

# Föreläsning 12 (Sista)

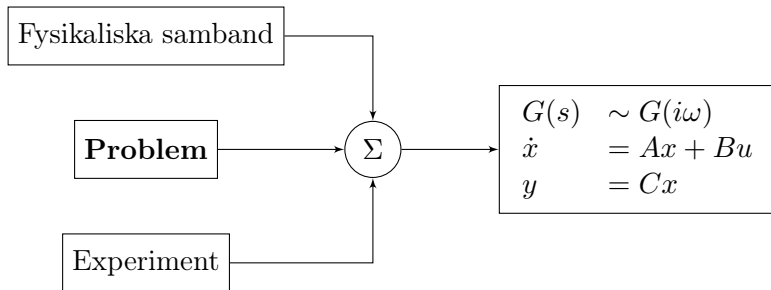
## Reglerteknik AK

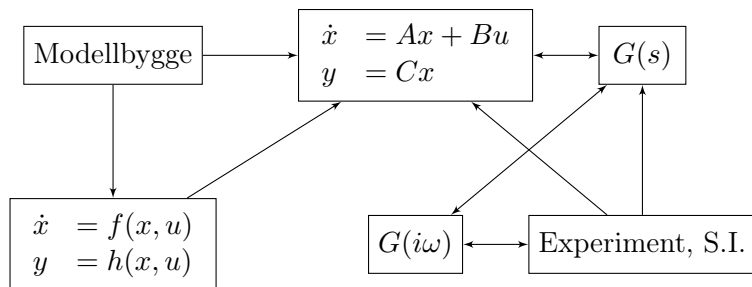
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Avdelningen för reglerteknik  
Skolan för elektro- och systemteknik

9 Oktober 2014



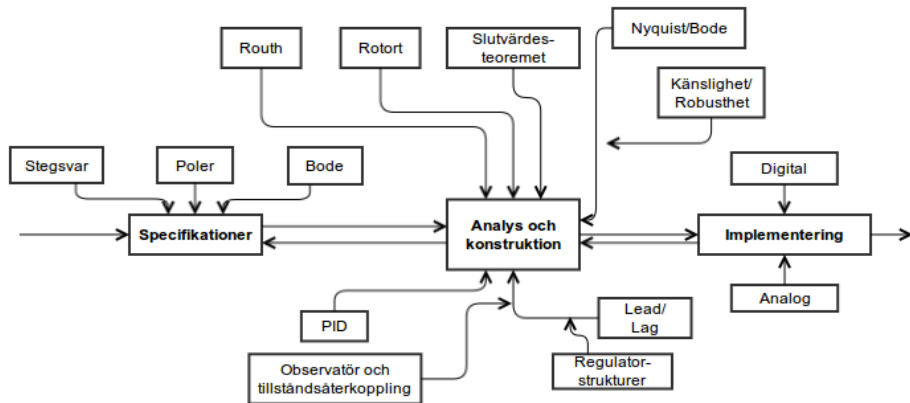




Verkliga system är komplicerade:

$$G^0(s) = G(s)[1 + \Delta_G(s)], \quad |\Delta_G(i\omega)| \leq g(\omega) \quad \forall \omega$$

# Sammanfattning



## Rotort:

- I.  $n$  Startpunkter ( $K = 0$ )
- II.  $m$  Ändpunkter ( $K = \infty$ )
- III. Var ligger  $\infty$ ? (Asymptoter)  
Riktning:  $\frac{\pi}{n-m} + k \cdot \frac{2\pi}{n-m}$   
Skärningspunkt:  $\frac{1}{n-m} (\sum p_i - \sum q_j)$
- IV. Skärning med reella axeln. ”*Udda summa*”
- V. Skärning med imaginära axeln. Ansätt  $s = i\omega$
- VI. Rita rotort och **dra slutsats**

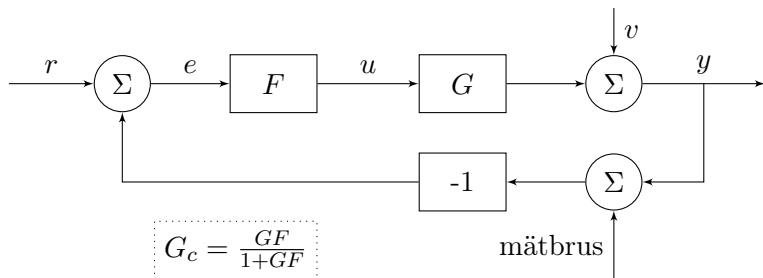
## Slutvärdesteoremet:

Kom ihåg att kolla att slutvärdet existerar! (slutna systemets poler strikt i V.H.P.)

Steg  $\frac{1}{s}$

Ramp  $\frac{1}{s^2}$

# Sammanfattning - Specifikationer



## Tidsdomänen:

Stigtid:  $T_r$

Insvängningstid:  $T_s$

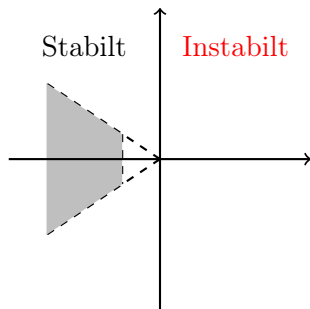
Översläng:  $M$

## Frekvensdomänen:

Bandbredd:  $\omega_B$

Resonanstopp:  $M_p$

Resonansfrekvens:  $\omega_r$



Avstånd till origo  $\approx$  snabbhet

Vinkel  $\approx$  svängighet



**Nyquist:**

$$G_o(i\omega)$$

**Bode:**

$$|G_o(i\omega)|, \arg [G_o(i\omega)]$$

Tolkning  $\leftrightarrow$  rita

$$\left. \begin{array}{l} \text{skärfrekvens: } \omega_c \\ \text{fasmarginall: } \varphi_m \end{array} \right\} \iff |G(i\omega_c)| = 1$$

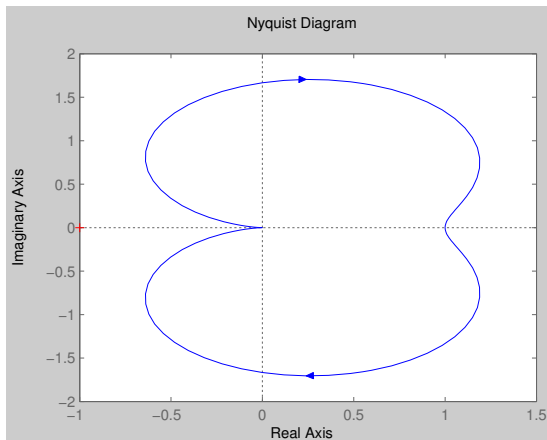
Amplitudmarginalen kan läsas av i Bodediagram eller Nyquistkurva (se figur 5.2 samt 5.3 i boken).

# Sammanfattning - Nyquistkriteriet

Antag att  $G_o(s)$  saknar poler i H.H.P. och att Nyquistkurvan  $\mathbf{e}j$  omcirklar  $-1$ .

$\Rightarrow G_c(s)$  saknar poler i H.H.P.

$\Rightarrow$  Stabilt återkopplat system.



Öppna systemets Bodediagram  $\leftrightarrow$  Slutna systemets Bodediagram

Fördubbla  $\omega_c \leftrightarrow$  Fördubbla  $\omega_B$

$$\varphi_m \sim M_p$$

liten  $\rightarrow$  stor ( $\varphi_m \approx 50^\circ - 60^\circ$  OK)

$$G_o(i\omega) \text{ stor} \Rightarrow G_c(i\omega) \approx 1$$

$$G_o(i\omega) \approx -1 \Rightarrow G_c(i\omega) \text{ stor}$$

Känslighet (störningar):

$$S = \frac{1}{1 + FG}$$

Robusthet (modellfel):

$$T = \frac{FG}{1 + FG} = 1 - S$$

**PID-regulator:**

$$U(s) = K \left( 1 + \frac{1}{T_I} \frac{1}{s} + T_D s \right) = K_P + K_I \frac{1}{s} + K_D s$$

**Lead-/Lag-länk:**

$$F(s) = K \frac{\tau_D s + 1}{\beta \tau_D s + 1} \frac{\tau_I s + 1}{\tau_I s + \gamma}$$

Önska  $\bar{\omega}_c$  (Lägg till  $5.7^\circ$  extra på fasmarginalen,  $\varphi_m$ )

$$\implies \beta \implies \tau_D \implies K$$

$$\tau_I = \frac{10}{\bar{\omega}_c} \text{ (iterera)}$$

Välj  $\gamma$  liten.

$$\begin{cases} \dot{x} &= Ax + Bu \\ y &= Cx \end{cases}$$

$$\begin{aligned} \dot{\hat{x}} &= A\hat{x} + Bu + K(y - C\hat{x}) \\ \det [sI - (A - KC)] &= 0 \end{aligned}$$

$$\begin{aligned} u &= -Lx + l_0r \\ \det [sI - (A - BL)] &= 0 \end{aligned}$$

⇓

$$u = -L\hat{x} + l_0r$$

Styrbarhet + Observerbarhet

## Regulatorstrukturer:

- Framkoppling
- Kaskadreglering
- Otto Smith

## Implementering:

- Euler bakåt
- Tustins formuel

Differentialekvationer  $\mapsto$  differensekvationer

- Man får ha boken och Beta med sig (samt. miniräknare).  
**Läs boken innan tentan!**
- Problemlösning (ej utantillavskrivningar). Träna på gamla tentor!
- **Observera** att man måste vara anmäld för att få skriva tentan!




Master's programme in Systems, Control and Robotics!







- Olinjär reglering, period 2
- Hybrida och inbyggda reglersystem, period 3
- Reglerteknik, fortsättningskurs , period 4
- Modellering av dynamiska system, period 1

Disruptive technologies: Advances that will transform life, business, and the global economy

According to McKinsey Global Institute (Maj 2103):

## Speed, scope, and economic value at stake of 12 potentially economically disruptive technologies

	Illustrative rates of technology improvement and diffusion	Illustrative groups, products, and resources that could be impacted <sup>1</sup>	Illustrative pools of economic value that could be impacted <sup>1</sup>
	<b>Mobile Internet</b> <b>\$5 million vs. \$400<sup>2</sup></b> Price of the fastest supercomputer in 1975 vs. that of an iPhone 4 today, equal in performance (MFLOPS) <b>5x</b> Growth in sales of smartphones and tablets since launch of iPhone in 2007	<b>4.3 billion</b> People remaining to be connected to the Internet, potentially through mobile Internet <b>1 billion</b> Transaction and interaction workers, nearly 40% of global workforce	<b>\$1.7 trillion</b> GDP related to the Internet <b>\$25 trillion</b> Interaction and transaction worker employment costs, 70% of global employment costs
	<b>Automation of knowledge work</b> <b>100x</b> Increase in computing power from IBM's Deep Blue (chess champion in 1997) to Watson (Jeopardy winner in 2011) <b>400+ million</b> Increase in number of users of intelligent digital assistants like Siri and Google Now in past 3 years	<b>230+ million</b> Knowledge workers, 9% of global workforce <b>1.1 billion</b> Smartphone users, with potential to use automated digital assistance apps	<b>\$9+ trillion</b> Knowledge worker employment costs, 27% of global employment costs
	<b>The Internet of Things</b> <b>300%</b> Increase in connected machine-to-machine devices over past 5 years <b>80-90%</b> Price decline in MEMS (microelectromechanical systems) sensors in past 5 years	<b>1 trillion</b> Things that could be connected to the Internet across industries such as manufacturing, health care, and mining <b>100 million</b> Global machine to machine (M2M) device connections across sectors like transportation, security, health care, and utilities	<b>\$36 trillion</b> Operating costs of key affected industries (manufacturing, health care, and mining)
	<b>Cloud technology</b> <b>18 months</b> Time to double server performance per dollar <b>3x</b> Monthly cost of owning a server vs. renting in the cloud	<b>2 billion</b> Global users of cloud-based email services like Gmail, Yahoo, and Hotmail <b>80%</b> North American institutions hosting or planning to host critical applications on the cloud	<b>\$1.7 trillion</b> GDP related to the Internet <b>\$3 trillion</b> Enterprise IT spend
	<b>Advanced robotics</b> <b>75-85%</b> Lower price for Baxter <sup>3</sup> than a typical industrial robot <b>170%</b> Growth in sales of industrial robots, 2009-11	<b>320 million</b> Manufacturing workers, 12% of global workforce <b>250 million</b> Annual major surgeries	<b>\$6 trillion</b> Manufacturing worker employment costs, 19% of global employment costs <b>\$2-3 trillion</b> Cost of major surgeries
	<b>Autonomous and near-autonomous vehicles</b> <b>7</b> Miles driven by top-performing driverless car in 2004 DARPA Grand Challenge along a 150-mile route <b>1,540</b> Miles cumulatively driven by cars competing in 2005 Grand Challenge <b>300,000+</b> Miles driven by Google's autonomous cars with only 1 accident (which was human-caused)	<b>1 billion</b> Cars and trucks globally <b>450,000</b> Civilian, military, and general aviation aircraft in the world	<b>\$4 trillion</b> Automobile industry revenue <b>\$155 billion</b> Revenue from sales of civilian, military, and general aviation aircraft

	<b>Next-generation genomics</b>	<b>10 months</b> Time to double sequencing speed per dollar  <b>100x</b> Increase in acreage of genetically modified crops, 1995–2012	<b>26 million</b> Annual deaths from cancer, cardiovascular disease, or type 2 diabetes  <b>2.6 billion</b> People employed in agriculture	<b>\$6.5 trillion</b> Global health-care costs  <b>\$1.1 trillion</b> Global value of wheat, rice, maize, soy and barley
	<b>Energy storage</b>	<b>40%</b> Price decline for a lithium-ion battery pack in an electric vehicle since 2009	<b>1 billion</b> Cars and trucks globally  <b>1.2 billion</b> People without access to electricity	<b>\$2.5 trillion</b> Revenue from global consumption of gasoline and diesel  <b>\$100 billion</b> Estimated value of electricity for households currently without access
	<b>3D printing</b>	<b>90%</b> Lower price for a home 3D printer vs. 4 years ago  <b>4x</b> Increase in additive manufacturing revenue in past 10 years	<b>320 million</b> Manufacturing workers, 12% of global workforce  <b>8 billion</b> Annual number of toys manufactured globally	<b>\$11 trillion</b> Global manufacturing GDP  <b>\$85 billion</b> Revenue from global toy sales
	<b>Advanced materials</b>	<b>\$1,000 vs. \$50</b> Difference in price of 1 gram of nanotubes over 10 years  <b>116x</b> Strength-to-weight ratio of carbon nanotubes vs. steel	<b>7.6 million tons</b> Annual global silicon consumption  <b>45,000 metric tons</b> Annual global carbon fiber consumption	<b>\$1.2 trillion</b> Revenue from global semiconductor sales  <b>\$4 billion</b> Revenue from global carbon fiber sales
	<b>Advanced oil and gas exploration and recovery</b>	<b>3x</b> Increase in efficiency of US gas wells, 2007–11  <b>2x</b> Increase in efficiency of US oil wells, 2007–11	<b>22 billion</b> Barrels of oil equivalent in natural gas produced globally  <b>30 billion</b> Barrels of crude oil produced globally	<b>\$90 billion</b> Revenue from global sales of natural gas  <b>\$3.4 trillion</b> Revenue from global sales of crude oil
	<b>Renewable energy</b>	<b>85%</b> Lower price for a solar photovoltaic cell per watt since 2000  <b>19x</b> Growth in solar photovoltaic and wind generation capacity since 2000	<b>21,000 TWh</b> Annual global electricity consumption  <b>13 billion tons</b> Annual CO <sub>2</sub> emissions from electricity generation, more than from all cars, trucks, and planes	<b>\$3.5 trillion</b> Value of global electricity consumption  <b>\$80 billion</b> Value of global carbon market transactions

1 Not comprehensive; indicative groups, products, and resources only.

2 For CDC-7600, considered the world's fastest computer from 1989 to 1975; equivalent to \$32 million in 2013 at an average inflation rate of 4.3% per year since launch in 1969.

3 Baxter is a general-purpose basic manufacturing robot developed by startup Rethink Robotics.

SOURCE: McKinsey Global Institute analysis