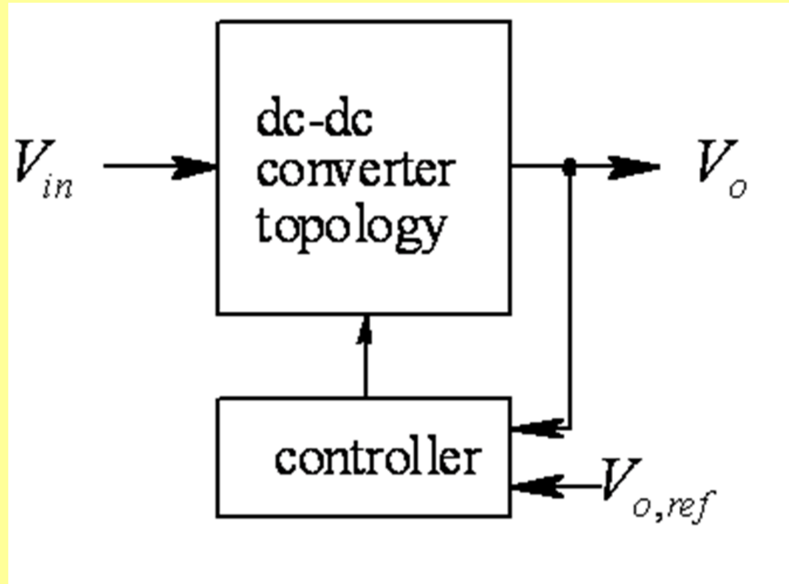
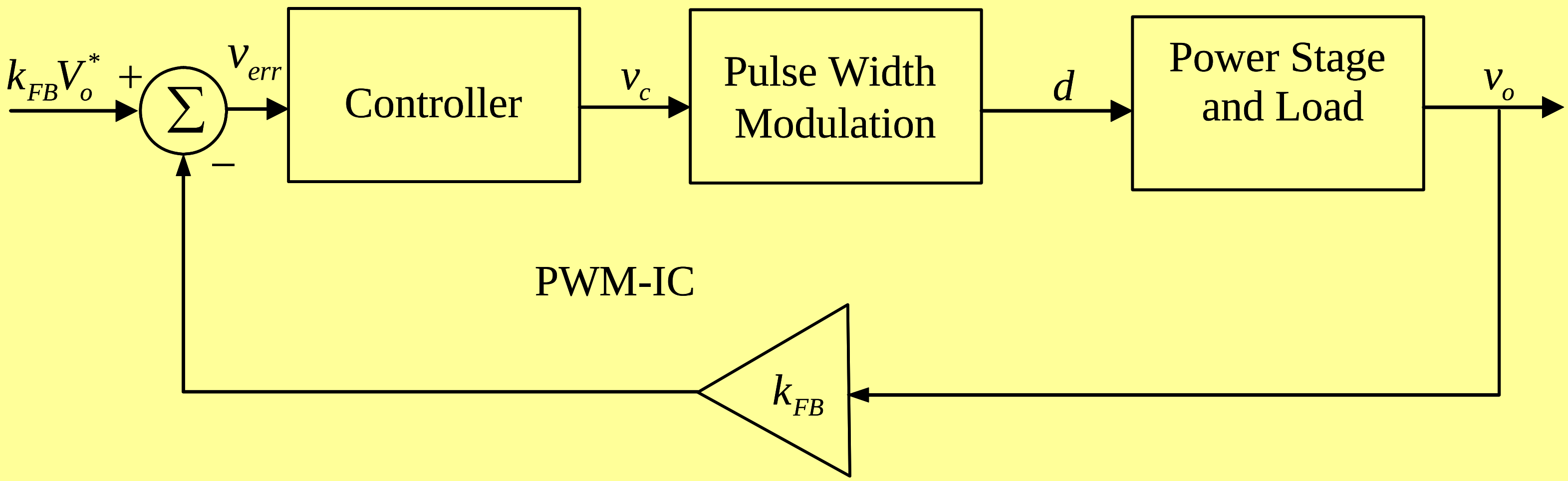
# Regulated DC Power Supply

- Voltage-Mode Control

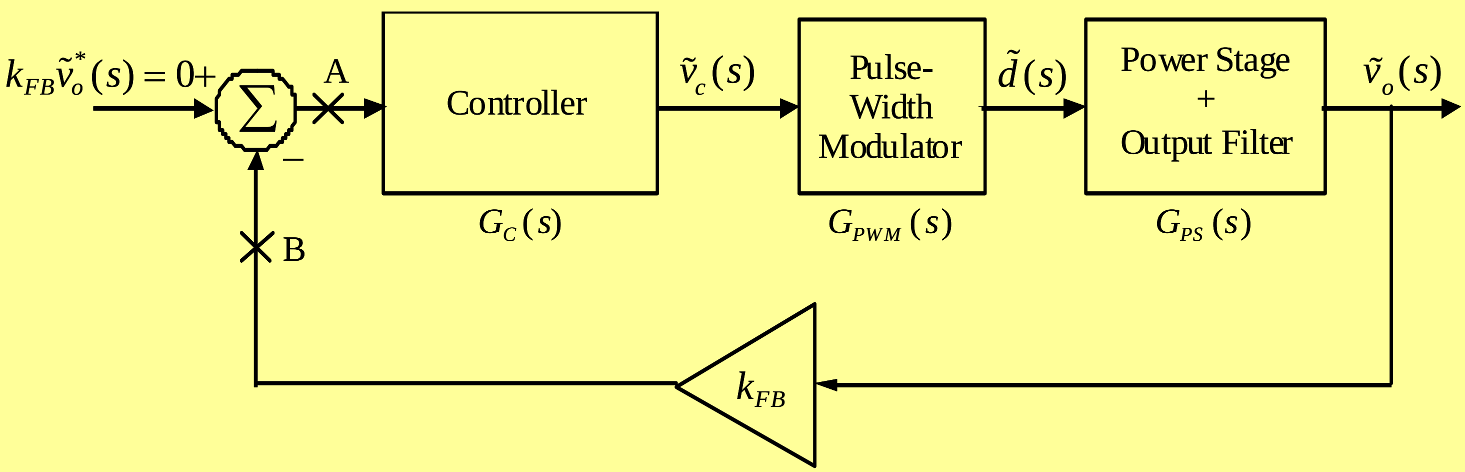


# APPLYING LINEAR CONTROL THEORY



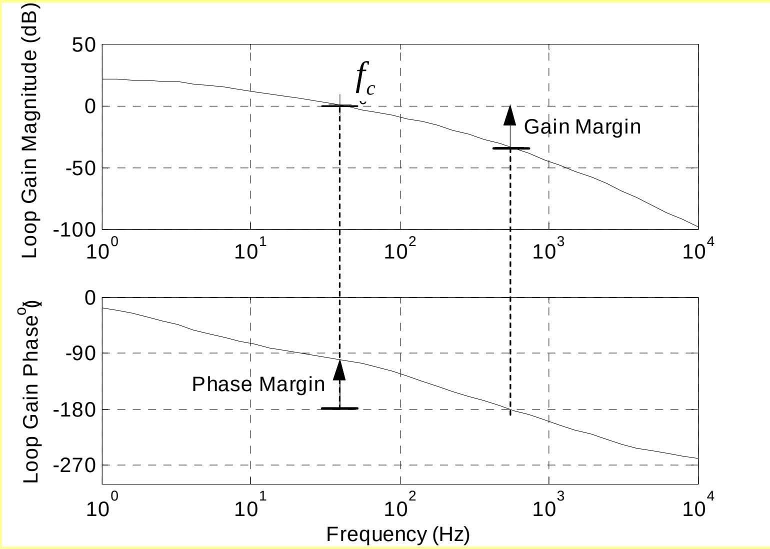

## Small signal representation:

$$\bar{v}_o(t) = V_o + \tilde{v}_o(t)$$
$$d(t) = D + \tilde{d}(t)$$
$$v_c(t) = V_c + \tilde{v}_c(t)$$



Loop Transfer Function:

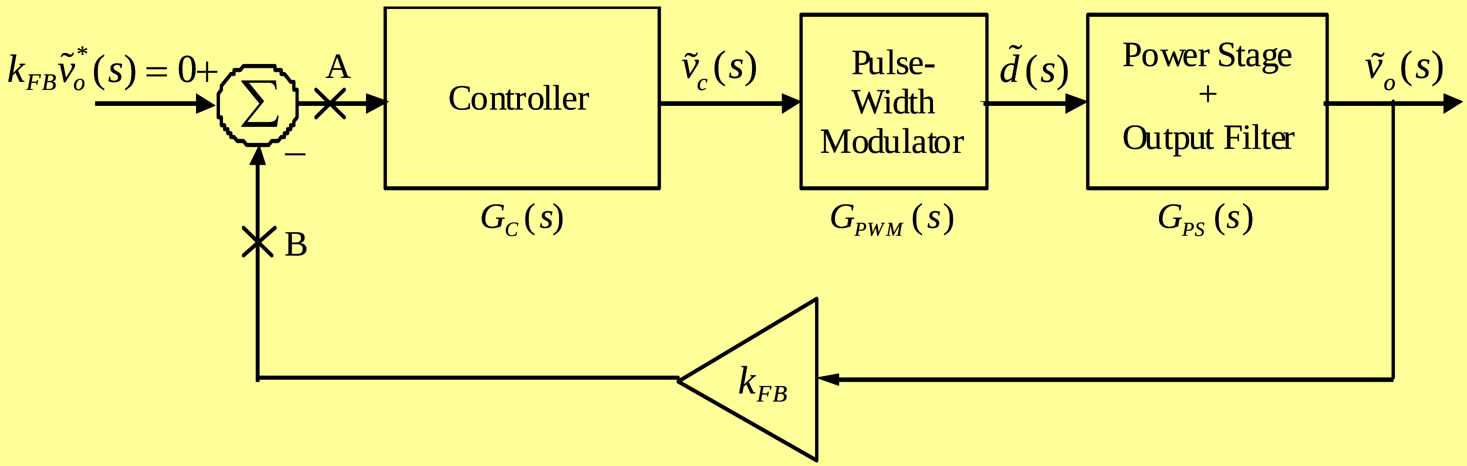
$$G_L(s) = G_C(s)\,G_{PWM}(s)G_{PS}(s)\,k_{FB}$$




Phase Margin:

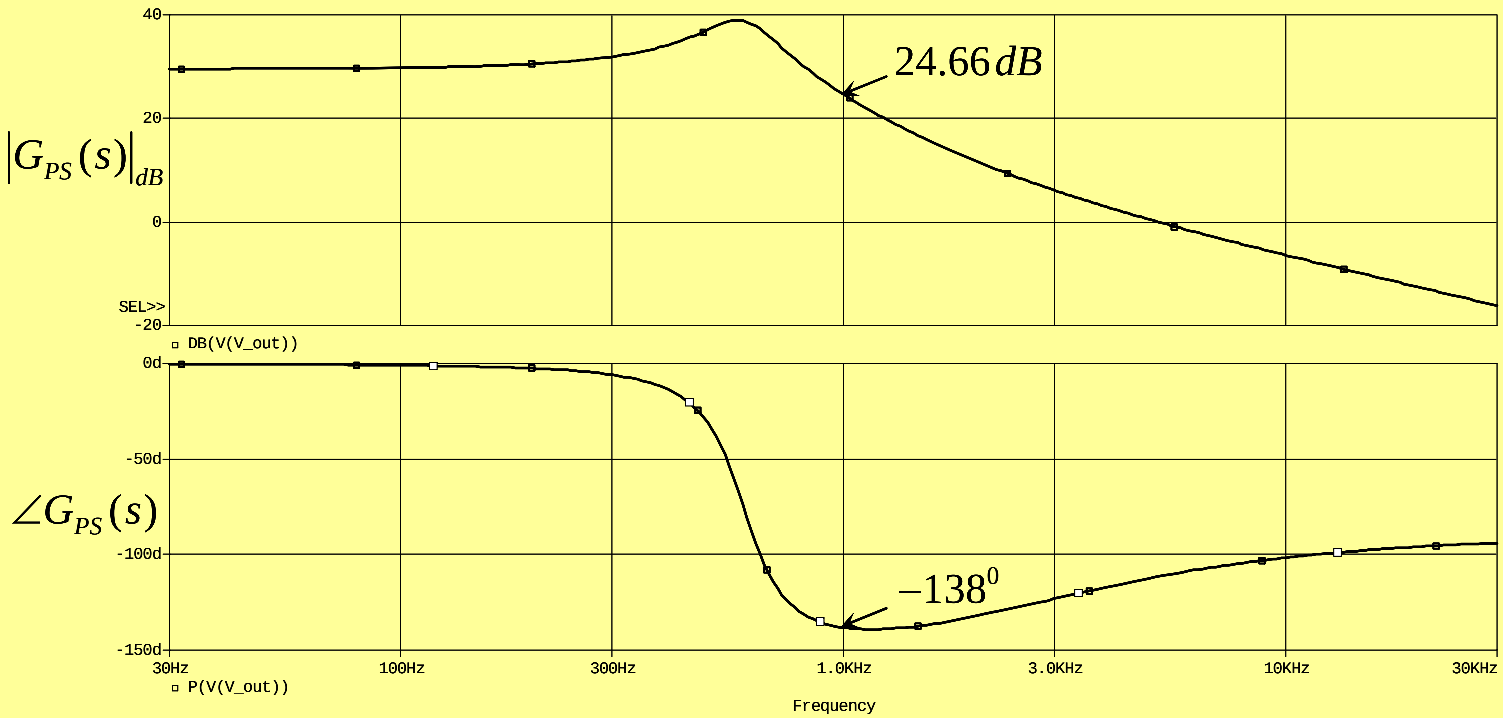
$$\phi_{PM} = \phi_L\Big|_{f_c} - (-180^0) = \phi_L\Big|_{f_c} + 180^0$$

# Form of the Controller Transfer Function:




$$G_c(s) = \frac{k_c}{s} \frac{\left(1 + s/\omega_z\right)^2}{\left(1 + s/\omega_p\right)^2}$$

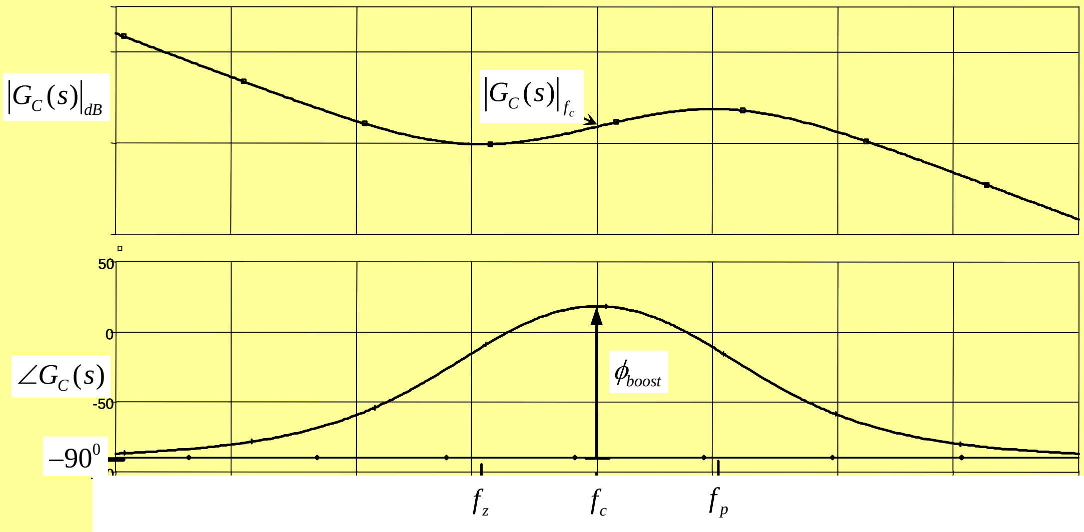
# Select the Crossover Frequency $f_c$




$$G_c(s) = \frac{k_c}{s} \quad \frac{\left(1 + s/\omega_z\right)^2}{\left(1 + s/\omega_p\right)^2}$$

# Calculate the needed Phase Boost:

$$G_c(s) = \frac{k_c}{s} \quad \frac{\left(1 + s/\omega_z\right)^2}{\left(1 + s/\omega_p\right)^2}$$




$$\angle G_C(s)\Big|_{f_c} = -90^o + \phi_{boost}$$

$$\angle G_L(s)\Big|_{f_c} = \angle G_{PS}(s)\Big|_{f_c} + \angle G_C(s)\Big|_{f_c} = -180^o + \phi_{PM}$$

$$\phi_{boost} = -90^o + \phi_{PM} - \angle G_{PS}(s)\Big|_{f_c}$$

$$\sqrt{\frac{\omega_p}{\omega_z}} = \tan\left(45^o + \frac{\phi_{boost}}{4}\right)$$

$$\omega_c = \sqrt{\omega_z \omega_p}$$

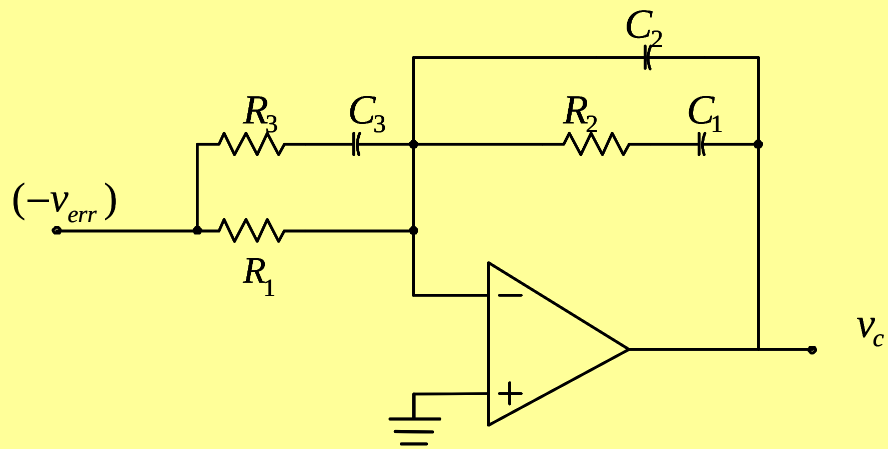
# Calculating the Controller Gain $k_c$

$$G_c(s) = \frac{k_c}{s} \quad \frac{\left(1 + s/\omega_z\right)^2}{\left(1 + s/\omega_p\right)^2}$$

$$\left|G_L(s)\right|_{f_c} = \left|G_C(s)\right|_{f_c} \times \left|G_{PWM}(s)\right|_{f_c} \times \left|G_{PS}(s)\right|_{f_c} \times k_{FB} = 1$$

## Implementation of the controller by an op-amp

$$G_c(s) = \frac{k_c}{s} \quad \frac{\left(1 + s/\omega_z\right)^2}{\left(1 + s/\omega_p\right)^2}$$




$$C_2 = \omega_z /(k_c \omega_p R_1)$$

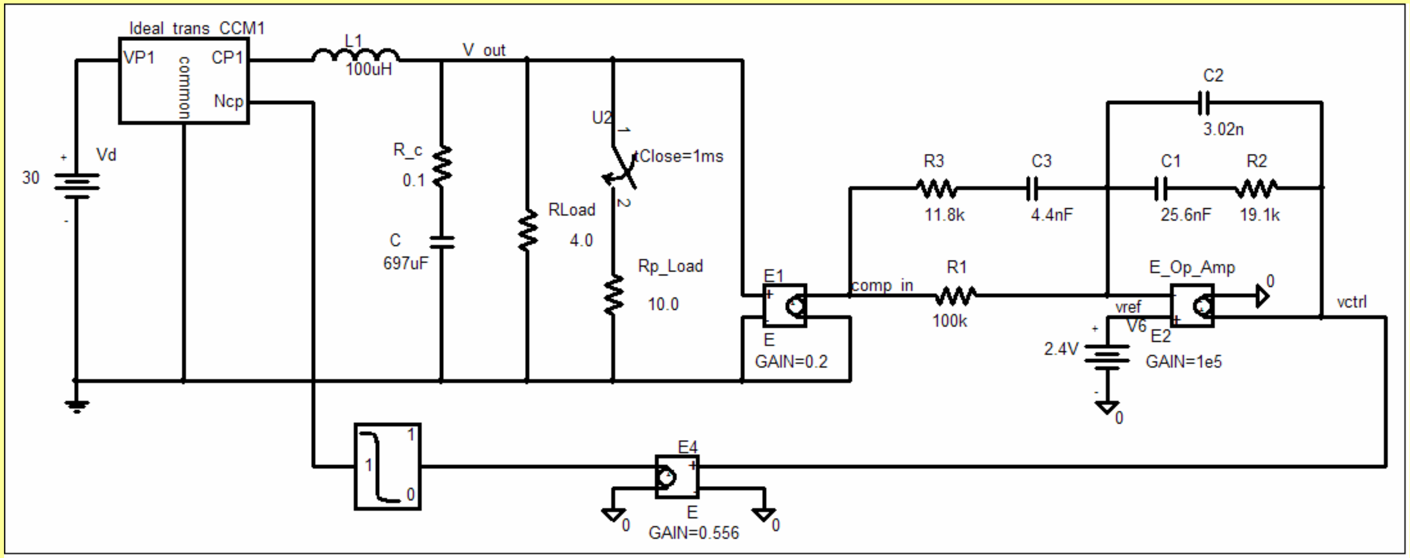
$$C_1 = C_2\left(\omega_p / \omega_z - 1\right)$$

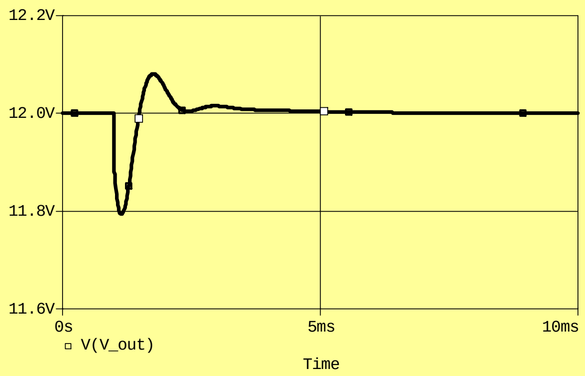
$$R_2 = 1/(\omega_z C_1)$$

$$R_3 = R_1 /(\omega_p / \omega_z - 1)$$

$$C_3 = 1/(\omega_p R_3)$$

# PSpice model of the Buck converter with voltage-mode control



# Summary

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- Voltage-Mode Control