

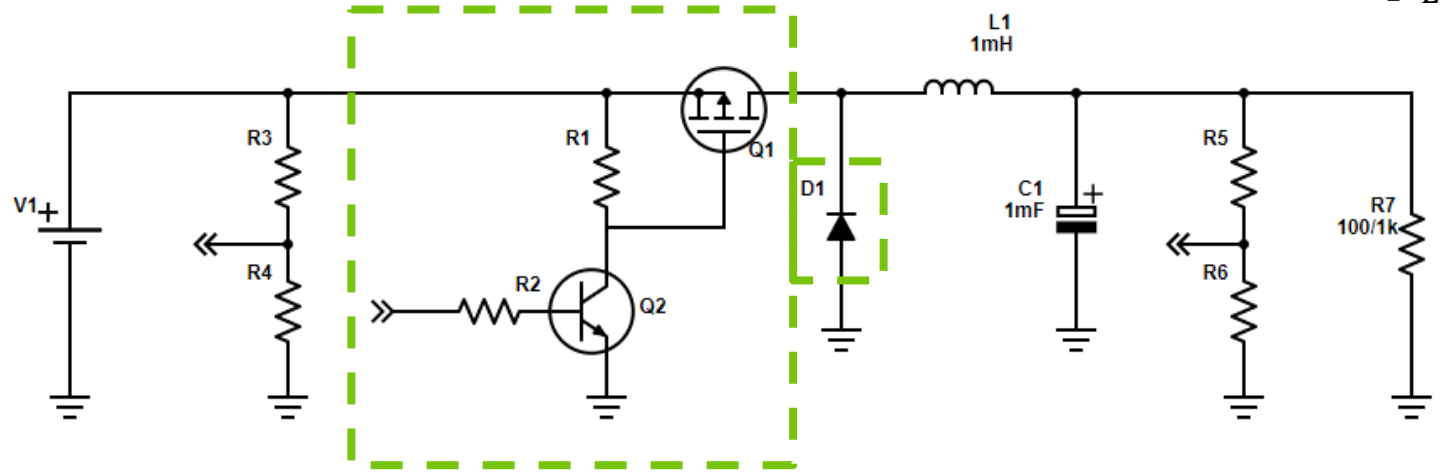


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Damiano Laurendi

Controlli Automatici A.A. 2018/2019

Buck Converter

Circuito e  
modellizzazione



$$x = \begin{bmatrix} V_C \\ I_L \end{bmatrix}$$

$$\dot{x} = \begin{bmatrix} -\frac{1}{RC} & \frac{1}{C} \\ \frac{1}{L} & 0 \end{bmatrix} x + \begin{bmatrix} 0 \\ \frac{E}{L} \end{bmatrix} d$$

$$y = [1 \quad 0]x$$

R=100Ω

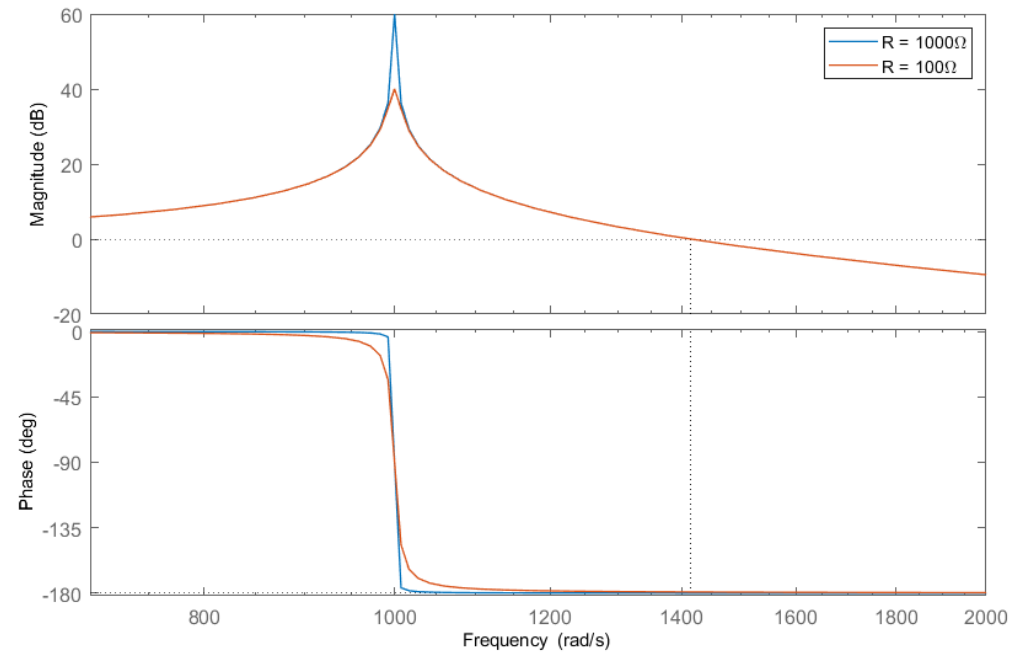
$$\dot{x} = \begin{bmatrix} -100 & 1000 \\ -1000 & 0 \end{bmatrix} x + \begin{bmatrix} 0 \\ 1000 \end{bmatrix} d * E$$

$$y = [1 \quad 0]x$$



Buck Converter

# Funzione di Trasferimento



$$R=100\Omega \longrightarrow G(s) = \frac{1}{\frac{s^2}{10^6} + \frac{s}{10^5} + 1}$$

$$\omega_n = \frac{1}{\sqrt{LC}}$$

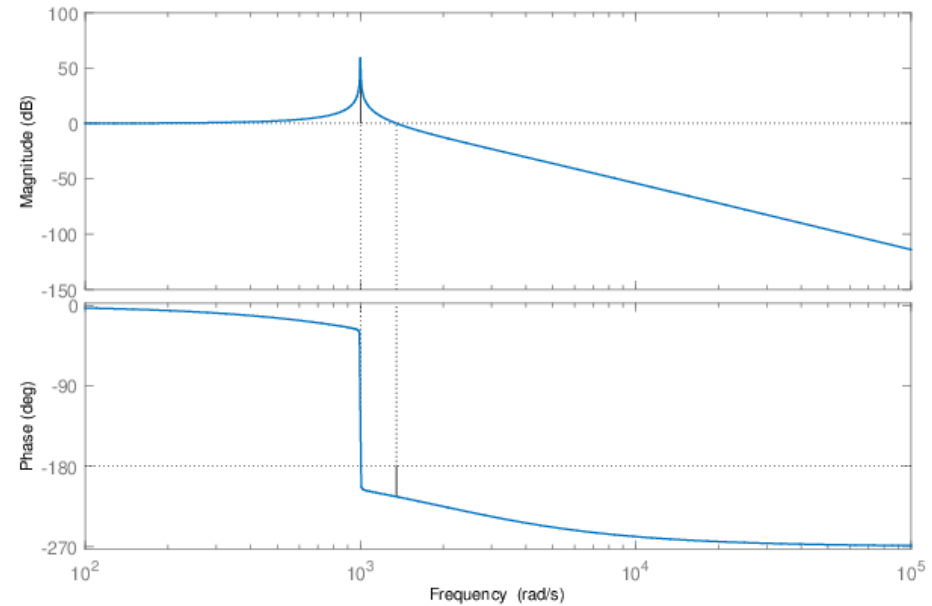
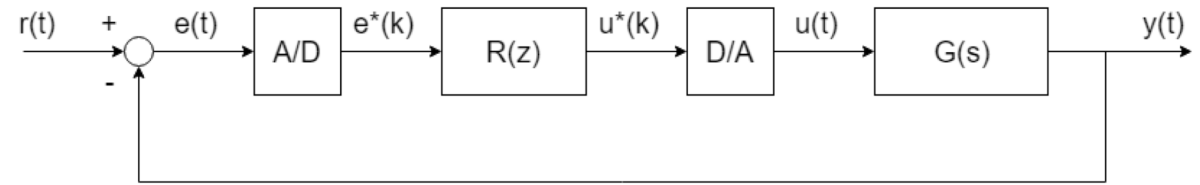
$$R=1000\Omega \longrightarrow G(s) = \frac{1}{\frac{s^2}{10^6} + \frac{s}{10^6} + 1}$$

$$\zeta = \frac{1}{2R} \sqrt{\frac{L}{C}}$$

## Controllo Digitale

Volendo realizzare un controllo digitale bisogna considerare un polo alla pulsazione :

$$\frac{2}{T_C}$$

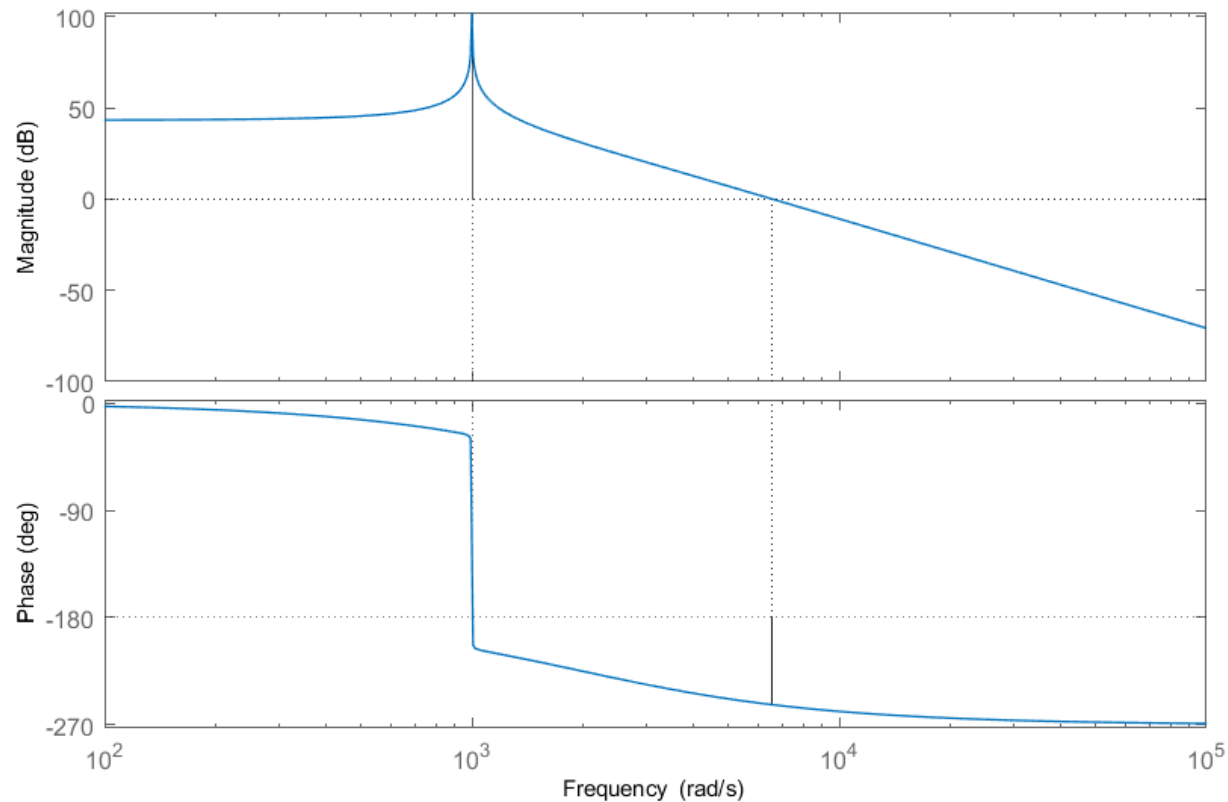


$$G^*(s) = \frac{1}{1 + \frac{T_C}{2}s} * \frac{1}{\frac{s^2}{10^6} + \frac{s}{10^6} + 1}$$

The image features a central green speech bubble with a white outline and a small tail pointing downwards. Inside the bubble, the text "Loop Shaping" is written in a white, sans-serif font. The background is white with several thin, light gray curved lines, some solid and some dashed, creating a sense of motion or a signal path.

# Loop Shaping

# Definizione delle Specifiche

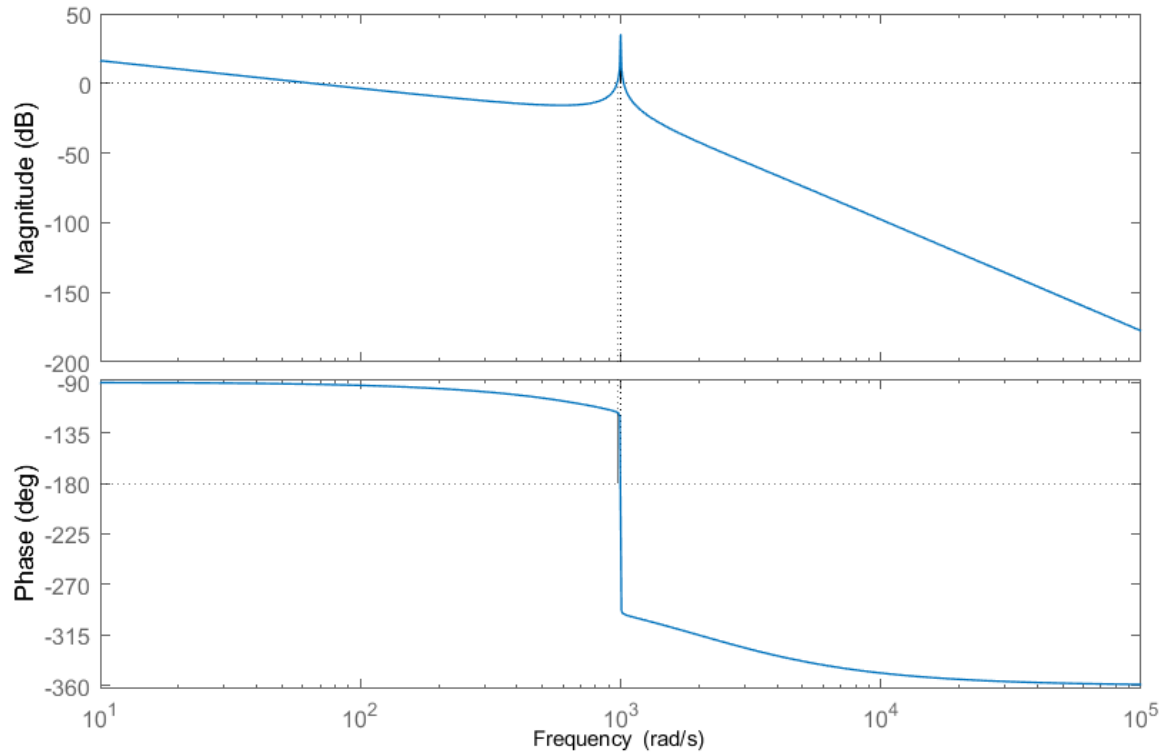


$$T_{a5} = 1ms \quad \longrightarrow \quad \omega_c = -\frac{\ln(0.01 * 5)}{T_{a5} * \zeta} \approx 6571 \text{ rad/s}$$

$$S_{\%} = 20\% \quad \longrightarrow \quad \phi_m \approx 54.25^\circ + 10^\circ = 64.25^\circ$$

$$f_c = \frac{100}{T_{a5}} = 100kHz$$

# Definizione delle Specifiche



$$f_c = \frac{100}{T_{a5}} = 1 \text{ kHz}$$



$$T_{a5} = 100 \text{ ms}$$



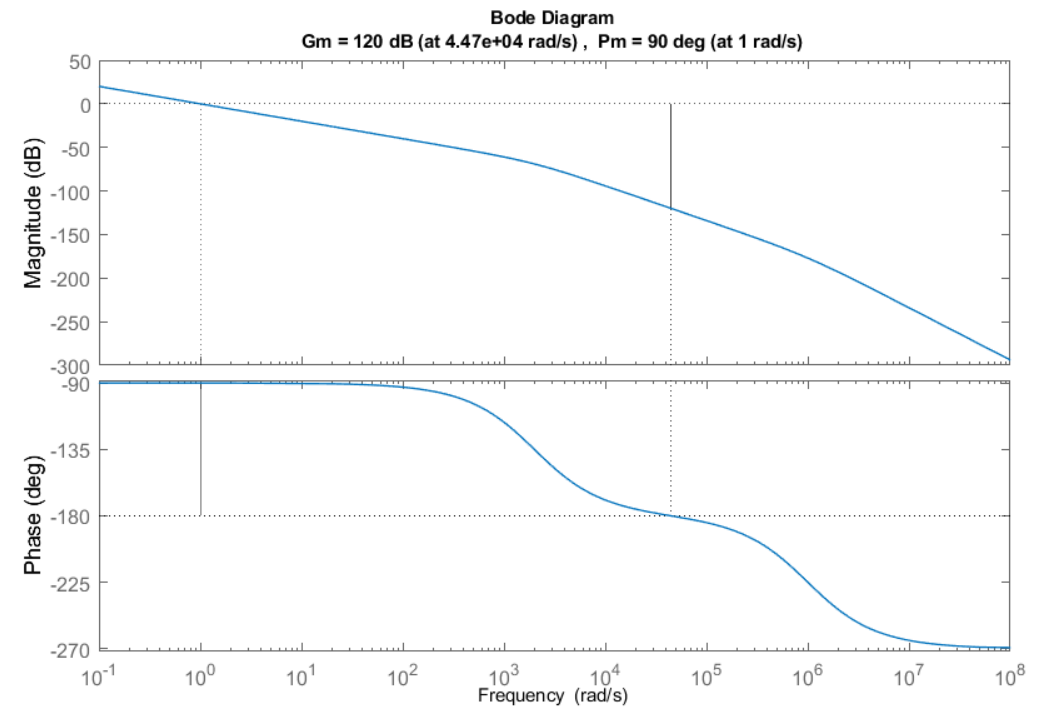
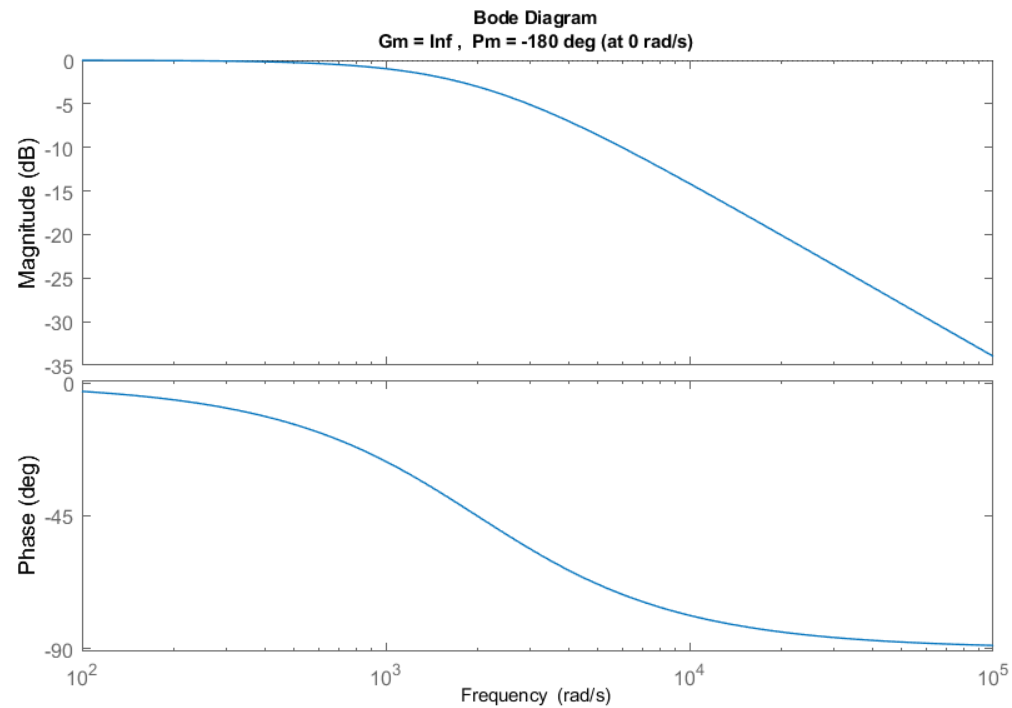
$$\omega_c = -\frac{\ln(0.01 * 5)}{T_{a5} * \zeta} \approx 65.71 \text{ rad/s}$$

$$R(s) = \frac{k}{s}$$

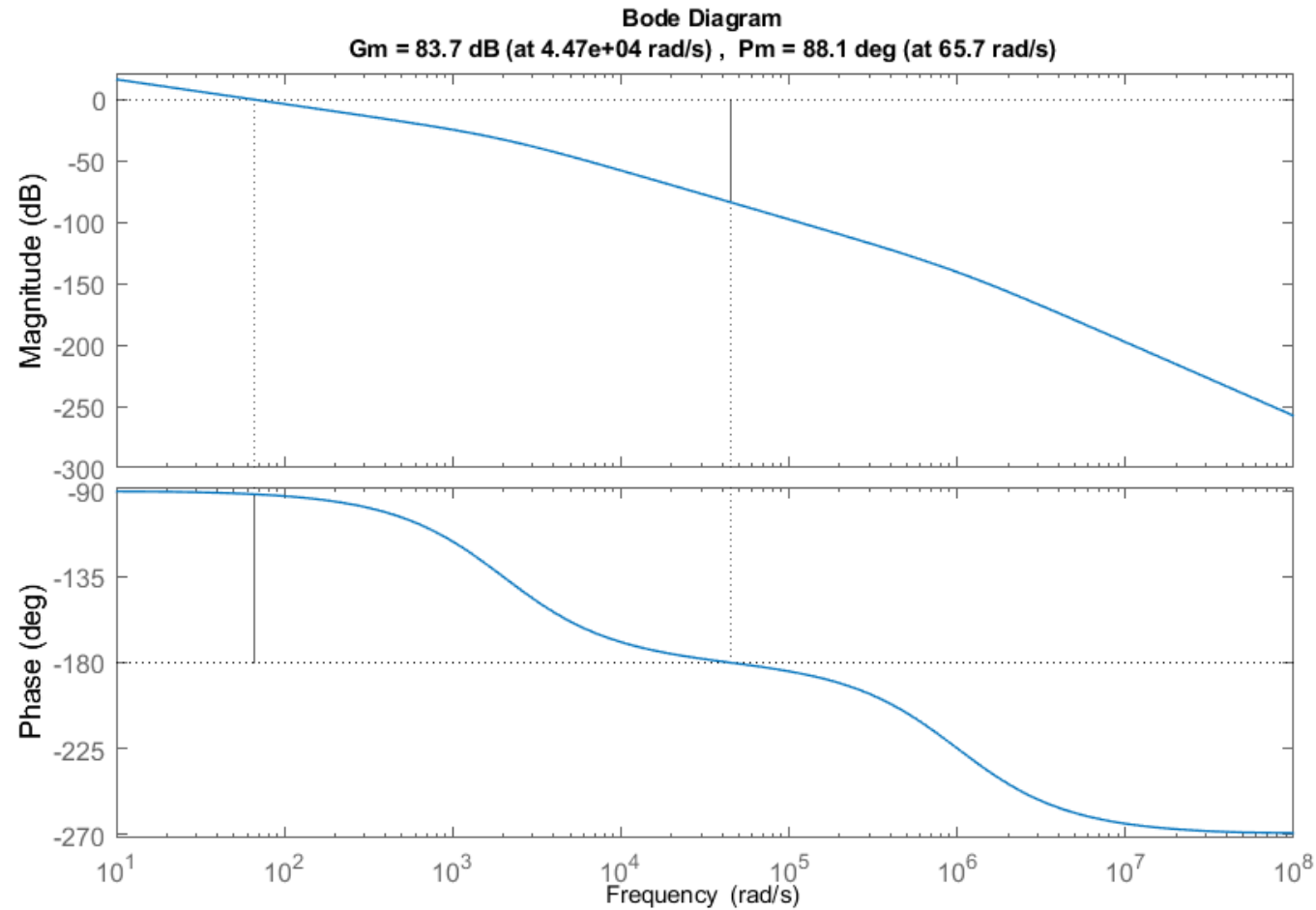
# Progettazione del Regolatore – Loop Shaping

$$R(s) = \frac{s^2}{10^6} + \frac{s}{10^6} + 1$$

$$R(s) = \frac{\frac{s^2}{10^6} + \frac{s}{10^6} + 1}{s \left( \frac{s}{10^6} + 1 \right)}$$

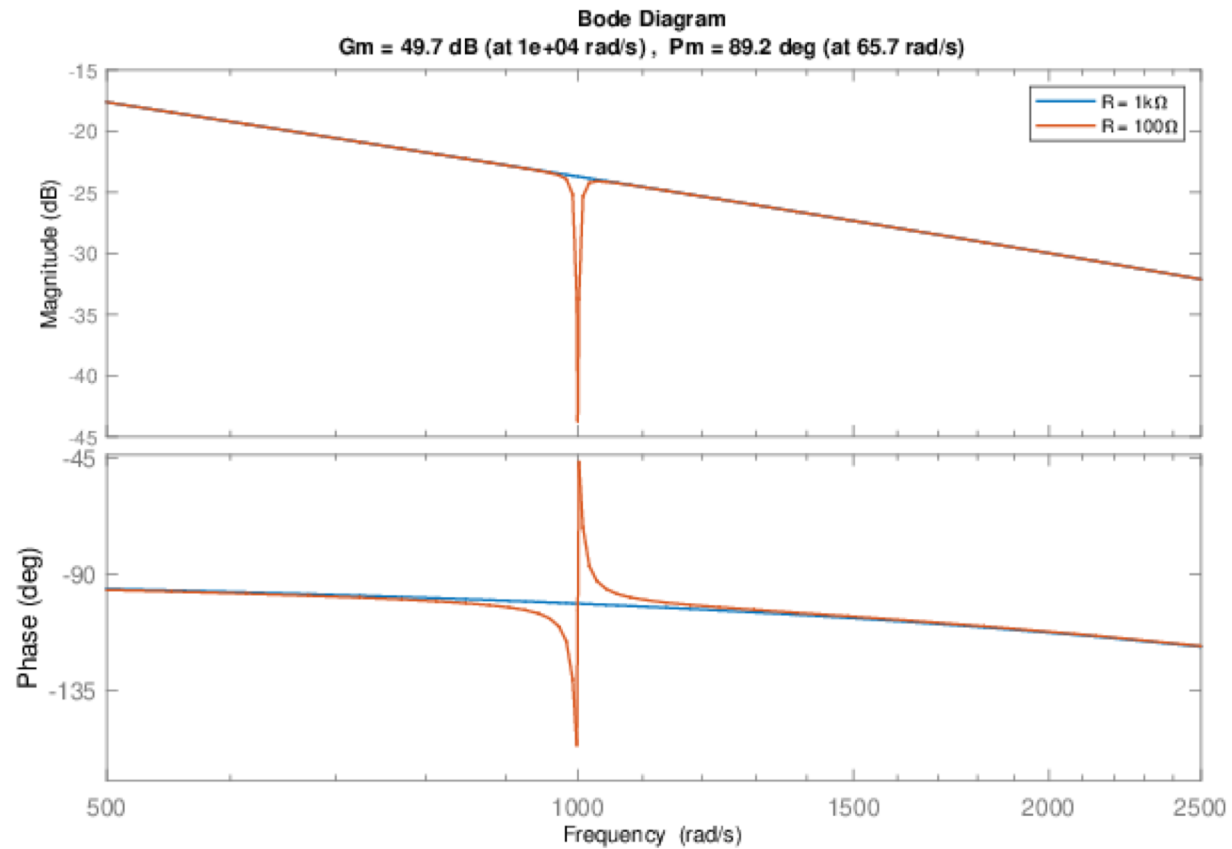


# Progettazione del Regolatore – Loop Shaping

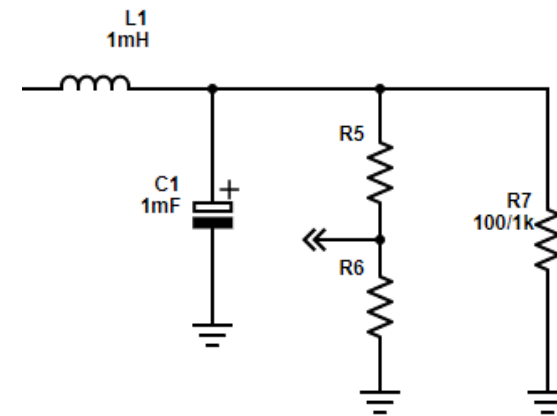


$$R(s) = 65.7895 * \frac{\frac{s^2}{10^6} + \frac{s}{10^6} + 1}{s \left( \frac{s}{10^6} + 1 \right)}$$

# Considerazioni – Loop Shaping



$$R = 100 \div 1000\Omega$$





The background features several concentric circles of varying radii, some solid and some dashed, in a light gray color. A prominent green callout box is centered on the page, containing the text 'Sintesi per Cancellazione'. The callout box has a rectangular top and a pointed bottom, resembling a speech bubble or a pointer.

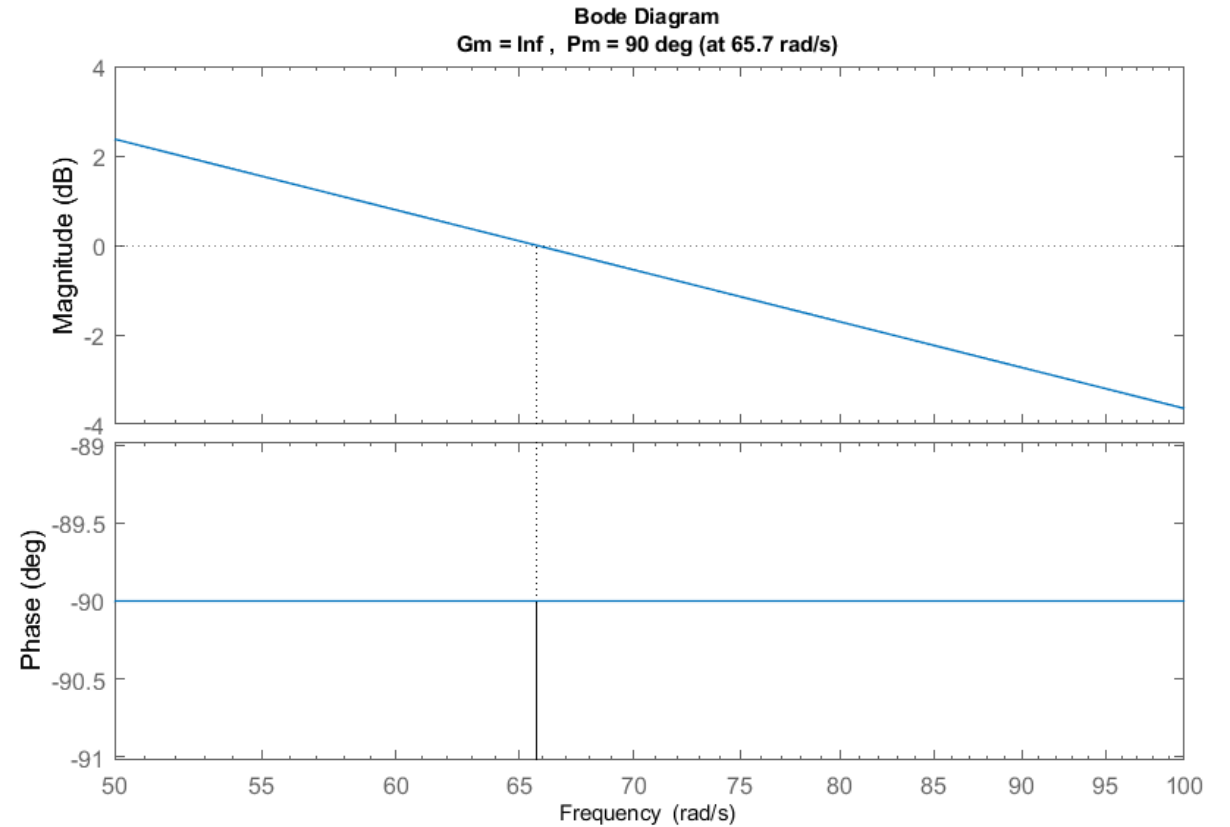
# Sintesi per Cancellazione

# Specifiche - Cancellazione

$$T_{a5} = 100ms \quad \longrightarrow \quad \omega_c \approx 65.7 \text{ rad/s}$$

$$S_{\%} = 20\% \quad \longrightarrow \quad \phi_m \approx 64.25^\circ$$

$$L(s) = \frac{65.7895}{s}$$



# Progettazione del Regolatore - Cancellazione

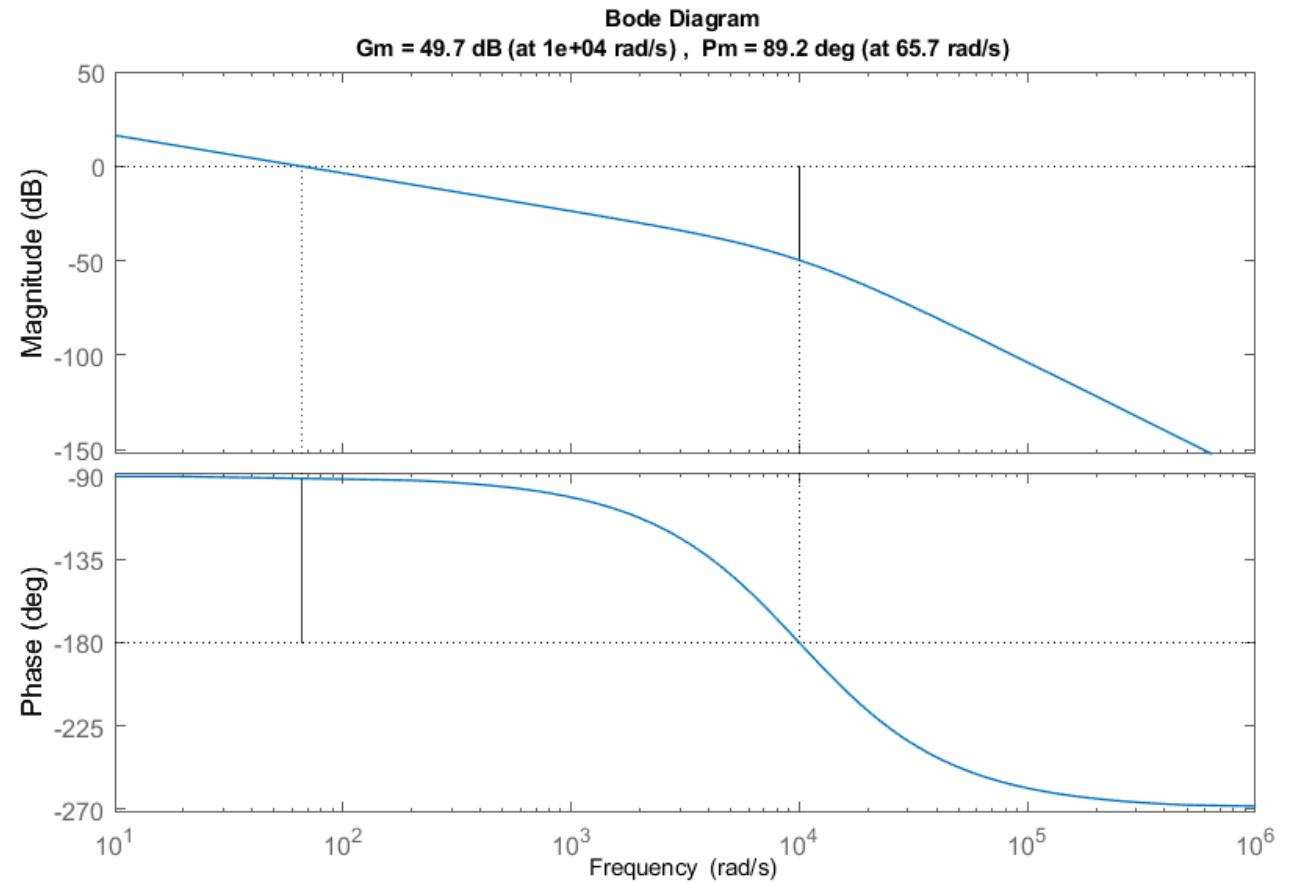
$$L(s) = R(s) * G^*(s)$$



$$R(s) = \frac{L(s)}{G^*(s)} = \frac{65.7895 \left(1 + \frac{T_C}{2} s\right) \left(\frac{s^2}{10^6} + \frac{s}{10^6} + 1\right)}{s}$$



$$R(s) = \frac{L(s)}{G^*(s)} = \frac{65.7895 \left(1 + \frac{T_C}{2} s\right) \left(\frac{s^2}{10^6} + \frac{s}{10^6} + 1\right)}{s \left(1 + \frac{s}{10^4}\right)^2}$$



# Discretizzazione

Discretizzazione

Metodo bilineare (o di Tustin)  $\longrightarrow$

$$R(z) = R(s) \Big|_{s = \frac{2(z-1)}{T_C(z+1)}}$$

Metodo dell'invarianza della risposta all'impulso  $\longrightarrow$

$$R(z) = \frac{z-1}{z} Z \left\{ L^{-1} \left\{ R(s) \frac{1}{s} \right\} \Big|_{t=kT_C} \right\}$$

$$R(z) = \frac{0.1641z^2 - 0.1968z + 0.164}{z^2 - 0.003992z + 0.996}$$

Loop Shaping - Tustin

$$R(z) = \frac{0.2283z^3 - 0.2738z^2 + 0.2281z + 2.884 * 10^{-16}}{z^3 + 0.3333z^2 - 0.8889z - 0.4444}$$

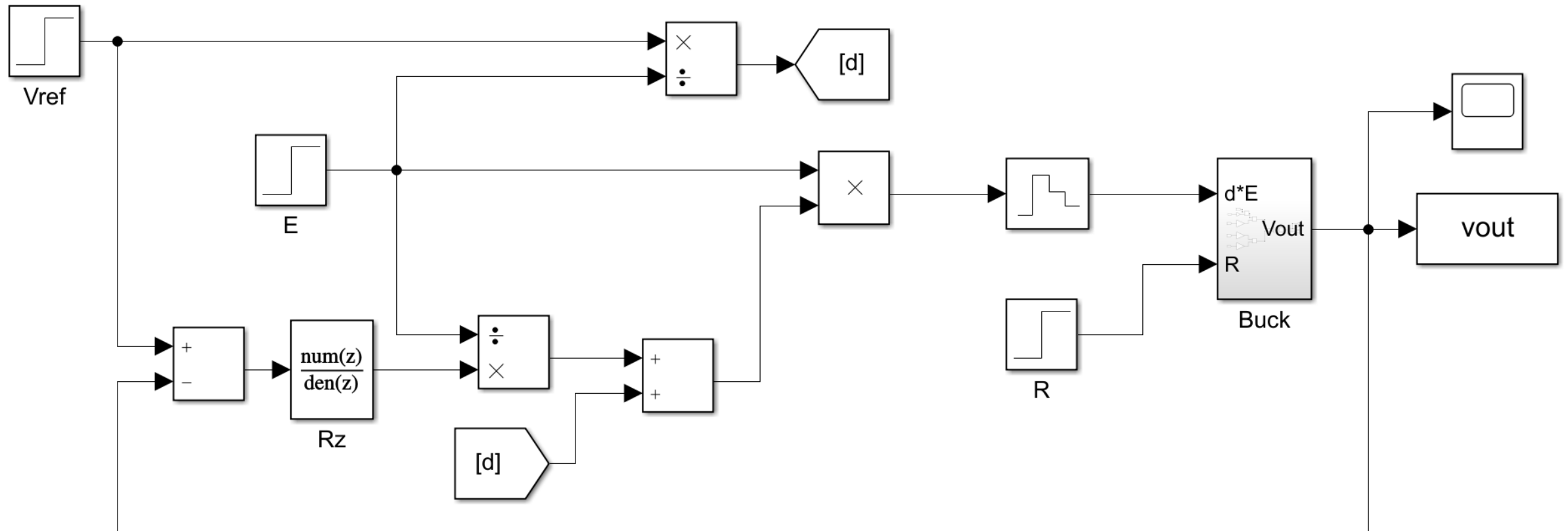
Cancellazione - Tustin

`R = tf(c2d(SYSC,TS,METHOD));`

The background features a series of concentric, overlapping circles and arcs in light gray, some solid and some dashed, creating a sense of depth and movement. A bright green callout box is centered on the page, containing the text.

# Simulazioni e Prove Sperimentali

# Schema di controllo



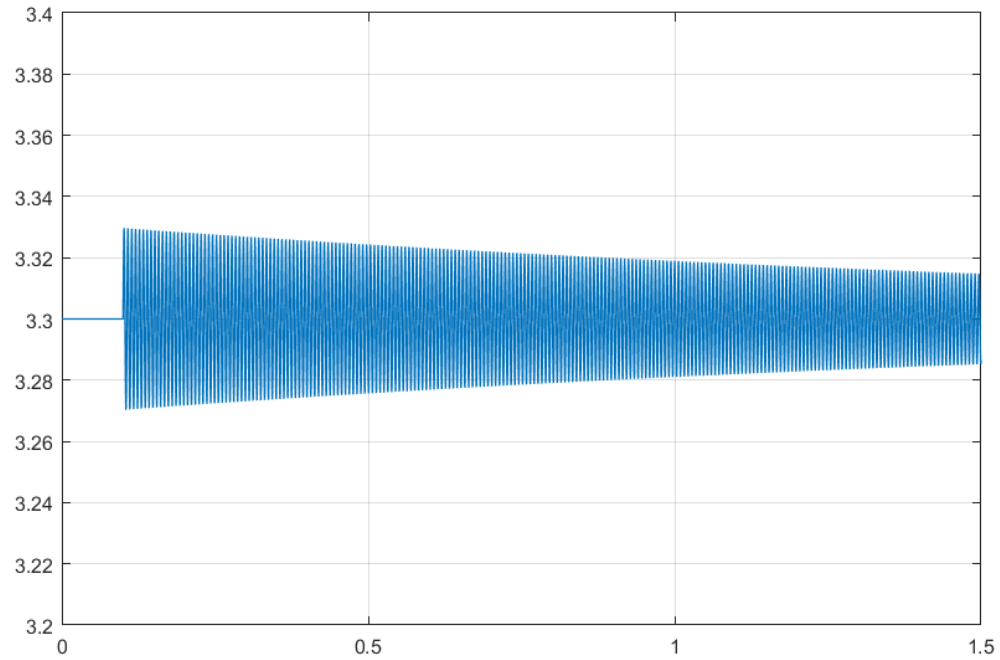
$t = 0.1s$   $\longrightarrow$

$R = 100\Omega \rightarrow R = 1000\Omega$

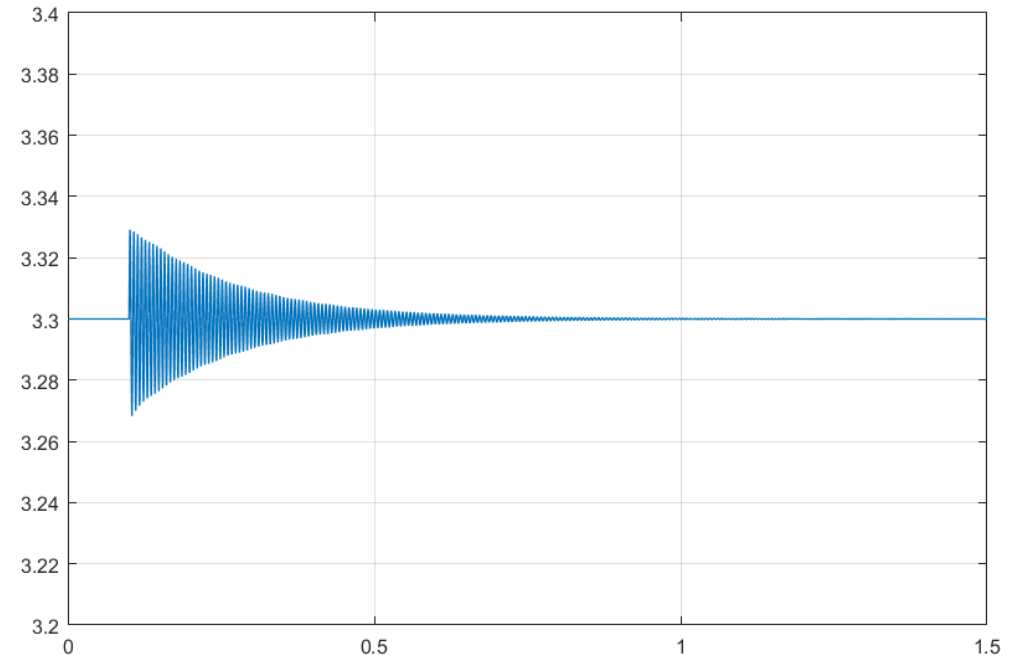
$t = 0.6s$   $\longrightarrow$

$E = 6V \rightarrow E = 8V$

# Simulazione – Loop Shaping

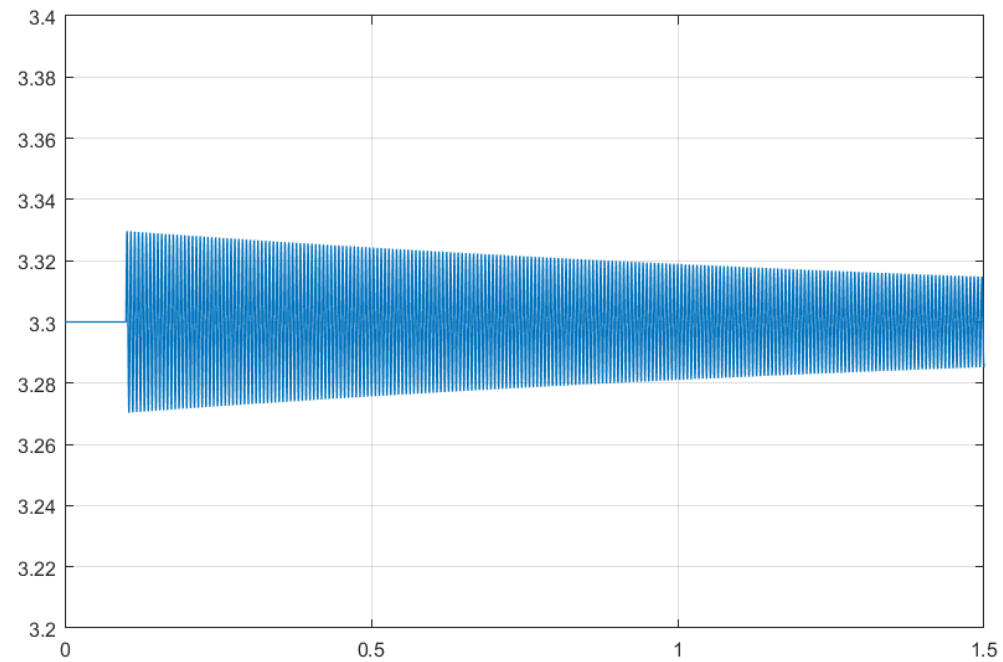


Risposta del sistema ad  
anello aperto

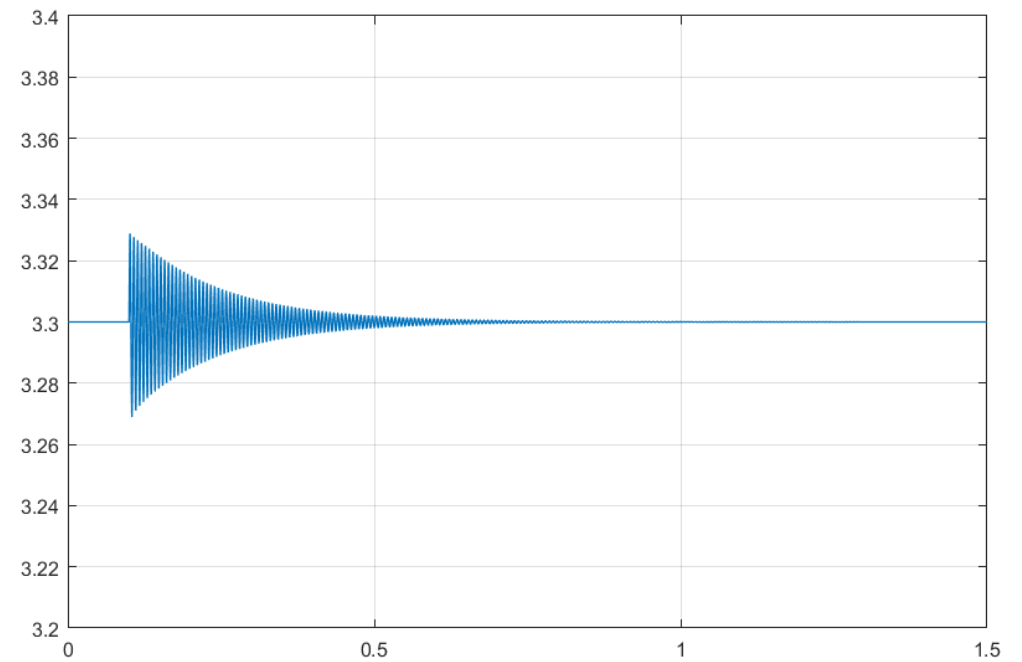


Risposta del sistema ad  
anello chiuso

# Simulazione – Cancellazione



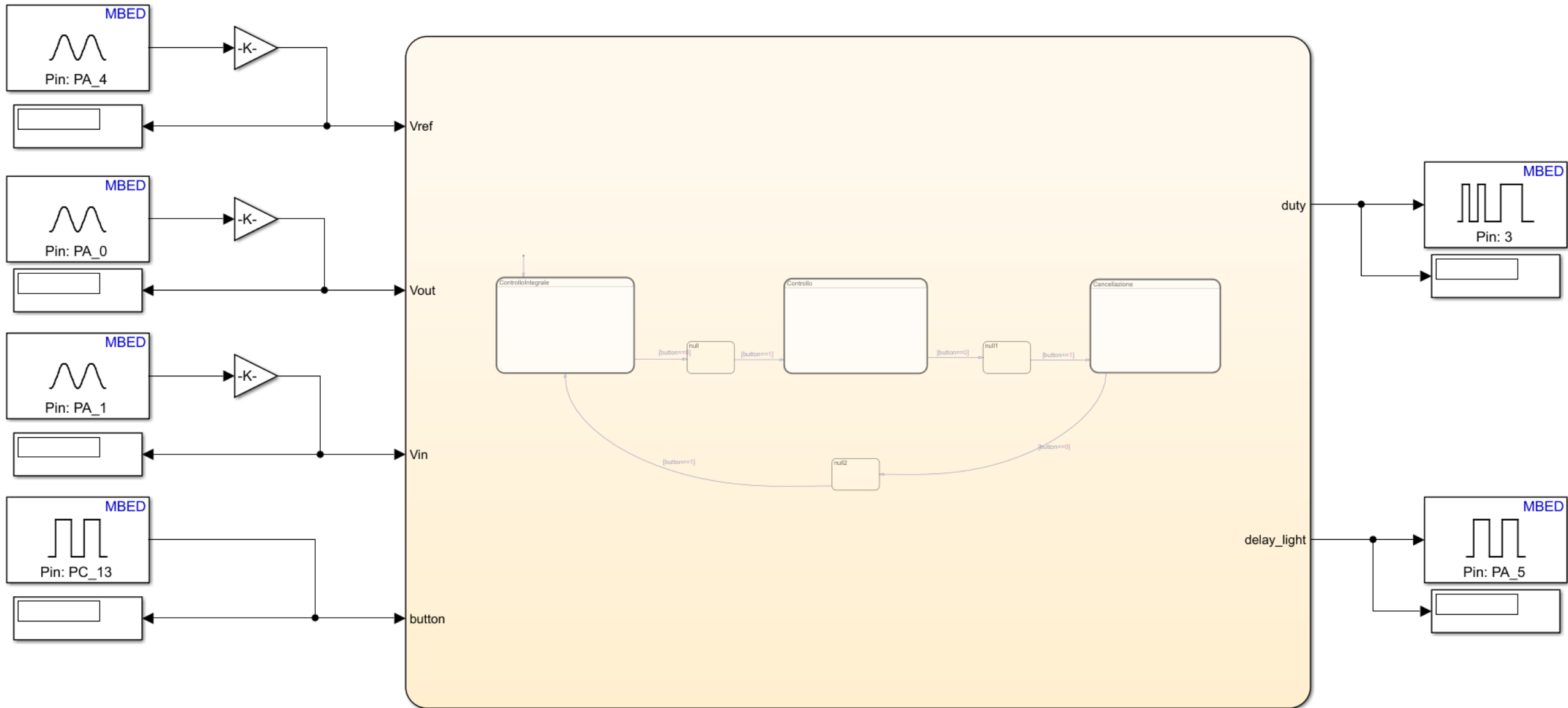
Risposta del sistema ad  
anello aperto



Risposta del sistema ad  
anello chiuso



# Implementazione - Simulink



# Prove Sperimentali

$$E = 10V$$

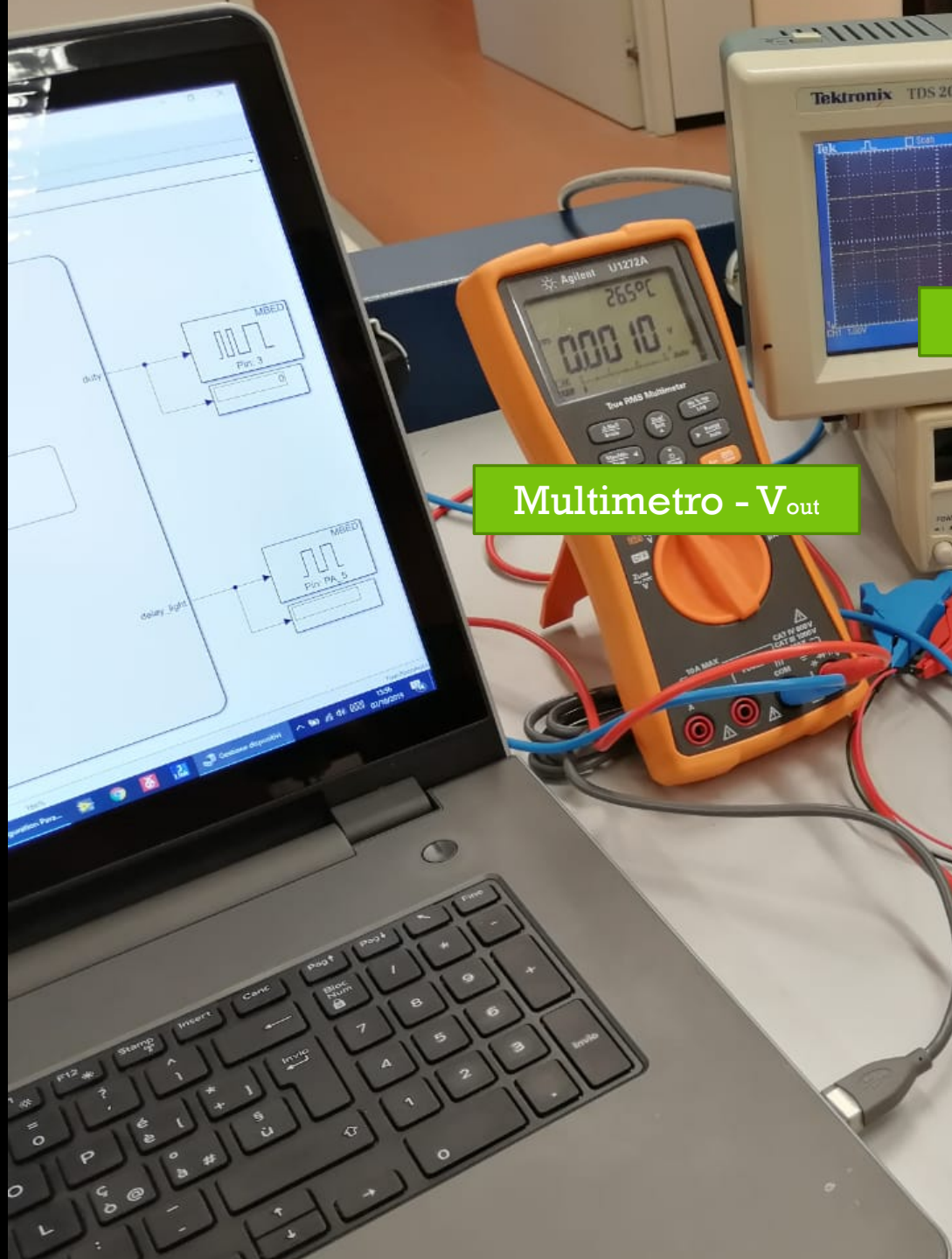
<b>Controllo</b>	<b>T<sub>a5</sub>(ms)</b>	<b>S%(%)</b>
Integrale	390	28.4
Loop Shaping	600	16.4
Cancellazione	600	18

$$R = 100\Omega \rightarrow R = 1000\Omega$$

$$V_{ref} = 5V$$

$$E = 8V$$

<b>Controllo</b>	<b>T<sub>a5</sub>(ms)</b>	<b>S%(%)</b>
Integrale	640	20.4
Loop Shaping	360	11.6
Cancellazione	450	14.4



Oscilloscopio -  $V_{out}$

Multimetro -  $V_{out}$

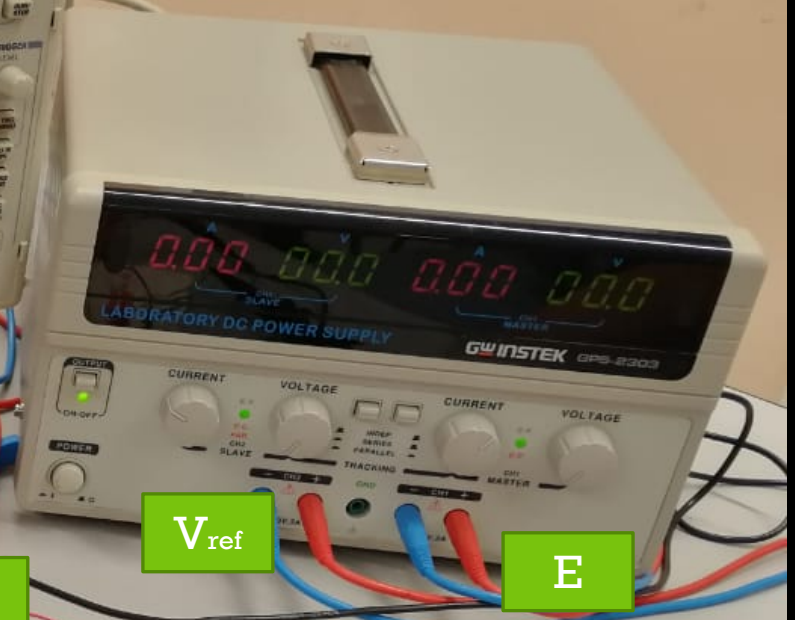
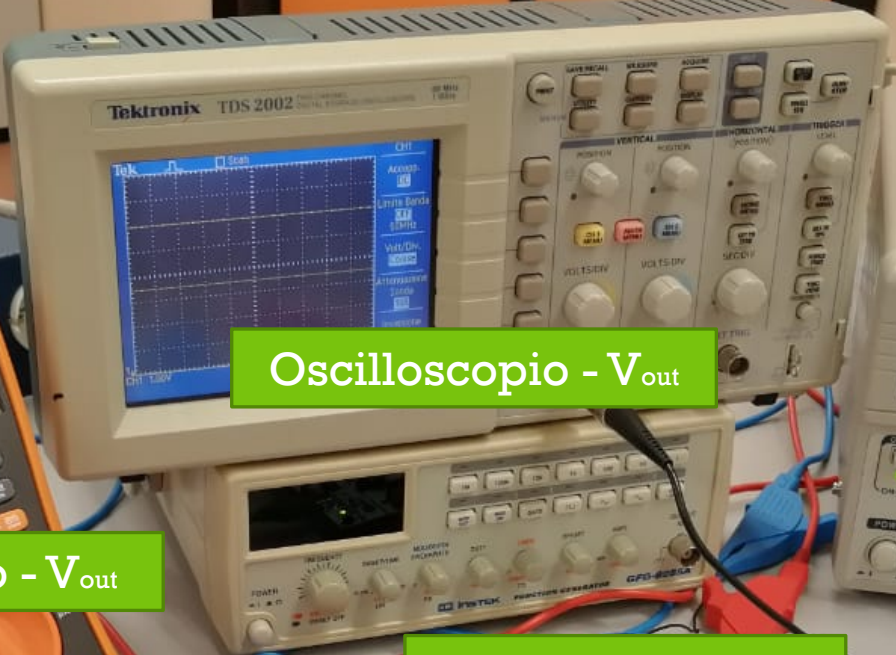
Microcontrollore

Buck Converter

Resistenza di carico

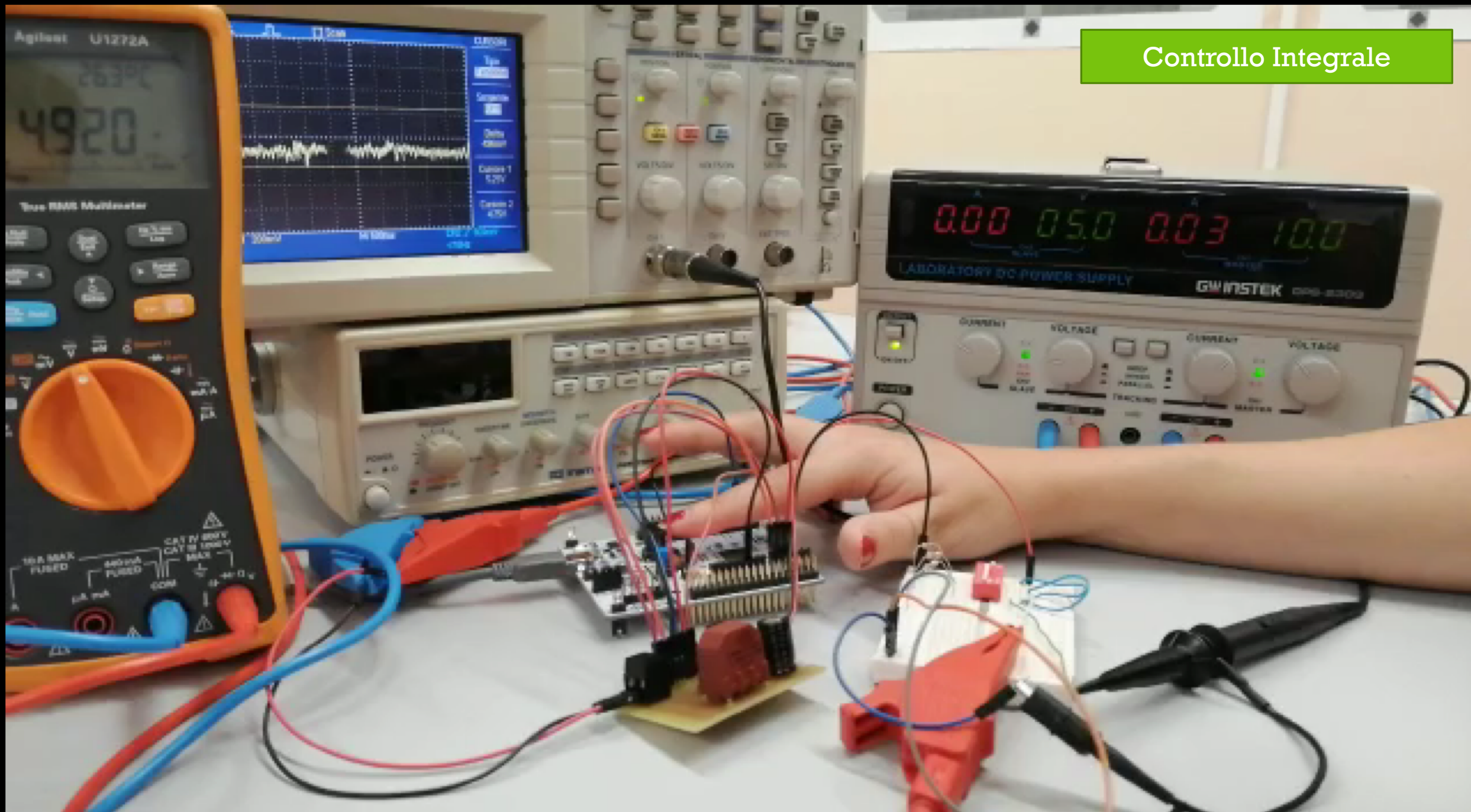
$V_{ref}$

E



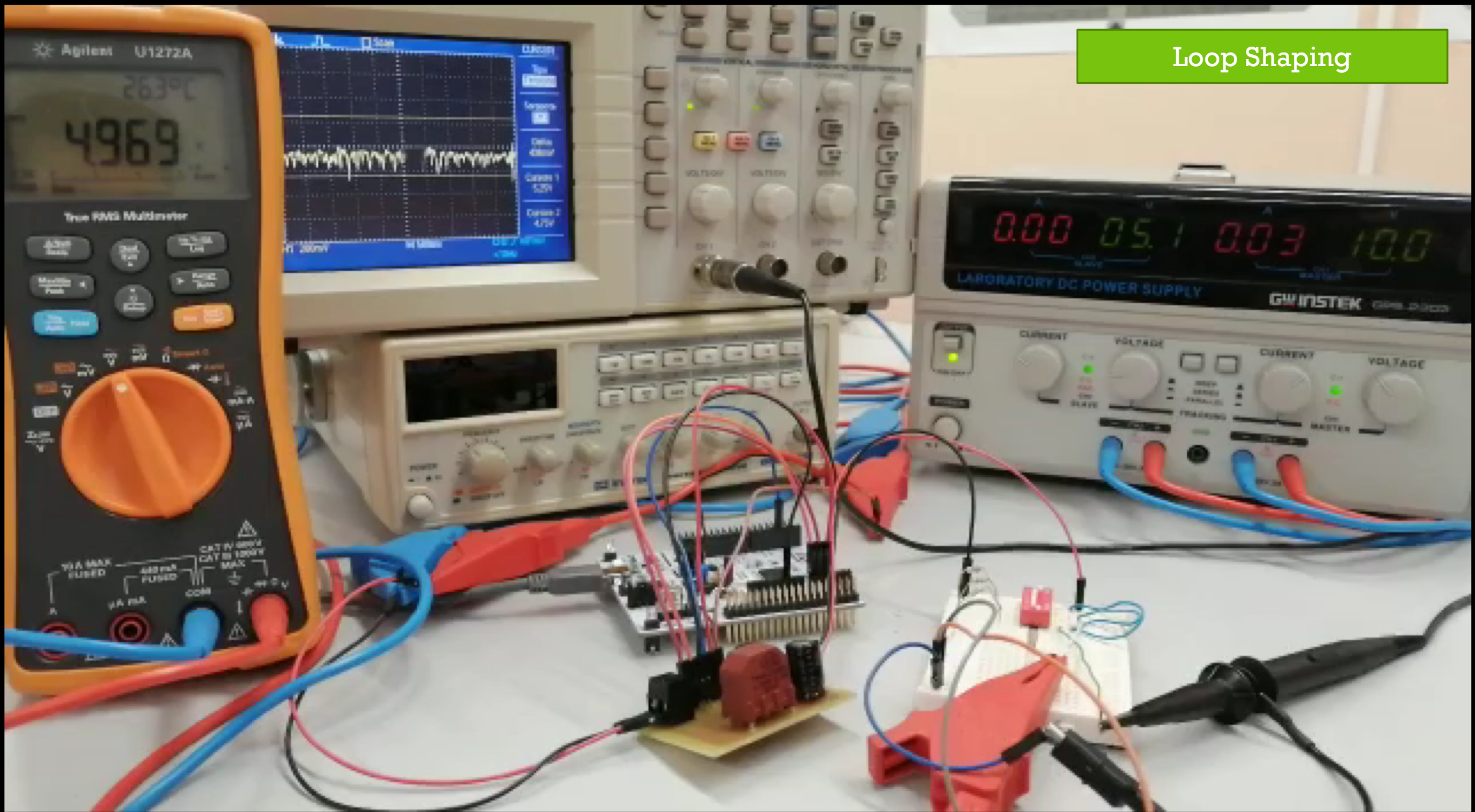


## Controllo Integrale



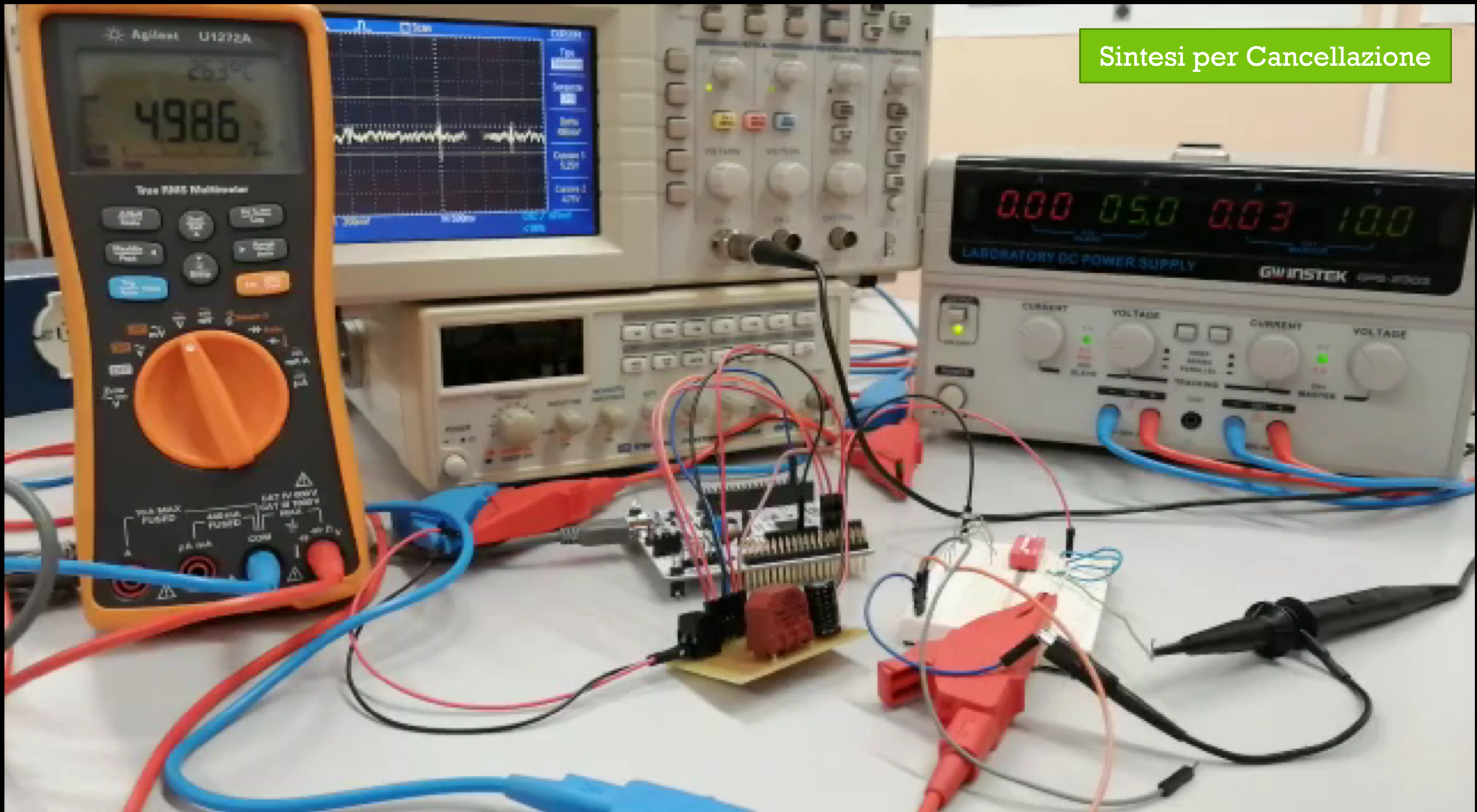


# Loop Shaping





Sintesi per Cancellazione





Variazione  $V_{ref}$

