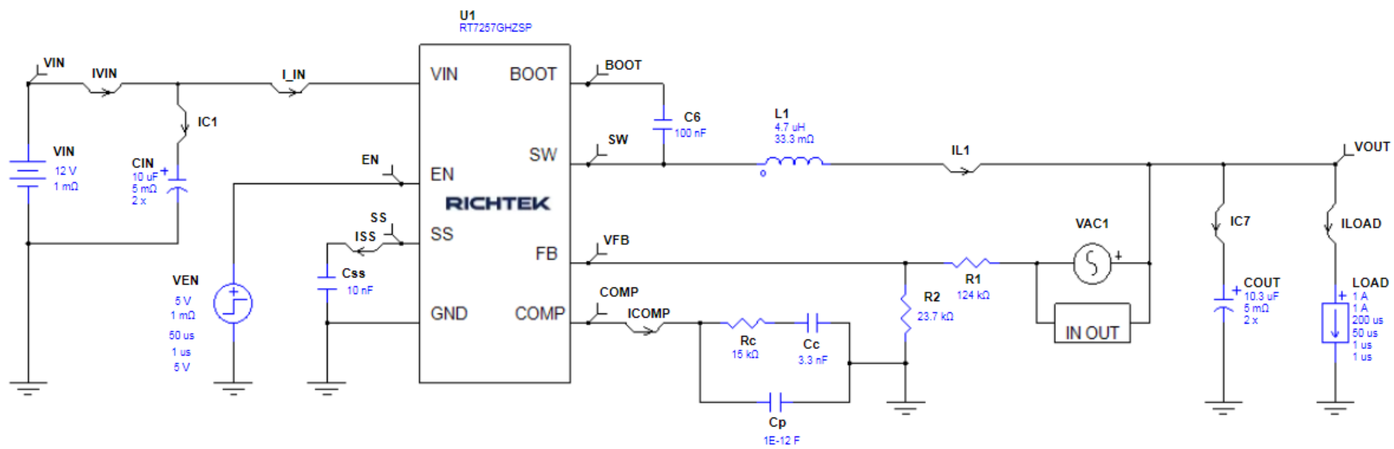
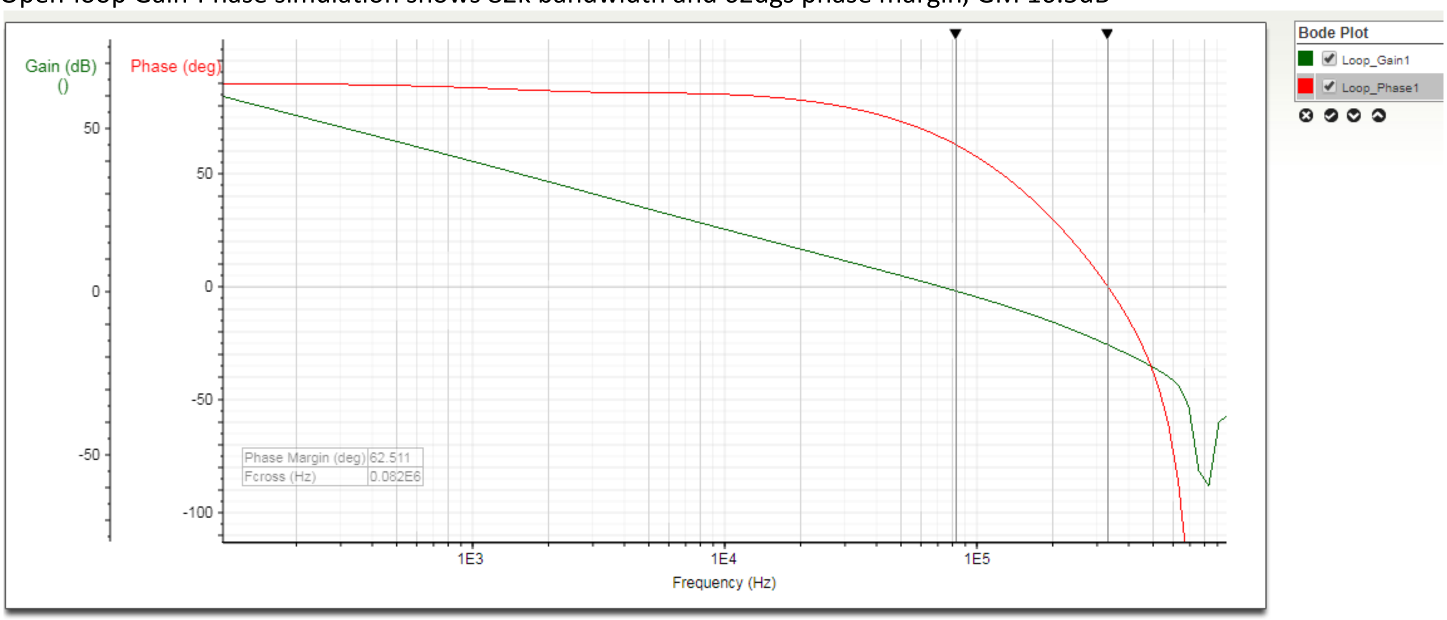
Roland van Roy Feb 7 2018

RT7257GH 800kHz current mode buck in 12V to 5V application. Reference is the DIY buck converter prototype as described in https://www.youtube.com/watch?v=l9CWE6rGXG8.

Richtek Designer simulation:



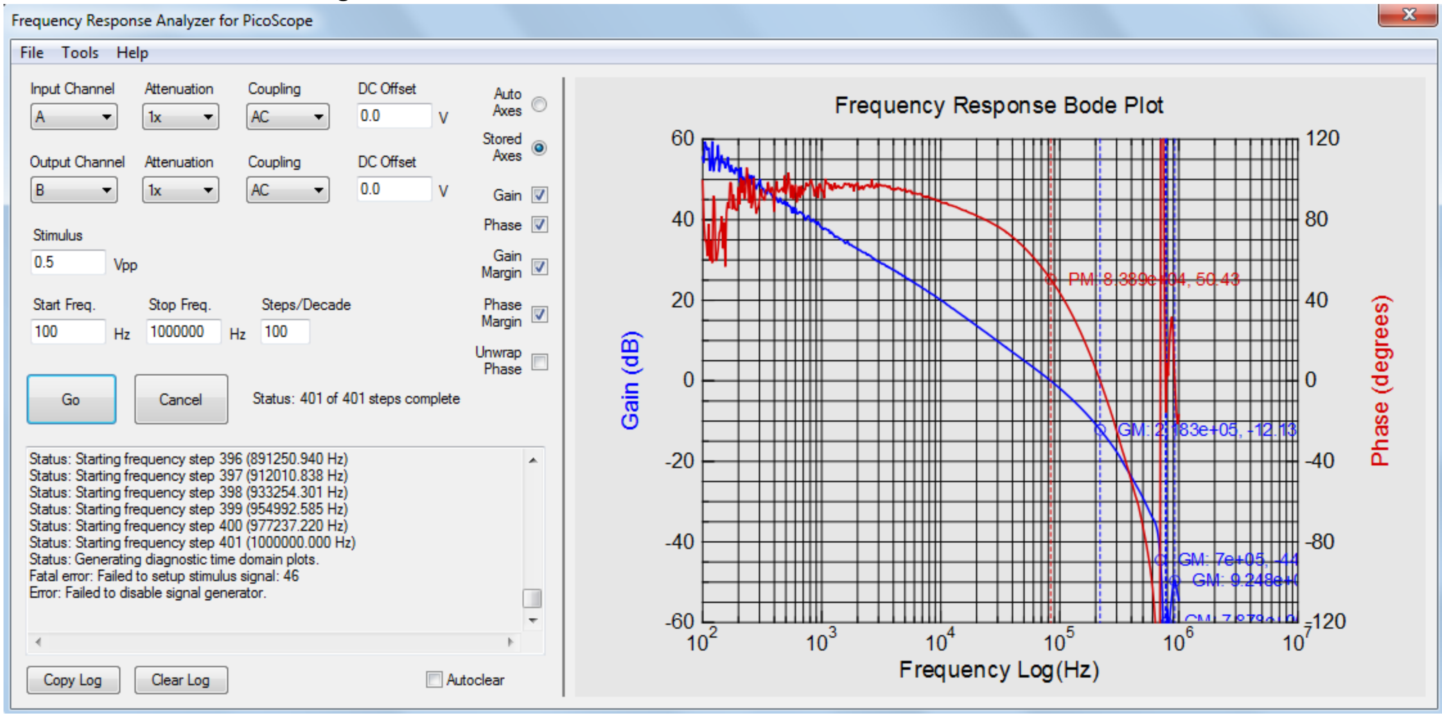
I lowered the Rc compensation value to match the lower output capacitance due to MLCC DC bias capacitance drop
Open-loop Gain-Phase simulation shows 82k bandwidth and 62dgs phase margin, GM 16.5dB

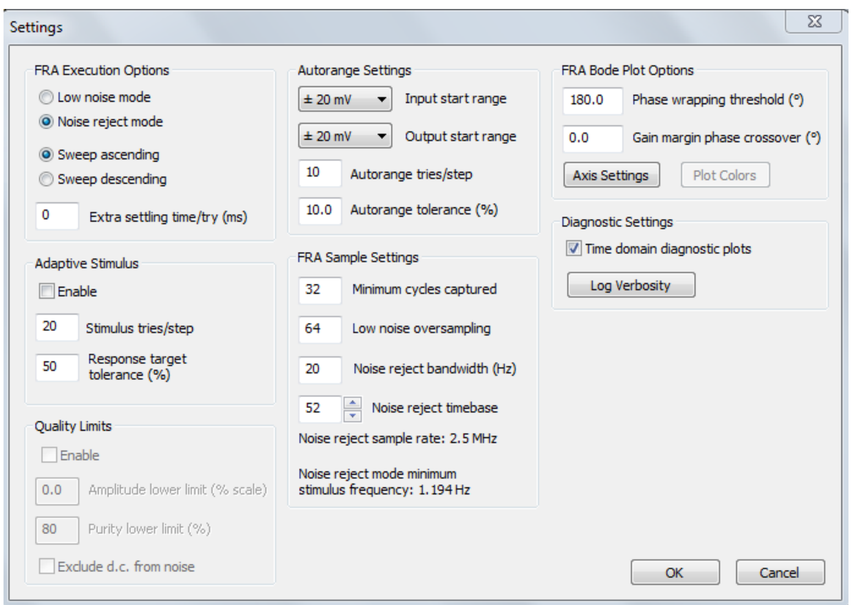


	F1	F2	ΔF
	0.082E6	0.329E6	0.247E6
Loop_Gain1	0.021	-16.49	-16.511
Loop_Phase1	62.567	-0.122	-62.689

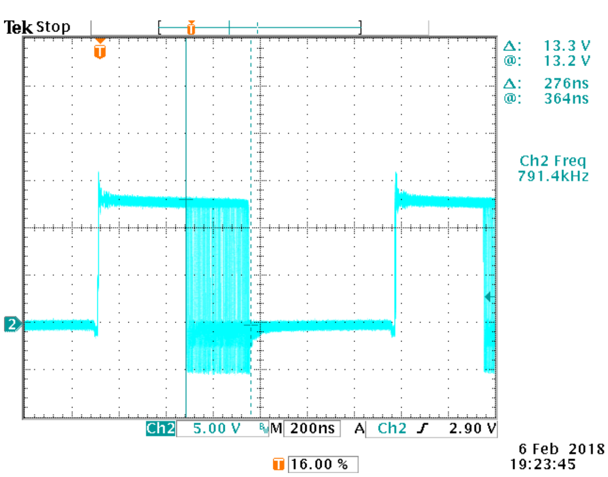
(Note: we know that the simulation results show a bit better PM than the actual IC)

Measured with Pico scope 2208B and FRA 0.6.1b
FRA shows 83kHz BW, 50.4dgs PM and -12dB GM





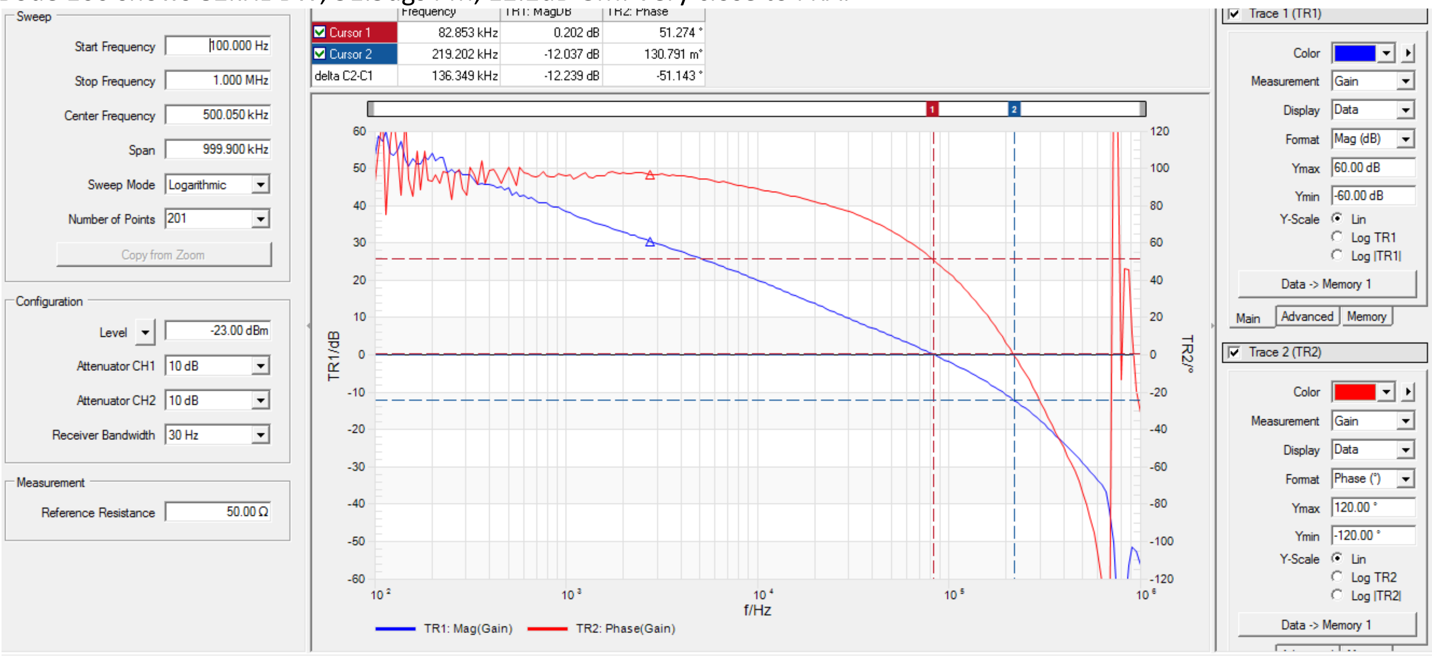
Transformer termination: 51Ω,
2208B generator source impedance is 600Ω
Stimulus amplitude at 0.5Vpp setting: 39mVpp
Fixed over the full measuring frequency range



Maximum converter duty-cycle swing at 0dB area ~ 21% worst case
Converter stays in linear range over the full measurement.

Open loop Gain phase measurement with Bode-100

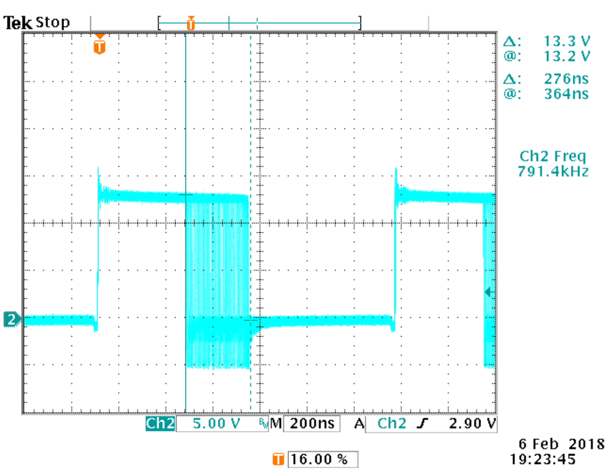
Bode 100 shows 82kHz BW, 51.5dgs PM, 12.2dB GM. Very close to FRA.



Measured with normal fixed stimulus amplitude:

1:1 transformer termination = 51Ω , source impedance 50Ω

Fixed level -23dBm: stimulus = 42mVpp over the full measuring frequency range

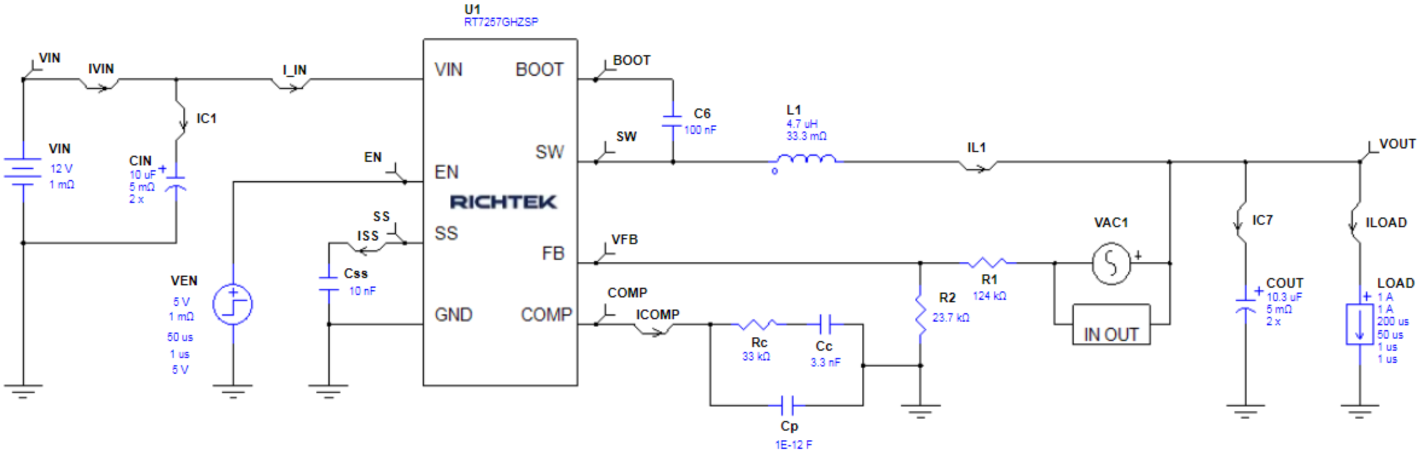


Maximum converter duty-cycle swing at 0dB area ~ 21% worst case around 100kHz stimulus frequency.
Converter stays in linear range over the full measurement.

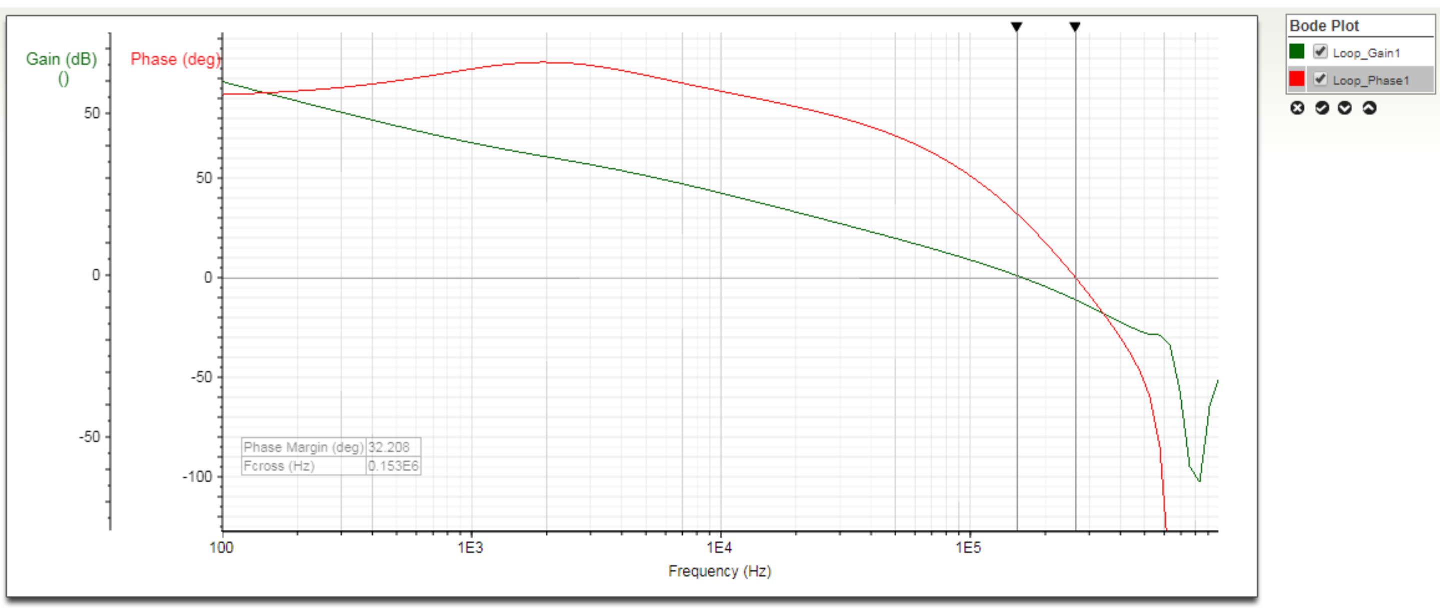
Basically the fixed 42mVpp stimulus over entire frequency range can be used here: some noise at low frequency due to high gain, but it is not very important for this measurement.

If different stimulus at different frequencies are used, select higher stimulus for frequencies below ~10kHz. The converter LC filter resonance is 1/(2πSQRT(4.7uH*20.6uF)) = 16.1kHz, above this frequency lower stimulus is needed to keep duty-cycle swing within linear region.

Check the converter in unstable condition:
Increased Rc from 15k to 33k (value belonging to 2x22uF output capacitance): converter bandwidth will increase, PM will drop.



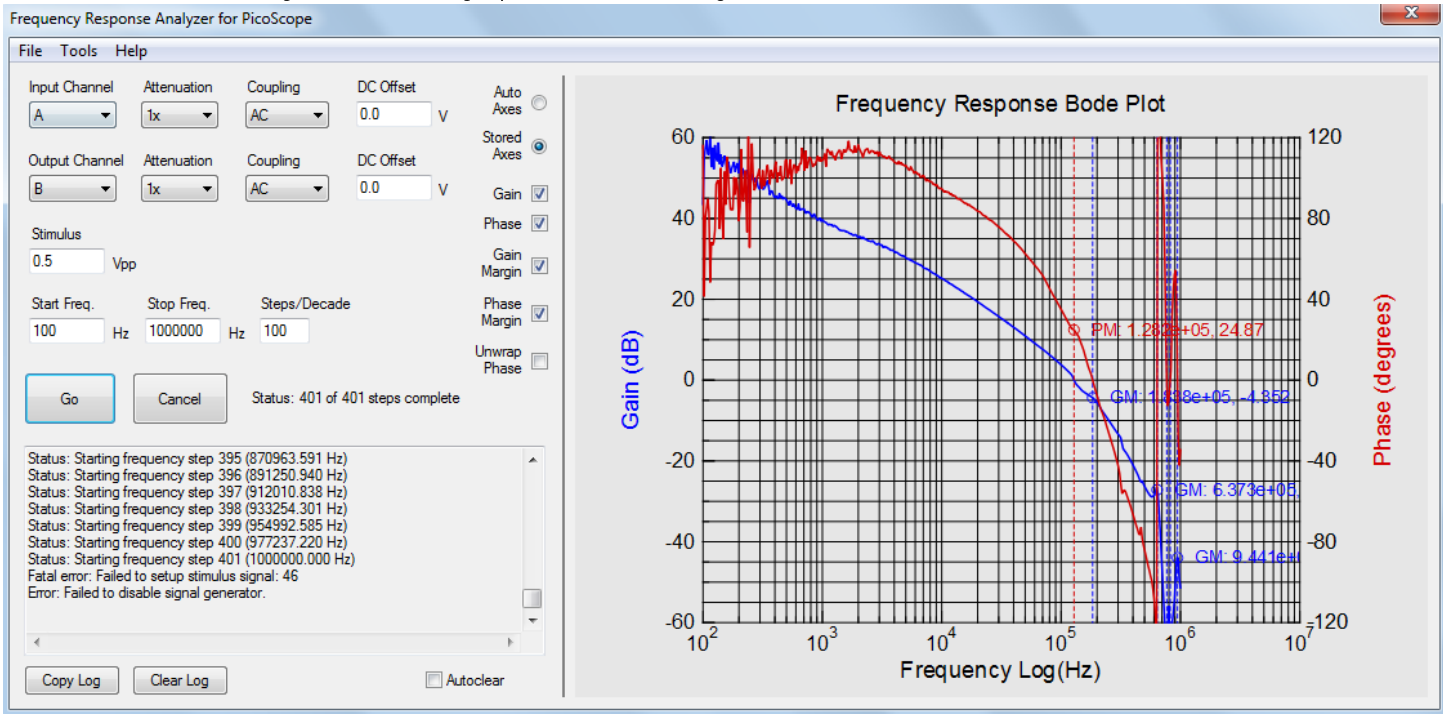
Now Gain-Phase shows 153kHz bandwidth and 32dgs phase margin from simulation



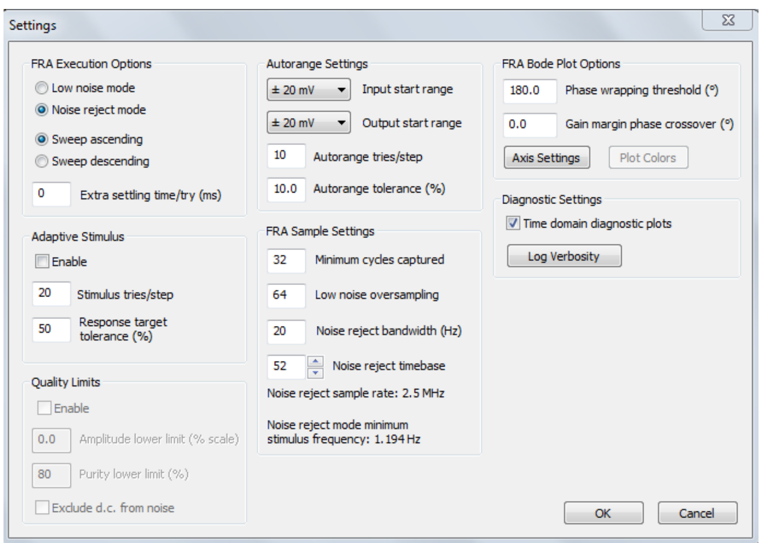
	F1	F2	ΔF
	0.153E6	0.263E6	0.11E6
Loop_Gain1	-0.072	-7.546	-7.475
Loop_Phase1	31.909	-0.026	-31.934

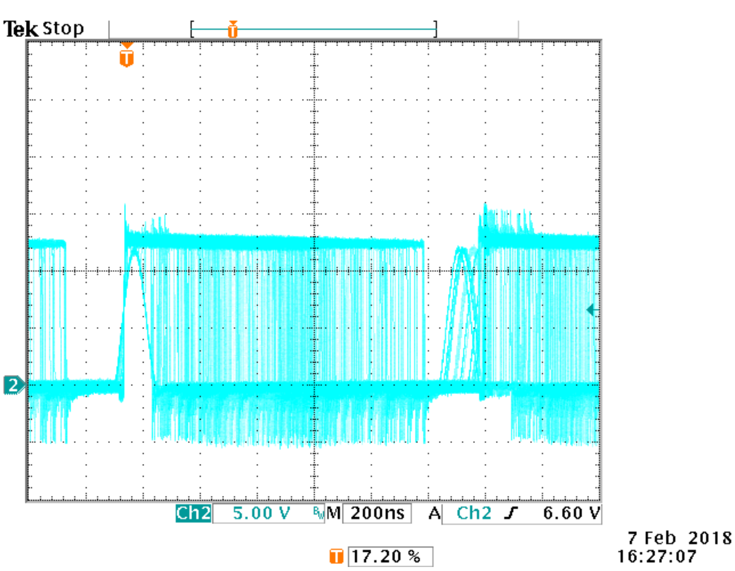
Same application now using FRA :

BW=128kHz, PM=24.9dgs, GM=4.3dB; graph also shows irregularities at 0dB area.



Transformer termination: 51Ω,
2208B generator source impedance is 600Ω
Stimulus amplitude at 0.5Vpp setting: 39mVpp
Fixed stimulus over the full measuring frequency range



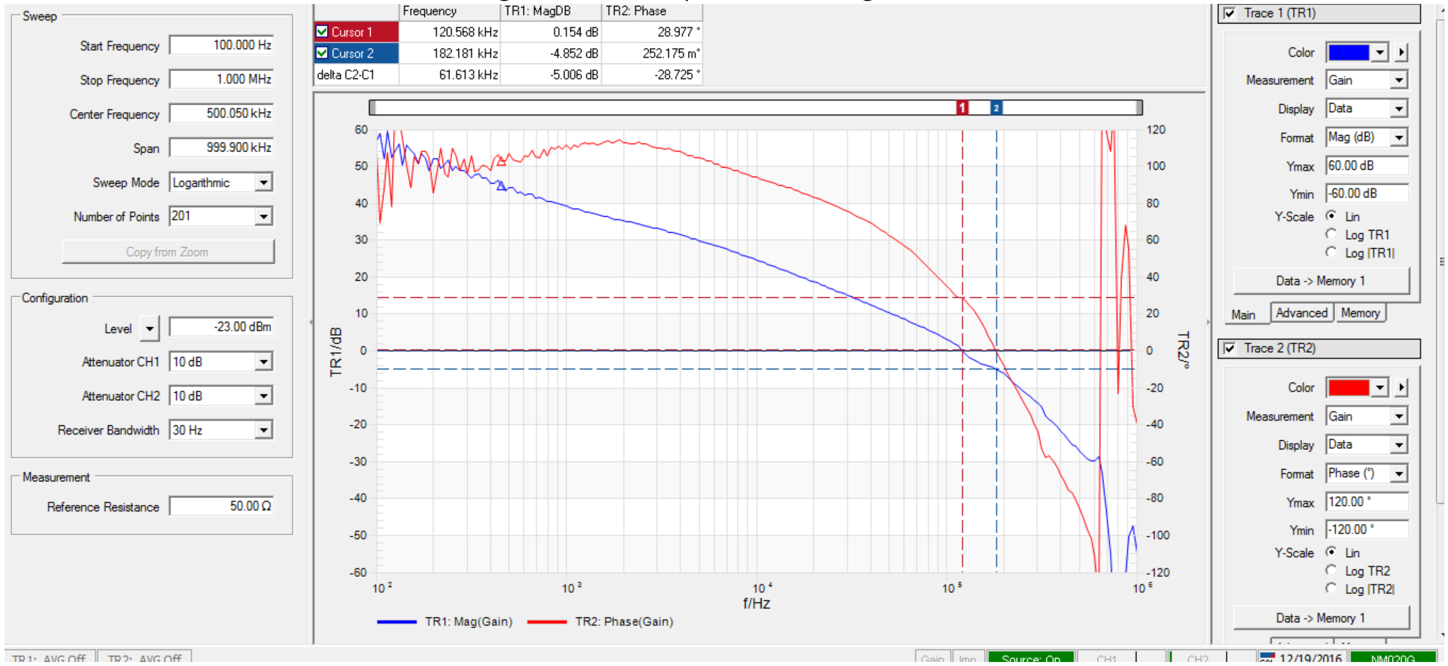


Switching signal shows severe duty-cycle overdriving, including discontinuous mode ring.
This happens near the loop gain zero dB crossing.

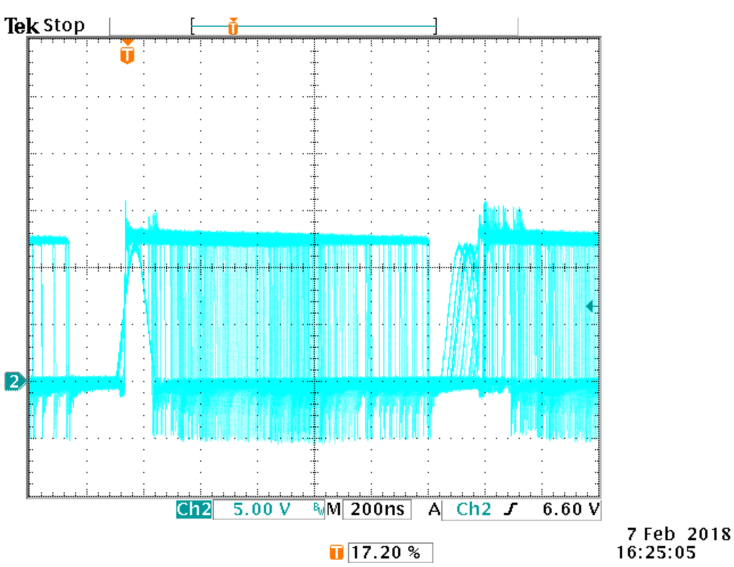
Stimulus needs to be reduced at the 100k ~ 300kHz range

Measure unstable converter with Bode-100

Bode-100 shows BW=120.5kHz, PM = 29dgs, GM = 4.8dB plot shows irregularities, same as FRA



Measured with normal fixed stimulus amplitude:
1:1 transformer termination = 51Ω , source impedance 50Ω
Fixed level -23dBm: stimulus = 42mVpp over the full measuring frequency range

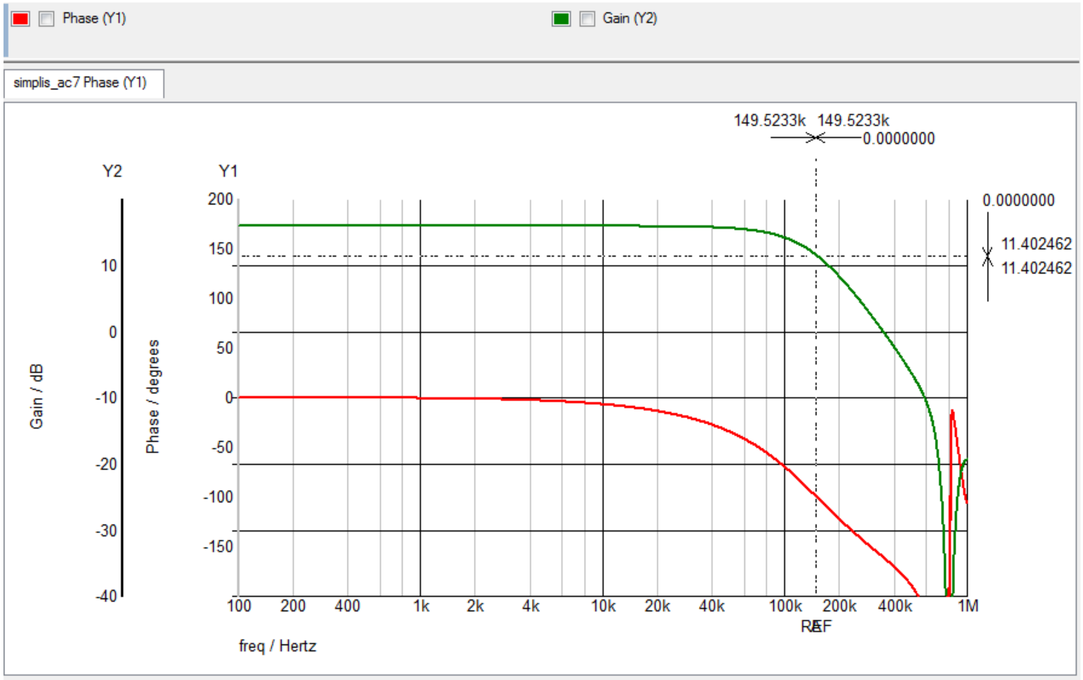


Same as FRA:
Switching signal shows severe duty-cycle overdriving, including discontinuous mode ring.
This happens near the loop gain zero dB crossing.

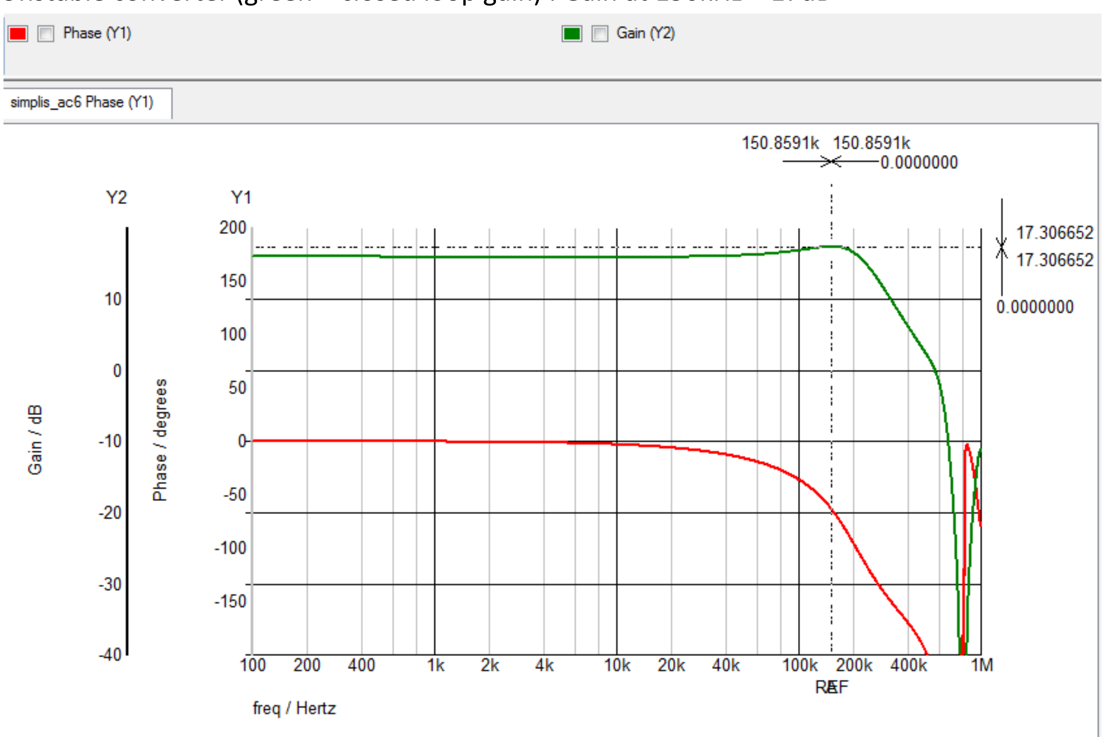
The reason for the high duty-cycle swing around the cross-over frequency for marginally stable converters:

When looking at the ***closed loop response*** (i.e. modulating the reference with a stimulus) in simulation:

Stable converter (green = closed loop gain) : Gain at 150kHz = 11dB



Unstable converter (green = closed loop gain) : Gain at 150kHz = 17dB

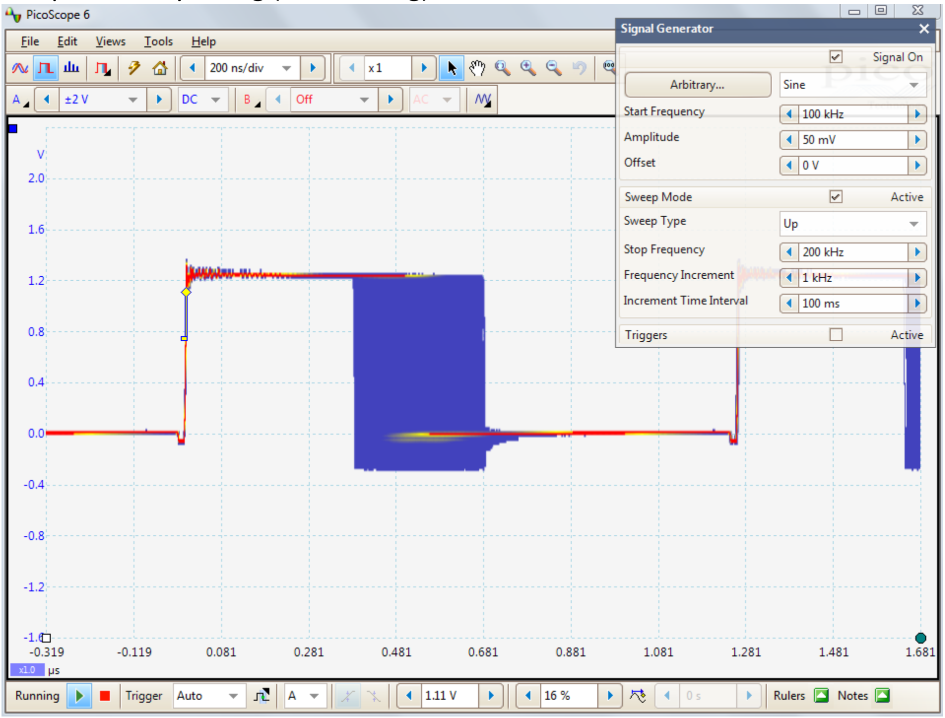


The unstable converter has lower damping, resulting in gain boost (peaking) around the crossover frequency.

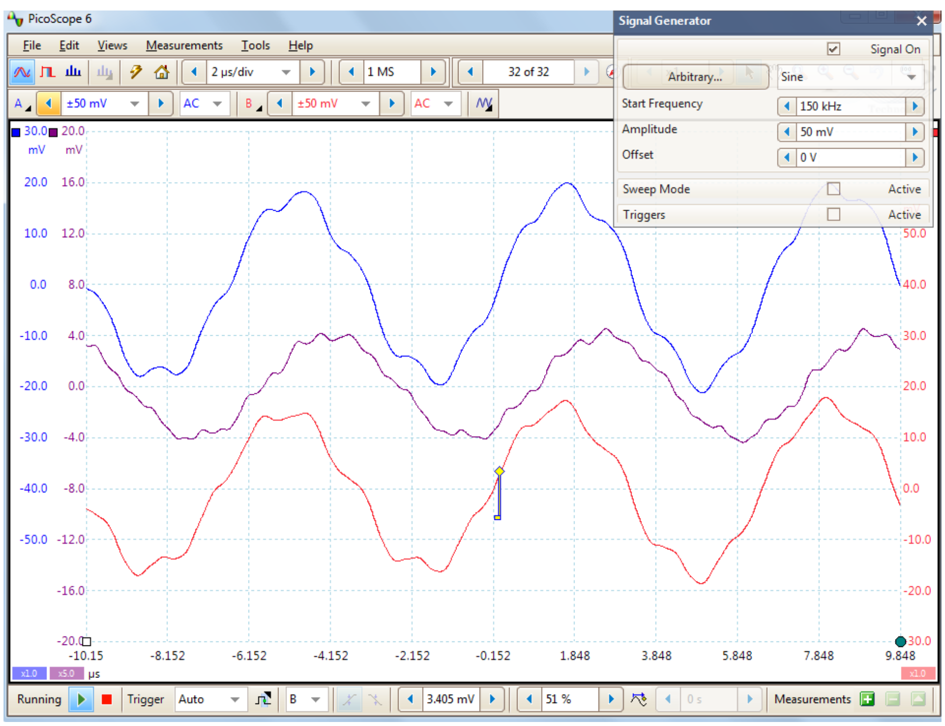
With the fixed stimulus, the duty-cycle needs to vary much more at crossover frequency range to achieve the increased amplitude at crossover and thus will easily saturate.

Unstable converters need much reduced stimulus around the crossover frequency!

Use Pico Scope to check max stimulus: Measure switching signal and sweep frequency and adjust stimulus for acceptable duty-swing (~20% swing)

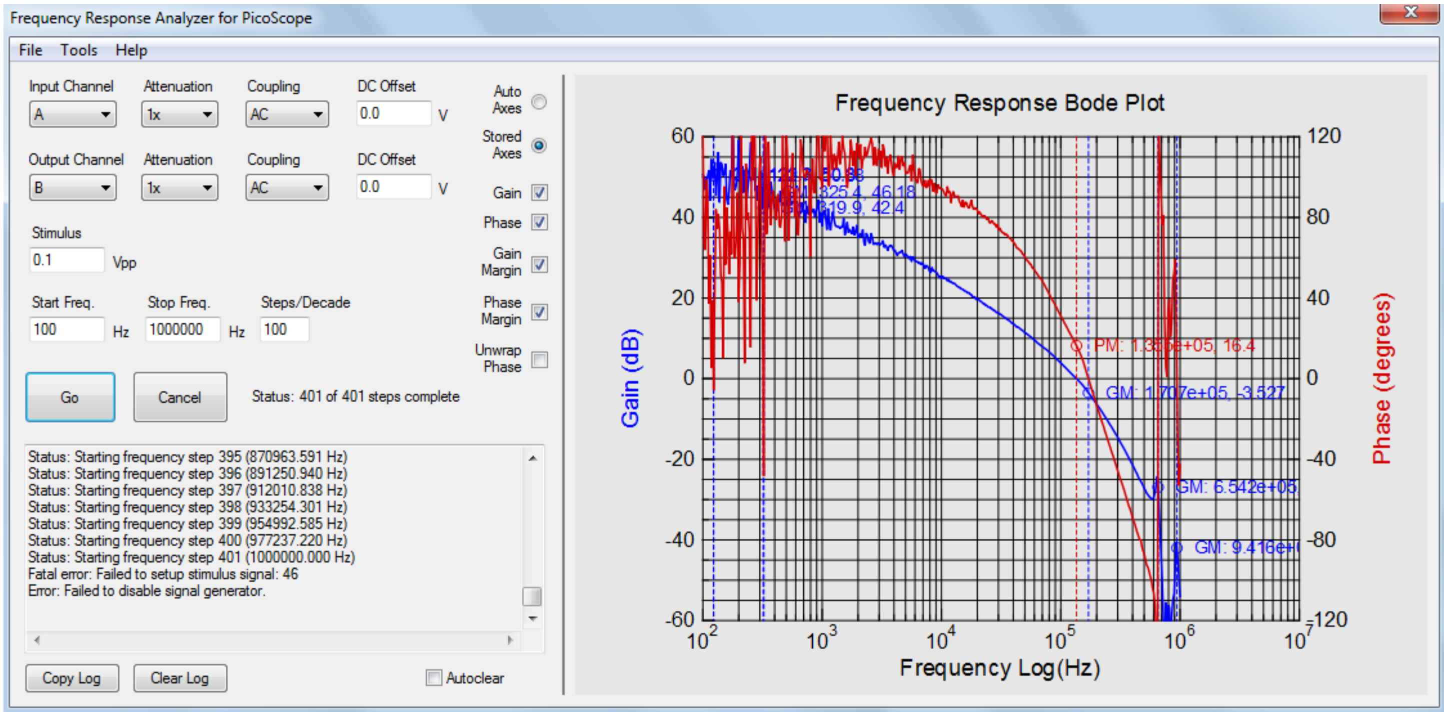


Max duty-swing was found around 150kHz. Measurement shows loop input and output and input-output (=stimulus)

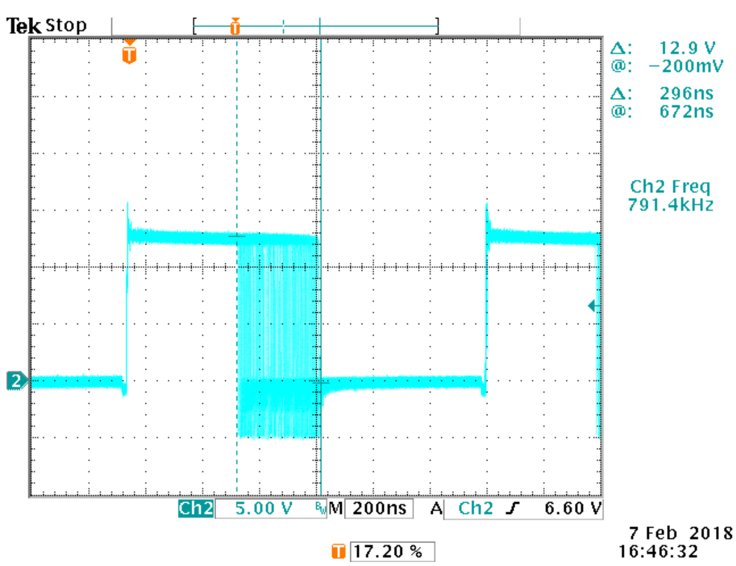


Re-measure unstable converter with 0.1Vpp setting: (note generator amplitude in scope mode = Vp, FRA uses Vpp)

BW = 135kHz, PM = 16.4dgs, GM=3.5dB smooth response at cross-over area. But noisy at low frequency due to low stimulus.



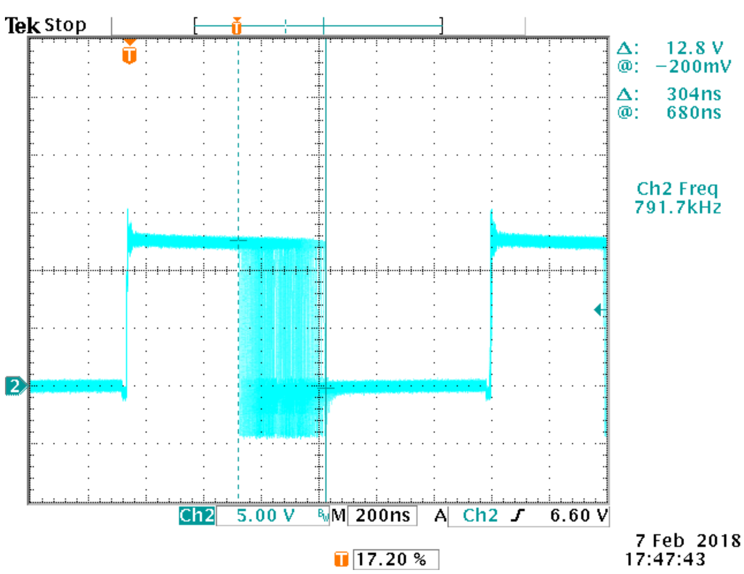
Transformer termination: 51Ω,
2208B generator source impedance is 600Ω
Stimulus amplitude at 0.1Vpp setting: 7.8mVpp
Fixed stimulus over the full measuring frequency range



Maximum converter duty-cycle swing at 0dB area ~ 22% worst case. Converter stays in linear range over the full measurement.

Re-measure unstable converter with Bode-100: due to 50Ω generator impedance, the generator minimum setting is too high to get ~8mVpp stimulus: -27dBm in 51Ω transformer termination gives 28mVpp. Choose 10Ω transformer termination to get 9.4mVpp stimulus at -27dBm.

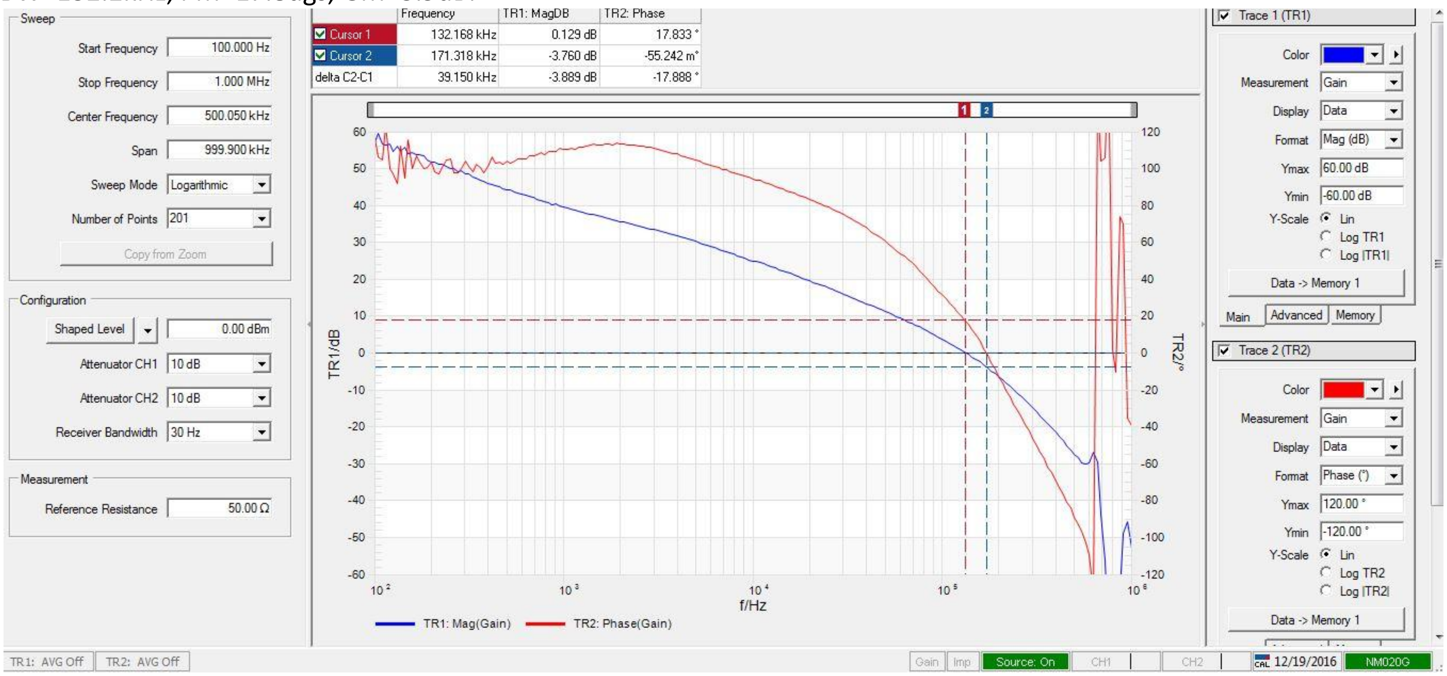
Fixed stimulus measurement: BW=133.7kHz, PM=17.2dgs, GM=3.7dB. Close to FRA!

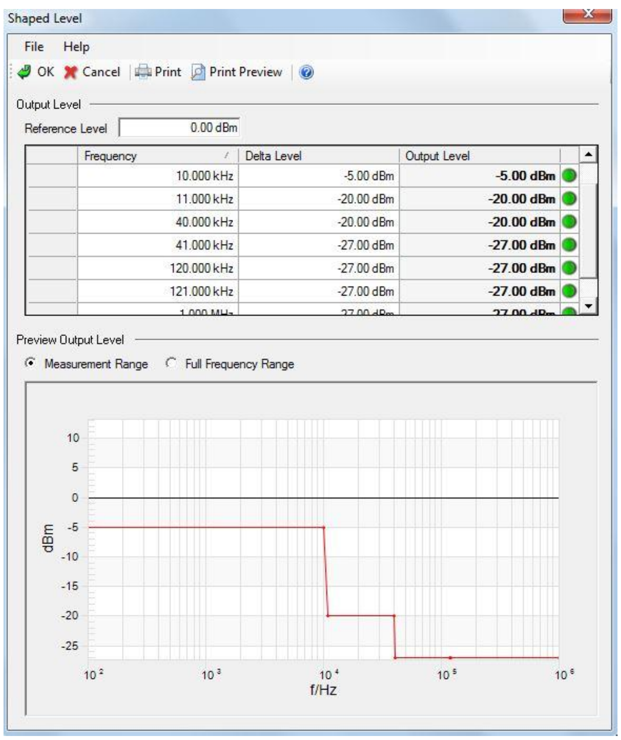


Maximum converter duty-cycle swing at 0dB area ~ 23% worst case. Converter stays in linear range over the full measurement.

For better S/N at low frequency, use Bode-100 with different stimulus at different frequency (shaped level)

BW=132.2kHz, PM=17.8dgs, GM=3.9dB.





Shaped stimulus amplitude:

1:1 transformer termination = 10Ω

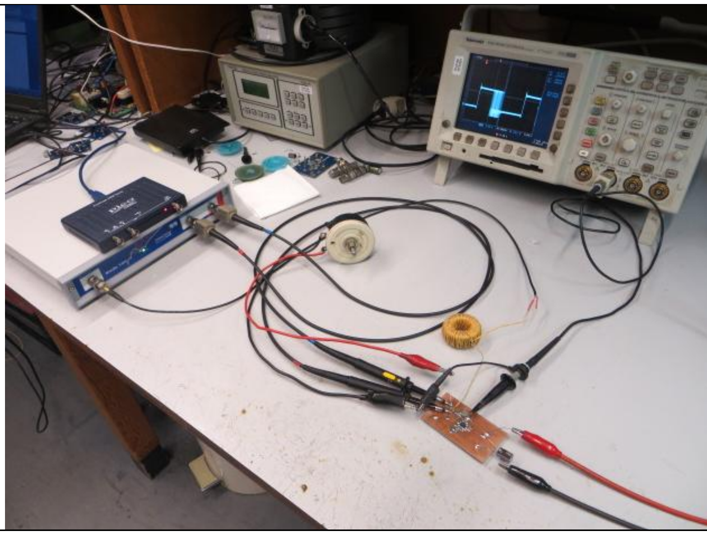
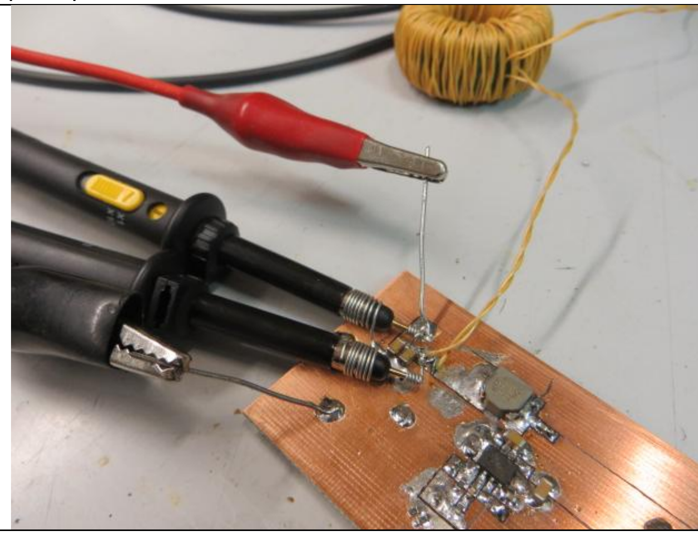
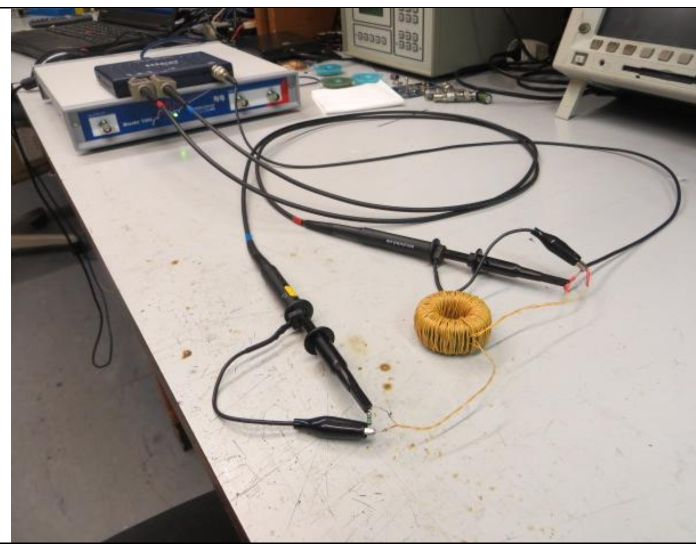
-5dBm: stimulus = 118mVpp

-20dBm: stimulus = 21mVpp

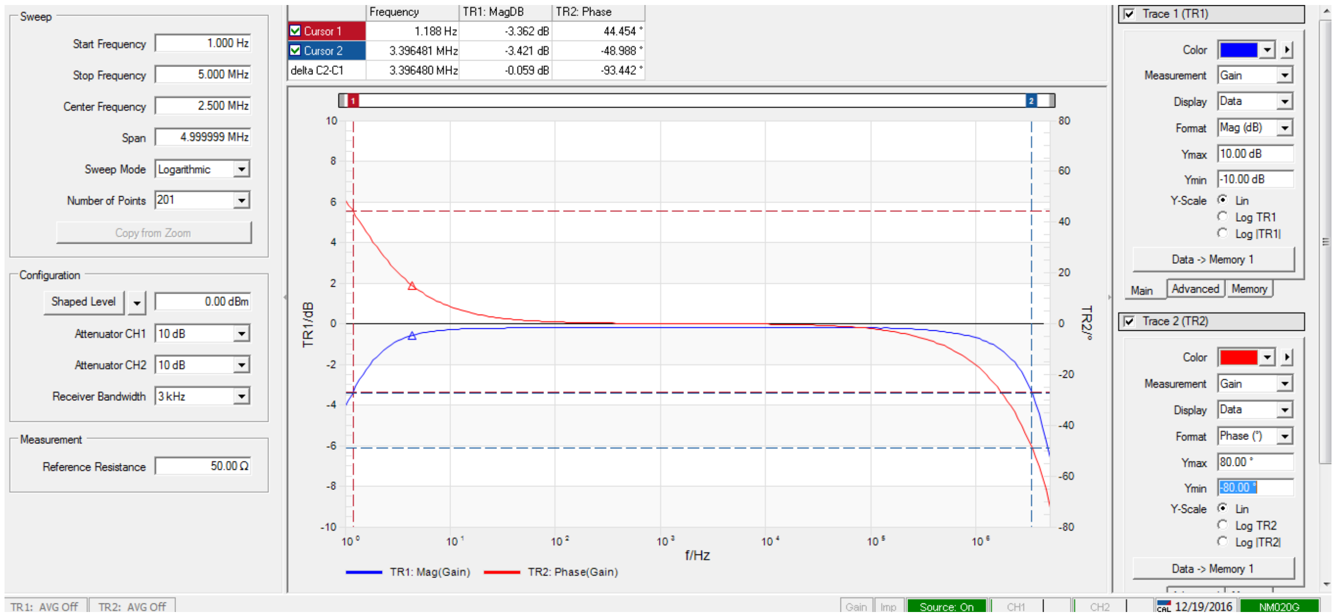
-27dBm: stimulus = 9.4mVpp

Above adjustable stimulus at different frequencies is a very important feature when doing gain-phase measurements on SMPS.!

Measurement pictures:

Gain-phase measurement setup with Bode-100, PicoScope 2208B and an extra scope for switch waveform checking.	Measure with very short probe loops, close to output capacitors. use shielded buck inductor for less noise pickup.
	
DIY insertion transformer: 70 turns twisted wire on 40mm diameter green toriod core (from common mode filter)	Measurement of insertion transformer transfer.
	

DIY 1:1 insertion transformer measurement: transfer plot with 51Ω termination: -3dB 1.2Hz - 3.3MHz with Bode 100.



Same results using FRA