LECTURE 320 – DIFFERENTIAL OUTPUT OP AMPS
(READING: AH – 384-393, GHLM – 808-857)

Objective

The objective of this presentation is:

1.) Design and analysis of differential output op amps

2.) Examine the problem of common mode stabilization

Outline

- Advantages and disadvantages of fully differential operation
- Six different differential output op amps
- Techniques of stabilizing the common mode output voltage
- Summary

Why Differential Output Op Amps?

- Cancellation of common mode signals including clock feedthrough
- Increased signal swing

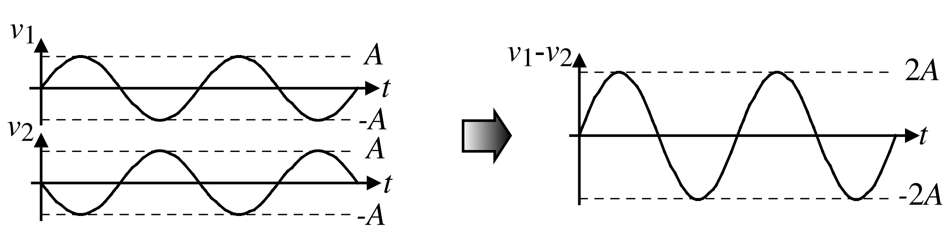

Fig. 7.3-1

- Cancellation of even-order harmonics

Symbol:

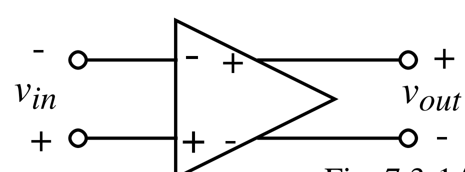

Fig. 7.3-1A

Common Mode Output Voltage Stabilization

If the common mode gain not small, it may cause the common mode output voltage to be poorly defined.

Illustration:

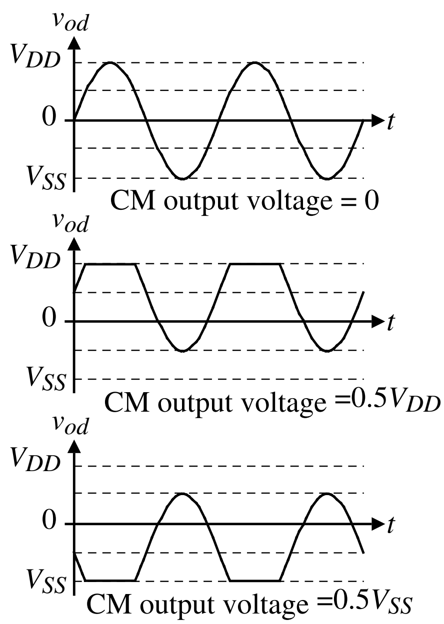

Fig. 7.3-2

Two-Stage, Miller, Differential-In, Differential-Out Op Amp

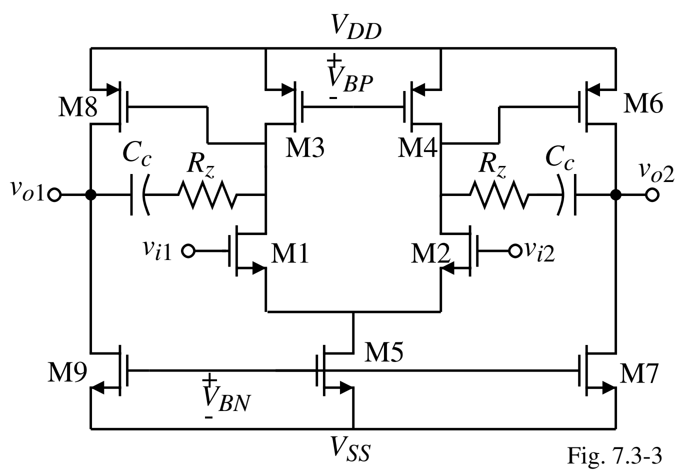

Fig. 7.3-3

Output common mode range ($OCMR$) = V_{DD}+ $|V_{SS}|$ - V_{SDP}(sat) - V_{DSN}(sat)

The maximum peak-to-peak output voltage ≤ 2·$OCMR$

Conversion between differential outputs and single-ended outputs:

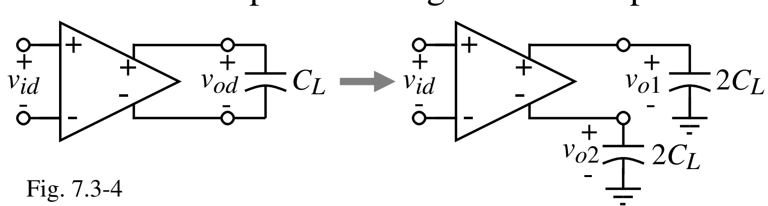

Fig. 7.3-4

Differential-Output, Folded-Cascode, Class-A Op Amp

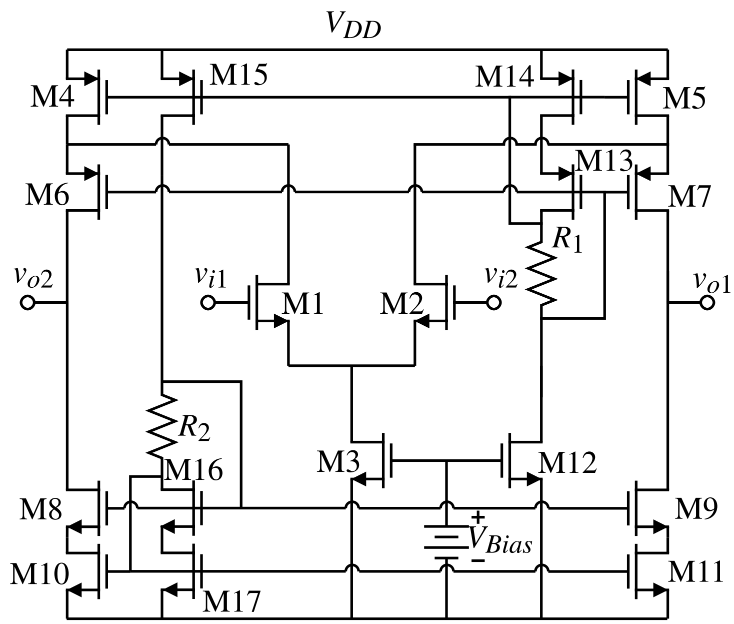

Fig. 7.3-5

$$OCMR = V_{DD} + |V_{SS}| - 2V_{SDP}(\text{sat}) - 2V_{DSN}(\text{sat})$$

Two-Stage, Miller, Differential-In, Differential-Out Op Amp with Push-Pull Output

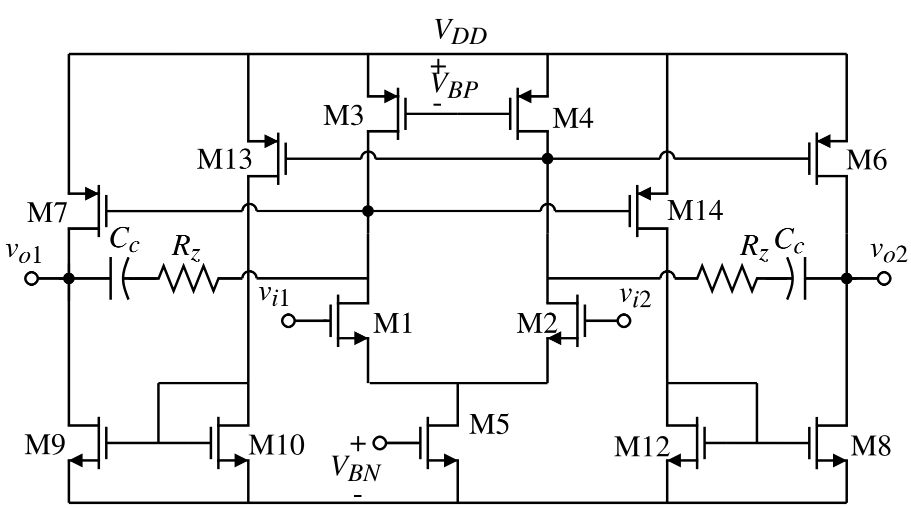

Fig. 7.3-6

Comments:

- Able to actively source and sink output current
- Output quiescent current poorly defined

Two-Stage, Differential Output, Folded-Cascode Op Amp

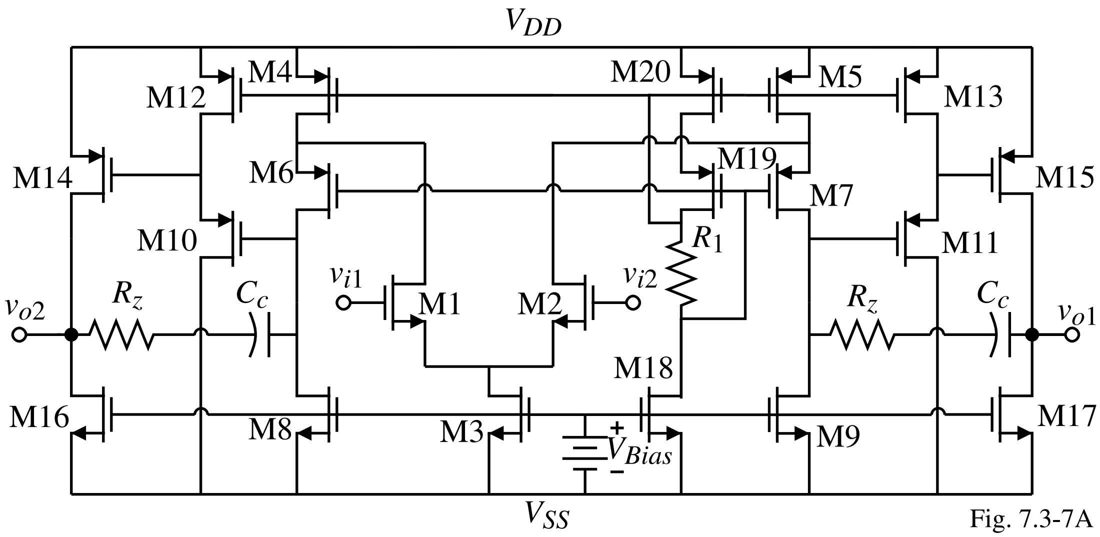

Fig. 7.3-7A

Note that the followers M11-M13 and M10-M12 are necessary for level translation to the output stage.

Unfolded Cascode Op Amp with Differential-Outputs

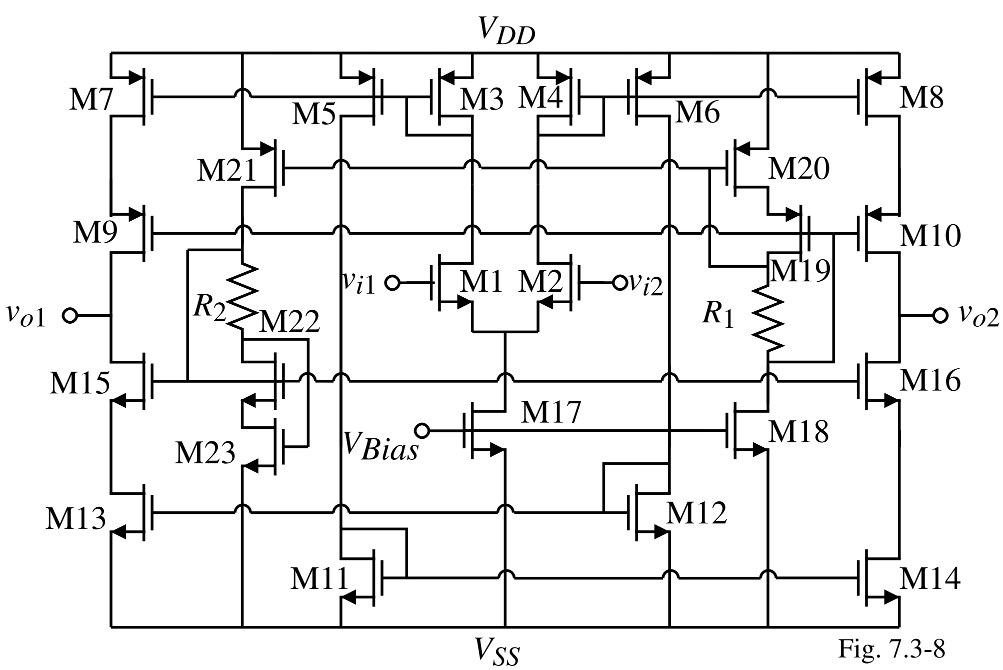

Fig. 7.3-8

Cross-Coupled Differential Amplifier Stage

One of the problems with some of the previous stages, is that the quiescent output current was not well defined.

The following input stage solves this problem.

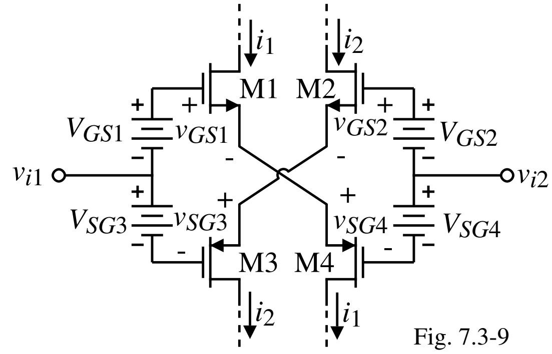

Fig. 7.3-9

Operation:

Voltage loop $v_{i1} - v_{i2} = -V_{GS1} + v_{GS1} + v_{SG4} - V_{SG4} = V_{SG3} - v_{SG3} - v_{GS2} + V_{GS2}$

Using the notation for ac, dc, and total variables gives,

$$v_{i2} - v_{i1} = v_{id} = (v_{sg1} + v_{gs4}) = -(v_{sg3} + v_{gs2})$$

If M1 = M2 = M3 = M4, then half of the differential input is applied across each transistor with the correct polarity.

$$\therefore \quad i_1 = \frac{g_{m1}v_{id}}{2} = \frac{g_{m4}v_{id}}{2} \qquad \text{and} \qquad i_2 = -\frac{g_{m2}v_{id}}{2} = -\frac{g_{m3}v_{id}}{2}$$

Class AB, Differential Output Op Amp using a Cross-Coupled Differential Input Stage

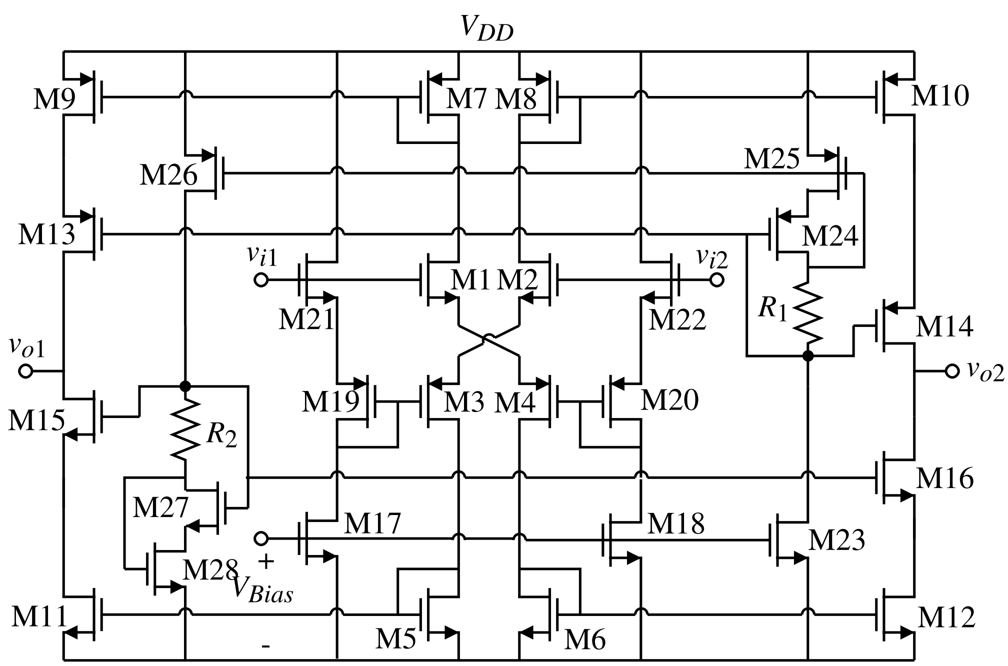

Fig. 7.3-10

Quiescent output currents are defined by the current in the input cross-coupled differential amplifier.

Common-Mode Output Voltage Stabilization

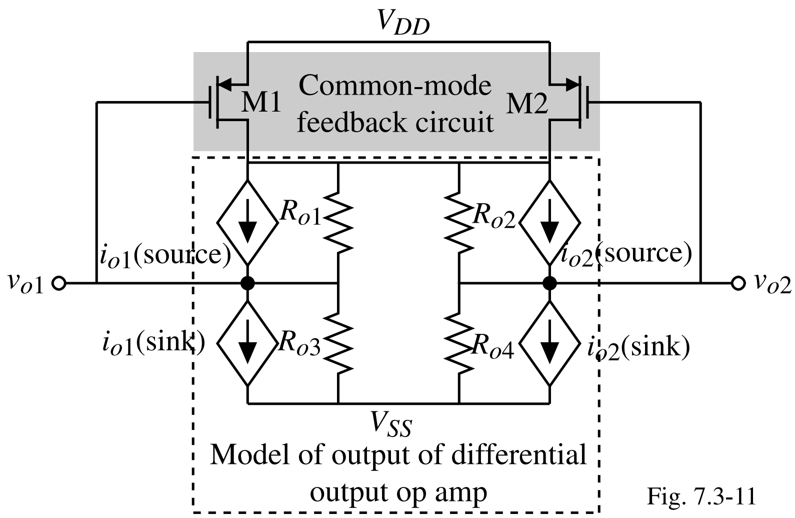

Fig. 7.3-11

Operation:

M1 and M2 sense the common-mode output voltage.

If this voltage rises, the currents in M1 and M2 decrease.

This decreased current flowing through R_{o3} and R_{o4} cause the common-mode output voltage to decrease with respect to V_{SS}.

Two-Stage, Miller, Differential-In, Differential-Out Op Amp with Common-Mode Stabilization

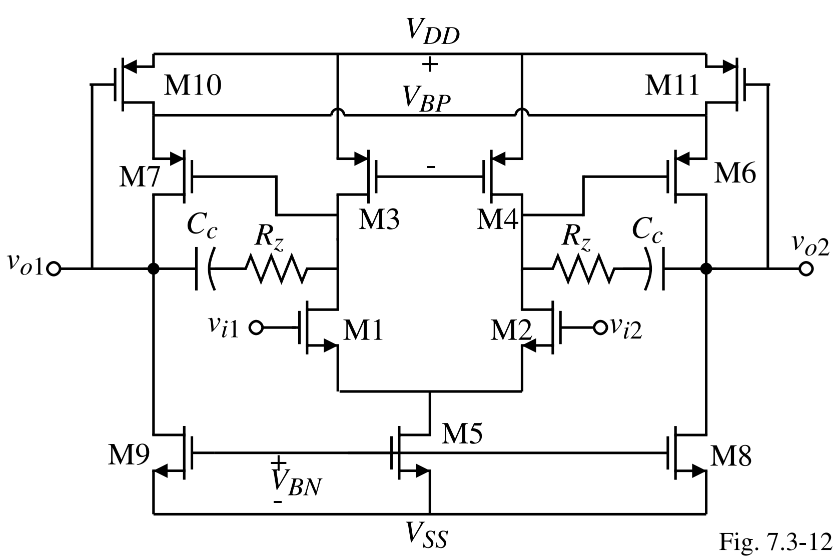

Fig. 7.3-12

Comments:

- Simple
- Unreferenced

A Referenced Common-Mode Output Voltage Stabilization Scheme

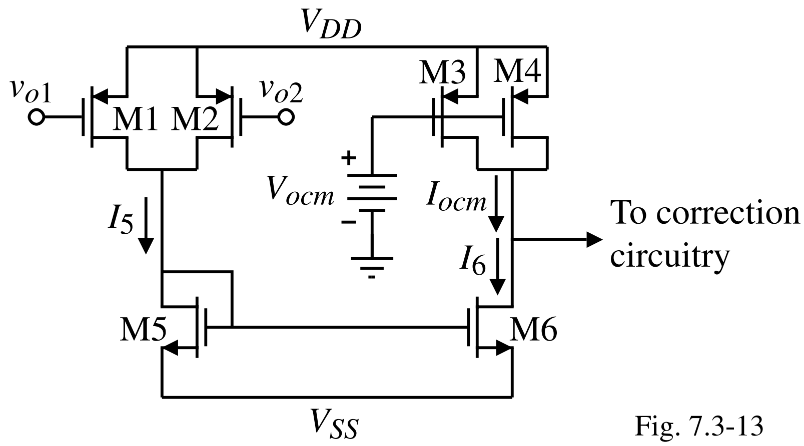

Fig. 7.3-13

Operation:

1.) The desired common-mode output voltage, V_{ocm}, creates I_{ocm}.

2.) The actual common-mode output voltage creates current I_5 which is mirrored to I_6 .

3.) If M1 through M4 are matched and the current mirror is ideal, then when $I_{ocm} = I_6$ the actual common-mode output voltage should be equal to the desired common-mode output voltage.

4.) The above steps assume that a correction circuitry exists that changes the common-mode output voltage in the correct manner.

Common Mode Feedback Circuits

Implementation of common mode feedback circuit:

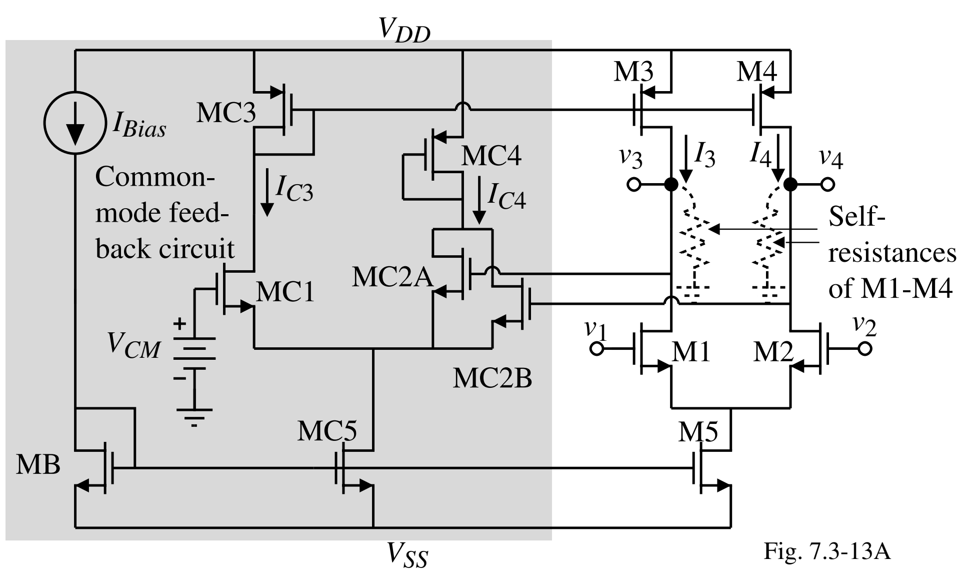

Fig. 7.3-13A

This scheme can be applied to any differential output amplifier.

Caution:

Be sure to check the stability of common-mode feedback loops, particularly those that are connected to op amps that have a cascode output. The gain of the common-mode feedback loop can easily reach that of a two-stage amplifier.

Common Mode Feedback Circuits – Continued

The previous circuit suffers in performance when the differential output voltage becomes too large and one of the MC2A-MC2B transistors shuts off.

The following circuit alleviates this disadvantage:

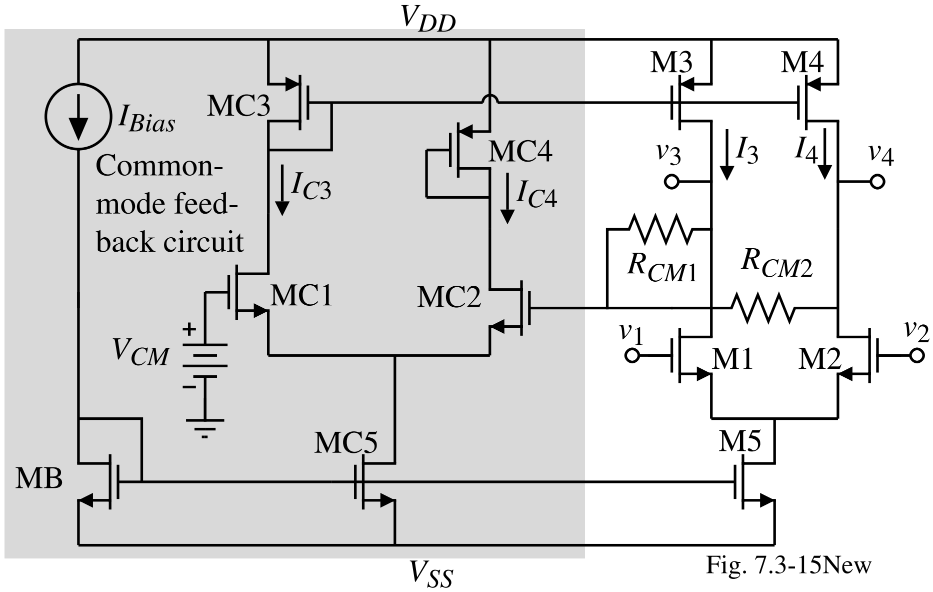

Fig. 7.3-15New

External Common-Mode Output Voltage Stabilization Scheme for Discrete-Time Applications

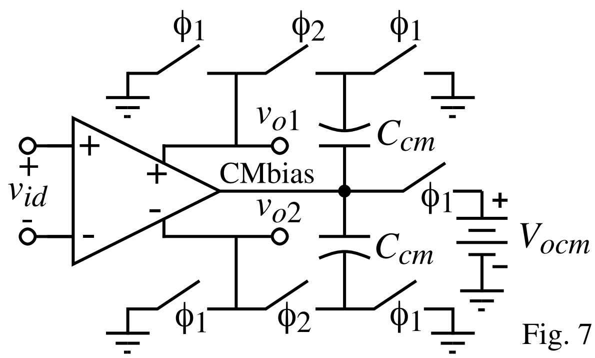

Fig. 7.3-14

Operation:

1.) During the ϕ_1 phase, both C_{cm} are charged to the desired value of V_{ocm} and CMbias = V_{ocm}.

2.) During the ϕ_2 phase, the C_{cm} capacitors are connected between the differential outputs and the CMbias node. The average value applied to the CMbias node will be V_{ocm}.

SUMMARY

- Advantages of differential output op amps:
  - 6 dB increase in signal amplitude
  - Cancellation of even harmonics
  - Cancellation of common mode signals including clock feedthrough
- Disadvantages of differential output op amps:
  - Need for common mode output voltage stabilization
  - Compensation of common mode feedback loop
  - Difficult to interface with single-ended circuits
- Most differential output op amps are truly balanced
- For push-pull outputs, the quiescent current should be well defined
- Common mode feedback schemes include,
  - Unreferenced
  - Referenced