POWER SUPPLY CONTROL LOOP RESPONSE MEASUREMENTS (BODE PLOT)

With a Rohde & Schwarz oscilloscope

Your task

To ensure the stability of voltage regulators and switched-mode power supplies, e.g. multiphase buck-converters, the control loop behavior must be measured and characterized. A well compensating voltage controller enables stable output voltages and reduces the influence of load changes and supply voltage variations. The quality of this control circuit determines the stability and dynamic response of the entire DC/DC converter.

Rohde & Schwarz solution

Easily and quickly analyze low frequency response on your oscilloscope with the R&S®MXOx-K36 frequency response analysis (Bode plot) option. Characterize the frequency response of a variety of electronics, including passive filters and amplifier circuits. Measure the control loop response and power supply rejection ratio of switched-mode power supplies. The R&S®MXOx-K36 frequency response analysis (Bode plot) option uses the oscilloscope's built-in waveform generator to create stimulus signals ranging in frequency from 10 mHz to 100 MHz. Measuring the ratio of the DUT signal input and output at each test frequency, the oscilloscope plots gain logarithmically and phase linearly.

The R&S®MXOx-K36 frequency response analysis (Bode plot) option allows you to quickly determine the gain and phase margin of switched-mode power supplies or linear regulators. These measurements help determine the control loop stability.

The R&S®MXOx-K36 frequency response analysis (Bode plot) option displays the system response to changes in operating conditions, such as supply voltage changes or load current changes.

Measurement setup

Power supply control loops compare reference voltage (V_{ref}) and feedback voltage ($V_{feedback}$) and create a negative feedback to ensure a stable output voltage.

Control loop response testing requires injecting an error signal over a band of frequencies into the feedback path of the control loop. To inject an error signal, a small resistor must be inserted into the feedback loop. The 5 Ω injection resistor shown in the graphic Choosing the correct injection point on the next page is insignificant in comparison to the series impedance of R1 and R2. Some users choose to permanently design in this low-value injection resistor ($R_{injection}$) for test purposes. An injection transformer, such as Picotest's J2100A, isolates the AC distortion signal and eliminates any DC bias.

Injection point and probing

To measure the loop gain of a voltage feedback loop, the loop needs to be broken at a suitable point. A distortion signal is injected at this point. The distortion signal will be distributed in the loop circuit. Depending on the loop gain, the injected distortion signal will be amplified or attenuated and shifted in phase. For the R&S®MXOx-K36 option, the generator of the oscilloscope generates the distortion signal. The oscilloscope measures the transfer function of the loop.

To ensure that the measured loop gain equals the real loop gain, choose a suitable point:

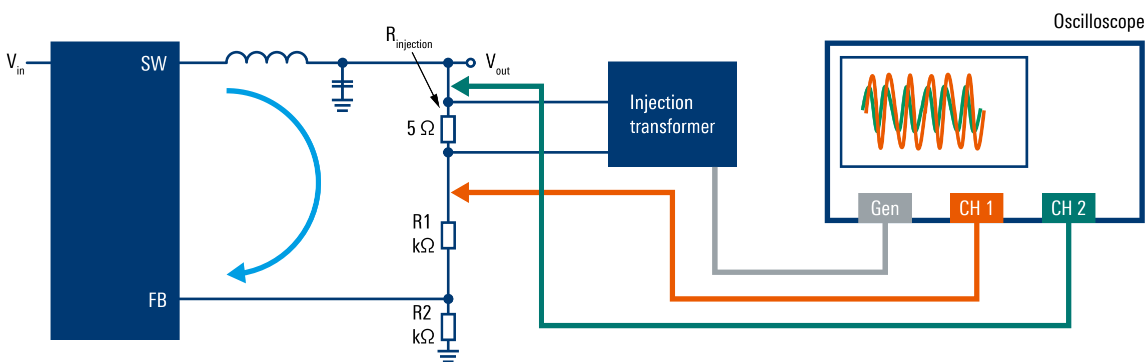
- Find a point where the loop is restricted to one single path to make sure that there are no parallel signal flows.
- Ensure that the impedance in the direction of the loop is much bigger than the backwards impedance at this point. The backwards impedance equals the output impedance of the converter, a very low value in the range of several mΩ. The impedance in the direction of the loop is formed by the compensator and the voltage divider and is in the range of several kΩ.

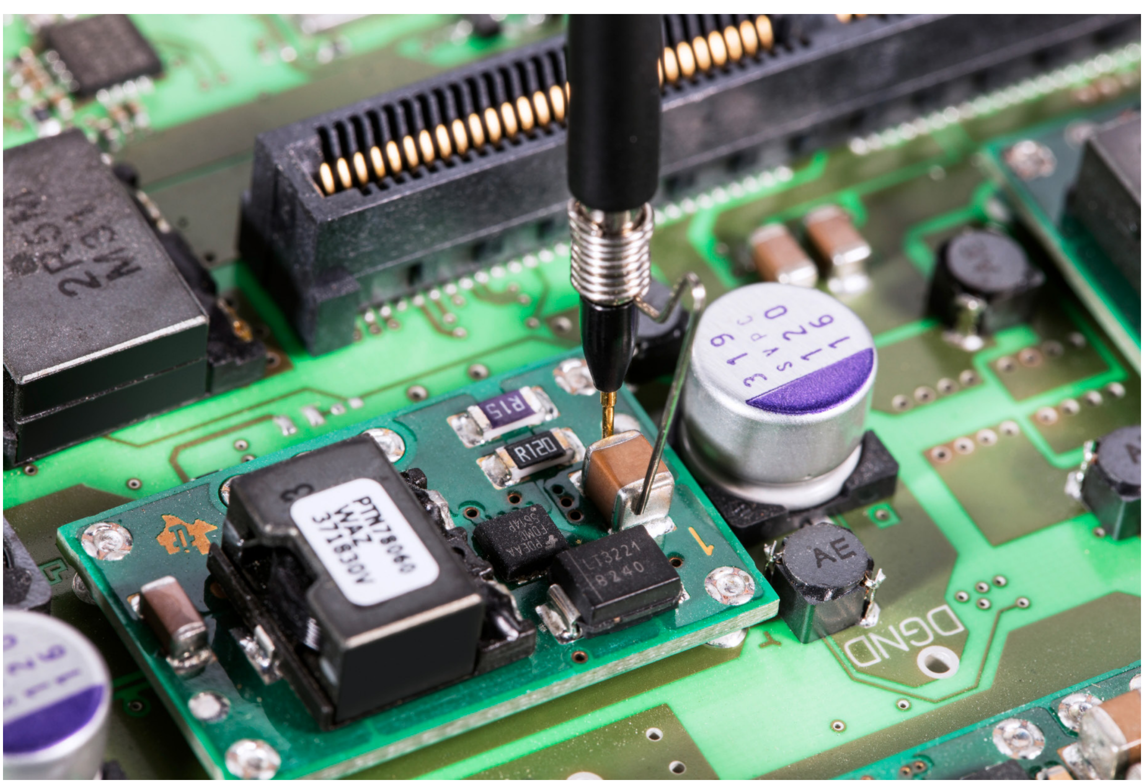
Accurate control loop response characterization depends on good probing. Peak-to-peak amplitudes of both V_{in} and V_{out} can be very low at some test frequencies. These values would be buried either in the oscilloscope's noise floor and/or in the switching noise of the DUT itself.

This is why increasing the SNR of your measurements will significantly improve the dynamic range of your frequency response measurements. Most oscilloscopes usually come with 10:1 passive probes that have more noise. Using low-noise 1:1 passive probes will reduce measurement noise and improve SNR. Rohde & Schwarz recommends the R&S®RT-ZP1X 1:1 passive probes with 38 MHz bandwidth for this application.

Reducing the length of your probe's ground connection minimizes inductive ground loops. The standard ground lead of your probe can sometimes act as an antenna and amplify unwanted switching noise. Find a ground post near the V_{in} and V_{out} test points. Use the provided ground spring of the R&S®RT-ZP1X probe to shorten the ground connection. This will provide a good low-noise ground for your measurement.

Choosing the correct injection point





Using a ground spring will provide the best signal-to-noise ratio for your power supply rejection ratio measurement

Device setup

After connecting the oscilloscope to the circuit under test, start the application:

- ▶ Set start and stop frequency between 10 mHz and 100 MHz and determine the generator output level.
- ▶ Set the points per decade to improve and modify the resolution of your acquisition. The oscilloscope supports up to 500 points per decade.
- ▶ Profile the amplitude of the generator output (up to 100 steps) to suppress the noise behavior of the circuit under test.
- ▶ Press run to start your measurement. The measurement results are plotted as gain/phase over frequency. Set your markers to your point of interest.

Measurement results

The Bode plot diagrams represent the circuit transmission function and help verify system stability by displaying the amplitude behavior (in dB) as well as the phase characteristics (in degrees) versus input frequency. Individual markers can be directly set to the desired positions on the plotted trace, along with a legend displaying the marker coordinates. To determine the crossover frequency, set one marker to 0 dB and the second marker to –180° phase shift. Now you can easily determine the phase and gain margin.

The measurement results table provides detailed information about each measured point (frequency, gain and phase shift). When using markers, the associated row of the result table is highlighted. For reporting, quickly save screenshots, table results or both to a USB device.

Measurement of the stability of a DC/DC converter (blue trace: gain; red: phase). The tables on the right indicate the measurement results, as well as the marker and margin measurement results.

Summary
Oscilloscopes are the primary measurement tools used today by engineers to test and characterize their power supply designs. The R&S®MXOx-K36 frequency response analysis (Bode plot) option provides a low-budget alternative to low frequency network analyzers or dedicated standalone frequency analyzers.

Ordering information

Designation	Type	Order No.	Option	Order No.
Oscilloscope, 200 MHz, 4 channels	MXO 4	1335.5050.04	R&S®MXO4-K36	1335.5572.02
			R&S®MXO4-B6 required	1335.4147.02
Oscilloscope, 350 MHz, 4 channels	MXO 54	1802.1008K04	R&S®MXO5-K36	1802.1943.02
			R&S®MXO5-B6 required	1802.0753.02
Oscilloscope, 100 MHz, 8 channels	MXO 58	1802.1008K08	R&S®MXO5-K36	1802.1943.02
			R&S®MXO5-B6 required	1802.0753.02
Oscilloscope, 100 MHz, 8 channels	R&S®MXO5C-81	1802.3000P81	R&S®MXO5C-K36	1802.3146.02
Passive probe, 38 MHz, 1 MΩ, 1:1, 55 V, 39 pF, 2.5 mm	R&S®RT-ZP1X	1333.1370.02		

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Power supply control loop response measurements (Bode plot)

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