DC-DC Fundamentals

1.5 Converter Control
What is Converter Control?

- A converter can provide a constant voltage output at various conditions because of the closed-loop control system implemented in the circuit.
- A simple control system has a feedback path from output to input.
  - System gain is the ratio of controlled output to the reference input: without the feedback path $H$, it’s open loop system and the gain is $G$; with the feedback, it’s closed loop system and the gain is $G/(1+G*H)$.
How Does a Control System Work?
Bode Plots

• A control system is often analyzed in the plot of the gain magnitude and phase over the frequency domain, known as the Bode plot.

• A control system can be expressed in transfer functions and therefore be plotted in Bode plots.

• The gain magnitude is shown in dB (20log) unit, the phase is in angle degree, and the frequency is usually plotted in logarithmic scale.

\[ G(s) = \frac{G_0}{\left(1 + \frac{s}{\omega_1}\right)\left(1 + \frac{s}{\omega_2}\right)} \]

\[
\begin{align*}
g_{||G||} & = 40 \Rightarrow 32 \text{ dB} \\
g_{\angle G} & = 0^\circ \\
f_1 & = 100 \text{ Hz} \\
f_2 & = 2 \text{ kHz} \\
f_1/10 & = 10 \text{ Hz} \\
f_2/10 & = 200 \text{ Hz} \\
10f_1 & = 1 \text{ kHz} \\
10f_2 & = 20 \text{ kHz} \\
\end{align*}
\]
Poles and Zeros

\[ \frac{1}{1 + s} \]

- **Slope changes by** -20 dB/decade
- **Phase shift of** -90° (max)
- **Most of the effect is within one decade (up or down) of** \( f_p \)

\[ \frac{1 + s}{1} \]

- **Slope changes by** +20 dB/decade
- **Phase shift of** +90° (max)
- **Acts like an “anti-pole”, which means it can cancel out the pole**
How to Get a Bode Plot

• The transfer function of a converter can be derived from its circuit model, then the Bode plot can be obtained from it.

• Or, the Bode plot can be measured on a network analyzer by injecting a small AC signal into the feedback loop, sweeping its frequency and probing and comparing the signals.

Probe the voltage signals at A, B, C. The loop gain is $V_{A}/V_{B}$. The error amplifier gain is $V_{C}/V_{B}$. The power stage gain is $V_{C}/V_{A}$. 
Control Stability

• A closed-loop system becomes unstable when the phase of the loop gain approaches 180 degree while the gain is still positive

• To ensure the stability, the phase margin must be positive at the crossover frequency
  – Crossover frequency $f_c$ is the frequency where the loop gain magnitude is unity
  – Phase margin $\phi_m$ is the phase different of the loop gain and -180 degree at crossover frequency
Compensator

• A compensator is included in the closed loop system to tune the loop gain that it ensure the system is stable and good transient response.

• The compensation is usually adjusted by changing the R-C components around the error amplifier.

\[
\begin{align*}
G(s) H(s) & \Rightarrow \text{Loop Gain} \\
\text{Gain without compensator} & \quad \text{Gain of the compensator}
\end{align*}
\]

Effectively push the loop bandwidth higher.
Summary

• Introduction to converter control
• Bode plot basics
• Control stability and compensation
Thank you!