Design of Feedback Controllers in Power Electronics

- Need for Feedback Controllers in Power Electronics
- Basic Principles
- Focus on Regulated Switch-Mode Power Supplies

Applications of Feedback Controllers

Examples:

- Electric generation in wind turbines
- Photovoltaic systems
- Electric drives in transportation
- Regulated Switch-Mode Power Supplies

Design of Feedback Controllers

OBJECTIVES:

- zero steady state error
- fast response
- low overshoot
- low noise susceptibility

The steps in designing the feedback controller:

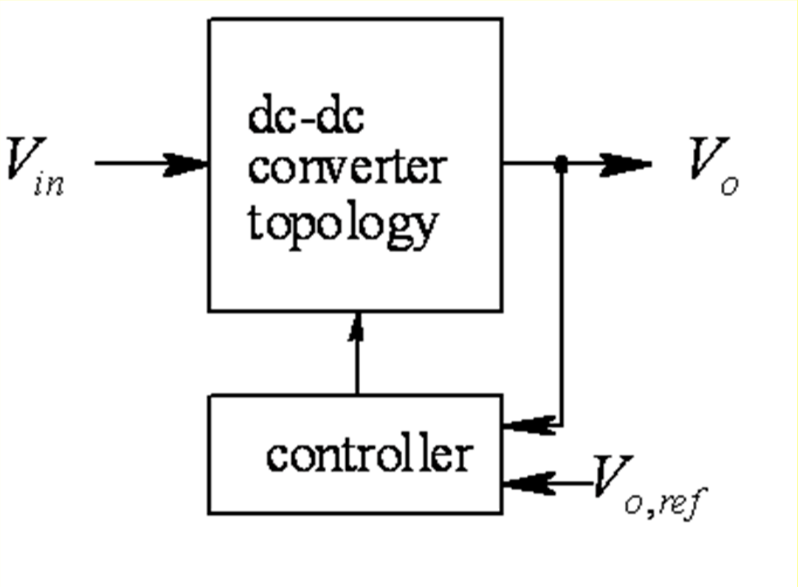
Linearize the system for small changes around the dc steady state operating point

Design the feedback controller using linear control theory

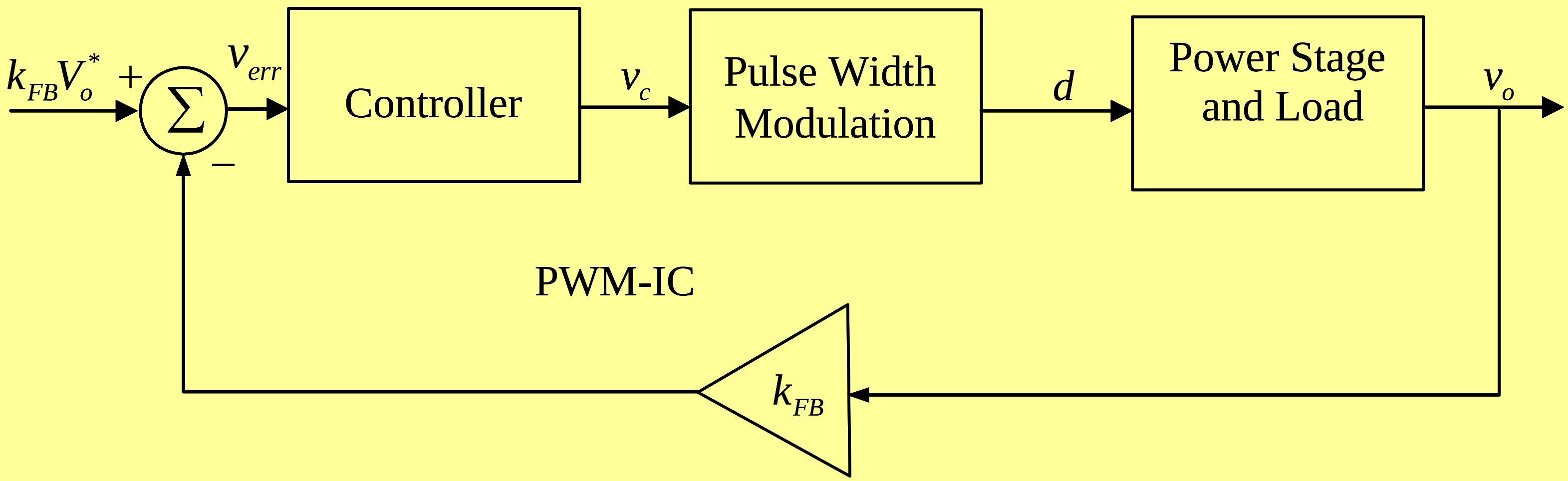
Confirm and evaluate the system response by simulations for large disturbances

Regulated DC Power Supplies

- Linearization
  - Use of PSpice

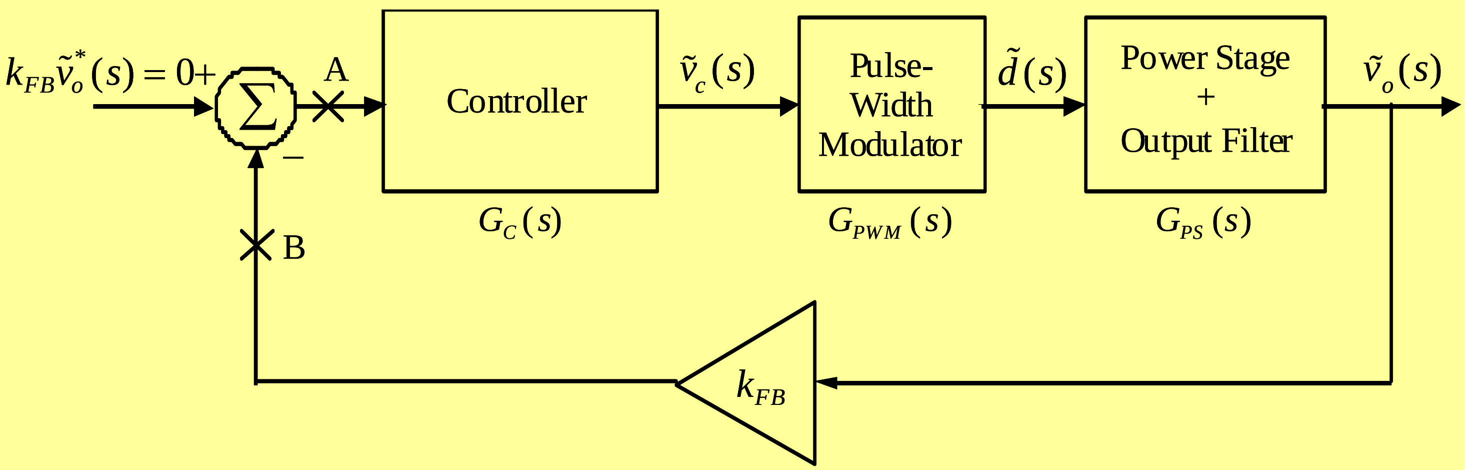


APPLYING LINEAR CONTROL THEORY

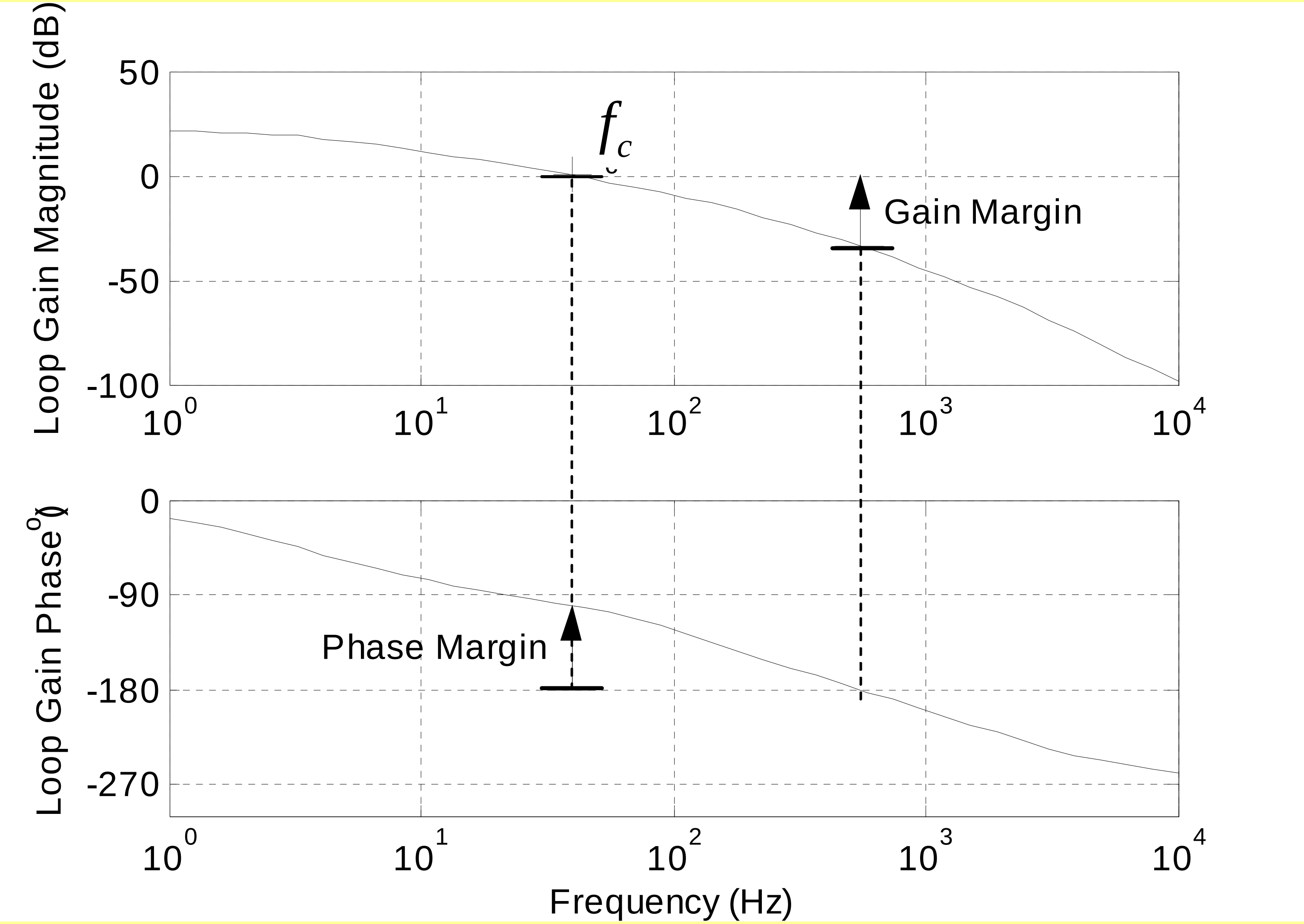


Small signal representation:

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



Loop Transfer Function: $G_L(s) = G_C(s)G_{PWM}(s)G_{PS}(s)k_{FB}$



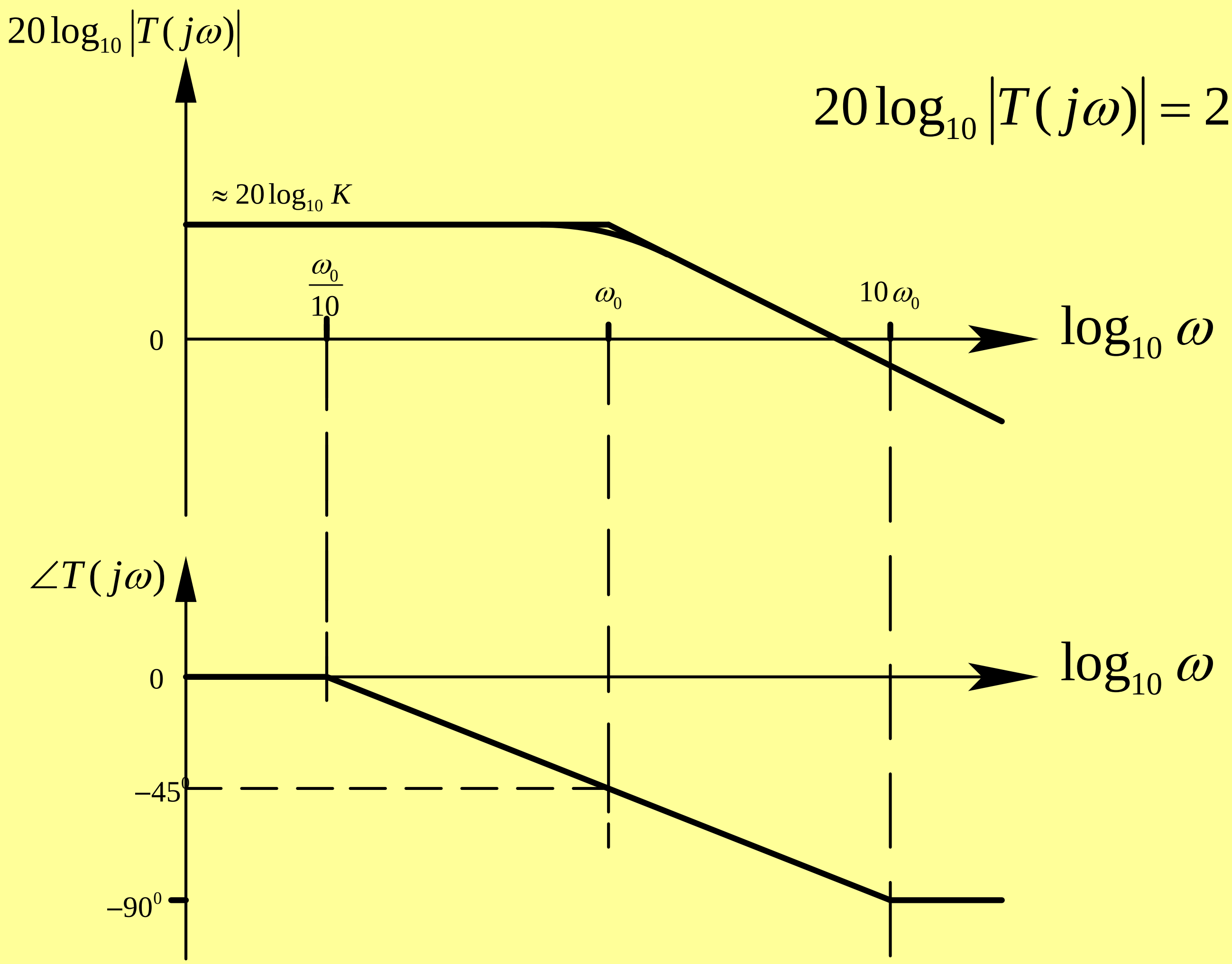
Phase Margin:

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

Example:

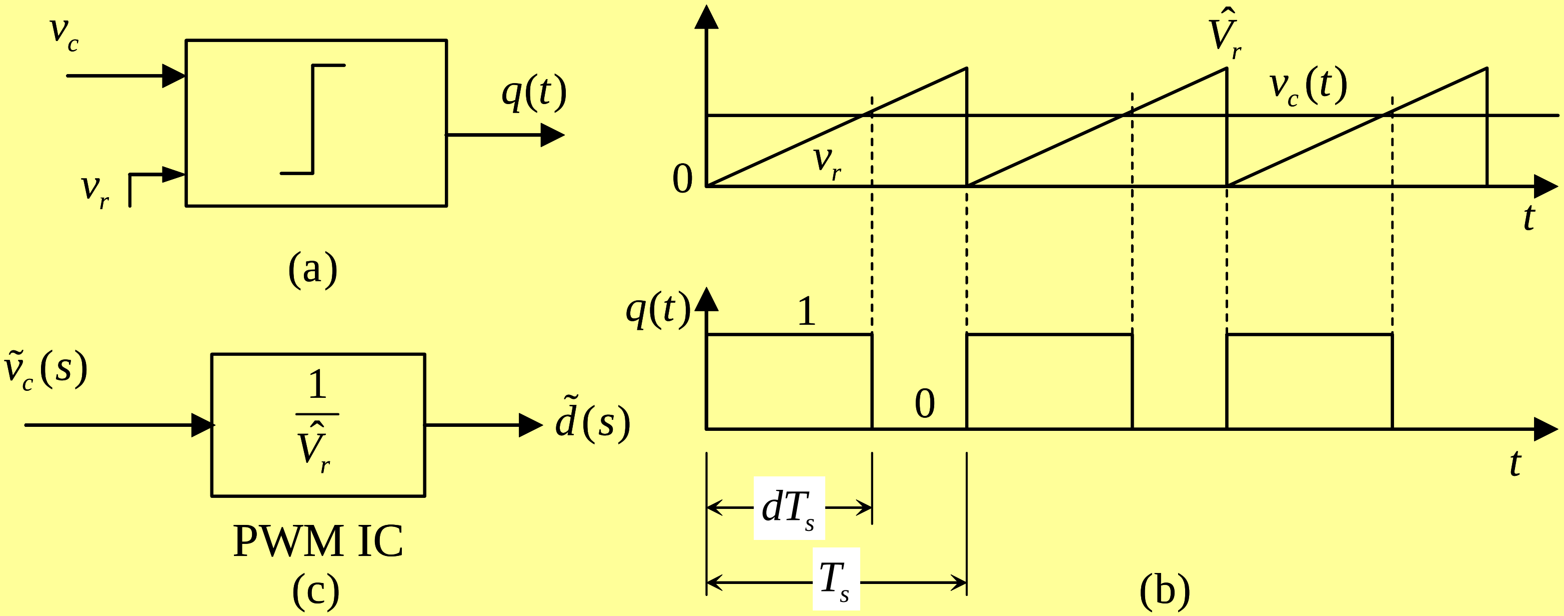
$$T(s) = \frac{K}{1 + \frac{s}{\omega_0}}$$

$$20\log_{10}|T(j\omega)| = 20\log_{10}\frac{K}{\sqrt{1+(\omega/\omega_0)^2}}$$



LINEARIZATION OF VARIOUS TRANSFER FUNCTION BLOCKS

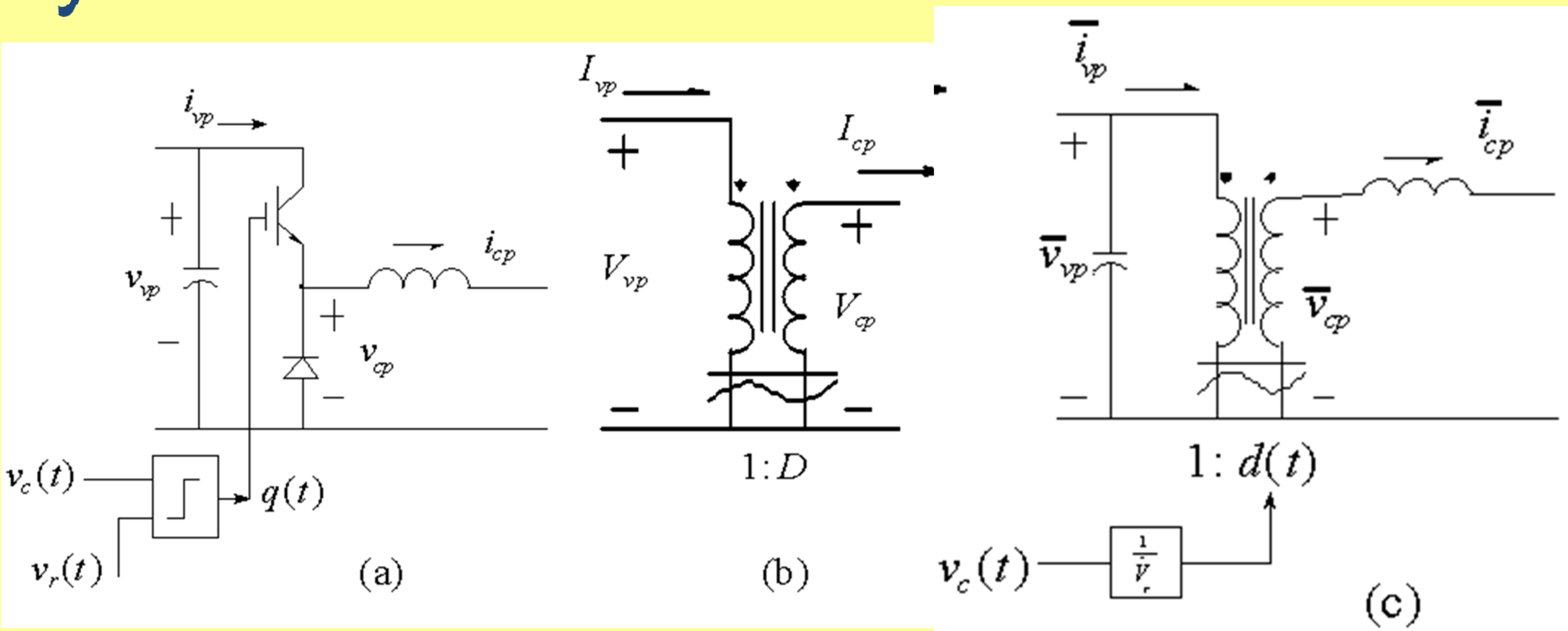
Linearizing the PWM Controller IC



$$d(t) = \frac{v_c(t)}{\hat{V}_r} \qquad v_c(t) = V_c + \tilde{v}_c(t)$$

$$d(t) = \underbrace{\frac{V_c(t)}{\hat{V}_r}}_{D} + \underbrace{\frac{\tilde{v}_c(t)}{\hat{V}_r}}_{\tilde{d}(t)} \qquad G_{PWM}(s) = \frac{\tilde{d}(s)}{\tilde{v}_c(s)} = \frac{1}{\hat{V}_r}$$

Average Representation Under Dynamic Conditions :



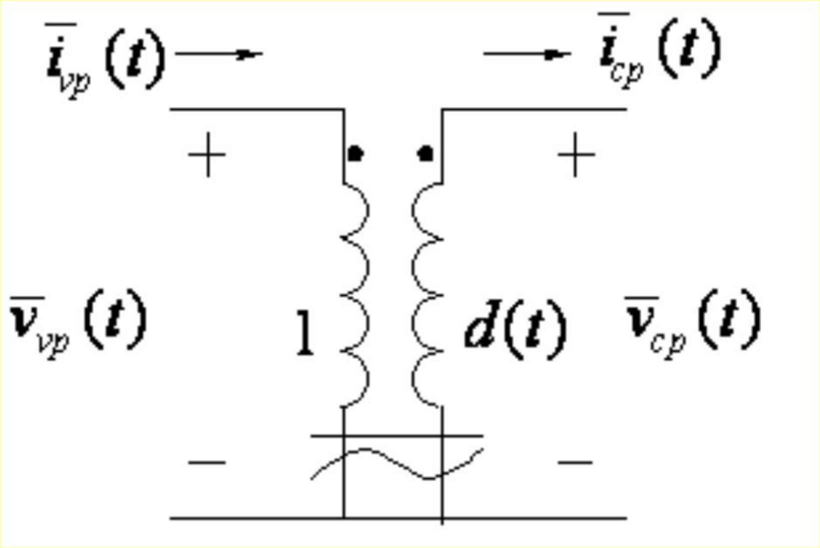
$$V_{cp} = DV_{vp}$$

$$I_{vp} = DI_{cp}$$

$$\bar{v}_{cp}(t) = d(t)\bar{v}_{vp}(t)$$

$$\bar{i}_{vp}(t) = d(t)\bar{i}_{cp}(t)$$

Linearizing the Power Stage of DC-DC Converters in CCM



$$d(t) = D + \tilde{d}(t)$$

$$\bar{v}_{vp}(t) = V_{vp} + \tilde{v}_{vp}(t)$$

$$\bar{v}_{cp}(t) = V_{cp} + \tilde{v}_{cp}(t)$$

$$\bar{i}_{vp}(t) = I_{vp} + \tilde{i}_{vp}(t)$$

$$\bar{i}_{cp}(t) = I_{cp} + \tilde{i}_{cp}(t)$$

$$V_{cp} + \tilde{v}_{cp} = (D + \tilde{d})(V_{vp} + \tilde{v}_{vp})$$

$$I_{vp} + \tilde{i}_{vp} = (D + \tilde{d})(I_{cp} + \tilde{i}_{cp})$$

$$\tilde{v}_{cp}(t) = D\tilde{v}_{vp} + V_{vp}\tilde{d} + \cancel{\tilde{d}\tilde{v}_{vp}}$$

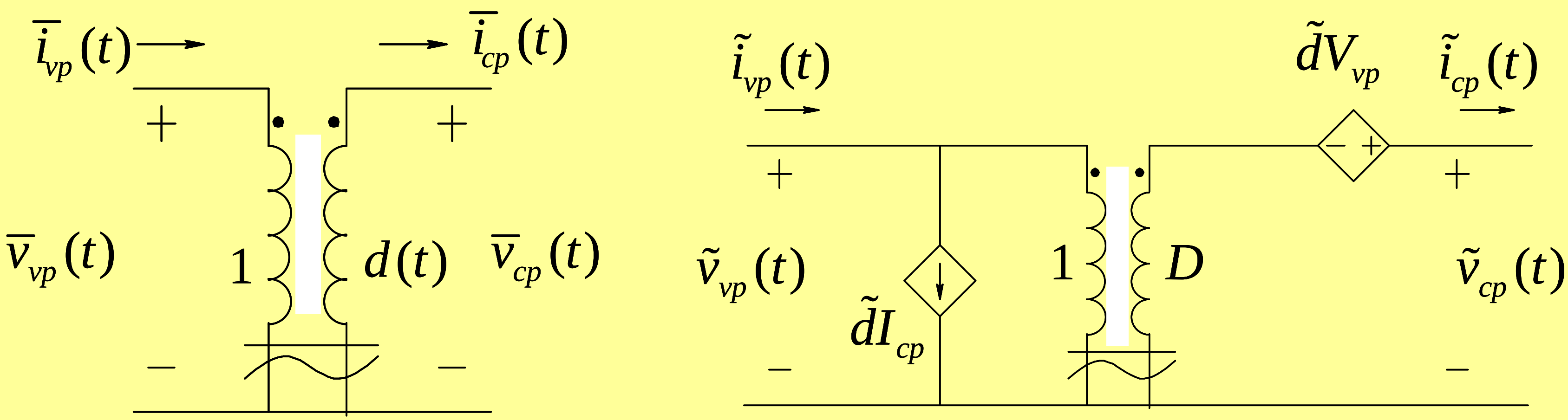
$$\tilde{i}_{vp} = D\tilde{i}_{cp} + I_{cp}\tilde{d} + \cancel{\tilde{d}\tilde{i}_{cp}}$$

$$\tilde{v}_{cp}(t) = D\tilde{v}_{vp} + V_{vp}\tilde{d}$$

$$\tilde{i}_{vp} = D\tilde{i}_{cp} + I_{cp}\tilde{d}$$

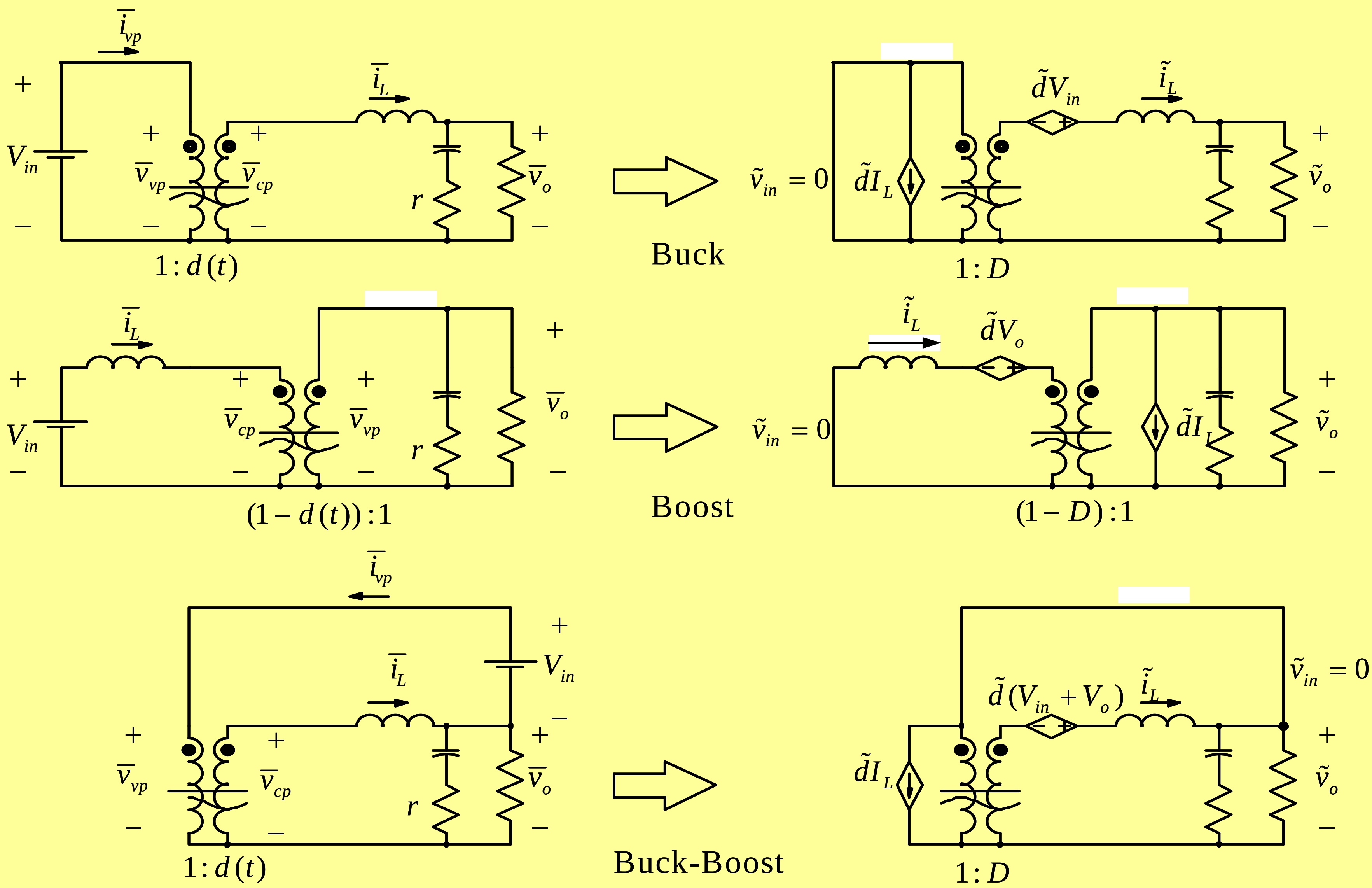
$$\tilde{v}_{cp}(t) = D\tilde{v}_{vp} + V_{vp}\tilde{d}$$

$$\tilde{i}_{vp} = D\,\tilde{i}_{cp} + I_{cp}\tilde{d}$$



(a) (b)

Linearizing single-switch converters



Small signal transfer function for Buck, Boost and Buck-Boost converters

$$\frac{\tilde{v}_o}{\tilde{d}} = \frac{V_{in}}{LC} \frac{1 + srC}{s^2 + s\left(\frac{1}{RC} + \frac{r}{L}\right) + \frac{1}{LC}} \qquad \text{(Buck)}$$

$$\frac{\tilde{v}_o}{\tilde{d}} = \frac{V_{in}}{(1-D)^2}\left(1 - s\frac{L_e}{R}\right) \frac{1 + srC}{L_e C\left(s^2 + s\left(\frac{1}{RC} + \frac{r}{L_e}\right) + \frac{1}{L_e C}\right)} \qquad \text{(Boost)}$$

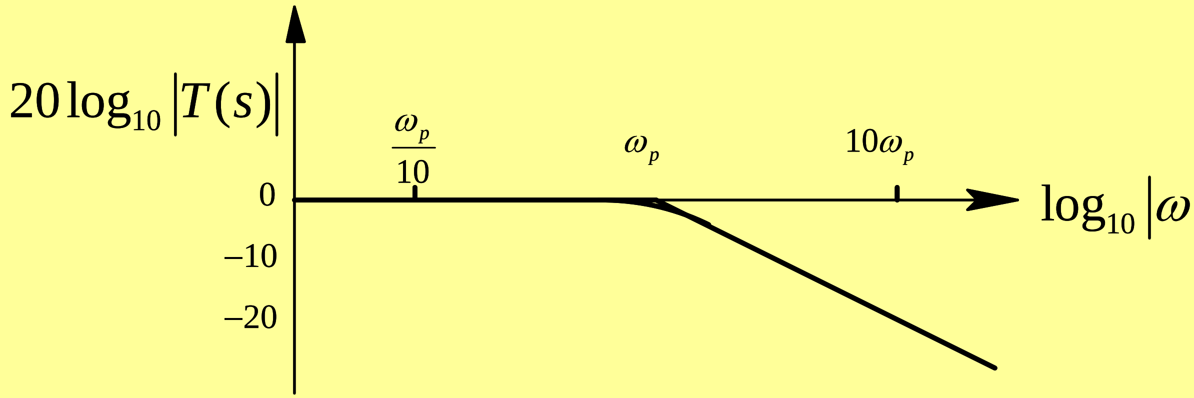
$$\frac{\tilde{v}_o}{\tilde{d}} = \frac{V_{in}}{(1-D)^2}\left(1 - s\frac{DL_e}{R}\right) \frac{1 + srC}{L_e C\left(s^2 + s\left(\frac{1}{RC} + \frac{r}{L_e}\right) + \frac{1}{L_e C}\right)} \qquad \text{(Buck-Boost)}$$

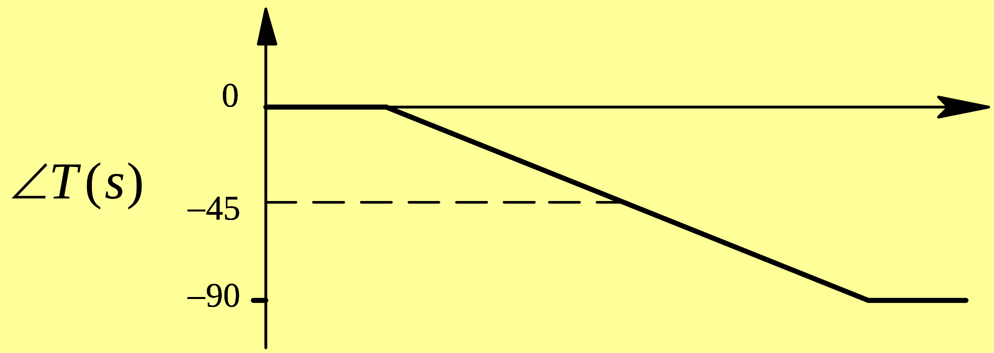
$$L_e = \frac{L}{(1-D)^2} \qquad \text{(Boost and Buck-Boost)}$$

BODE PLOTS OF TRANSFER FUNCTIONS WITH POLES AND ZEROS

A Pole in a Transfer Function

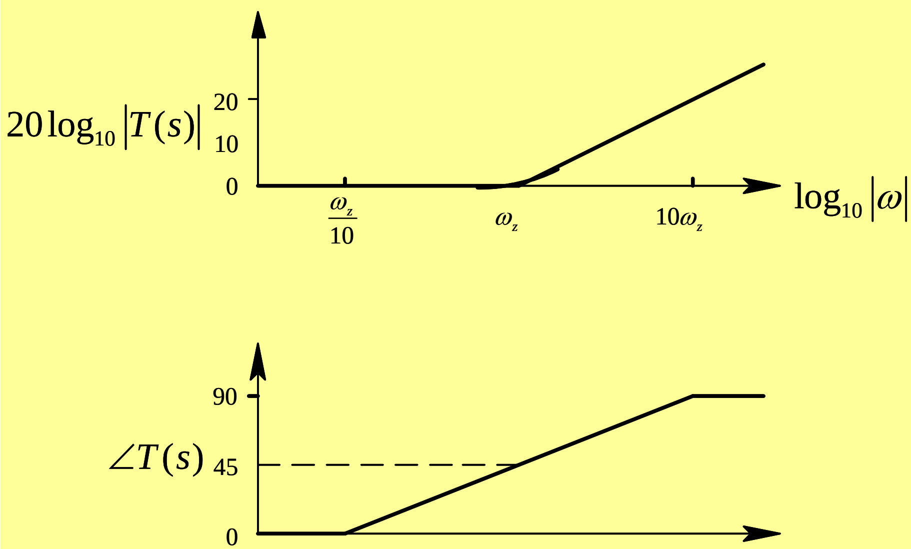
$$T(s) = \frac{1}{1 + s/\omega_p}$$





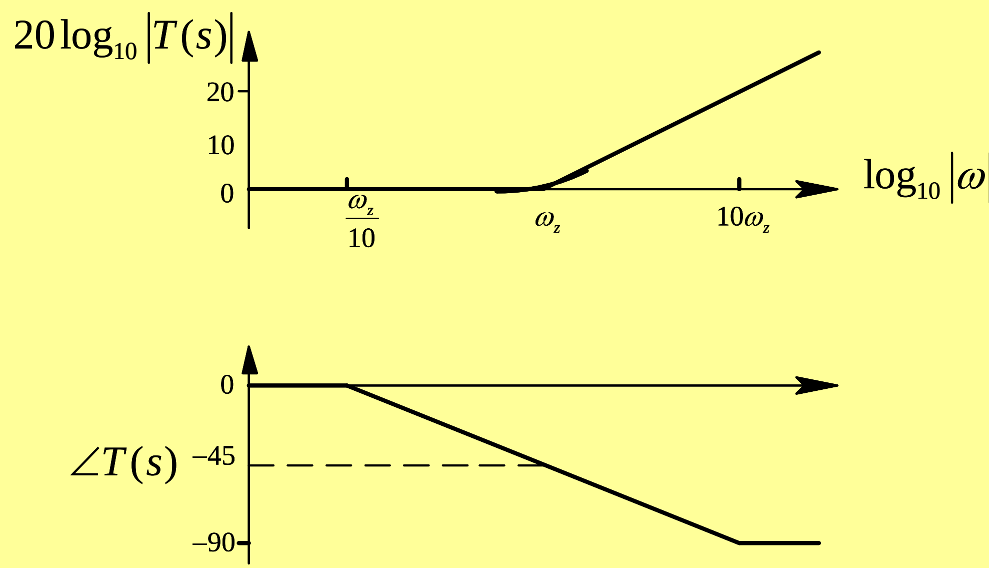
A Zero in a Transfer Function

$$T(s) = 1 + s/\omega_z$$



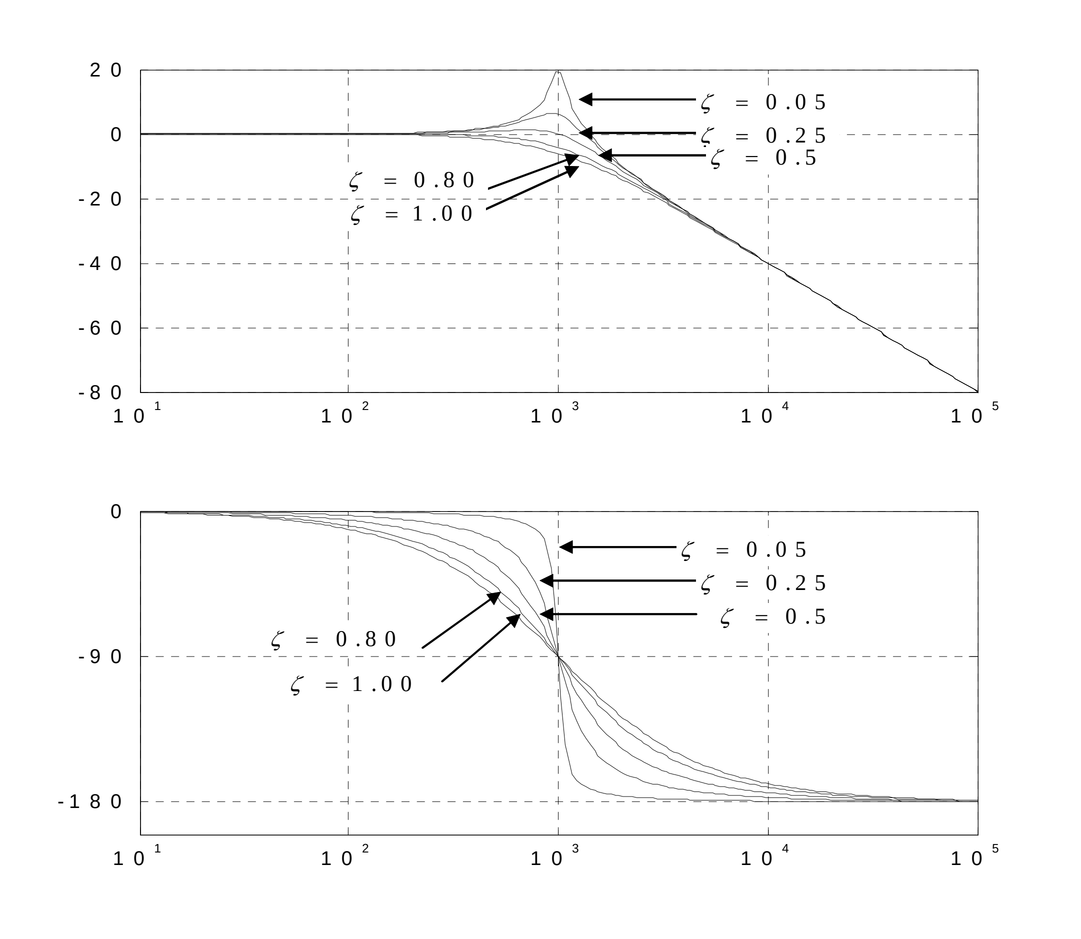
A Right-Hand-Plane (RHP) Zero in a Transfer Function

$$T(s) = 1 - \frac{s}{\omega_z}$$



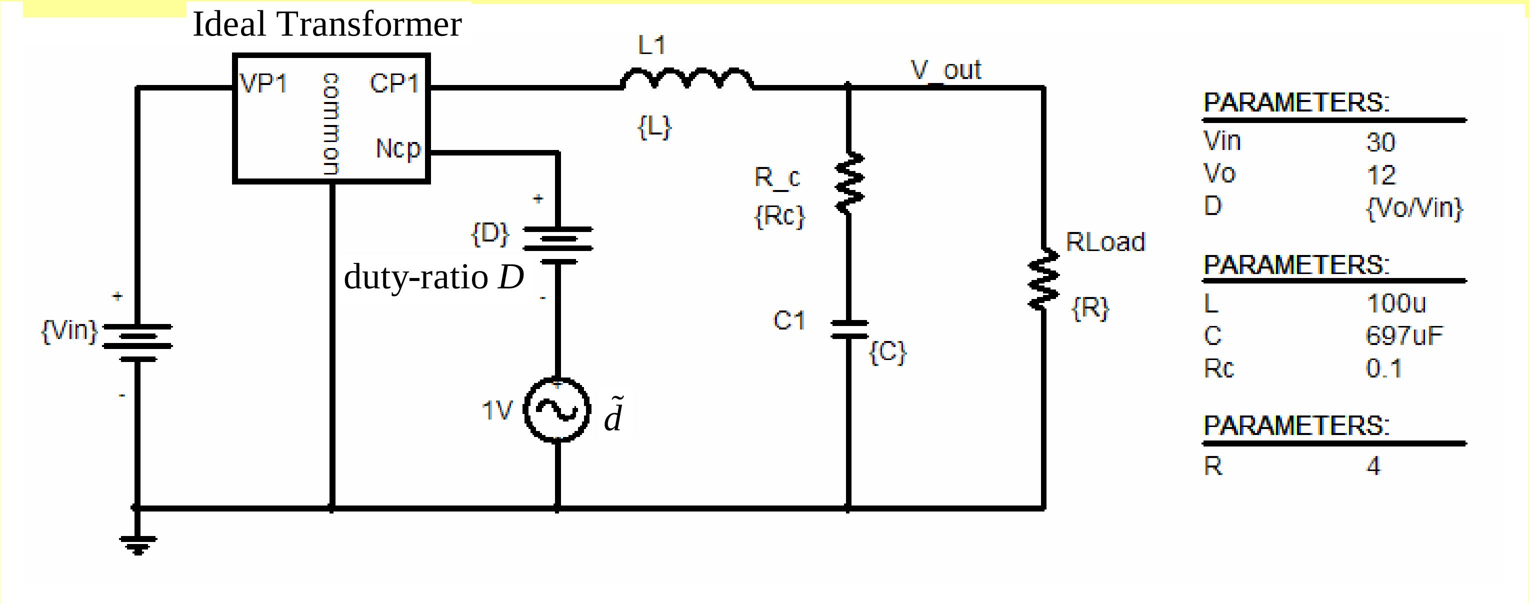
Two Poles in a Transfer Function

$$T(s)=\frac{1}{1+\alpha s+\left(\frac{s}{\omega_o}\right)^2} \qquad \xi=(\alpha/2)\omega_o$$

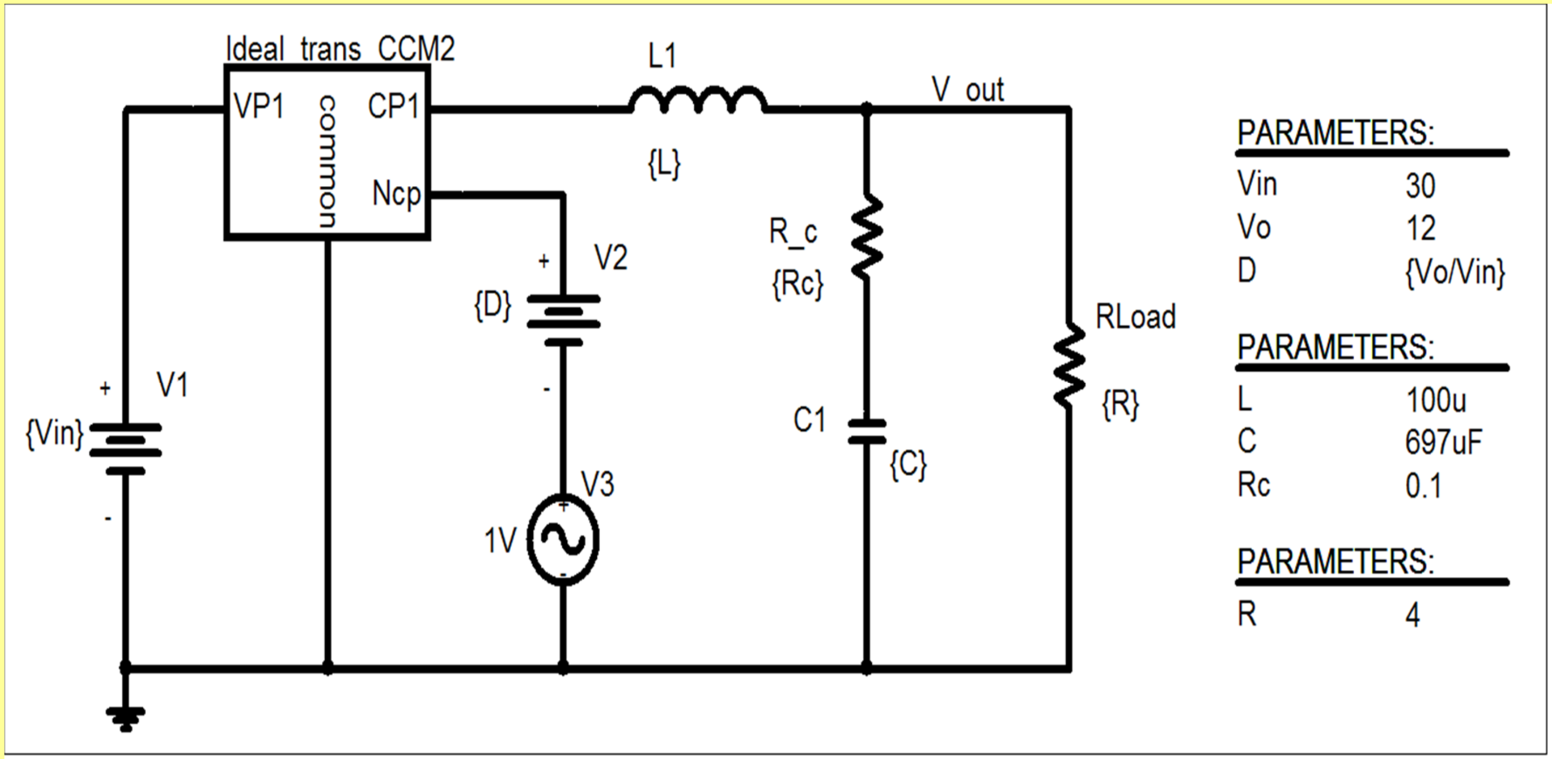


Using Computer Simulation to Obtain the transfer function Bode Plots

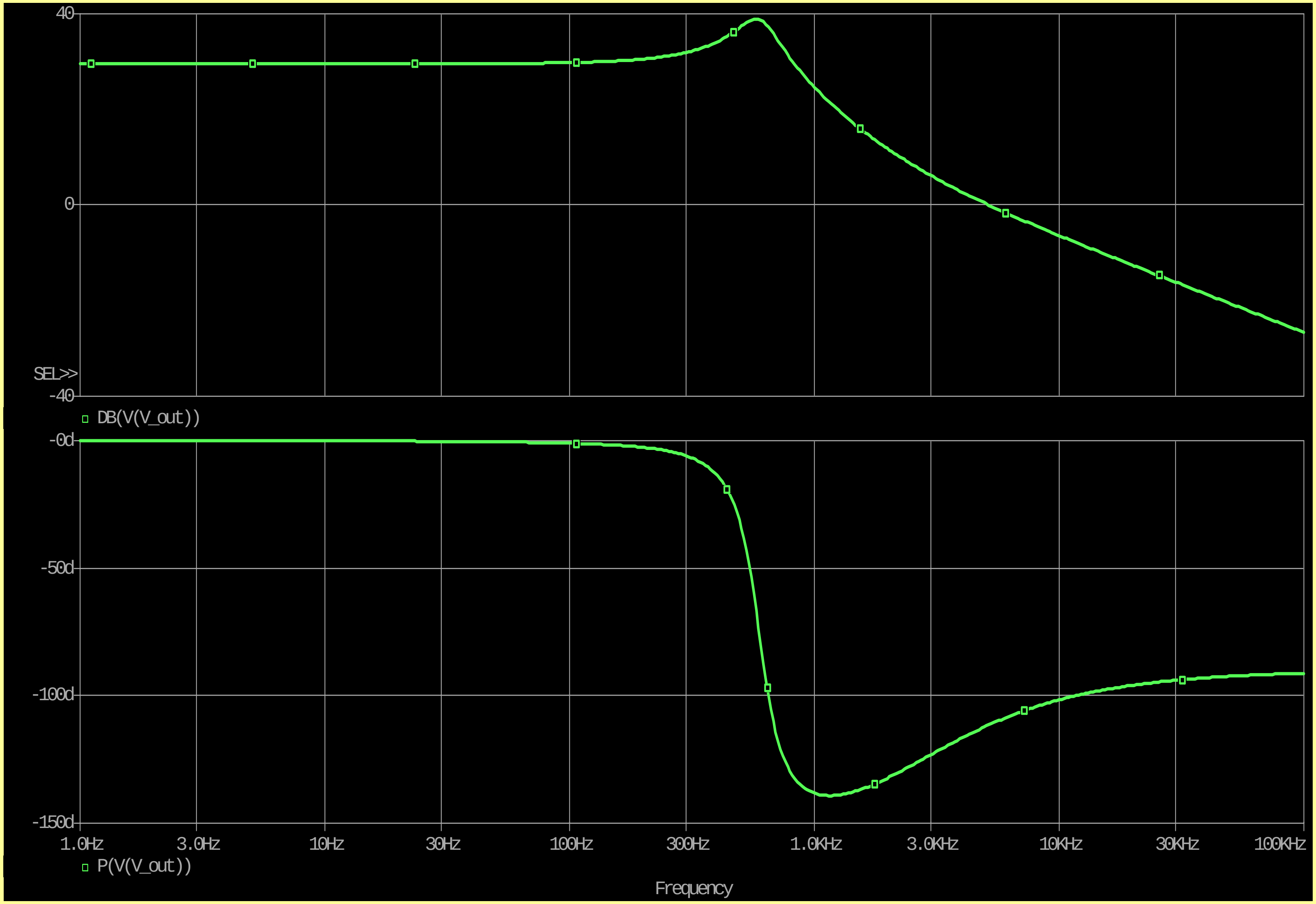
A Buck converter has the following parameters and is operating in CCM: $L = 100\,\mu H$, $C = 697\,\mu F$, $r = 0.1\Omega$, $f_s = 100\,kHz$, $V_{in} = 30V$, and $P_o = 36W$. The duty-ratio D is adjusted to regulate the output voltage $V_o = 12V$. Obtain both the gain and the phase of the power stage $G_{PS}(s)$ for the frequencies ranging from 1 Hz to 100 kHz.



PSpice Modeling:



Simulation Results



Summary

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