# Lecture 2

# Amplification and Single-rail Op-amp

Prof Peter YK Cheung Imperial College London

URL: www.ee.ic.ac.uk/pcheung/teaching/EE2\_CAS/ E-mail: p.cheung@imperial.ac.uk

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# What you will learn in Lectures 2 and 3?



- Small input signal
- High gain amplification
- Working with single power supply rail
- Low impedance load (next Lecture)

# **Non-inverting Amplifier & Voltage Follower**



- Year 1 circuits module, part 1, lecture 9, slides 11 and 12
- Non-inverting amplifier using op-amp, Gain x4
- ♦ Special case: R2 = 0,  $R1 = \infty$ , Gain = 1
  - Voltage follower or unity gain buffer

### Real-life Op Amp

# МICROCHIP MCP6001/1R/1U/2/4

1 MHz, Low-Power Op Amp

#### Description

The Microchip Technology Inc. MCP6001/2/4 family of operational amplifiers (op amps) is specifically designed for general-purpose applications. This family has a 1 MHz Gain Bandwidth Product (GBWP) and 90° phase margin (typical). It also maintains 45° phase margin (typical) with a 500 pF capacitive load. This family operates from a single supply voltage as low as 1.8V, while drawing 100  $\mu$ A (typical) quiescent current. Additionally, the MCP6001/2/4 supports rail-to-rail input and output swing, with a common mode input voltage range of V<sub>DD</sub> + 300 mV to V<sub>SS</sub> – 300 mV. This family of op amps is designed with Microchip's advanced CMOS process.

- Limited to 1MHz signal frequency (GBP) (not infinite gain at all frequencies)
- Stable under high capacitance load (linked to phase margin)
- Single power supply operation
- Rail-to-rail input/output swing
- Low supply current when idle
- Near rail-to-rail common mode input voltage

### MCP6001/2/4 as a near ideal op-amp





#### ✓ $Z_{in}$ of MCP6001 is very large

Common Mode Input Impedance	Z <sub>CM</sub>	10 <sup>13</sup>   6	Ω  pF
Differential Input Impedance	ZDIFF	10 <sup>13</sup>   3	Ω  pF

#### Input current is negligible

Input Bias Current:	IB	±1.0	pA	
Industrial Temperature	I <sub>B</sub>	19	pA	T <sub>A</sub> = +85°C
Extended Temperature	Ι <sub>Β</sub>	1100	pА	T <sub>A</sub> = +125°C

#### Gain is near infinite (true at low frequency)

DC Open-Loop Gain (Large Signal)	A <sub>OL</sub>	112 >1 x10 <sup>5</sup>	dB
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#### ✓ Output impedance is low (specified as I<sub>SC</sub>)

Output Short Circuit Current	I <sub>SC</sub>	±6	mA	V <sub>DD</sub> = 1.8V
		±23	mA	V <sub>DD</sub> = 5.5V

# **Problem with single supply rail**

#### Output swing limited to rail voltages

Maximum Output Voltage Swing	V <sub>OL</sub> , V <sub>OH</sub>	V <sub>SS</sub> + 25 V <sub>DD</sub> - 25	mV	
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Input cannot be a sinewave with 0V DC offset



Need to add DC offset to input



# X4 amplifier fail

Amplifier Gain = +4, output swing = 2V to 6V – not possible



# Attempt 1 – AC coupling signal

- ✤ AC couple input signal block DC offset to amplifier
- Does not work for single supply op-amp



# Attempt 2 – Add bias to V+ input

- Bias input V+ to half of power supply rail voltage
  - Maximize input voltage swing
  - Still not working bias voltage is now the unwanted DC offset!



# **Final working solution**

- Final solution: Add C3 such that gain of op-amp = 1 at 0 Hz (DC)
- ♦ Gain of op-amp at valid signal frequency is  $G = 1 + \frac{R^2}{R^1}$



### **Better Bias Circuit**

- ✤ Generate bias voltage using a voltage reference circuit, e.g. AP431i
- Bias voltage NOT susceptible to noise on 5V supply



# AP431i voltage reference in detail



	Min	Typical	Max	
V <sub>REF</sub> 1% Reference Voltage V <sub>KA</sub> = V <sub>REF</sub> , I <sub>KA</sub>	= 1mA 2.475	2.500	2.525	v

Typical Max

Z <sub>KA</sub> Dynamic Impedance $V_{KA} = V_{REF}$ , I <sub>KA</sub> = 1 to 100mA, f ≤ 1.0kHz 0.1 0.3 Ω				•		
	Z <sub>KA</sub>	Dynamic Impedance	$V_{KA} = V_{REF}$ , IKA = 1 to 100mA, f ≤ 1.0kHz	0.1	0.3	Ω

# **Open-loop Gain vs Frequency for MCP6001**



### Amplify 10kHz signal with Gain of 200



### **Solution - Two stage amplification**



# **Problem with driving low impedance load**



- Needs AC coupling due to output bias voltage of 2.5V
- Maximum current is over 600mA!
- MCP6001 cannot drive  $8\Omega$  speaker