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Control loop stability measurement in power supplies

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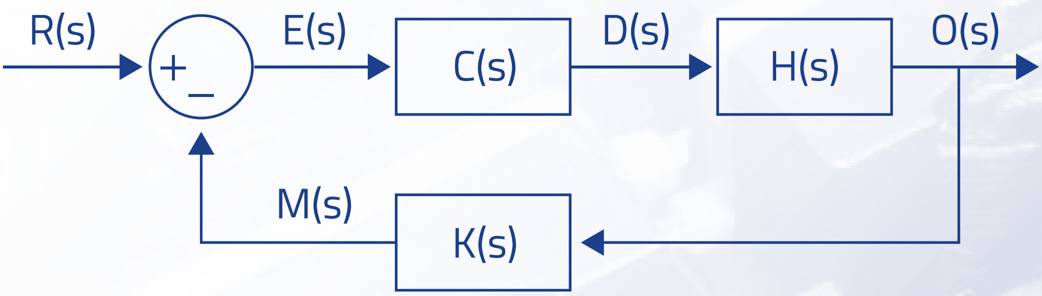
Introduction

Switched Mode Power Supplies (SMPS) use control loops to ensure that the working point is obtained with the minimum steady state error and fast transient response. To achieve these objectives, a strong control action is needed. But if this action is too aggressive, it can make the system unstable, leading to oscillations that can increase ripples, component stress or even damage the converter or loads.

The control action can be estimated with linear control calculation techniques. Even though SMPS are nonlinear, time-varying systems due to the switching actions can be modeled with an averaged small-signal linearized model.

Stability of power converters

The stability analysis of SMPS is usually tackled by using their averaged models, where resulting no linear models are linearized around the operating point. The averaged model of the control loop of any power converter can be described as:



Where H(s) is the plant to control, C(s) is the compensator, and K(s) is the dynamics´ feedback. As a result, we can describe the system gain with the following equations, where T(s) is the loop gain:

$$\frac{M(s)}{R(s)} = \frac{K(s) \cdot C(s) \cdot H(s)}{1+K(s) \cdot C(s) \cdot H(s)} = \frac{T(s)}{1+T(s)}$$

The control loop´s goal is that the measured output M(s) follows the reference R(s). To achieve it, the gain M(s)/R(s) must be close to 1, which happens when the loop gain T(s) is very high.

What happens if T(s) is close to -1?

In this case, the denominator 1 + T(s) is close to 0 and the gain of the system is approaching to infinite. This leads to instability, causing the system to saturate or oscillate.

If we want to analyze the stability of the system, we need to verify how close T(s) can be to -1, meaning when the loop gain is 1 (0 dB) and the loop phase is -180º. A bode plot, as the one shown in Figure 1, is a useful tool to do that.

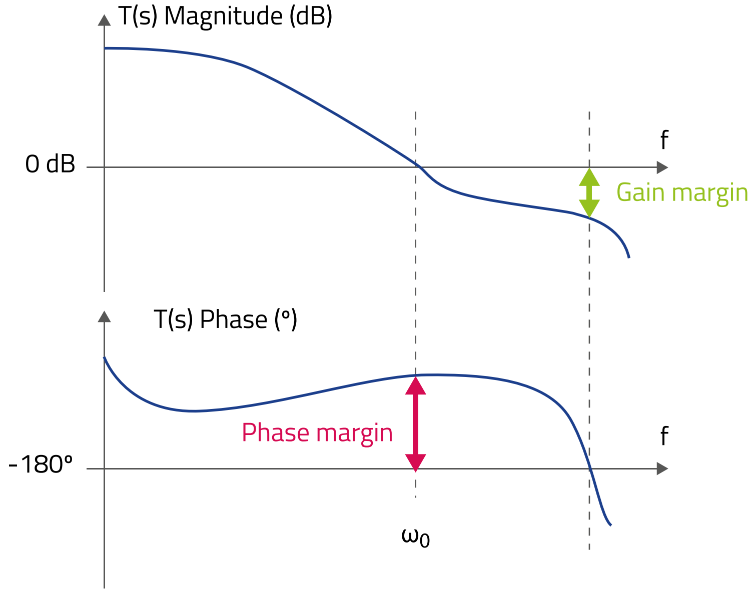


Figure 1

The phase margin is the difference between -180º and the phase at 0 is the crossover point (at 0 dB) of T(s) magnitude. That is the system´s phase margin before becoming unstable.

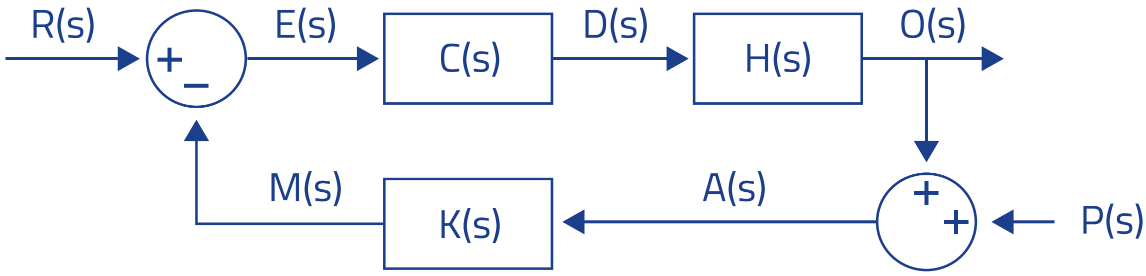
The gain margin is the opposite of the T(s) magnitude when the phase reaches -180º. That is the attenuation of the signal at instability point.

We are mentioning stability margins because we need to keep a safety margin to assure that the system is stable in any condition during all its life. For instance, more margin is needed when electrolytic capacitors or optocouplers are used, because their parameters change with temperature and aging.

Another interesting outcome from the Bode plot is the bandwidth 0. This is the maximum frequency of the perturbations that can be rejected.

Measuring control loop

We can measure the loop gain T(s) breaking the loop and injecting a disturbance signal P(s).



We will obtain T(s) observing how the system modifies this disturbance signal.

$$\frac{O(s)}{A(s)} = -K(s) \cdot C(s) \cdot H(s) = -T(s)$$

Good practices measuring control loop

- Choose the correct injection point following these requirements:
  - It is accessible
  - It is a single path (no parallel signal flows)
  - The impedance looking in the direction of the loop is much bigger than the impedance looking backwards
- Calibrate the setup before measuring
- Choose the correct signal level:
  - If it is too low, the measurement will be noisy
  - If it is too high, the measurement will be erroneous as the system is out of linear zone
- The system gain can change depending on the working point. It is convenient to verify stability changing:
  - Output power
  - Input and output voltages
  - Temperature

Tips for control loop adjust

- Control loop analysis is only valid up to SMPS switching frequency (fsw) divided by 2
- The maximum bandwidth of an SMPS should be lower than 1/10 of fsw
- A 45° phase margin is, usually, acceptable. But a 60° phase margin is preferred in systems with low accuracy elements
- 10 dB gain margin is usually desired
- Gain attenuation greater than 8 dB at fsw/2 is desired, to attenuate switching noises in the feedback compensation loop

ABOUT PREMIUM PSU

Premium PSU is one of the largest power supply companies in Europe, offering solutions to the industrial market in high-tech machinery, transportation, energy, or extreme environments applications. Founded in 1981, Premium PSU designs and manufactures power conversion systems for customers all around the world.

Premium PSU's power conversion system range includes DC/DC converters, uninterrupted power supplies, DC/AC inverters, AC/DC power supplies and any solution that requires high reliability from 50W to 60kW.

All products comply with the specifications and regulations that each application requires and all projects, from the concept, design and until the homologation of the product, are carried out in Barcelona under strict quality controls.

Custom is Premium PSU's standard, so any current product variation or new development can be done by our R&D department, a team of over 50 engineers with a wide know-how.

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