Electronic System Design 3

Lecture 11.1:
Low noise Amplifier Noise Analysis

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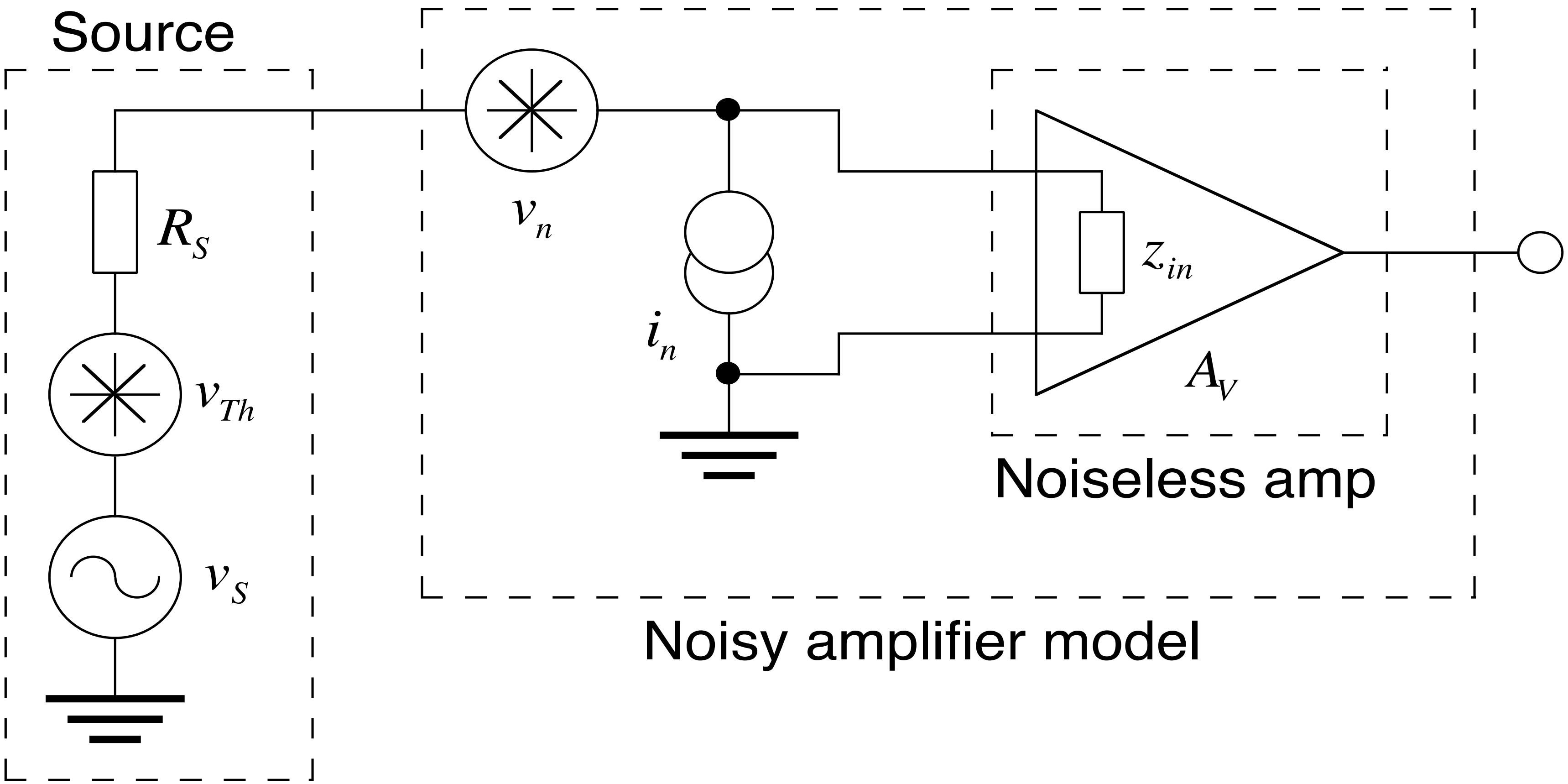
Example 1



$R_S = 10k\Omega$ $T = 300K$ $v_n = 15nV \cdot Hz^{-1/2}$ $i_n = 1pA \cdot Hz^{-1/2}$

B=20kHz

What is equivalent input noise level?

Example 1 (2)

$$R_S = 10k\Omega; \quad T = 300K \quad \therefore v_{Th} = \sqrt{4k_B TR} = 12.9nV \cdot Hz^{-1/2}$$

$$v_{ni}^2 = v_{Th}^2 + v_n^2 + i_n^2 \left|R_S\right|^2$$

$$= \left(12.9nV \cdot Hz^{-1/2}\right)^2 + \left(15nV \cdot Hz^{-1/2}\right)^2 + \left(1pA \cdot Hz^{-1/2}\right)^2 \cdot \left(10k\Omega\right)^2$$

$$\Rightarrow v_{ni} = \sqrt{0.491 fV^2 Hz^{-1}} = 22.2nV \cdot Hz^{-1/2}$$

Multiply noise spectral density by the √**bandwidth** to get total noise

$$V_{total} = 22nV \cdot Hz^{-1/2} \cdot \sqrt{20kHz} = 3.13\mu V$$

Noise Figure

How much worse is this than thermal noise?

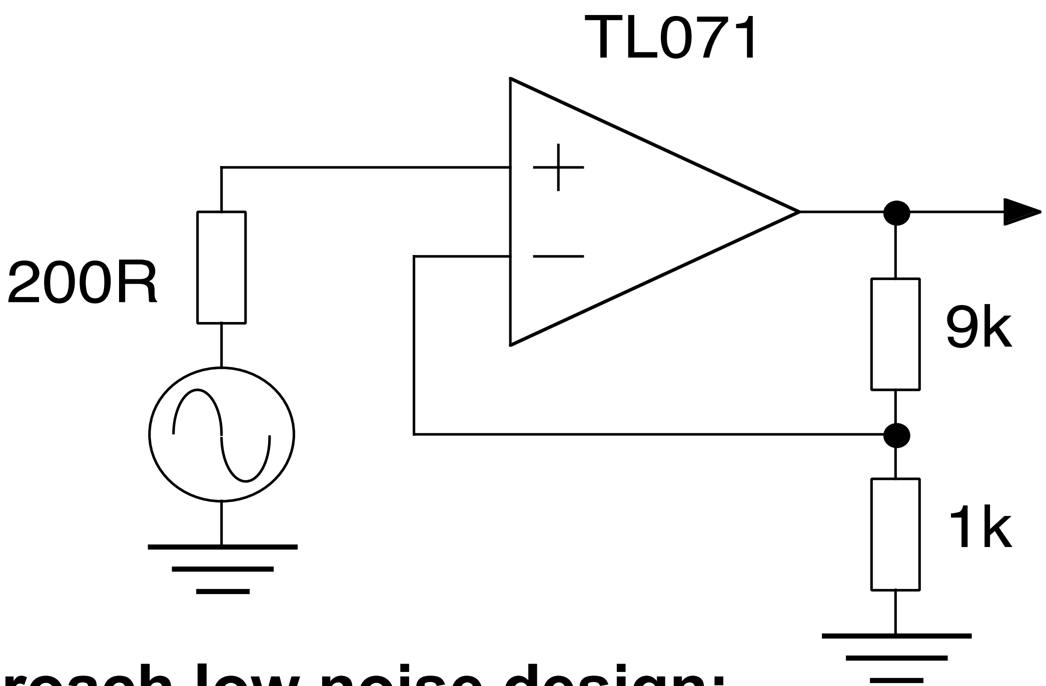
Noise figure (NF) is the ratio of equivalent input power density to the thermal noise of the source. Usually expressed in dB

<u>A perfect amplifier adds no noise</u> to the signal: NF= 1 = 0dB: NF is always positive in dB (i.e. total noise > thermal noise)

$$\text{Noise Figure} = 20 \cdot \log_{10} \frac{v_{ni}}{v_{Th}}$$

$$\text{Noise Figure} = 20 \cdot \log_{10} \frac{22.2nV \cdot Hz^{-1/2}}{12.9nV \cdot Hz^{-1/2}} = 4.7dB$$

Example 2: Low noise design



How to approach low noise design:

1. Analyse circuit
2. Identify main sources of noise
3. Design a better amplifier

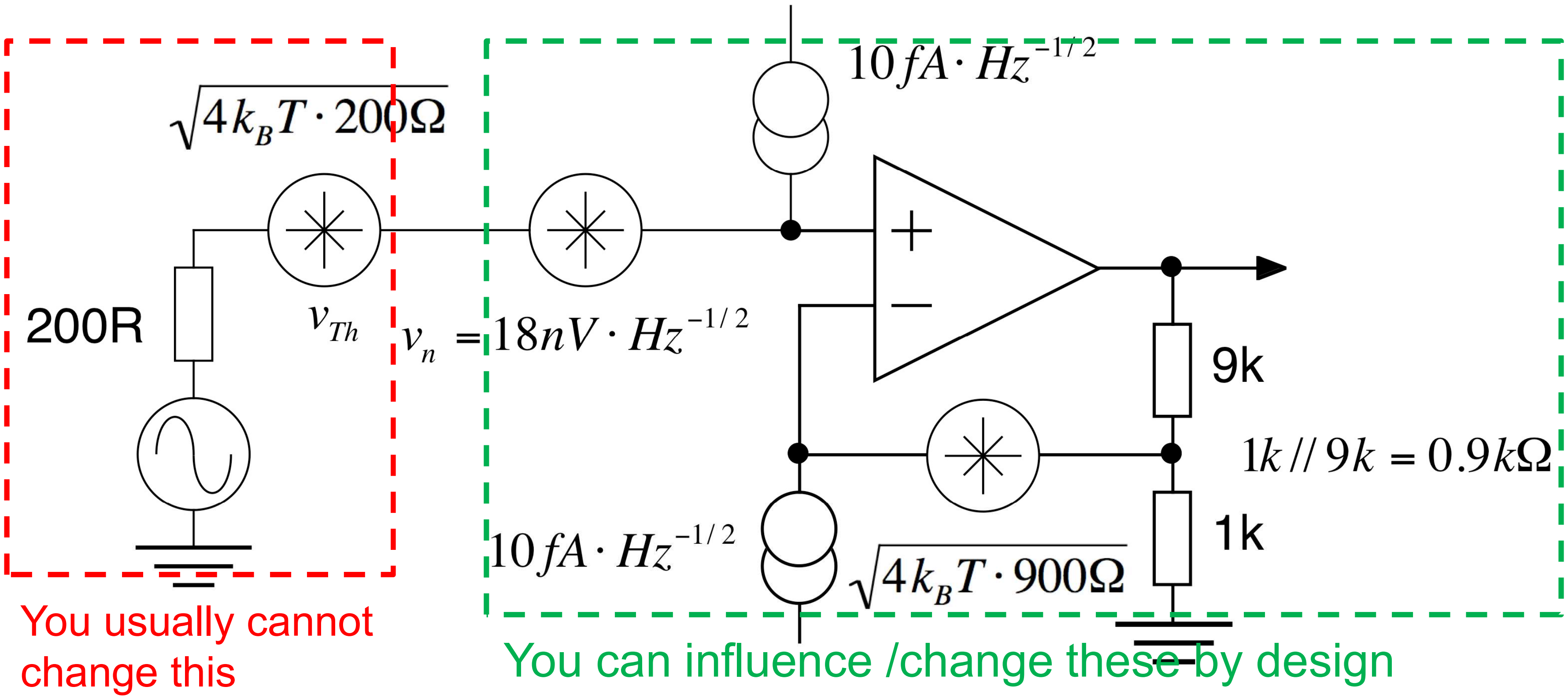
Design 2 (2)

Circuit analysis

TL071: $v_n = 18nV \cdot Hz^{-1/2}; \quad i_n = 10fA \cdot Hz^{-1/2}$

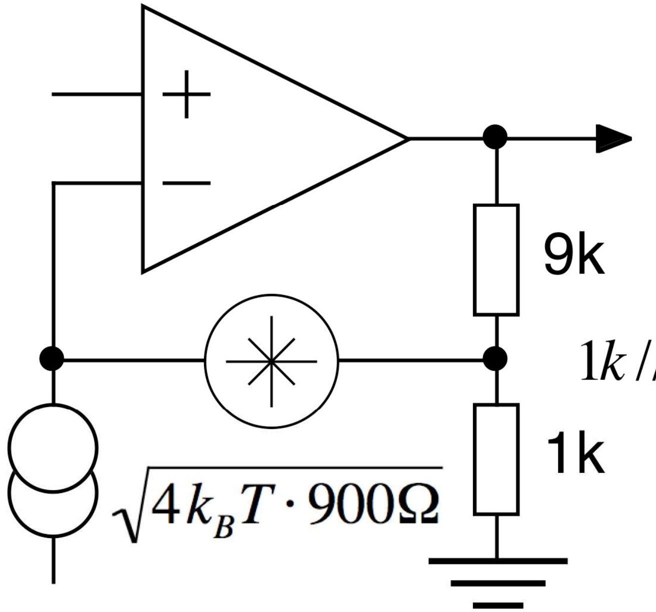
Input noise current density flows into both inputs

Derive noisy amplifier model equivalent circuit:



Design 2 (3)

Analysing feedback network:



$$1k\,//\,9k = 0.9k\Omega$$

$$10\,fA \cdot Hz^{-1/2}$$

$$\sqrt{4k_BT \cdot 900\Omega}$$

Noise voltage at inverting input

= Johnson noise in resistors + noise current *x* impedance

$$v_n(-) = \sqrt{\left(i_n \cdot 0.9k\Omega\right)^2 + \left(\sqrt{4k_BT \cdot 0.9k\Omega}\right)^2}$$

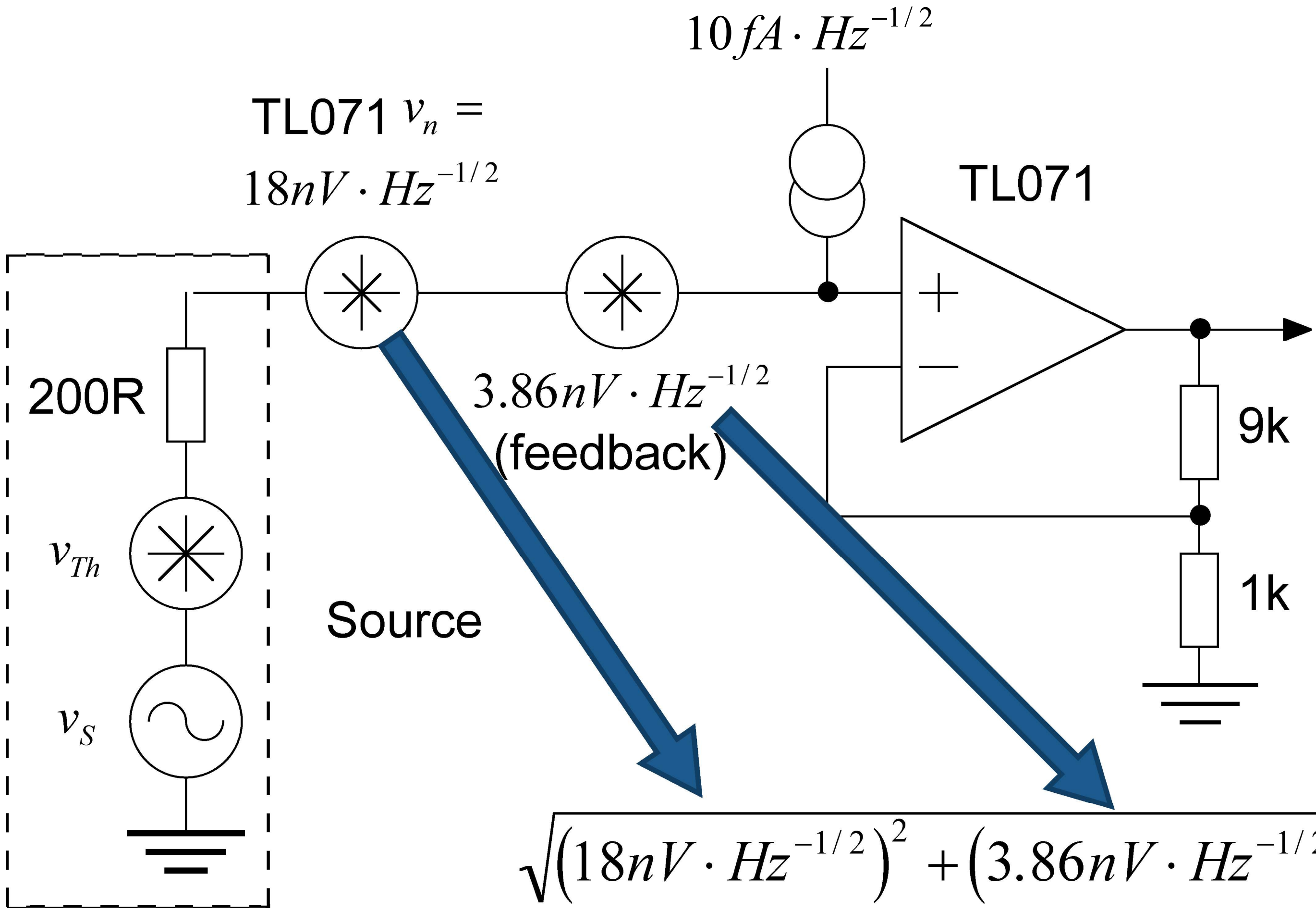
$$= \sqrt{\left(9 \cdot 10^{-3}\,nV \cdot Hz^{-1/2}\right)^2 + \left(3.86nV \cdot Hz^{-1/2}\right)^2}$$

Noise current is negligible: $v_n(-) = 3.86nV \cdot Hz^{-1/2}$

Design 2 (4)

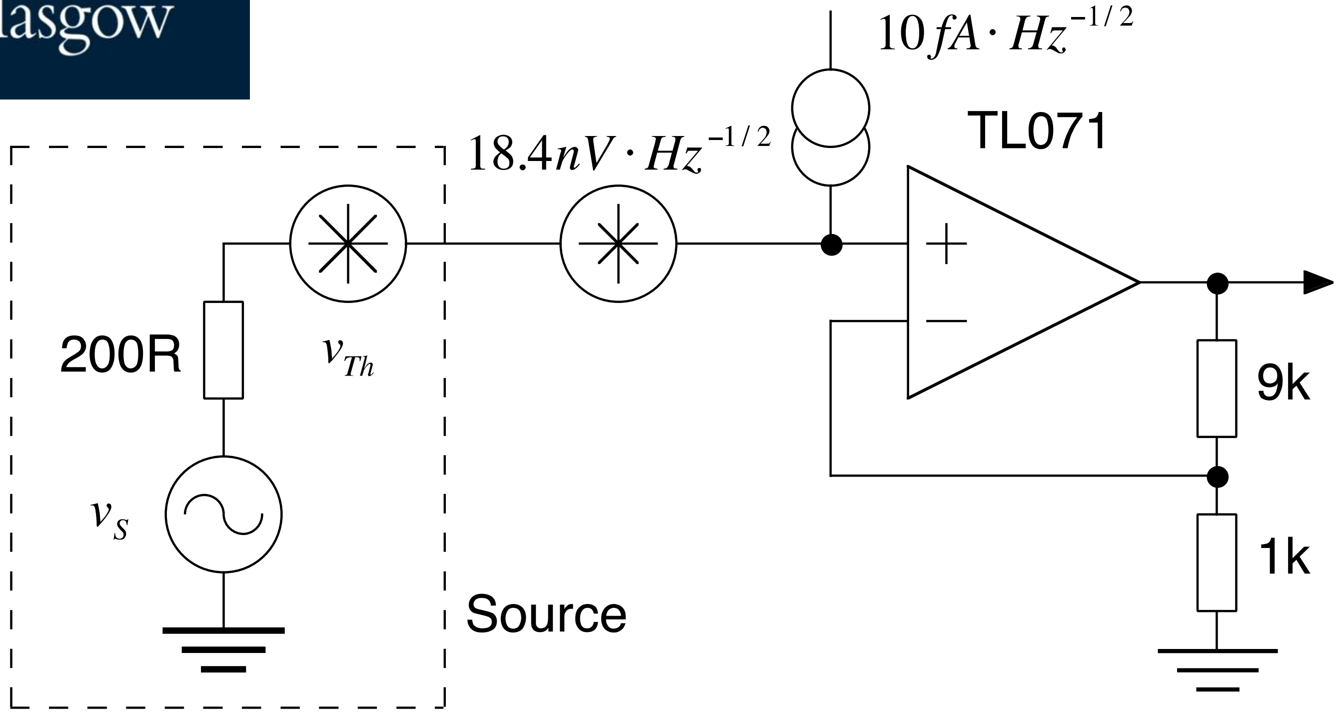
Feedback makes 2 inputs equal:

Feedback network noise adds to input voltage noise:



$$\sqrt{\left(18nV \cdot Hz^{-1/2}\right)^2 + \left(3.86nV \cdot Hz^{-1/2}\right)^2} = 18.4nV \cdot Hz^{-1/2}$$

Design 2 (5)



Now in the same form as the standard model

$$v_n = 18.4nV\cdot Hz^{-1/2} \quad i_n = 10\,fA\cdot Hz^{-1/2} \quad v_{Th} = \sqrt{4k_B TR} = 1.82nV\cdot Hz^{-1/2}$$

$$v_{ni} = \sqrt{v_{Th}^2 + v_n^2 + i_n^2 |R_S|^2} = \sqrt{3.3\cdot 10^{-18} + 338\cdot 10^{-16} + 4\cdot 10^{-24}} = 18.5nV\cdot Hz^{-1/2}$$


University of Glasgow
Thank you
谢谢
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