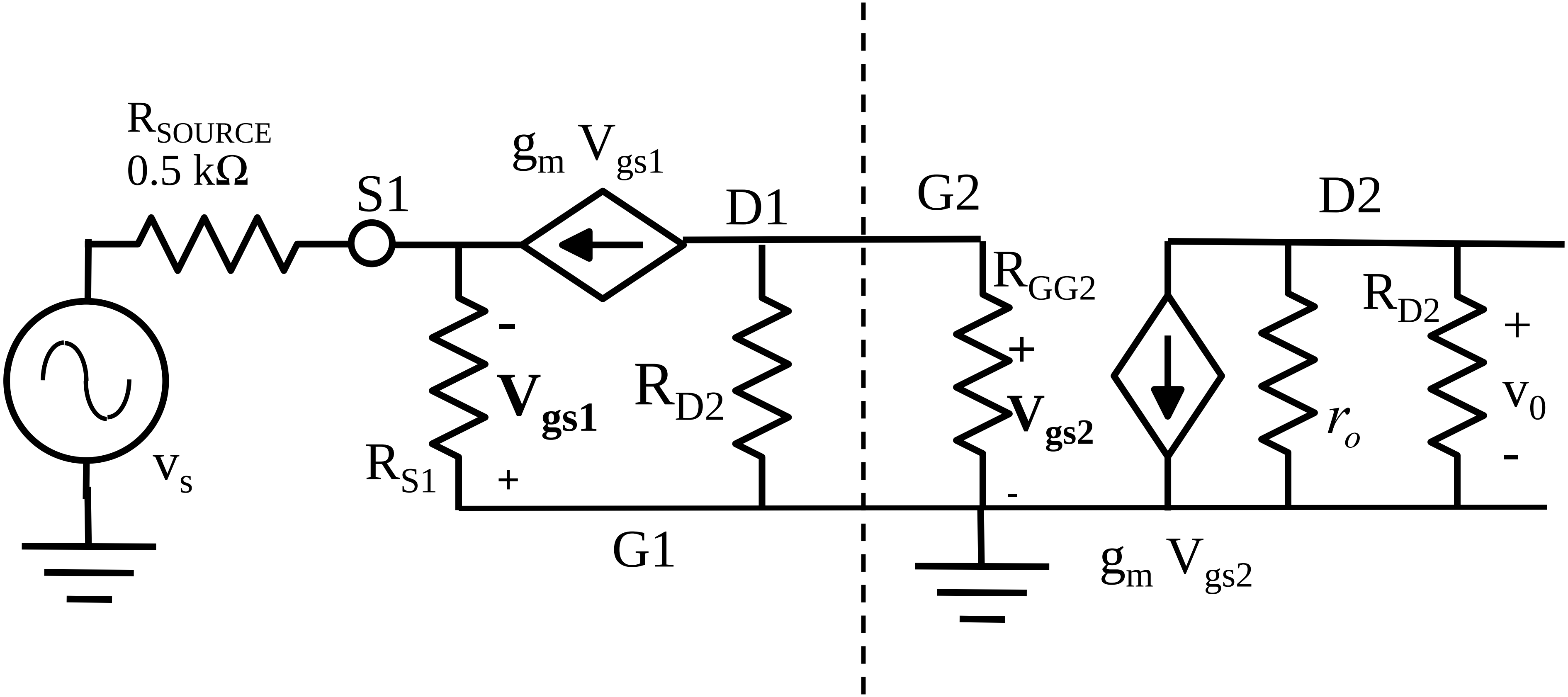
1) Cascaded amplifier stages – small signal

2) Discussion/alternate stage gain approach

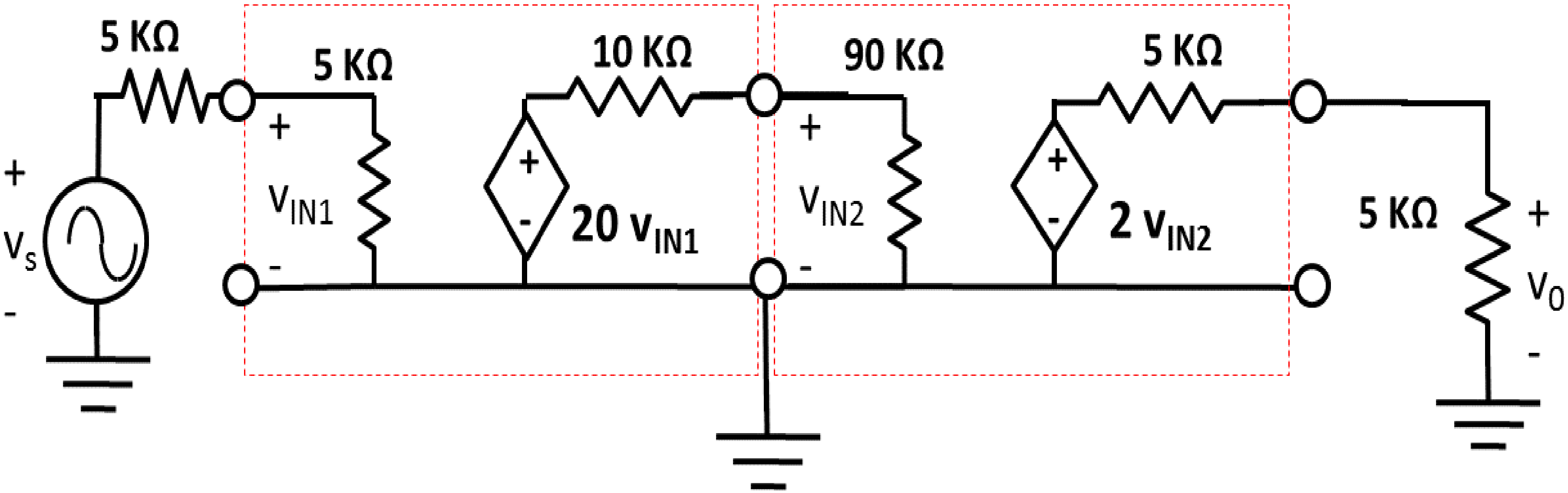
Multi-stage (cascaded) amp



Multi-stage (cascaded) amp



$A_{vo}/R_{in}/R_{out}$ Representation

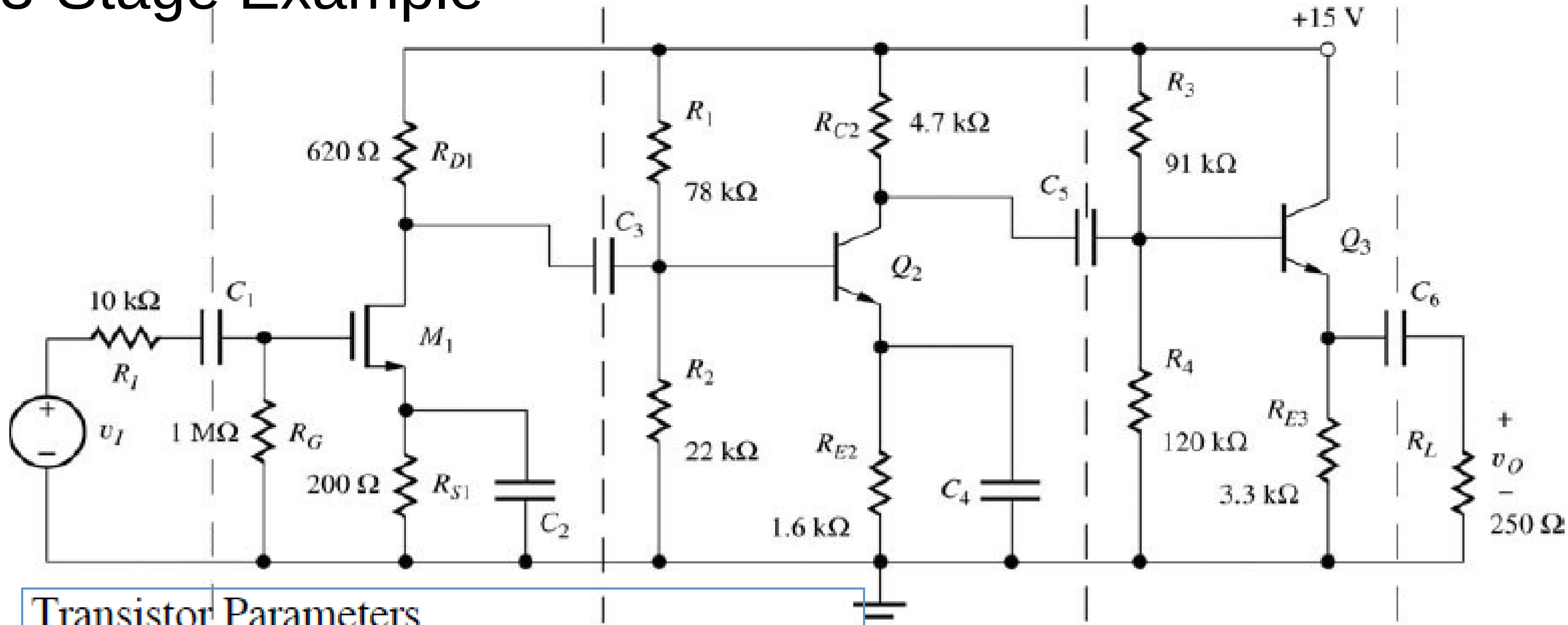


$A_v = v_o/v_s = v_{in1}/v_s \times v_{in2}/v_{in1} \times v_o/v_{in2}$

$A_v = 5k/(5k+5k) \times (-20)\ (90k/90k+10k) \times 2\ (5k/(5k+5k)$

$= 0.5 \times -18 \times 1 = -9$

3-Stage Example



Transistor Parameters

M_1: $K_n = 10\ mA/V^2$, $V_{TN} = -2\ V$, $\lambda = 0.02V^{-1}$

Q_2 : $\beta_F = 150$, $V_A = 80V$, $V_{BE} = 0.7V$

Q_3 : $\beta_F = 80$, $V_A = 60V$, $V_{BE} = 0.7V$

Q-Points

M_1: (5.00 mA, 10.9 V)

Q_2 : (1.57 mA, 5.09 V)

Q_3 : (1.99 mA, 8.36 V)

Small-Signal Parameters

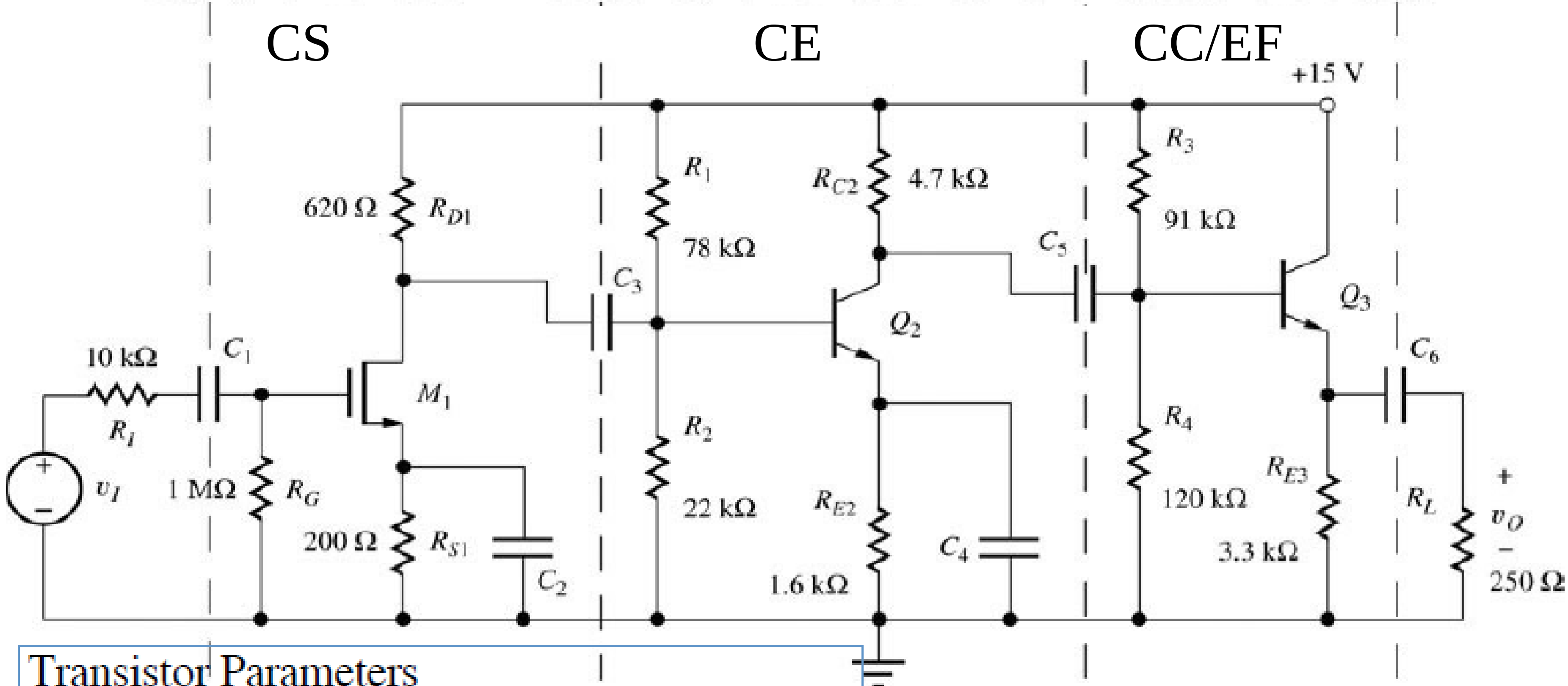
M_1: $g_{m1} = 10.0\ mS$, $r_{o1} = 12.2\ k\Omega$

Q_2: $g_{m2} = 62.8\ mS$, $r_{\pi 2} = 2.39\ k\Omega$,

$r_{o2} = 54.2\ k\Omega$

Q_3: $g_{m3} = 79.6\ mS$, $r_{\pi 3} = 1.00\ k\Omega$,

$r_{o3} = 34.4\ k\Omega$



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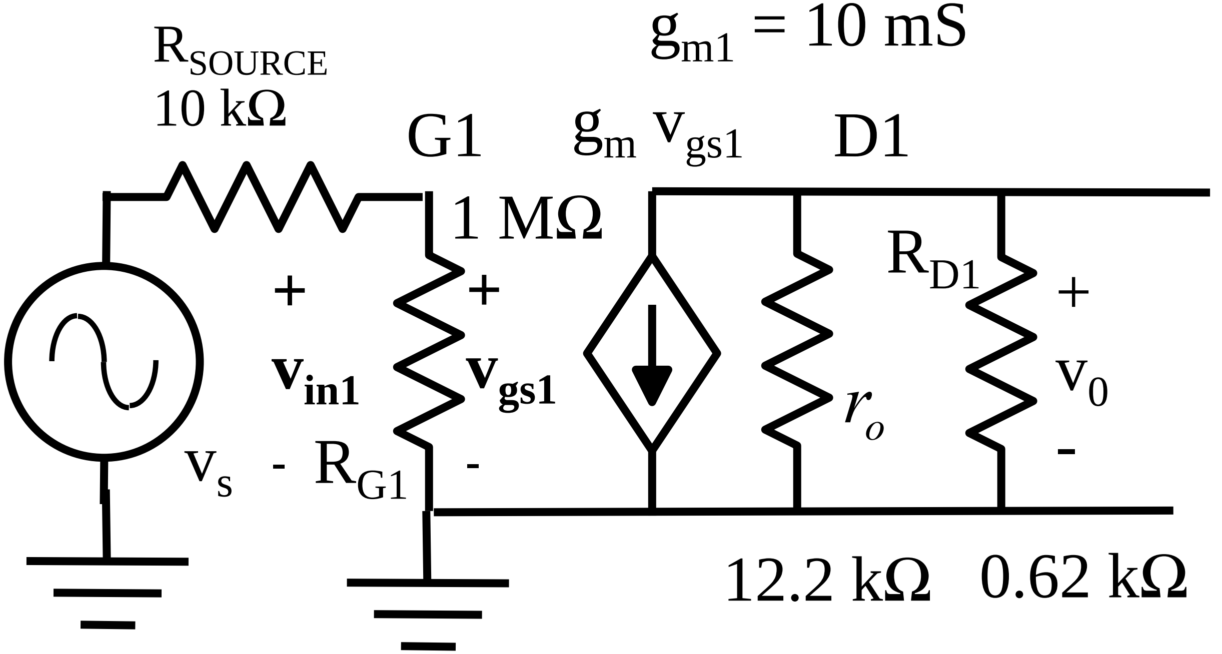
Stage 1 -- CS

g_{m1} = 10 mS



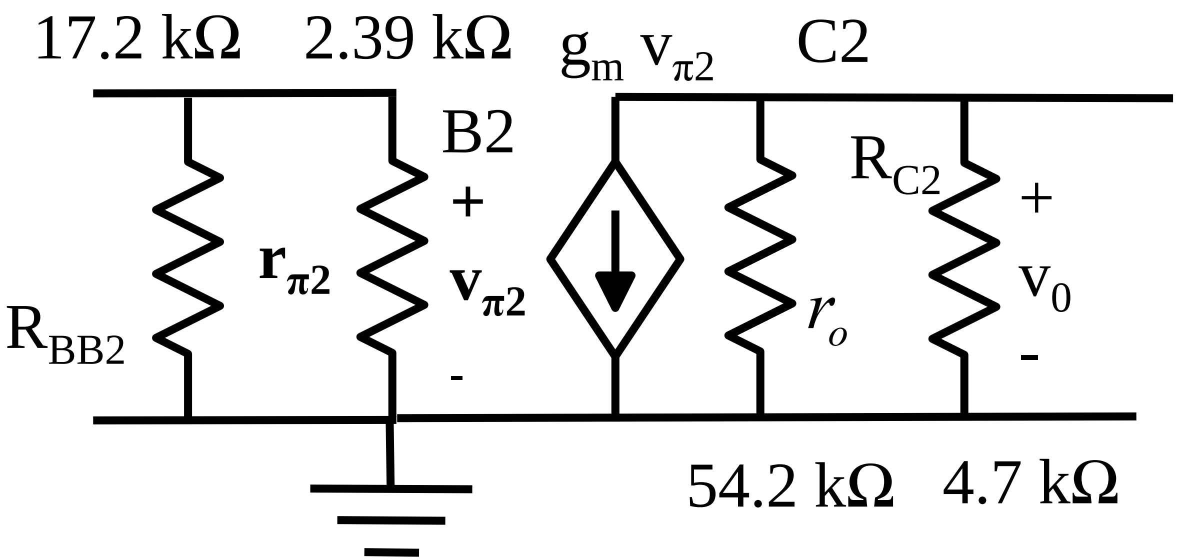
$R_{o1} = (r_o \parallel R_{D1})$
$= 0.59$ kΩ

$A_{vo} = -g_m (r_o \parallel R_{D1})$
$= -5.9$

$v_{in1} = v_s (R_{G1} /(R_{source} + R_{G1})$
$= 0.99$

Stage 2 -- CE

$g_m = 68.2$ mS



$R_{o2} = (r_o \parallel R_{C2})$
$= 4.3$ kΩ

$A_{vo} = -g_m\ (r_o \parallel R_{C2})$
$= -\ 293$

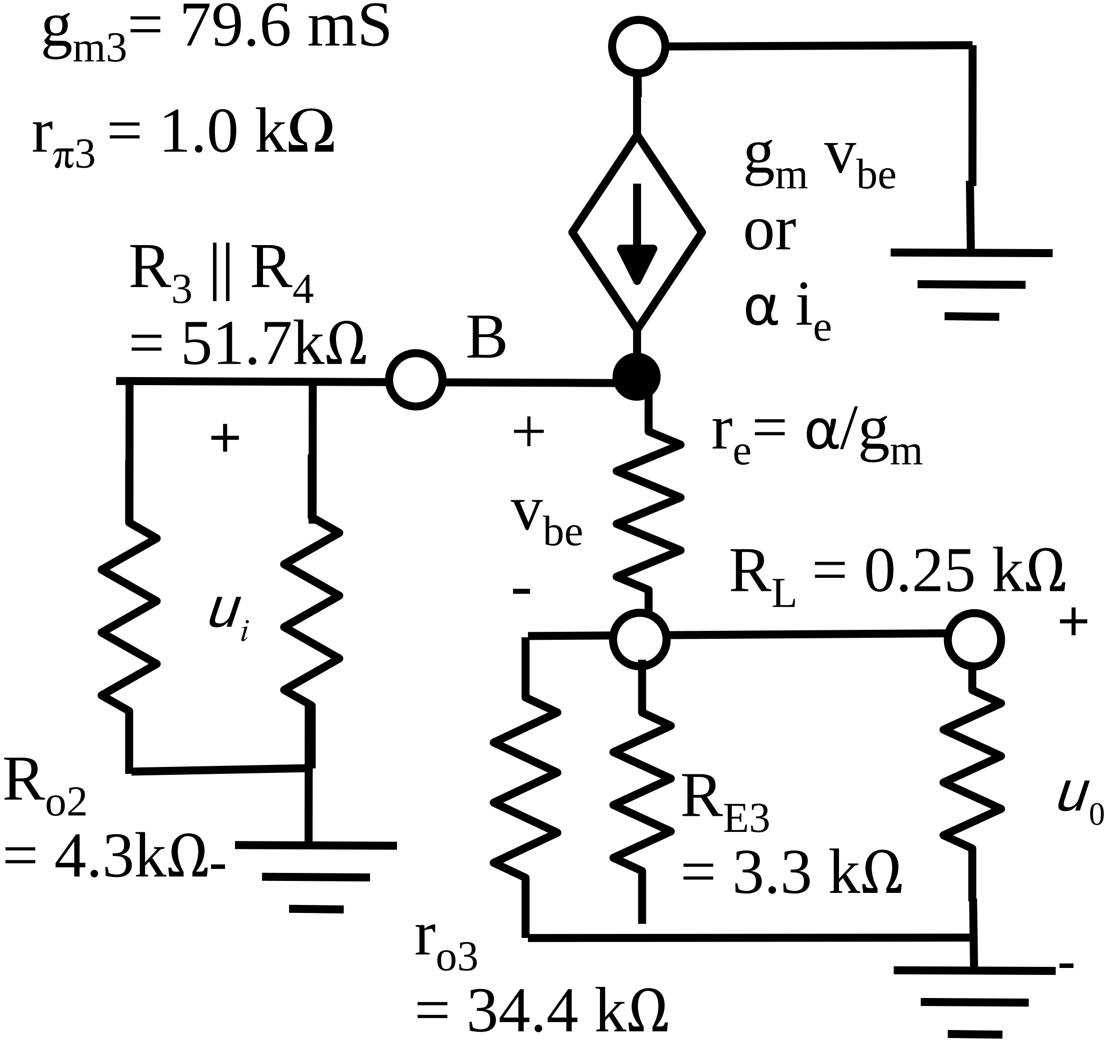
$R_{in2} = (R_{BB2} \parallel r_{\pi 2}) = 2.1$ kΩ

Stage 3 -- EF

β= 80

g_{m3}= 79.6 mS

$r_{\pi 3}$ = 1.0 kΩ



R_E’ = (r_{o3} || R_{E3} || R_L)
= 0.23 kΩ

$$A_v = \frac{u_o}{u_i} = +\frac{(b+1)R_E}{r_p + (b+1)R_E} = 0.95$$

$$R_{in} = r_p + (b+1)R_E$$

R_{in3}’ = 19.6 kΩ

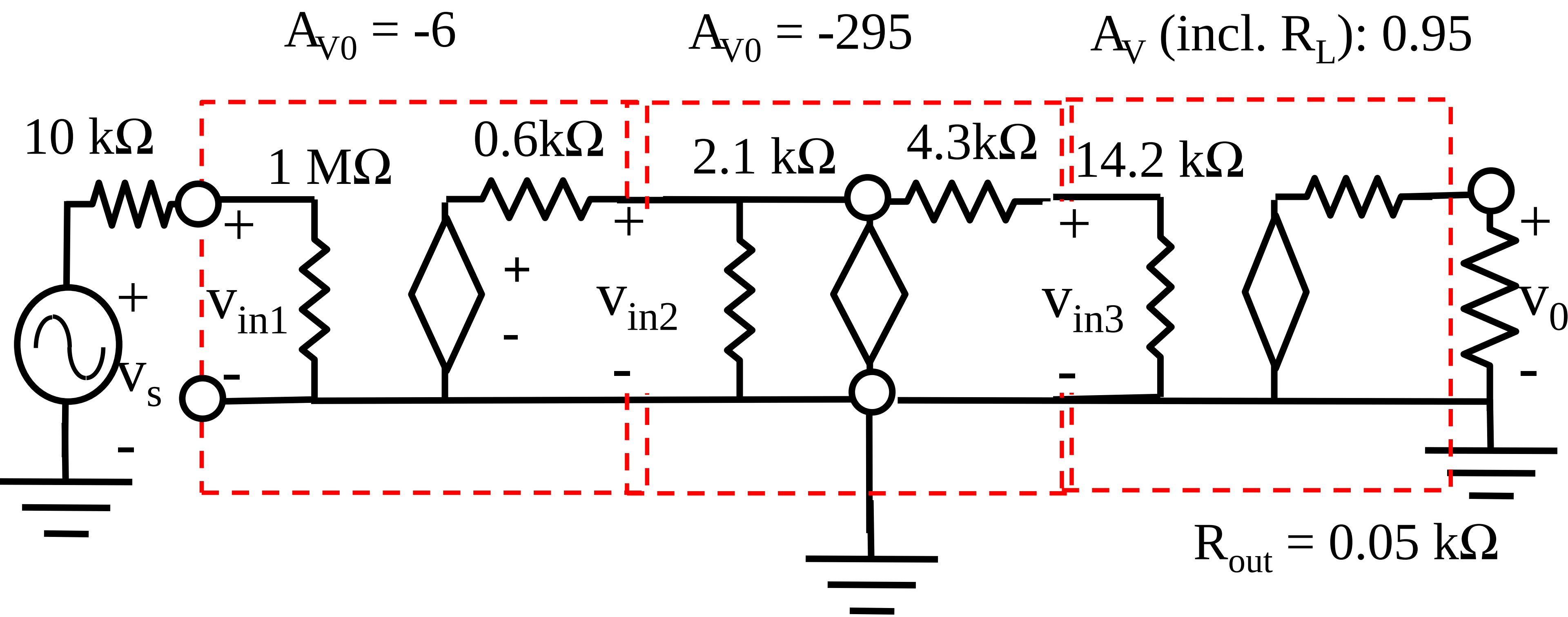
R_{in3}= 19.6k || 51.7k =14.2k

$$R_o = R_E \,||\left(\frac{r_p + R_{series}}{b+1}\right)$$

$R_{series3}$ = R_3 || R_4 ||R_{out2}
= 4.0 kΩ

R_{out3} =0.05kΩ

Combine 3 Stages



$$A_v = v_o/v_s = v_{in1}/v_s \times v_{in2}/v_{in1} \times v_{in3}/v_{in2} \times v_o/v_{in3}$$

$$A_v = \frac{1M}{(10k+1M)}(-5.9)\frac{2.1k}{(2.1k+0.6k)}(-293)\frac{14.2k}{(14.2k+4.3k)}(0.95)$$

$$= 0.99 \times -4.6 \times -225 \times 0.95 = +973$$

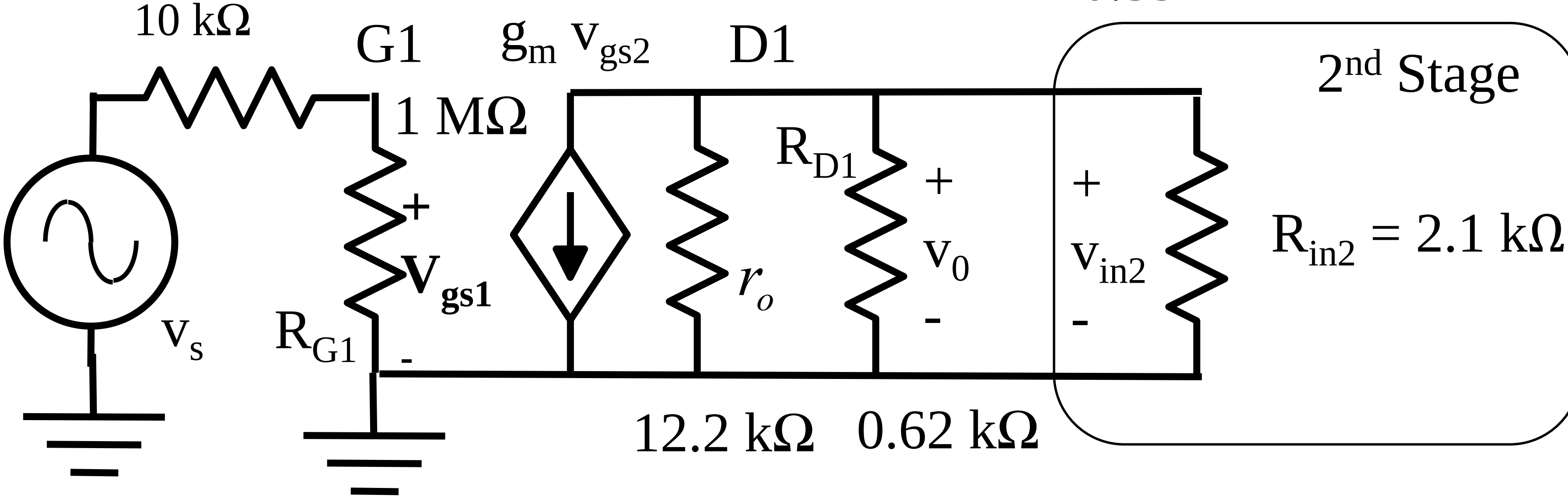
Perspective

1) Analyze cascaded amplifier stages in terms of individual stage gain, input/output impedances.
2) Pay attention to cases in which $R_{in,i}$ depends on subsequent stage, or $R_{out,i}$ depends on previous stage (e.g. R_{series} of follower includes R_{out} of previous stage)
3) Example used A_{Vo} for each stage, then a voltage divider between $R_{out,i}$ and $R_{in,i+1}$. You can also find overall A_V for a stage by considering $R_{in,i+1}$ in calculation.

Alternate Stage 1 – CS with $R_{LOAD} = R_{in2}$

$g_m = 10$ mS

$R_{o1} = (r_o \parallel R_{D1})$
$= 0.59$ kΩ

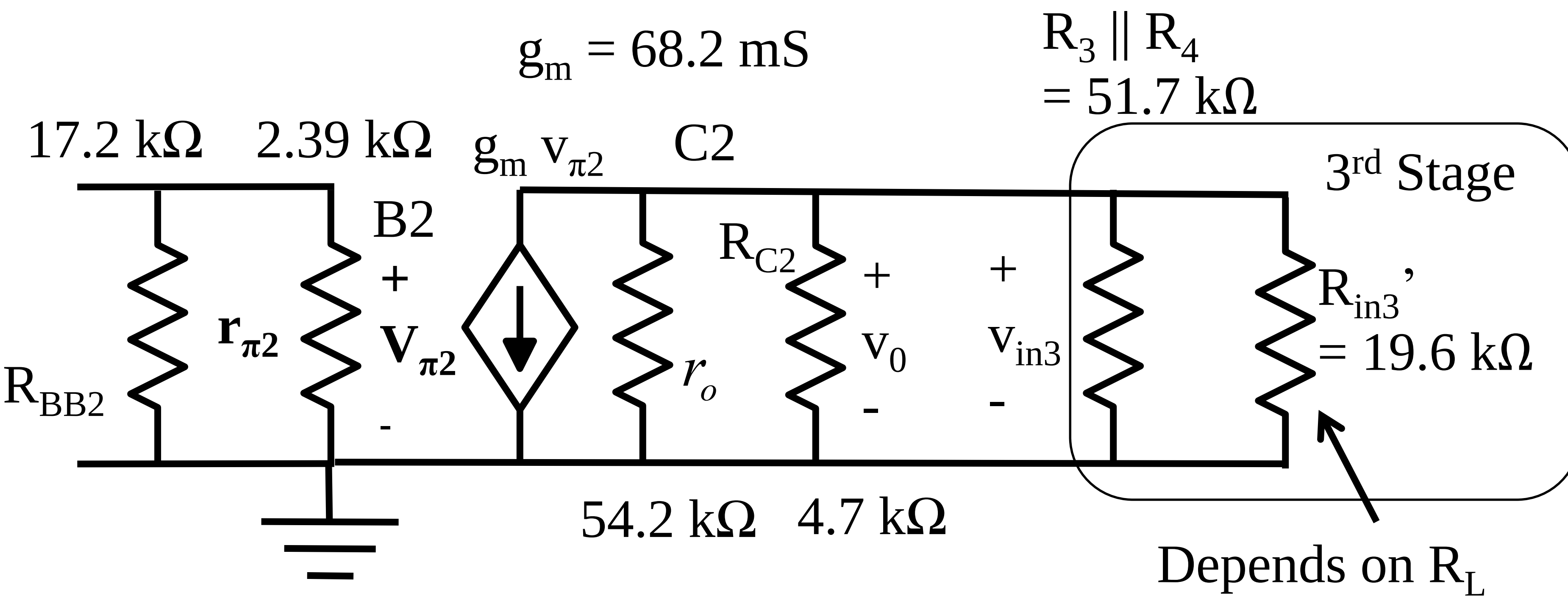


$v_{in1} = v_s\,(R_{G1} /(R_{source} + R_{G1})$
$= 0.99$

$A_{vtotal} = v_{in2}/v_{in1} = -g_m\,(r_o \parallel R_{D1} \parallel R_{in2}) = -4.6$

Previously, had $A_{vo} = -5.9$, then voltage divider.

Alternate Stage 2 – CE with R_{in3}



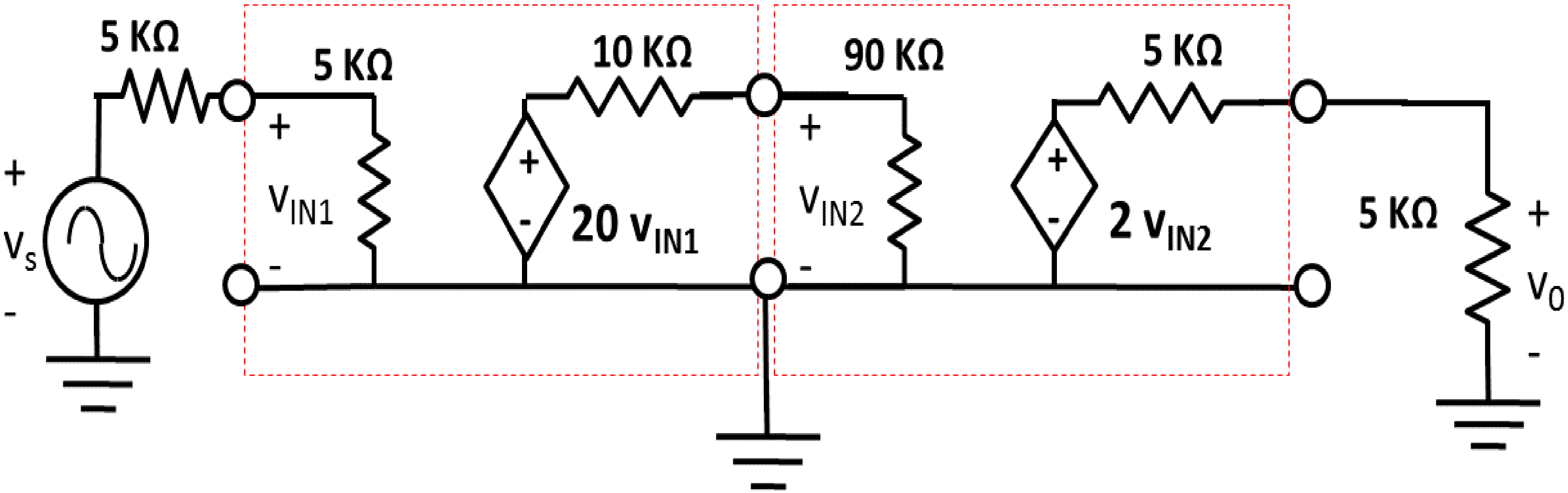
$A_{vtotal} = v_{in3}/v_{in2} = -g_m\ (r_{o2} \parallel R_{C2} \parallel R_3 \parallel R_4 \parallel R_{in3}')$
$= -\ 68.2$ ms x 3.3 kΩ = - 226

$R_{in2} = (R_{BB2} \parallel r_{\pi 2}) = 2.1$ kΩ

$R_{o2} = (r_o \parallel R_{C2}) = 4.3$ kΩ

vs A_{vo} = - 293, then voltage divider.

Summary



$$A_v = v_o/v_s = v_{in1}/v_s \text{ x } v_{in2}/v_{in1} \text{ x } v_o/v_{in2} \text{ x } \ldots$$

- $A_{vo}/R_{in}/R_{out}$ Representation and chain rule
- Have to calculate stage input/output resistances in order to evaluate intermediate voltage gains
  - Open-circuit Av, then resistance dividers, or…
  - Directly calculate stage i gain in presence of $R_{in,i+1}$