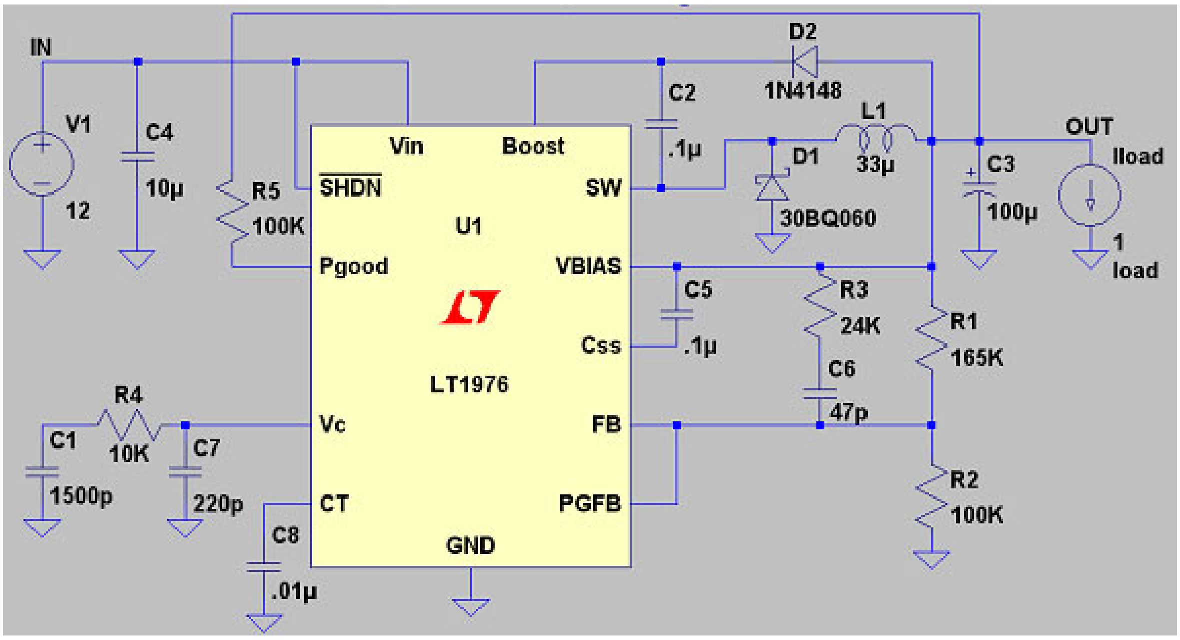
Measurement of Step-Down DC / DC Converters with Bode 100



Strongly supported by Linear Technology

by Stephan Synkule

Visit www.omicron-lab.com for more information.
Contact support@omicron-lab.com for technical support.

Table of Contents

Note: Basic procedures like setting-up, adjusting and calibrating Bode 100 are described in the operational manual of Bode 100. Therefore these procedures are not described in detail in this application note.

Note: All measurements with Bode 100 were done using the Bode Analyzer Suite V2.2 some mentioned functions may not be available if you use an earlier version of the Bode Analyzer Suite. You can download the latest version at www.omicron-lab.com.

All pictures showing Linear Technology components are used with the permission of Linear Technology Germany.

1 Executive Summary

This application note explains how to analyze the stability and the control loop behavior of DC power supplies containing step-down DC/DC converters. You will be given an insight on methods to asses the stability of switched mode power supplies. In addition you will be shown how you can visualize the influence of supply voltage or load changes.

2 Measurement Tasks

To minimize the influences of supply voltage variations and load changes on the output voltage of a DC/DC converter loop, compensation designs are necessary. The quality of this control circuit design defines the stability of the entire DC/DC converter. The following pages show you how you can asses the stability of such control loops with Bode 100.

All measurements in this application note were performed using a Linear Technology demo circuit 481A for which the main component is the LTC1976IFE Step-Down Switching Regulator. Based on measurements with this demo circuit the following topics are assessed:

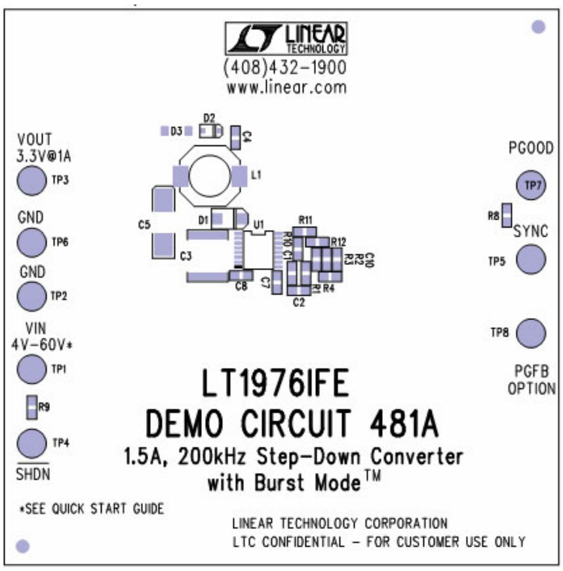
1.) A short note on designing DC/DC converters with SwitcherCAD III

2.) Setup for the signal injection into a control loop

3.) Stability analysis of control circuits including gain margin and phase margin

4.) Analysis of influences caused by supply voltage and load changes

5.) Using the shaped level function of Bode 100



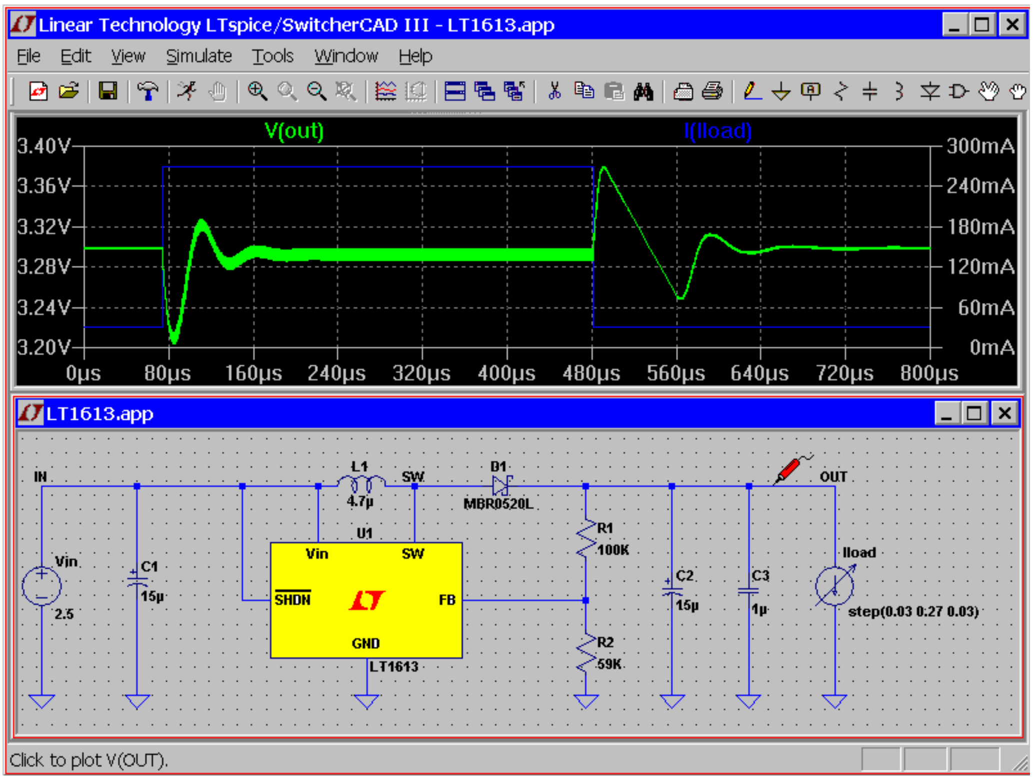
Detailed information on all the LT products used can be found at http://www.linear.com.

3 Measurement Setup & Results

3.1 A short note on designing DC/DC converters with SwitcherCAD III

A quick way to design and simulate DC/DC converters as well as other electronic circuits is the use of the design software SwitcherCAD III which is distributed by Linear Technology and can be downloaded for free at www.linear.com/designtools/software/switchercad.jsp.

SwitcherCAD III is a powerful circuit simulator and schematic capture program, providing macro models for 80% of Linear Technology's switching regulator, over 200 Op-Amp models, as well as resistors, transistors and MOSFET models.



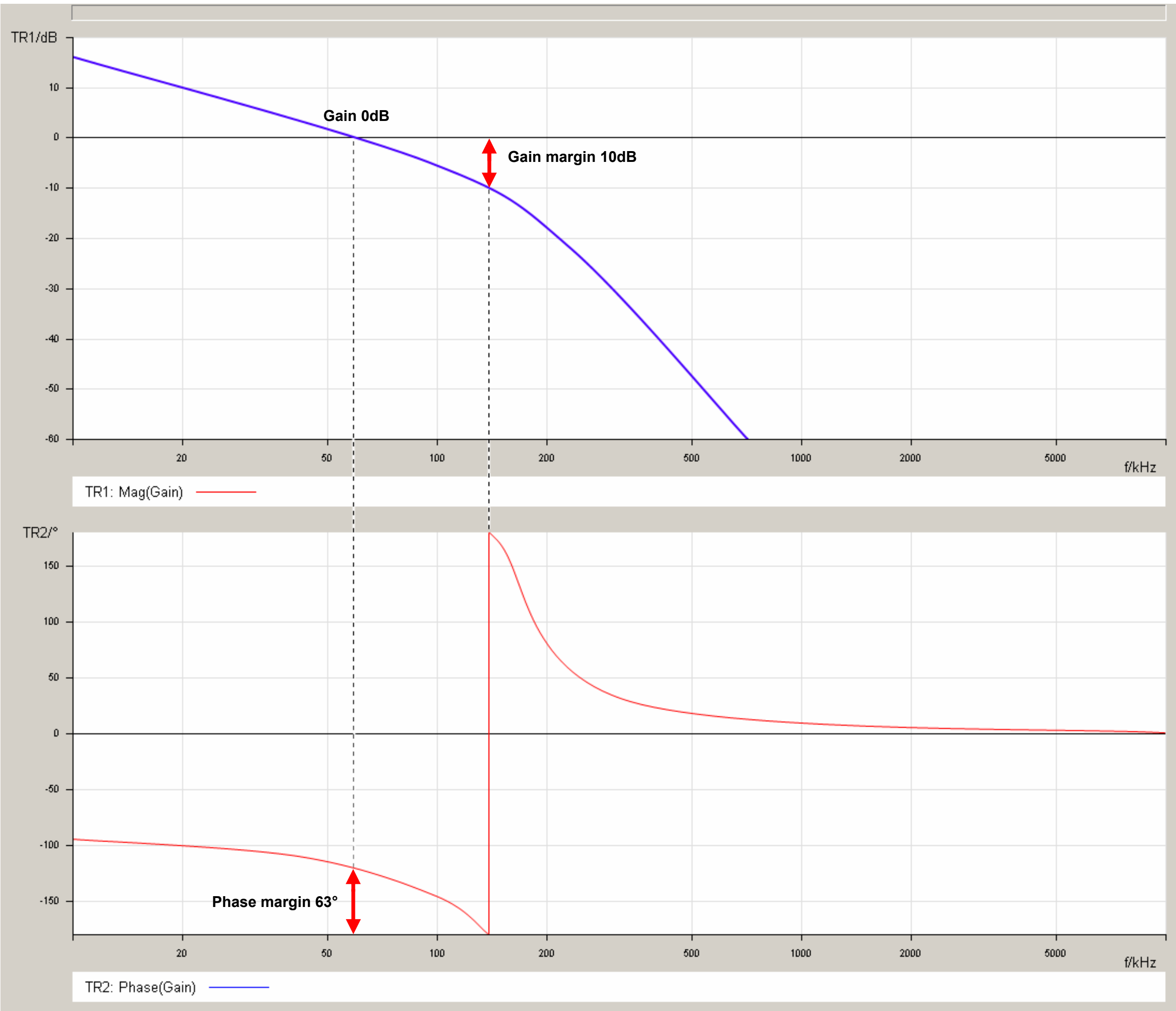
SwitcherCAD III is the third generation switching regulator design program by Linear Technology. The program consists of a high performance SPICE simulator extended with a mixed mode simulation capability that includes new intrinsic SPICE devices for macro modeling Switch Mode Power Supply (SMPS) controllers and regulators. The program includes an integrated hierarchical schematic capture program that allows users to edit example SMPS circuits or design new circuits. An integrated waveform viewer displays the simulated waveforms and allows further analysis of the simulation data. There is a built-in database for most of Linear Technology's power ICs and many passive components. The device database, schematic editing, simulation control and waveform analysis are integrated into one program.

All schematics used in this application note were drawn with SwitcherCAD III.

3.2 Stability analysis of a LT1976 control circuit

3.2.1 Theory and measurement setup

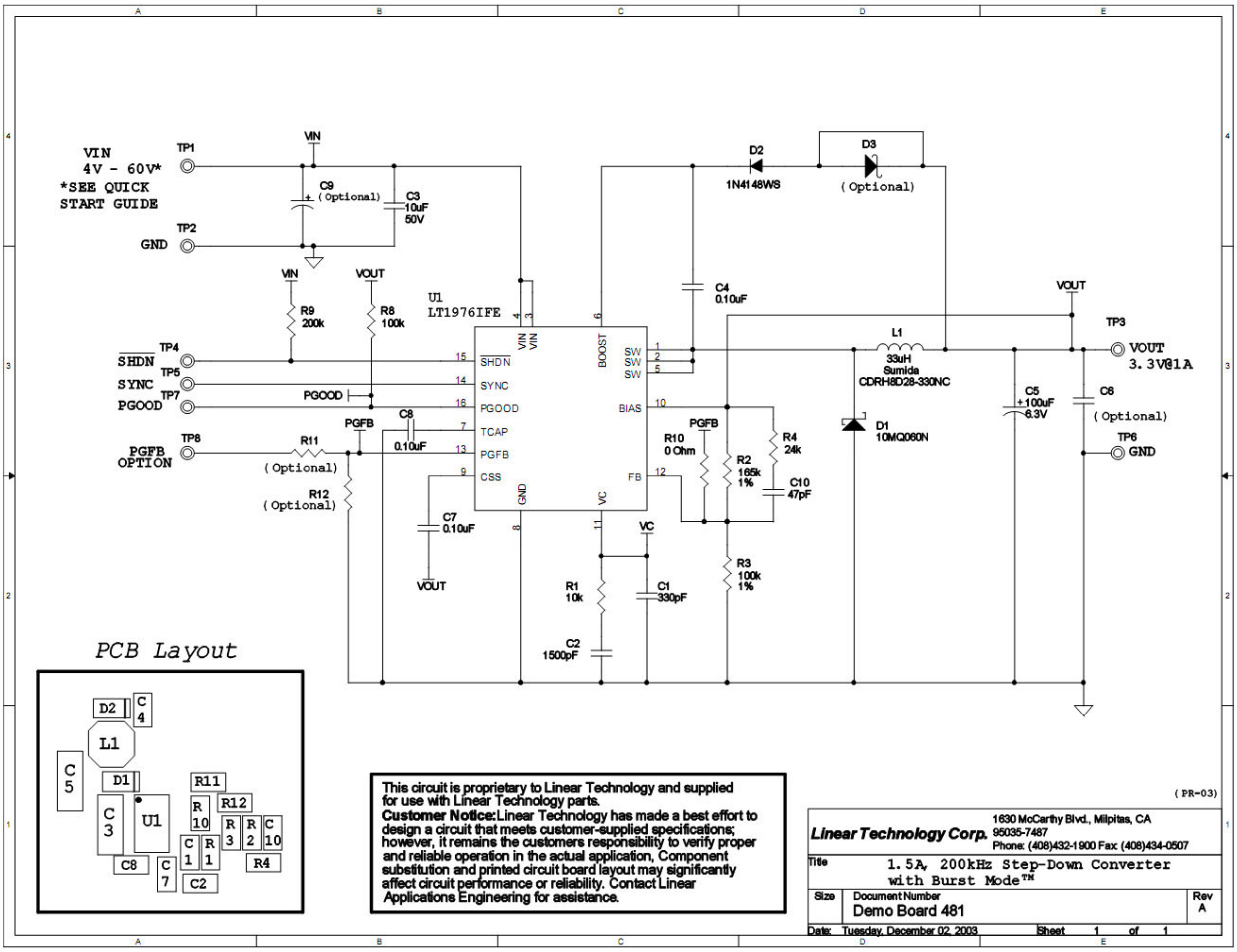
A loop is stable when its phase reaches -180° after the gain has dropped below 1 (=0dB). If this condition is not fulfilled a frequency exists at which the gain is higher than 1 and the phase shift is exactly 180°. In this specific case we have a positive feedback which will lead to instability of the control loop.



The Bode plot above shows a phase shift of 117° at a gain of 0dB. From these values we can calculate a phase margin of 63° (=180°-117°). The Bode plot further shows a gain of -10dB at the point where a phase shift of -180° is reached – the gain margin is therefore 10dB (= 0dB -(-10dB)).

Note: : Depending on the chosen feedback behaviour at the measurement point the phase margin is either referenced towards +/- 180° or 0°.

The following schematic shows the circuit of the demo board 481A:

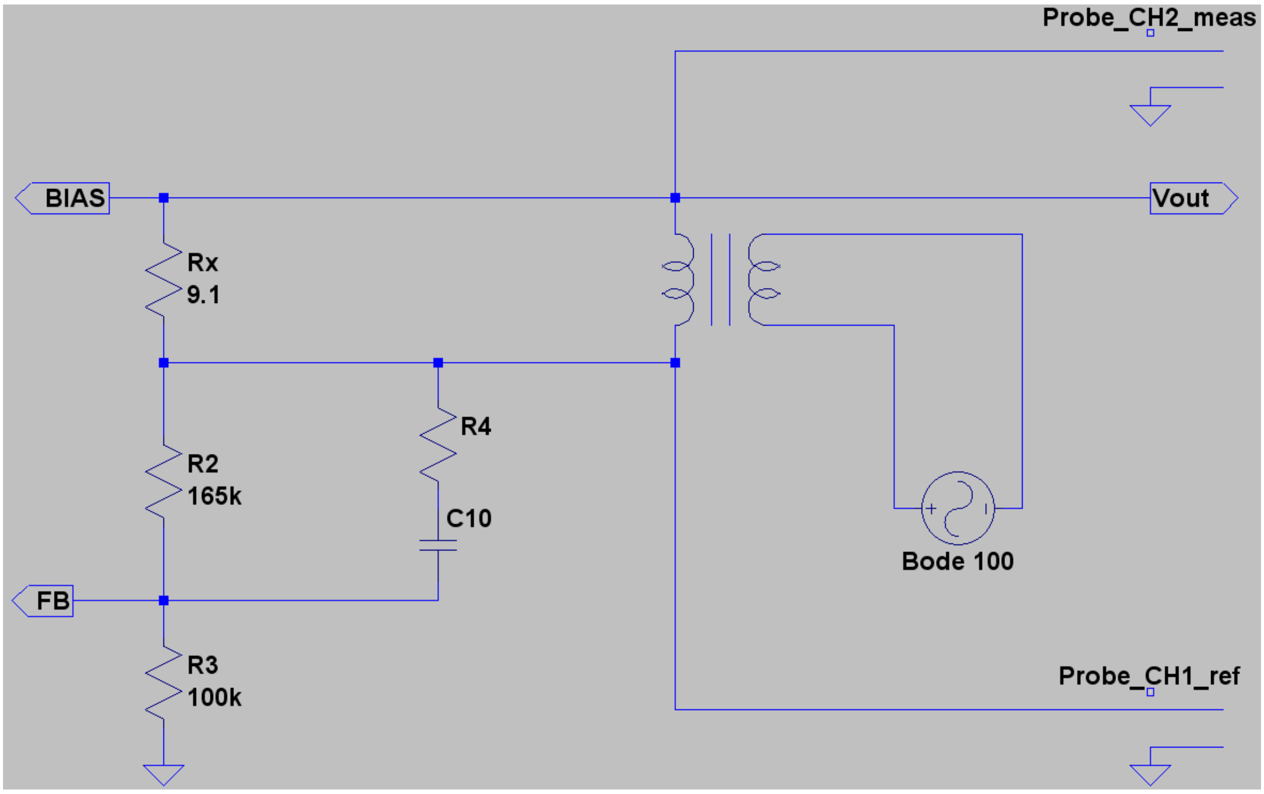


To inject Bode 100's source signal into the control loop we need to hook a resistor R_X into the feedback loop. To avoid any influences on the measurement result R_X needs to be negligible (= very small, we used 9.1Ω) in comparison to R_2 and R_3, which build the feedback divider of the selected DC/DC converter.

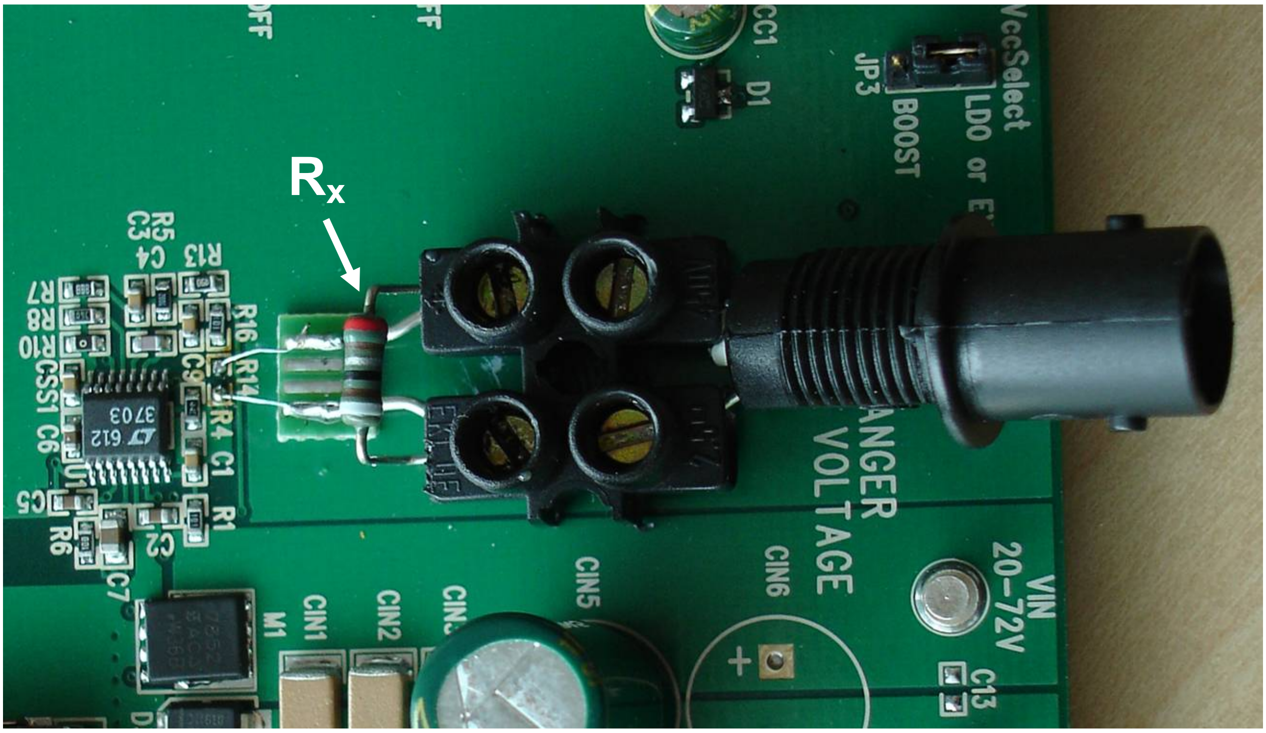
The Bode 100's source signal itself is injected via R_X using an injection transformer. The measurement signal for Bode 100 is picked up at the pin of R_X which is connected to the DC/DC converter's output.

The reference for the measurement is picked up from the other pin of R_X. It is recommended to use probes to pick up these signals. In our example we used 1:1 probes but 10:1 probes are possible as well.

The described connection setup is shown on the next page.



To ensure good measurement results it is strongly recommended to minimize the distance between R_x and the rest of the circuit. Furthermore, it is very important to avoid any mechanical stress to the soldering pads to prevent damage to the test object. Below you can see how we have realized the modification of a comparable demo board.

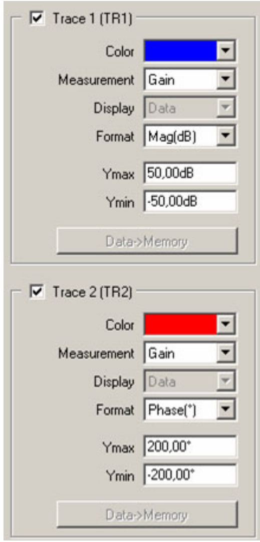


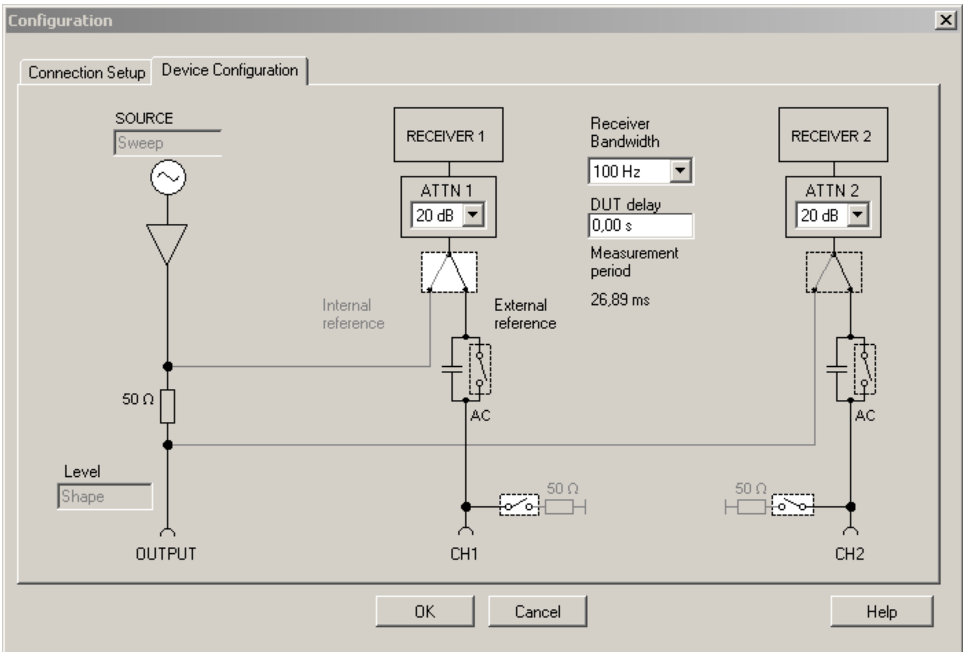
3.2.2 Influences of supply voltage changes on the stability

With our first measurement we will check how supply voltage changes influence the characteristic of the LT1976's control circuit.

Apply the following settings in the frequency sweep mode:

- f(min) = 1 kHz
- f(max) = 200 kHz
- Reference external
- Attn 20 dB
- Receiver Bandwidth: 100 Hz or less
- DUT delay 0s
- Number of points: 401 or more
- high impedance for CH1 and CH2
- Sweep mode: logarithmic
- Trace 1: - Measurement = Gain
  - Format = Mag (dB)
- Trace 2: -Measurement = Gain
  - Format = Phase (°)



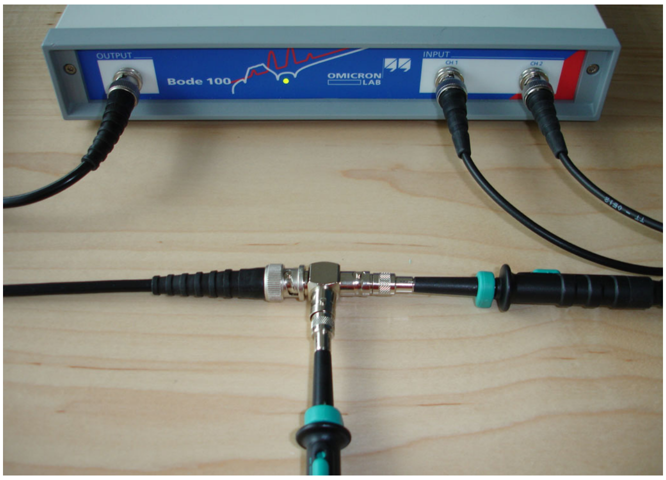


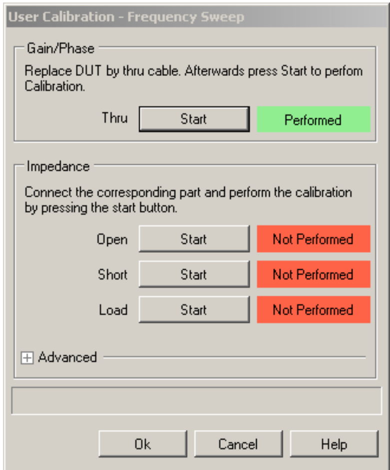
Note: With a narrow receiver bandwidth only little noise will affect the measurement but the sweep time will increase.

Note: By using the external reference input the measured Gain is defined as the ratio between the voltages measured at the input of CH1 and CH2. For the calibration of the probes the only required condition is that both probes get the same signal. Therefore we recommend connecting both probes directly to the source output of Bode 100 as shown on the next page.

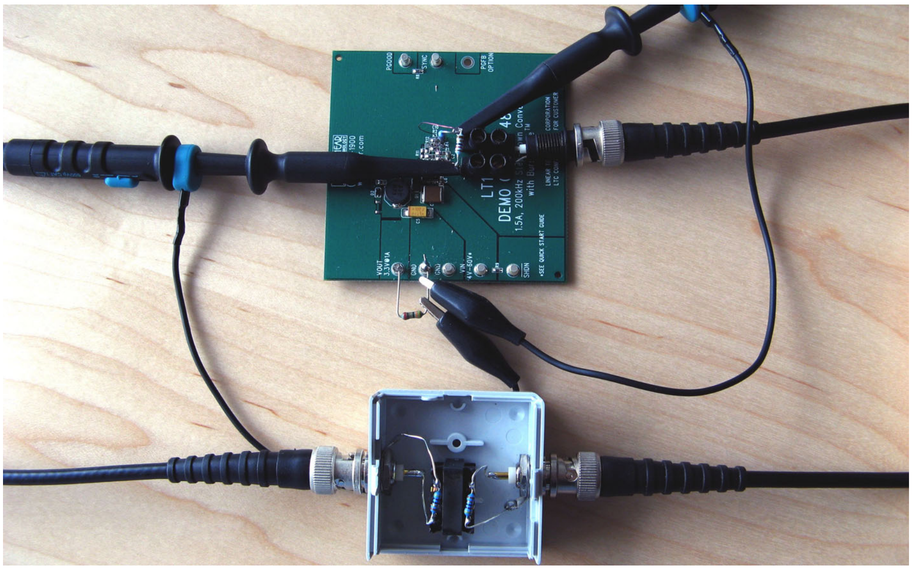
Hint: Probe to BNC adapters are a big help during calibration.

- Perform a THRU calibration to remove the probe influences



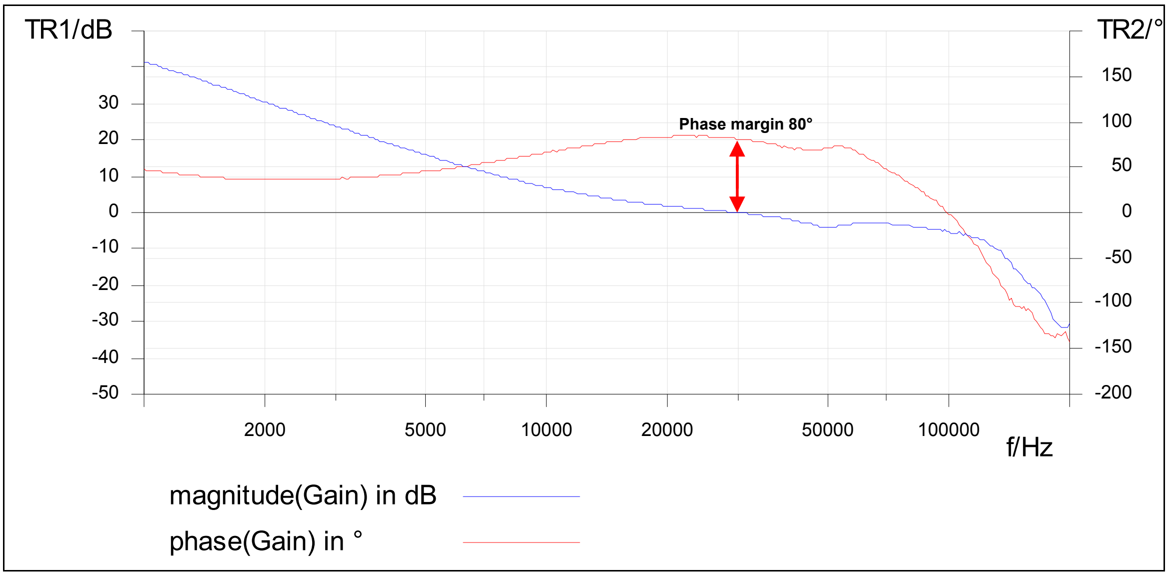


- After calibration the chart should show a flat magnitude (0dB) and phase (0°).
- Connect the probes and the injection transformer to your board as shown below:

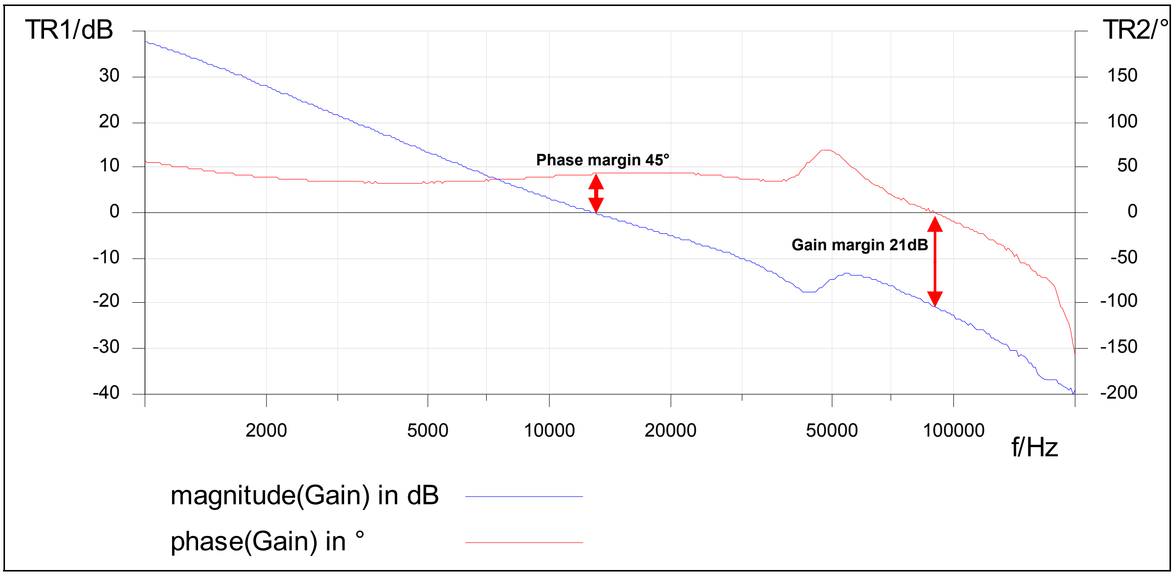


- For our measurements we have chosen a load current of 1A. This allows us to directly compare our results with charts in the LT Quick Start Guide for the demo circuit 481. To achieve this current we used a 3.3Ω resistor as load for the board (V_{out} = 3.3V). The measured curves can be directly compared with the extract from the Linear Quick Start Guide on the next page.

- Supply your demo circuit 481A with 12V and initiate the frequency sweep



- Change the supply voltage to 5.0V and perform a sweep again



Note: We injected our signal into a degenerative feedback loop and measure this signal at the output of the DC/DC converter. For a stable circuit it is required that the signal measured at the output of the DC/DC converter is not in phase with the injected signal. Therefore the phase margin and the amplitude margin are referenced towards 0°.

Note: To compare to measurements you can use the Data→Memory function as described in the user manual.

QUICK START GUIDE FOR DEMONSTRATION CIRCUIT 481
1.5A, 200KHZ STEP-DOWN CONVERTER WITH BURST MODE

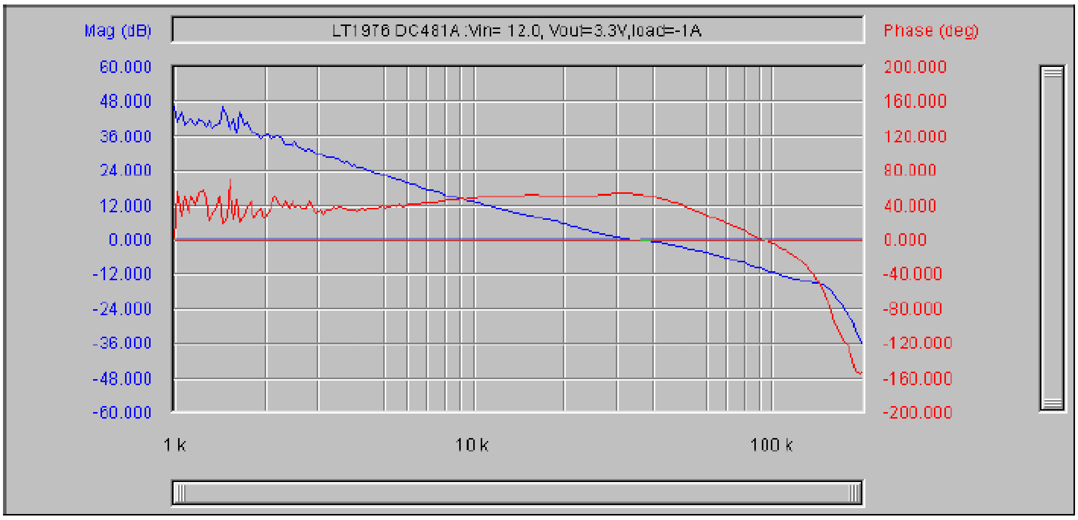


Figure 16. Bode Plot (Phase and Gain I_{OUT} = 1A, V_{IN} = 12V, T_A = 25°C, V_{OUT} = 3.3V)

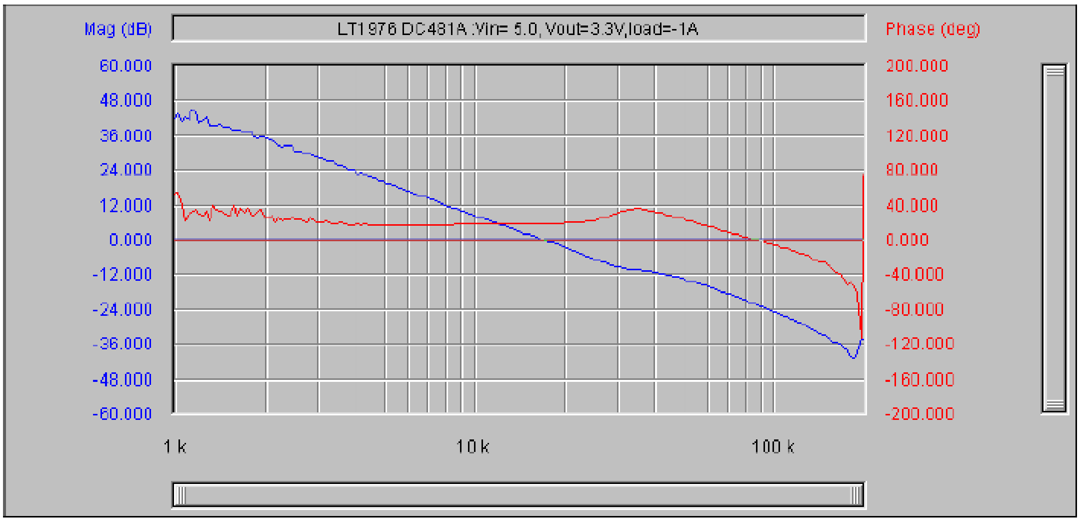


Figure 15. Bode Plot (Phase and Gain I_{OUT} = 1A, V_{IN} = 5V, T_A = 25°C, V_{OUT} = 3.3V)

12

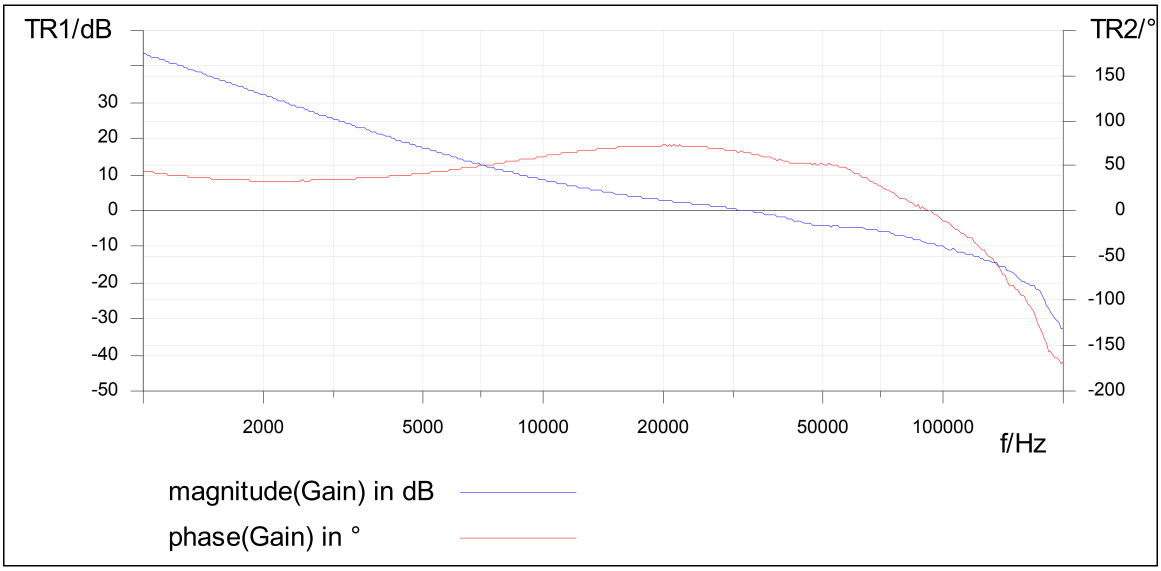
Result: The measurements received with Bode 100 match almost the results published by Linear Technologies in the Quick Start Guide for the selected Demonstration Circuit. In the second measurement you can see a higher rising of the phase and a deeper drop in gain at a frequency around 50 kHz. These deviations can result from different injection resistors R_X and different capacitive loads of the probes used for the different measurements. The increased noise in the results above may result from a wider receiver bandwidth.

The most important point is that the gain crossover frequencies match for both measurements.

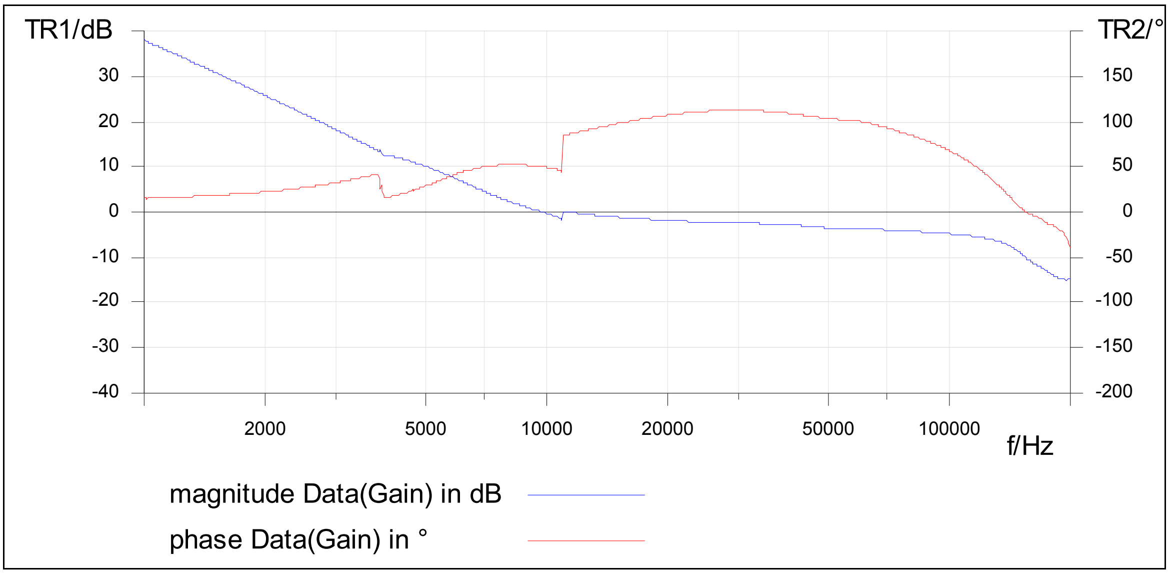
3.2.3 Influences of load changes on the stability

The following steps will illustrate the influences of different load currents on the control circuit. To perform these measurements we used a constant supply voltage of 10V.

- For the first measurement we used a load resistor of 5.1Ω (=0.647A), the measurement itself was performed with the settings and as described in 3.2.2

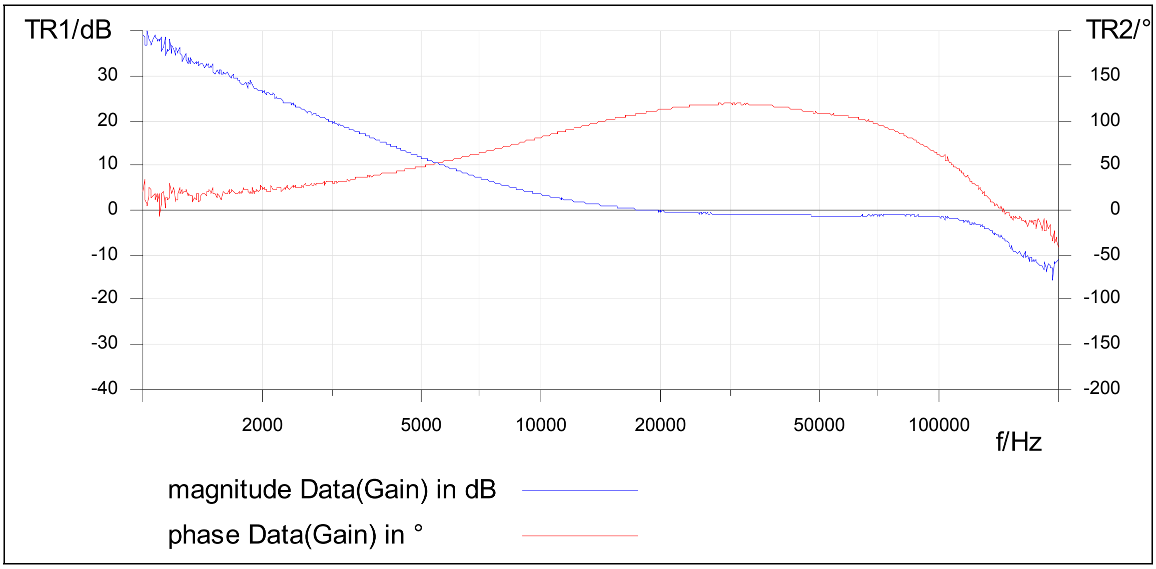


- The next measurement was done with a load resistor of 43Ω (=76.7mA). As a result we received a curve showing a non-linearity between 3.5 kHz and 11 kHz.



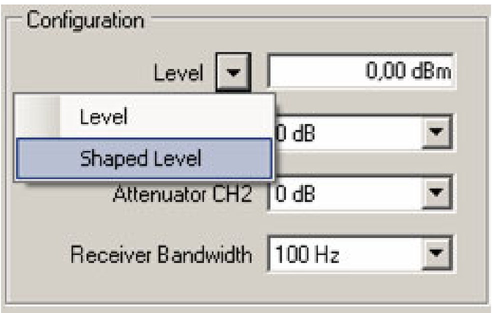
Result: This is caused due to slew rate distortions. These distortions can be also visualized measuring the V_{out} of the power supply unit using an oscilloscope.

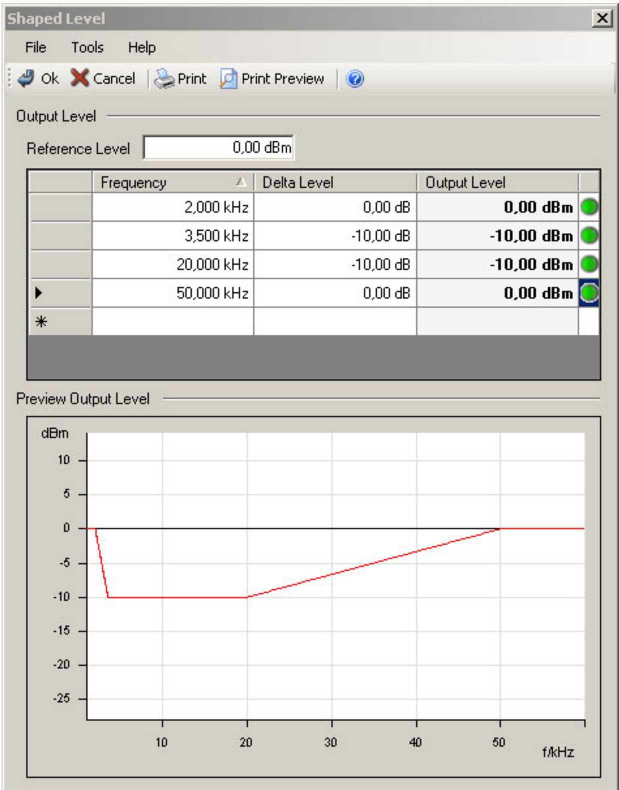
- By reducing Bode's output signal to -10dBm this non-linearity can be avoided.



Result: The circuit is back in its linear operation mode. But the reduced output signal level results in an increased noise at the lower and upper end of the frequency range. The noise is a result of the decreased output level in combination with the band-pass like behavior of the terminated injection transformer.

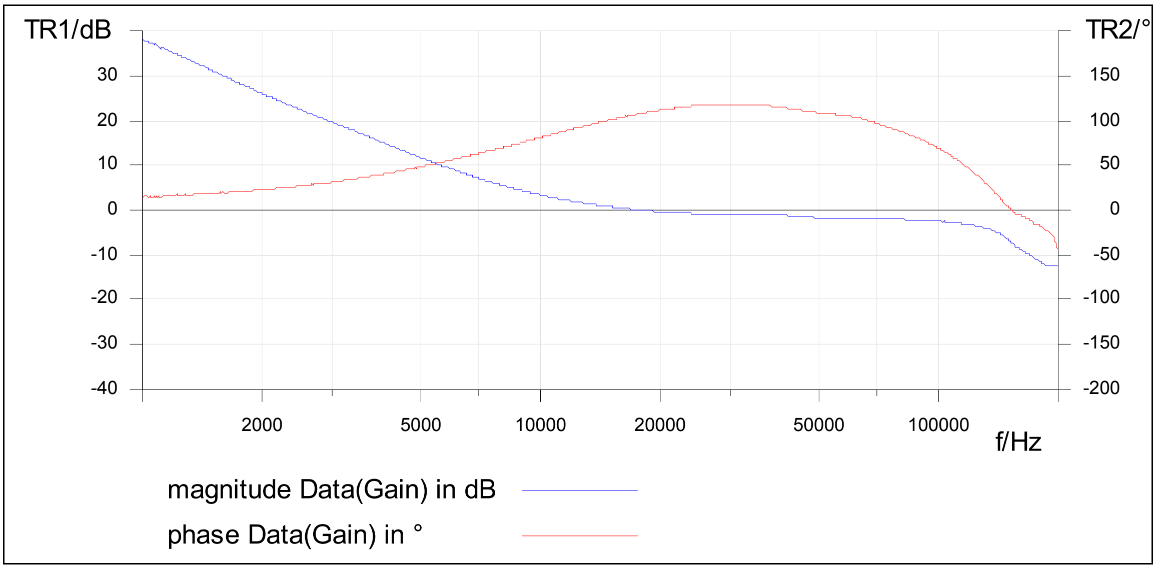
To avoid this noise as well as the non linearity you can use the shaped level function of Bode 100. This function allows you to selectively reduce the output level of Bode 100 for the critical frequency range (3.5 kHz – 11 kHz), while keeping the level high for the rest of the sweep.





Note: Detailed information on the shaped function can be found in chapter 5.

- After having adjusted the level shape you can restart your measurement again:



Result: Due to the higher output level at low and high frequencies the noise in the curve is eliminated while the level reduction in the critical area (3.5 kHz – 11 kHz) removes the non-linearity.

4 Conclusion

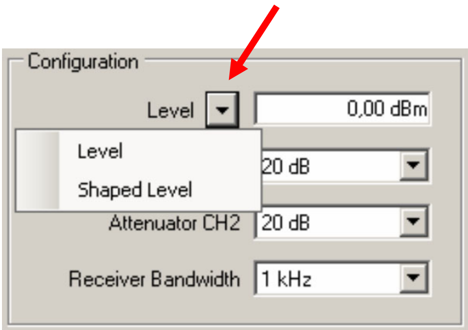
Bode 100 can be easily used to measure the gain margin and phase margin which are indicators for the stability of a control loop. Furthermore, the influence of supply voltage and load current changes can be visualized, which provides precious information on the behavior of a DC/DC converter in real life operation.

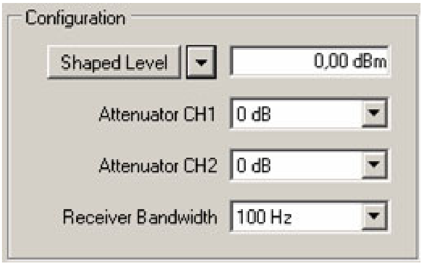
In addition we demonstrated how non-linearity can be overcome by using Bode 100's level shape function.

5 Annex:

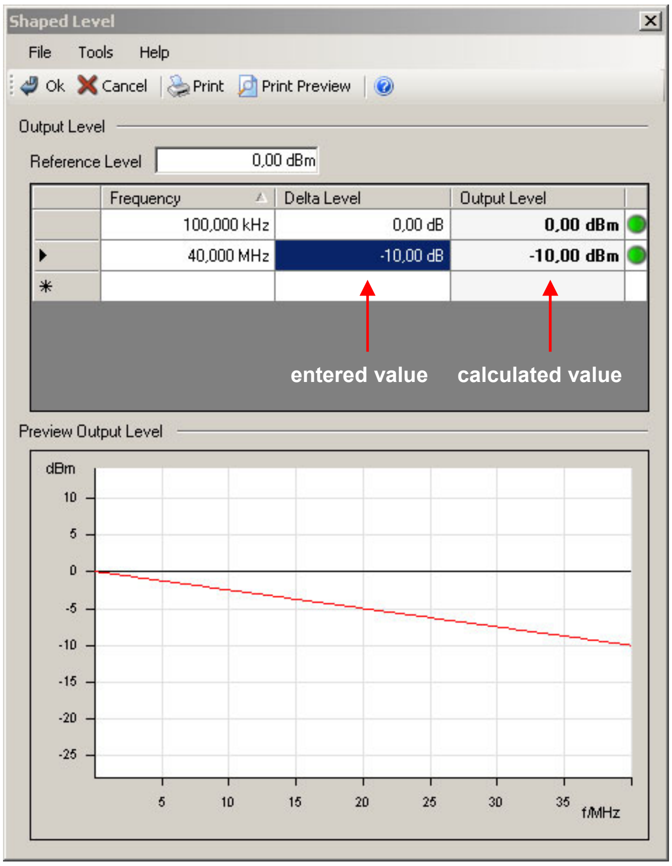
The Shaped Level Function allows varying the Bode 100's output level throughout its frequency range.

To activate this functionality change from the "Level" to the "Shaped Level" mode by pushing the button beside the word "Level " as shown in the picture below.

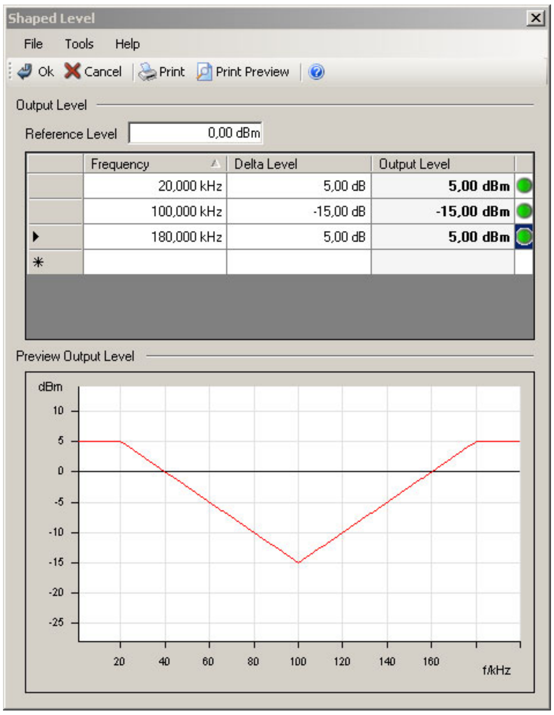




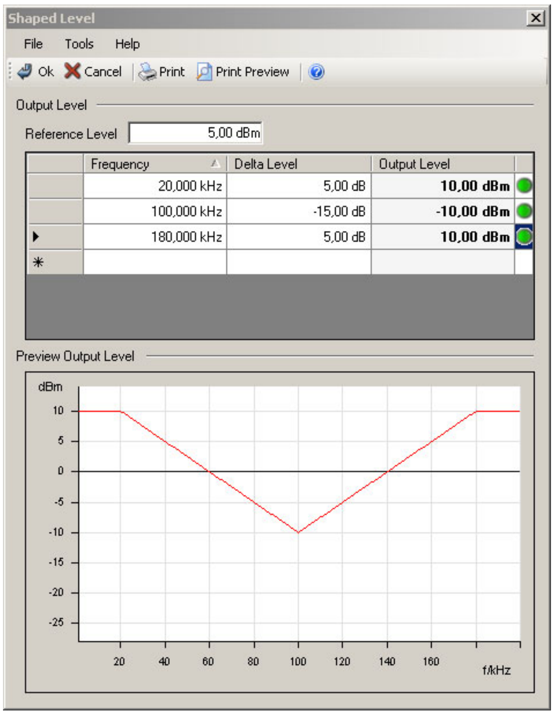
By clicking the shaped level button you can open the Shaped Level window which allows predefining Bode 100's output level at various frequencies.
Just enter the delta level for a defined frequency point and Bode 100 will calculate the output level for the respective frequency (Output Level = Reference Level + Delta Level)



The example below shows a level curve defined by entering delta levels at three different frequencies. By changing the reference level the entire level curve can be shifted up or down.

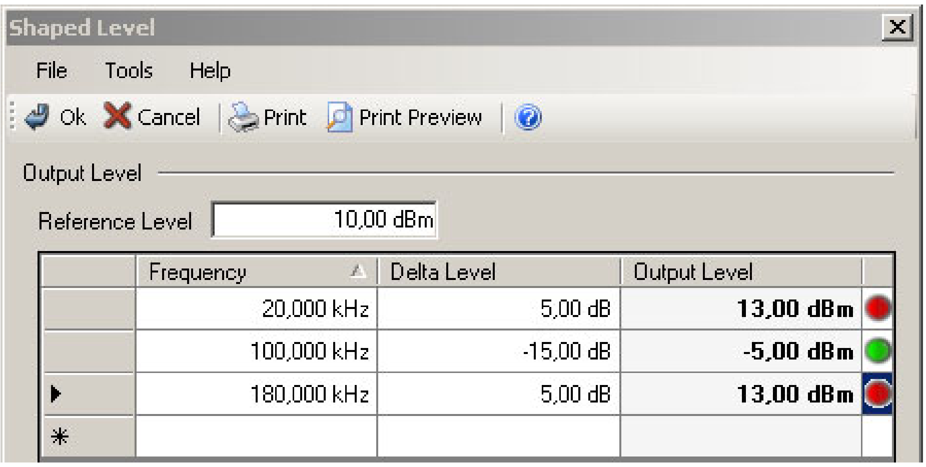


original curve (ref. level: 0dBm)



changed curve (ref. level: 5dBm)

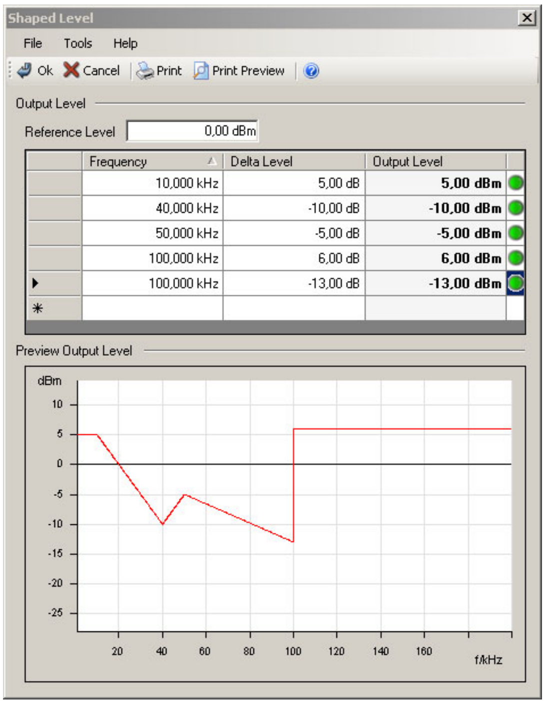
The green indicators beside the output level reading confirm that Bode 100 is able to generate the required output level (Bode 100's output level range is -27dBm to 13 dBm).



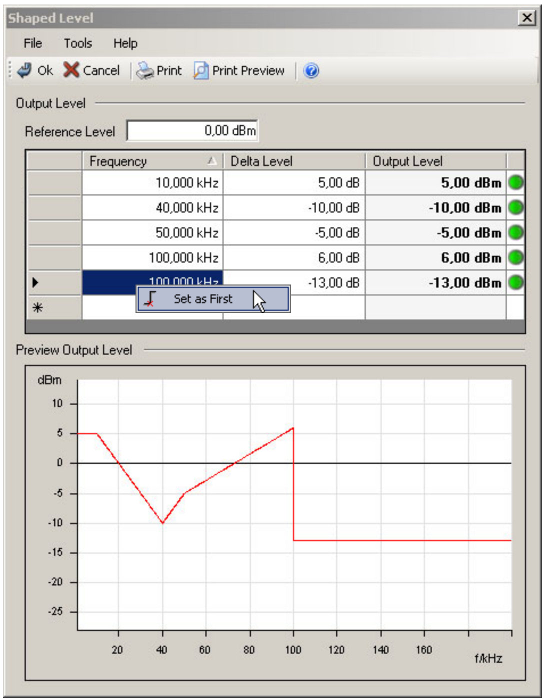
If an entered delta level results in an output level outside Bode 100's source level range the output level is limited accordingly. In addition a red indicator is displayed.

It is possible to program very steep slopes by entering two delta level values for one frequency point. By adjusting the order of theses entries it is possible to select if the slope shows a rising or falling edge.

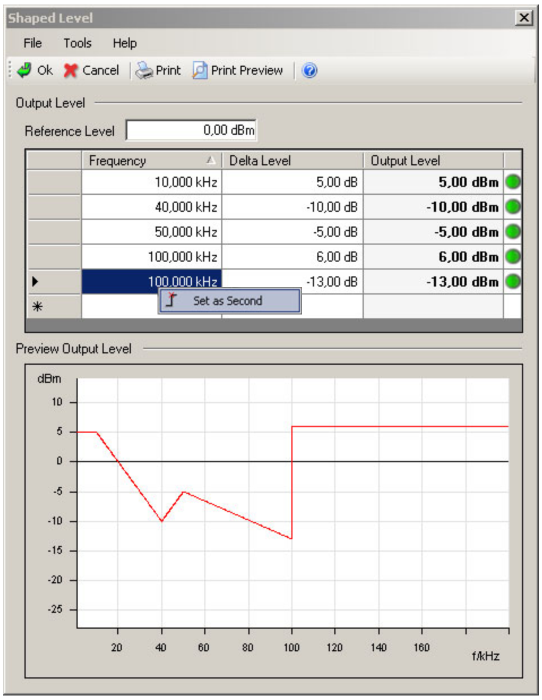
The order of the delta levels at one frequency point can be adjusted by right mouse click on the respective frequency cell.



original curve



changed curve



reset curve