Electronic System Design 3
Lecture 5.2: Figure of Merit Worked Examples

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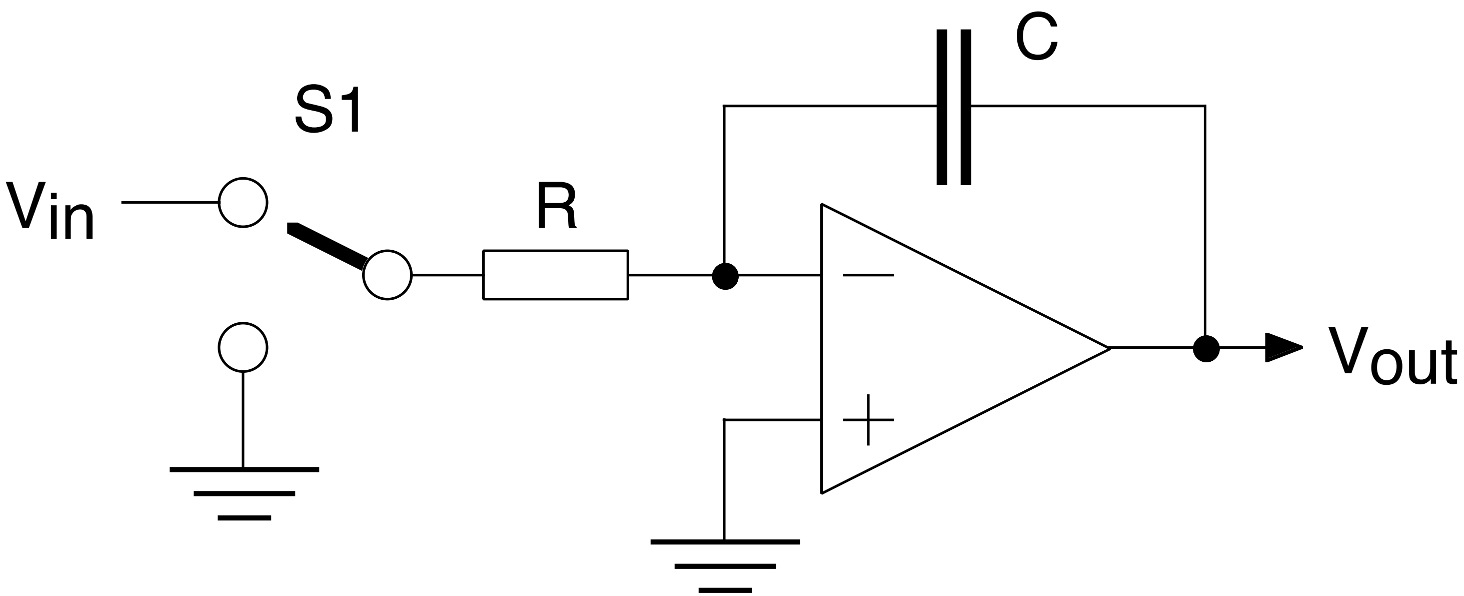
Integrate-and-Hold circuit:- Revisited



If S1 connects to V_{in} circuit is an integrator $V_{out} = -\int \frac{V_{in}}{RC} dt$

If S1 connects to 0V circuit is a memory V_{out} = constant

How can we use analysis to improve performance?

Figure of merit (1)

To improve performance we need a better opamp…

Performance depends significantly on I_B and V_{OS}.

$$\left|\frac{dV_{out}}{dt}\right| = \frac{1}{\tau}\boxed{(I_B R + V_{OS})}$$

Make this bit good!

Given a choice of two opamps best opamp has smaller $(I_B R + V_{OS})$

You don't care if the problem is a big I_B or a big V_{OS} or a combination

$$I_B R + V_{OS} = F \text{ (Figure of merit)} = I_B \cdot 2M + V_{OS}$$

TL071CP: F = 200pA · 2MΩ + 10mV = 10.4mV

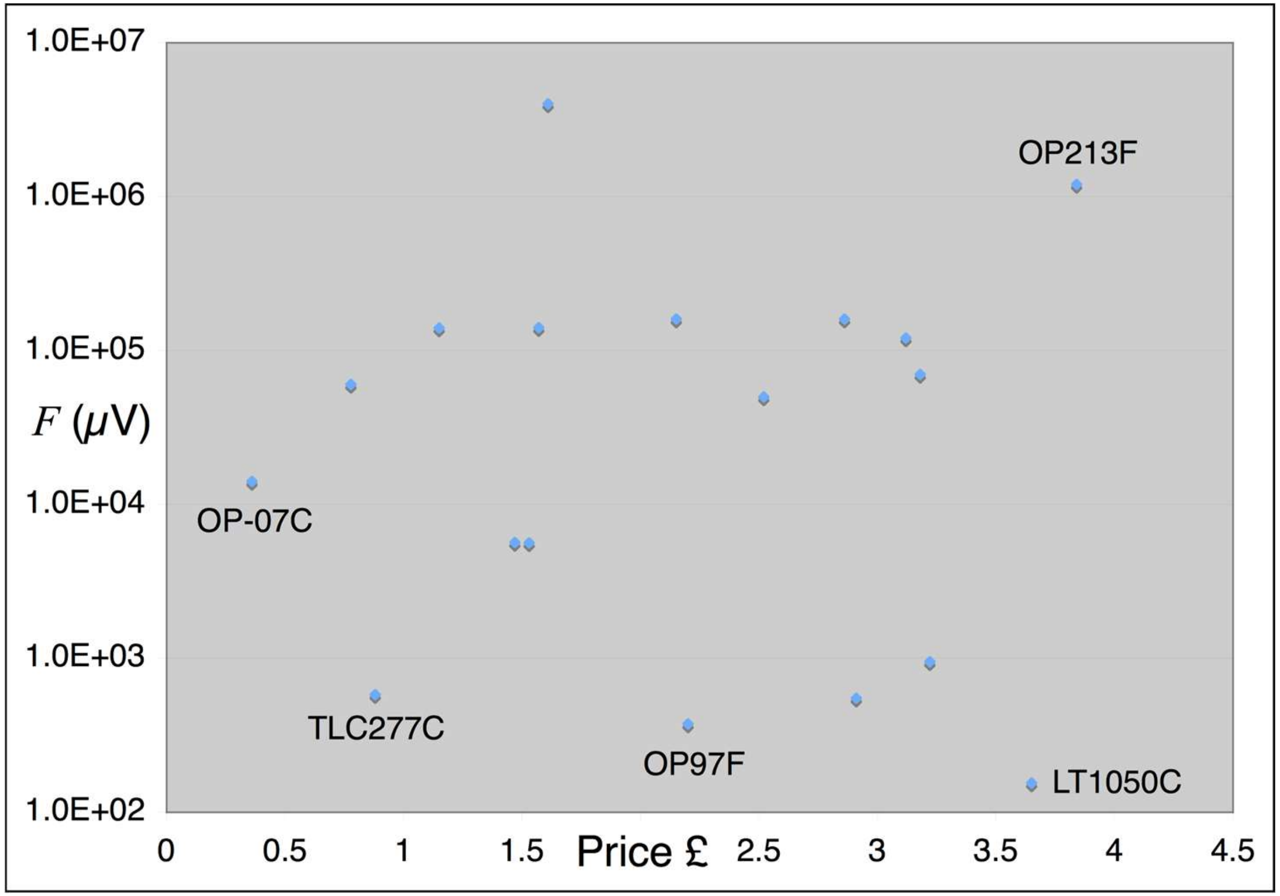
Note that F is a function of the external circuit: Different circuits have different Figures of Merit. There is no "Best" opamp

Figure of Merit (2)

Having downloaded data on many opamps use a spreadsheet to calculate F. Using the same data set as before:

Opamp	Price	Vos μV (max)	Ib pA(max)	F(μV)
OP07C	0.36	150	7000	1.42E+04
LT1013CP	0.778	300	30000	6.03E+04
TLC277CP	0.88	500	40	5.80E+02
TLE2022IP	1.15	500	70000	1.41E+05
OP177GP	1.47	60	2800	5.66E+03
OPA277PA	1.53	50	2800	5.65E+03
TLE2021CP	1.57	600	70000	1.41E+05
TLE2141CP	1.61	1400	2000000	4.00E+06
OP37GPZ	2.15	100	80000	1.60E+05
OP97FPZ	2.2	75	150	3.75E+02
LT1006CN8	2.52	80	25000	5.01E+04
OP27GPZ	2.86	100	80000	1.60E+05
LT1097CN8	2.91	50	250	5.50E+02
MAX492CPA	3.12	500	60000	1.21E+05
MAX437CPA	3.18	15	35000	7.00E+04
LT1057CN8	3.22	800	75	9.50E+02
LT1050CN8	3.65	5	75	1.55E+02
OP213FPZ	3.84	150	600000	1.20E+06

Figure of Merit (3)

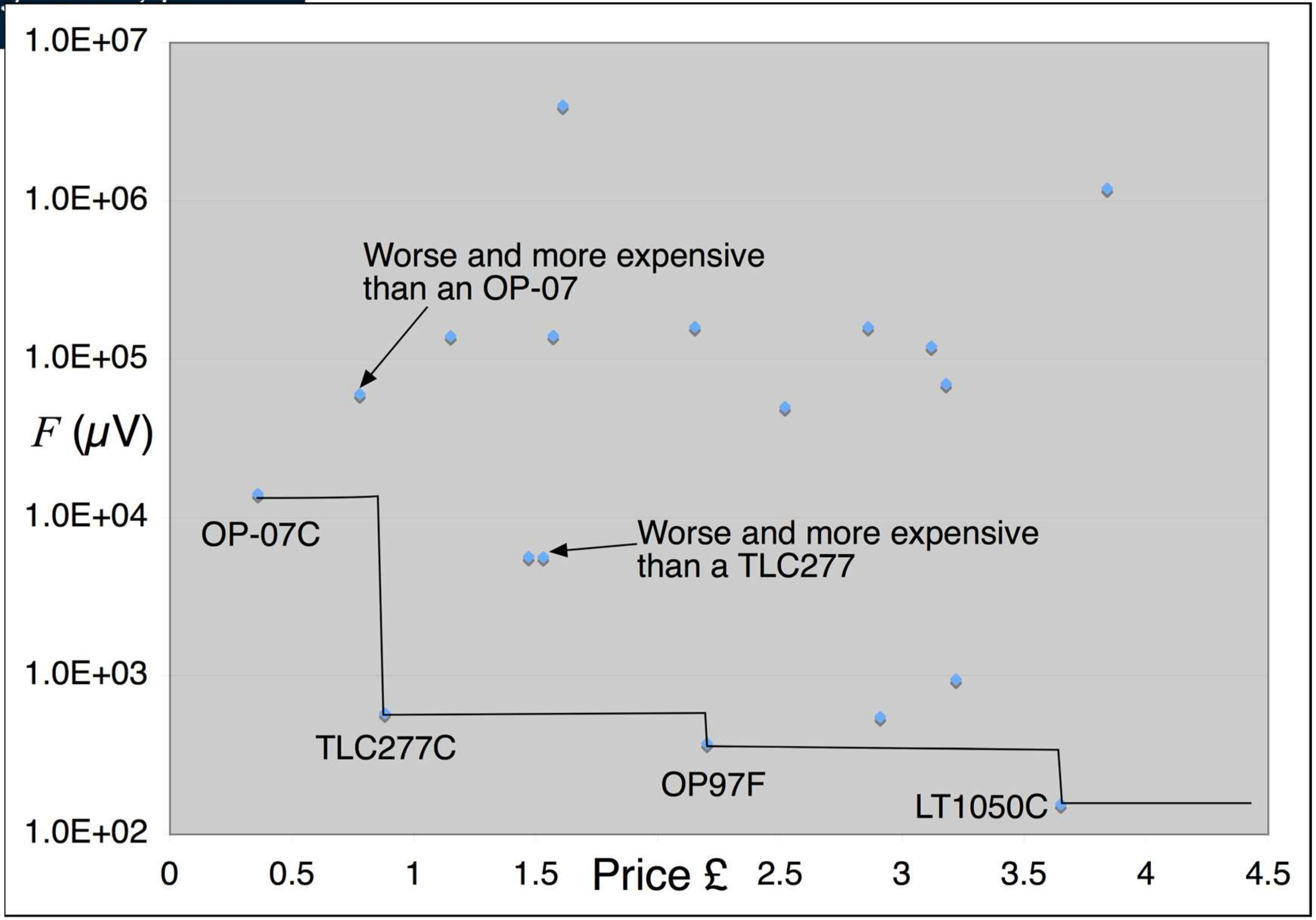


TLC277 is 4x worse Than the best and is 88p (dual). Best is LT1050C, 4x more expensive.

OP213 is even more expensive and second worst.

Choose cheapest which meets spec.

Figure of Merit (4)



Only good choices are OP07, then TLC277, then OP97, then LT1050. **All others are more expensive than a better opamp.**

Figure of Merit(5)

Things to take away

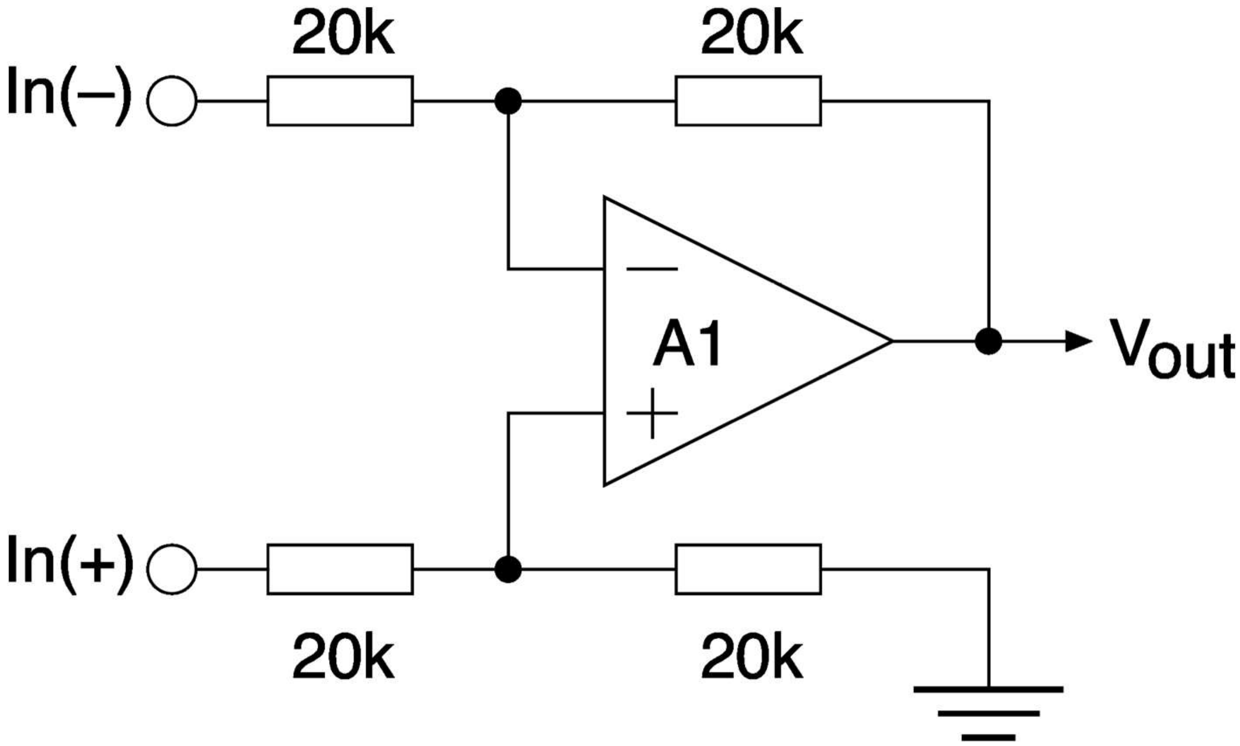
- “Best” opamp depends on what it is used for
- Second worst design **is 8 000x** worse than the best for the same price
- Good cheap design is only 4x worse than most expensive

Money does not buy success!

- Expensive design may have other problems (chopper)
- Hunting for components is a pain (=> acquire favourites)

Proper system design is always worth it.

Figure of Merit Example 2



Differential amplifier

Note: Impedances are already matched: Ignore I_B, just I_{OS}

Figure of Merit Example 2 (2)

Calculate error RTO: (Set inputs to zero: Superposition!)

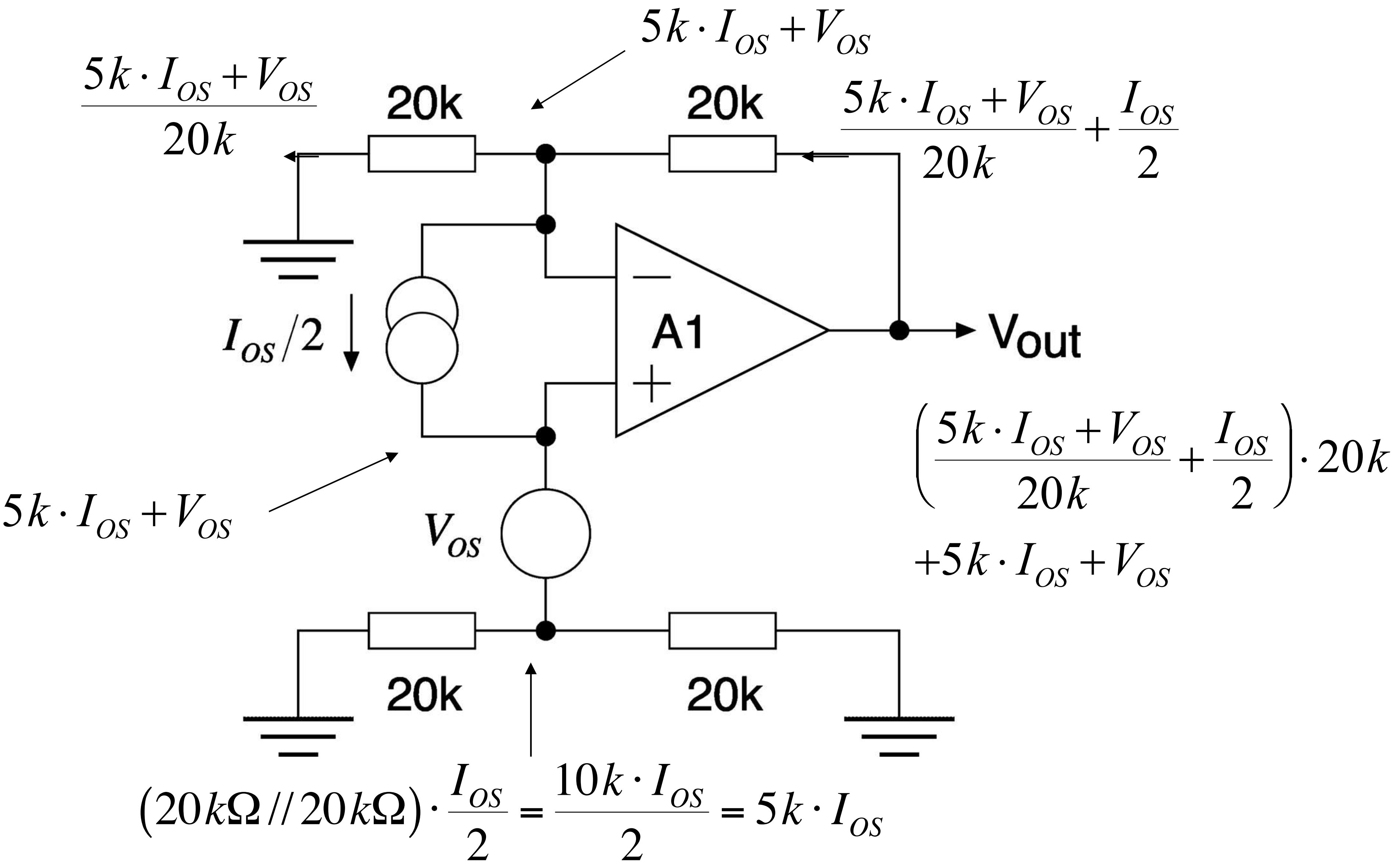


Figure of Merit Example 2 (3)

$$\mathrm{Error(RTO)} = \left(\frac{5k \cdot I_{OS} + V_{OS}}{20k} + \frac{I_{OS}}{2} \right) \cdot 20k + 5k \cdot I_{OS} + V_{OS}$$

$$= 2V_{OS} + 20k \cdot I_{OS}$$

Let this be the figure of merit:

$$F = 2V_{OS} + 20k \cdot I_{OS}$$

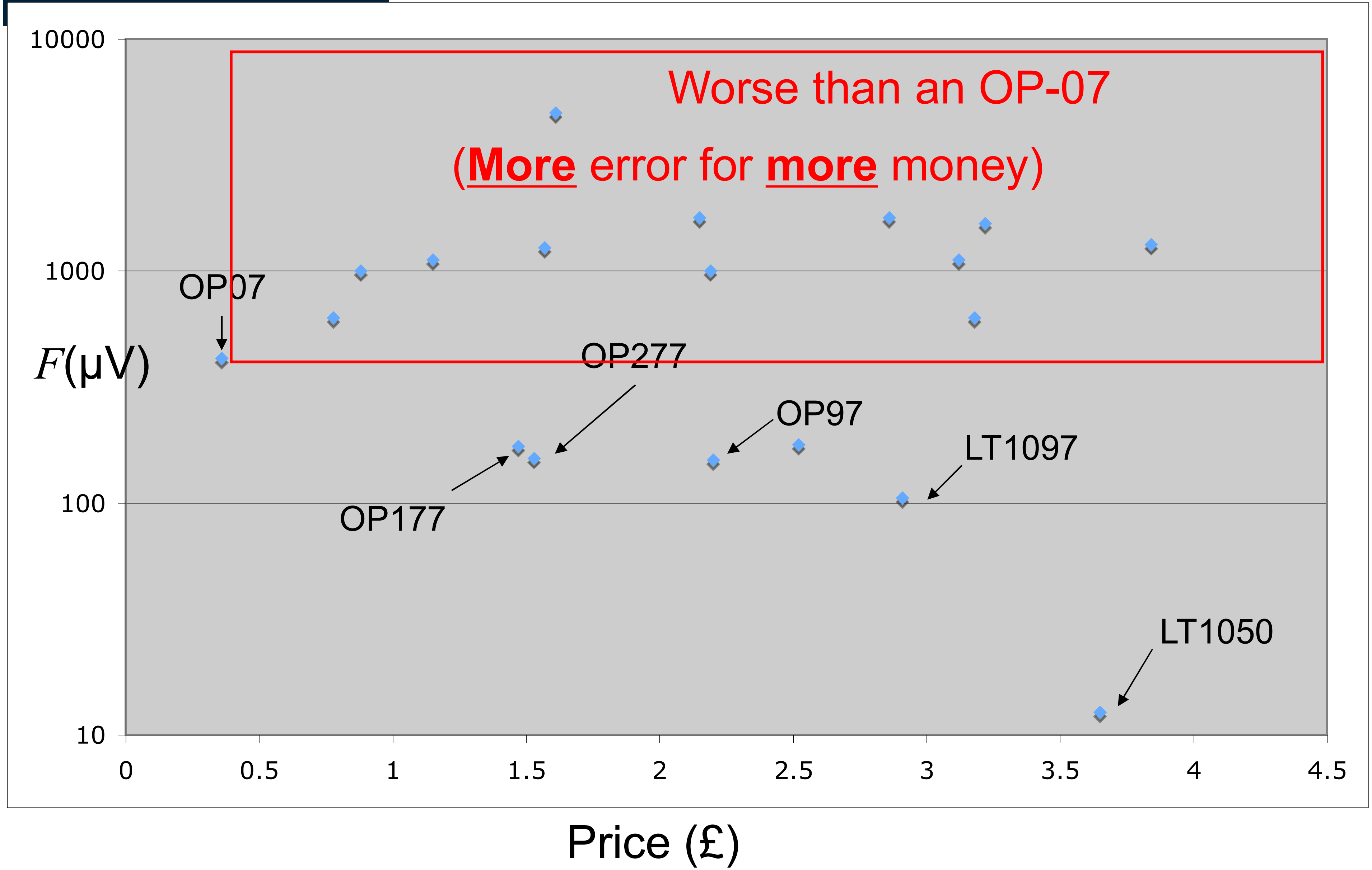
Figure of Merit Example 2 (4)

Using the same set of opamps:

Opamp	Price	Vos µV (max)	Ios pA(max)	F (µV)
OP07C	0.36	150	6000	420
LT1013CP	0.778	300	1500	630
TLC277CP	0.88	500	7	1000.14
TLE2022IP	1.15	500	6000	1120
OP177GP	1.47	60	2800	176
OPA277PA	1.53	50	2800	156
TLE2021CP	1.57	600	3000	1260
TLE2141CP	1.61	1400	100000	4800
OP37GPZ	2.15	100	75000	1700
TLC2201CP	2.19	500	<1>	1000.02
OP97FPZ	2.2	75	150	153
LT1006CN8	2.52	80	900	178
OP27GPZ	2.86	100	75000	1700
LT1097CN8	2.91	50	250	105
MAX492CPA	3.12	500	6000	1120
MAX437CPA	3.18	15	30000	630
LT1057CN8	3.22	800	50	1601
LT1050CN8	3.65	5	125	12.5
OP213FPZ	3.84	150	50000	1300

Figure of Merit Example 2 (5)

Graphing:



Final check

Final choice: Read the datasheet for other specifications which may be important, especially changes with time, temperature, power supply etc. Also any "*Unusual*" normal specifications (LMC660)

LMC660
CMOS Quad Operational Amplifier

General Description

The LMC660 CMOS Quad operational amplifier is ideal for operation from a single supply. It operates from +5V to +15.5V and features rail-to-rail output swing in addition to an input common-mode range that includes ground. Performance limitations that have plagued CMOS amplifiers in the

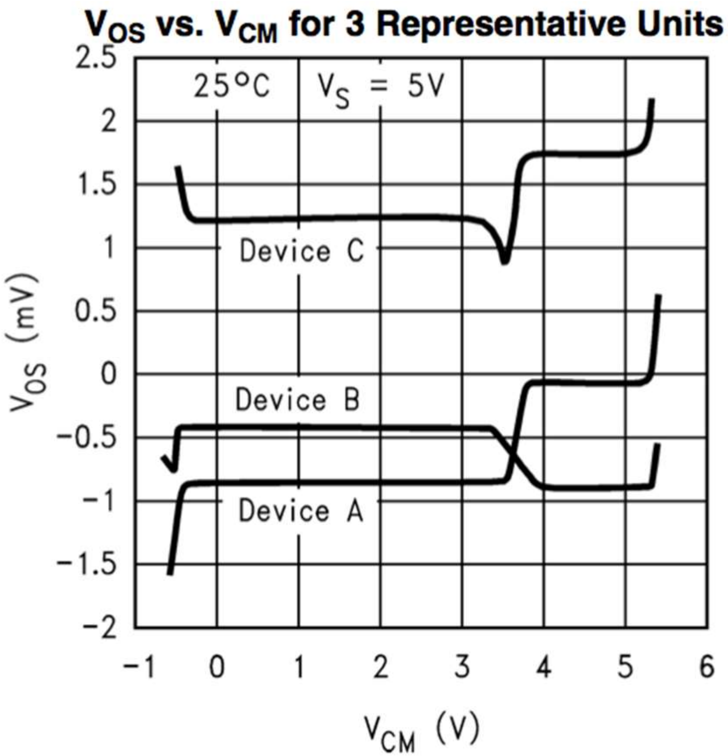
- Low input offset voltage: 3 mV
- Low offset voltage drift: 1.3 µV/°C
- Ultra low input bias current: 2 fA
- Input common-mode range includes V^-
- Operating range from +5V to +15.5V supply
- I_{SS} = 375 µA/amplifier; independent of V^+

Parameter	Conditions	Typ (Note 4)	LMC660AI Limit (Note 4)	LMC660C Limit (Note 4)	Units
Output Swing	$V^+ = 5V$	4.87	4.82	4.78	V
	$R_L = 2\ k\Omega$ to $V^+/2$		**4.79**	**4.76**	min
		0.10	0.15	0.19	V
			0.17	**0.21**	max
Input Common-Mode Voltage Range	$V^+ = 5V$ & 15V	−0.4	−0.1	−0.1	V
	For CMRR ≥ 50 dB		**0**	**0**	max
		$V^+ - 1.9$	$V^+ - 2.3$	$V^+ - 2.3$	V
			V^+ – 2.5	**V^+ – 2.4**	min

Incompatible with its own output!

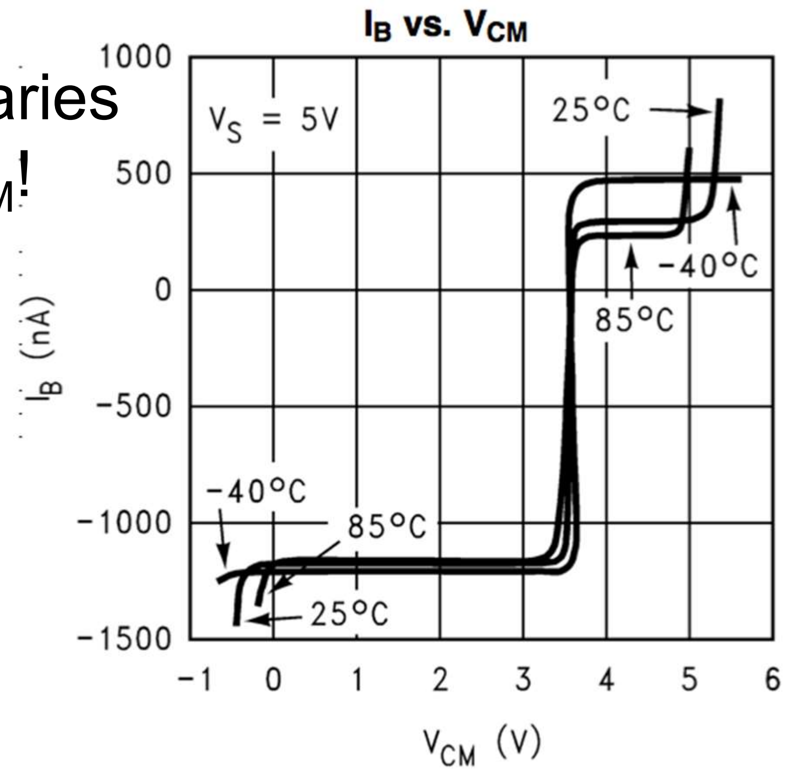
Single supply opamp LM8261:

Symbol	Parameter	Condition	Typ(2)	Limit(3)	Units
V_{OS}	Input Offset Voltage	V_{CM} = 0.5V & V_{CM} = 2.2V	+/−0.7	+/−5 **+/−7**	mV max
TC V_{OS}	Input Offset Average Drift	V_{CM} = 0.5V & V_{CM} = 2.2V(4)	+/−2	–	μV/C
I_B	Input Bias Current	V_{CM} = 0.5V(5)	−1.20	−2.00 **−2.70**	μA max
		V_{CM} = 2.2V(5)	+0.49	+1.00 **+1.60**	



Parameter varies
A lot with V_{CM}!
e.g. dI_B/dV_{CM}

$=R_{IN}$



LM8261: Why is this happening: check the datasheet !

7.1.1 A) Input Stage

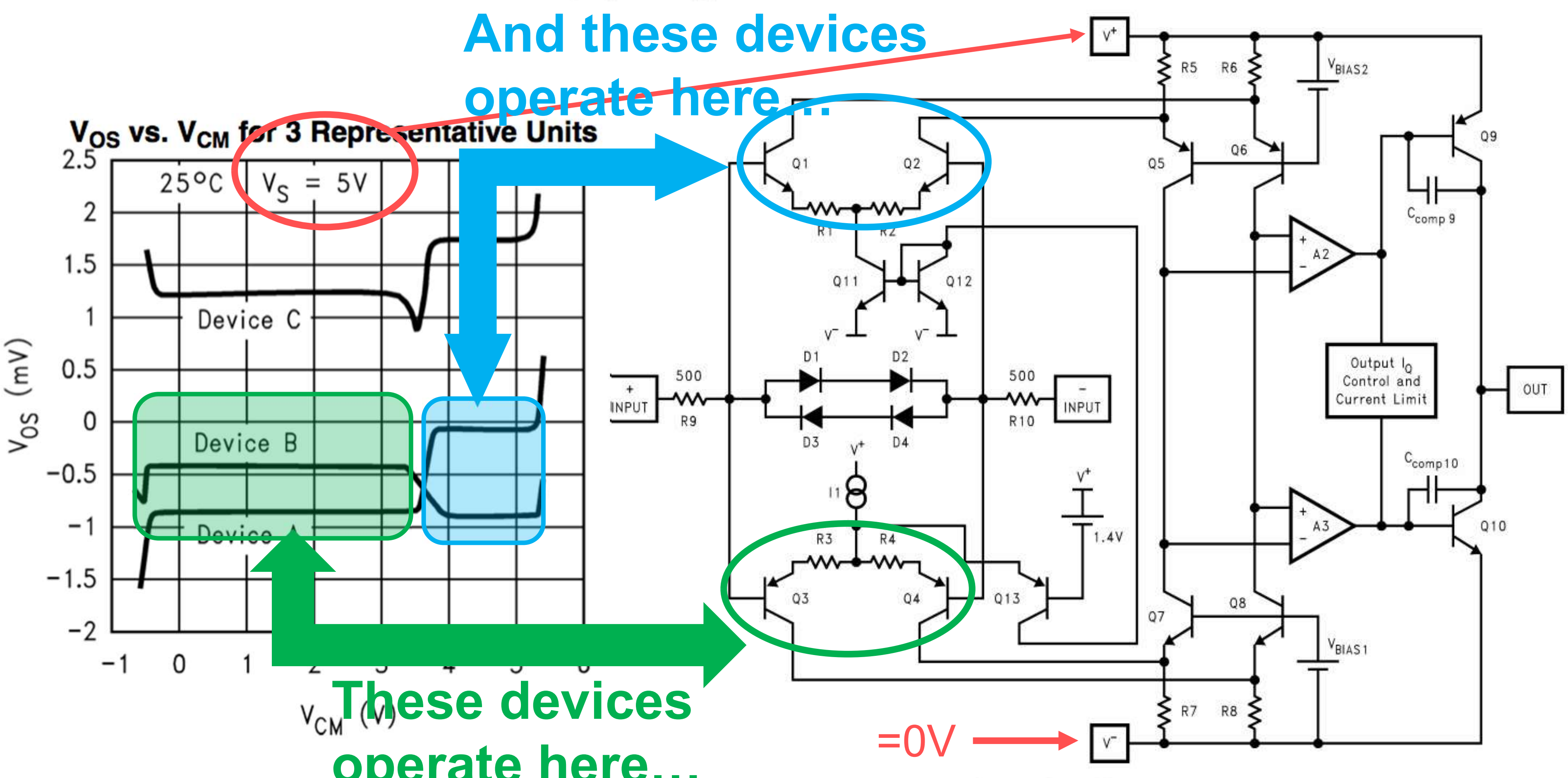


Figure 49. Simplified Schematic Diagram

Read the datasheet to find out the full story!!!


University of Glasgow
Thank you
谢谢
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