UESTC 3003: Electronic System Design

Static Errors

Lecture 2.5: Input Offset Currents

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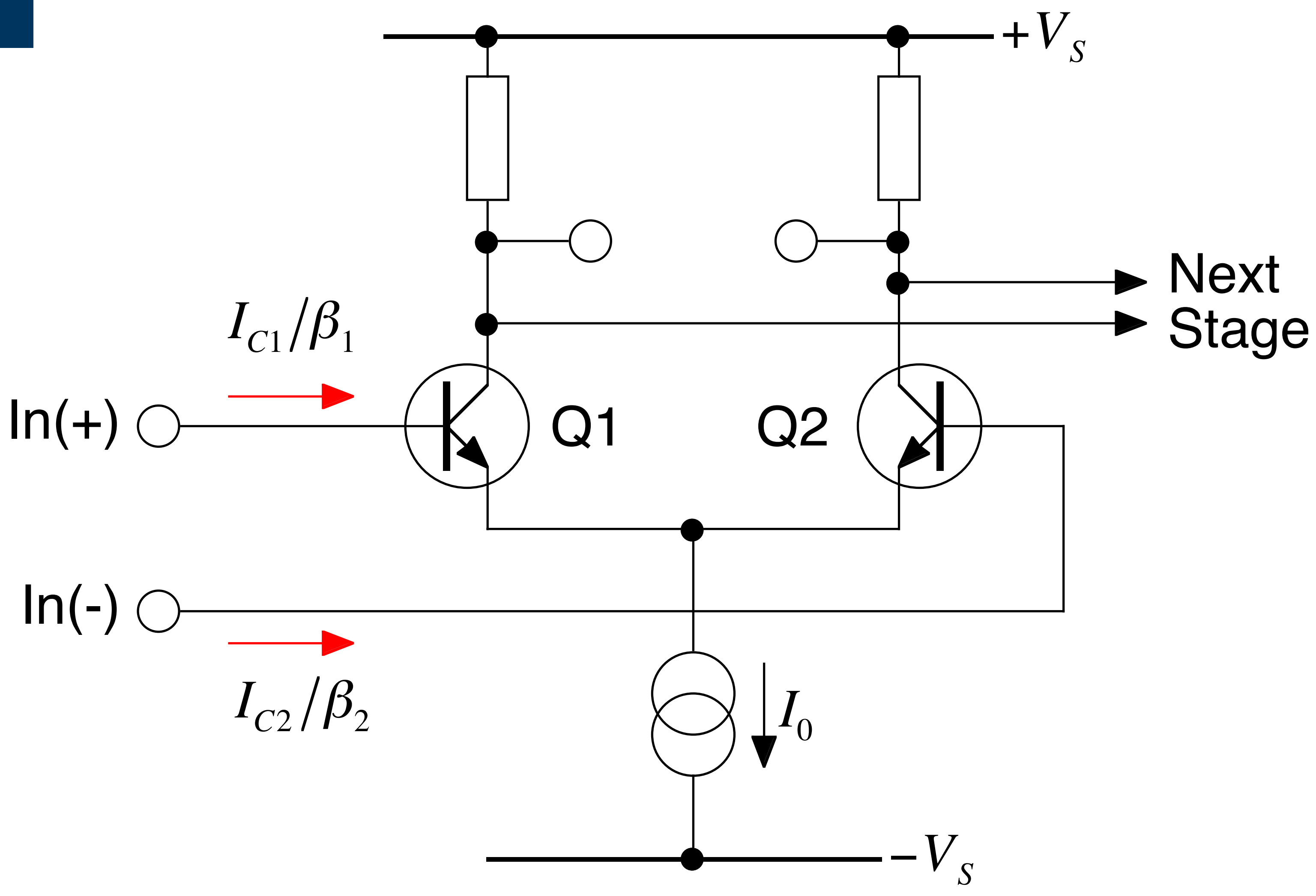
WORLD CHANGING GLASGOW

Offset Current



Transistors are closely matched, but... β is up to $\approx$ 5% out

Offset Current (2)

The difference between the bias currents is the *Offset Current:*

$$I_{OS} = \left| I_B(+) - I_B(-) \right|$$ (Ignore sign)

Note that matching DC resistance compensates for I_B not I_{OS}

Matched resistor trick is only good to about 5% of the total error

Many modern opamps correct for bias current
Exceptions are

- Cheap opamps
- Fast opamps (esp. current feedback)
- Some specialised opamps (e.g. audio)

In the worst case the currents flowing into the inputs are equal and opposite: $I_{OS} \leq 2I_B$

If bias current has been corrected only the error is left

=> Balancing resistors makes things worse

READ THE DATA SHEET **CAREFULLY (it is not always easy to see)**!

ANALOG DEVICES

Low Noise, Precision Operational Amplifier

Data Sheet

OP27

…you need to read carefully

FEATURES

Low noise: 80 nV p-p (0.1 Hz to 10 Hz), 3 nV/√Hz
Low drift: 0.2 μV/°C
High speed: 2.8 V/μs slew rate, 8 MHz gain bandwidth
Low V_{OS}: 10 μV
CMRR: 126 dB at VCM of ±11 V
High open-loop gain: 1.8 million
Available in die form

GENERAL DESCRIPTION

The OP27 precision operational amplifier combines the low offset and drift of the OP07 with both high speed and low noise. Offsets down to 25 μV and maximum drift of 0.6 μV/°C make the OP27 ideal for precision instrumentation applications. Low noise, e_n = 3.5 nV/√Hz, at 10 Hz, a low 1/f noise corner frequency of 2.7 Hz, and high gain (1.8 million), allow accurate high-gain amplification of low-level signals. A gain bandwidth product of 8 MHz and a 2.8 V/μs slew rate provide excellent dynamic accuracy in high speed, data-acquisition systems.

A low input bias current of ±10 nA is achieved by use of a bias current cancellation circuit. Over the military temperature range, this circuit typically holds I_B and I_{OS} to ±20 nA and 15 nA, respectively.

The output stage has good load driving capability. A guaranteed swing of ±10 V into 600 Ω and low output distortion make the OP27 an excellent choice for professional audio applications.

(Continued on Page 3)

PIN CONF

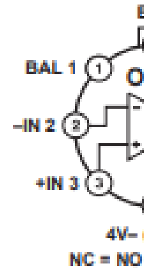


Figure 1. 8-Le

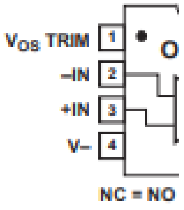


Figure 2. 8-Lead CERDIP - 8-Lead PDIP (P-Suffix)

FUNCTIONAL BLOC

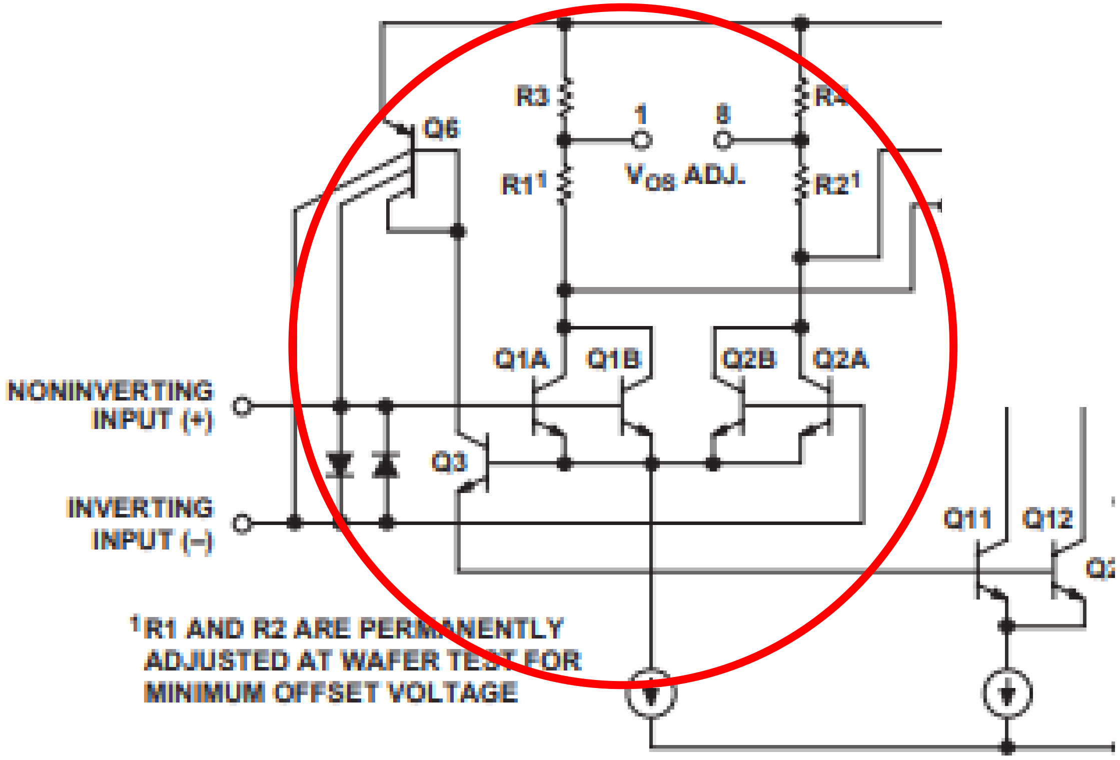
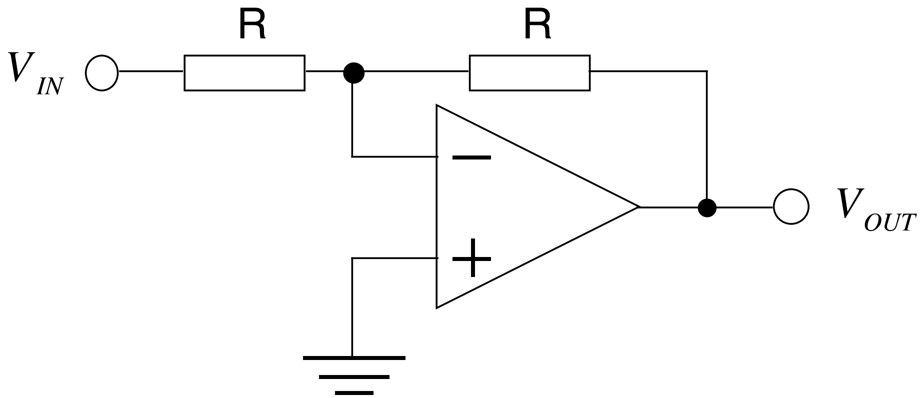


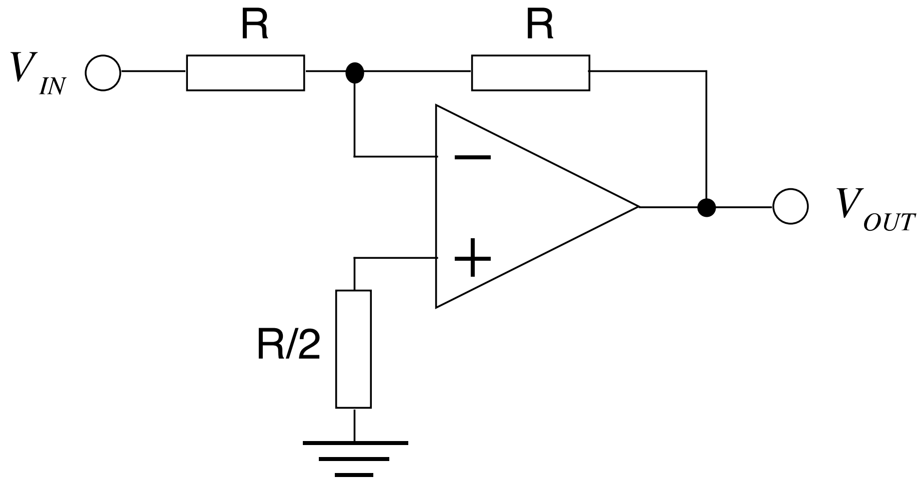
Figure 3

… and learn to read schematic diagrams
See reference MT-38 for how it works…

Offset Current (3)

Example: Inverting amplifier, gain of -1





Error if **<u>no</u>** compensation =

$$R \times I_B(-)$$

Error **<u>if</u>** compensated =

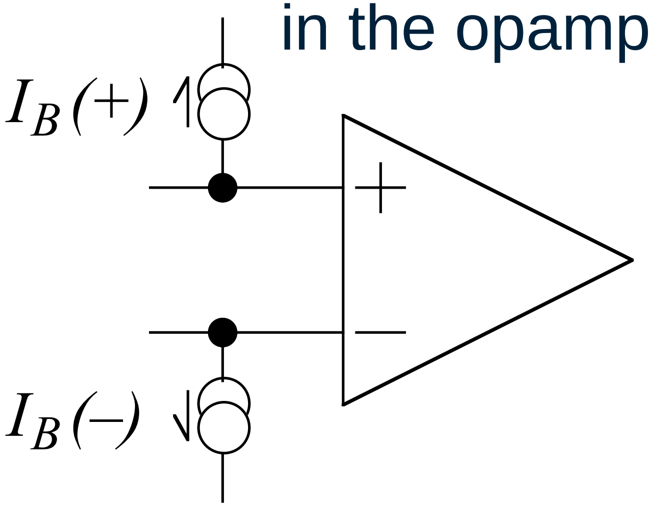
$$R \times \left(I_B(-) - I_B(+)\right) = R \times I_{OS}$$

$$\text{If } I_B(-) = -I_B(+) \text{ error } = 2R \times I_B(-)$$

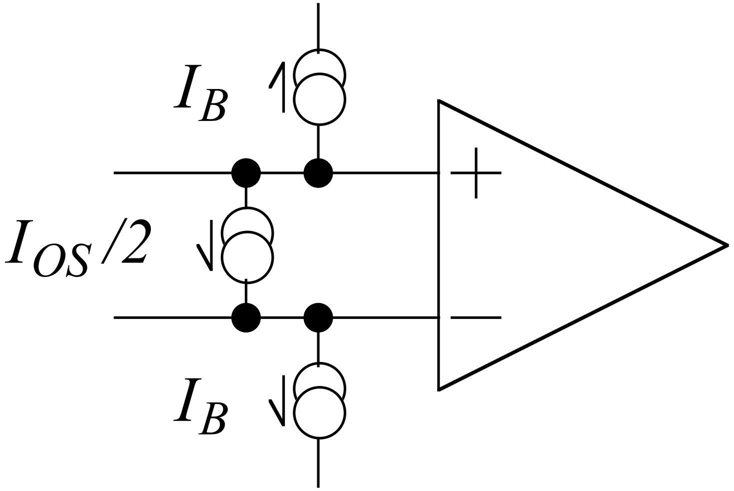
Potentially worse than uncompensated

Offset Current (4)

The model for current errors in the opamp is now:-



But we express $I_B(-)$ and $I_B(+)$ in terms of their average and difference:

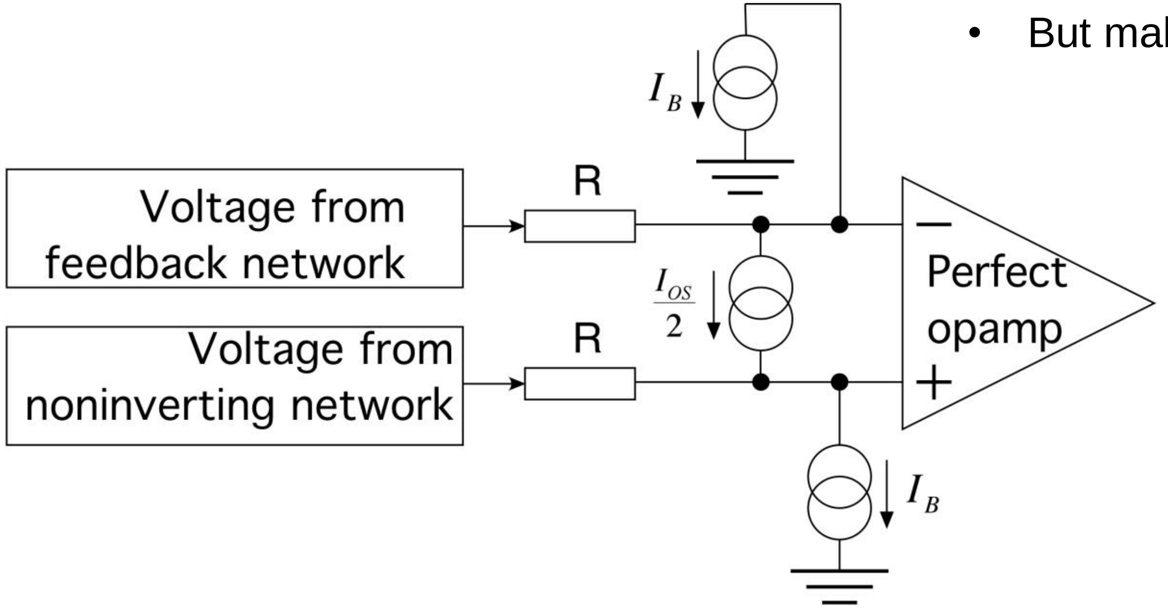


This is how the currents are defined in data sheets

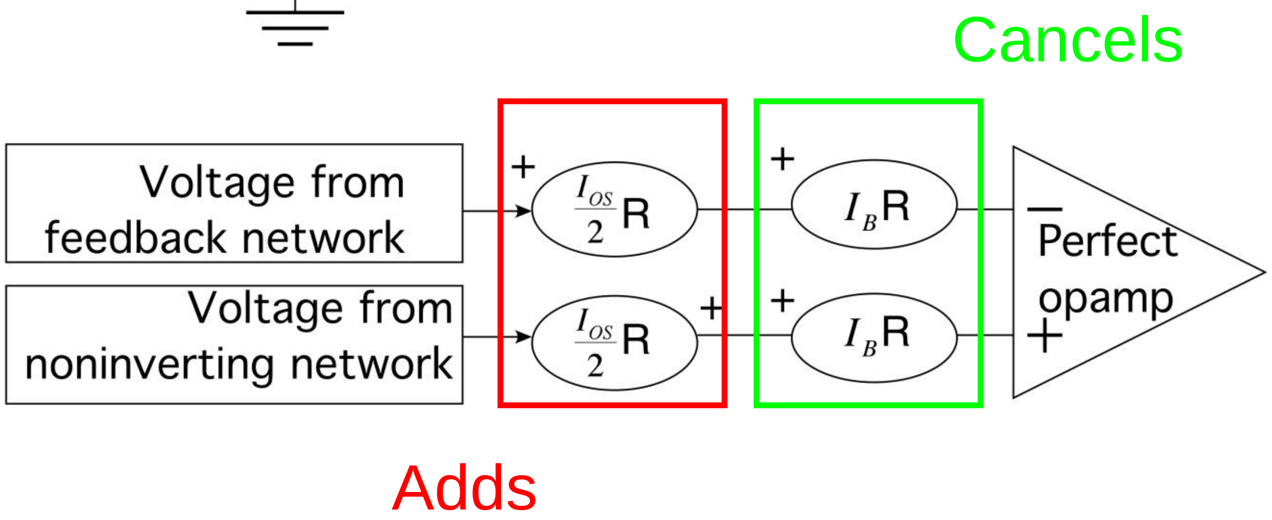
From now on, use this model only

Offset Current (5)

- Equal source impedances compensate for bias current *in general*
- But make offset current worse *in general*



is equivalent to



Offset Current (6)

Don't try to combine bias and offset current to work out specific values of current: these are only <u>limiting</u> specifications:

Example: NE5532, typical spec at 25°C $I_B = 200nA; \quad I_{OS} = 10nA$

maximum spec at 25°C $I_B = 800nA; \quad I_{OS} = 150nA$

Possible values:

$$I_B(+) = 800nA; \quad I_B(-) = 780nA$$

$$I_B(+) = 0nA; \quad I_B(-) = -150nA$$

$$I_B(+) = -780nA; \quad I_B(-) = -700nA$$

$$I_B(+) = -800nA; \quad I_B(-) = -800nA$$

Impossible values:

$$I_B(+) = 800nA; I_B(-) = 820nA$$

$$I_B = 810nA!$$

$$I_B(+) = -75nA; \quad I_B(-) = 76nA$$

$$I_{OS} = 151nA!$$

If impedances are (very) unbalanced, use bias current spec.
If impedances are balanced, use offset current spec.

A word about FETs

Practical consideration:

FET input opamps have very low bias current
But bias current is often exponential with temperature:

$$\mathrm{T} = 20^\circ\mathrm{C}, \quad \mathrm{I_B} = 50\,pA$$

$$\mathrm{T} = 30^\circ\mathrm{C}, \quad \mathrm{I_B} = 100\,pA$$

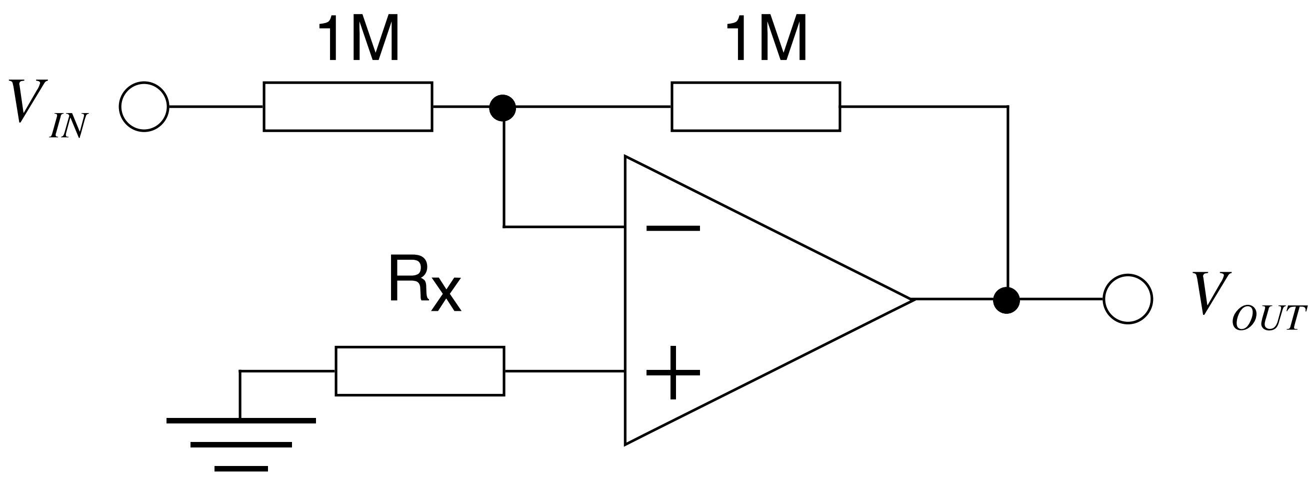
$$\mathrm{T} = 40^\circ\mathrm{C}, \quad \mathrm{I_B} = 200\,pA$$

$$\mathrm{T} = 80^\circ\mathrm{C}, \quad \mathrm{I_B} = 3.2\,nA!$$

Bipolar opamp's bias much more stable with temperature
Important point if designing for rugged environment
- Automotive
- Military / Aerospace

But not for normal domestic / lab conditions!

Example



$I_B = 100nA$

$I_{OS} = 5nA$

If R_x is 0, what is the error?

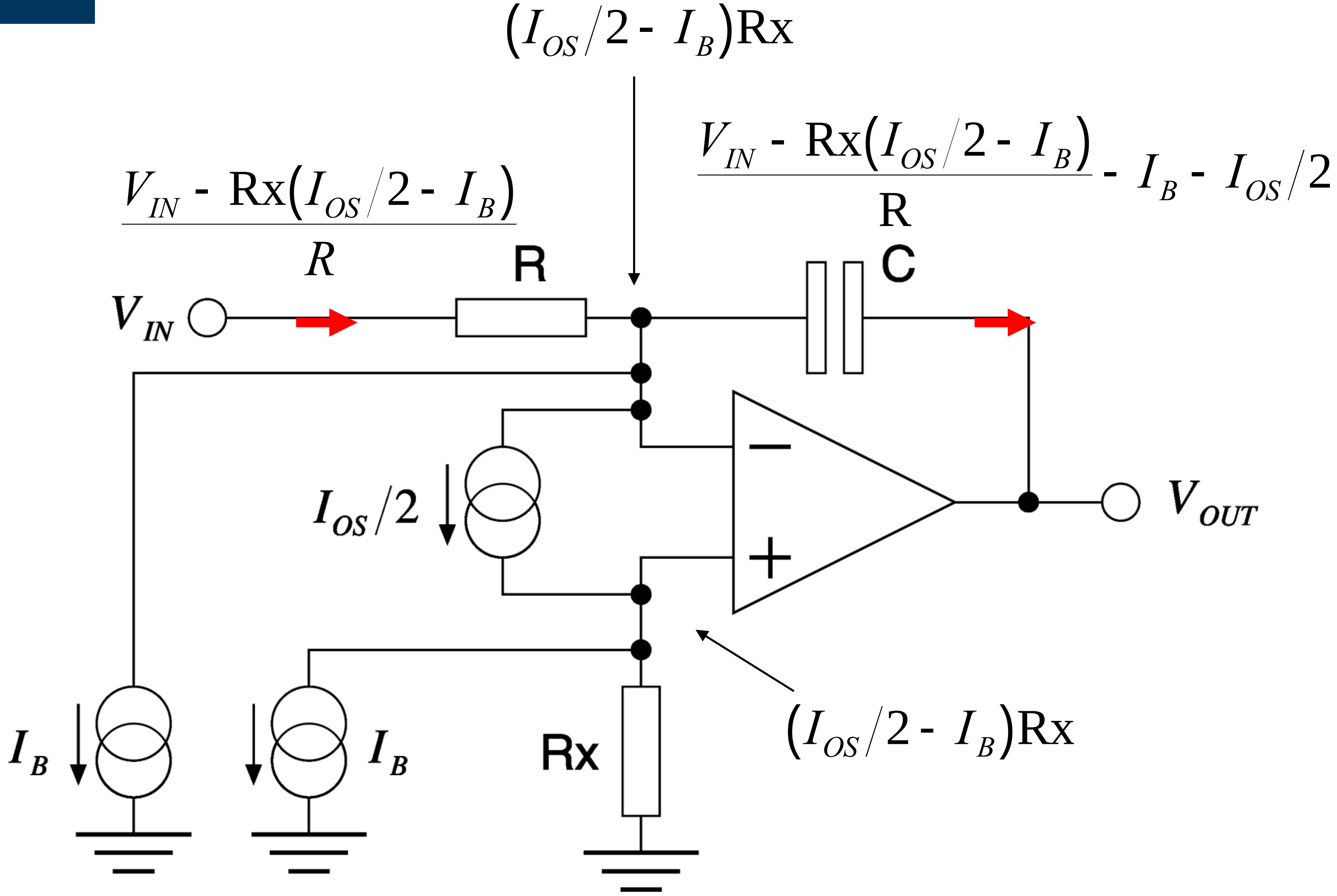
$$Error = R \times I_B(-) = R \times I_B = 100mV$$

If R_x is 500k, what is the error?

$$Error = R \times I_{OS} = 5mV$$

Question: What happens if all resistors are reduced e.g. x 0.1 ?
What is the limit on scaling resistors? **Hint: It's Free!**

Example: Integrator



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Example (2)

Neglecting constant terms
(including constant of integration)

$$V_{OUT} = \frac{-1}{C}\int idt = \frac{-1}{C}\int \frac{V_{IN} - \mathrm{Rx}\left(I_{OS}/2 - I_B\right)}{\mathrm{R}} - I_B - I_{OS}/2dt$$

$$= -\int \frac{V_{IN}}{\mathrm{R}C} - \frac{\left(\mathrm{Rx}\left(I_{OS}/2 - I_B\right) + \mathrm{R}I_B + \mathrm{R}\,I_{OS}/2\right)}{\mathrm{R}C}dt$$

$$\therefore \text{Error (RTI)} = -\left(\left[\mathrm{Rx}\left(I_{OS}/2 - I_B\right) + \mathrm{R}I_B + \mathrm{R}\,I_{OS}/2\right]\right)$$

$$= -\left(\left(Rx + R\right).\frac{Ios}{2} + \left(Rx - R\right).I_B\right)$$

If unmatched resistances,
Rx=0, just consider bias current

$$\text{Error (RTI)} = -\,\mathrm{R}I_B$$

If matched resistances,
Rx=R, just consider offset current

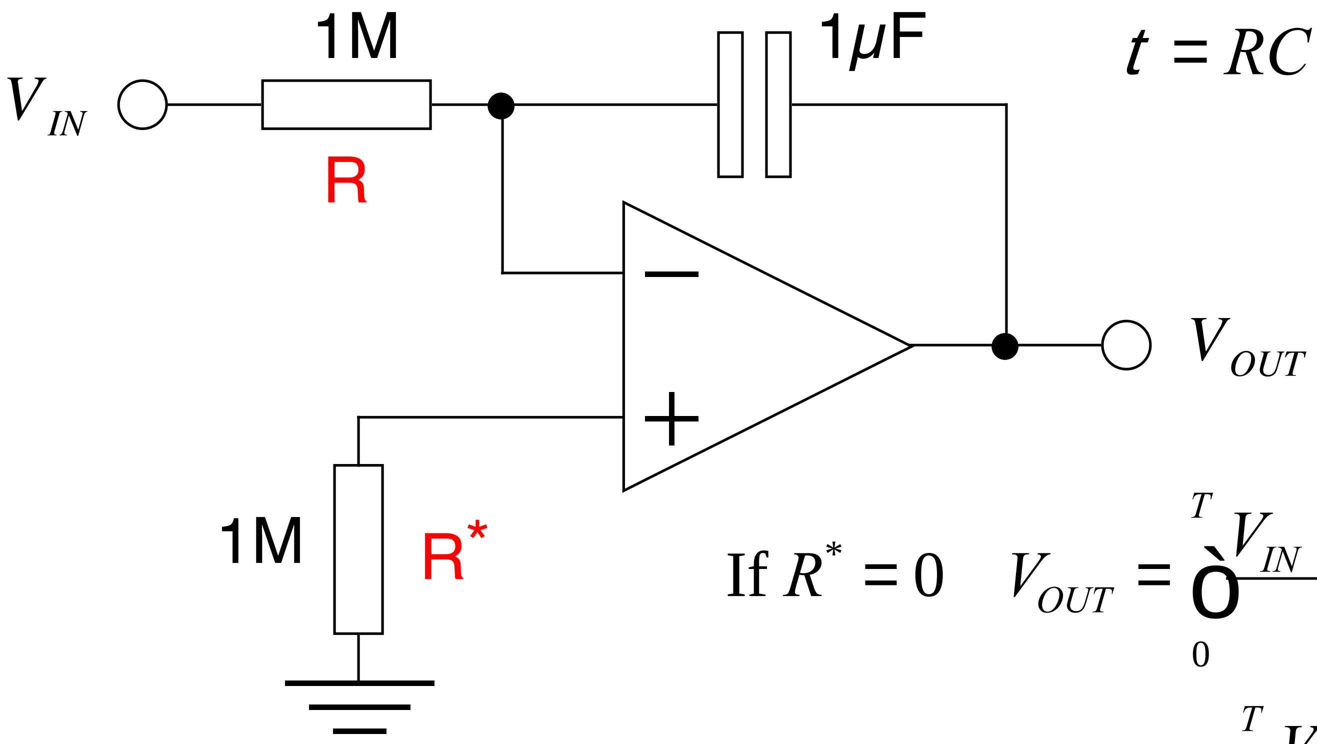
$$\text{Error (RTI)} =$$

$$-\,\mathrm{R}\left(I_{OS}/2 - I_B\right) - \mathrm{R}I_B - \mathrm{R}\,I_{OS}/2 = -\,\mathrm{R}I_{OS}$$

Example (3)

$$I_B = 100nA$$

$$I_{OS} = 5nA$$



$$\tau = RC = 1s$$

If $R^* = 0$ $\quad V_{OUT} = \int_0^T \frac{V_{IN} + 0.1V}{1s} dt$

If $R^* = 1M$ $\quad V_{OUT} = \int_0^T \frac{V_{IN} + 5mV}{1s} dt$

Note that the current error corresponds to a change to the input voltage. If R^*=1M then the error is "*5mV Referred to input*", *RTI*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Thank you
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