Loop Gain Measurements

OMICRON Lab Webinar Week 2015

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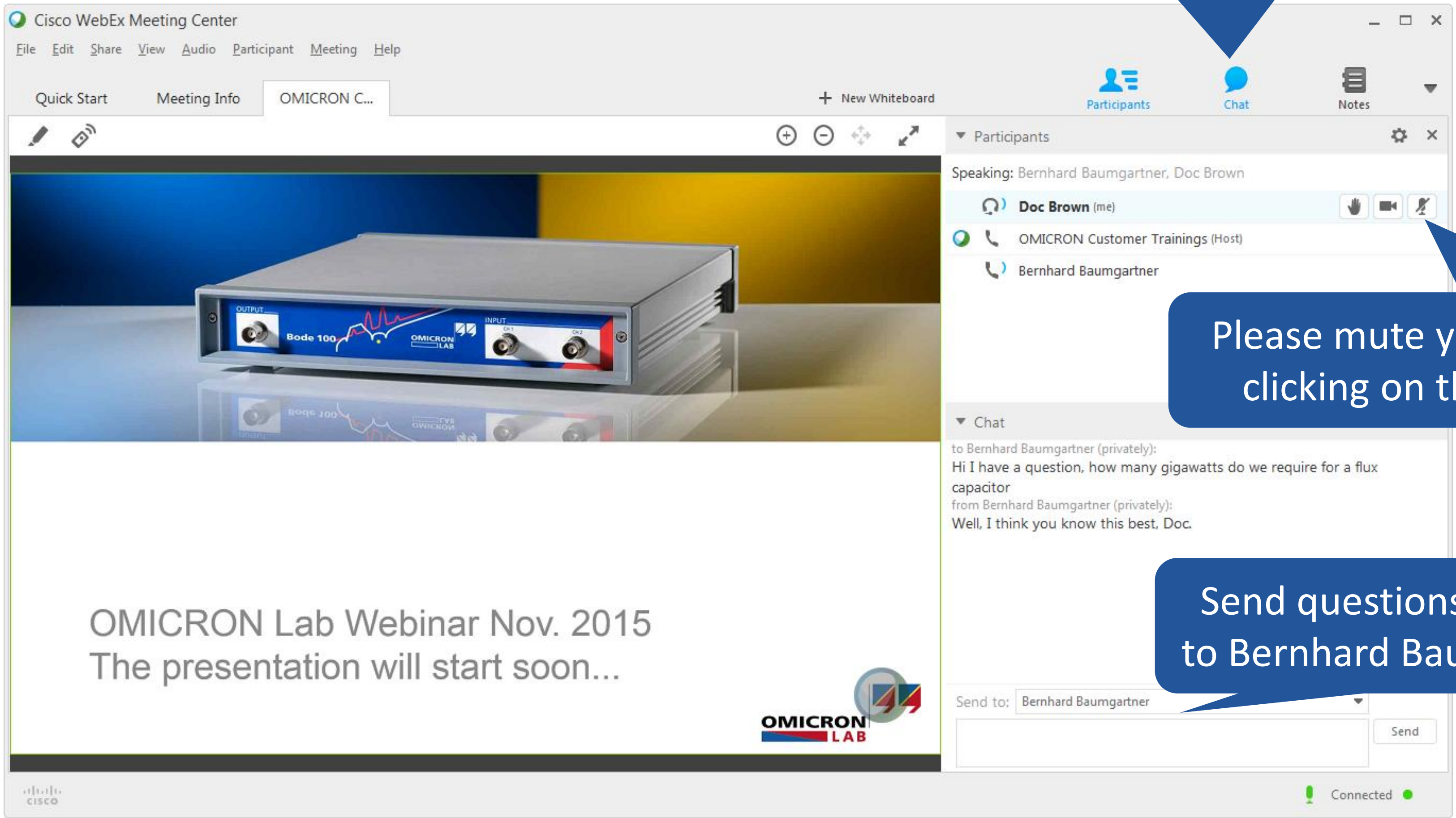
Webinar Hints

Activate the chat function



Please mute yourself by clicking on this icon!

Send questions via chat to Bernhard Baumgartner

Agenda

- Closed loop transfer functions & loop gain
- Stability – definition and verification
- Voltage injection method
- Injection signal level size
- Choosing the correct injection point
- Live loop gain measurement

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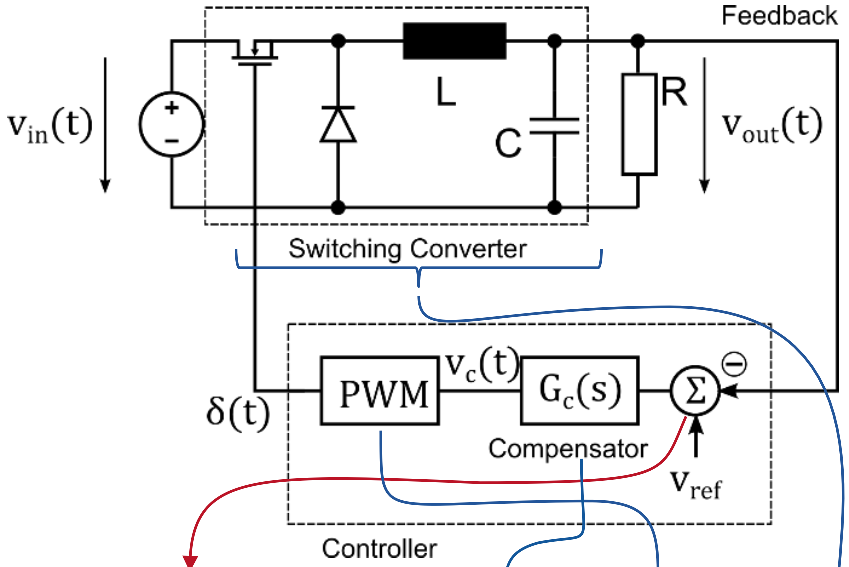
The Closed Loop Feedback System

Example: Buck Converter



Transfer functions:

$G_c(s)$ … Compensator

$G_{PWM}(s)$ … Pulse Width Mod.

$G_{vd}(s)$ … Switching Converter

$$\hat{v}_{out}(s) = \left(\hat{v}_{ref}(s) - \hat{v}_{out}(s)\right) \cdot \underbrace{G_c(s) \cdot G_{PWM}(s) \cdot G_{vd}(s)}_{\text{Loop Gain } T(s)}$$

Loop Gain T(s)

Closed Loop Reference to Output

$$G_{ref-out,CL}(s) = \frac{\hat{v}_{ref}(s)}{\hat{v}_{out}(s)} = \frac{G_c(s)G_{PWM}(s)G_{vd}(s)}{1+G_c(s)G_{PWM}(s)G_{vd}(s)}$$

Loop Gain $T(s) = G_c(s)G_{PWM}(s)G_{vd}(s)$
= product of all gains around the loop

$$G_{ref-out,CL}(s) = \frac{T(s)}{1+T(s)}$$

If $T(s) \gg 1$, then $G_{ref-out,CL}(s) \approx 1$.
This means the output follows the reference
→ Goal of the control loop

Closed Loop Input to Output

Open loop input to output transfer function

$G_{in-out}(s)$

Closing the feedback loop

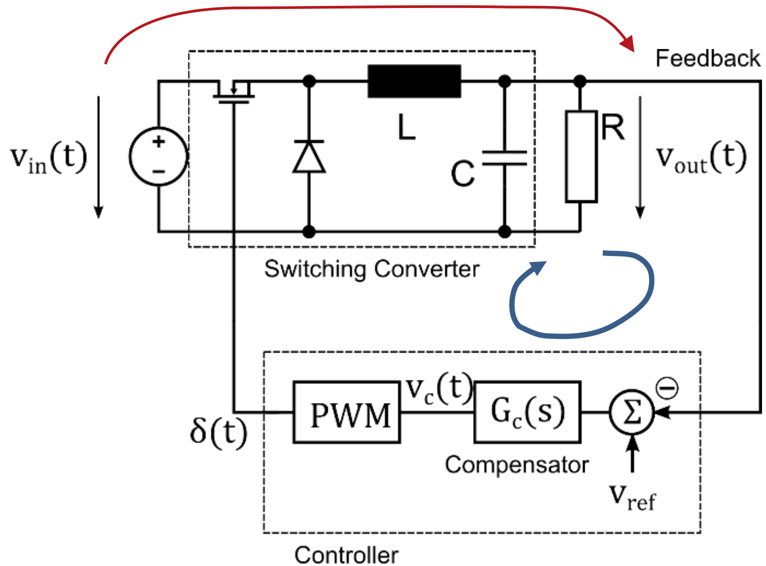
$\hat{v}_{out} = \hat{v}_{in} \cdot G_{in-out}(s) - \hat{v}_{out} \cdot T(s)$

therefore

$$G_{in-out,CL}(s) = \frac{G_{in-out}(s)}{1 + T(s)}$$

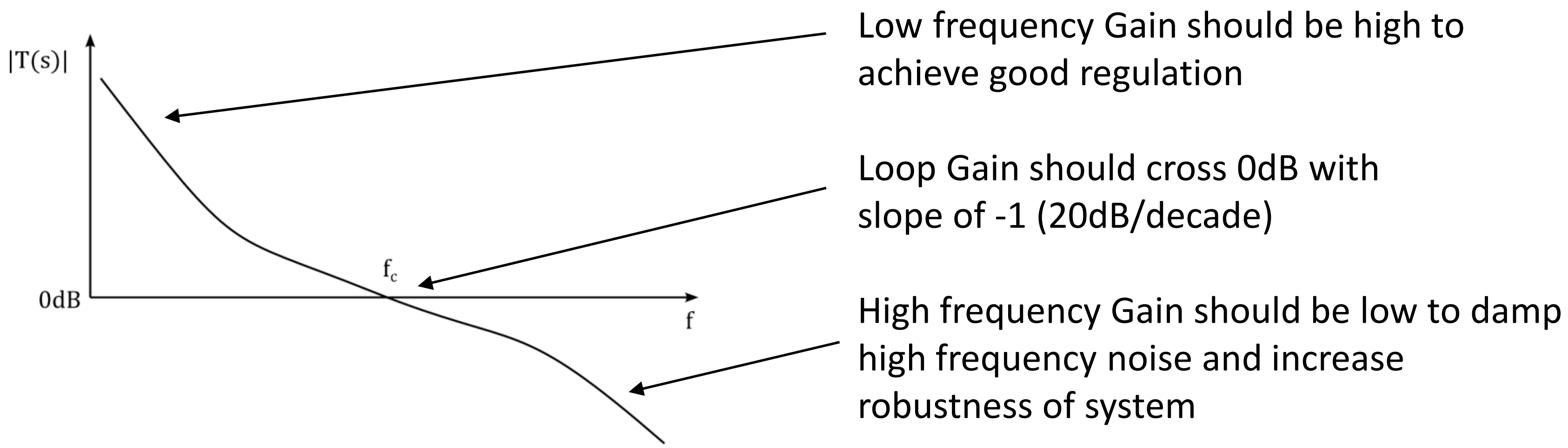
If $T(s) \gg$ then $\mathrm{G}_{\mathrm{in-out,CL}}(s) \ll$

→ Distortions at the input are rejected



The Design Rules

- For good output regulation we need **high loop gain**
- For $T(s) < 1$ the feedback has no effect
- High loop gain for all frequencies is not possible and not desired



Stability of the Closed Loop System

Transfer functions of the closed loop:

$$G_{ref-out,CL}(s) = \frac{T(s)}{1+T(s)} \qquad G_{in-out,CL}(s) = \frac{G_{in-out}(s)}{1+T(s)}$$

What happens if $T(s) = -1$?
→ Closed Loop Transfer function will tend to get "infinite"
→ Behavior of the loop is no longer defined (unstable)

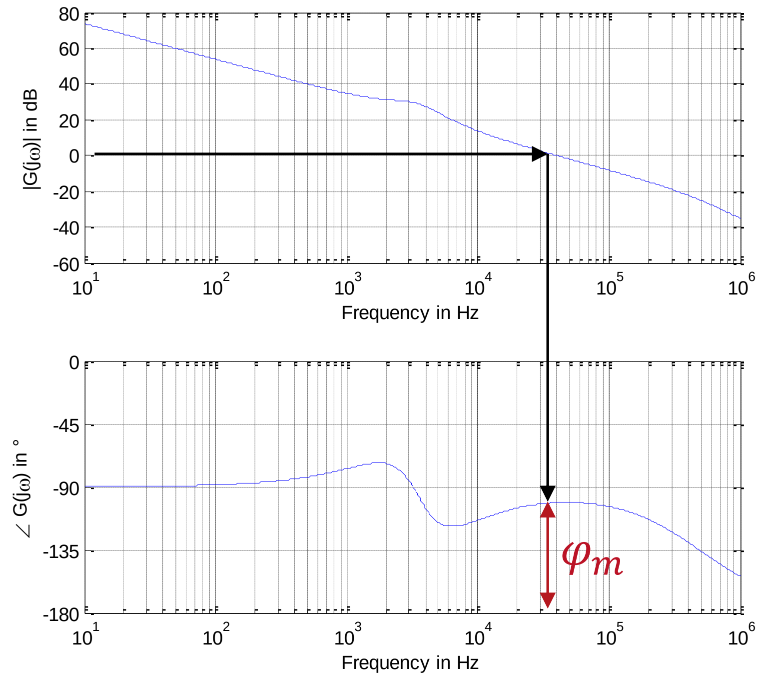
By checking the loop gain $T(s)$ we can check if the closed loop system will be stable or not.

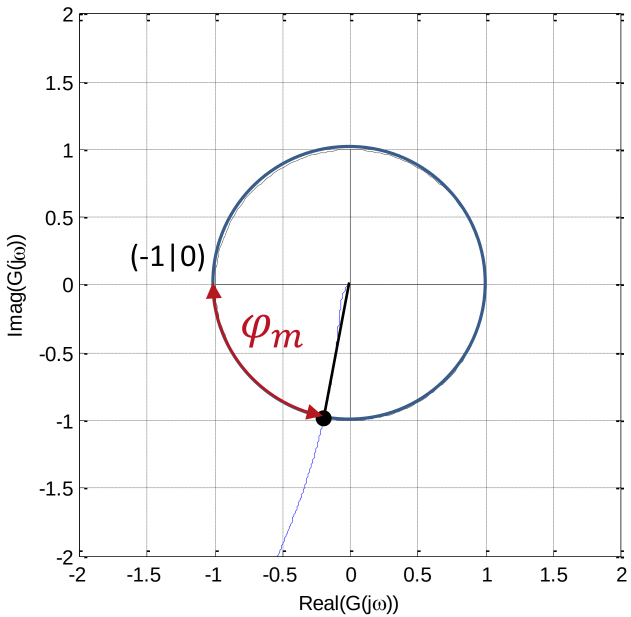
Test: How much distance does $T(s)$ have towards -1

The Phase Margin Test

(A special case of the general Nyquist stability criterion)

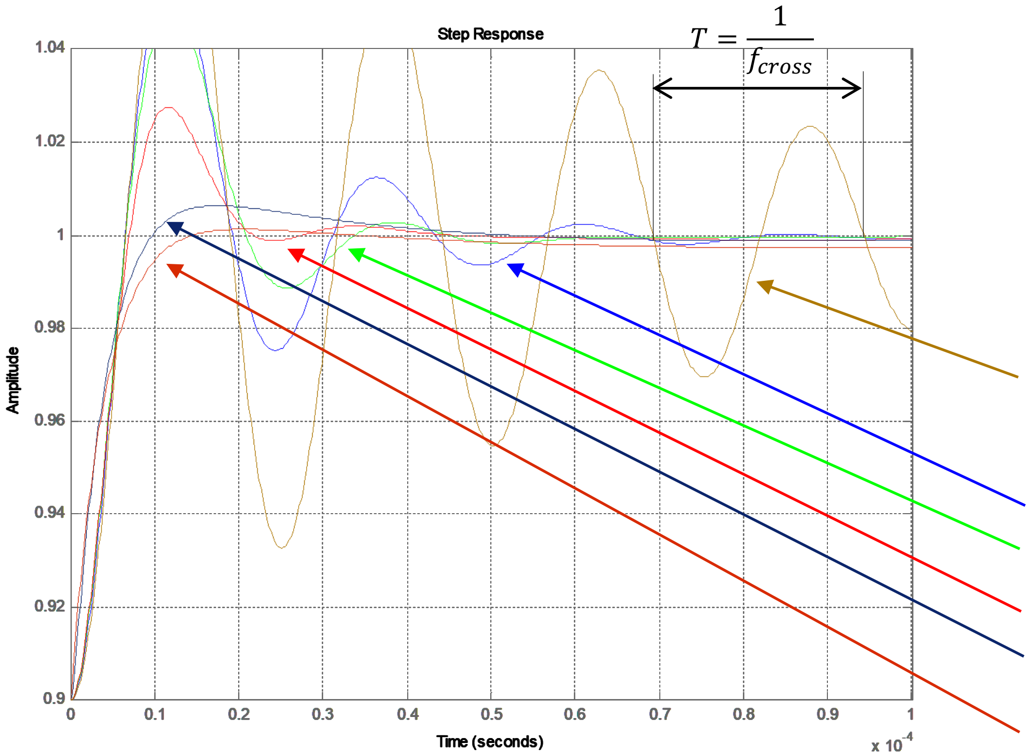
If phase margin >0° → the closed loop system is "stable"





How much Phase Margin do we need?

Example: Voltage-mode Buck Converter Reference to Output Step (Simulation)



Synchronous Buck Converter
(CCM, small signal model)
300 kHz switching frequency
≈40 kHz crossover frequency

$\varphi_m = 7.4°$ → High overshoot + ringing

$\varphi_m = 23°$

$\varphi_m = 31°$

$\varphi_m = 45°$

$\varphi_m = 78°$ → Highly damped

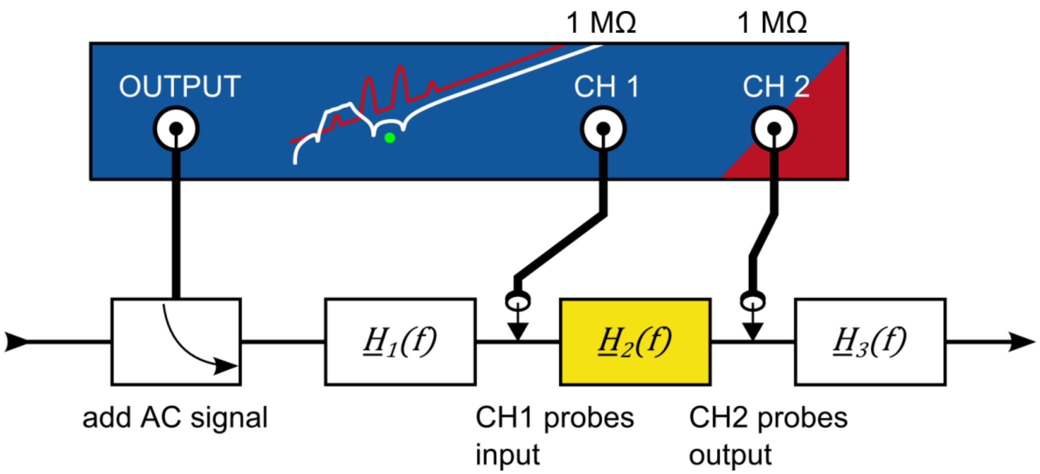
$\varphi_m = 87°$

Why Measuring Stability?

- Ensure stable operation at all operating points and different environmental conditions
- Low phase margin can add significant ringing and degrade system performance
- Especially linear regulators should show enough stability margin when powering clocks, opamps or ADCs
- Verify your simulation results

Measuring a Transfer Function

Bode 100 measures the transfer function $\underline{H}_2$ from CH1 to CH2

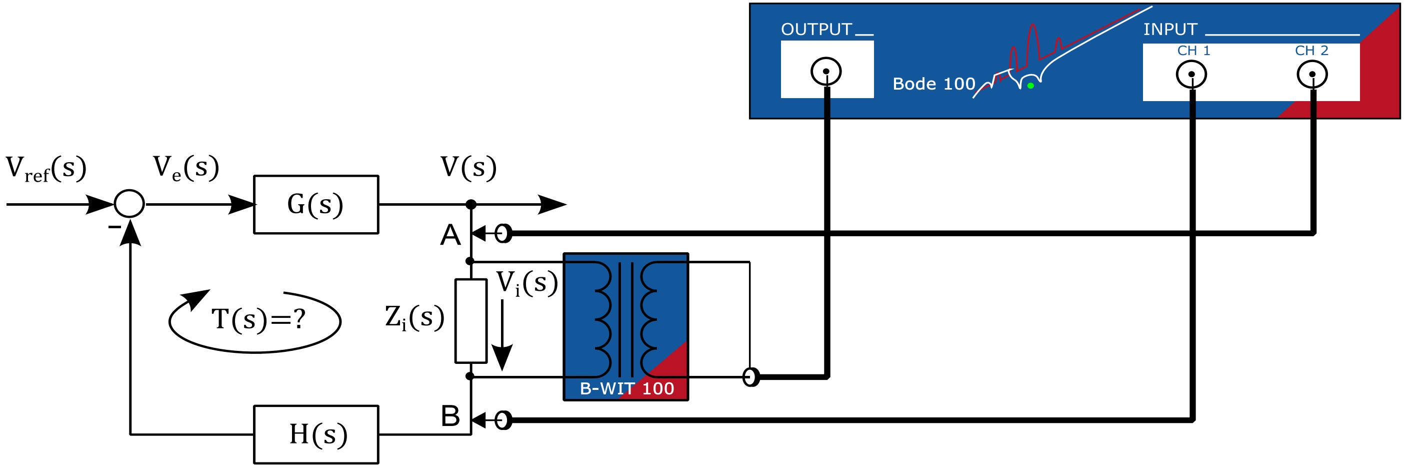


Note: Use the external reference function of the Bode 100 to enable CH1 input!

Measuring Loop Gain (Voltage Injection)

Loop gain is measured by “breaking” the loop at the injection point and inserting an injection resistor.

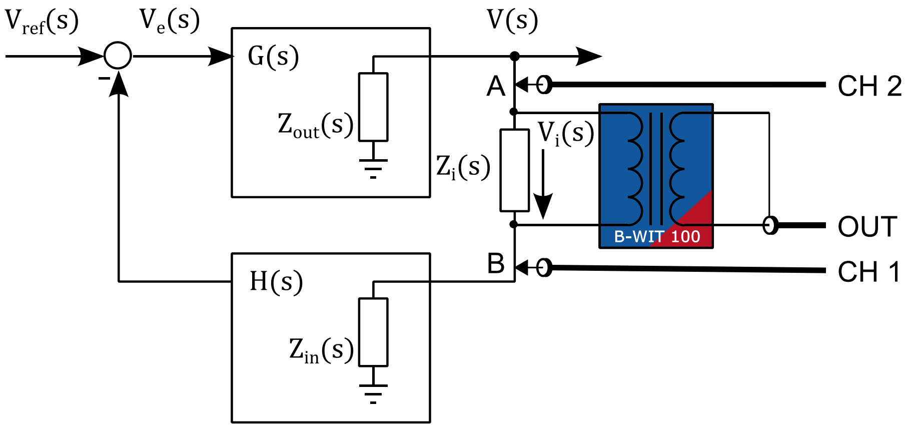
The voltage loop gain is measured by $T_v(s) = \frac{v_y(s)}{v_x(s)}$



Selecting the Injection Point

To keep the measurement error small we need to find a suitable injection point that fulfills the two conditions:

1. $|Z_{in}| \gg |Z_{out}|$
2. $|T| \gg \left|\frac{Z_{out}}{Z_{in}}\right|$



Generally well suited points:

- Output of a voltage source
- Input of an operational amplifier
- Output of an operational amplifier
- Best between two opamps

Reading Phase Margin from Measurement

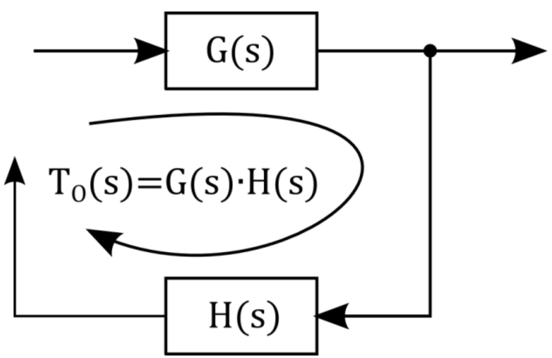
Phase Margin is read directly from the measurement!

φ_m is the distance to 0° and NOT to -180°

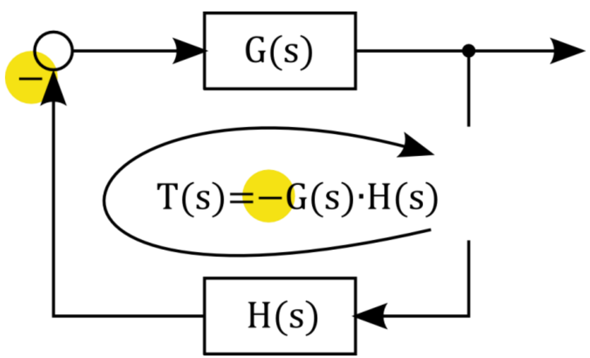
Reason: We measure in the closed loop system → our signal will run through the inverting error amp and get an additional 180° phase shift.

→ The instability point is at +1!

Theoretical open loop gain $T_o(s)$



Measured loop gain $T_v(s)$



Injection Signal Level

Control loop is designed based on small signal models (linear)

→ Measurement signal must be a “small signal”

Note:

Measurement result must be independent of signal size!

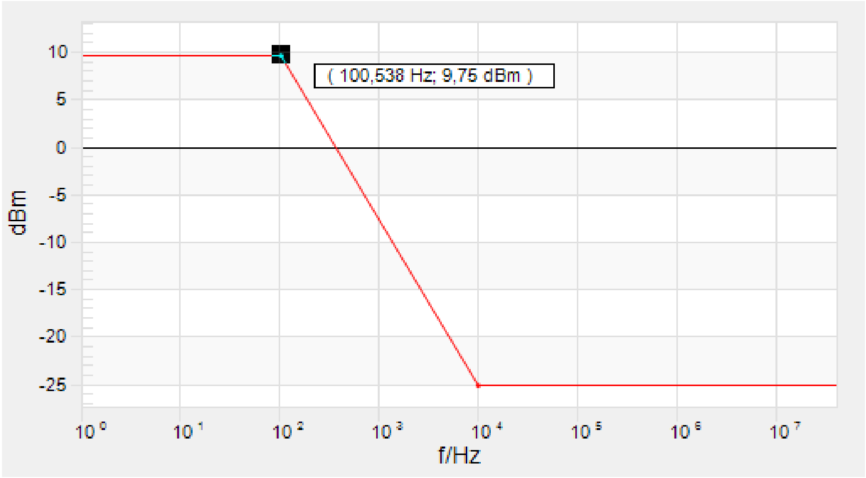
How to Check?

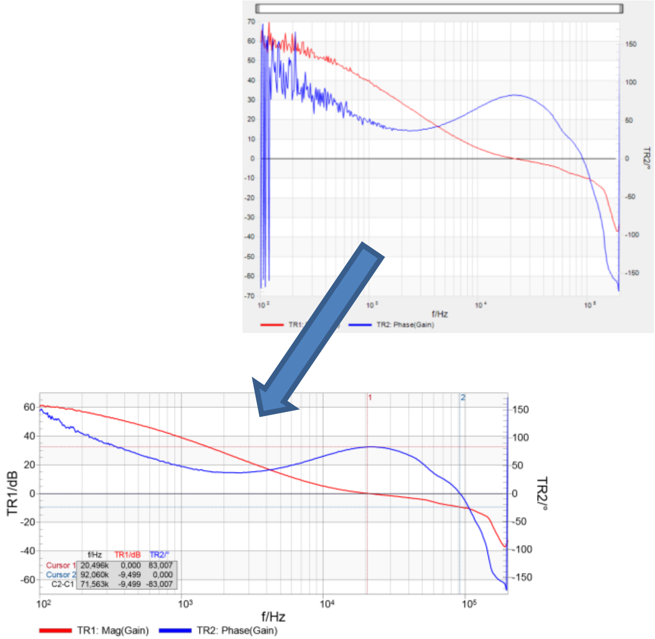
1. Choose an injection signal level and measure
2. Reduce the injection signal by e.g. 10dB

→ If the result has changed, do **further reduce** until the result stays constant!

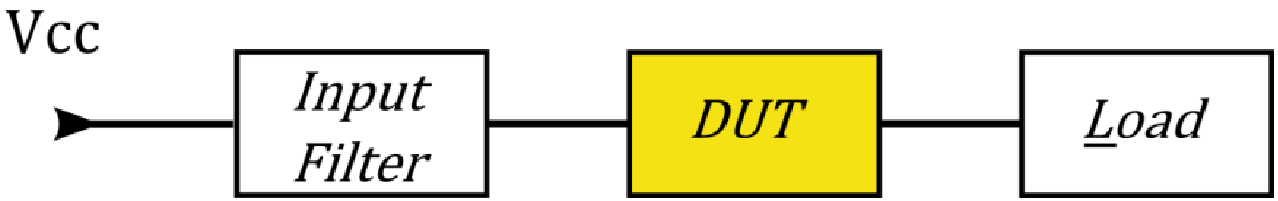
Shaped Level

- Correct results and clean curves? → use the “shaped level”!
- Low level at sensitive frequencies and high level where you need more disturbance power.





In-system measurements are important



- The input filter can influence the stability (Middlebrook)
- The load influences the stability margin

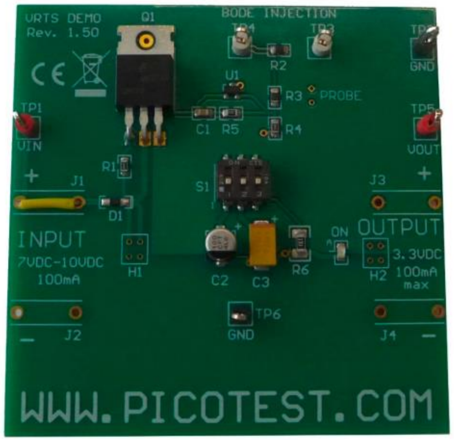
Always measure the loop gain under **all expected load conditions** and with the **input filter** connected.

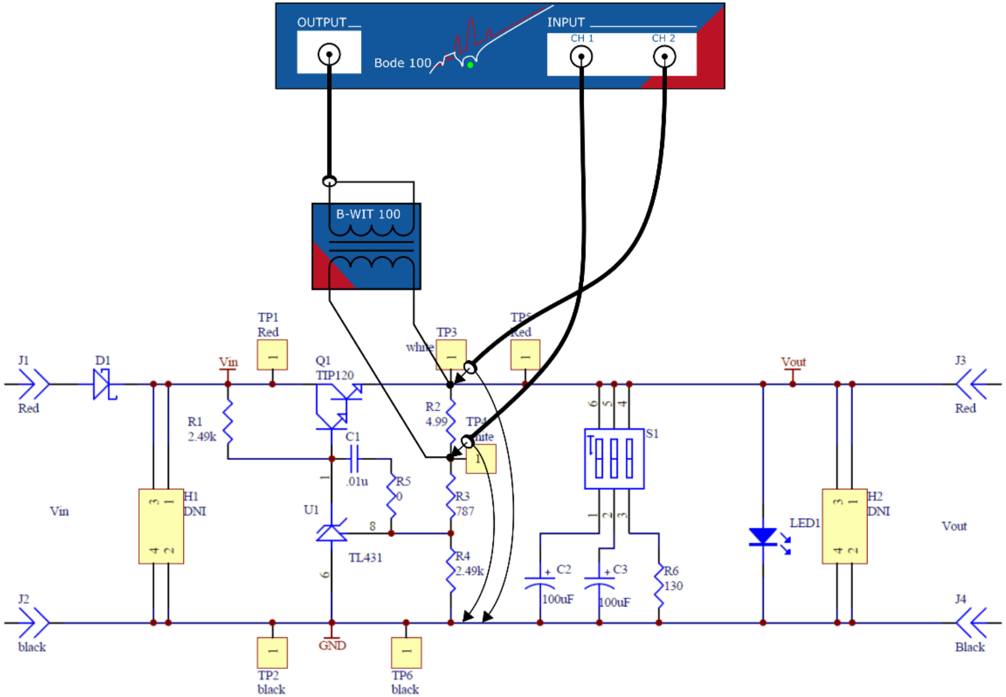
Choosing the right injection point

1. Linear Regulator (Picotest)
2. Buck Converter (LT6811)
3. Flyback Converter (LT3758)
4. LED Driver (LT3755)
5. SEPIC Converter (LT3758)

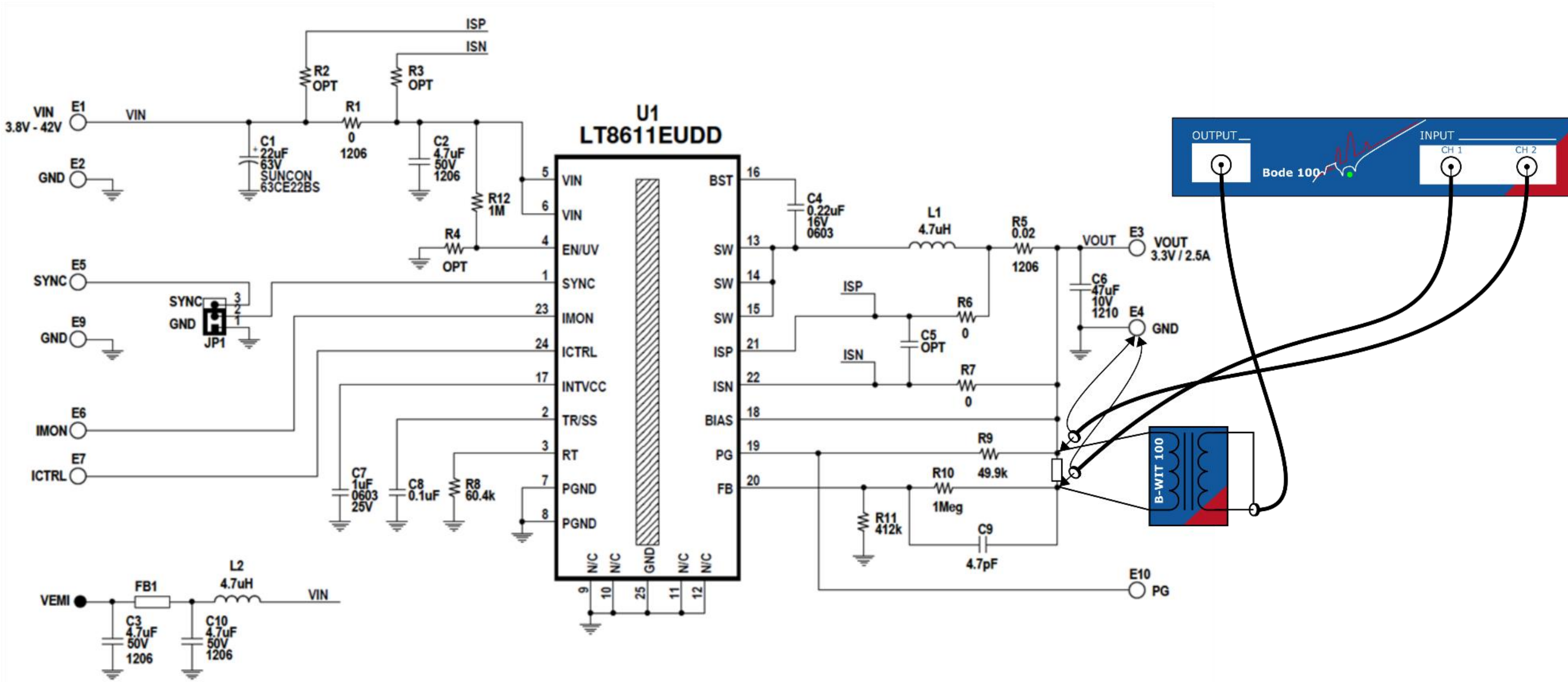
VRTS 1.5 board from Picotest

Linear regulator with 3.3V output voltage.





Step Down Converter: Demo 1750A



LINEAR TECHNOLOGY

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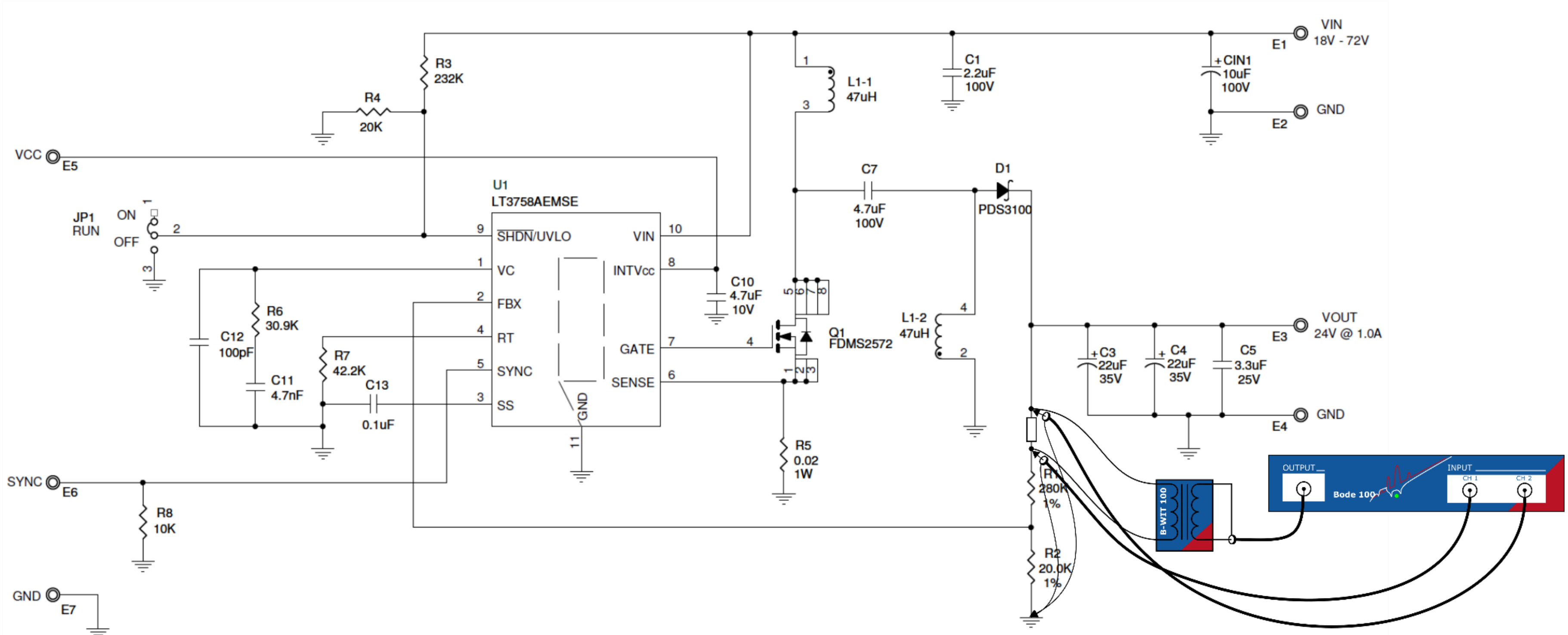
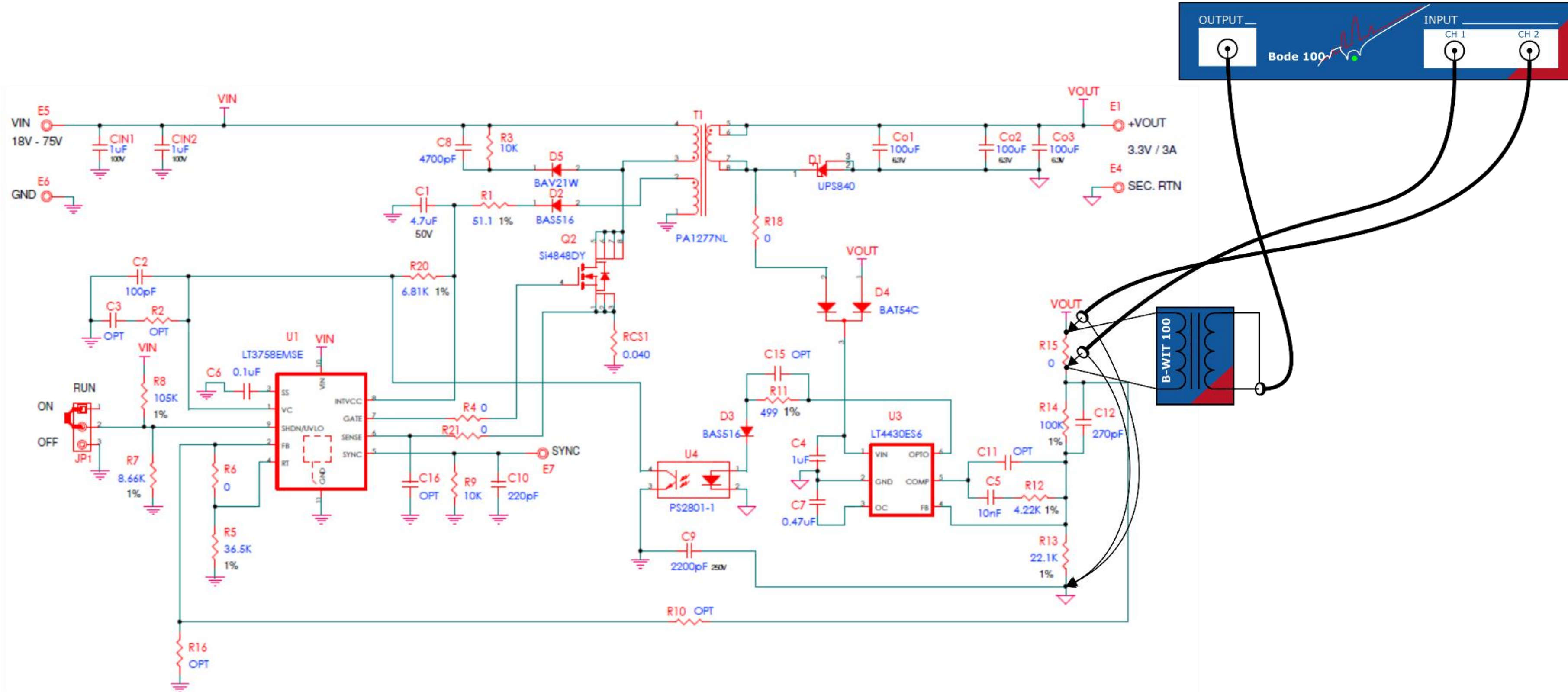
Sepic Converter: Demo 1342B



Flyback Converter: Demo 1412A



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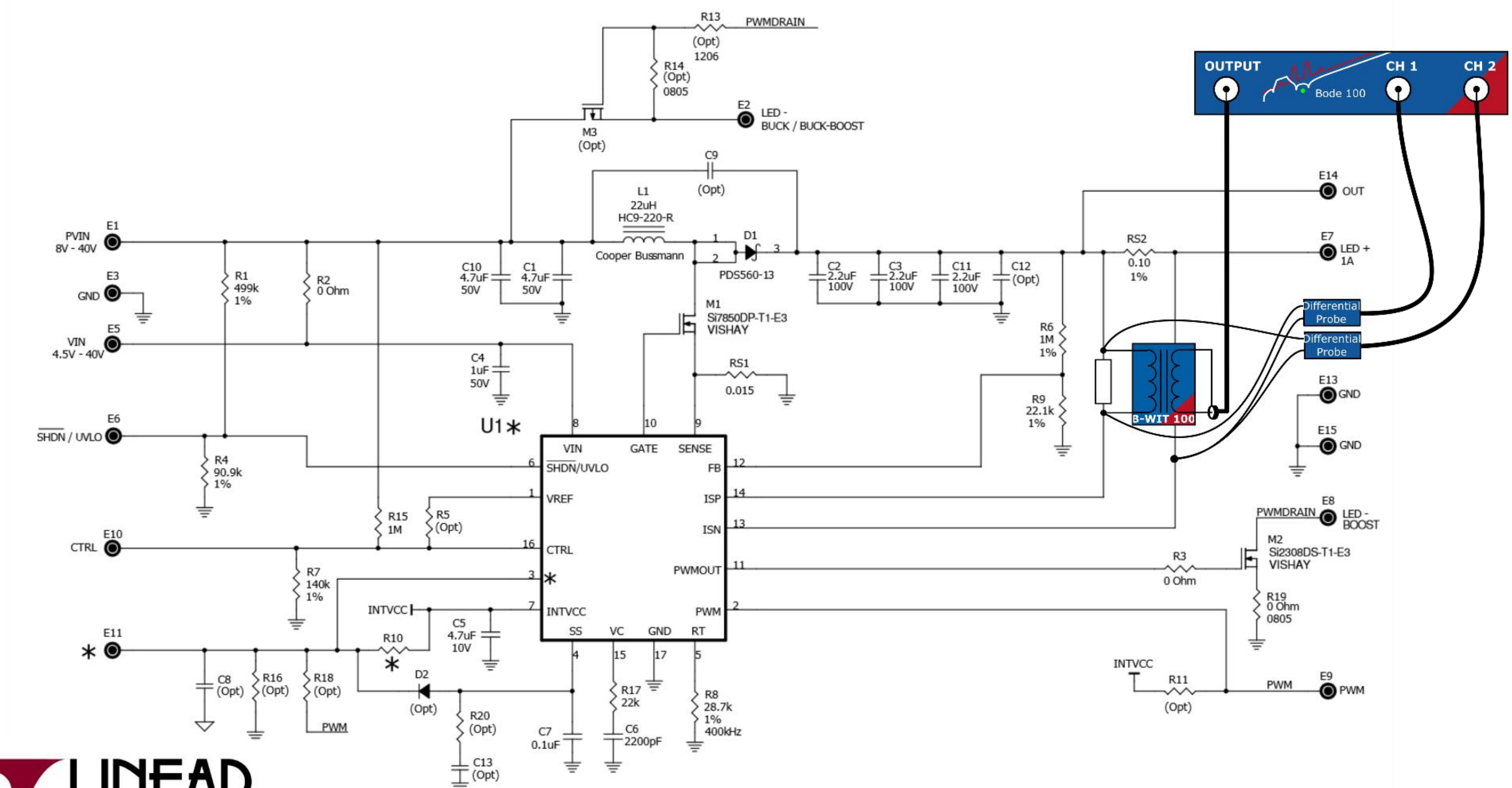
High Voltage LED Driver: Demo 1268b-A



LINEAR TECHNOLOGY

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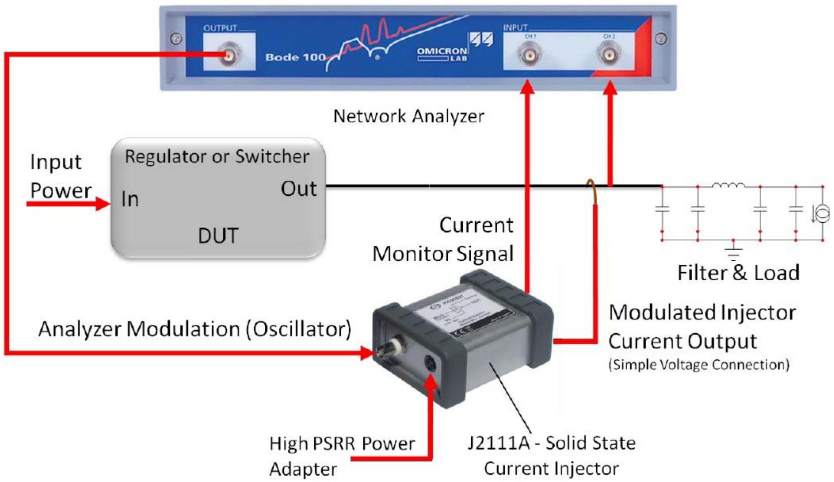
Live Measurements

- LED Driver
- Flyback Converter

What if you can‘t break the feedback loop?

Loop stability can be derived from an output impedance measurement

- → Non-Invasive Stability Measurement (NISM)
- → Find out more at: www.picotest.com



PICOTEST

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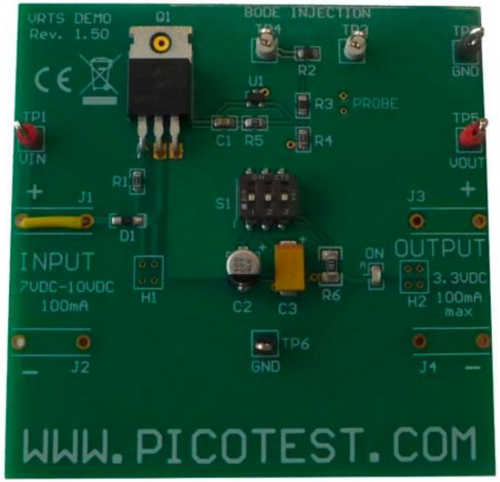
Do you want to measure more?

Measure:

- Loop Gain
- Output Impedance (NISM)
- PSRR
- Input Impedance and more...



Send us an E-Mail with subject **VRTS** and we will send you a board for free.

You can find all our power supply appnotes at:
https://www.omicron-lab.com/bode-100/application-notes-know-how/application-notes.html#3

Feel free to ask questions via the chat function...

If time runs out, please send us an e-mail and we will follow up.
You can contact us at: info@omicron-lab.com

Thank you for your attention!

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