MODELLISTICA

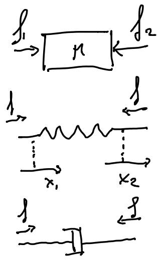
IMPEDENZA Z

$V = Ri$ — ● $G = R$

$v = \frac{1}{C}\int_{-\infty}^{t} i(t)\,dt$ — ● $G = \frac{1}{Cs}$

$D_{vC} = \frac{i}{C}$

$v = L\,Di$ — ● $G = sL$



● $MD^2x = f_1 - f_2$

● $f = k(x_1 - x_2)$

Dx_1

● $f = B(v_1 - v_2)$

$u \to \boxed{\Sigma} \to y$

- LINEARE
- STAZIONARIO

$\sum_0^n a_i D^i y = \sum_0^m b_i D^i u \qquad n \geq m$

SISTEMA CON MEMORIA (STATO)

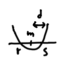
NON CONOSCE IL FUTURO

● $D\frac{f}{g} = \frac{f'g - fg'}{g^2}$ ● $De^{f(x)} = f'(x) \cdot e^{f(x)}$

● $Dfg = f'g + fg'$ ● $Dk = 0$

● $Dx^n = nx^{n-1}$ $\quad \int e^{cx}dx = \frac{e^{cx}}{c}$

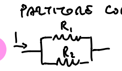
QUADRATICA



● $x^2 + bx + c = 0$ ← MONICO

$m = -b/2 \quad d^2 = m^2 - c \qquad r,s = m \pm d$

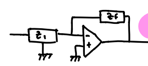
PARTITORE CORRENTE



● $I_{R_1} = I \cdot \frac{R_2}{R_1 + R_2}$

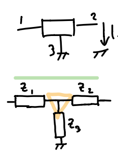
$R_{TOT} = \frac{R_1 \cdot R_2}{R_1 + R_2}$

OPERAZIONALE



● $G(s) \simeq -\frac{Z_F}{Z_i}$

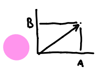
TRIPOLO



$\left.\begin{matrix} Z_{12}(s) \\ Z_{21}(s) \end{matrix}\right\} = \frac{V_1(s)}{I_{2c}(s)} \Big|$ COND. INIZ. NULLE

● $Z_{12}(s) = z_1 + z_2 + \frac{z_1 z_2}{z_3}$

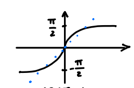
VETTORI



● $|P| = \sqrt{A^2 + B^2}$

$\angle P = \arctan\left(\frac{B}{A}\right)$

ARG



GRADO MAX CONTINUITÀ

$f(t) \in C^{\rho-1,\infty} \qquad \rho = n - m \qquad \frac{b_m s^m}{a_n s^n}$

LAPLACE

$$F(s) = \int_{0^-}^{+\infty} f(t)\, e^{-st}\, dt \qquad s = \sigma + j\omega$$

● $\mathcal{L}[D^i f] = s^i F(s) - \sum_j^{i-1} s^j D^{i-1-j} f(0^-)$

s^j D^i

$aD^2u = a(s^2U - sf(0^+) - Df(0^+))$

$$\mathcal{L}\left[\int_0^t f(v)\,dv\right] = \frac{1}{s}F(s)$$

NOTEVOLI

● $\mathcal{L}[1(t)] = \frac{1}{s} \qquad \mathcal{L}[t\,1(t)] = \frac{1}{s^2} \qquad \mathcal{L}[t^n] = \frac{n!}{s^{n+1}}$

$\mathcal{L}[\delta] = 1 \qquad \mathcal{L}[\delta^{(1)}] = s$

● $\mathcal{L}[e^{at}] = \frac{1}{s-a}$

● $\mathcal{L}[\sin(\beta t)] = \frac{\beta^2}{s^2 + \beta^2} \qquad \mathcal{L}[\cos(\beta t)] = \frac{s}{s^2 + \beta^2}$

TRASLAZIONE

$$\mathcal{L}[t^n e^{at}] = \frac{n!}{(s-a)^{n+1}}$$

CONVOLUZIONE

$$\mathcal{L}(f * g) = F(s) \cdot G(s)$$

$$f * g := \int_0^t f(v) \cdot g(t-v)\,dv$$

VALORE FINALE, INIZIALE

$\lim_{t \to +\infty} f = \lim_{s \to 0} sF \qquad \lim_{t \to 0^+} f = \lim_{s \to +\infty} sF$

$\exists \qquad \exists$

TRASLAZIONE TEMPO, S

● $\mathcal{L}[f(t-t_0) \cdot 1(t-t_0)] = F \cdot e^{-t_0 s}$

$\mathcal{L}[f e^{at}] = F(s-a)$

ANTITRASFORMATA

$$\mathcal{L}^{-1}[F] = f(t) = \frac{1}{2\pi j}\int_{\sigma_0 - j\infty}^{\sigma_0 + j\infty} F(s) \cdot e^{st}\, ds$$

● $\mathcal{L}^{-1}\left[\frac{1}{(s-a)^n}\right] = \frac{1}{(n-1)!} t^{n-1} e^{at}$ ← SEGNO!

SIMILE A k_{ij}

FRATTI COMPLESSI CONIUGATI

$\mathcal{L}^{-1}\left[\frac{k}{s-p} + \frac{\bar{k}}{s-\bar{p}}\right] = 2|k|e^{\Re p\, t}\cos(\Im p\, t + \arg k)$ $\quad \bar{p}$ = CONIUGATO $\quad k, p \in \mathbb{C}$

SCOMPOSIZIONE FRATTI SEMPL.

$$F = \frac{b(s)}{(s-p_1)^{r_1}(s-p_2)^{r_2}\cdots{}^{r_h}}$$

RELAZIONE RESIDUI

$\sum k_i = \begin{cases} 0 & n-m > 1 \\ \frac{b_m}{a_n} & n-m = 1 \end{cases}$

PIÙ BASSI

TIPO $k_{12} + k_{23} + k_3 = 0$

MONOMIO POT. MASSIMA

$\frac{b_m s^m \ldots}{a_n s^n \ldots}$

● $F = \frac{k_1}{(s-p_1)^{r_i}} + \frac{k_2}{(s-p_1)^{r_i - 1}} + \cdots = \sum_i^h \sum_j^{r_i} \frac{k_{ij}}{(s-p_i)^{r_i + 1 - j}}$

OCCHIO A GRADO DERIVATA

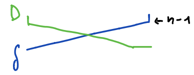
NON SCENDE

● $k_{ij} = \frac{1}{(j-1)!} D^{j-1}\left[(s-p_i)^{r_i} \cdot F\right]\Big|_{s=p_i}$

OCCHIO AL SEGNO

DERIVATE GENERALIZZATE

- $D^{*h} f(t) = D^h f(t) + \underbrace{(D^{h-1} f_+ - D^{h-1} f_-)}_{\text{SALTO}} \delta(t) + \dots + (f_+ - f_-)\, \delta^{(h-1)}(t)$



EGUAGLIANZA F. IMPULSIVE

$\cancel{c_{-1}} + \boxed{c_0}\,\delta + \boxed{c_1}\,\delta^{(1)} + \dots$

$\cancel{d_{-1}} + \boxed{d_0}\,\delta + \boxed{d_1}\,\delta^{(1)} + \dots$

VASCHY

$y_{FOR}(t) = \overbrace{\int_0^t u'(v) \cdot g_s(t-v)\, dv}^{*} + u(0^+) \cdot g_s(t)$

FUNZIONE DI TRASFERIMENTO

$Y = \dfrac{\sum^{m} b_i s^i}{\sum^{n} a_i s^i} U + \dfrac{\sum_{i=1}^{n} a_i \sum_{j=0}^{i-1} D^{i-1-j} y_- s^j - \sum_{i=1}^{m} b_i \sum^{i-1} \cdots}{\sum^{n} a_i s^i}$

RISPOSTA FORZATA G — POLINOMIO CARATTERISTICO — RISPOSTA LIBERA

$\sum^{n} a_i D^{*i} y = \sum^{m} b_i D^{*i} u$

ES: $Dy + 2y = 2Du + 2u \iff G = \frac{2s+2}{s+2} U + \text{LIB.}$

POLO = RADICE DEL POLINOMIO $a_n s^n$

= FREQUENZA CRITICA

ZERO = RADICE DEL POLINOMIO $b_m s^m$

- $g(t) = \mathcal{L}^{-1}(G)$ IMPULSO
- $g_s(t) = \mathcal{L}^{-1}(G \cdot \frac{1}{s})$ GRADINO (STEP)

$g(t) = D^{*} g_s(t)$

$G = \dfrac{\text{USCITA}}{\text{INGRESSO}}$ FUNZ. DI TRASFERIMENTO

$K = G(0) = \dfrac{b_0}{a_0}$ GUADAGNO STATICO

POLI

RADICI EQUAZIONE

$\sum^{n} a_i s^i \iff (s-p_1)(s-p_2)\dots$

$\to (s+5)(s+3)\dots$ SEGNO!

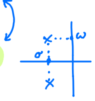
MODI DI UN POLO

- $e^{pt}, t e^{pt}, \dots t^{h-1} e^{pt}$ — ATTENTO A GRADO — h = MOLTEPLICITÀ

$e^{\sigma t} \sin(\omega t + \varphi_1),\ t e^{\sigma t} \sin(\omega t + \varphi_2)$

COMPLESSI $\quad p_{1,2} = \sigma \pm j\omega$

- $(s-\sigma)^2 + \omega^2$



POLI SINUSOIDE

TIPO DI UN SISTEMA

$\dfrac{\dots}{s^h (s-p_1)(s-p_2)\dots}$ QUANTI POLI IN ORIGINE

GRADO MAX CONTINUITÀ

$f \in C^{k,\infty}$ DERIVATA CONTINUA FINO A K-ESIMA

→ MASSIMO TRA GRADO $u(t)$ E GRADO RELATIVO G

ANALISI ARMONICA

$u(t) = U \sin(\omega t)$

SEGNALE INGRESSO

ES. $Y(1)$

- $y_\infty(t) = U\, Y(\omega) \cdot \sin(\omega t + \varphi(\omega))$

$F(\omega) := \dfrac{Y(\omega)}{U} e^{j\varphi(\omega)}$

FUNZIONE RISP. ARMONICA

$Y(s) = G(s) \cdot U(s) \leftarrow \dfrac{\beta^2}{s^2 + \beta^2}$

ES. $-\arctan\omega \dots$

$\varphi(\omega) = \angle G(j\omega)$ ARGOMENTO

FORME STANDARD

$[(s+2)^2+1]^2 \to$ • MOLTEPLICITÀ 2
• $s^2+2s+5 \to$ RADICI
• $-1 \pm 2i$

- $K_1 \dfrac{s^m + b_{m-1} s^{m-1} + \dots + b_0}{s^h + a_{n-1} s^{n-1} + \dots + a_0}$

POLINOMI MONICI

- $K_1 \dfrac{(s-z_1)(s-z_2)\dots}{(s-p_1)(s-p_2)\dots}$

POLI E ZERI

- $K \dfrac{(1+\tau_1' s)(1+\tau_2' s)\dots\left(1 + 2\delta_1 \frac{s}{\omega_{n1}} + \frac{s^2}{\omega_{n1}^2}\right)\dots}{s^h (1+\tau_1 s)(1+\tau_2 s)\dots}$

COSTANTE TRASF. — SISTEMI 1° ORDINE — SISTEMI 2° ORDINE — COPPIA POLI/ZERI COMP. CONIUGATI

TIPO SISTEMA — POLO ORIGINE — COSTANTI DI TEMPO — OCCHIO A SEGNI

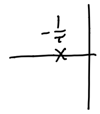
$K = K_1 \cdot \dfrac{b_0}{a_0}$

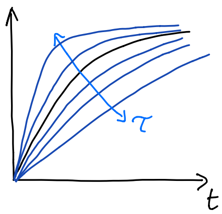
2020 JOHN WHITE

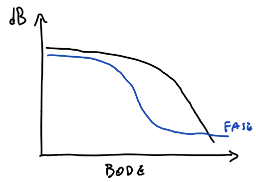
SISTEMI DINAMICI ORDINE 1

GUADAGNO STATICO NORMALIZZATO

$$G(s) = \frac{1}{(1+\tau s)}$$ COST. DI TEMPO







RISPOSTA A GRADINO

$$g_s(t) = 1 - e^{-\frac{t}{\tau}} \quad t \geq 0$$

$$t = 3\tau \Rightarrow 95\%$$

ORDINE 2

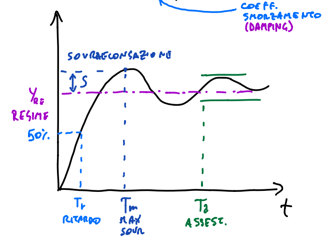
$$G(s) = \frac{\omega_n^2}{s^2 + 2\delta\omega_n s + \omega_n^2} \qquad 0 \leq \delta \leq 1$$

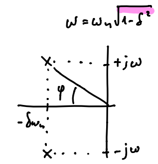
ω_n: PULSAZIONE NATURALE

δ: COEFF. SMORZAMENTO (DAMPING)

POLI: $-\delta\omega_n \pm j\omega_n\sqrt{1-\delta^2}$

MODI: $e^{-\delta\omega_n t}\sin\left(\omega_n\sqrt{1-\delta^2}\,t + \varphi_1\right)$





RISPOSTA A GRADINO

$$y(t) = 1 - \underbrace{A}_{\frac{1}{\sqrt{1-\delta^2}}} e^{-\delta\omega_n t}\sin(\overbrace{\omega}^{\omega_n\sqrt{1-\delta^2}} t + \varphi)$$

$\varphi = \arccos\delta = \operatorname{arctg}\frac{\sqrt{1-\delta^2}}{\delta}$

$$S = 100 \exp\left\{-\frac{\delta\pi}{\sqrt{1-\delta^2}}\right\}$$

DEVE AVERE POLI COMPL.

$$T_A \cong \frac{3}{\delta\omega_n} \qquad T_s \cong \frac{1.8}{\omega_n}$$

STABILITÀ

STABILE	y_{LIB} LIMITATA PER $t \to +\infty$	NO POLI $Re>0$, POLI PUR. IM. MOLTEP. $=1$	SEMPLICI
ASINTOT. STABILE	$\lim_{t\to+\infty} y_{LIB} = 0$	$\forall\, Re\, p < 0$	$\Rightarrow$ BIBO STABILE
SEMPL. STABILE	$\lim_{t\to+\infty} y_{LIB} \neq 0 \vee \nexists\, y_\infty$	$\exists$ POLI PURAM. IM.	DEVONO ESISTERE
INSTABILE	NON LIMITATA	$\exists\, Re\, p > 0 \vee$ POLO PURAM. IM. MOLT. >1	MOLTEPLICITÀ

BIBO

LIMITATEZZA AZIONE FORZANTE $\to$ FORZATA

$$\int_0^\infty |g(\tau)|\,d\tau < +\infty$$ RISPOSTA AD IMPULSO HA ENERGIA FINITA

POLI $\equiv$ RADICI $a(s)$ $\Rightarrow$ RADICI POSITIVE

CRITERIO ROUTH

EQUAZIONE CARATTERISTICA

$$a_n s^n + a_{n-1}s^{n-1} + \ldots + a_0 = 0$$

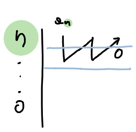
$$G = \frac{b(s)}{a(s)} \quad (\leftarrow 1 + L(s))$$

IN CASO DI SISTEMI IN RETROAZIONE

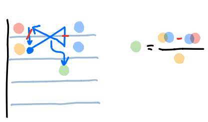
STABILITÀ LEGATA A RADICI (= POLI)

DETERMINA I SEGNI DELLE RADICI

SE SEGNI a_n DIVERSI $\Rightarrow$ INSTABILE



IMPOSTA LA TABELLA



DEFINIZIONE RIGHE SUCCESSIVE

$\to$ RIGA MOLTIPLICABILE PER $K > 0$

$\cancel{2}$ $\cancel{16}$ $\cancel{48}$ $\cancel{0}$

1 8 16 0

PRIMA COLONNA

$\downarrow$

γ_{01}, γ_{02}, $\vdots$, γ_{n1} — VARIAZIONI SEGNI

$-+, +-$ $\to$ RADICE POSITIVA $\to$ INSTABILE

$--, ++$ $\to$ RADICE NEGATIVA $\to$ STABILE

- PRIMO ELEMENTO = 0
  ⇒ INSTABILE
  → MOLTIPLICA PER $(-1)^p$ ← NUMERO DI ZERI
  → TRASLA DI P POSTI NUOVA RIGA $\cdot -1 \quad \cdot -1 \quad \cdot -1$
  → SOMMA LE DUE RIGHE

3	1	3	0
2'	0	-2	0
2''	2	0	0
2	2	-2	0

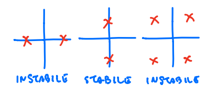
- TUTTI ELEM. NULLI
  ⇒ POLI COMP. CONIUGATI
  → TROVA POLINOMIO AUSILIARIO

$2i$	$\gamma_{n-2i,1}$	$\gamma_{n-2i,2}$	$\cdots$	$\gamma_{n-2i,m}$	0
$2i-1$	0	0	0	$\cdots$	0

$$\beta(s) = \gamma_{n-2i,1}\, s^{2i} + \gamma_{n-2i,2}\, s^{2i-2} + \cdots + \gamma_{n-2i,i}\, s^{2} + \gamma_{n-2i,i+1}$$

→ DERIVA
→ SOSTITUISCI ZERI IN TABELLA
→ RADICI IMMAGINARIE ATTENZIONE A MOLTEPLICITÁ

RADICI SIMMETRICHE RISPETTO A C



DIAGRAMMI BODE

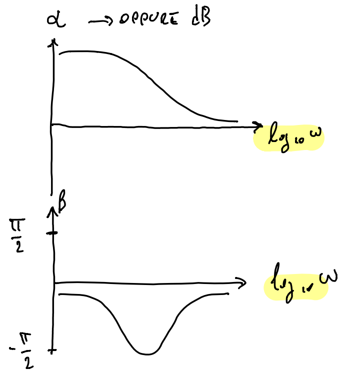
$$G(s) \to G(j\omega) = |G(j\omega)| + e^{j\arg(G(j\omega))}$$

FORMA POLARE

$\alpha = \log_{10} |G(j\omega)|$ AMPIEZZA $\qquad dB = 20\alpha$

$\beta = \arg(G(j\omega))$ FASE

→ POSSIBILE SOMMARE I DIAGRAMMI



PER TRACCIARE BODE

- TRASFORMA IN FORMATO STANDARD CON COSTANTI DI TEMPO
- SCOMPONI IN DIAGRAMMI ELEMENTARI ← OSSERVA COST. DI TEMPO
- SOMMA I CONTRIBUTI
  - POLI →
  - ZERI →

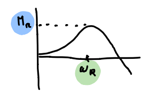
PARAMETRI TIPICI

$\omega_R := \arg\max |G(j\omega)|$

PULSAZIONE RISONANZA

$M_R := |G(j\omega_R)|$

PICCO RISONANZA

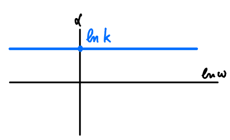


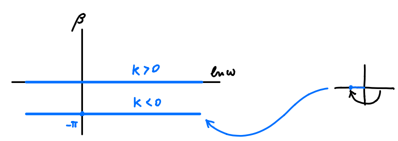
DIAGRAMMI ELEMENTARI

PER I POLI

K

COSTANTE



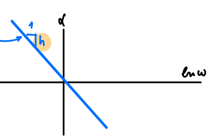


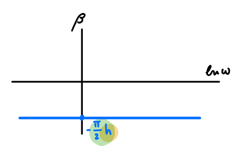
$(j\omega)^{-h}$

POLO ORIGINE

ESISTE ANCHE IN ALTRO SEMIPIANO → NO PER ZERO

COME SE STESSI SOMMANDO CONTRIBUTI



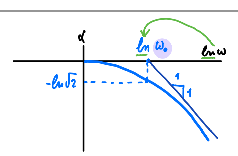


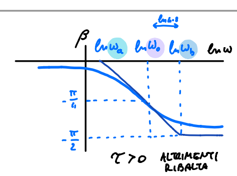
$$G(j\omega) = -h \ln|\omega| - j\frac{\pi}{2}h$$

SCALA

$(1+\tau j\omega)^{\pm 1}$

POLO/ZERO ORDINE 1





$\tau > 0$ ALTRIMENTI RIBALTA

$\omega_0 := \frac{1}{\tau}$ $\qquad f = \frac{1}{T}$? COST. TEMPO $\stackrel{?}{=}$ PERIODO

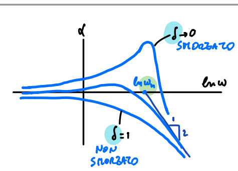
PULSAZIONE D'ANGOLO/DI ROTTURA /FREQ. DI TAGLIO

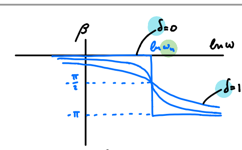
$\frac{\omega_0}{\omega_a} = \frac{\omega_b}{\omega_0} = e^{\frac{\pi}{2}} \approx 4.81$

PER +1 SI OTTIENE PER SIMMETRIA

$\left(1 - \frac{\omega^2}{\omega_n^2} + 2\delta\frac{j\omega}{\omega_n}\right)^{\pm 1}$

POLI/ZERI COMPLESSI CONIUGATI





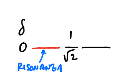
$\delta > 0$ ALTRIMENTI RIBALTA

$\omega_R = \omega_n\sqrt{1-2\delta^2}$ $\qquad M_R = \frac{1}{2\delta\sqrt{1-\delta^2}}$

PULSAZIONE NATURALE

$B_\omega = \omega_n\sqrt{(1-2\delta^2) + \sqrt{(1-2\delta^2)^2+1}}$

LARGHEZZA BANDA



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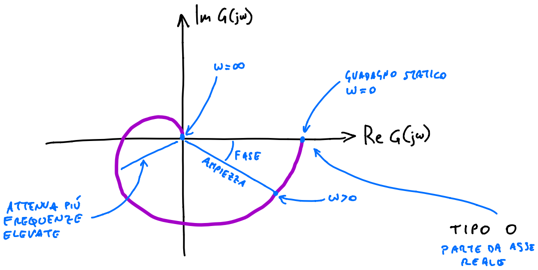
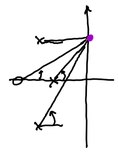
DIAGRAMMI NYQUIST

O DIAGRAMMI POLARI





$\arg = \sum \angle z - \sum \angle p$

$k_1 > 0$

$K_1 \dfrac{b_n s^n + \dots + b_0}{a_n s^n + \dots + a_0}$

$K_1 \dfrac{(1+\tau_1' s) \dots}{s^h (1+\tau_1 s) \dots}$

COST. TEMPO POLI — COMP CONIUG

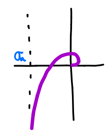
$\sigma_a = K_1 \dfrac{a_1 b_1 - a_2 b_0}{a_1^2} = k\left[\sum \tau_i' - \sum \tau_i + \sum 2\frac{\delta_i'}{\omega_{ni}'} - \sum 2 \frac{\delta_i}{\omega_{ni}}\right]$

$= k\left(\tau_1' + \tau_2' + \dots - \tau_1 - \tau_2 - \dots\right)$

TIPO 1

PARTE DA ASINTOTO

NON SEMBRA APPLICABILE A TIPO >1



$\omega \to 0$

$|L| \to \infty$

METODO

- $L(s) \to L(j\omega)$
  FORMA STANDARD

CALCOLA PER SINGOLI CONTRIBUTI

- TROVA $|G(j\omega)|$ E $\angle G(j\omega)$, σ_A
  ARGOMENTO
- $\omega \to 0^+$, $\omega \to +\infty$
  - STRETT. PROPRIO
  - $\odot$ PROPRIO
- INTERSEZ. RE + IM $\angle G = -\pi$ → TROVA ω
  - USA IL RISOLUTORE
  - METODO ITERATIVO APPROSSIMATO
- RIFLETTI X

CONSIDERA COME VETTORI!

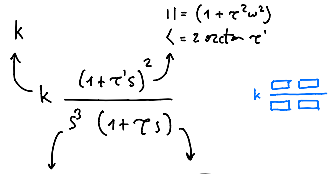
$|\,| = (1+\tau'^2\omega^2)$

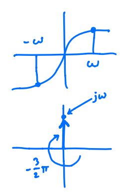
$\angle = 2\arctan \tau'$

$$k \; \frac{(1+\tau' s)^2}{s^3 \, (1+\tau s)}$$

$|\,| = \omega^3$ $\quad \angle = -\frac{3}{2}\pi$

$|\,| = \sqrt{1+\tau^2\omega^2}$ $\quad \angle = -\arctan \tau$





$\arctg(-\omega) = -\arctg(\omega)$

$\dfrac{1}{(j\omega)}$ ← + ← −

PENSA CON VETTORI

SEMPRE SENSO ANTIORARIO, POI RIFLETTI

SISTEMI A FASE MINIMA

SE FDT G È:

- RAZIONALE
- $Re(p/z) < 0$ = NESSUN POLO/ZERO POSITIVO

BASTA IL MODULO PER RAPPRESENTARE IL SISTEMA → FORMULA DI BODE

BANDA FREQ. →
- $|G|$ cost ⇒ arg → 0
- $|G| \searrow$ ⇒ arg $\searrow$ RITARDO
- $|G| \nearrow$ ⇒ arg $\nearrow$ ANTICIPO

APPROSSIM. PADÉ RITARDO FINITO

$$e^{-t_0 s} \xrightarrow{\text{ORDINE } 2} G_2(s, t_0) = \frac{1 - \frac{t_0}{2}s + \frac{t_0^2}{12}s^2}{1 + \frac{t_0}{2}s + \frac{t_0^2}{12}s^2}$$

G1 G2

SOSTITUISCI NELLE FDT QUANDO INCONTRI UN RITARDO

$P(s) = \dfrac{e^{-2s}}{1+4s}$

METODO ITERATIVO ARCTAN

VARIABILE ISOLATA

$\omega = f(\omega)$ ← FUNZIONE MALEFICA PIENA DI ARCTAN

$\omega = 1 \quad \omega' = f(1) \quad \omega'' = f(\omega') \quad \dots$

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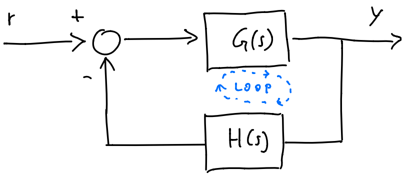
SISTEMI RETROAZIONATI

SOSTANZIALMENTE DEI SISTEMI DI INSEGUIMENTO



$$T_{ry} = \frac{G(s)}{\underbrace{1 + GH(s)}_{L(s)}} = \frac{FF}{1+L}$$

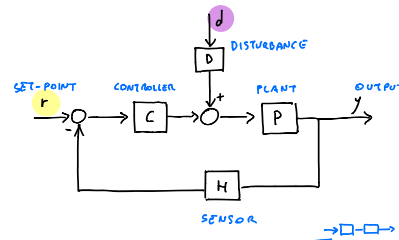
FEED FORWARD

EQUAZIONE CARATTERISTICA

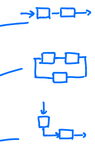
STABILE SE RADICI $Re<0$ (POLI)

$L(s) \rightarrow$ LOOP GUADAGNO ANELLO

DI SOLITO STUDIAMO QUESTO



$$T_{ry} = \frac{CP}{1 + CPH}$$



$$T_{dy} = \frac{DP}{1 + CPH}$$

ANALISI A REGIME

QUANTO BENE RIESCE AD INSEGUIRE IL SET POINT

$$G(s) = K \frac{(s+\tau_1')\dots}{s^h(s+\tau_1)\dots}$$

$$e_r = \lim_{t\to\infty} (r(t) - y(t))$$

ERRORE A REGIME

POSIZIONE, VELOCITÁ, ACCELERAZIONE

TIPO	K_p	K_v	K_a	r_0	$r_0 t$	$r_0 \frac{t^2}{2}$
0	K	0	0	$e_r = \frac{r_0}{1+K_p}$	$e_r = \infty$	$e_r = \infty$
1	∞	K	0	$e_r = 0$	$e_r = \frac{r_0}{K_v}$	$e_r = \infty$
2	∞	∞	K	$e_r = 0$	$e_r = 0$	$e_r = \frac{r_0}{K_a}$

SISTEMA FERMO — SISTEMA IN AZIONE

NON CE LA FA AD INSEGUIRE LA RAMPA

$$K_p = \lim_{s\to 0} G(s) = G(0)$$

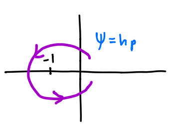
$$K_v = \lim_{s\to 0} s \cdot G(s)$$

CRITERIO DI NYQUIST

SISTEMA ASINT. STABILE SE IL DIAGRAMMA POLARE COMPLETO DI $L(s)$

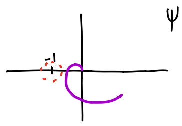
GIRI ↺ CURVA IMMAGINE DI $1+L(s)$ INTORNO A ORIGINE (O DI $L(s)$ INTORNO A -1)

$$\Psi = n_z - n_p$$



SE $\exists$ POLI $Re>0$

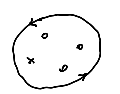
GIRI ANTIORARI SU -1 QUANTI POLI >0



SE $\nexists$ POLI $Re>0$

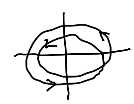
NON TOCCA O CIRCONDA -1

TEOR. INDICE LOG.



$\mathbb{C}_+$ SEMIPIANO POSITIVO

GIRI CURVA IMMAGINE ANTI-ORARIO ATTORNO ORIGINE $= N_z - N_p$

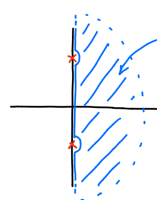


METODO

$\frac{1}{1+L(s)}$ DA EQ. CARATTERISTICA

- TROVA $|L|$ E $\angle L$
- LIMITI $\omega \to 0$ $\omega \to \infty$
- ASINTOTI, POLI SU Im $\quad s = \rho e^{i\theta}$
- TROVA ω PER $\angle = -\frac{\pi}{2}$
- TROVA $|L|$ PER ω
  - → MARGINE AMPIEZZA
  - → GUADAGNO MAX $K \cdot |L| < -1$

DIAGRAMMA DI $L(s)$ PER CAPIRE STABILITÁ $1+L(s)$ GUARDANDO IL PUNTO -1



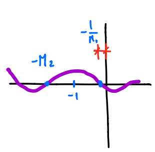
CONTORNO NYQUIST

TROVA POLI E ZERI CON PARTE REALE POSITIVA

↓

TROVA GIRI ATTORNO A -1 PER ANALIZZARE SISTEMA IN RETROAZIONE

MARGINI DI STABILITÁ



$$M_A = \min\{M_1, M_2\}$$

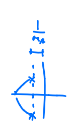
$$M_{A(dB)} = 20 \log M_A$$

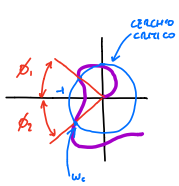
MARGINE AMPIEZZA

METODO

- TROVA ω PER $\angle G = -\pi$
- $M_A = \frac{1}{|G(\omega)|}$

$$L(s,\alpha) = \frac{1}{M_A}$$





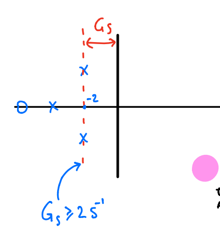
$$M_F = \min\{\phi_1, \phi_2\}$$

MARGINE FASE

METODO

- TROVA ω PER $|L| = 1$
- $M_F = \pi - \angle G(\omega)$

GRADO DI STABILITÁ



$G_s \geq 2 s$

DISTANZA MINIMA POLI DA ASSE Im

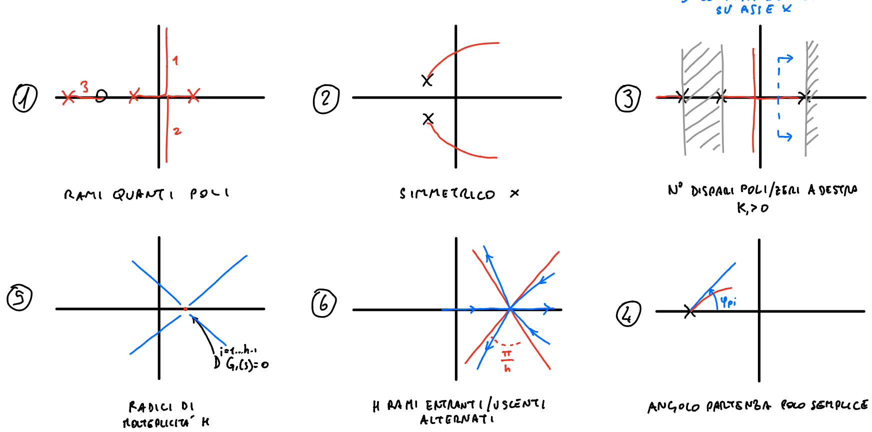
$$T_A \approx \frac{3}{G_s}$$

TEMPO ASSEST.

LUOGO DELLE RADICI

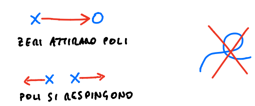
DIRETTO $K_1 > 0$ INVERSO $K_1 < 0$

RADICI EQ. $1 + K_1 L(s)$



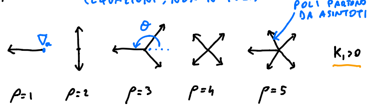
PROCEDURA

- INDIVIDUARE POLI E ZERI RELATIVI A GUADAGNO ANELLO
- GRADO RELATIVO → ASINTOTI
- ∇_a, INTERSEZ. ASCISSA, φ_{pi}
- ZONE AMMISSIBILI [DISPARI



ASINTOTI

$\rho = n - m$ GRADO RELATIVO (EQUAZIONI, NON N° POLI)



NUMERO ASINTOTI

$$\nabla_a = \frac{\overbrace{\sum_{i}^{n} p_i - \sum_{i}^{m} z_i}^{<0}}{\rho}$$

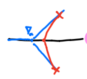
ASCISSA CENTRO ASINTOTI

$v = 0 \dots \rho-1$

$$\theta_v = \frac{(2v+1)\pi}{\rho}$$

ANGOLI

INTERSEZ. ASCISSA



$$\sum \frac{1}{s-p_i} - \sum \frac{1}{s-z_i} = 0$$

ANGOLI PARTENZA

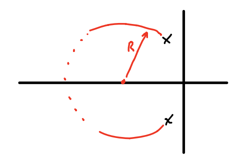
OGNI ZERO — ANGOLO POLO MENO ANGOLO ZERO — ALTRI POLI

$$h\,\varphi_{p_i} = \underset{K_1>0}{\pi} + \sum_{j}^{m} \arg(p_i - z_j) - \sum_{j \neq i} \arg(p_i - p_j) \mod 2\pi$$

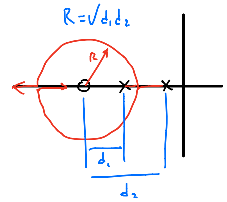
PER POLI CON MOLTEPLICITÀ

PER ANGOLI DI ARRIVO SI SOSTITUISCE z_i A p_i

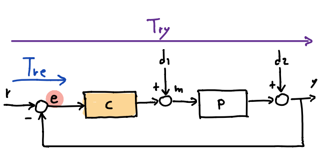
SECONDO ORDINE



$R = \sqrt{d_1 d_2}$



PROGETTO SIST. IN RETROAZIONE



$$T_{re} = \frac{1}{1+L(s)} = S$$

SENSITIVITÀ

$$T_{ry} = 1 - T_{re} = T$$

COMPLEMENTARE

	ORDINE PREFISSATO
0	$C(s) = k$
1 (CONTROLLORE DI ORDINE 1)	$C(s) = \dfrac{b_1 s + b_0}{s + a_0}$ (ZERO FACOLTATIVO)
2	$C(s) = \dfrac{b_2 s^2 + b_1 s + b_0}{s^2 + a_1 s + a_0}$

COME USARE UN TEMPLATE

STRUTTURA PREFISSATA
PARAMETRIZZAZIONI FDT

$$C(s) = k\,\frac{s-a}{s-b}$$

- RETI CORRETTRICI
  PER COMPORTAM. DINAMICO
- REGOLATORI PID

REQUISITI

- INTERN. ASINT. STABILE $\iff$ TUTTE FUNZIONI DI TRASFERIMENTO $\forall$ FDP $\{r, d_i, d_s\} \to \{e, m, y\}$ ASINT. STABILI
  - RADICI $1+L(s)=0$ $Re<0$
  - CANCELLAZ. POLI/ZERI $\mathbb{C}_-$
- BEN CONNESSO $\lim_{|s| \to \infty} 1 + L(s) \neq 0$
  - $C(s)$ PROPRIA $n \geq m$ — $P(s)$ STRETT. PROPRIA $n > m$

- PREST. STATICHE / ASINTOTICHE
  e_r
- PREST. DINAMICHE
  RISP $\int$, S, T_A ...
- ROBUSTEZZA — SIMULAZIONI NON LINEARI

SPECIFICHE DI PROGETTO

- $e_r = 0$ (ERRORE A REGIME) $\longrightarrow$ ORDINE CONTROLLORE ≥ 1
  ALMENO UN POLO IN ORIGINE ⁉
  DIPENDE DA SEGNALE? $T_{ry}(0)=1 \longrightarrow F\ \frac{L(0)}{1+L(0)} = 1$
- T_A PREFISSATO (TEMPO ASSESTAM.) $\longrightarrow T_A \approx \frac{3}{G_s} \longrightarrow G_s \gtrless \cdots \longrightarrow$ ROUTH?
  G_s GRADO STABILITÀ
  $1 + kL(s)\big|_{s=G_s} = 0$
- $S = 0$ (SOVRAELONG.) $\longrightarrow$ POLO DOMINANTE REALE — NESSUNA OSCILLAZIONE
- TIPO N $\longrightarrow$ N POLI IN ORIGINE
- ORDINE N $\longrightarrow$ USA IL TEMPLATE — ES. $k\frac{s-b}{s-a}$
- REIEZIONE FREQ. $\longrightarrow$ POLI CC CHE ANNULLANO SEGNALE IN INGRESSO IN CONTROLLER
  TEOR. ANALISI ARMONICA
  $(s+j3)(s-j3) = (s^2+9)$
- POLI SPECIFICI $\longrightarrow$ POLINOMIO CARATT. SISTEMA PARAMETRIZZATO
  $1 + CP = 0$ — $C = \frac{b(s)}{a(s)}$ — $p_c(s) = (s+p_1)(s+p_2)\ldots$

TECNICHE

- STUDIO LUOGO RADICI, ROUTH
  PER SPOSTARE I POLI NELLE ZONE DI STABILITÀ — $K>0$ $K<0$
  TROVA IL GUADAGNO GIUSTO
  G_s M_A
- CANC. POLO-ZERO
  SE NON SI PUÒ FARE ALTRIMENTI
- EGUAGLIA POLINOMI
  COSTRUISCI POLINOMIO PARAMETRICO ED EGUAGLIA CON SISTEMA CHE SI VUOLE OTTENERE
- DIAGRAMMI NYQUIST, FORM. INVERS.
  PROGETTI IN FREQ. CON MARGINI STAB.
- DIAGRAMMI BODE
  SPECIFICHE FREQUENZIALI

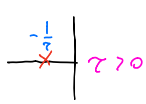
RETI CORRETTRICI

$$e \longrightarrow \boxed{K_c} \longrightarrow \boxed{C_r} \longrightarrow u$$

K_c: GUADAGNO STATICO

INTEGRATRICE

$$C_r = \frac{1}{1+\tau s}$$



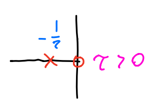
$-\frac{1}{\tau}$ — $\tau > 0$

RITARDO E ANTICIPO

...

DERIVATRICE

$$C_r = \frac{\tau s}{1+\tau s}$$



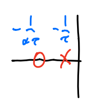
$-\frac{1}{\tau}$ — $\tau > 0$

T PONTICELLATO

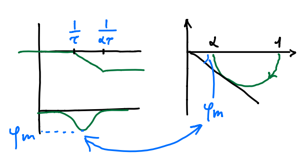
...

RITARDATRICE (DI FASE)

$$C_r = \frac{1+\alpha\tau s}{1+\tau s}$$



$-\frac{1}{\alpha\tau}$ $-\frac{1}{\tau}$ — $\alpha \in (0,1)$, $\tau > 0$



$$\varphi_m = -\arcsin\frac{1-\alpha}{1+\alpha}$$

$$\omega_m = \frac{1}{\sqrt{\alpha}\cdot\tau}$$

POCO USATO, TAGLIA ALTE FREQ.

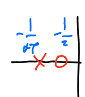
ANTICIPATRICE

ANTICIPA IL CAMPIONAMENTO?

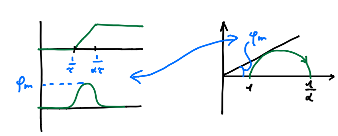
$$C_r = \frac{1+\tau s}{1+\alpha\tau s}$$

DISTINGUE DA RITARDATRICE

$$\boxed{\alpha \in (0,1) \quad \tau > 0}$$



$-\frac{1}{\alpha\tau}$ $-\frac{1}{\tau}$



$$\varphi_m = \arcsin\frac{1-\alpha}{1+\alpha}$$

REGOLATORI STANDARD

PROPORZIONALE P

$$R(s) = k_p$$

INTEGRALE I

$$R(s) = \frac{k_p}{T_i s}$$

PARAMETRO TEMPO

PROPORZ. INTEGRALE PI

$$\Rightarrow R(s) = k_p\left(1 + \frac{1}{T_i s}\right)$$

PROPORZIONALE DERIVATIVO PD

$$R_s = k_p\left(1 + \cancel{T_d s}\right)$$

$$\rightarrow R_s = k_p\left(1 + \frac{T_d s}{1+\tau s}\right) \quad \tau \ll T_d$$

= RETE ANTICIPATRICE

PID

$$R(s) = k_p\left(1 + \underbrace{\cancel{T_d s}}_{\frac{T_d s}{1+\tau s}} + \frac{1}{T_i s}\right) \cong k_p \frac{T_d T_i s^2 + T_i s + 1}{T_i s\,(1+\tau s)}$$

FORMULE INVERSIONE

RICERCA DELLE FORMULE INVERSE DELLE RETI

$$R(s) = M e^{j\varphi} \quad \begin{cases} \alpha = \dfrac{M \cos\varphi - 1}{M(M - \cos\varphi)} \\[2ex] \tau = \dfrac{M - \cos\varphi}{\omega_0 \sin\varphi} \end{cases}$$

← TROVA PARAMETRI PARTENDO DA MARGINI

$$M = \frac{\sqrt{1+(\tau\omega)^2}}{\sqrt{1+(\alpha\tau\omega)^2}}$$

$$\varphi = \operatorname{atg}(\tau\omega) - \operatorname{atg}(\alpha\tau\omega)$$

$$R(s) = \frac{1+\tau\omega j}{1+\alpha\tau\omega j}$$

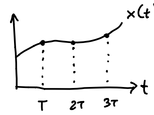
RETE ANTICIPATRICE

OMESSI: RETI T, AR, DIOFANTEA ECC...

CONTROLLO DIGITALE

CONVERTITORE A/D

$$x(t) \longrightarrow \tilde{x}(k) = x(kT) \quad k \in \mathbb{Z}$$



CONVERSIONE D/A

→ CAMPIONAMENTO SHANNON

RICOSTRUIBILE DA $\tilde{x}(k)$: $\Omega = \frac{2\pi}{T} \geq 2\omega_s$

SEQ. CAMPIONI

PULSAZ. CAMPIONAMENTO

SPETTRO LIMITATO $0 - \omega_s$

SOTTOCAMPION. ⇒ ALIASING ⇒ FILTRO LP

TRASFORMATA Z

$$\mathcal{Z}[x(k)] = \sum_{k=0}^{\infty} x(k) z^{-k}$$

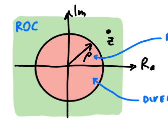
VARIABILE COMPLESSA

$$\| $$

$$X(z) = x(0) + x(1) z^{-1} + \dots$$

$$z = \sigma + j\omega$$

• LINEARE



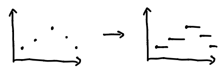
RAGGIO ASSOLUTA CONVERGENZA

DIVERGE A ∞

FUNZIONE CONVERGE SE Z È IN QUESTA ZONA

CONVERTITORE ZOH

ZERO-ORDER HOLD



PROPRIETÀ $X(z) = \mathcal{Z}[x(k)]$

K È LA VARIABILE, NON UNA COSTANTE $\mathbb{R}$

RITARDO N PASSI

$x(1) z^{-1} \cdot z^{-n}$

COME SI COMPORTA IL SISTEMA DURANTE IL RITARDO

- $$\mathcal{Z}[x(k-n)] = z^{-n} \mathcal{Z}[x(k)] + \underbrace{\sum_{k=0}^{n-1} x(k-n) z^{-k}}_{\text{CONDIZ. INIZIALI NON NULLE}}$$

ANTICIPO N PASSI

- $$\mathcal{Z}[x(k+n)] = z^{n} \mathcal{Z}[x(k)] + \sum_{i=0}^{n-1} x(i) z^{n-i}$$

- $$\mathcal{Z}[1(k)] = \frac{z}{z-1}$$

- $$\mathcal{Z}[k1(k)] = \frac{z}{(z-1)^2}$$

$$\mathcal{Z}[k^2 1(k)] = \frac{z(z+1)}{(z-1)^3}$$

- $$\mathcal{Z}[a^k x(k)] = X\left(\frac{z}{a}\right)$$

$$\Downarrow$$

- $$\mathcal{Z}[a^k 1(k)] = \frac{z}{z-a}$$

VEDI ANTITRASF.

VALORE INIZIALE

$$x(0) = \lim_{z \to +\infty} X(z)$$

VALORE FINALE

$$\lim_{z \to +\infty} x(k) = \lim_{z \to 1} (z-1) X(z)$$

CONVOLUZIONE

$$(x * y)(k) = \sum_{i=-\infty}^{+\infty} x(k-i) y(i)$$

$$\mathcal{Z}[x * y] = X \cdot Y$$

DERIVATA

$$-z \frac{dX(z)}{dz} = \mathcal{Z}[k \cdot x(k)]$$

DOVE ANALITICA

ANTITRASF.

METODO RESIDUI

POLI

$$x(k) = \sum_i \mathrm{Res}\left\{X(z)z^{k-1}, p_i\right\}$$

- $\mathcal{Z}^{-1}\left[\frac{1}{z-a}\right] = a^{k-1}\,1(k-1)$
- $\mathcal{Z}^{-1}\left[\frac{1}{(z-a)^2}\right] = (k-1)\,a^{k-2}\,1(k-1)$

$$\mathcal{Z}^{-1}\left[\frac{1}{(z-a)^3}\right] = \frac{(k-1)(k-2)}{2}\,a^{k-3}\,1(k-1)$$

$$\mathcal{Z}^{-1}\left[\frac{1}{(z-a)^n}\right] = \underbrace{\frac{(k-1)(k-2)\dots(k-n+1)}{(n-1)!}}_{\binom{k-1}{n-1}}\,a^{k-n}\,1(k-1)$$

$\xleftrightarrow{K-1}$

- $\mathcal{Z}^{-1}\left[\frac{z}{z-a}\right] = a^{k}\,1(k)$

$$\mathcal{Z}^{-1}\left[\frac{z}{(z-a)^2}\right] = k\,a^{k-1}\,1(k)$$

$$\mathcal{Z}^{-1}\left[\frac{z}{(z-a)^3}\right] = \frac{k(k-1)}{2}\,a^{k-2}\,1(k)$$

$$\mathcal{Z}^{-1}\left[\frac{z}{(z-a)^n}\right] = \binom{k}{n-1}\,a^{k-(n-1)}$$

USUALE

- $\mathcal{Z}^{-1}[a] = a\cdot\delta(k)$

...OMESSI COMPLESSI

$$c\frac{z}{z-p} + \bar{c}\frac{z}{z-\bar{p}}$$

METODO SVILUPPO FRATTI

- $$F(z) = \frac{b(z)}{(z-p_1)^{r_1}(z-p_2)^{r_2}\cdot\ldots\cdot(z-p_h)^{r_h}} = c_0 + \frac{c_{1,1}}{(z-p_1)^{r_1}} + \dots + \frac{c_{1,r_1}}{z-p_1} + \dots + \frac{c_{h,1}}{(z-p_h)^{r_h}} + \dots$$

- $$c_{ij} = \frac{1}{(j-1)!}\,D^{j-1}\left[(z-p_i)^{r_i}\,F(z)\right]\Big|_{z=p_i} \qquad \begin{array}{l} i=1,\dots h \\ j=1,\dots r_i \end{array}$$

UGUALE

$$c_0 = \lim_{z\to+\infty} F(z)$$ $\longrightarrow$ ASSIUNGI $\delta(k)$ QUANDO ANTITRASF.

SISTEMI A TEMPO DISCRETO

$$u(k) \longrightarrow \boxed{\Sigma_d} \longrightarrow y(k)$$

SEGNALE INGRESSO DISCRETO

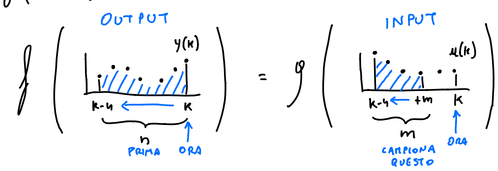
EQ. ALLE DIFFERENZE

DESCRIVE COME SI COMPORTA IL MODELLO DEL SISTEMA

$$f\big(y(k), y(k-1), \dots y(k-n)\big) = g\big(u(k-n+m), u(k-n+m-1), \dots u(k-n)\big) \qquad m \leq n$$

$\longleftarrow$ CAUSALITÀ

LA USCITA DIPENDE SOLO DAL PASSATO DELL'ENTRATA



→ PER f, g LINEARI

$$a_n y(k) + a_{n-1} y(k-1) + \dots + a_0 y(k-n) = b_m u(k-n+m) + \dots + b_0 u(k-n)$$

EQUAZIONE ALLE DIFFERENZE

$$\begin{array}{c} y(-1) \dots y(-n) \\ u(-1) \dots u(-n) \end{array} + u(k) \longrightarrow y(k) \qquad k \geq 0$$

CONDIZIONI INIZIALI

SEGNALE INGRESSO

DETERMINARE SEGNALE USCITA

FUNZIONE TRASFERIMENTO

$$\sum^{n-1} a_i\, y(k-n-i) = \sum^{n-1} b_i\, u(k-n-i)$$

$$\sum^{n-1} a_i\, \mathcal{Z}[y(k-n-i)] = \sum^{n-1} b_i\, \mathcal{Z}[u(k-n-i)]$$

$\Big\}\ \mathcal{Z}$ $\Big\}\ \dots$

APPLICHIAMO LA TRASFORMATA

$$a(z)\,Y(z) = b(z)\,U(z) + c(z)$$

$$a(z) = \sum^{n} a_i z^i \qquad b(z) = \sum^{n} b_i z^i \qquad c(z) = \sum\sum\dots - \sum\sum\dots$$

ES.

$$y(k) + 0.5\,y(k-1) + 0.4\,y(k-2)$$

$$z^2 + 0.5z + 0.4$$

$$\boxed{Y(z) = \frac{b(z)}{a(z)}U(z) + \frac{c(z)}{a(z)}}$$

RISPOSTA FORZATA — RISPOSTA LIBERA

$$H(z) = \frac{b(z)}{a(z)} = \frac{b_m z^m + \dots + b_0}{a_n z^n + \dots + a_0}$$

$$\mathcal{Z}[y(k)] = H(z)\,\mathcal{Z}[u(k)]$$

CONDIZIONI INIZIALI NULLE

$$y_{f\alpha}(k) = \sum^{k} h(k-i)\,u(i)$$

CONVOLUZIONE

$$G_s = Z(1)$$

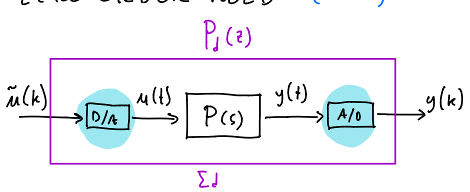
GUADAGNO STATICO

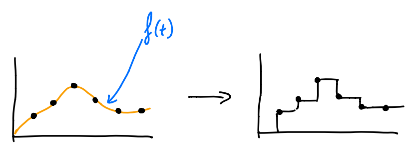
$$\delta \xrightarrow{\mathcal{Z}} 1$$

$$h(k) = \mathcal{Z}^{-1}[H(z)]$$

RISPOSTA A IMPULSO

ZERO ORDER HOLD (ZOH)





DEFINIZIONE

$$\mathcal{Z}[f(t), T] \triangleq \mathcal{Z}[f(kT)]$$

PERIODO CAMPION. — CAMPIONO F. CONTINUA

TRASFORMATA Z SEGNALE CONTINUO CAMPIONATO

$$\parallel$$

$$\mathcal{Z}[F(s), T] \triangleq \mathcal{Z}\left[\mathcal{L}^{-1}[F(s)]_{t=kT}\right]$$

QUANDO INDICHIAMO Z DI f OPPURE F SONO LA STESSA COSA

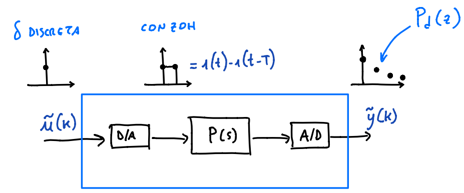
$$P_d(z) = \frac{z-1}{z}\,\mathcal{Z}\left[\frac{P(s)}{s}, T\right]$$

$1(t) - 1(t-T)$

SISTEMA REALE

INTEGRA PER ZOH

TRASF Z RISPOSTA IMPULSO δ APPLICATA A ZOH



$$p_s(t) = \mathcal{L}^{-1}\left[\frac{P(s)}{s}\right]$$ RISPOSTA A GRADINO

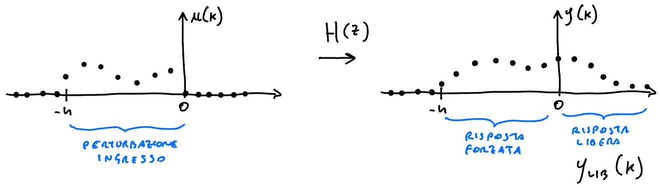
$$\tilde{y}(k) = p_s(kT) - p_s(kT-T)$$

POSIZIONA NEL SEGNALE CONTINUO

METODO

- USA FORMULA
- $\mathcal{L}^{-1}$ $P/s \rightarrow p(t)$ $\frac{K}{s-p_i}\dots$
- $\mathcal{Z}$ $P(t) \rightarrow P(kT) \rightarrow P(z)$
  CAMPIONA CON T
- SIST. RETROAZ. $T(z) = \frac{L(z)}{1+L(z)}$
- $1 + L(z) = 0 \rightarrow$ EQ.
- CRITERIO JURY 1,2,3

STABILITÀ



• STABILE	$y_{LIB}(k)$ LIMITATA	POLI DENTRO CERCHIO UNITARIO	MOLTEPLICITÀ 1 FRONTIERA
• ASINT. STABILE	$\lim_{k \to +\infty} y_{LIB}(k) = 0$		$\Rightarrow$ BIBO STABILE
• SEMP. STABILE	$\exists \lim_{k \to +\infty} y_{LIB}(k)$		DEVE ESISTERE
• INSTABILE			ESTERNO, MOLTEPLICITÀ

CRITERIO DI JURY

PER STUDIARE STABILITÀ

$a(z) = a_n z^n + \dots + a_0 \quad a_n > 0$

PER AVERE RADICI $|p| < 1$ QUINDI UN SISTEMA STABILE

① $a(1) > 0$

② $(-1)^n a(-1) > 0$

③ $|a_0| < a_n$

④ CRITERIO
$|b_0| > |b_{n-1}|$
$|c_0| > |c_{n-2}|$
$\vdots$

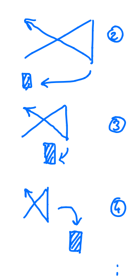
SOLO PER $n > 2$

TABELLA

$b_k = \begin{vmatrix} a_0 & a_{n-k} \\ a_n & a_k \end{vmatrix}$

z^0	z^1	...			z^n
a_0	a_1	...	a_{n-k}	...	a_n
a_n	a_{n-1}	...	a_k	...	a_0
b_0		...			b_{n-1}
b_{n-1}					b_0

INUTILE CALCOLARE QUI



RADICI MODULO < 1 SE

- $a(-1) \neq 0 \Rightarrow$ OK
- ZERI DI $a\left(\frac{1+w}{1-w}\right)$ $Re < 0$

PERIODO CAMPIONAMENTO

$\omega_b \rightarrow$ BANDA DESIDERATA (PULSAZIONE)

$\omega_s \geq 2\omega_b \rightarrow$ BANDA CAMPIONAMENTO (SHANNON)

$\omega_s = \frac{2\pi}{T}$ $T \rightarrow$ TEMPO CAMPIONAMENTO (PERIODO)

IN PRATICA
$6 \leq \frac{\omega_s}{\omega_b} \leq 20$

CONVERSIONE CONTROLLER A → D

EULERO IN AVANTI

$s = \frac{z-1}{T}$

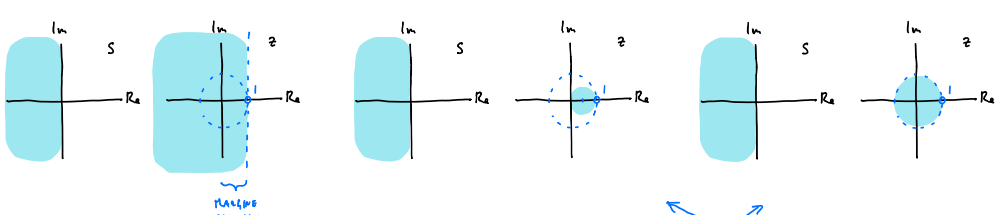
INDIETRO

$s = \frac{z-1}{Tz}$

TUSTIN

$s = \frac{2}{T}\frac{z-1}{z+1}$

STABILE SE



SE $C(s)$ ASINT. STABILE, $C_d(z)$ PUÒ ESSERE INSTABILE

$C(s)$ ASINT. STABILE $\Rightarrow C(z)$ ASINT. STABILE

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