Control of SMPS – a Refresher

Part 3

Colin Gillmor (APP, HPC)

Control of SMPS – a Refresher:

Agenda

Part 1
1. Concepts
2. Transfer Functions
3. Control Systems

Part 2
4. Loop Transfer Functions
   - Control to Output: G(s) — Power Stage (Plant)
   - Output to Control: H(s) — Feedback (Control)
5. Loop Compensation

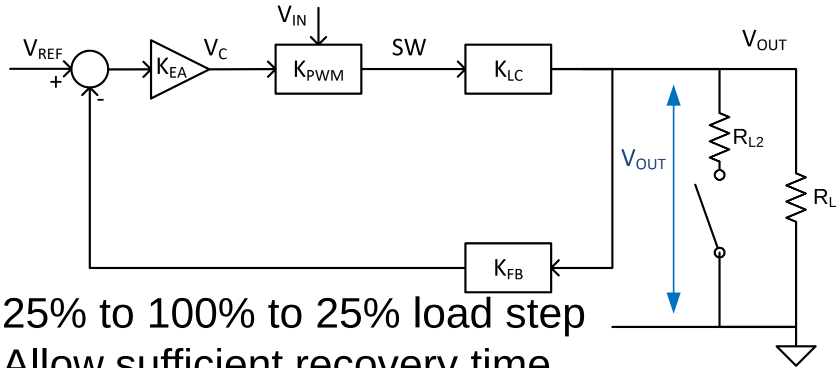
Part 3
6. Measuring the Control Loop
7. Summary and other issues
8. References

Control of SMPS – a Refresher:

1. Concepts
2. Transfer Functions
3. Control Systems
4. Loop Transfer Functions
   Control to Output: G(s) Power Stage (Plant)
   Output to Control: H(s) Feedback (Control)
5. Loop Compensation
6. **Measuring the Control Loop**
7. Summary and other issues
8. References

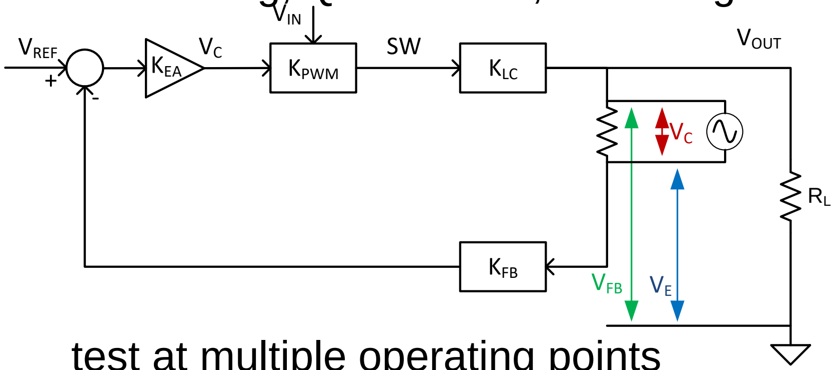
Measuring the control loop:

Transient Response
Quick, Qualitative, Large Signal



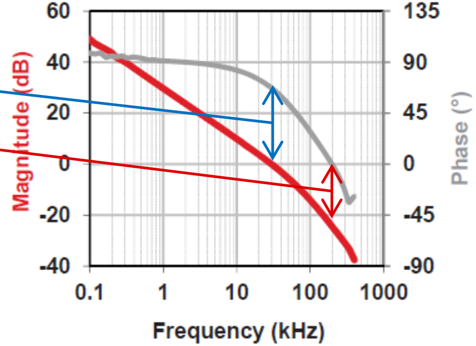
25% to 100% to 25% load step
Allow sufficient recovery time

Loop Response
Time Consuming, Quantitative, Small Signal



test at multiple operating points

Loop b/w 30kHz
Phase Margin ≈ 60°
Gain Margin ≈ 20 dB



Laplace Transform →

← Inverse Laplace Transform

Measuring the control loop: Bode Plot

Signal injection:
Isolation transformer couples test signal into circuit

- Wide bandwidth – typ 100Hz to 100kHz

Signal injection location must be chosen carefully

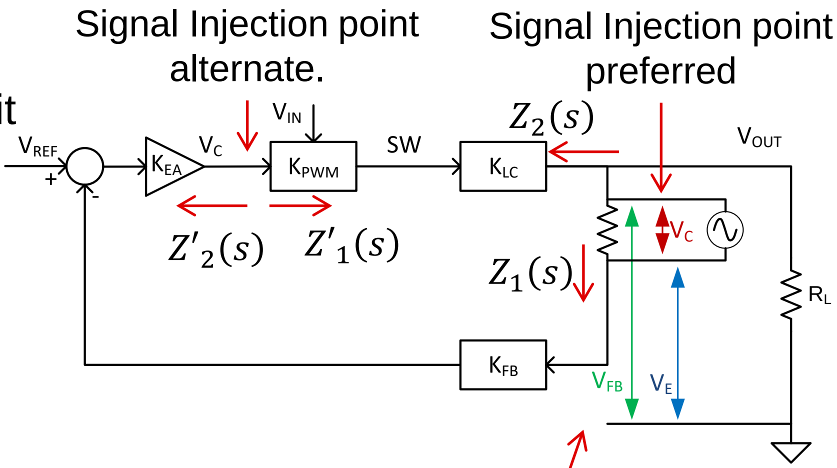
- Low Z looking 'back' into the loop, $Z_2(s)$
- High Z looking 'forward' around the loop, $Z_1(s)$

$$T(s) = M(s) * \frac{Z_1(s)}{Z_1(s) + Z_2(s)}$$

Where T(s) is the true loop gain, M(s) is the measured loop gain
$Z_1(s)$ and $Z_2(s)$ are difficult to quantify but if $Z_1(s) >> Z_2(s)$ then

$$T(s) \approx M(s)$$

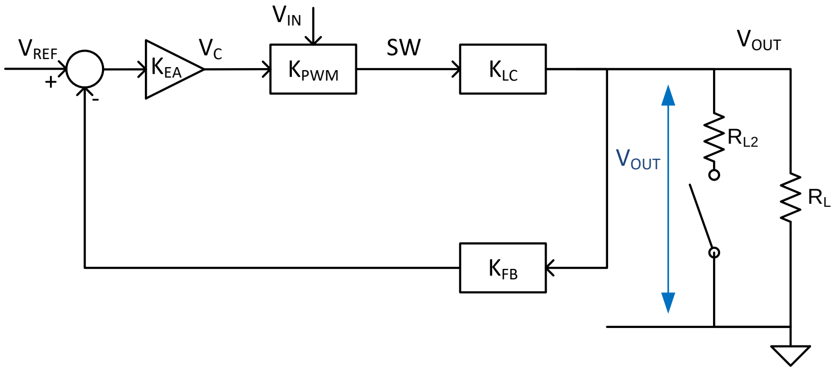
Ref 10, Ref 14



In series with K_{FB} is ideal but meters may limit use at high Vout

Measuring the control loop: Transient Response

Transient Response
Quick, Qualitative, Large Signal



Fourier transform of a step waveform contains components at all frequencies.

Large amplitude Load change

- Typically 25% to 75% to 25% load steps
- 0% to 100% to 0% load steps are also used
-

Load di/dt must be significantly faster than the loop response.

- Electronic Load step function
- Resistor with MOSFET switch

Signal amplitude can be 'buried' in noise

- Apply repeated transients and average the result

Measuring the control loop

Formal relationship between Gain/Phase plot and Transient Response (LTI system)

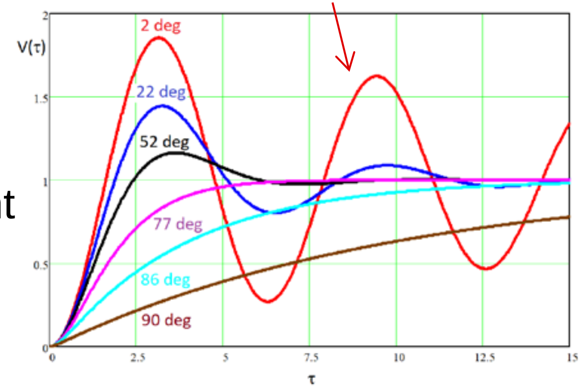
Phase Margin can be estimated from the shape of the transient response

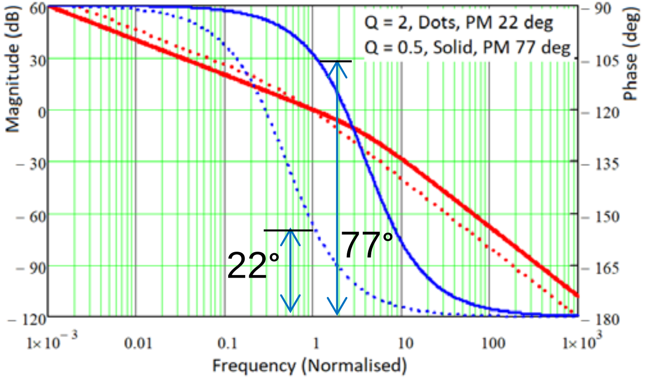
Plots here are normalised to a crossover at 1Hz

Underdamped transient response implies small phase margin

Loop stability can be estimated from a load transient test

Oscillation at crossover frequency of the loop (approx.)





Ref 11, PP342

Control of SMPS – a Refresher:

1. Concepts
2. Transfer Functions
3. Control Systems
4. Loop Transfer Functions
   Control to Output: G(s) Power Stage (Plant)
   Output to Control: H(s) Feedback (Control)
5. Loop Compensation
6. Measuring the Control Loop
7. **Summary and other issues**
8. References

The Iceberg Analogy

Most instability problems have nothing to do with classical control theory !

Noise Pickup
Non Linearity – insufficient control range/authority
Over Current protections
Input Filter Oscillations
Problems with Remote Sensing
Source Instability
Load Instability
Etc. etc
Etc.

Control of SMPS: Summary

Control theory is sometimes thought to be difficult to understand

- Complex Mathematics, Complex Frequency, Laplace Transform, Poles, Zeros etc etc
- An intuitive overview is possible without too much complexity

SMPS control

- Voltage Mode:
- Current Mode: Peak Current Mode, Average Current Mode

Loop Transfer Functions

- Control to Output: G(s), Output to Control: H(s), Complete Loop
- Loop Compensation: Type 1, Type 2, Type 3

Testing

- Gain Phase Measurements (Bode Plot), Transient Tests, Evaluation of results.

References

Control of SMPS – a Refresher:

1. Concepts
2. Transfer Functions
3. Control Systems
4. Loop Transfer Functions
   Control to Output: G(s) Power Stage (Plant)
   Output to Control: H(s) Feedback (Control)
5. Loop Compensation
6. Measuring the Control Loop
7. Summary and other issues
8. **References**

References

1/ The Right Half plane Zero, A Simplified Explanation, Dixon: https://www.ti.com/seclit/ml/slup084/slup084.pdf
2/ Fundamentals of Power Supply Design: Mammano: Texas Instruments, 2017
3/ SMPS compensation made easy, Sheehan: https://www.ti.com/seclit/ml/slup340/slup340.pdf
4/ Control Loop Cookbook, Dixon: https://www.ti.com/seclit/ml/slup113/slup113.pdf
5/ Compensation Design with TL431 for UCC28600: http://www.ti.com/lit/an/slua671/.pdf
6/ Designing with the TL431, Ridley: https://www.researchgate.net/publication/280308828_Designing_with_the_TL431_-_the_first_complete_analysis
7/ A more Accurate Current-Mode Control Model, Ridley: https://www.ti.com/seclit/ml/slup122/slup122.pdf
8/ Modelling, Analysis and Compensation of the Current Mode Converter: http://www.ti.com/lit/an/slua101/slua101.pdf
9/ Average Current Mode Control of Switching Power Supplies, Dixon: https://www.ti.com/seclit/ml/slup091/slup091.pdf
10/ Considerations for measuring loop gain in power supplies: https://www.ti.com/seclit/ml/slup386/slup386.pdf
11/ Fundamentals of Power Electronics: Erickson and Maksimovic, ISBN 0-7923-7270-0
12/ Modern Control Systems: Dorf, Addison Wesley, ISBN: 0-201-51713-2
13/ http://www.how2power.com/pdf_view.php?url=/newsletters/1204/articles/H2PToday1204_design_TexasInstruments.pdf
14/ http://venable.biz/uploads/files/01-Technical-Paper-Testing-Power-Sources-for-Stability.pdf

15/ https://en.wikipedia.org/wiki/Bicycle_and_motorcycle_dynamics

Control of SMPS – a Refresher

End of Part 3

Colin Gillmor (APP, HPC)

colingillmor@ti.com