Lecture 8

ECEN 4517/5517

Experiment 4

Lecture 7: Step-up dc-dc converter and PWM chip

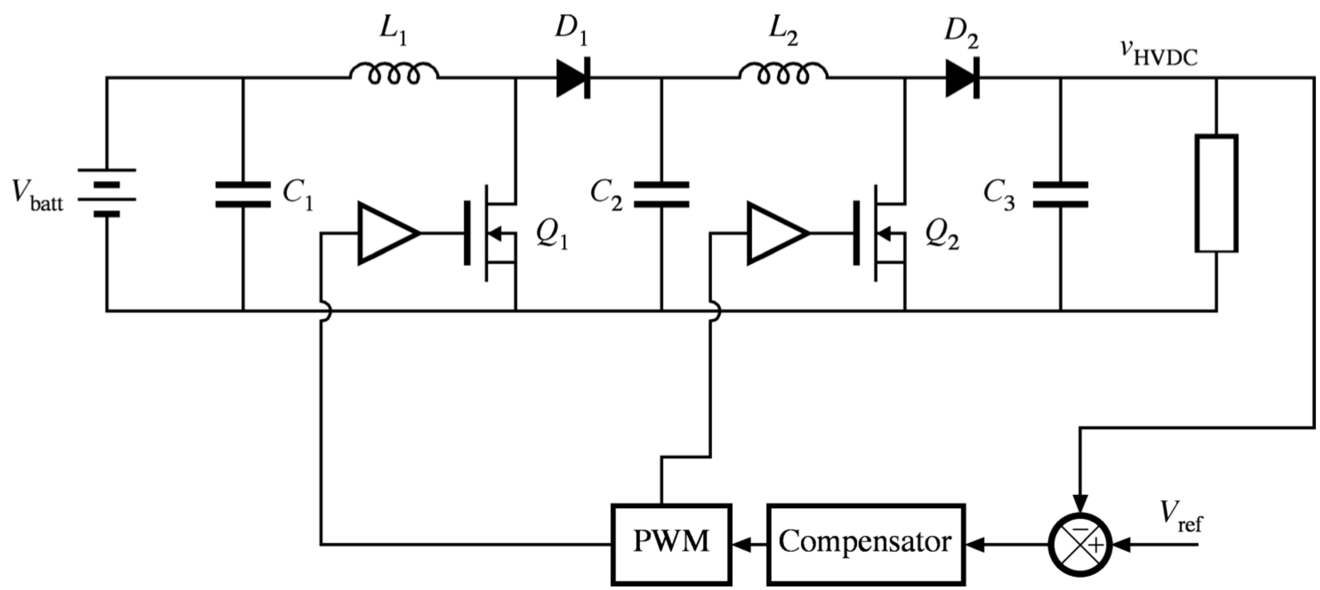
Lecture 8: Design of analog feedback loop

Part I—Controller IC:

- Demonstrate operating PWM controller IC (UC 3525)

Part II—Power Stage:

- Demonstrate operating power converter (cascaded boost converters)



Part III—Closed-Loop Analog Control System:

- Demonstrate analog feedback system that regulates the dc output voltage
- Measure and document loop gain and compensator design

Due dates

This week: Tuesday at noon (Mar. 10):

- Prelab assignment for Exp. 4 (one from every student)

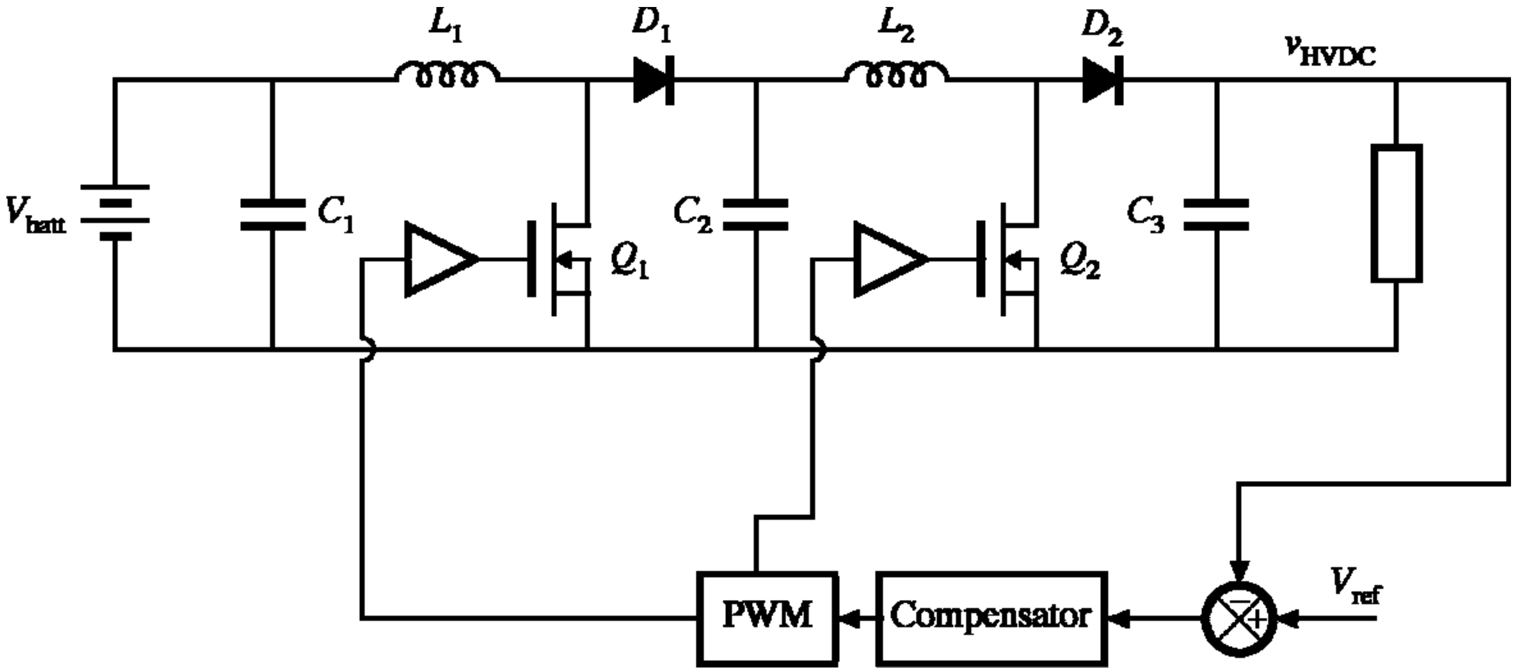
This week in lab (Mar. 10-12):

- Start Exp. 4

This Friday at 5 pm (Mar. 13):

- Exp. 3 part 2 report due

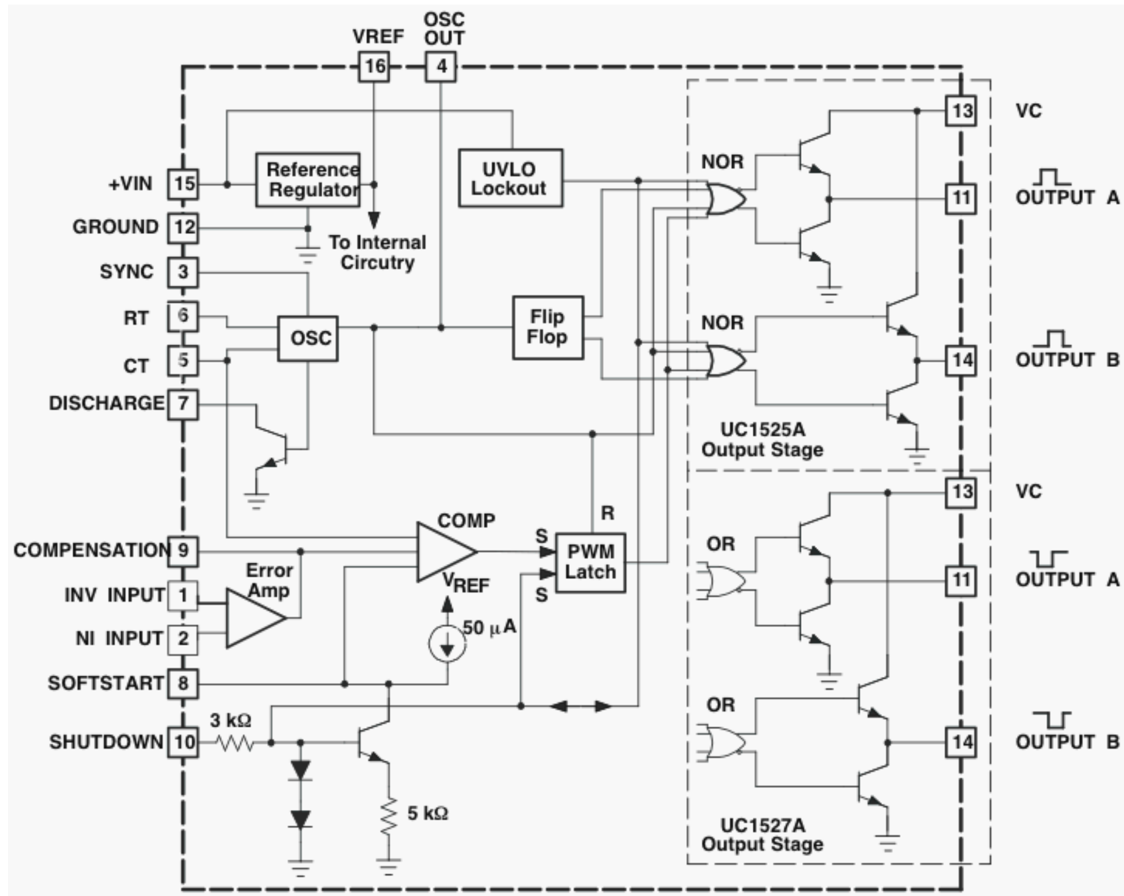
Discussion: Lab 4 prelab



Soft Start

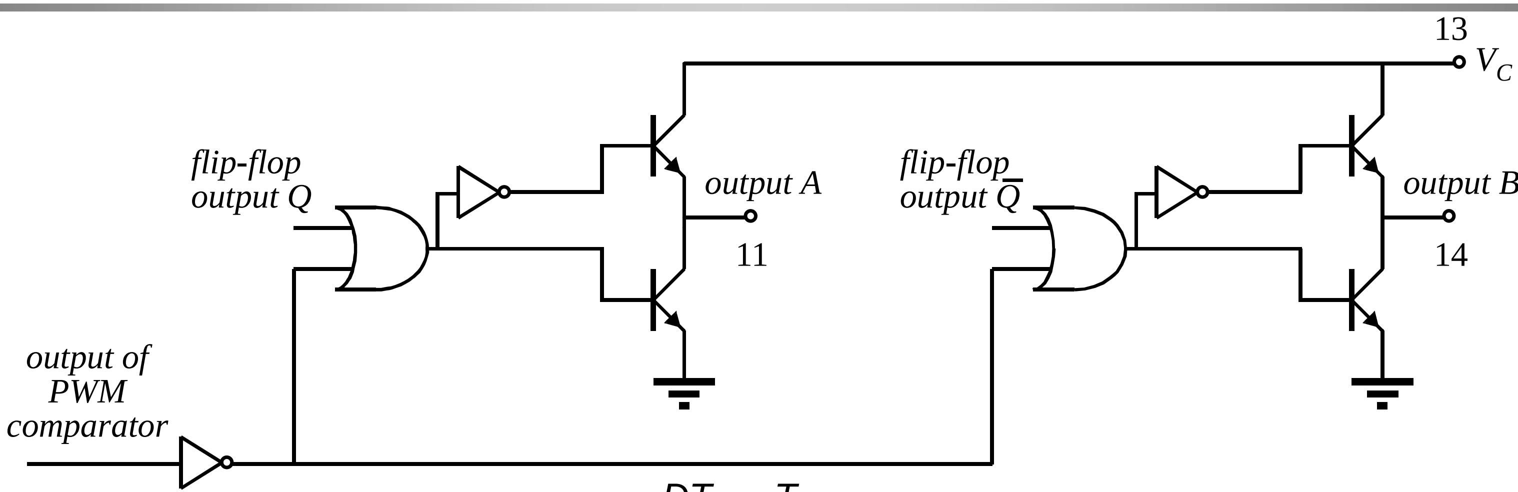
- Reduce inrush current when closed-loop system starts up
- Connect capacitor to pin 8
- Capacitor voltage limits maximum duty cycle
- Capacitor is slowly charged by 50 μA current source
- After capacitor charges, feedback loop takes over control of duty cycle

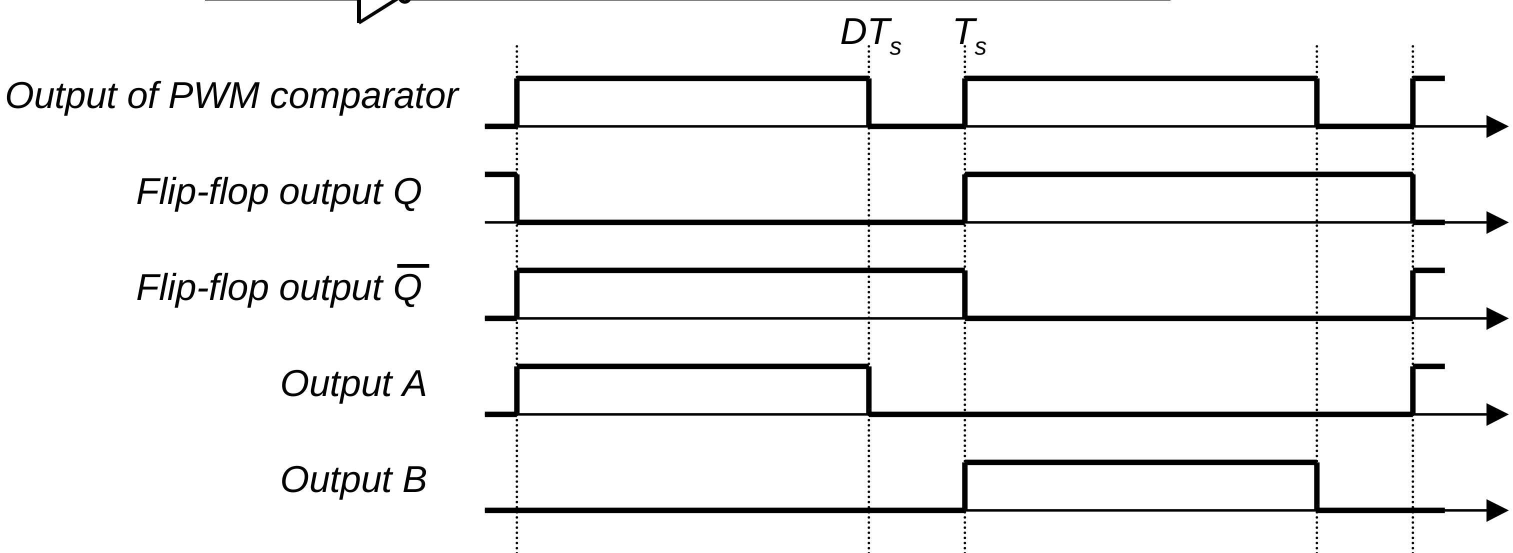
You might not be able to get your closed-loop converter to turn on without soft start…



UC3525

Outputs of the UC3525A



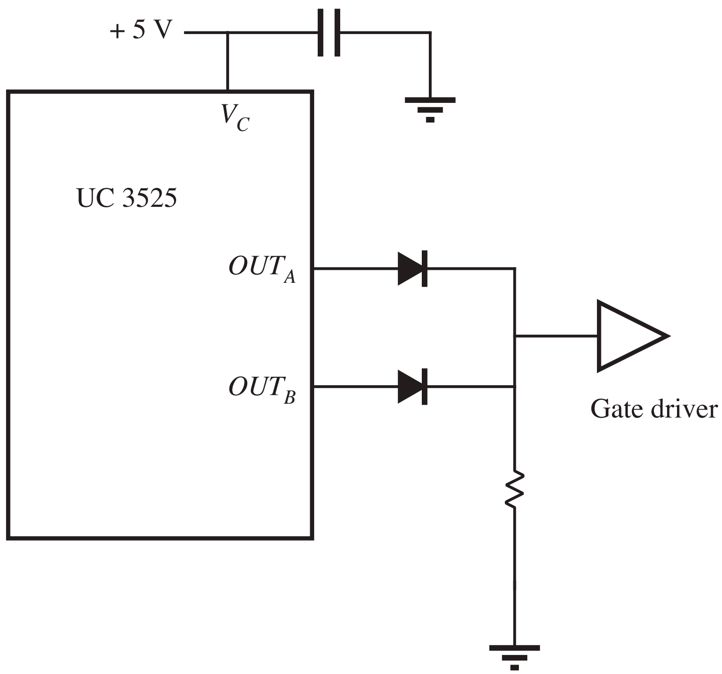


Frequency of the outputs is one half the oscillator frequency. Duty cycle cannot be greater than 50%.

Such outputs are needed in some types of switching converters such as “push-pull.”

Outputs A and B can be OR-ed to restore the PWM pulses at the oscillator frequency.

OR-ing the outputs



A cheap way to OR the outputs of the UC3525

The + 5 V *can be obtained from the* 5 V *reference of the* UC3525

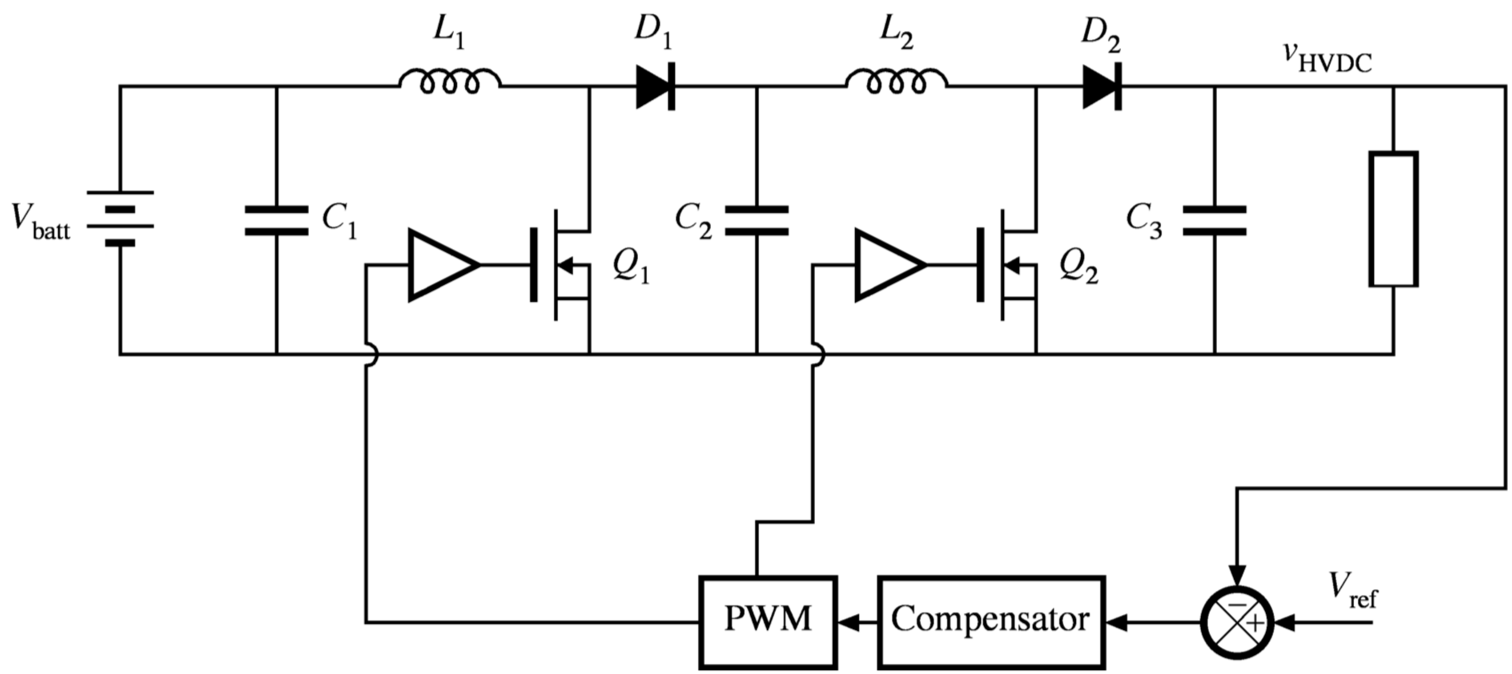
Bypass the + 5 V *so that the switching EMI of this circuit does not disrupt the internal control circuitry of the* UC3525*, which also uses the* + 5 V.

More* UC3525 *tips:

- *You will need to ground the SHUTDOWN pin. Otherwise the* UC3525 *will shut down.*
- R_T *must be greater than* 2 kΩ*; otherwise the* UC3525 *oscillator will not work*
- R_D *is usually a few hundred Ohms;* R_D *must be substantially smaller than* R_T.

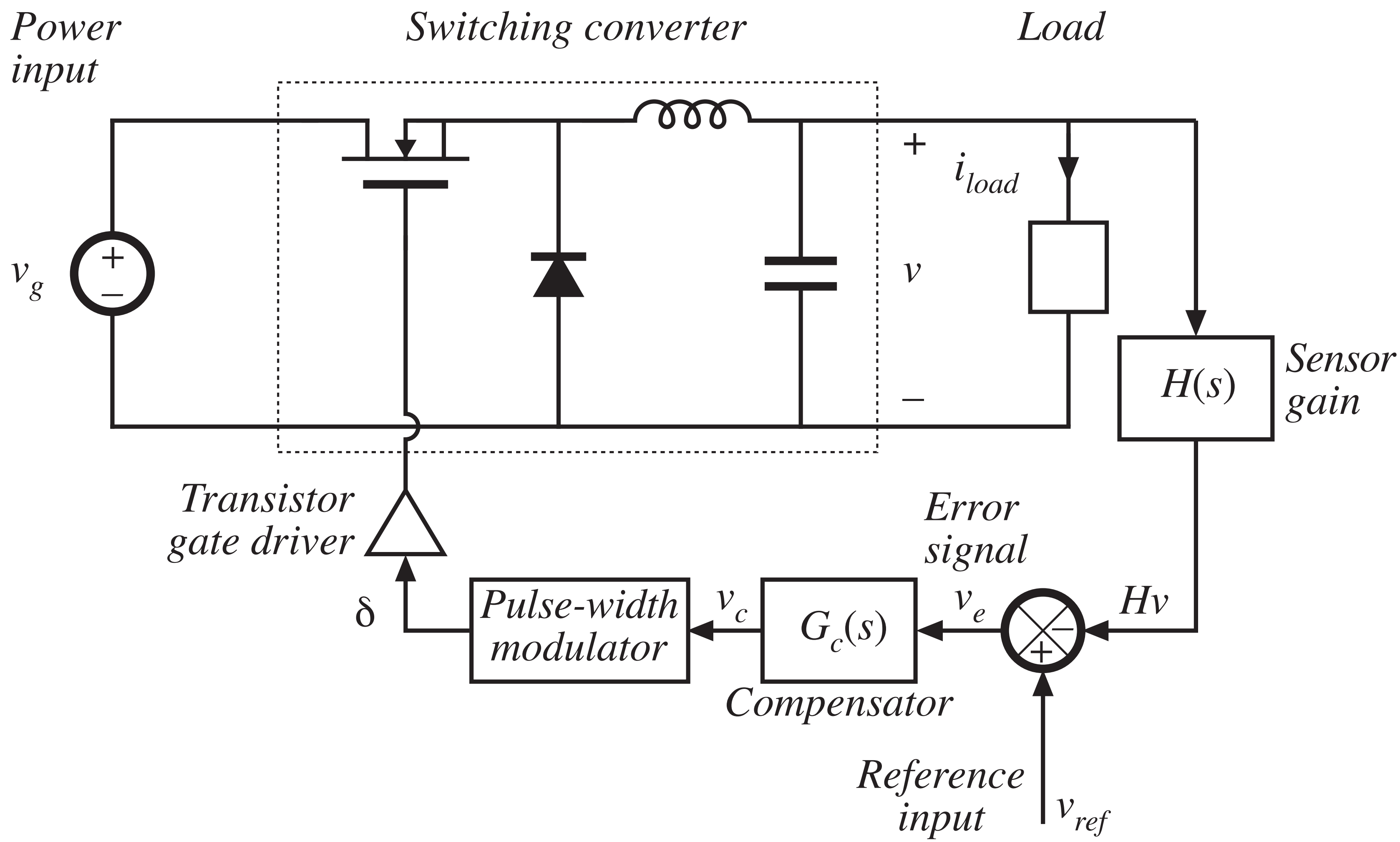
Exp. 4 Part III

Regulation of output voltage via feedback



- Model and measure control-to-output transfer function $G_{vd}(s)$
- Design and build feedback loop
- Demonstrate closed-loop regulation of v_{HVDC}

Negative feedback:
a switching regulator system



Transfer functions of some basic CCM converters

Table 8.2. Salient features of the small-signal CCM transfer functions of some basic dc-dc converters

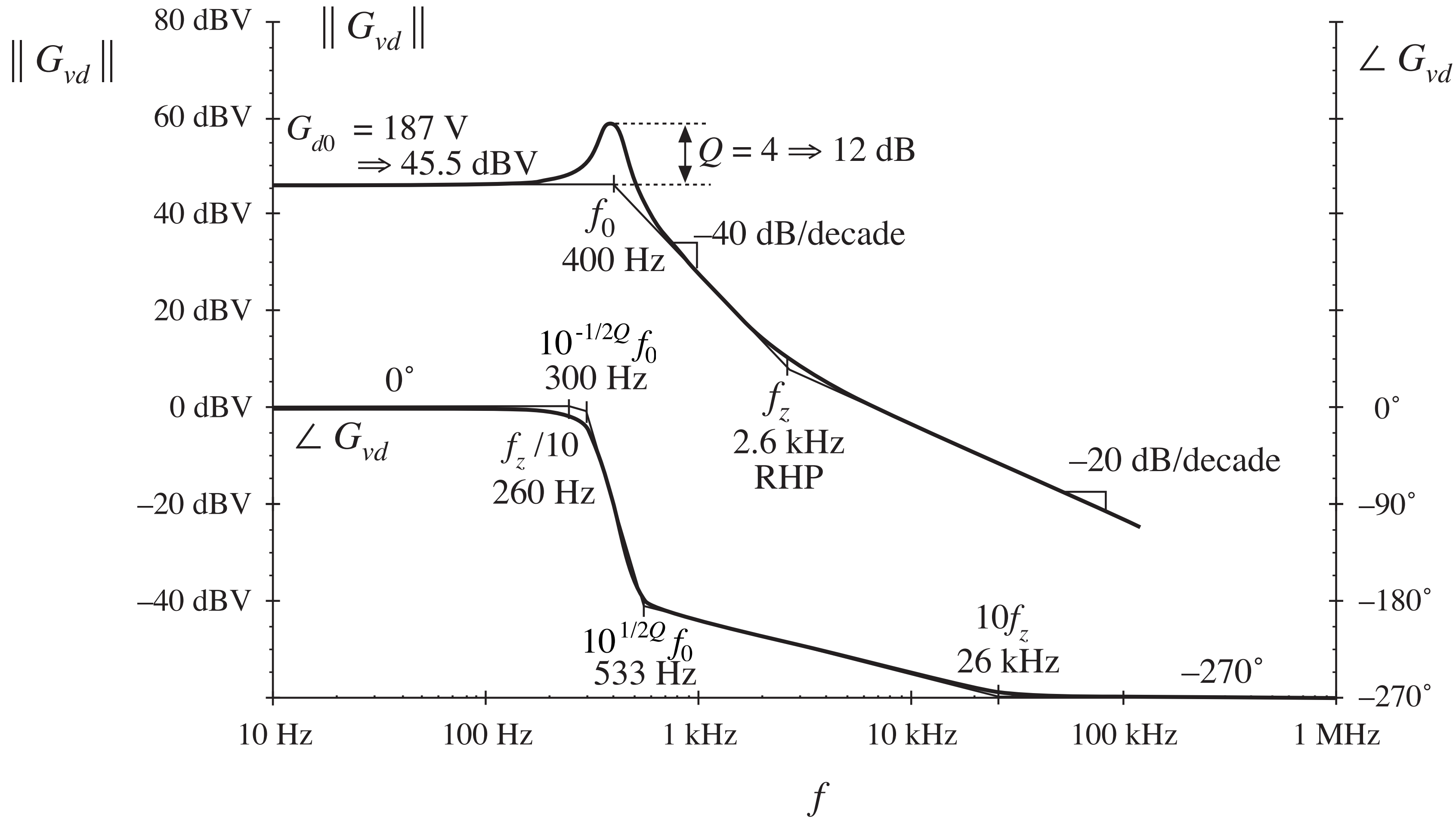
Converter	G_{g0}	G_{d0}	ω_0	Q	ω_z
buck	D	$\frac{V}{D}$	$\frac{1}{\sqrt{LC}}$	$R\sqrt{\frac{C}{L}}$	∞
boost	$\frac{1}{D'}$	$\frac{V}{D'}$	$\frac{D'}{\sqrt{LC}}$	$D'R\sqrt{\frac{C}{L}}$	$\frac{D'^2R}{L}$
buck-boost	$-\frac{D}{D'}$	$\frac{V}{D\,D'^2}$	$\frac{D'}{\sqrt{LC}}$	$D'R\sqrt{\frac{C}{L}}$	$\frac{D'^2R}{D\,L}$

where the transfer functions are written in the standard forms

$$G_{vd}(s) = G_{d0}\frac{\left(1 - \frac{s}{\omega_z}\right)}{\left(1 + \frac{s}{Q\omega_0} + \left(\frac{s}{\omega_0}\right)^2\right)} \qquad G_{vg}(s) = G_{g0}\frac{1}{1 + \frac{s}{Q\omega_0} + \left(\frac{s}{\omega_0}\right)^2}$$

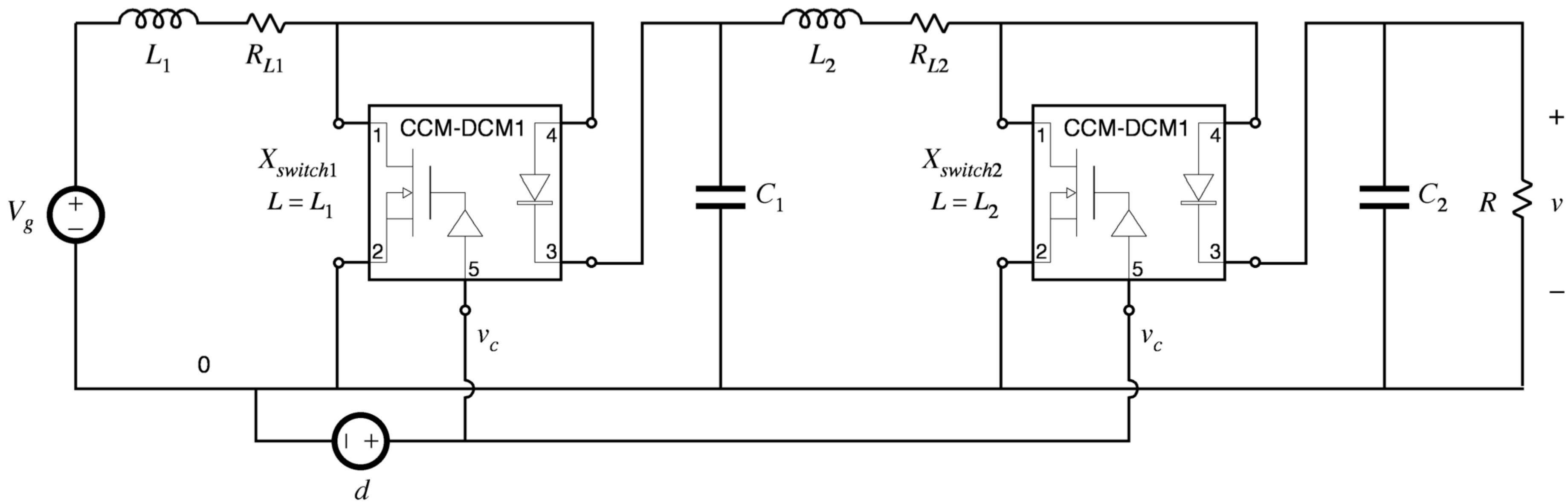
Flyback: push L and C to same side of transformer, then use buck-boost equations. DC gains G_{g0} and G_{d0} have additional factors of n (turns ratio).

Bode plot: control-to-output transfer function buck-boost or flyback converter example



Spice Simulation

Open-loop simulation of control-to-output transfer function

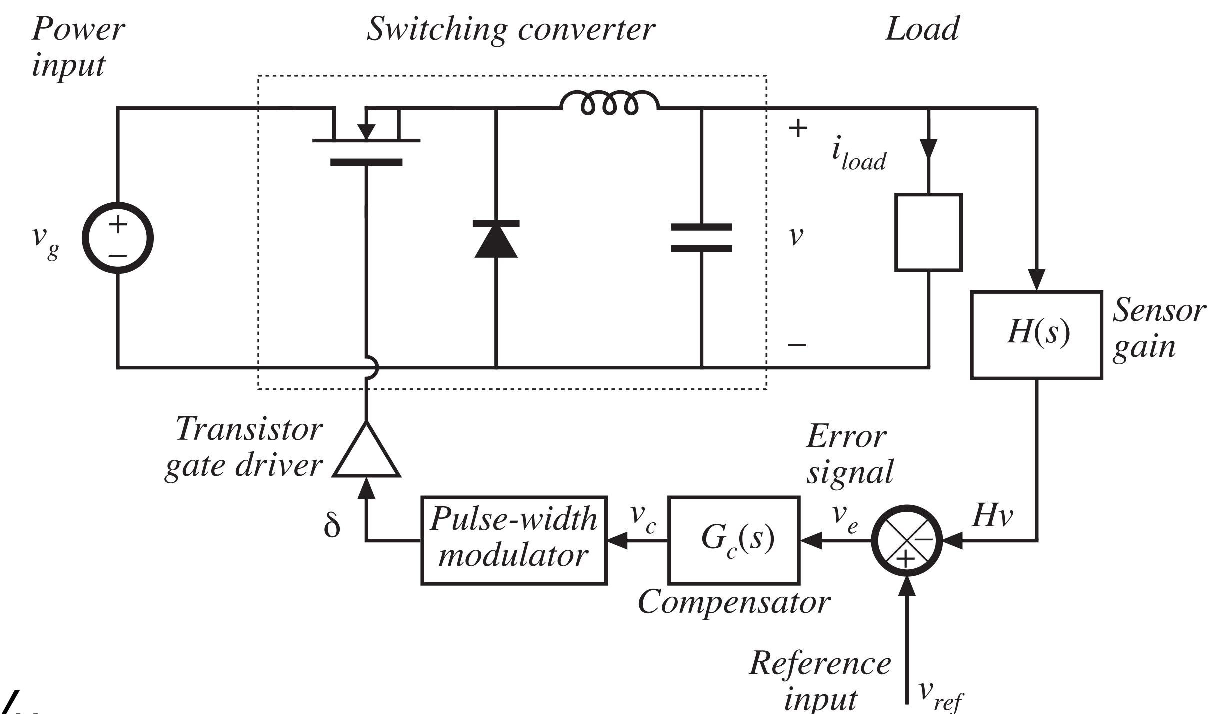


- Replace boost converter switches with averaged switch model
- CCM-DCM1 and other switch models are linked to course web site, inside switch.lib file
- Apply dc voltage (to set steady-state duty cycle) plus ac variation, to terminal 5 of CCM-DCM1 model. Plot output voltage magnitude and phase using ac analysis within Spice.

The loop gain $T(s)$

Loop gain T(s) = product of gains around the feedback loop

More loop gain ||T|| leads to better regulation of output voltage



$T(s) = G_{vd}(s)\ H(s)\ G_c(s)\ /\ V_M$

$G_{vd}(s)$ = power stage control-to-output transfer function

PWM gain = $1/V_M$. V_M = pk-pk amplitude of PWM sawtooth

Phase Margin

A test on $T(s)$, to determine stability of the feedback loop

The crossover frequency f_c is defined as the frequency where

$$\| T(j2\pi f_c) \| = 1, \text{ or } 0 \text{ dB}$$

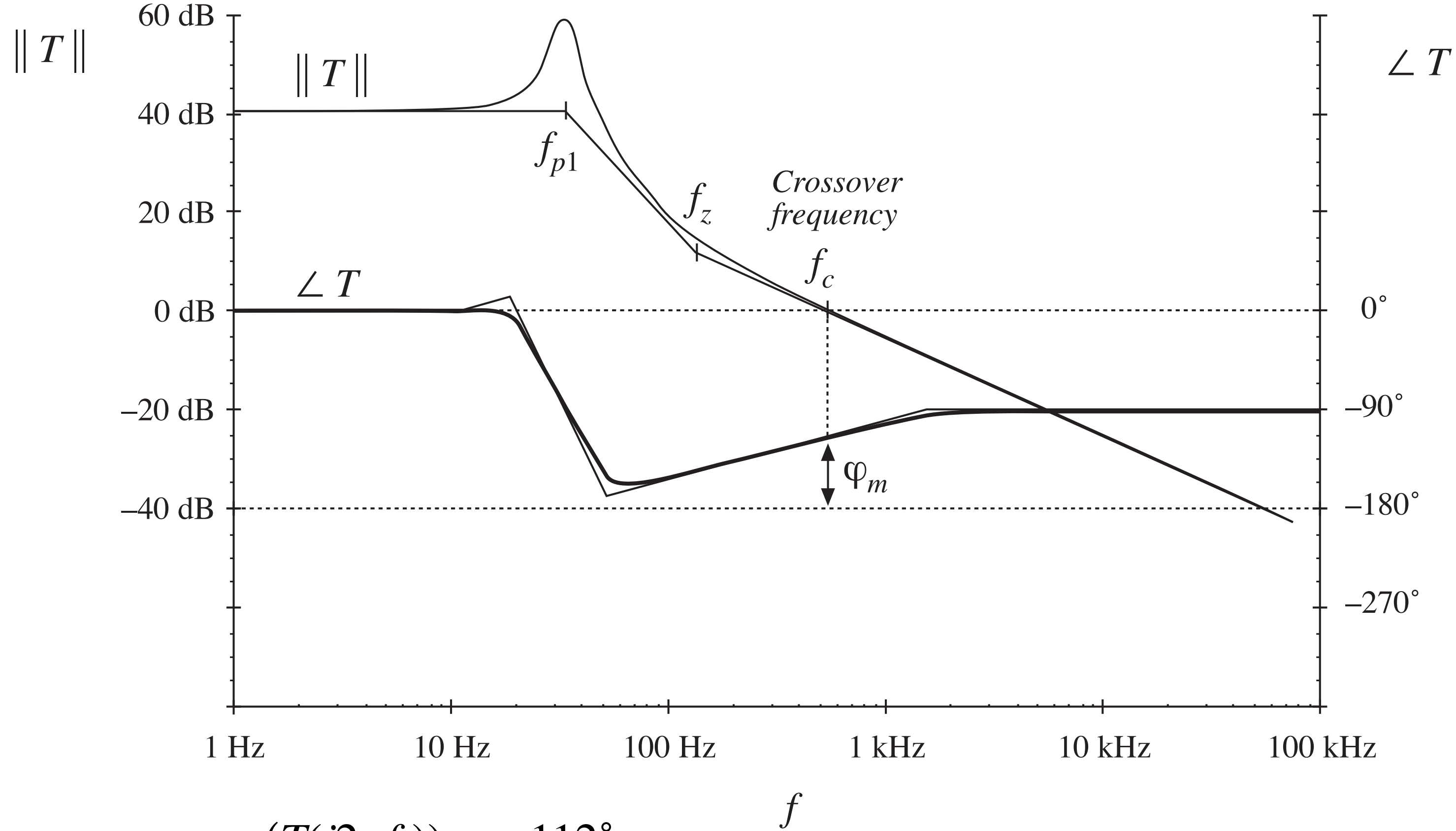
The phase margin φ_m is determined from the phase of $T(s)$ at f_c , as follows:

$$\varphi_m = 180^\circ + \arg(T(j2\pi f_c))$$

If there is exactly one crossover frequency, and if $T(s)$ contains no RHP poles, then

> the quantities $T(s)/(1+T(s))$ and $1/(1+T(s))$ contain no RHP poles whenever the phase margin φ_m is positive.

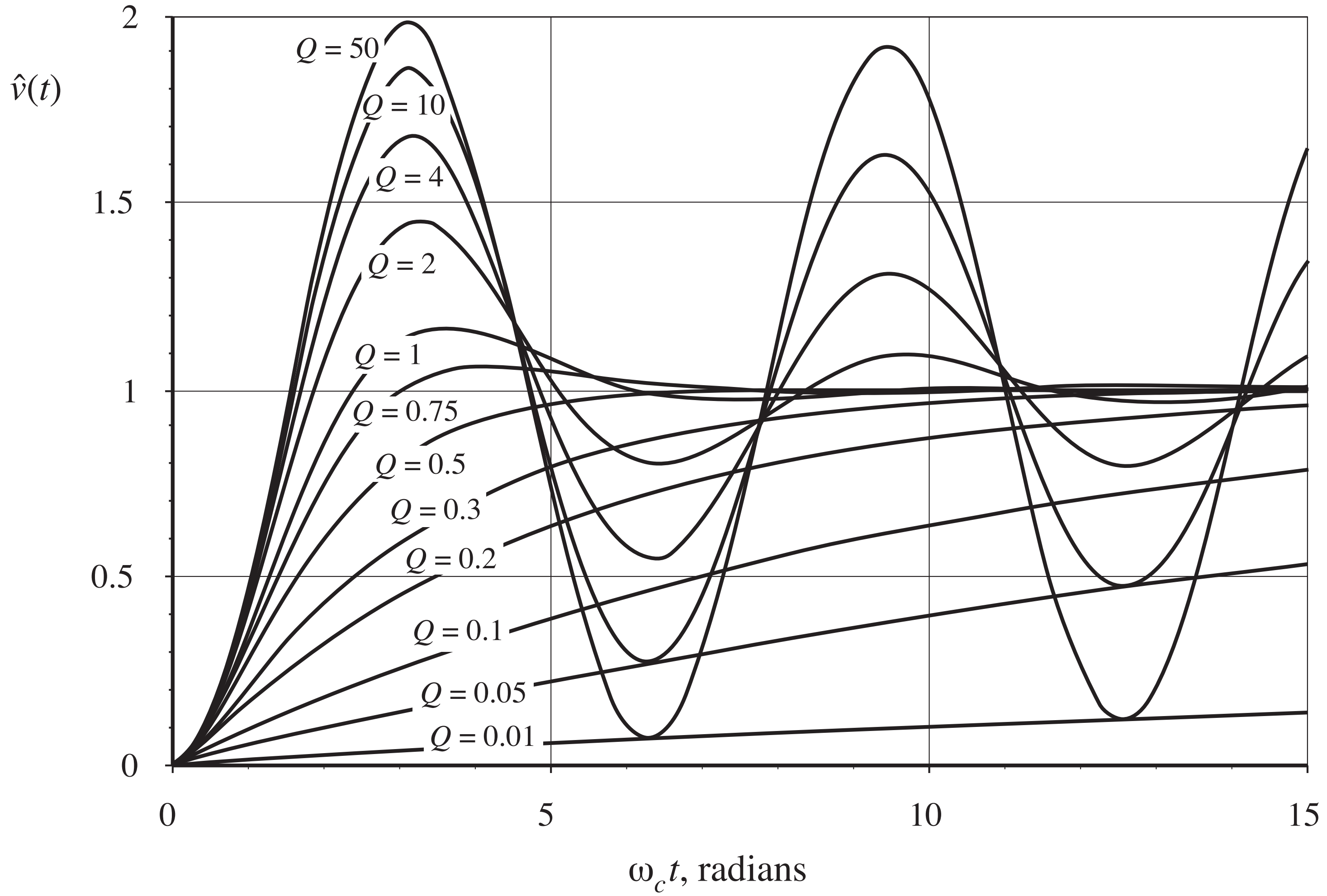
Example: a loop gain leading to a stable closed-loop system



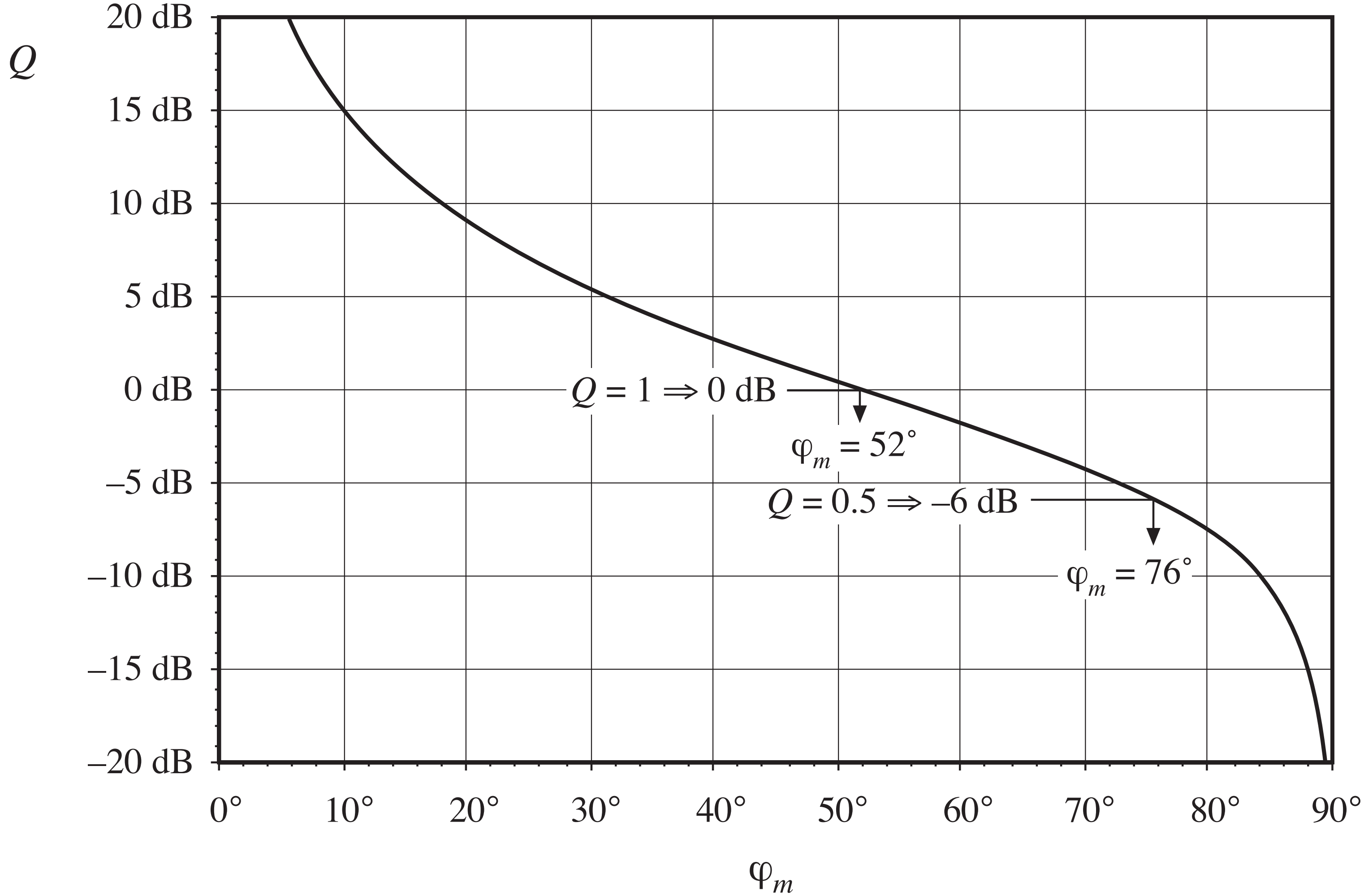
$\arg(T(j2\pi f_c)) = -\ 112^\circ$

$\varphi_m = 180^\circ - 112^\circ = +\ 68^\circ$

Transient response vs. damping factor



Q vs. φ_m

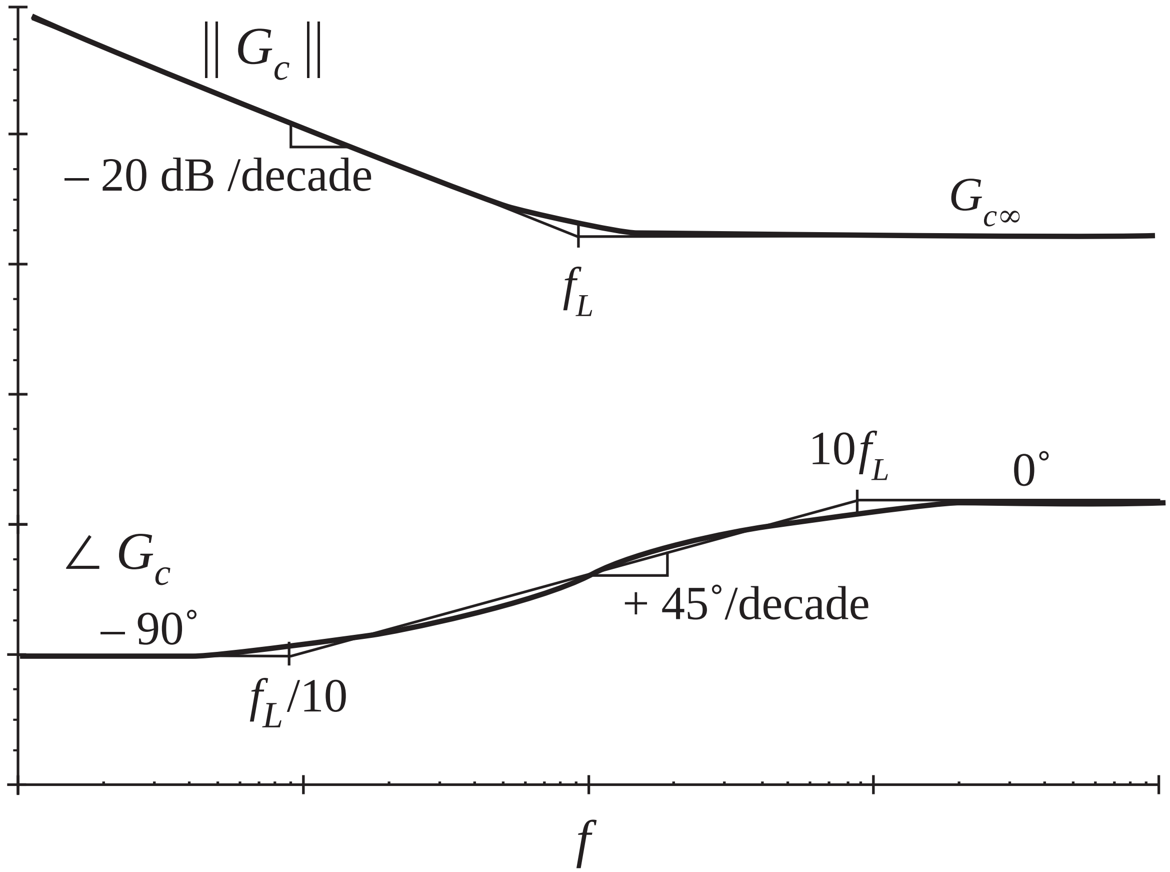


Q
20 dB
15 dB
10 dB
5 dB
0 dB
–5 dB
–10 dB
–15 dB
–20 dB
Q = 1 ⇒ 0 dB
φm = 52˚
Q = 0.5 ⇒ –6 dB
φm = 76˚
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
φm

9.5.2. Lag (PI) compensation

$$G_c(s) = G_{c\infty}\left(1 + \frac{\omega_L}{s}\right)$$

Improves low-frequency loop gain and regulation



Example: lag compensation

original (uncompensated) loop gain is

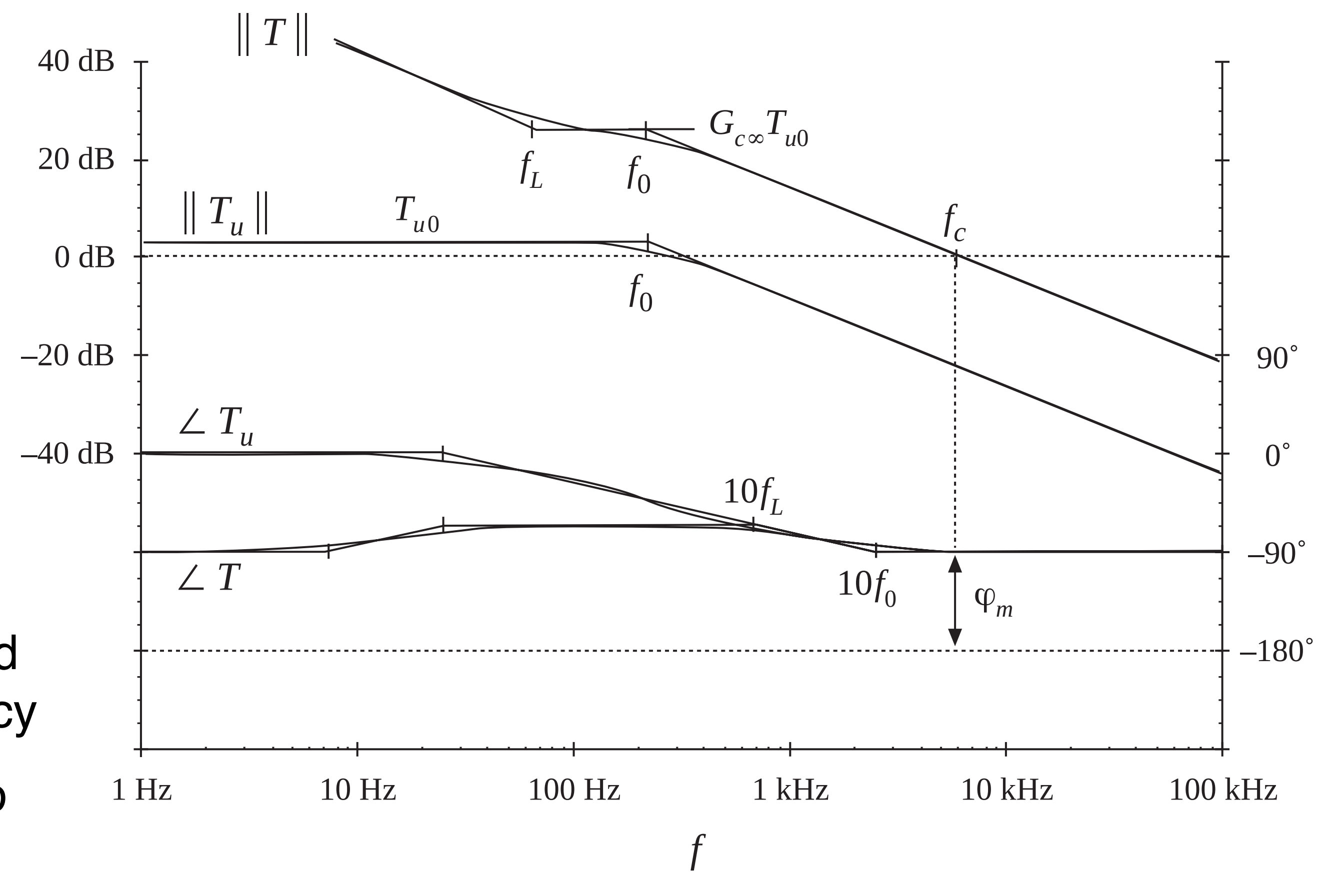
$$T_u(s) = \frac{T_{u0}}{\left(1 + \frac{s}{\omega_0}\right)}$$

compensator:

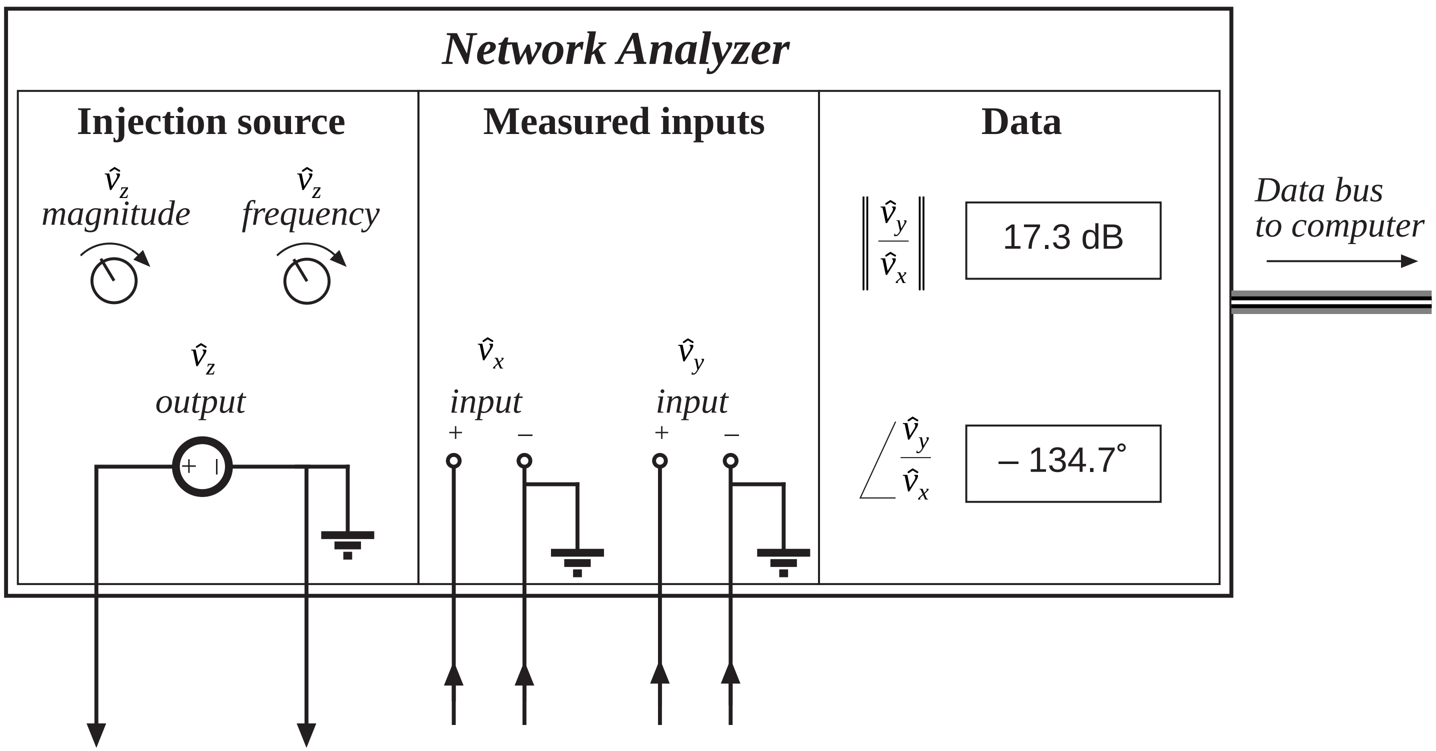
$$G_c(s) = G_{c\infty}\left(1 + \frac{\omega_L}{s}\right)$$

Design strategy: choose

- $G_{c\infty}$ to obtain desired crossover frequency
- ω_L sufficiently low to maintain adequate phase margin



8.4. Measurement of ac transfer functions and impedances



Swept sinusoidal measurements

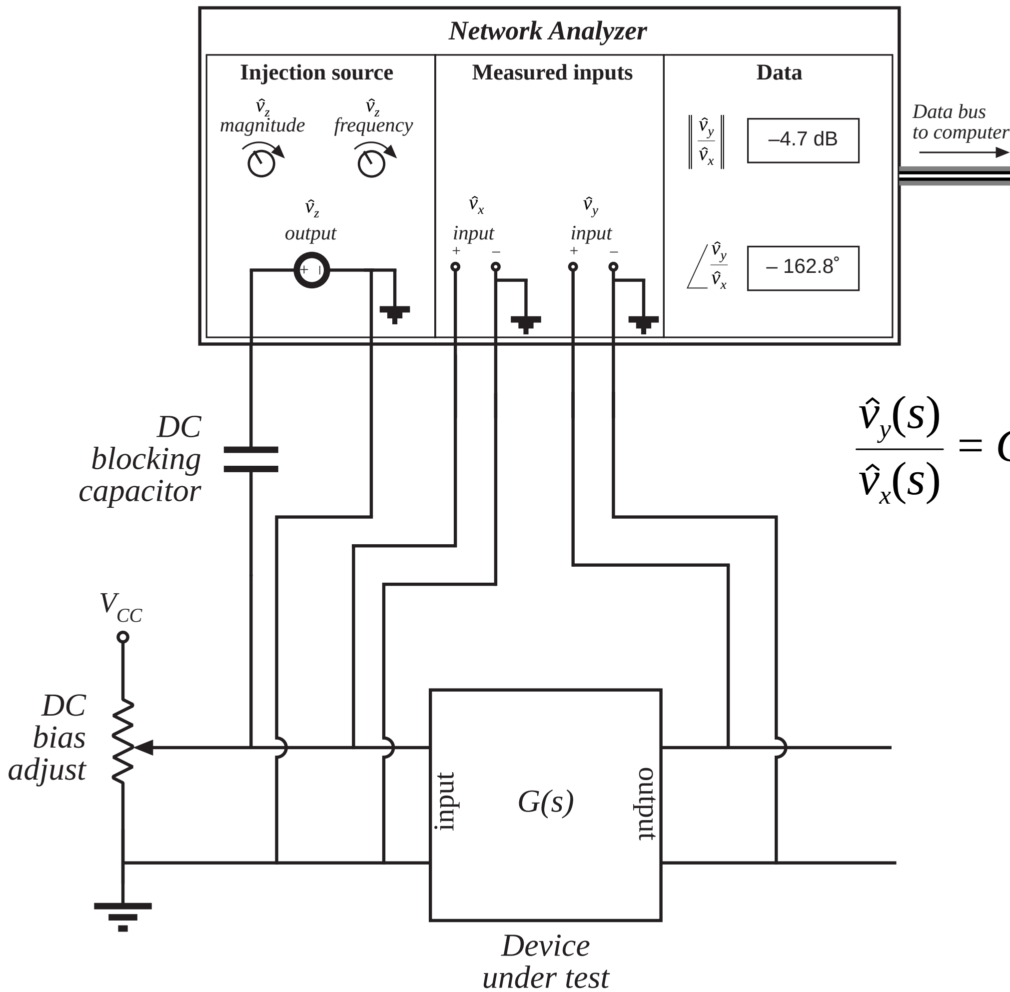
- Injection source produces sinusoid $\hat{v}_z$ of controllable amplitude and frequency
- Signal inputs $\hat{v}_x$ and $\hat{v}_y$ perform function of narrowband tracking voltmeter:

  Component of input at injection source frequency is measured

  Narrowband function is essential: switching harmonics and other noise components are removed
- Network analyzer measures

$$\left\| \frac{\hat{v}_y}{\hat{v}_x} \right\| \qquad \text{and} \qquad \angle \frac{\hat{v}_y}{\hat{v}_x}$$

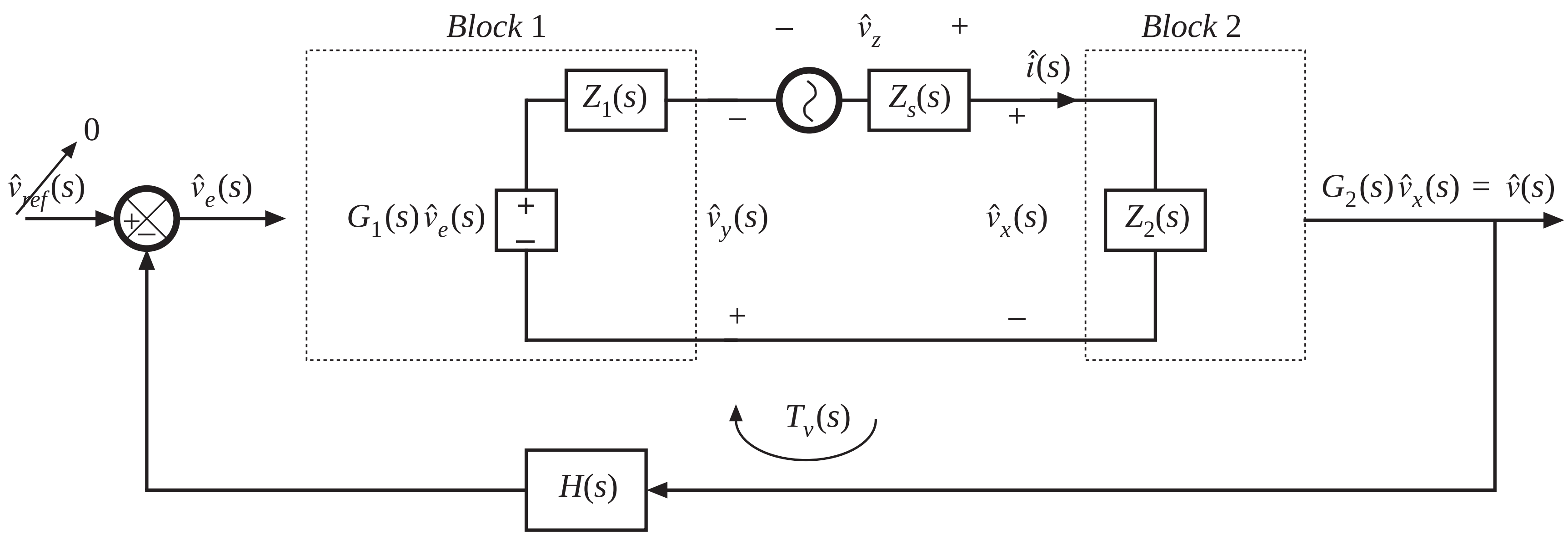
Measurement of an ac transfer function



$$\frac{\hat{v}_y(s)}{\hat{v}_x(s)} = G(s)$$

- Potentiometer establishes correct quiescent operating point
- Injection sinusoid coupled to device input via dc blocking capacitor
- Actual device input and output voltages are measured as $\hat{v}_x$ and $\hat{v}_y$
- Dynamics of blocking capacitor are irrelevant

9.6.1. Voltage injection



- Ac injection source v_z is connected between blocks 1 and 2
- Dc bias is determined by biasing circuits of the system itself
- Injection source does modify loading of block 2 on block 1