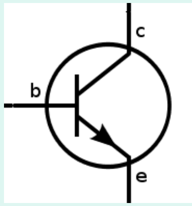
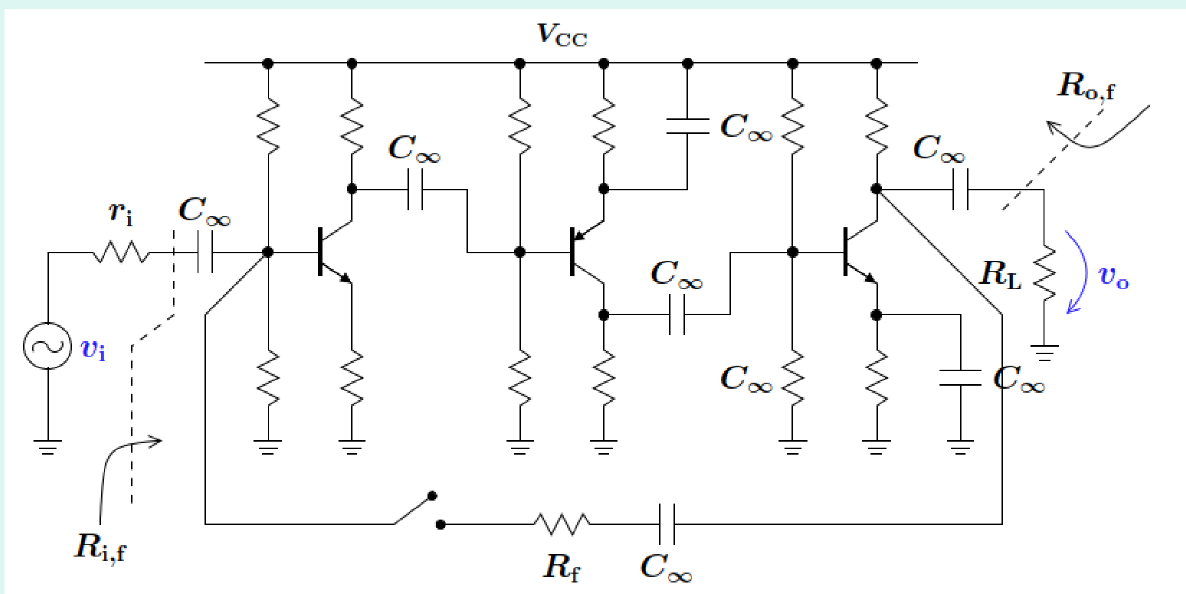
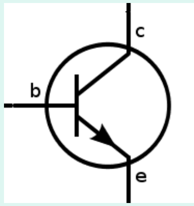


ELEC 301 - Electronic Circuits

L02 - Sep 08

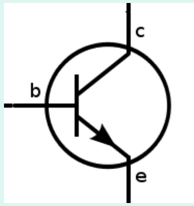
Instructor: Edmond Cretu





Last time

- Course introduction
- Information flow vs. energy flow
- Digital vs. analog world - are analog circuits still relevant in a sea of digital information and signal processing?



Administrative issues

- **Instructor:**

Dr. Edmond Cretu

Email address:

edmondc@ece.ubc.ca

Course website: Canvas

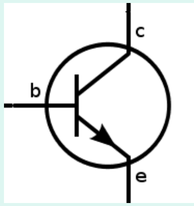
Prerequisites: Either

(a) one of ELEC 201, ELEC 203 and ELEC 202; or

(b) ELEC 204

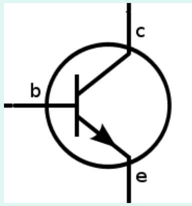
- Lect/Tut/Lab = 4/0/0
- Mon: 3:30 - 4:30pm, MCLD2018
- Tue, Thu – 3:30 - 5pm, DMP110
- Lectures provided for download from website
- Complementary references:
- Sedra+Smith - Microelectronic Circuits
- Sansen[2006]Analog design essentials, Springer

- Articles related to specific topics



Grading system

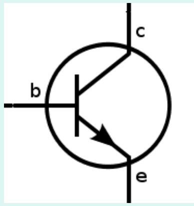
- Final Examination: 45%
- iClicker: 5%
- Midterm: 20%
- 2-3 mini-projects: 30%



UBC Calendar - important dates

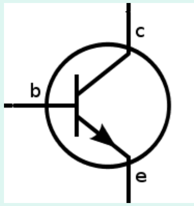
- Term 1 - Sep 02 - Dec 05, 2025
- Midterm break: Nov 10-12, 2025
- Exams period: Tue, Dec 09 - Sat, Dec 20

- Last day to drop without W standing: Sep 15
- Course withdrawal with a W standing: Sep 16 - Oct 24



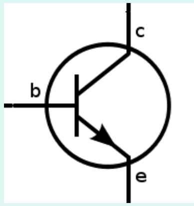
Is analog electronics still relevant?

- Analog circuits serve as physical-to-digital interface
- Lower power consumption for certain operations (filtering) - use in IoT systems
- Better performance for high-speed processing (RF circuits, telecom) - avoid latencies
- Higher resolution in advanced instrumentation - no quantization errors
- Analog computing revival: Custom analog AI chips - analog processors are good for parallel processing of complex computation - efficient neural networks operations
- Information flow can be simulated by analog circuits



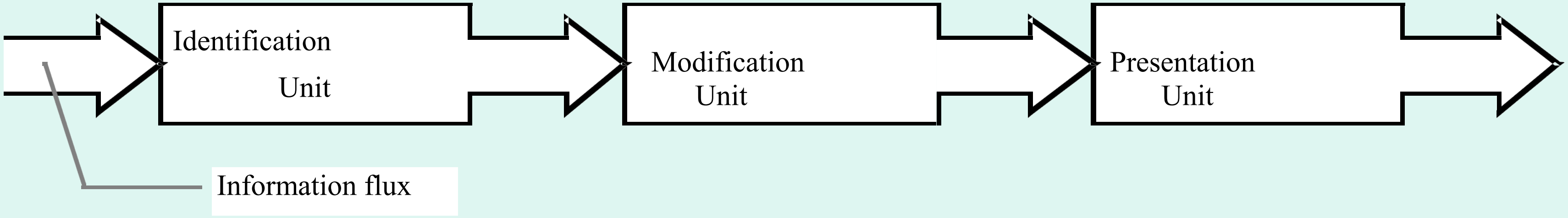
Key performance indicators for a system

- Noise - limits the sensing resolution and accuracy: signal-to-noise ratio (SNR), noise factor (N), noise figure (NF)
- Bandwidth - the operating frequency range
- Power consumption, output power
- Nonlinearities, distortions
- Cost, area
- Application specific requirements: biocompatibility, disposable, etc.



Information processing system

- Milestone: Claude E. Shannon – "A mathematical theory of communication," in Bell System Tech. J., July 1948
- Central problem: transmission of information over a noisy channel



Limits in information transmission

- **Shannon's Channel Capacity theorem**:

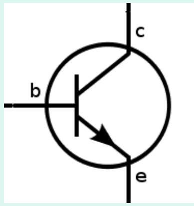
$$C_{[bits/\sec]} = B\log_2\left(1+\frac{S}{N}\right)$$

B= bandwidth [Hz]
S = signal power [W]
$N=N_0*B$ total noise power [W]

• This expression applies to information in any format and to both analog and data communications

• The **channel capacity theorem** is one of the most important results of information theory. In a single formula it highlights the interplay between 3 key system parameters: channel bandwidth, average transmitted or received signal power, noise power at the channel output.

• For a given average transmitted power S and channel bandwidth, B, we can transmit information at the rate C bits/s with no error, by employing sufficiently complex coding systems. It is not possible to transmit at a rate higher than C bits/s by any coding system without a definite probability of error. Hence the channel capacity theorem defines ***the fundamental limit*** on the rate of error-free transmission for a power-limited, band-limited channel.



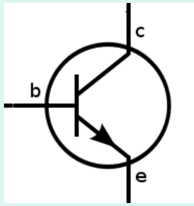
Capacity versus bandwidth

- An increase of the bandwidth B yields more improvement than a comparable increase in S/N
- In reality, $N=N_0 * B$ (for white noise) → increasing the bandwidth will finally decrease S/N

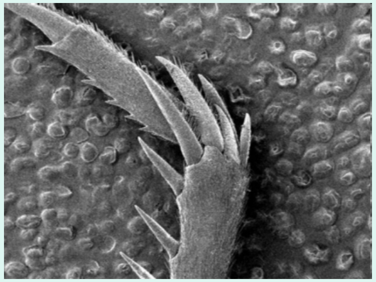
$$C_{[bits/\sec]} = B\log_2\left(1+\frac{S}{N_0 \bullet B}\right) \xrightarrow{B\to\infty} \frac{S}{N_0}\log_2 e = 1.44\frac{S}{N_0}$$

$$\lim_{x\to\infty} x\ln\left(1+\frac{1}{x}\right) = 1$$

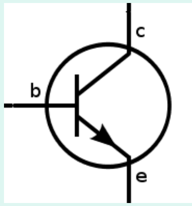
In terms of cost, there is an **optimum bandwidth for a given signal**, which might dictate if the optimum solution is to be analog or digital.



Information handling vs. bandwidth

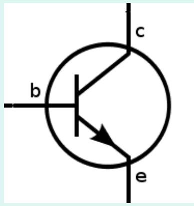


- We have assumed white noise (uniform spectral density) – reconsider the formula if different noise sources are to be considered (exm: 1/f noise – generally originating from surface processes, dominant in low-frequency range)
- Using nonlinear techniques can alleviate S/N constraints by modifying the spectral characteristics of the noise (exm: "noise shaping" in sigma-delta converters)
- Nature beats us again! - the best sensor known to us: the filiform hairs on the cricket's legs operate with an energy threshold of the same order of magnitude (10^{-21}J) as the thermal energy (use stochastic resonance as a specific nonlinear technique to actually exploit the energy of the noise!)
- For detection of a signal: the energy necessary to detect a signal depends on the noise generated either externally (interference) or intrinsic to the detection mechanism
- C(S) dependence establishes a **coupling between information and energy** with respect to signal processing/transmission. Similar fundamental constraints exist for the other aspects (exm: minimum energy necessary for storing a bit of information)



Simplifying design by orthogonality

- ***Design strategy: decouple B,N,S (assume they are orthogonal during the design, or take special measures to ensure this)***
  - ***when noise is evaluated, power aspects like distortion are generally not considered (linear small-signal models). Frequency behavior is taken into account, but the bandwidth demands on the complete system are not considered***
  - ***When power is evaluated, neither noise nor frequency behavior are considered (static large-signal models)***
  - ***When bandwidth is evaluated, power (distortion) and noise behavior are not considered (small-signal models)***

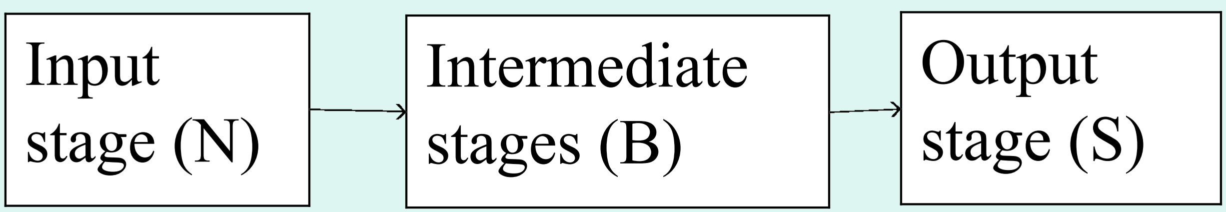


Structured electronic design in electronics

- ***C. J. M. Verhoeven, A. van Staveren et.al[2003] "Structured electronic design. Negative-feedback amplifiers",***
- ***https://link.springer.com/book/10.1007/b106382***

Design methodology - amplifiers

- ***Design by separate optimization of N (noise power), B (bandwidth), S (signal power)***
- ***The influence of feedback theory in order to enhance the validity of our assumptions***



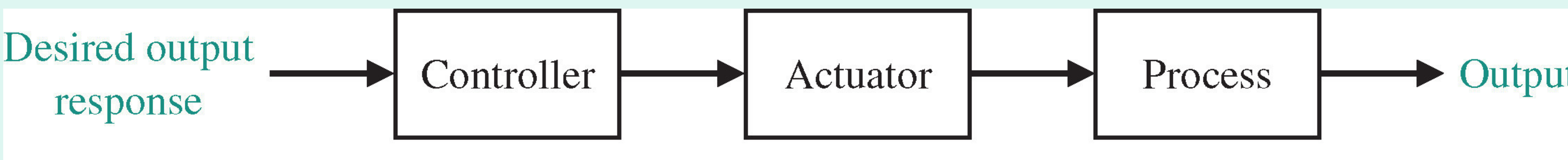
System configurations

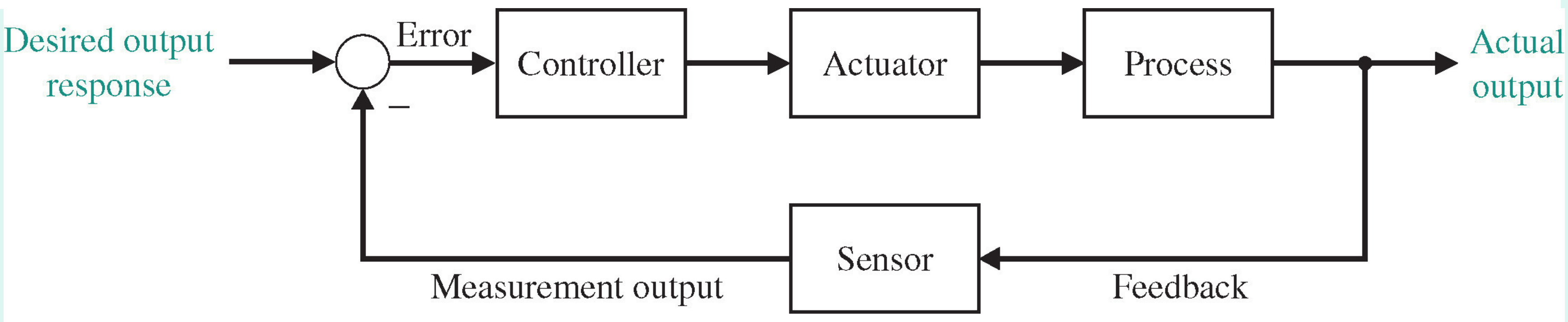
Open loop vs. closed loop architecture

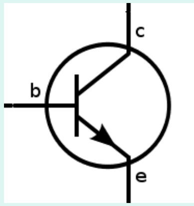
Control action = the quantity responsible for activating the system to produce an output

Open-loop control system - the control action is independent of the output

Closed-loop control system - the control action is dependent on the output as well



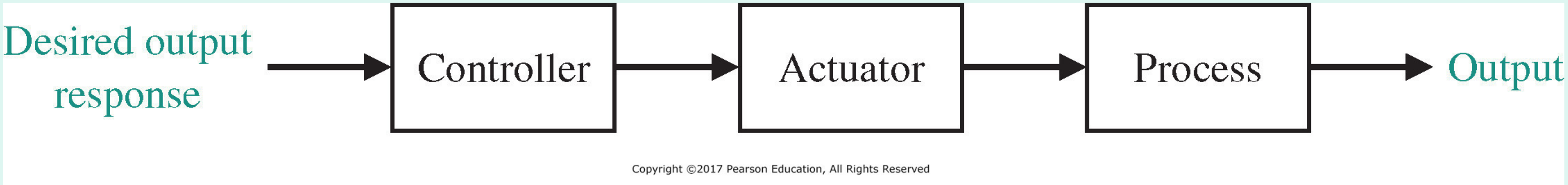




Open loop control

Features:

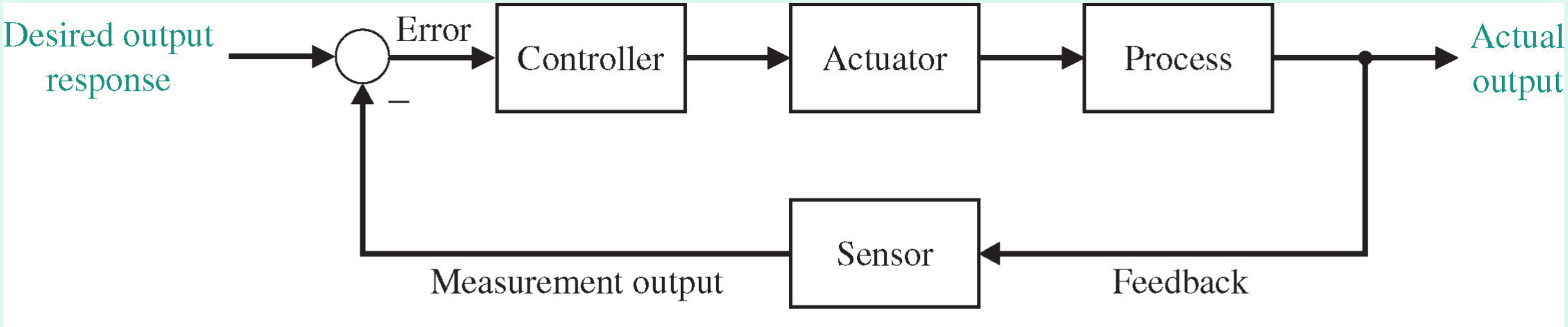
- Ability to perform accurately determined by its calibration (set an input-output relation to get a desired system accuracy)
- Usually not suffering from instability



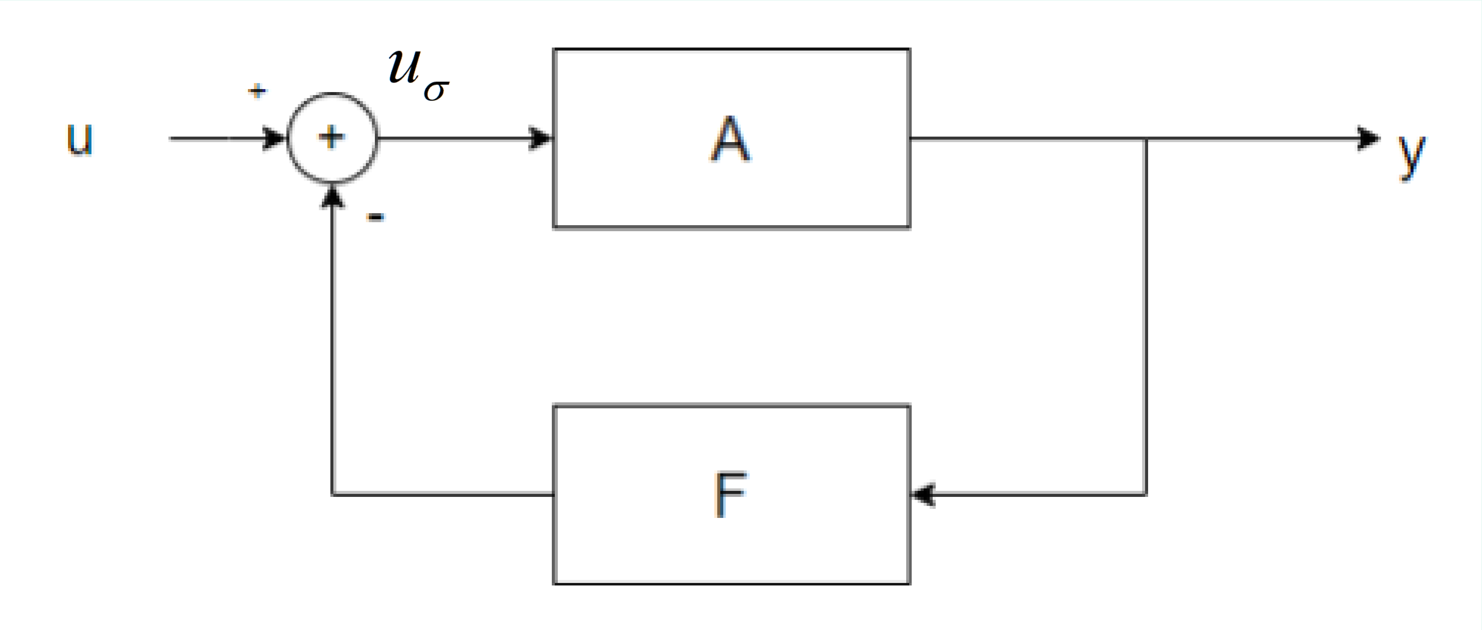
Closed- loop control (Feedback control systems)

Features:

- Increased accuracy
- Tendency toward oscillation or instability
- Q: is self-oscillation tendency or instability always a negative phenomenon?
- Reduced sensitivity to variations in system parameters
- Reduced effects of nonlinearities
- Reduced effects of external disturbances and noise
- Increased system bandwidth

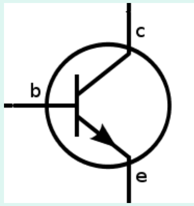


Feedback - information/signal flow



$$Y(s)=\frac{A(s)}{1+A(s)F(s)}U(s)\overset{|A(s)|\to\infty}{\approx}\frac{U(s)}{F(s)}$$

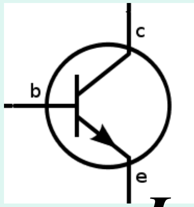
$$U_\sigma(s)=U(s)-F(s)Y(s)=\frac{U(s)}{1+A(s)F(s)}\overset{|A(s)|\to\infty}{\approx}0$$



Remarks on feedback

- Use negative feedback to correct imperfections/uncertainties:
  - $A \sim 10^5 - 10^7$ - large amplification, but not accurate
  - $F \sim 0.001 - 0.1$ - very well controlled attenuation
  - $A_{CL} = 1/F$ - **large and accurate gain**!
- The negative feedback enhances the assumption of small input signal

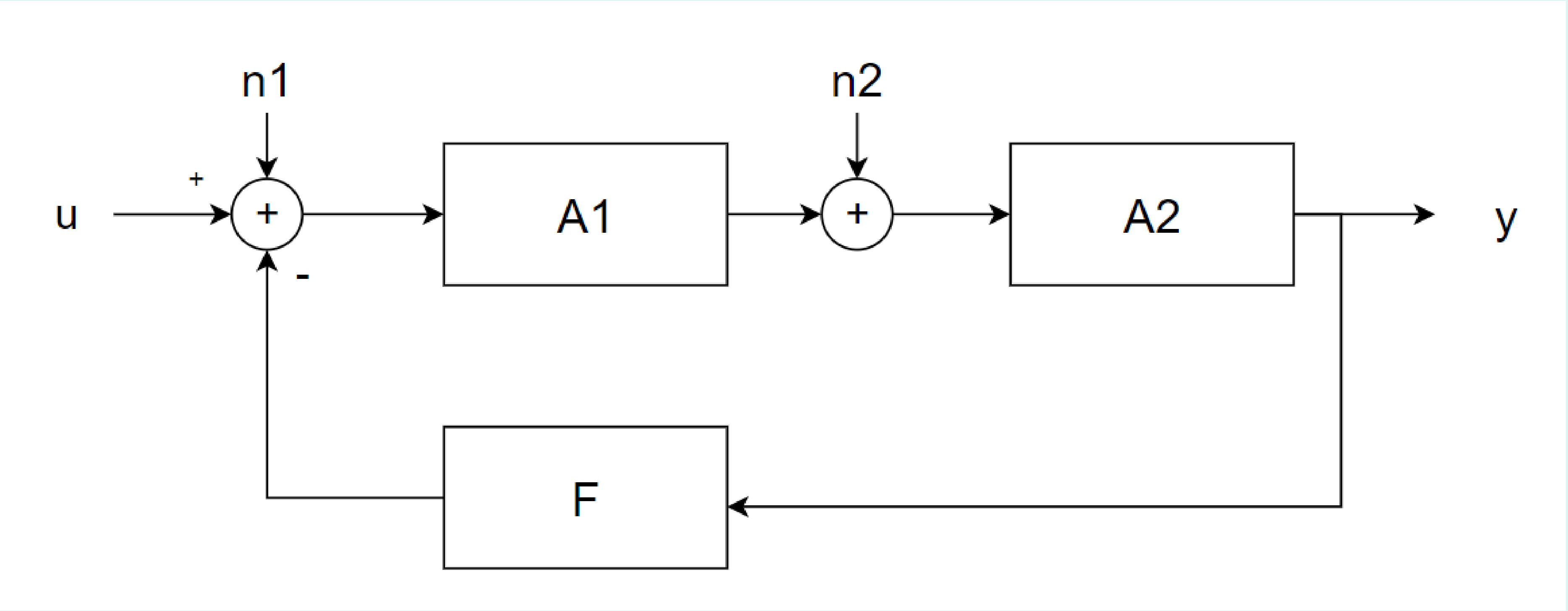
$$U_\sigma(s) = U(s) - F(s)Y(s) = \frac{U(s)}{1 + A(s)F(s)} \overset{|A(s)| \to \infty}{\approx} 0$$



Example: noise considerations

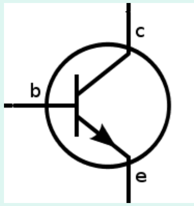
- ***In a general system, S/N is essentially given by the input stage (when the signal is very small)***
- ***The small amplitudes of the signal justifies the use of small-signal models for the subsystems (linearization around the static operating point)***
- ***Additional measures to ensure the validity of this assumption: architectural solutions → a negative feedback at the system level ensures that the input signal operates very close to zero***

Noise in feedback systems



$$Y(s) = \frac{A_1(s)A_2(s)}{1 + A_1(s)A_2(s)F(s)}\left(U(s) + N_1(s)\right) + \frac{A_2(s)}{1 + A_1(s)A_2(s)F(s)}N_2(s)$$

$$SNR_1 = \frac{H_u(s)}{H_{n1}(s)}\frac{U(s)}{N_1(s)} = \frac{U(s)}{N_1(s)} \qquad SNR_2 = \frac{H_u(s)}{H_{n2}(s)}\frac{U(s)}{N_2(s)} = A_1(s)\frac{U(s)}{N_2(s)}$$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