E4332: VLSI Design Laboratory

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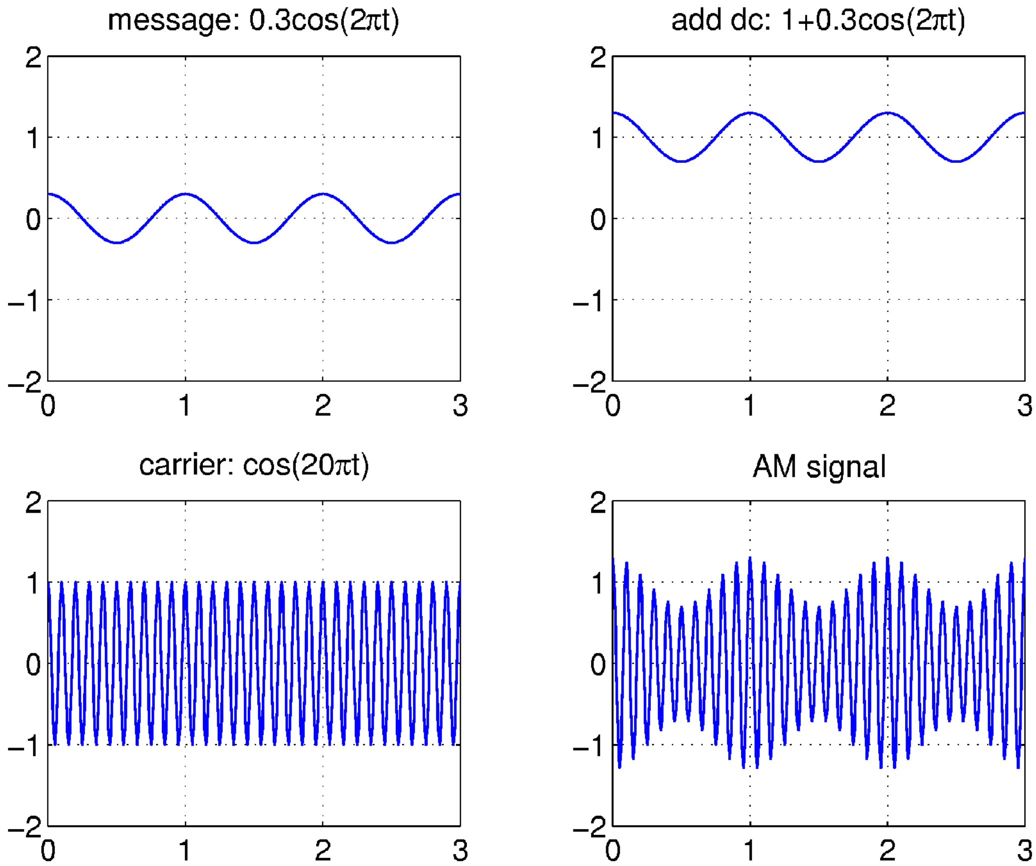
AM radio receiver

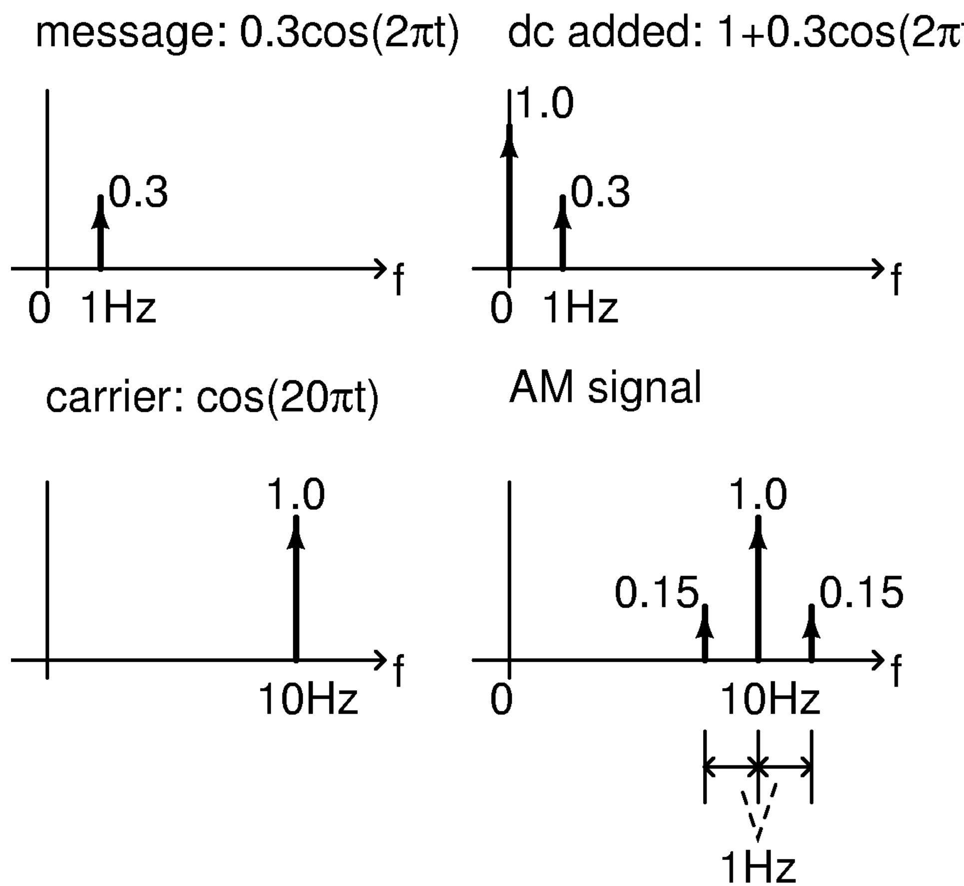
- AM radio signals: Audio signals on a carrier
- Intercept the signal
- Amplify the signal
- Demodulate the signal-recover the audio
- Amplify the audio to drive a speaker

AM signal basics: time domain



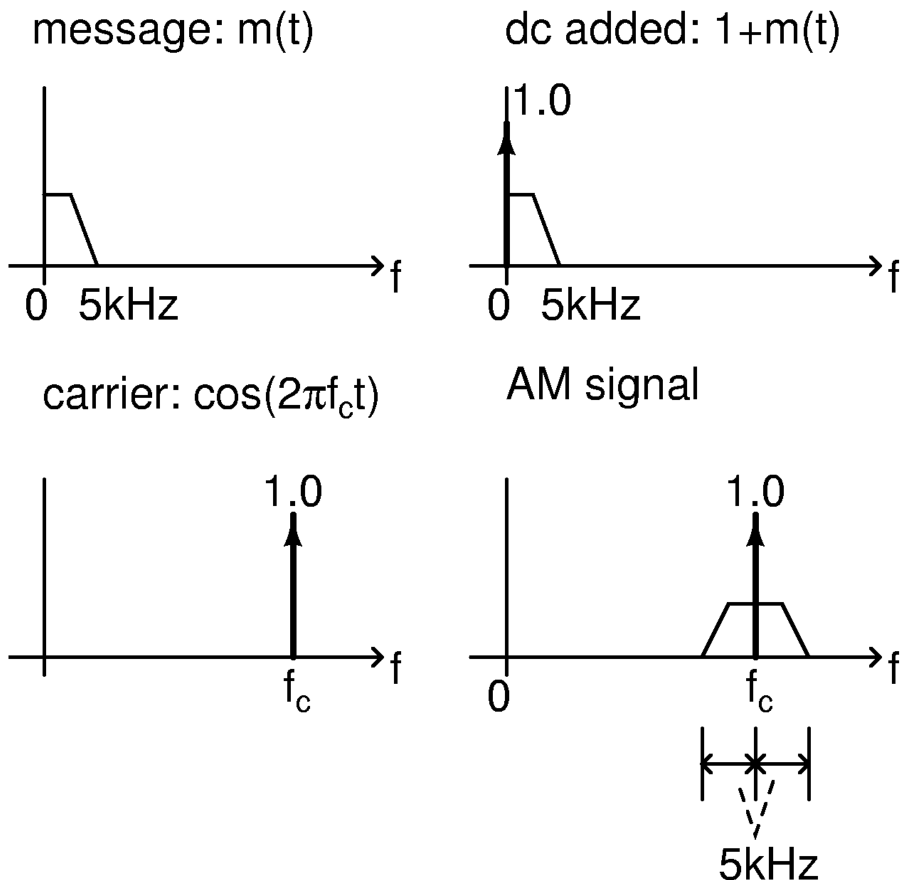
- Envelope(peak) of the carrier is the message

AM signal basics: frequency domain



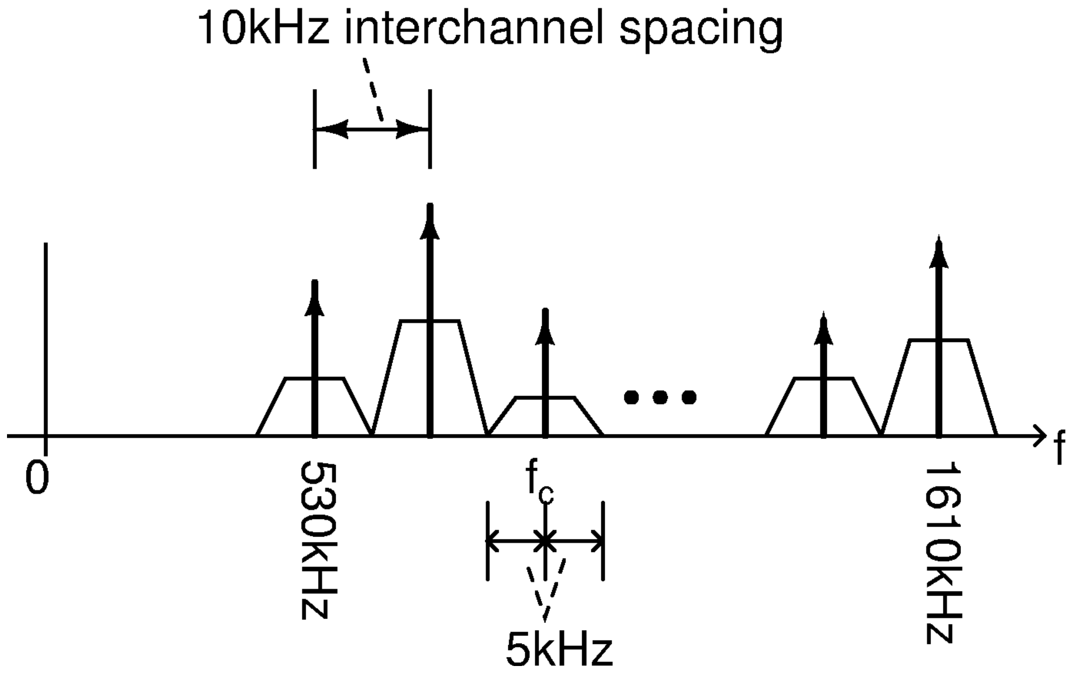
- Sidebands around the carrier

AM signals



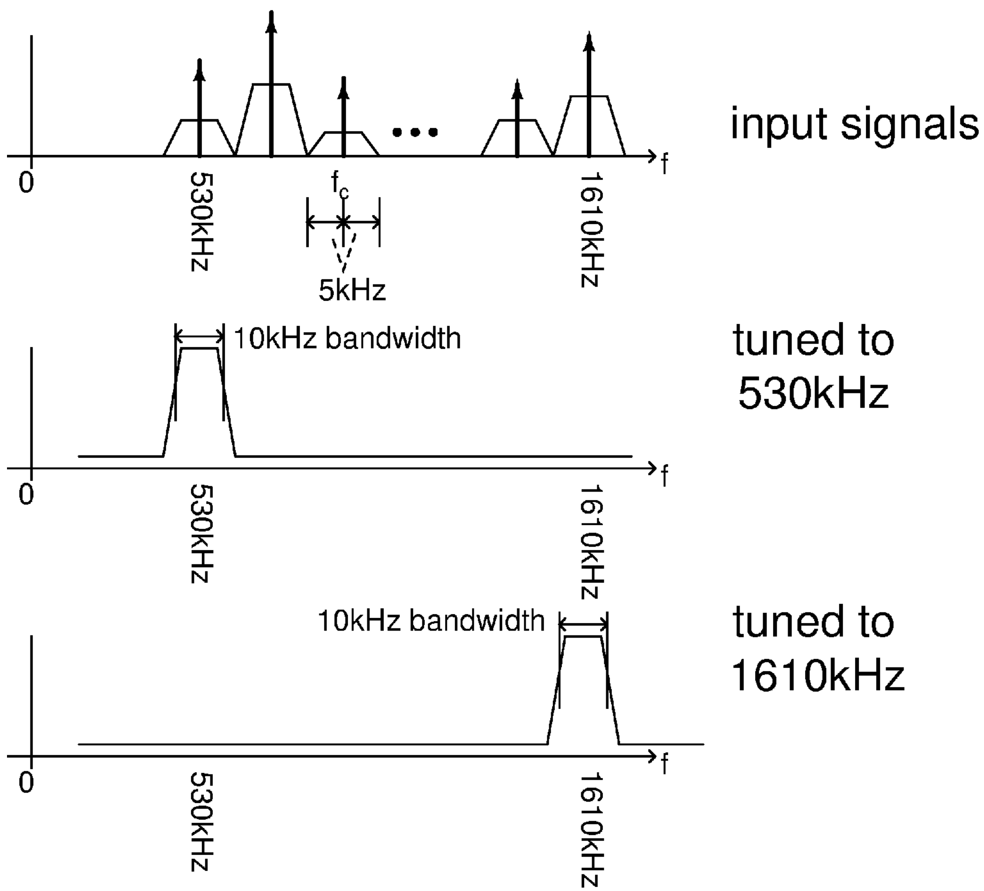
- Sidebands around the carrier

Broadcast AM signals



- Broadcast AM channels 10kHz from each other

Receiver bandwidth



- Receiver bandwidth must be constant

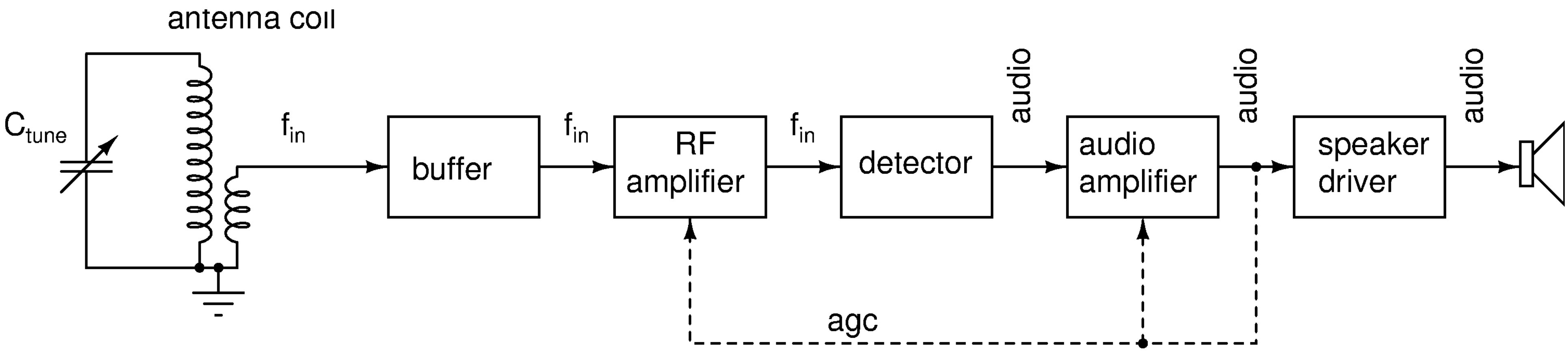
Receiver bandwidth

- f_c/f_{bw}=53 at the lowest end
- f_c/f_{bw}=161 at the highest end
- High Q (~ quality factor)
- Maintain constant bandwidth

Receiver sensitivity and selectivity

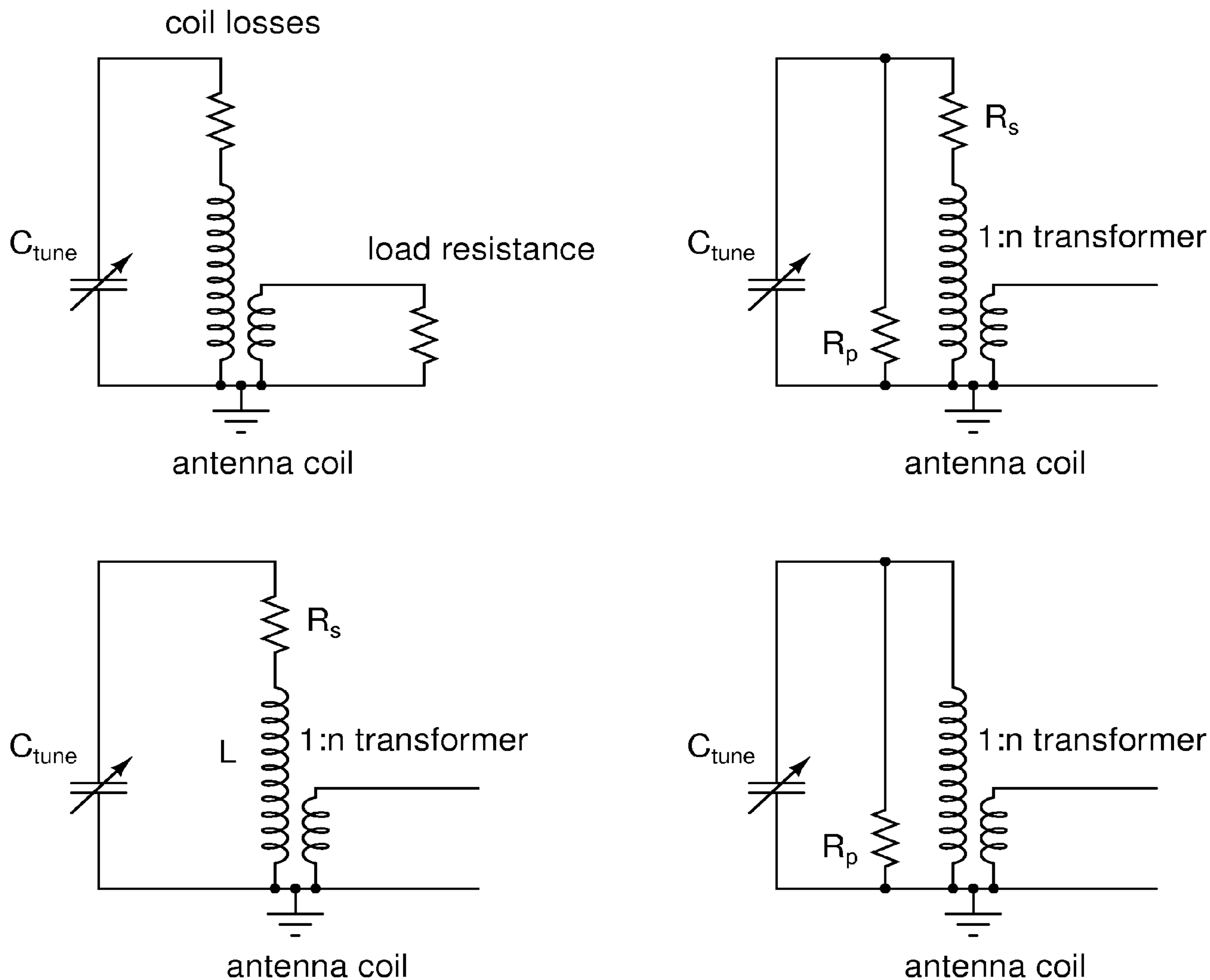
- Sensitivity: ability to detect small signals
  - AM radio sensitivity: ~50uV signals with 30% modulation
- Selectivity: ability to reject adjacent signals
  - Dictated by the choice of architecture in our case

Tuned Radio Frequency(TRF) receiver



- Input tuned circuit is the only filter providing selectivity
- Coil on a ferrite rod

TRF receiver: input tuning



2^{nd} order filter basics

- Resonant frequency(radians per second) $\omega_o = 1/\mathrm{sqrt}(LC_{tune})$
- 3dB bandwidth ω_b
- Quality factor $Q = \omega_0/\omega_b$
- Series loss: $Q_s = 1/R_s \mathrm{sqrt}(L/C)$
  - Bandwidth = R_s/L
- Parallel loss: $Q_p = R_p \mathrm{sqrt}(C/L)$
  - Bandwidth = $1/CR_p$

TRF receiver: input tuning

- Resonant frequency($1/\mathrm{sqrt}(LC_{tune})$) varies from 530 to 1610kHz, approx 3x
- Fixed L, $\Rightarrow C_{tune}$ varies by 9x
- Series loss(R_s) only
  - Bandwidth = R_s/L
  - No change with C_{tune}
- Parallel loss(R_p) only
  - Bandwidth = $1/C_{tune}R_s$
  - varies by 9x with change in C_{tune}

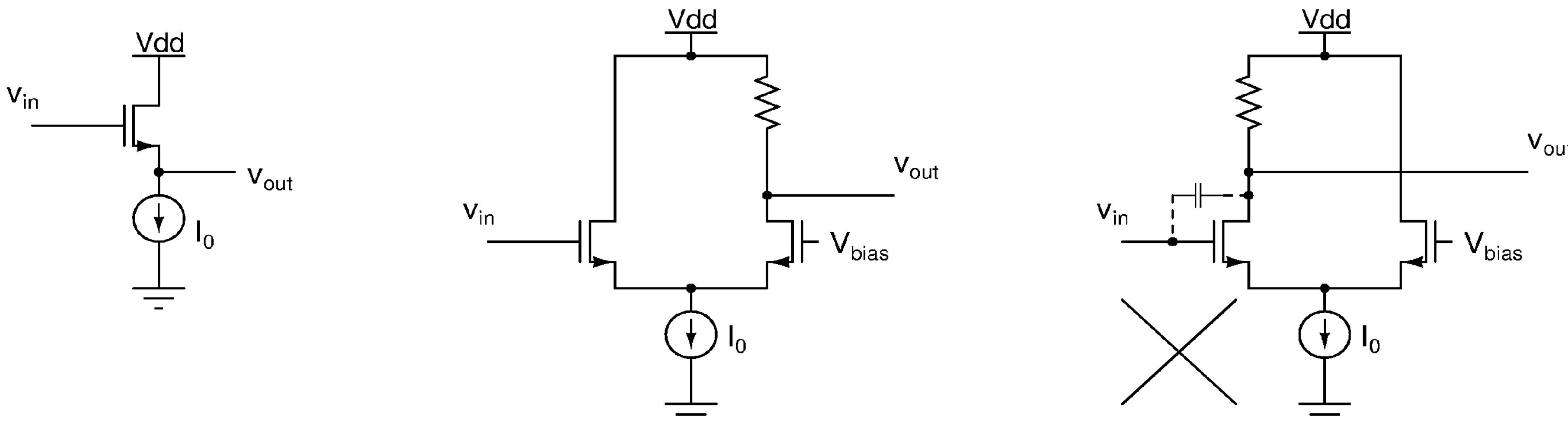
TRF receiver: input tuning

- Some bandwidth variation with tuning
  - Bandwidth < 10kHz at low end
  - Bandwidth > 10kHz at high end
- 2nd order filter. Limited out of band attenuation

⇒ Poor selectivity in a TRF receiver

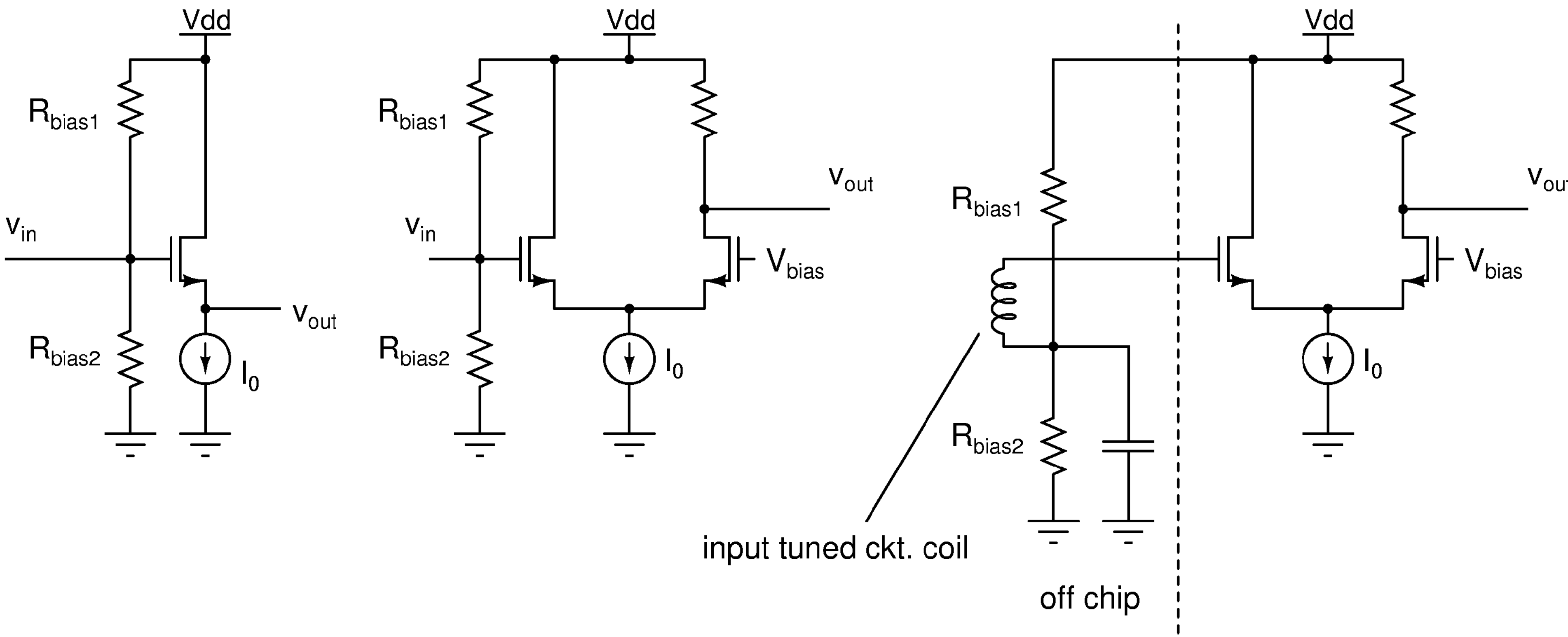
- Suggestion: Use a very large on chip R_p to maintain as high a Q as possible

TRF receiver: Input amplifier



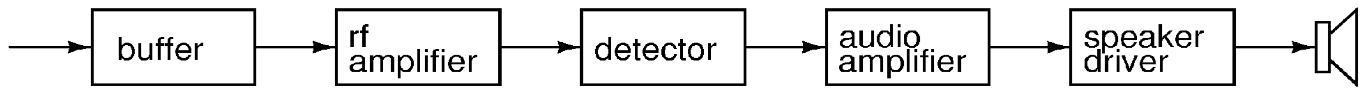
- High impedance input necessary
  - Source follower buffer
  - Differential amplifier

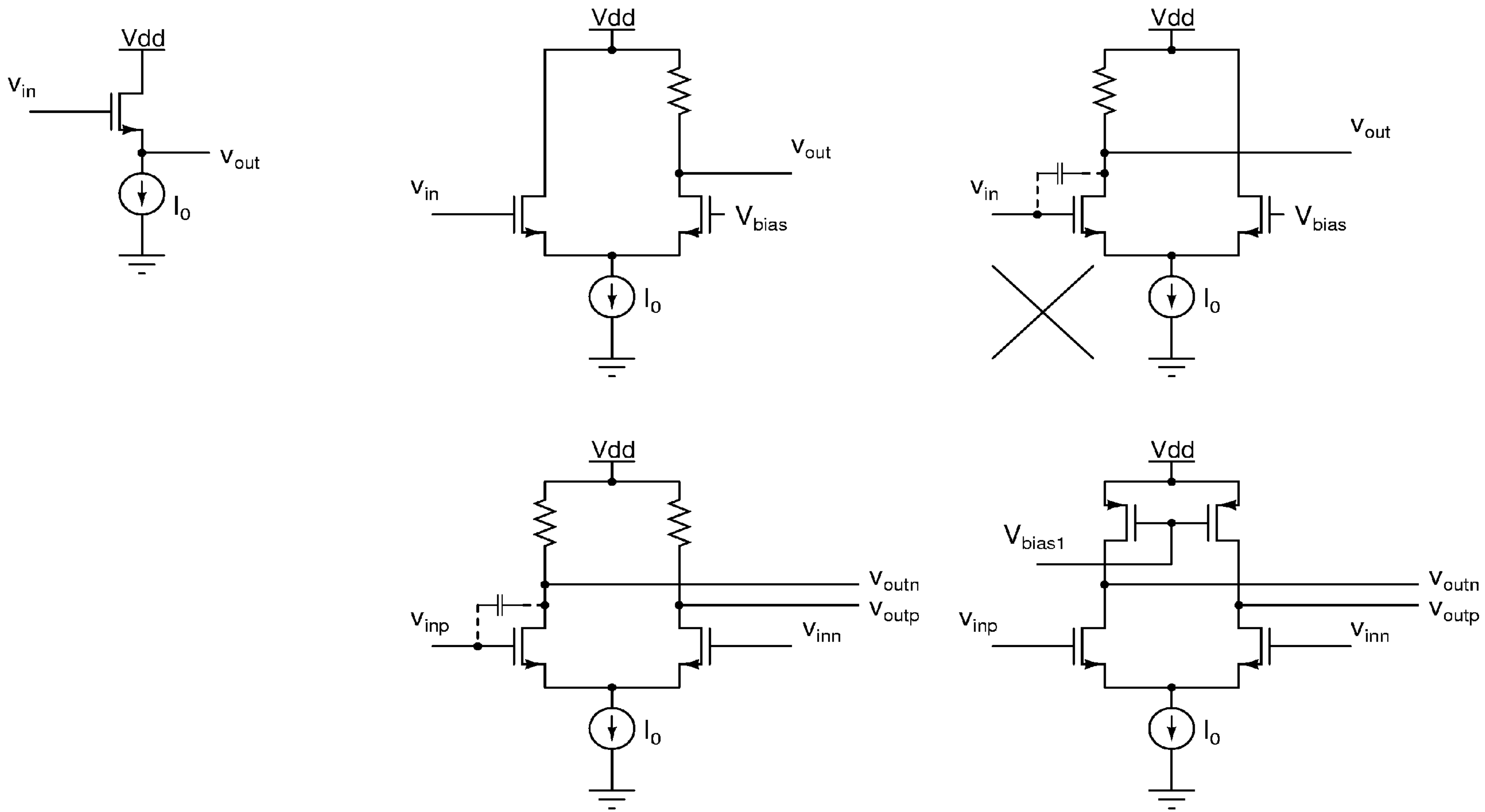
TRF receiver: Input amplifier



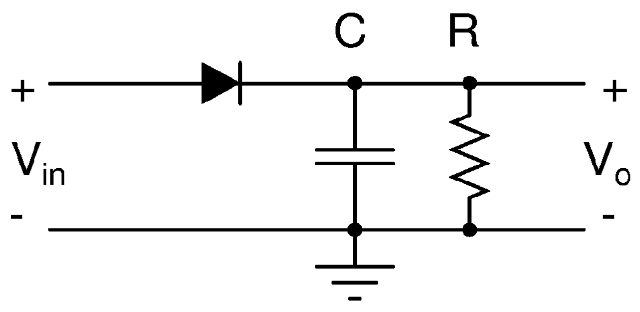
- Use large resistors for input biasing

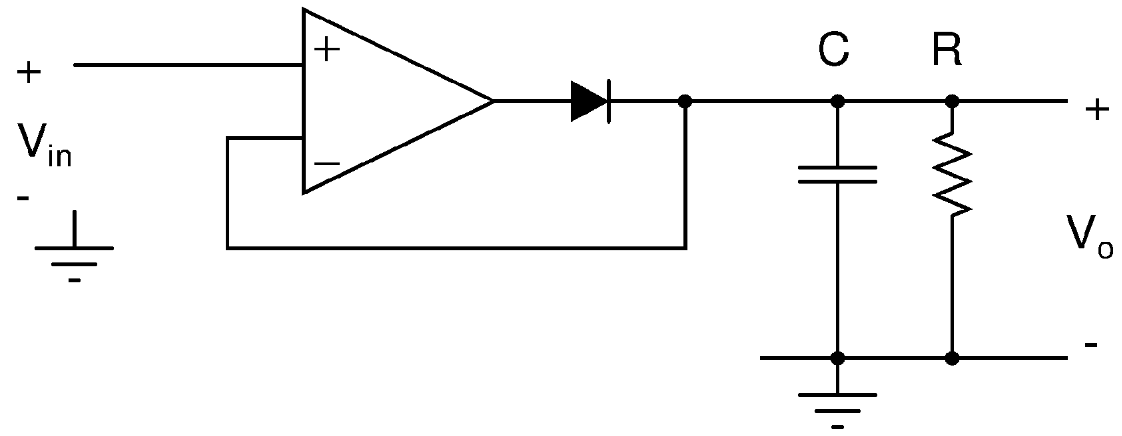
TRF receiver: Input amplifier





TRF receiver: Detector





- No diodes in CMOS process
- Input amplitude > diode drop
- Use of an amplifier in feedback to improve sensitivity

AM radio: specifications

Signal levels:

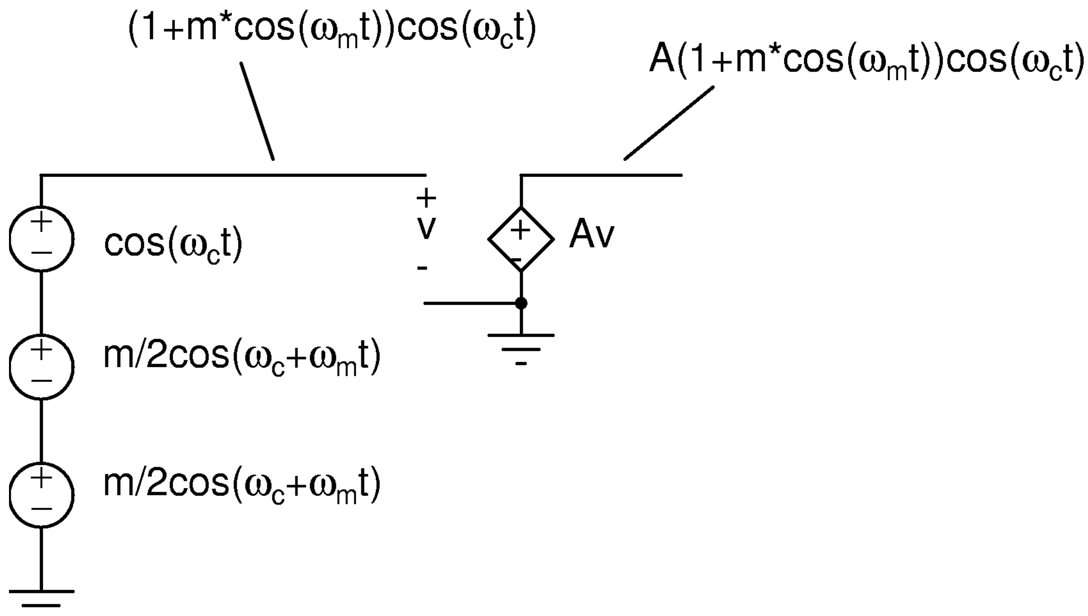
- Input from 50μV to 5mV
- RF amplifier with AGC
- Output of RF amplifier with AGC from 50mV to 200mV
  - Max. gain = 50mV/50μV = 1000 (60dB)
  - Min. gain = 200mV/5mV = 40 (32dB)
  - Total gain variability = 1:25 (28dB)
- Detector must work with 50mV-200mV inputs
- Audio output max. ~ $1V_{pk}$ into 8Ω speaker

AM radio: specifications

Misc.:

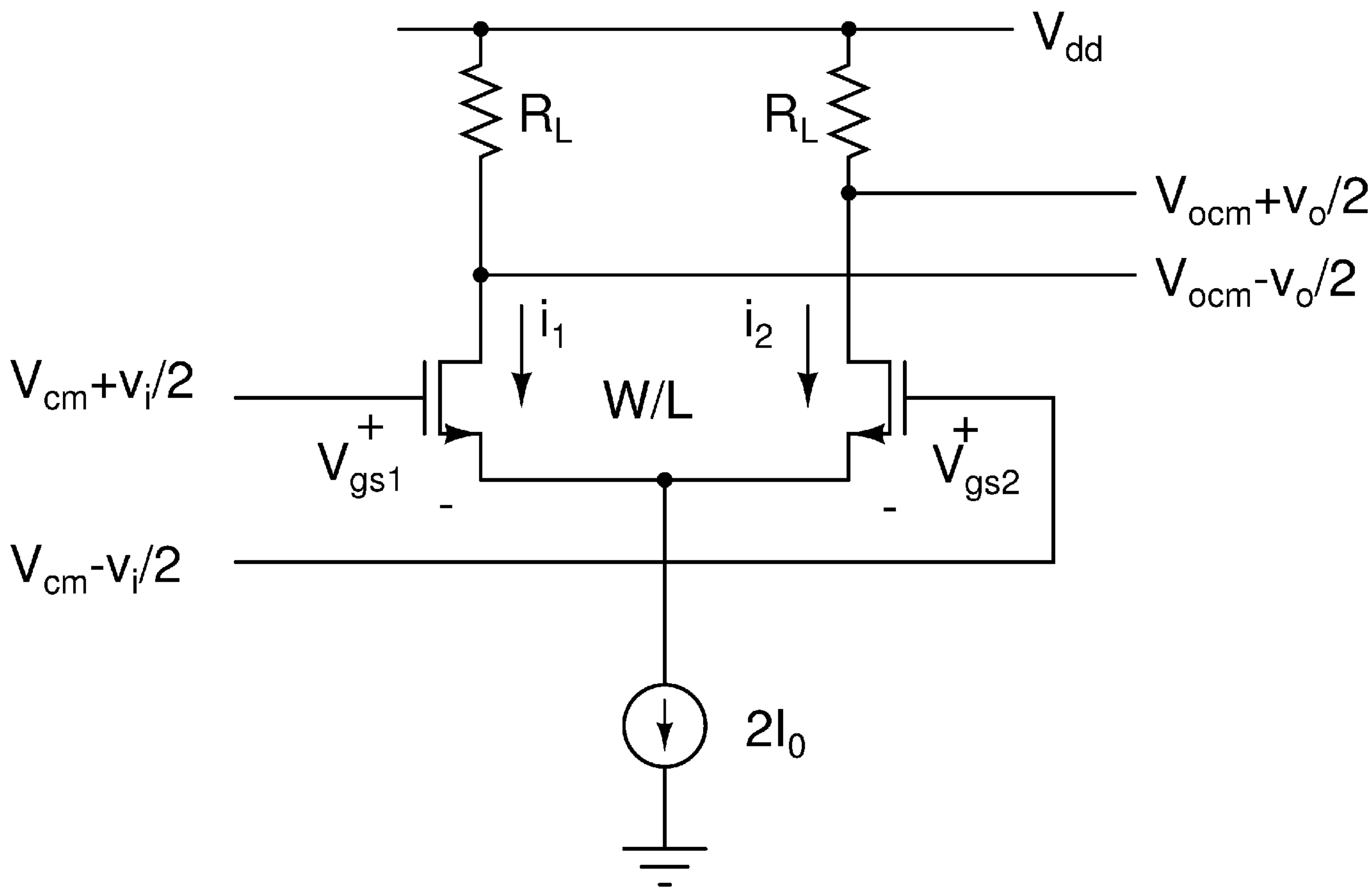
- Supply voltage: 4.2-4.5V
  - Operation with 3x 1.5V batteries
  - Try to design for 4.2V

AM radio: input signal generation



- Use A from 50μV to 5mV
- Parameterized subcircuit(using pPar(“m”), pPar(“A”) etc.) to make an AM source in Cadence

Amplifier basics

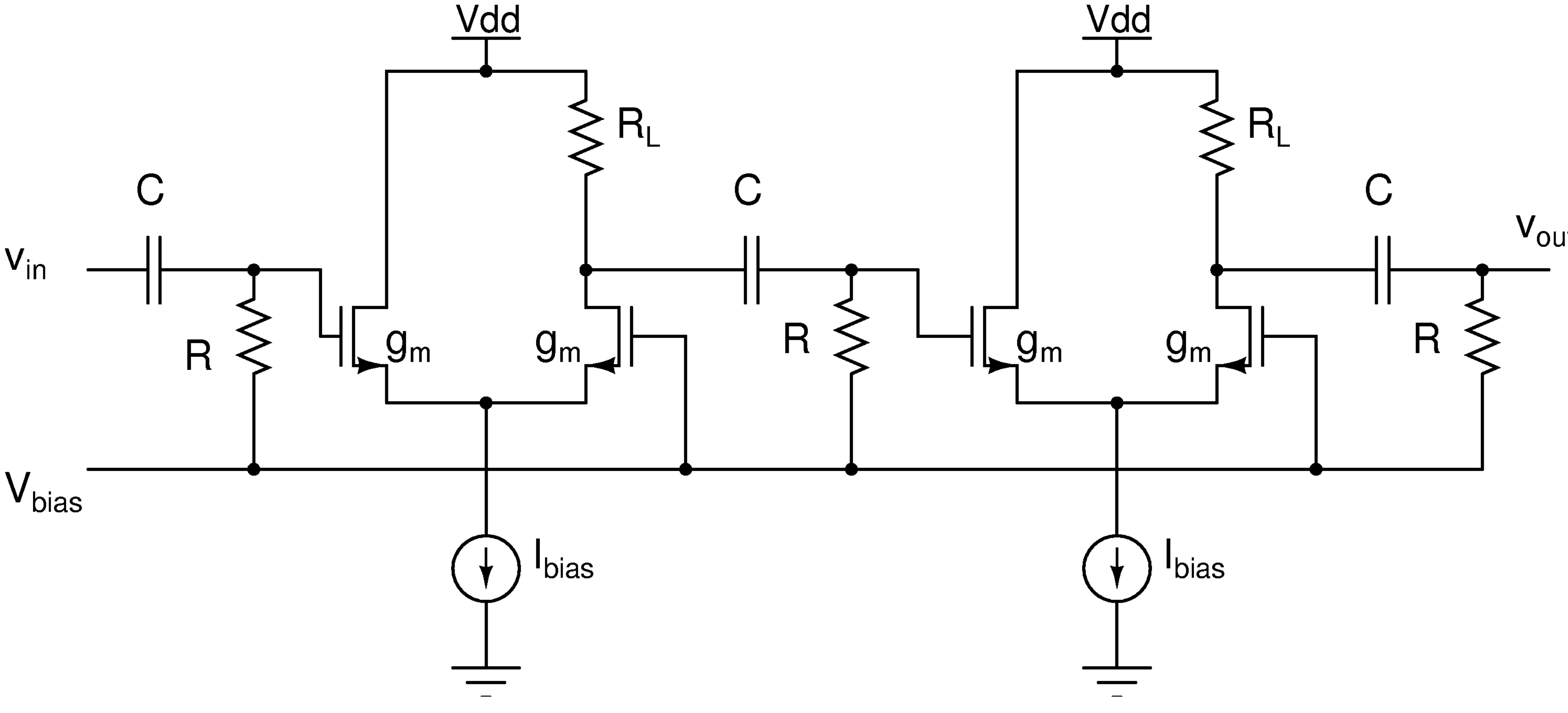


transistors: g_m,g_{ds},g_{mbs} at I_0

Amplifier basics

- Gain = $g_m(R_L+1/g_{ds}) \sim g_m R_L$
- Gm = $\mathrm{sqrt}(\mu C_{ox}/2 * W/L * I_0) = I_0/V_{GS}-V_T$
- Gain = $g_m R_L = I_0 R_L / V_{GS}-V_T$
  - To change gain, $I_0 R_L$ (the dc voltage drop across R_L) or $V_{GS}-V_T$ (related to transistor current density) has to be changed
- Linearity improves with increasing $V_{GS}-V_T$
  - Amplifier: larger $V_{GS}-V_T$
  - Switch: smaller $V_{GS}-V_T$

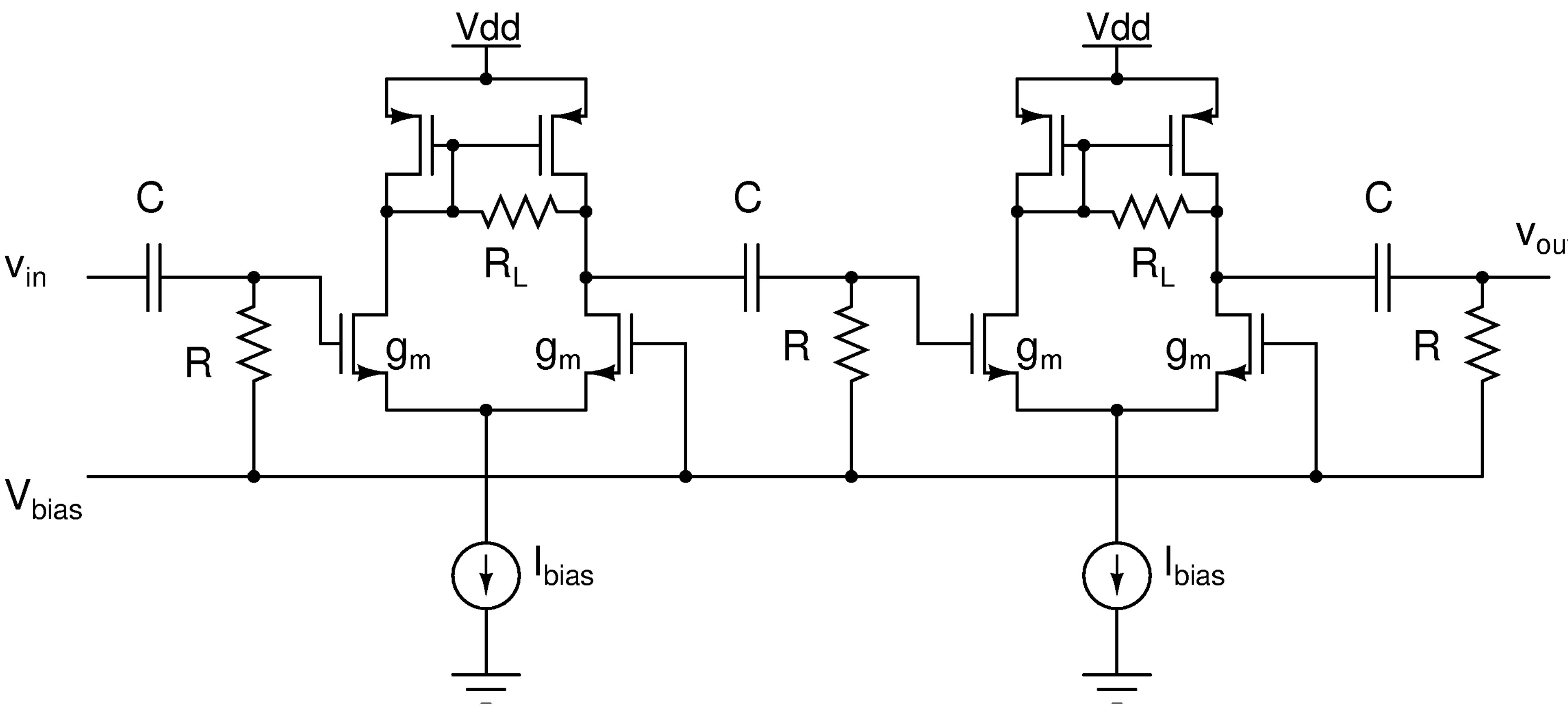
RF amplifier I



RF amplifier I

- AC coupled to remove offsets
- Single ended input/output-simple
- Gain = $g_m R_L/2$(Analyze this!)
- Ac coupling resistors: pMOS transistors
- Ac coupling corner frequency: ~ 1dB attenuation at lower end of AM band
- Capacitor values: 5pF or less
  - Linear capacitor density ~ 0.9fF/μm^2
- Resistor values: upto 10kΩ
  - Resistivity ~ 800Ω/sq.

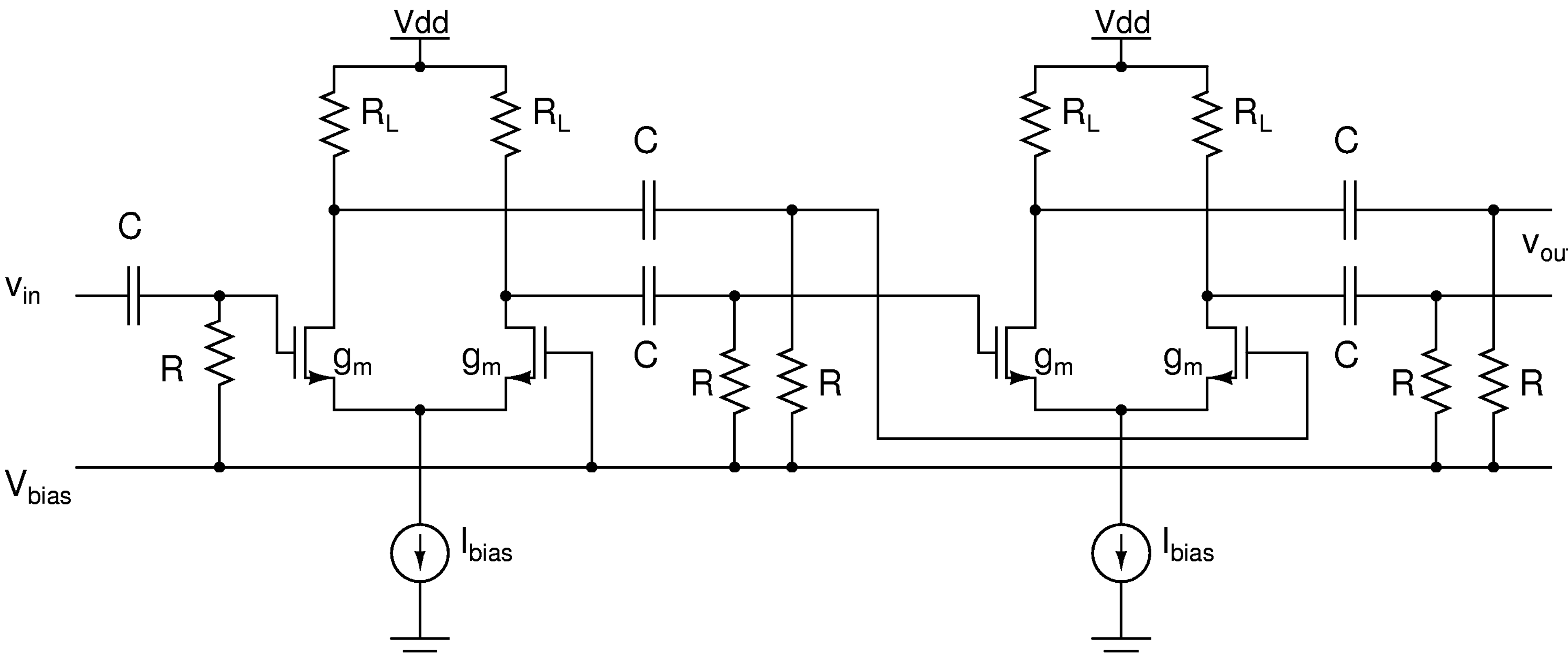
RF amplifier II



RF amplifier II

- AC coupled to remove offsets
- Single ended input/output-simple
- Gain = $g_m R_L$ (Analyze this!)
- Ac coupling resistors: pMOS transistors
- Ac coupling corner frequency: ~ 1dB attenuation at lower end of AM band
- Capacitor values: 5pF or less
  - Linear capacitor density ~ 0.9fF/μm^2
- Resistor values: upto 10kΩ
  - Resistivity ~ 800Ω/sq.

RF amplifier III



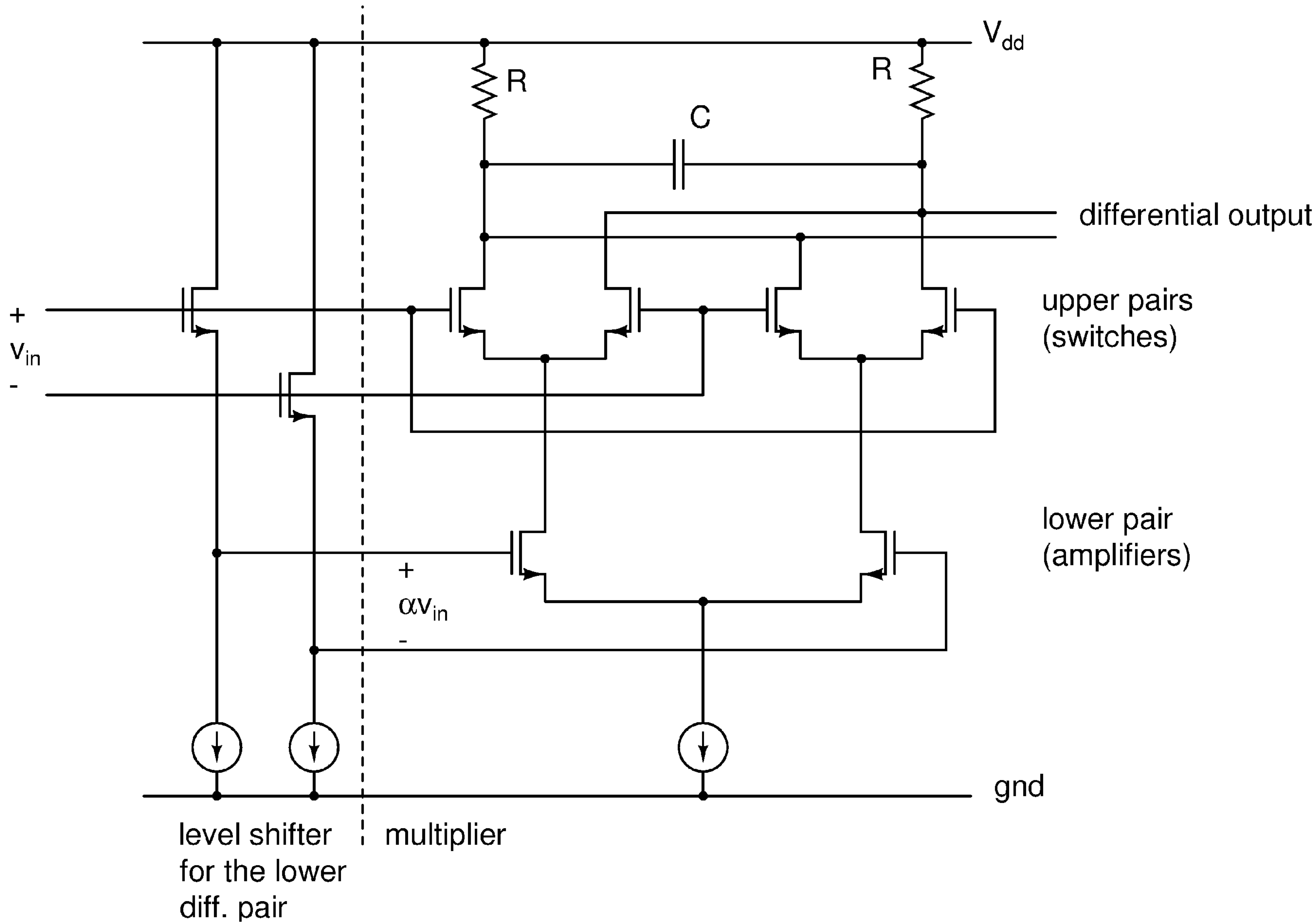
single ended input
differential output

differential input
differential output

RF amplifier III

- AC coupled to remove offsets
- Differential stages
  - 2x ac coupling capacitors
- Gain = $g_m R_L$ (Analyze this!)
- Ac coupling resistors: pMOS transistors
- Ac coupling corner frequency: ~ 1dB attenuation at lower end of AM band
- Capacitor values: 5pF or less
  - Linear capacitor density ~ 0.9fF/μm^2
- Resistor values: upto 10kΩ
  - Resistivity ~ 800Ω/sq.

Detector I

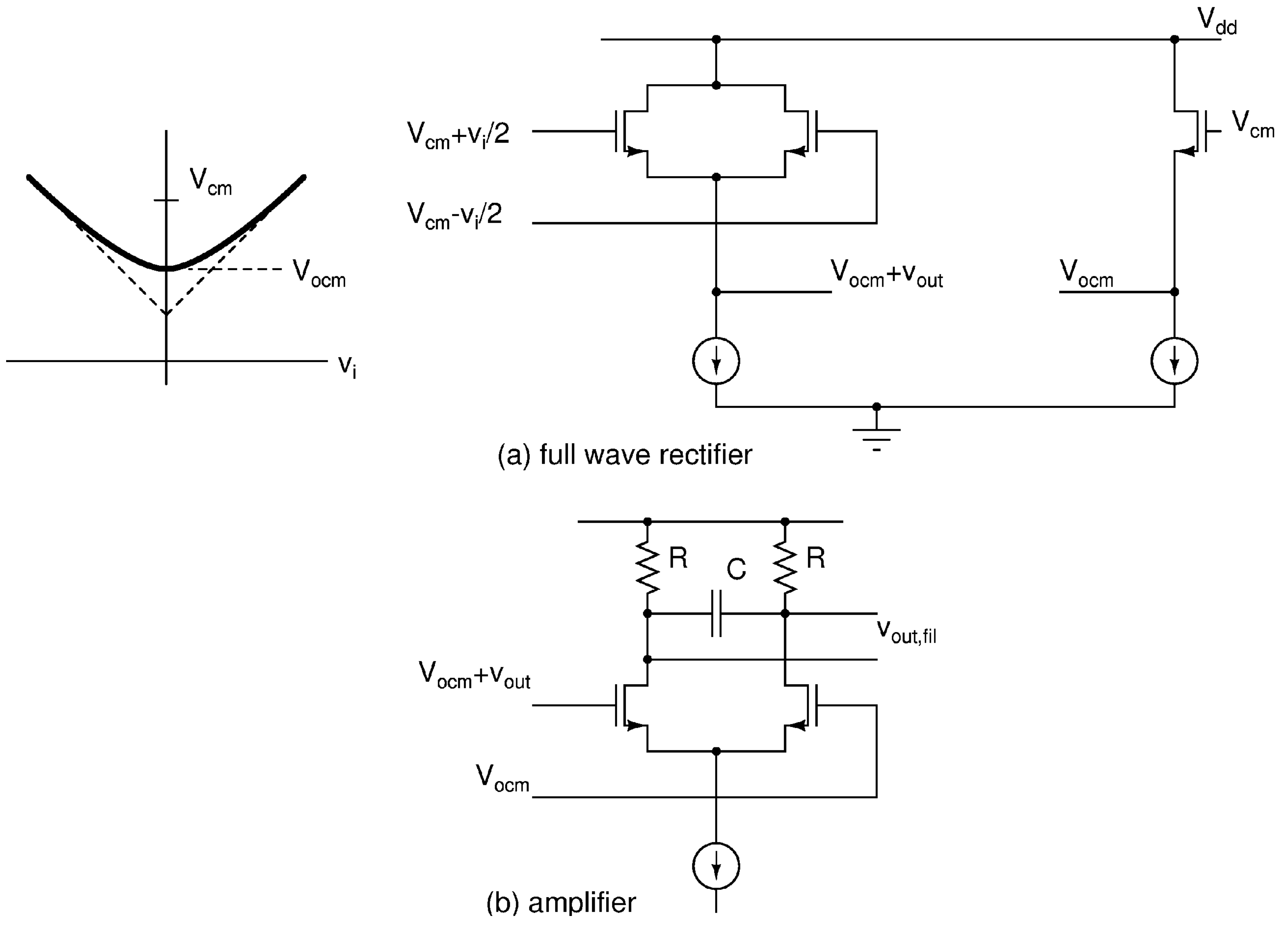


V_{dd}
R
R
C
differential output
upper pairs
(switches)
+
v_{in}
-
lower pair
(amplifiers)
+
αv_{in}
-
gnd
level shifter
for the lower
diff. pair
multiplier

Detector I

- Implement $v_i(t)*sgn(v_i(t))$ and filter the result
  - Full wave rectification and filtering
- Filtering capacitor C
  - retain audio, remove RF
  - External, if too large
- Upper pair should act as a switch: $sgn(v_i(t))$
- Lower pair should act as a linear amplifier (over the entire range of input signals)

Detector II

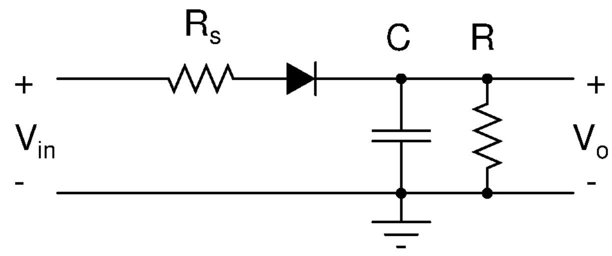


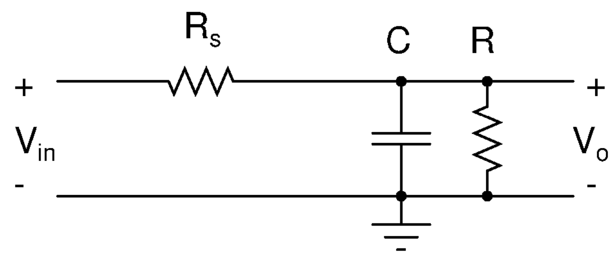
V_cm
V_ocm
v_i
V_dd
V_cm+v_i/2
V_cm-v_i/2
V_cm
V_ocm+v_out
V_ocm
(a) full wave rectifier
R
C
R
v_out,fil
V_ocm+v_out
V_ocm
(b) amplifier

Detector II

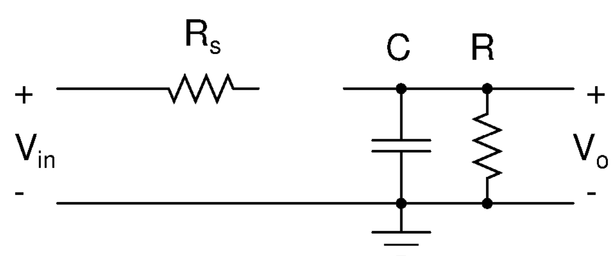
- Full wave rectifier with differential inputs
- Half wave rectifier with single ended inputs
- Followed by amplifier and filter
- Filtering capacitor C
  - retain audio, remove RF
  - External, if too large

Peak detector





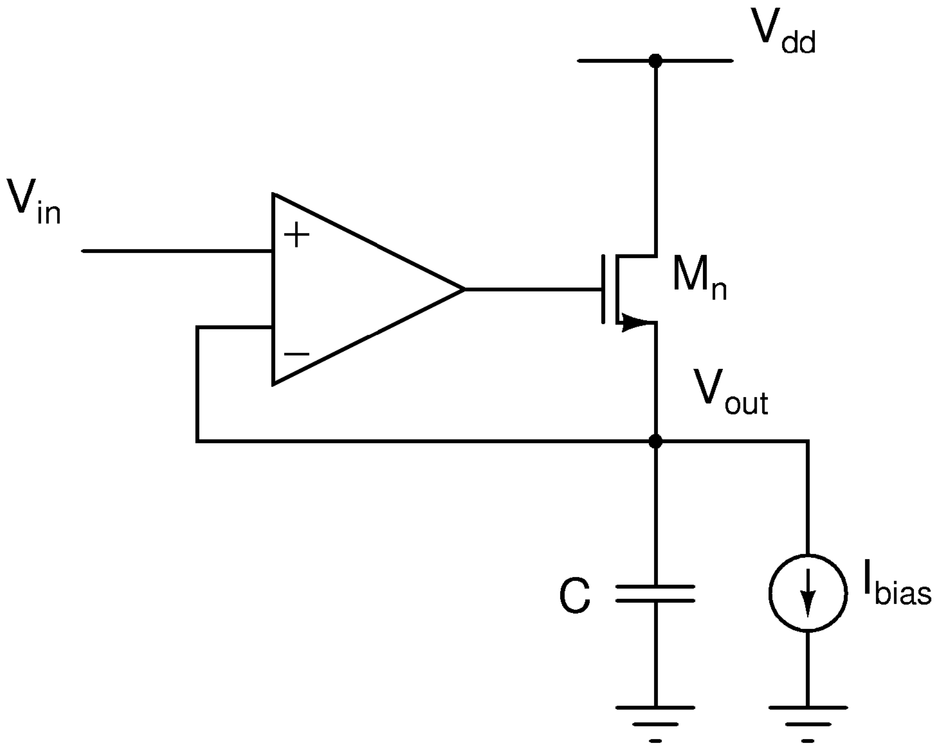
diode on
charge through R_s



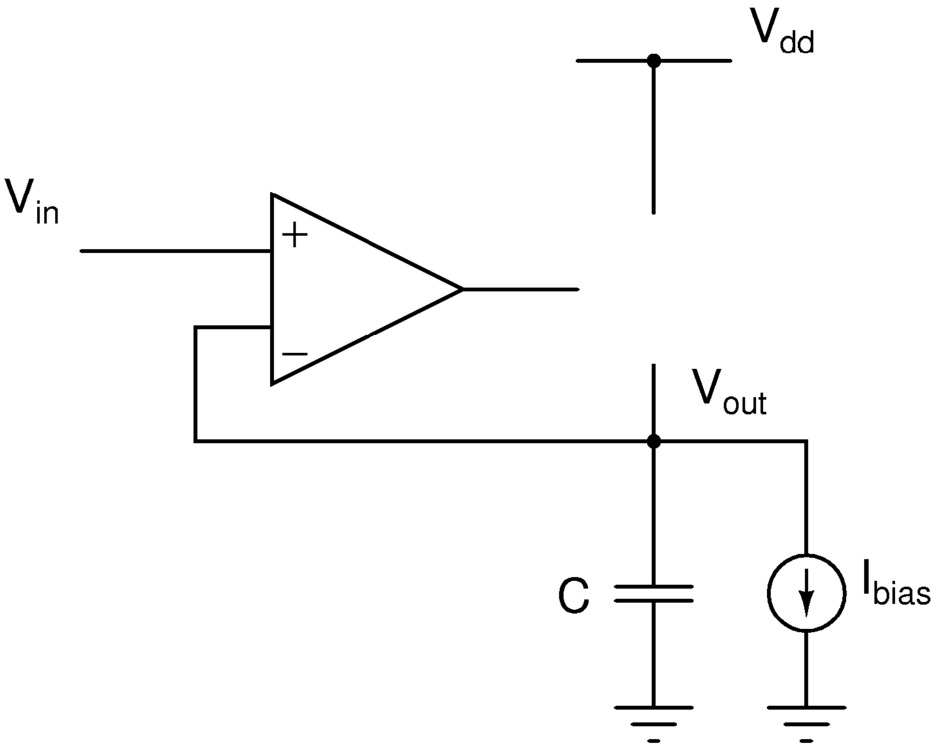
diode off
discharge through R

$$T_{audio,max} \gg RC \gg T_{RF,min}$$

Detector III

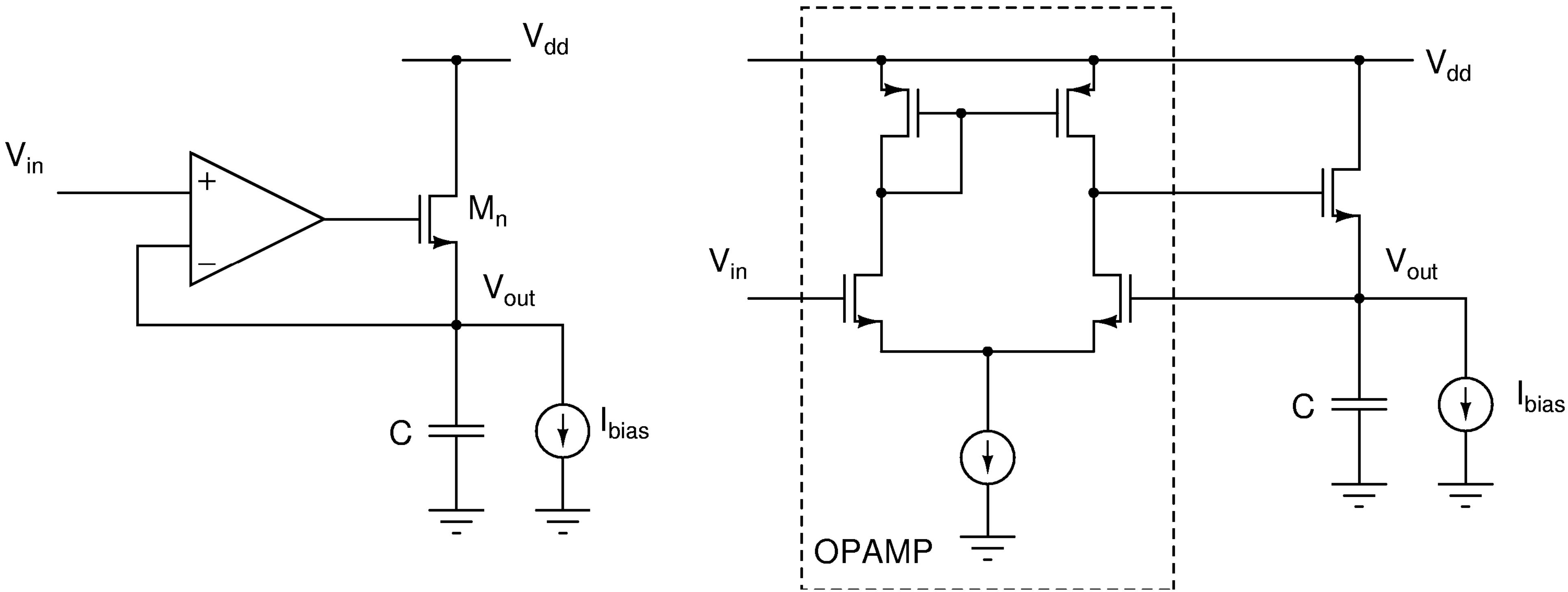


capacitor charge (through M_n)



capacitor discharge (I_{bias})

Detector III

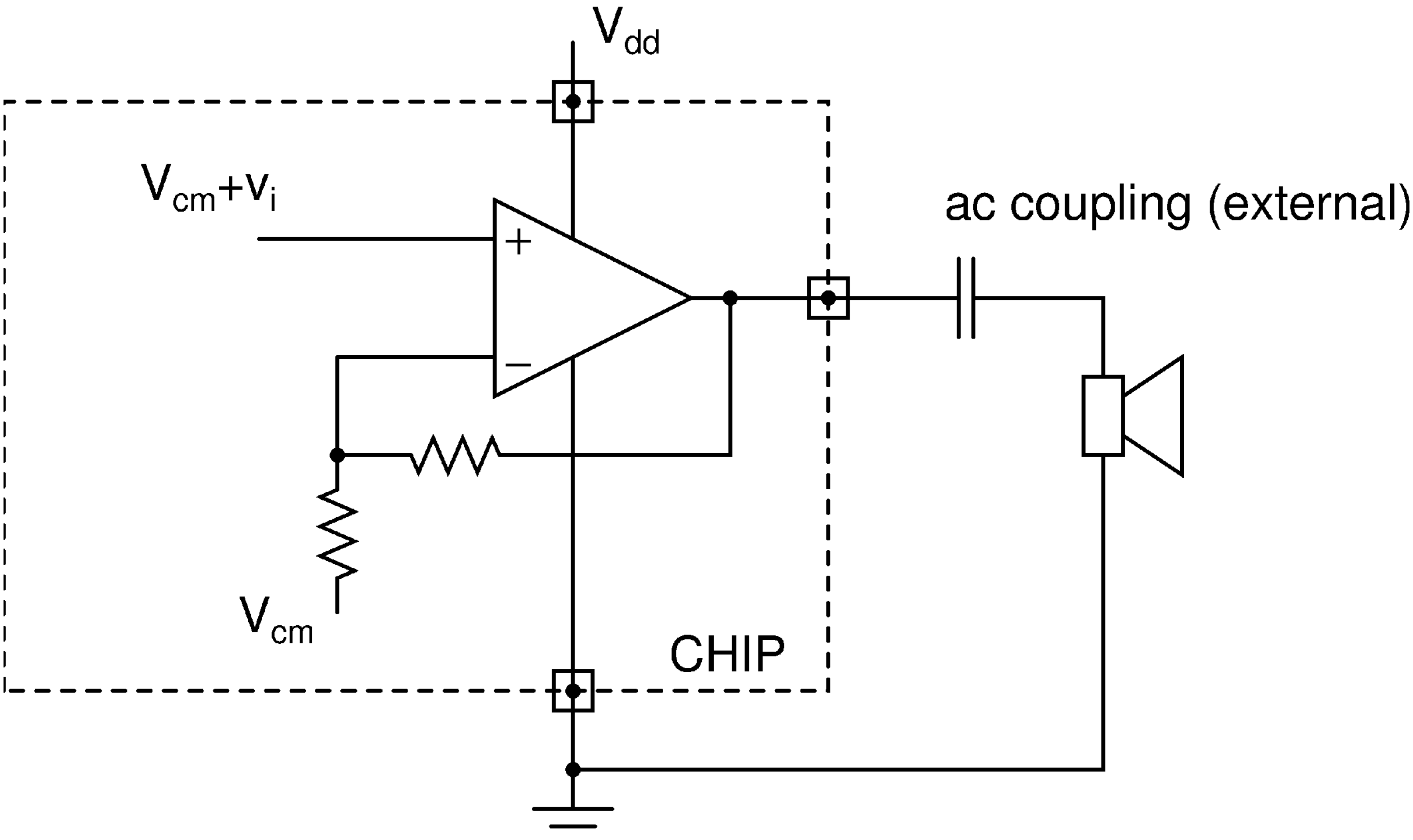


- Single stage "op amp"

Detector III

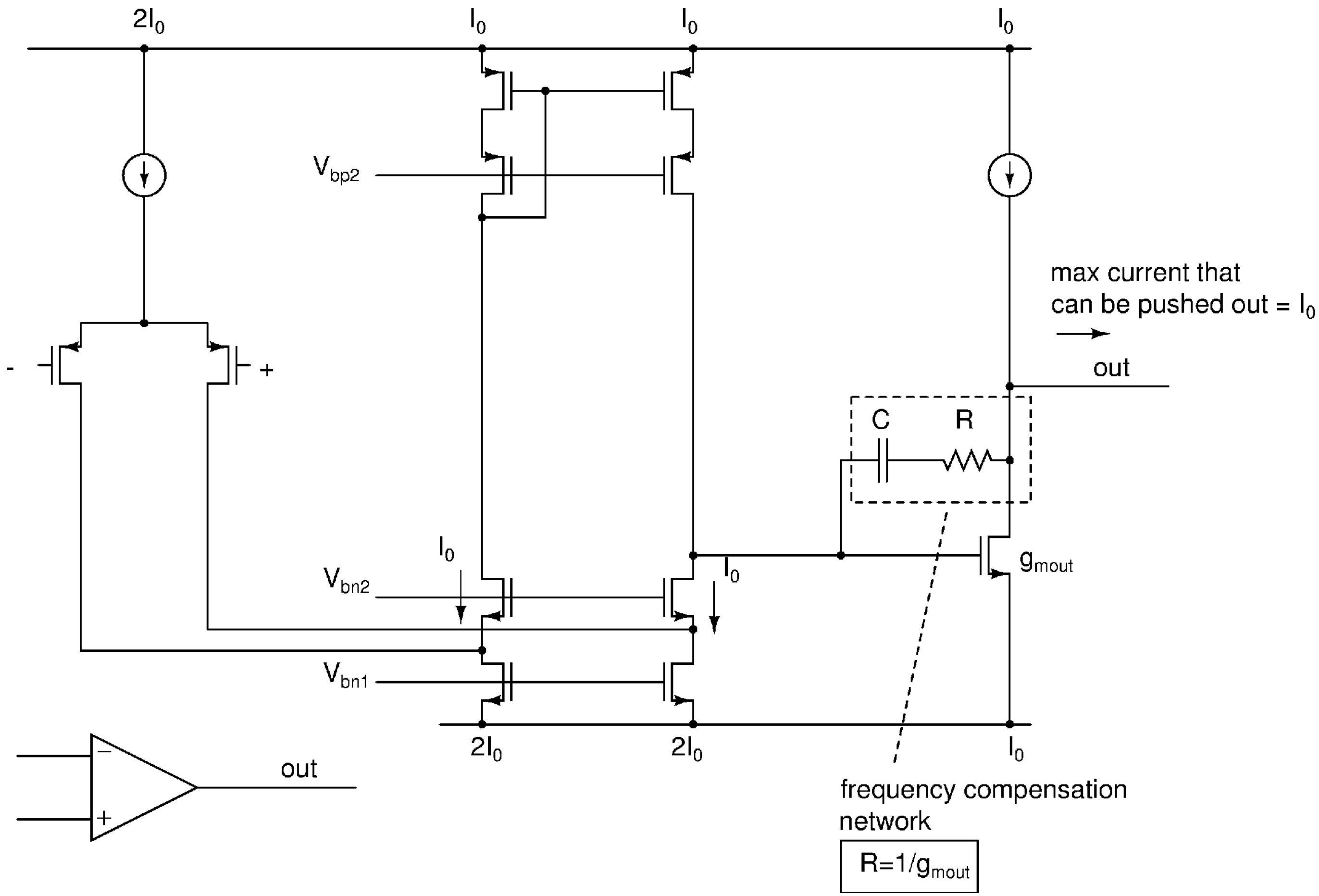
- Peak detector
- Discharge time constant slower than charging time constant
  - Negligible discharge between RF cycles
  - Full discharge between audio cycles

Audio amplifier



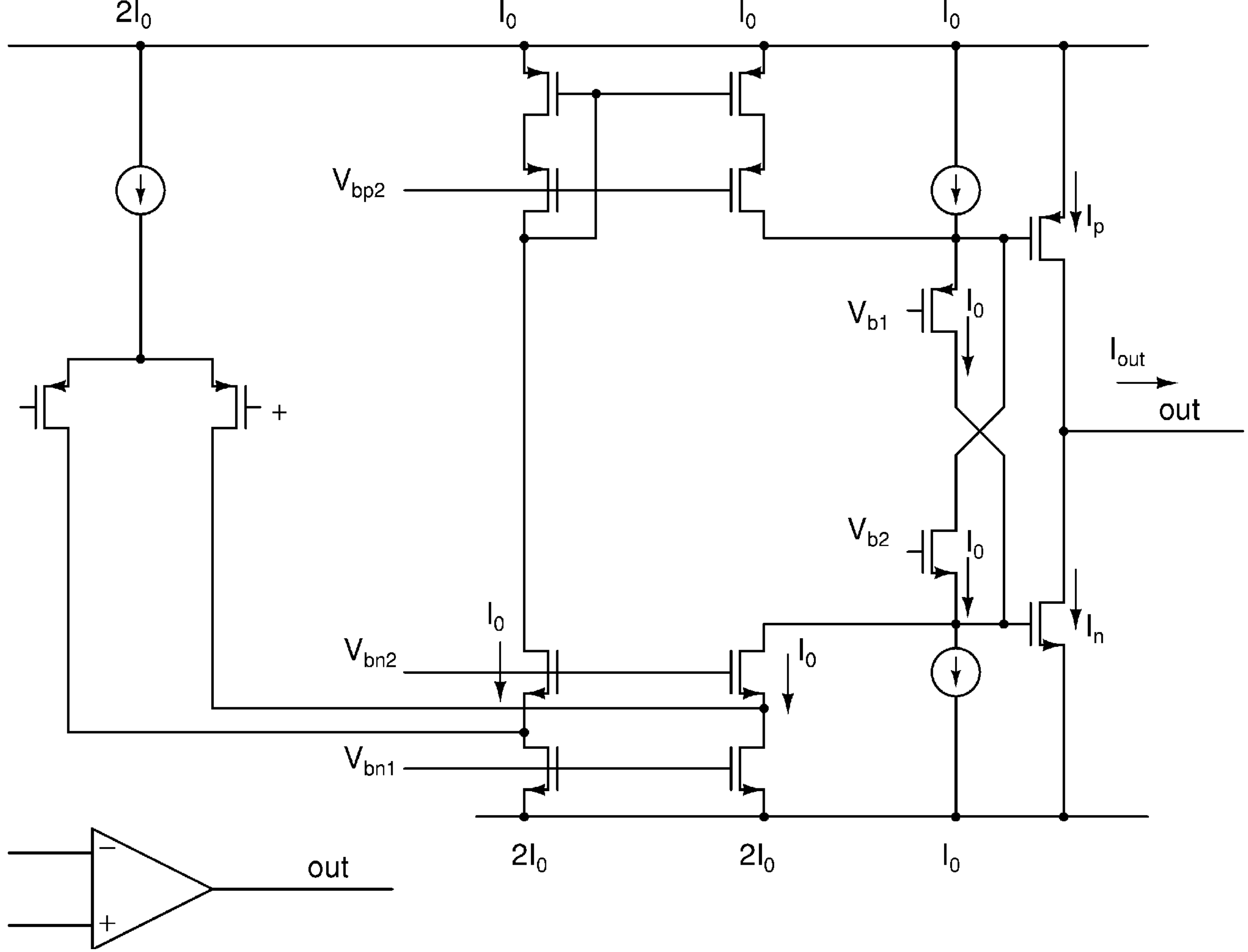
- Feedback for linearity
- Output current ~ 1V/8Ω = 125mA

Class A opamp



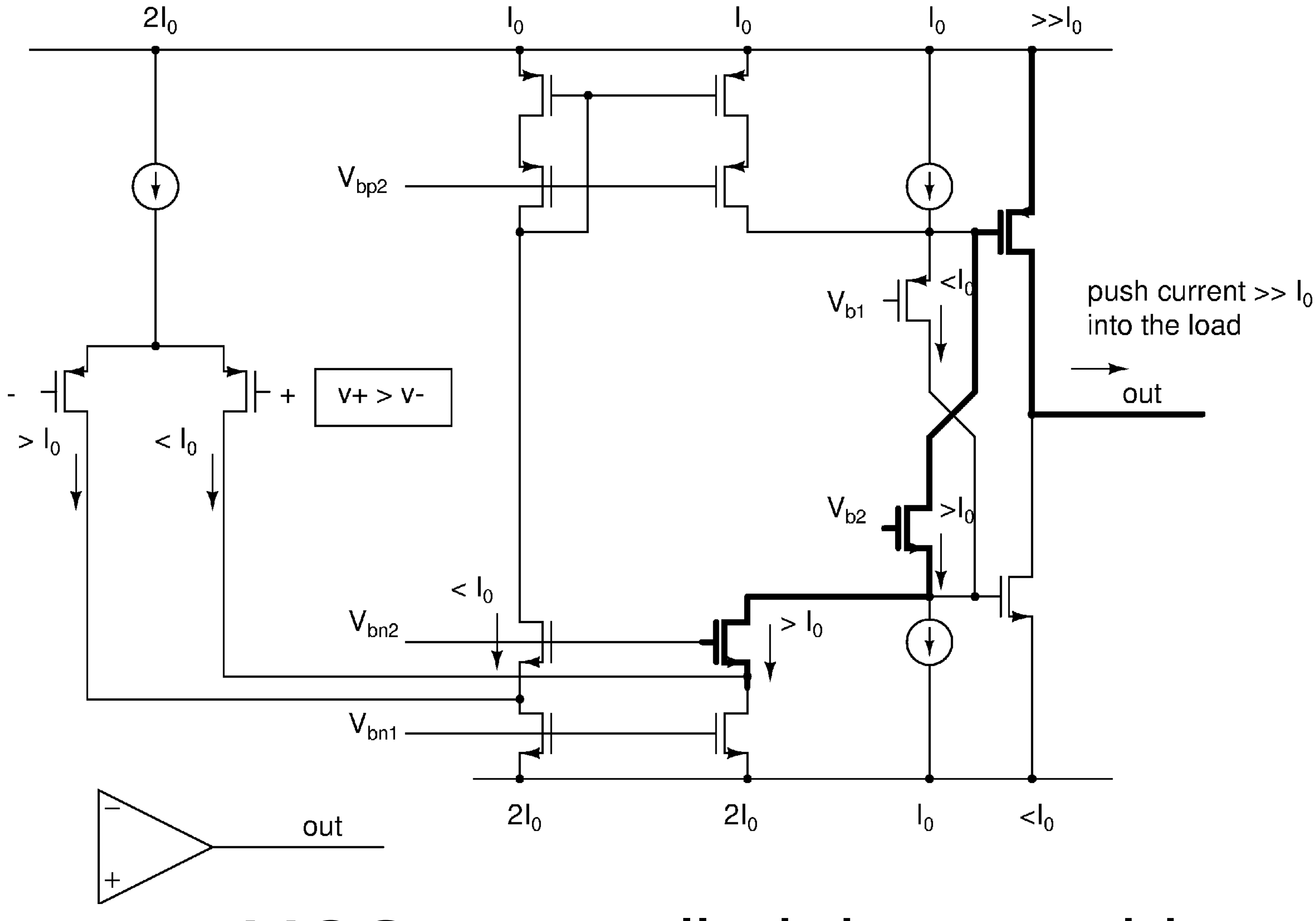
- Need to bias with I0 = 125mA!

Class AB opamp



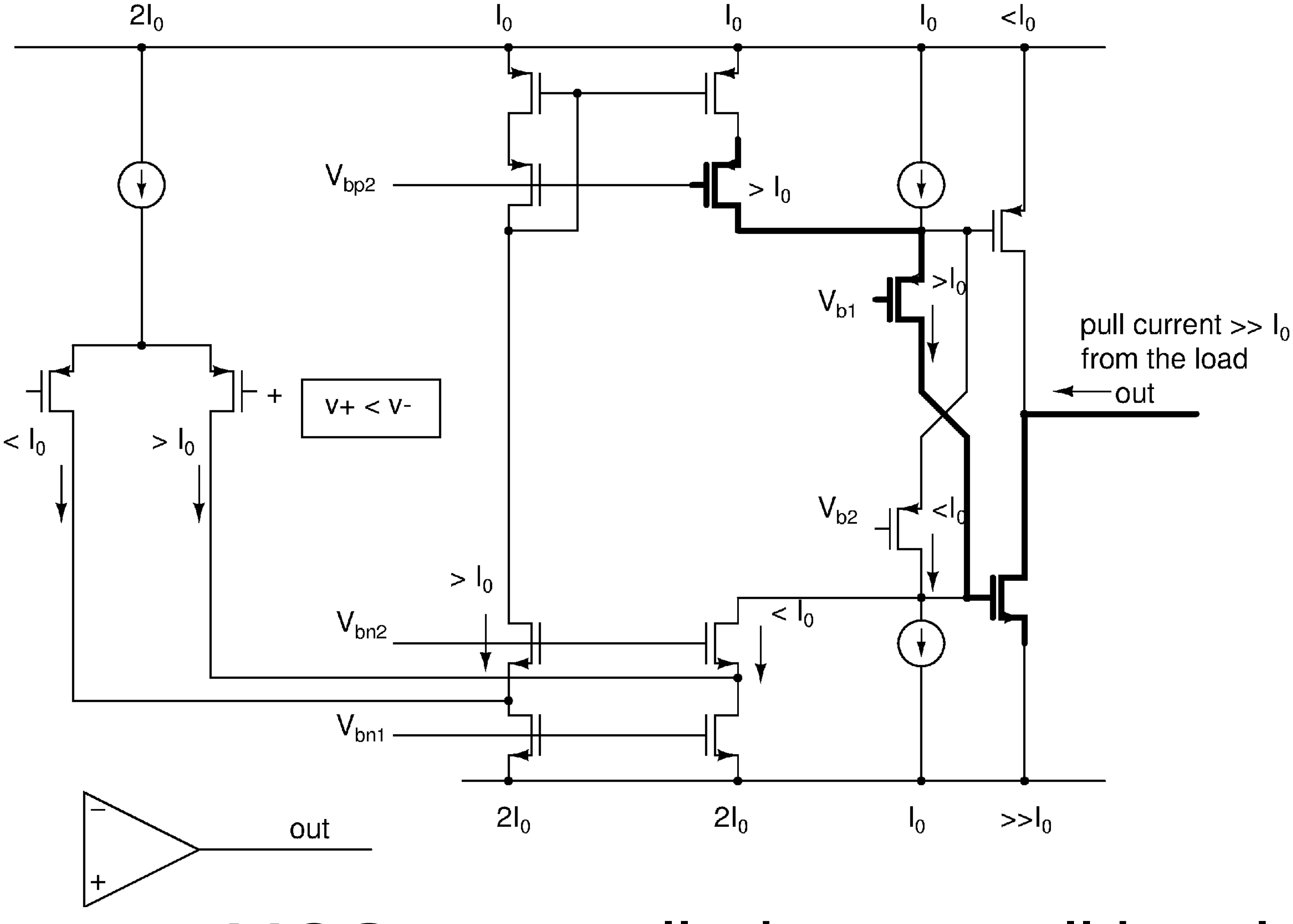
- V_{b1} and V_{b2} adjusted so that output branch current is I_0

Class AB opamp



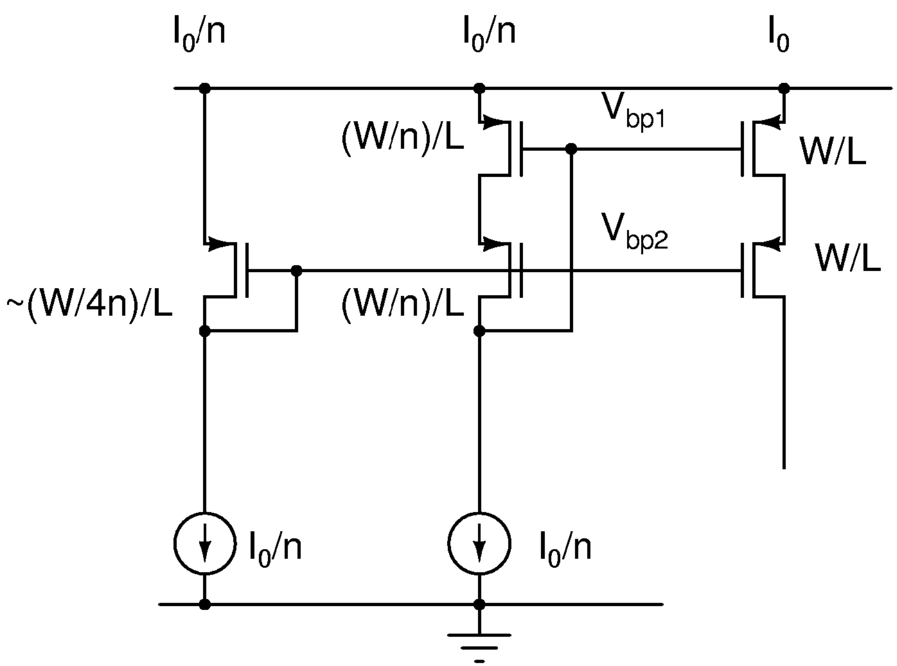
- Output pMOS gate pulled down to drive out a large current (> bias)

Class AB opamp

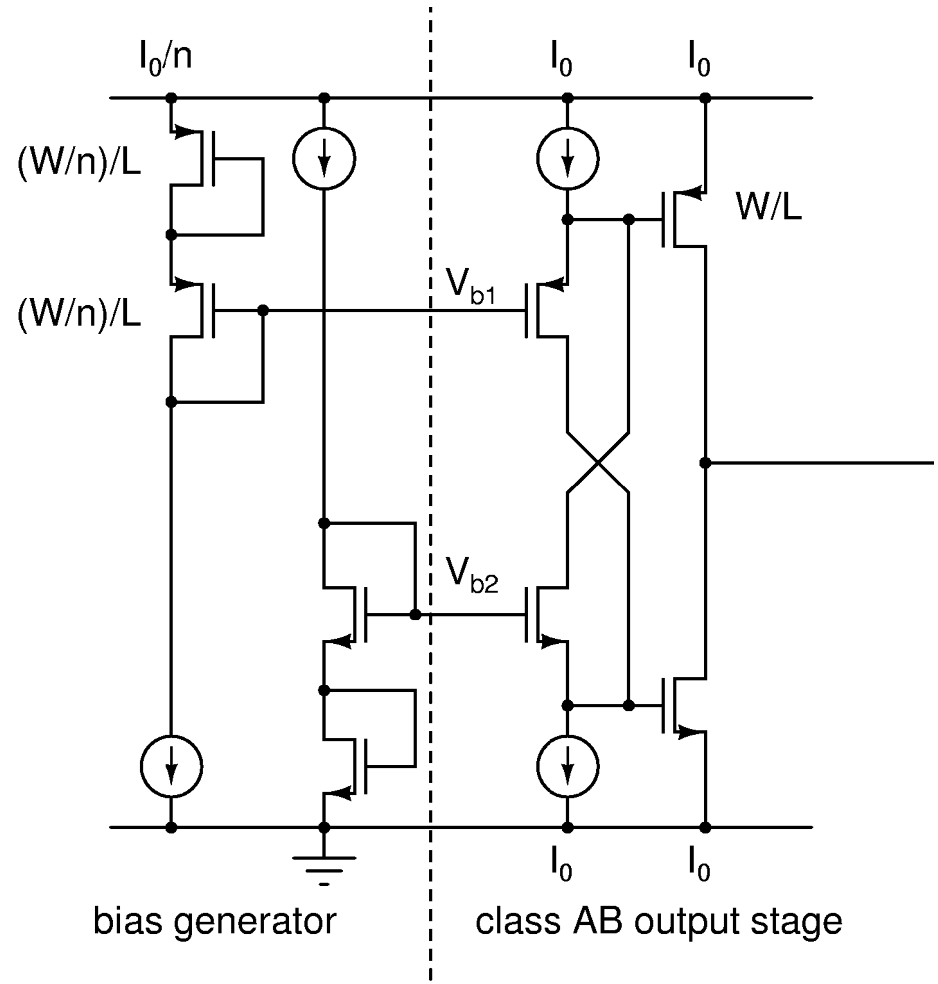


- Output nMOS gate pulled up to pull in a large current (> bias)

Class AB opamp: bias generation

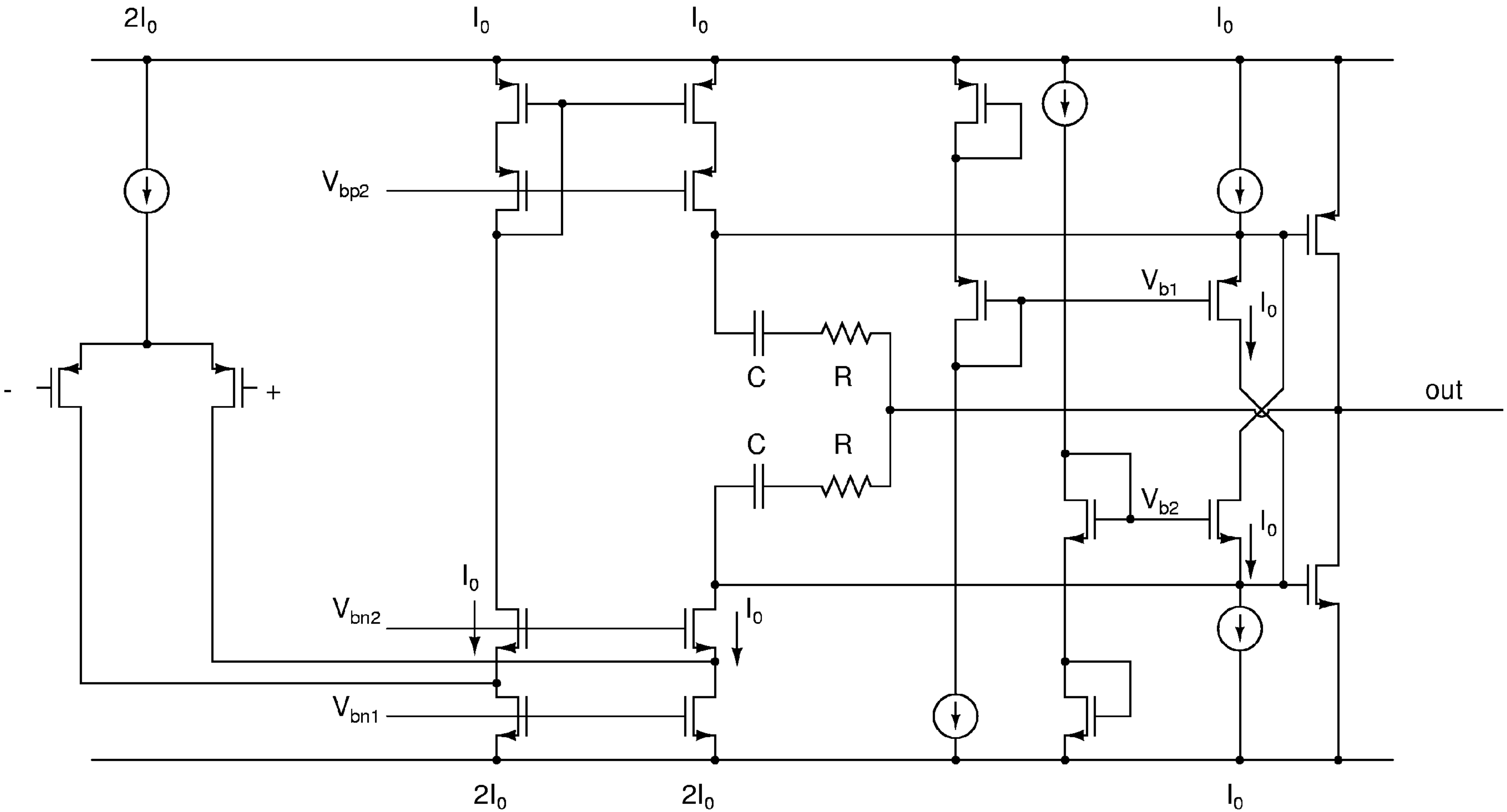


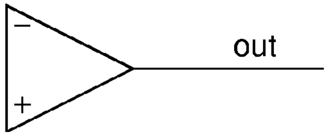
cascode current source bias generator



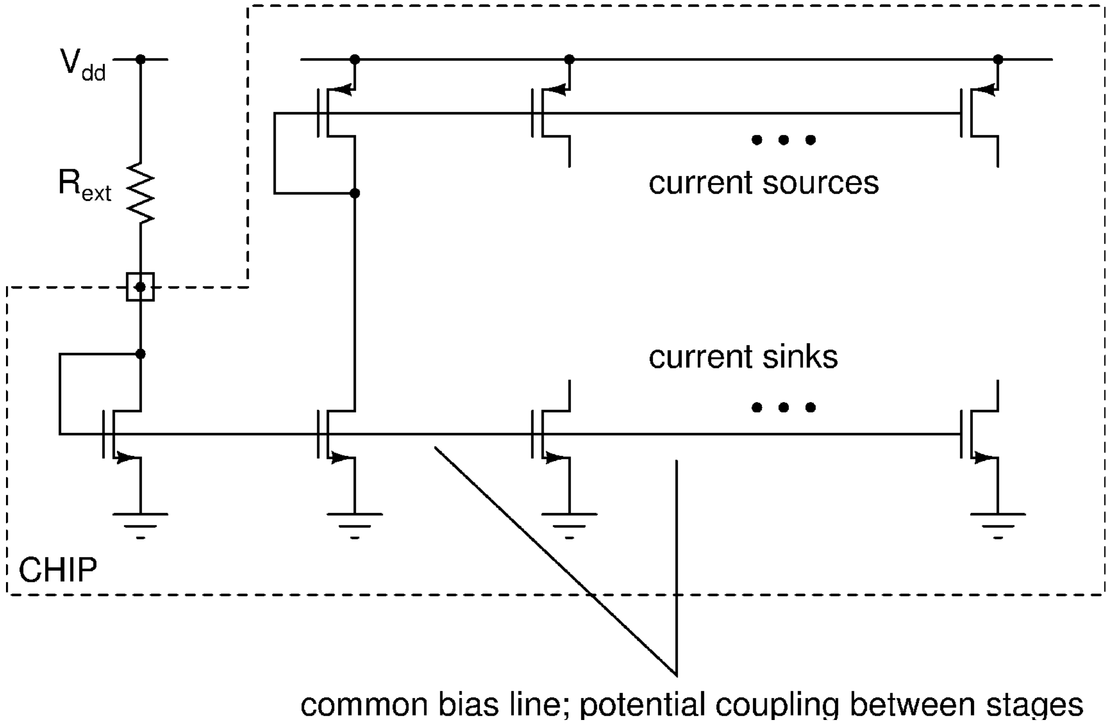
class AB output bias generator

Class AB opamp: full schematic



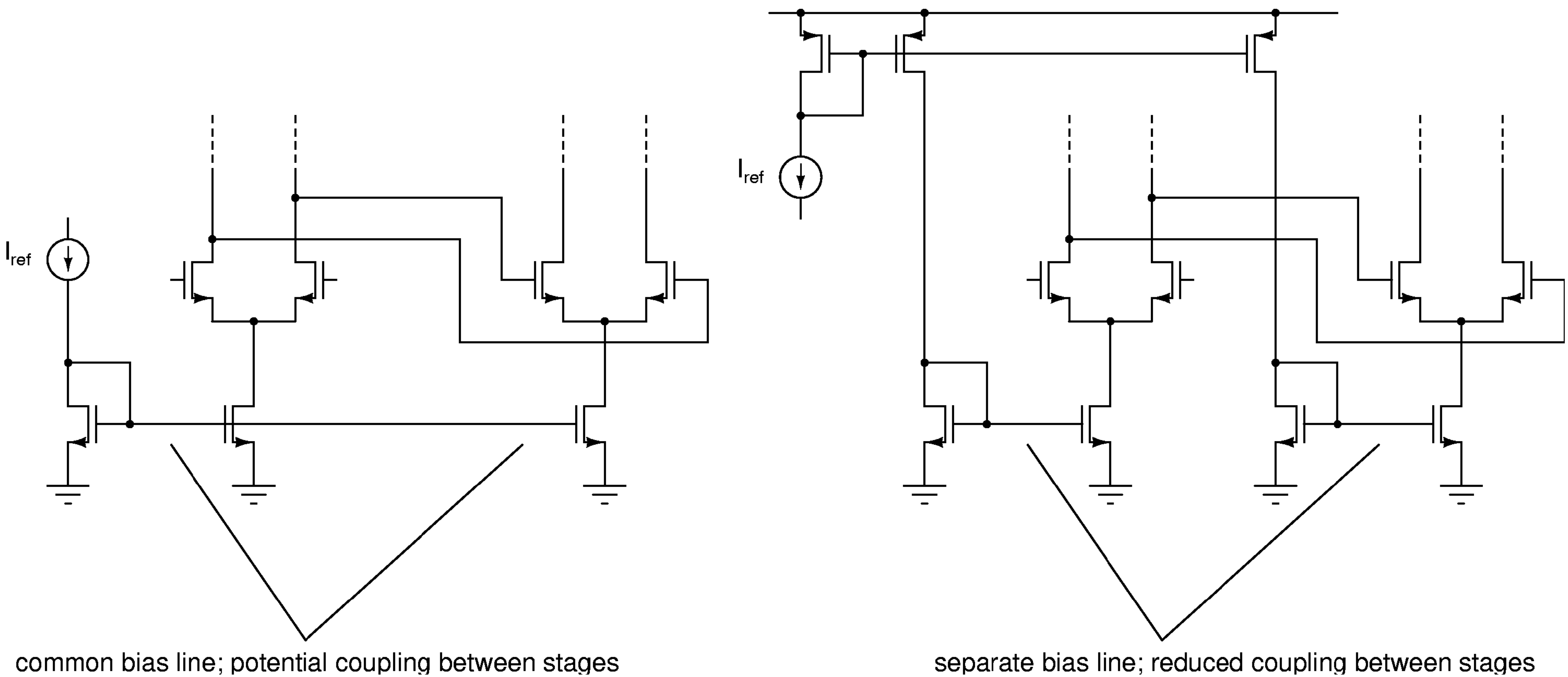


Bias current generation



- One external resistor to fix bias currents
  – Bias line coupling can lead to problems in high gain multistage circuits

Bias current generation

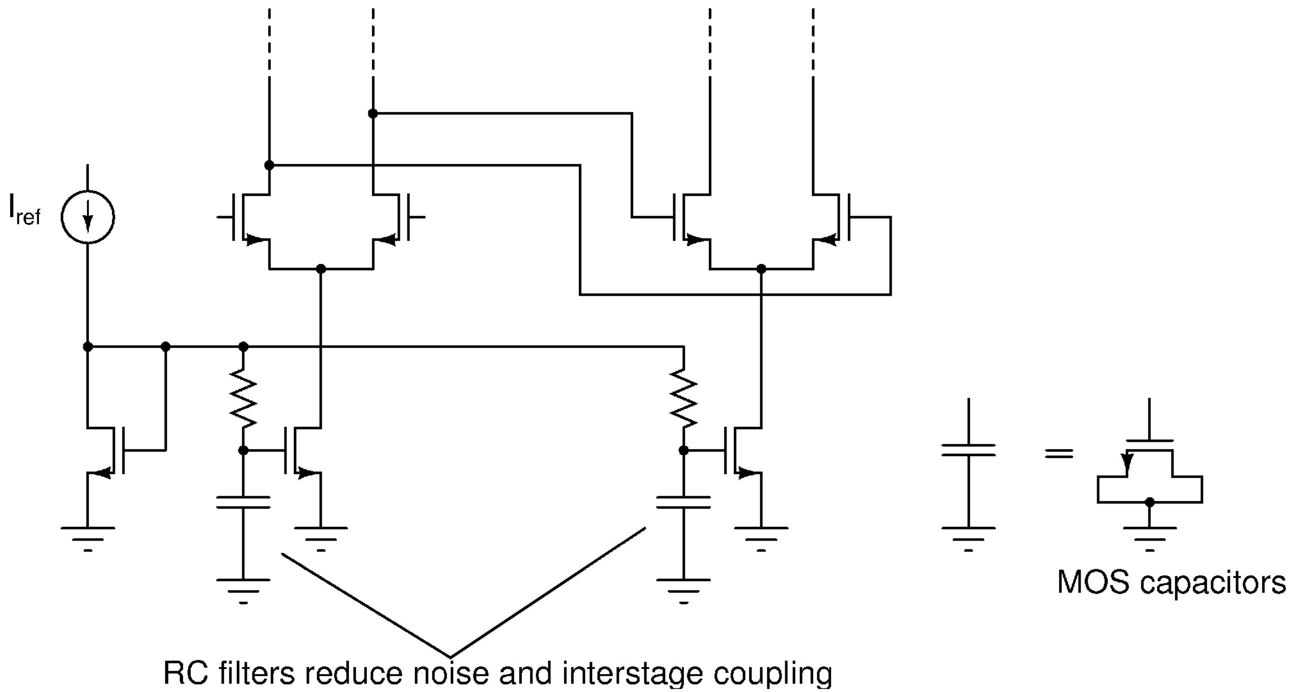


- Separate mirroring branch for each stage

+ Reduced interstage coupling

– Increased current in bias branches

Bias current generation



- RC filter to each biasing MOS transistor

+ Reduced interference and noise

+ No increase in bias currents

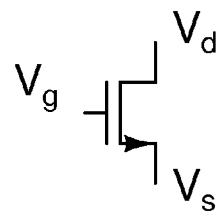
Passive components

resistor

R_{sheet}=800Ω/sq.

(linear)

R = 800(L/W)

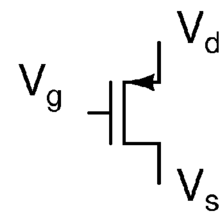


nMOS

V_d,V_s: closer to gnd

(nonlinear)

$R = 1/\mu_n C_{ox}(V_{GS}-V_T)*(L/W)$

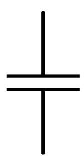


pMOS

V_d,V_s: closer to Vdd

(nonlinear)

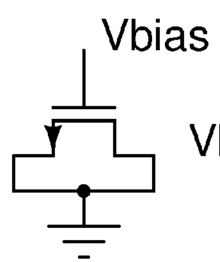
$R = 1/\mu_p C_{ox}(V_{GS}-V_T)*(L/W)$



poly1-poly2 capacitor

(passive, linear)

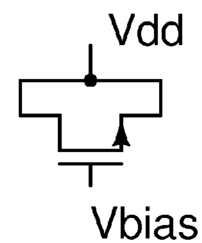
C = 0.8fF*WL



Vbias > VT

capacitors connected
to ground

C = 3fF*WL



Vdd-Vbias > VT

C = 3fF*WL

Passive components: Resistors

- Passive resistor
  - Min. width=; few kOhms
- MOS resistors
  - Need bias
  - Greater range of values
  - Voltage tunability

Passive components: capacitors

- Passive (poly1-poly2)
  - Few pF
  - Bottom plate to ground parasitic
- MOS capacitors
  - Higher capacitor density
  - Need to be biased in strong inversion