

Lecture 2

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Open-loop versus closed-loop

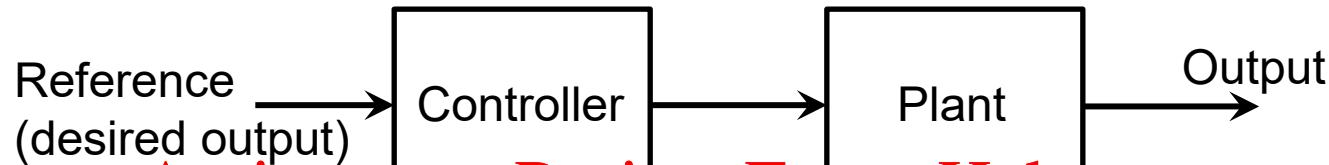
Outline

- Motivation
- Static example (car cruise control)
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- Dynamic systems - general case
- Operational amplifier
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- Conclusions Add WeChat powcoder

Motivation

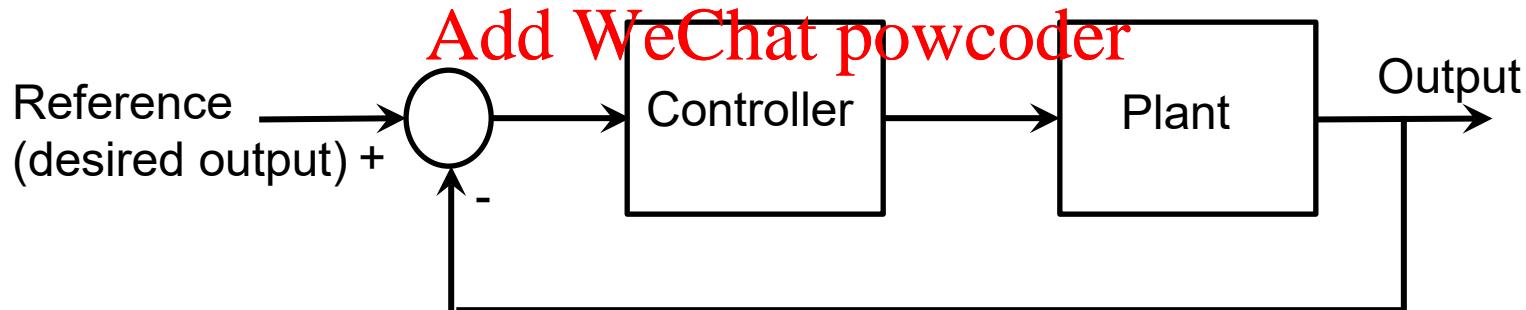
- This subject is mainly about closed loop (feedback) control, but open loop control is sometimes useful.
- The considered [examples](https://powcoder.com) capture the main differences between open and closed loop.
- More details will be given in the following lectures.

Open loop and closed loop



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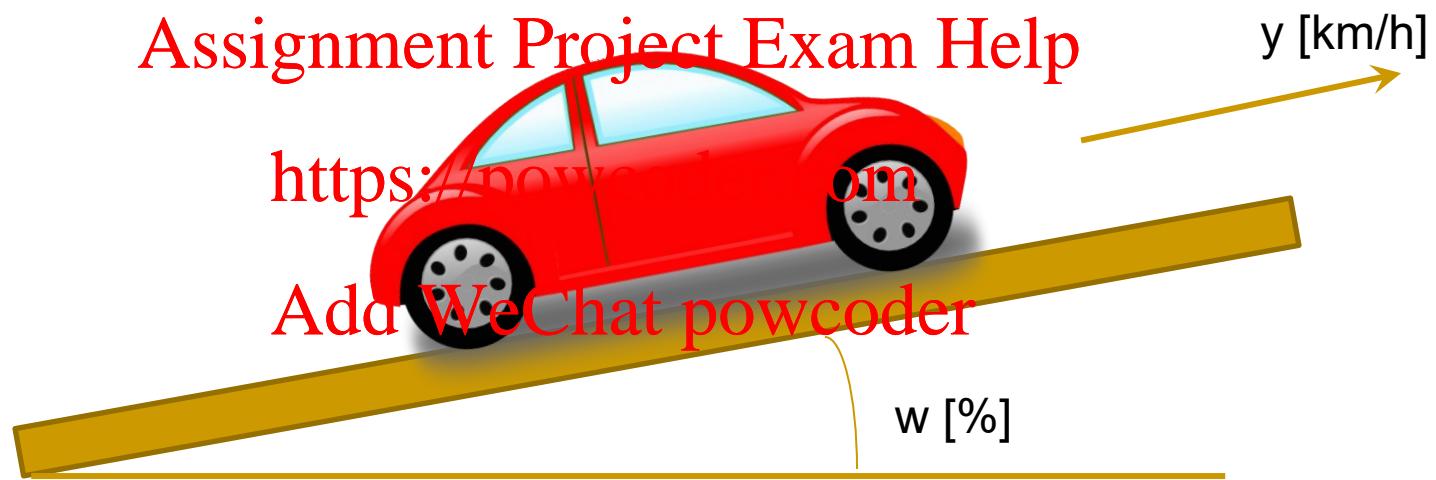
CLOSED LOOP CONTROL

Open or Closed Loop?

- Toaster
 - Electric Kettle
 - Hand drier
 - Washing machine
 - Dishwasher
 - Power Steering
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Open versus closed loop

- Cruise control problem (ignore dynamics):

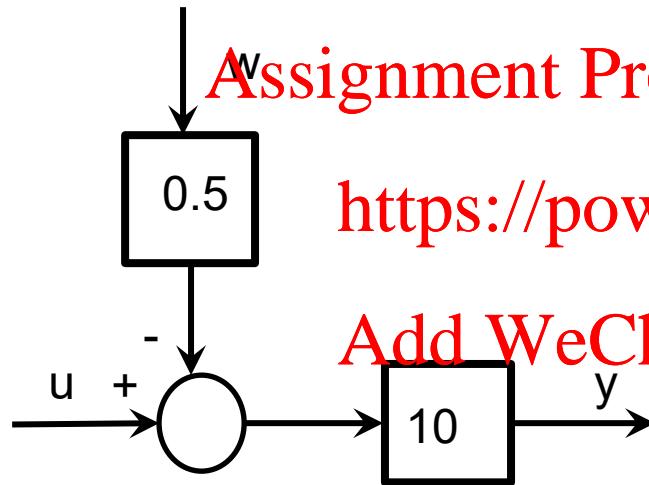


Model is found to be $y = 10 (u - 0.5 w)$

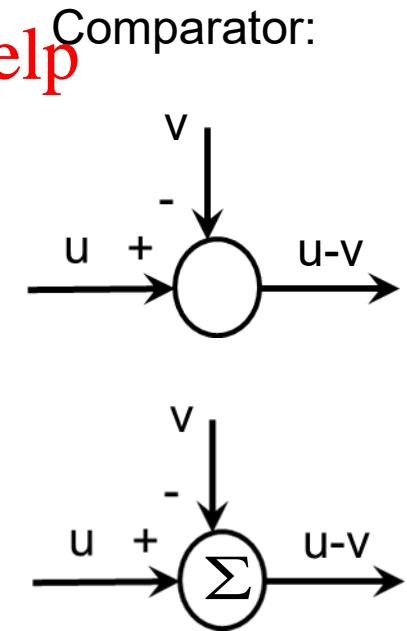
u [degrees] is the throttle angle

Block diagram

- We have the following block diagram:

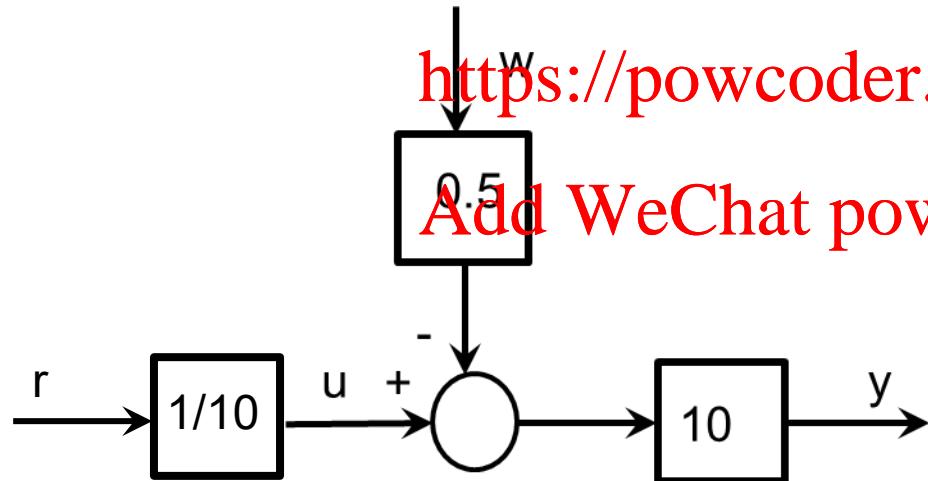


$$y = 10(u - 0.5w)$$



Open loop controller

- We have the following block diagram:



Assignment Project Exam Help $y_{ol} = 10(u - 0.5w)$

$$= 10 \left(\frac{r}{10} - 0.5w \right)$$
$$= r - 5w$$

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$$e_{ol} = r - y_{ol} = 5w$$

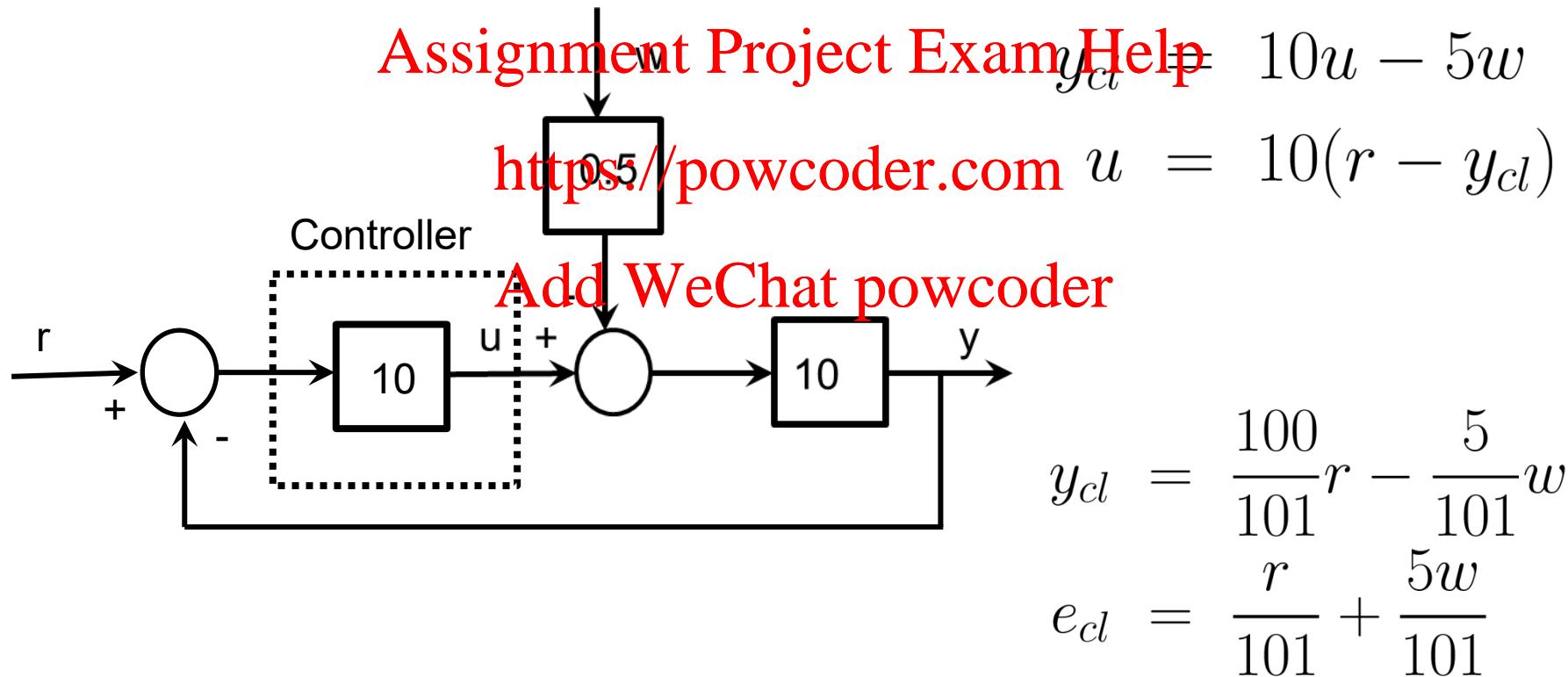
$$\% \text{error} = 500 \frac{w}{r}$$

Comments on open loop

- *When disturbance is zero, we have perfect tracking* $r=y$ or in other words the error is zero. [Assignment](#) [Project](#) [Exam](#) [Help](#)
- When $w=1$, ~~$r=65$, then $y=60$~~ and we get 7.69% error in speed. [Add WeChat](#) [powcoder](#)
- When $w=2$, $r=65$, then $y=55$ and we get 15.38% error in speed.
- We can say that *the scheme is not robust* with respect to disturbance.

Closed loop controller

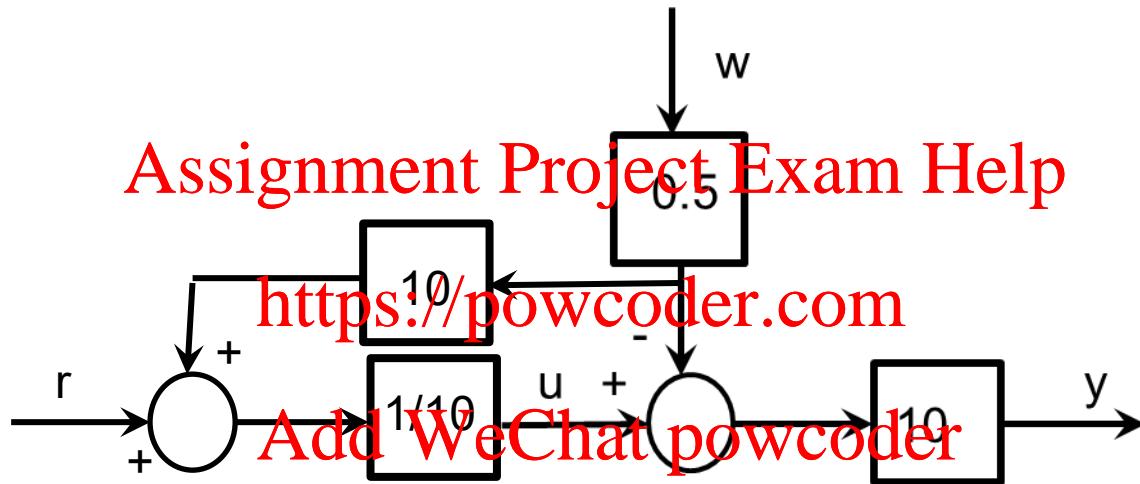
- We have the following block diagram:



Comments on closed loop

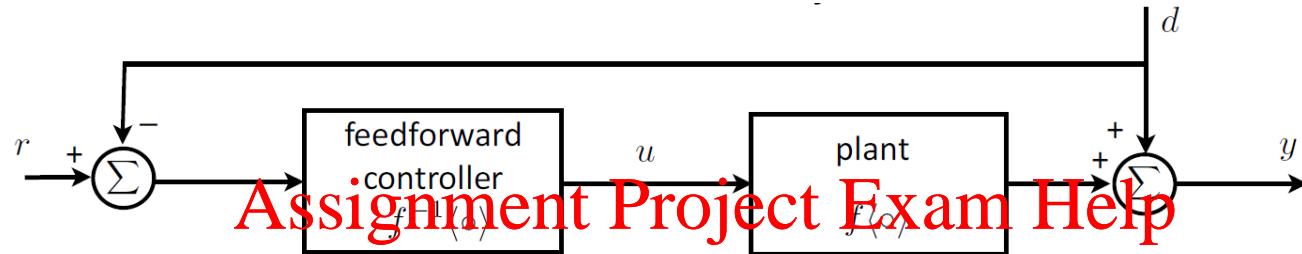
- *When disturbance is zero, we do not have perfect tracking! The error is 0.643%*
- If $w=1$, $r=65$, the error is 0.693%. Note that it is 10 times ~~smaller than in the open loop case!~~ Assignment Project Exam Help
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- We can say that *feedback improves robustness* of the system in general.

What if we measure disturbance?



$$y = 10(u - 0.5w) = 10 [1/10(r+5w) - 0.5w] = r$$

General case open loop (we measure disturbance)



- We want

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$$r = y = f(u) + d \quad \Longleftarrow \quad u = f^{-1}(r - d)$$

where $f(\circ)$ is a causal mapping and $f^{-1}(\circ)$ is its inverse.

Comments

- Open loop control gives perfect tracking in a perfect scenario (no disturbance, perfect model). [Assignment](#) [Project](#) [Exam](#) [Help](#)
- Open loop control ~~requires~~ a lot:
 - The disturbance ~~Add WeChat~~ [powcoder](#) needs to be measured
 - The model needs to be inverted exactly
 - The inverse may not be realisable
 - Model and inverse need to be “BIBO stable”

An alternative implementation (no disturbance)

$$u=100$$

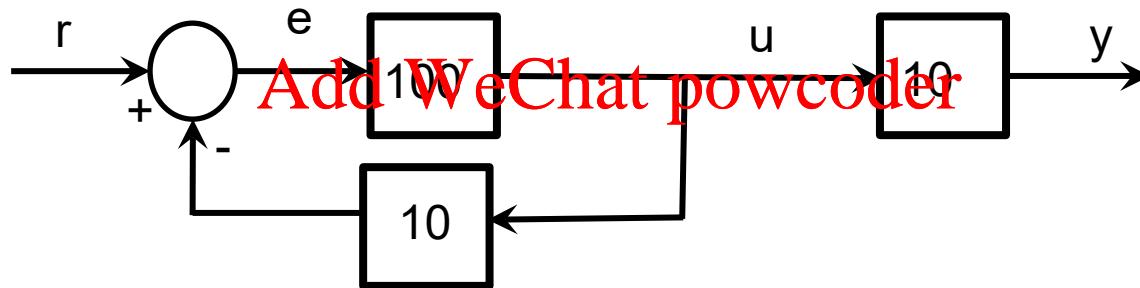
$$e = r - 10u$$

$$u+1000u=100r$$

$$u=100 r/(1+1000) \approx r/10$$

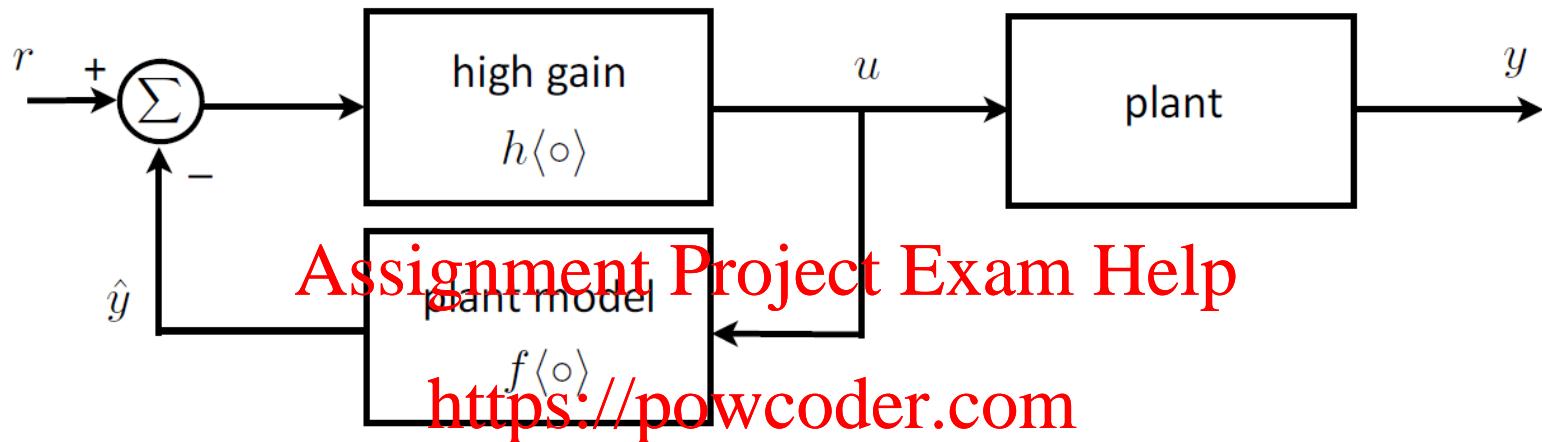
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$$y = 10 u = 10 (100/(1+1000) r) \approx 10 (1/10 r) = r$$

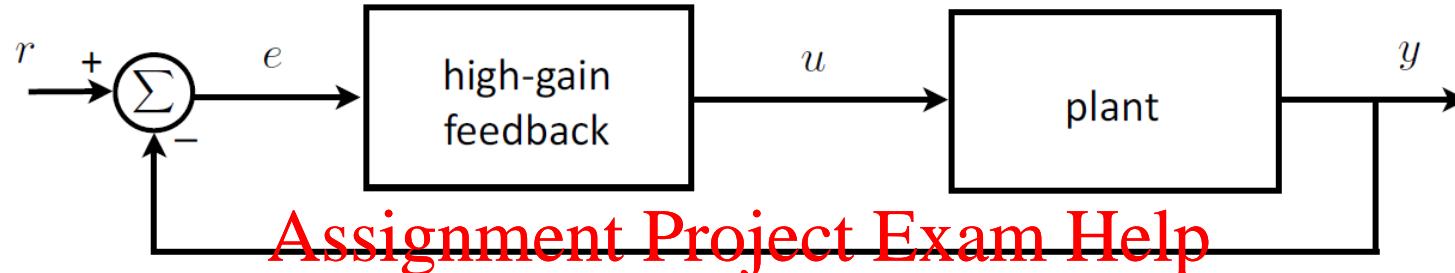
Approximate open-loop inversion..



- We have here Add WeChat powcoder

$$\begin{aligned} u = h \langle r - f \langle u \rangle \rangle &\implies r - f \langle u \rangle = h^{-1} \langle u \rangle \\ &\implies u = f^{-1} \langle r - h^{-1} \langle u \rangle \rangle \stackrel{\text{for high-gain } h}{\approx} u = f^{-1} \langle r \rangle \implies y \approx r \end{aligned}$$

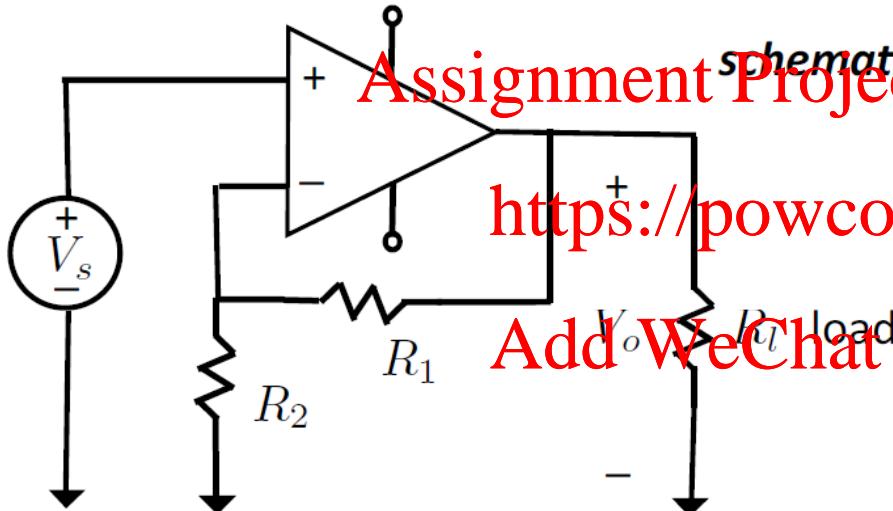
→ High-gain closed-loop control!



- This scheme can be viewed as an alternative to approximate open loop control <https://powcoder.com> Add WeChat powcoder
- High-gain feedback controllers respond aggressively to small errors. May destabilise the system.
- But feedback can help make the system robust to disturbances and uncertainty

Example: Operational amplifier in feedback configuration

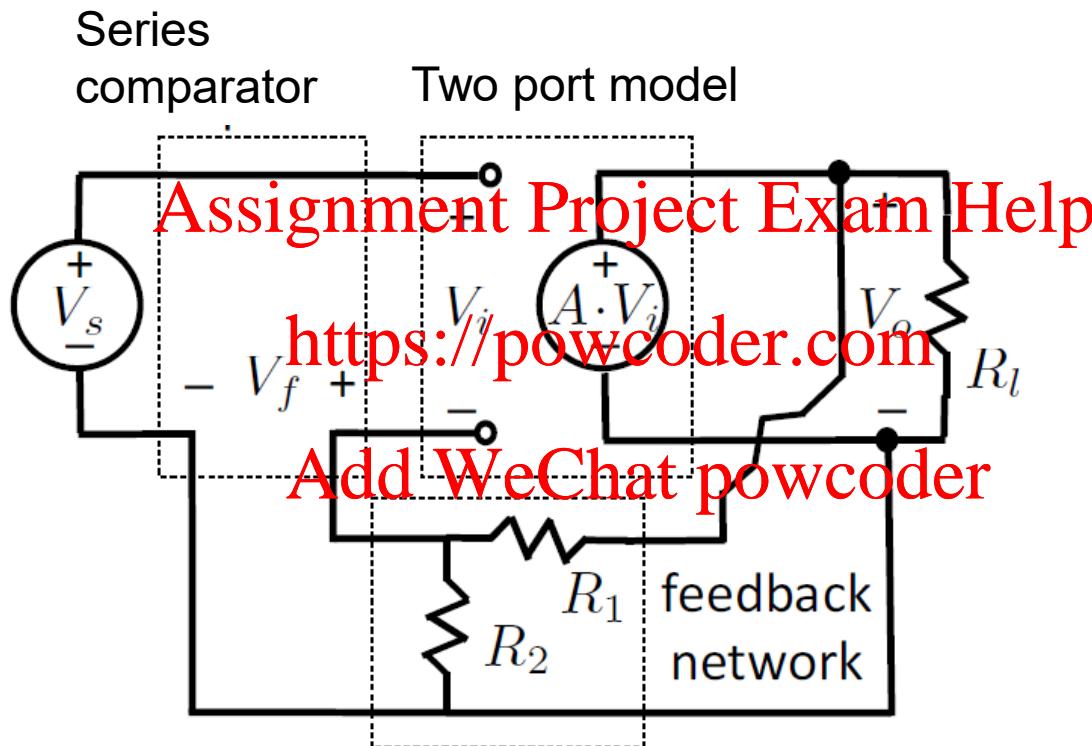
- High gain amplifiers are crucial in long-distance telecoms
- Major issue: very uncertain gain
- Feedback mitigates this uncertainty



Comments

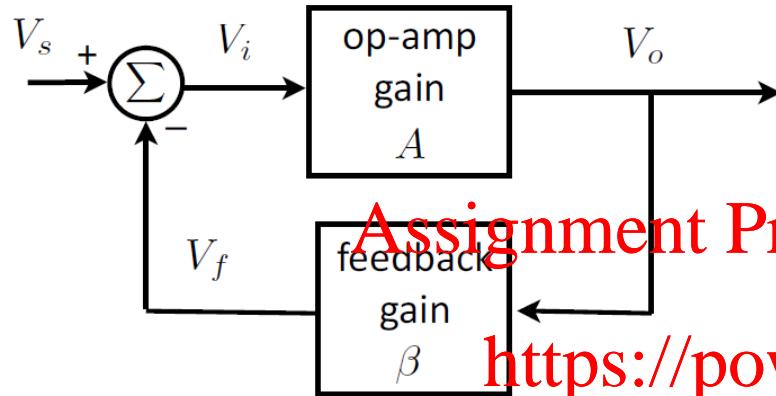
- Too high a gain may destabilise the system.
- But too low a gain can lead to poor robustness against disturbances
- Nyquist and Bode in Bell Labs formalised these trade-offs from 1920-40, sparking the “Golden Age of Invention” in the US, and the birth of feedback control theory.

Opamp model



$$\beta = R_2 / (R_1 + R_2)$$

Simplified analysis



$$\beta = R_2 / (R_1 + R_2)$$

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$$\left. \begin{array}{l} V_i = V_s - V_f \\ V_o = A \cdot V_i \\ V_f = \beta \cdot V_o \end{array} \right\} \rightarrow V_o = A \cdot (V_s - \beta \cdot V_o)$$

$$V_o = \left(\frac{A}{1 + \beta \cdot A} \right) \cdot V_s \text{ for large } A \approx \frac{1}{\beta} \cdot V_s$$

Summary

- Open loop control gives perfect tracking when there are no disturbances and model uncertainties. However, it is NOT robust to disturbances and modelling errors.
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- Closed loop (feedback) may give imperfect tracking when there are no disturbances and model uncertainties. However, the scheme is robust to disturbances and modelling errors.