plug & play instruments
oscilloscopes

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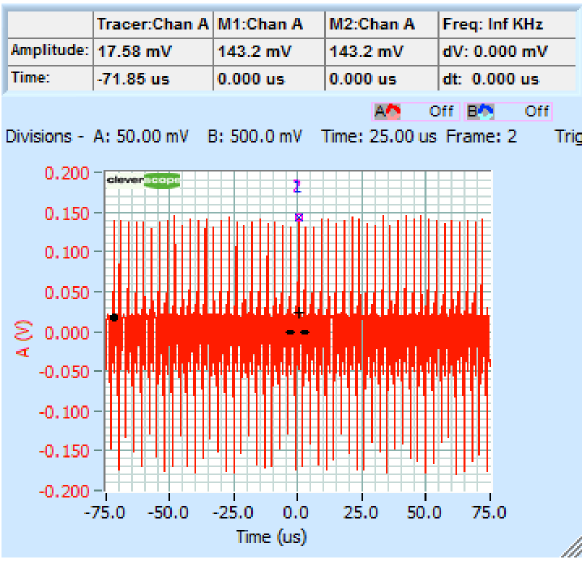
FRA response to TI TPS55340 evm

Summary

A Cleverscope CS328A was used with a Jensen VB-1BB video isolation transformer to check the gain/phase response of a TI TPS55340EVM-148. The Cleverscope application was modified to provide easier setup of the FRA functions. The version number is 4.672, and is available as an update on the cleverscope.com website. An instructional step by step video is also on the website.

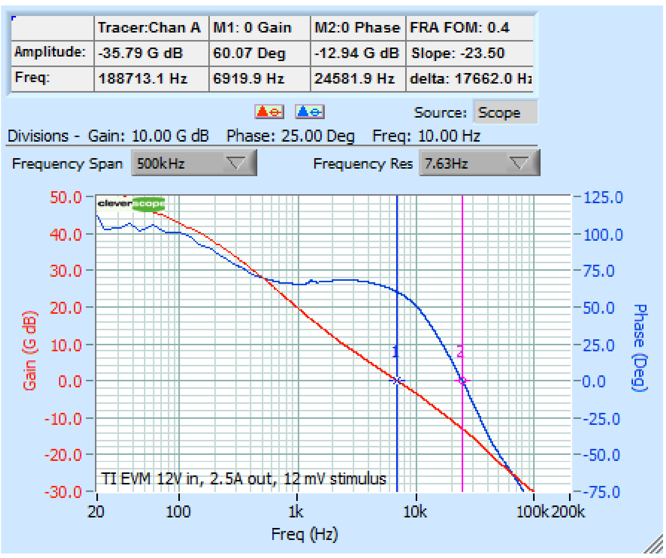
The Problem



You've designed a power supply, and it's on your board. You have many varying loads - an FPGA, analog and digital interfaces - How do you know it's stable?

Turn on an unexpected load, and you might get slow response, or even oscillation that causes the power supply voltage to go out of spec. The normal solution is to make a transient response measurement, but this could damage your system if you get it wrong. An alternate way is to inject a small signal (so as not to perturb the power supply out of its normal operating range) into the power supply feedback loop, vary it's frequency, and measure gain/phase around the loop. **But** all you see is switching noise (such as that shown to the left for the TPS55340).. You can't see what the heck is going on.

The Solution



Use a Cleverscope! Inject 10 mV into the feedback loop (for minimum perturbation), and use the synchronous gain/phase plot to check gain and phase margin. Do it on your actual board. Check out a video at htttp://youtu.be/8fQpHgL5L9Q.

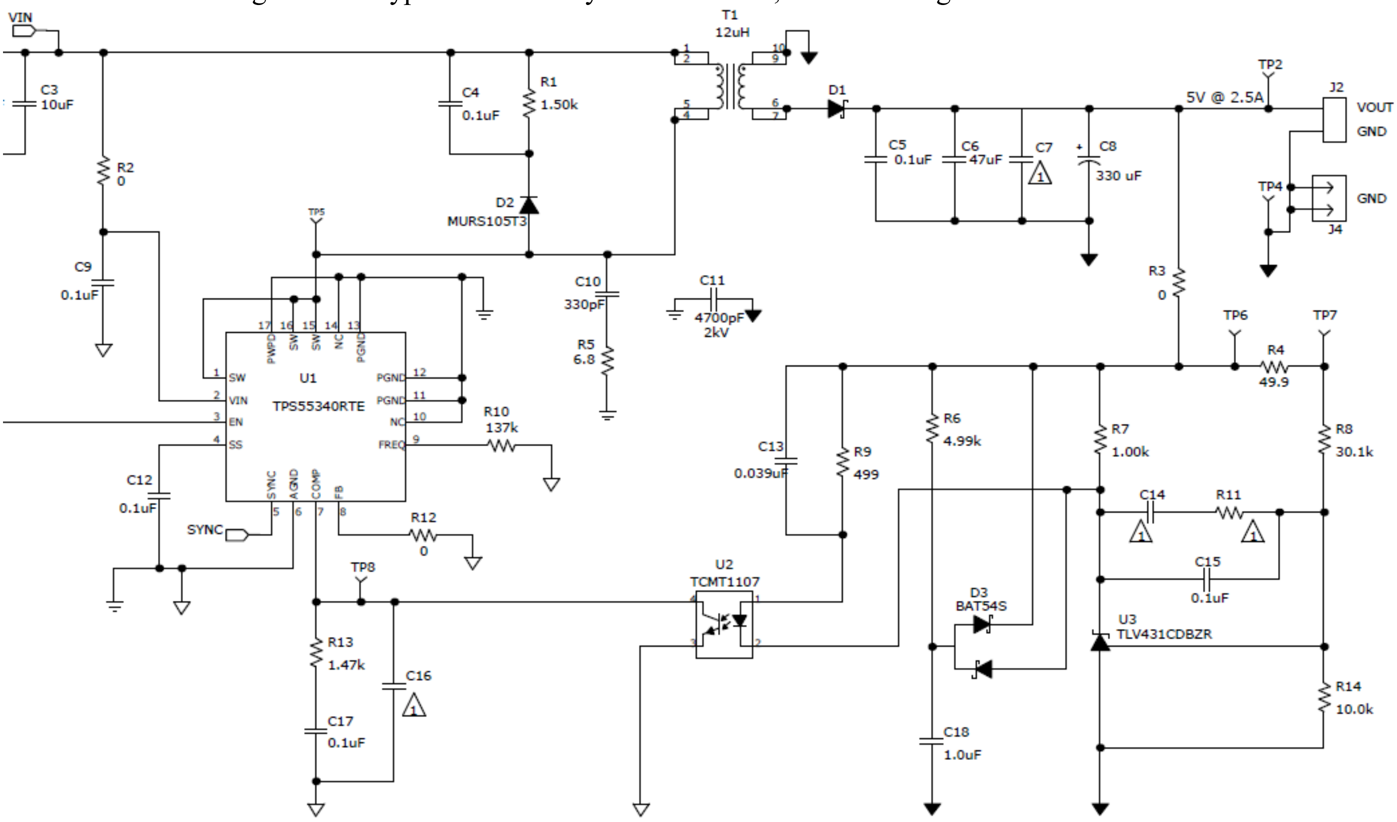
The Cleverscope sweeps the signal generator synchronously with signal capture, and then uses narrow band correlation to measure the gain/phase at that frequency without being affected by the surrounding switch mode power supply noise. In this example, using a TI TPS553430 flyback converter the Phase margin (under the M1 heading) is 60 deg at Unity Gain (0dB). Values between 45 and 60 deg are optimal for transient response. This is a good power supply! As well as that, the Gain Margin (the M2 heading) is -13 dB, and that means this design can tolerate a change of up to 13 dB (4.4x) in tolerances or temperature before things will go wrong. And bandwidth is a reasonable 7 kHz. Very good!

A quick bit of background

Most power supplies have feedback between the output voltage and a reference voltage. The power supply runs a control loop which maintains the output voltage constant based on an error term derived from the difference between the output voltage and a reference voltage.

The output (for a voltage supply) is always low impedance (that being the goal of the power supply), while the error amplifier input is usually high impedance to minimize feedback branch component heating and leakage current. For this reason it is usually easy to insert a low value resistor (say 50 ohms) in series with the feedback branch, and then apply a small voltage across it. This small voltage will be seen by the error amplifier as an error, and the control loop will attempt to compensate for it. If the voltage is small (for example 10mV), the effect on the output voltage will also be small, and so the system powered by the power supply will not be affected.

Here is the circuit diagram for a typical isolated flyback converter, this one using the TI TPS55340:



The TPS55340 COMP input (which is the output of a transconductance amplifier biased to a fixed value by the FB input) is used to measure an error voltage generated as the difference between the reference voltage set by the TLV431 reference, and the output voltage. This difference is transferred to the COMP input via U2 operating in linear mode - an increase in LED current is reflected by a decrease in the U2 transistor impedance, which in turn is reflected by a change in the voltage developed at the COMP pin. The anode of the photo LED is driven directly by the output voltage node, while the cathode is connected to the reference output. The voltage divider R8 - R14 sets the output voltage. There are , in effect, two feedback paths - one via R9//C13, and the other via R4 - R8 - R14.

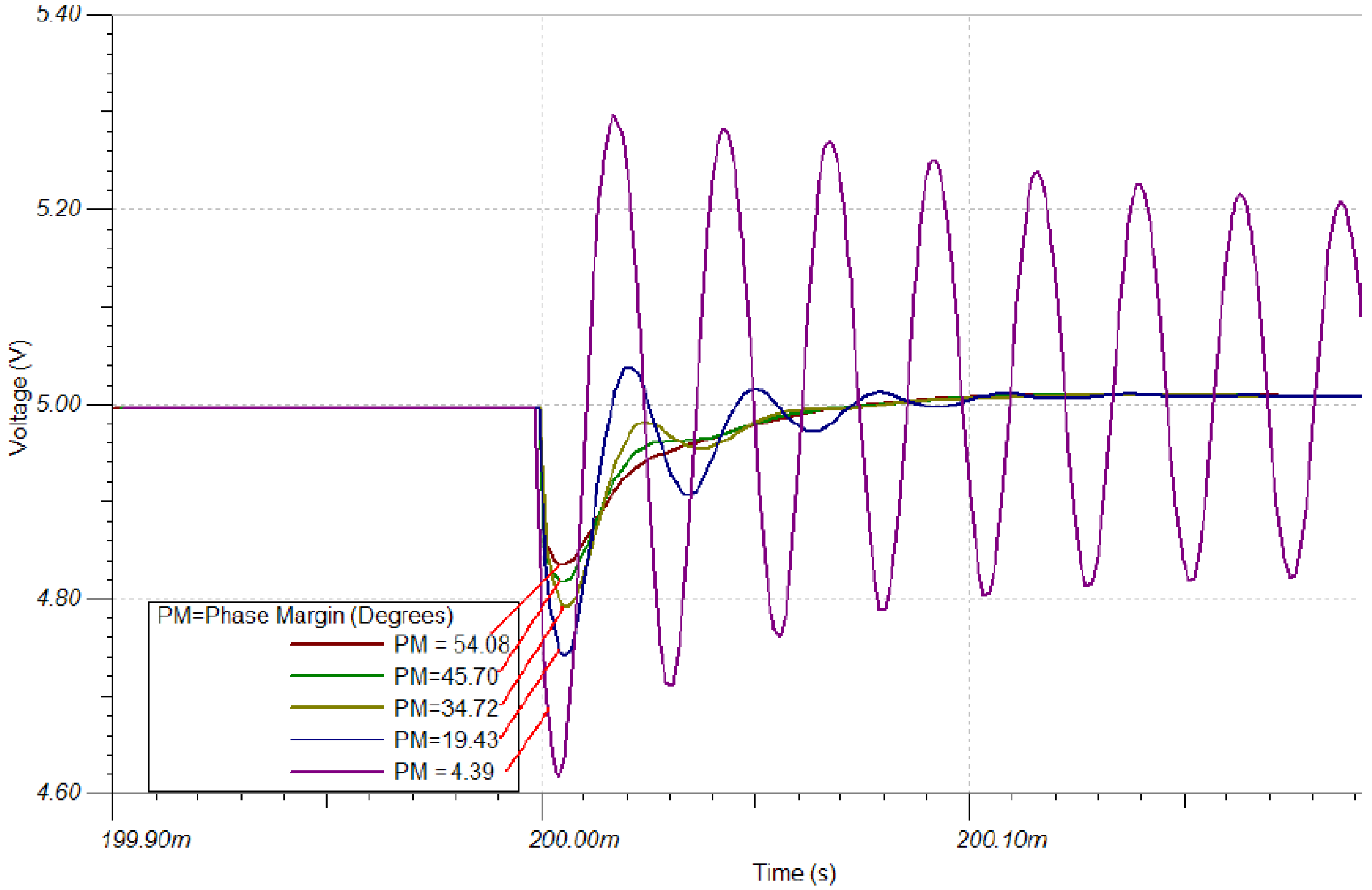
Looking at this supply we can see an opportunity to replace R3 with a 50 ohm resistor (still low compared to the feedback impedances) and then impress a small voltage across it. We should discover the power supply compensating for this small voltage with an opposing voltage such that the effective sum of the impressed voltage and the compensating voltage is zero. A gain/phase plot of the impressed voltage vs the compensating voltage will give us a measure of the amplifier stability, all without perturbing it very much at all. However this means measuring the very small response in the presence of large amounts of switch noise. Happily we can use the Fourier transform, and correlation to select a narrow bandwidth in which the switch noise power density is low, and make sure the stimulating signal is correlated with the measured signal. This is what the Cleverscope application does.

We need to inject the signal across R3, and this means an isolated signal generator. We use a transformer for this. Next we need to measure the input signal, and the response. We can assume the AC impedance of the output is low (the capacitance of 330uF//47uF//0.1uF sees to that), and so an AC measurement of TP6 will be the injected signal. Any switch mode noise, or output voltage perturbations, will be common mode to both TP2 and TP6 because the resistance of R3 is so low.

An AC measurement of TP2 will see both the switch mode power supply transitions, and the compensating voltage. Typical power supplies have a second order response - the gain falls off with frequency at about 20 dB/decade. The gain at low frequencies will be high. The Cleverscope application plots the gain and phase, and also displays the slope.

For a second order response the phase margin is a good indicator of stability. For a power supply such as this, the phase between the compensating voltage and the impressed voltage is usually positive while the gain is positive. This means the phase margin is simply the phase between the two. This phase is displayed under the *M1: 0 Gain* heading in the Cleverscope Gain/Phase display.

Here is a plot of output voltage in response to a Load Step with different phase margins:



As you can see ringing and overshoot occurs for phase margins of 35 degrees or less. Margins from 45 to 70 degrees are well damped (meaning the response still slews reasonably quickly without oscillation), but values of greater than 70 degrees exhibit poorer transient response (it takes longer for the output voltage to settle back to the target value).

The load step response is also affected by the bandwidth. In the graph above, the bandwidth is equivalent to the oscillation frequency. With a higher bandwidth the power supply will respond to a load step more quickly. So the power supply needs to have good phase margin, and sufficient bandwidth to manage the expected load demand.

For the TI TPS55340 we measured these values:

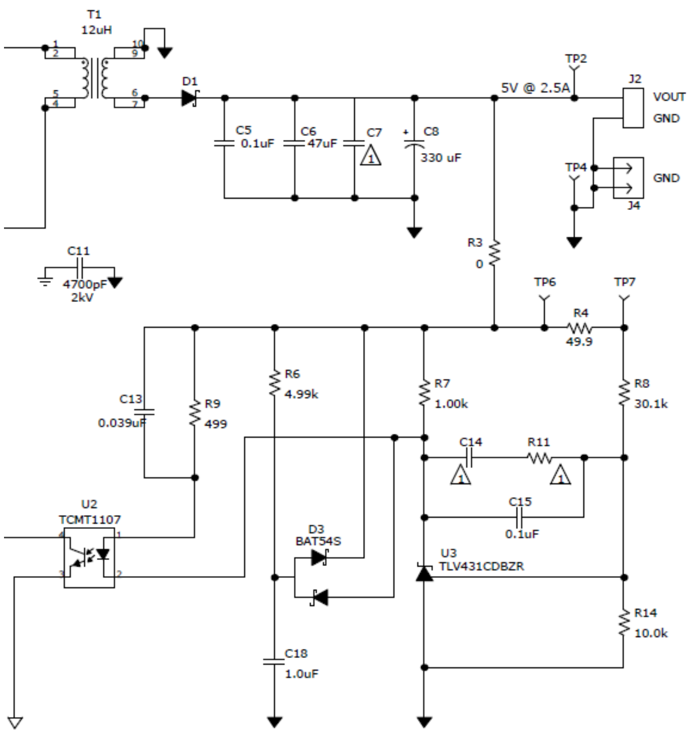
M1: 0 Gain	M2:0 Phase	FRA FOM: 0.4
60.07 Deg	-12.94 G dB	Slope: -23.50
6919.9 Hz	24581.9 Hz	delta: 17662.0 Hz

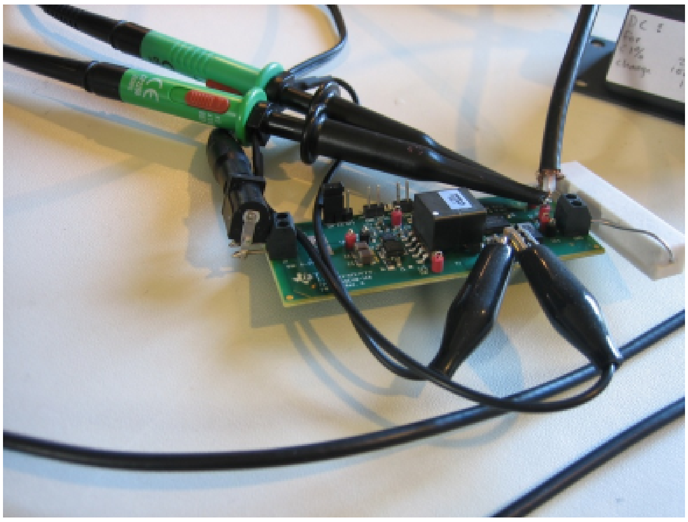
The unity gain point (M1) was 6919 Hz, with a phase margin of 60 degrees. Thus load changes of something up to half of this frequency can be handled well, and with stability.

You can see from the graph above that stability decreases as the phase margin decreases. An increase in gain because of process changes will also decrease the phase margin. M2 shows we have a gain margin of 13 dB beforethe phase becomes 0 (oscillation). It is very unlikely that component or temperature variation will cause us problems. Finally, the slope of -23.5 dB/decade confirms that this is a second order system, and so our stability assumptions are valid.

Setup

Here is a portion of the EVM circuitry, and a photo of the setup:





The Cleverscope signal generator is used to output the test signal via Jensen 1:1 video transfomer.

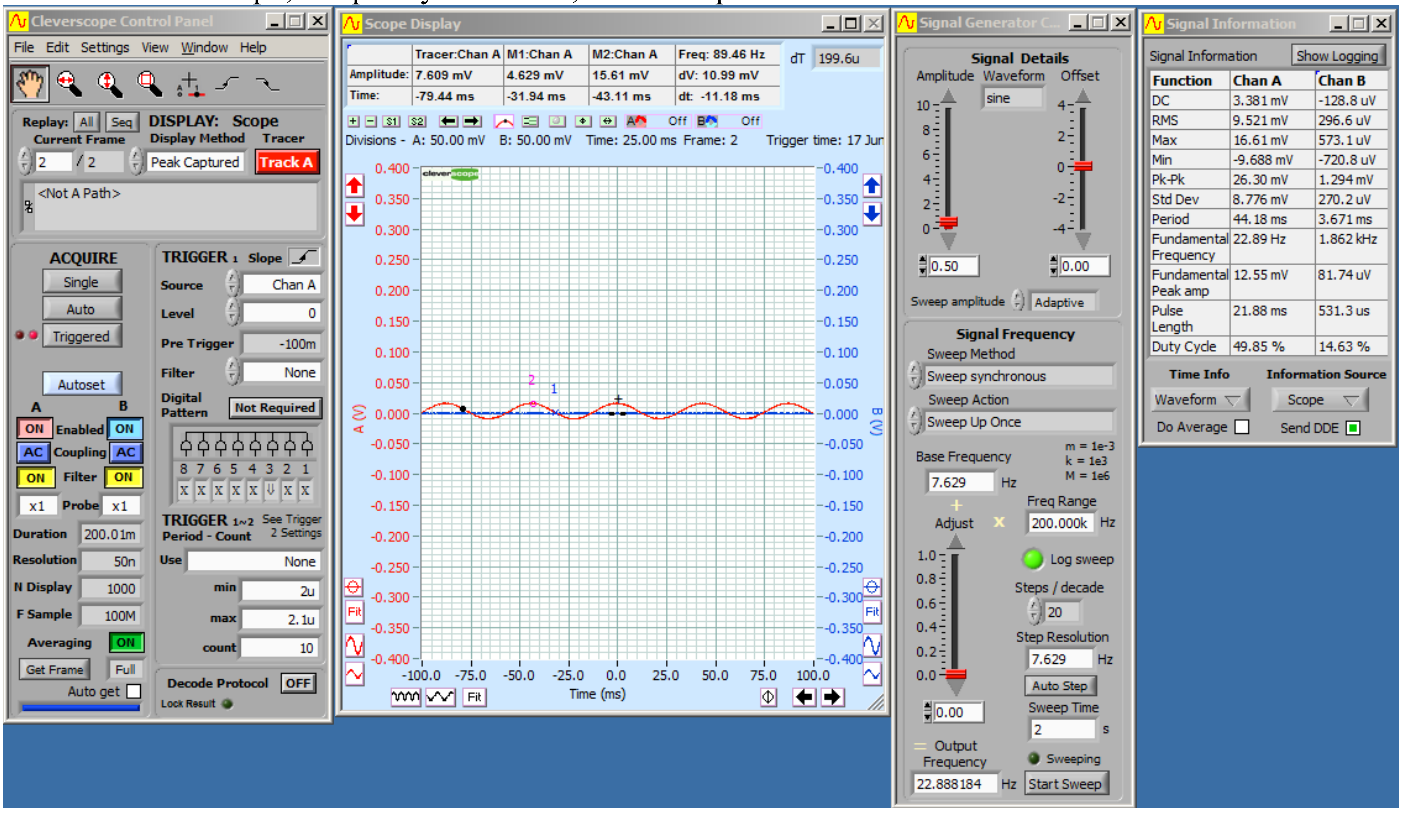
The test signal was injected across R3, using TP2 and TP6. R3 was changed to be 50 ohms. The CS328A signal generator, isolated using the VB-1BB transformer fed via a 20 dB attenuator (x 0.1) supplied the test signal. The test signal amplitude was about 13 mV peak. The signal was swept from 20 Hz to 200 kHz. The VB-1BB showed no sign of saturation until below 20 Hz. Injecting across R3 allows the regulator feedback loops to be stimulated.

Channel A of the scope was connected to TP6, as the input signal, and Channel B was connected to TP2, as the output signal. A 2 ohm load resistor was used to achieve a load of 2.5A, and a 5 ohm resistor to achieve a 1A load. The power supply was set to 12V (nominal level) and 8V (low line).

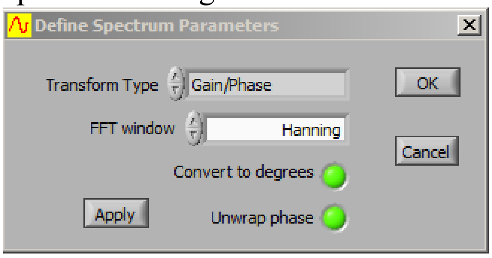
Measurements were done using a 14 bit ADC. The 1.28us moving average filter was turned on to reduce high frequency noise.

Here are the time domain setups. Left most is the Control Panel. The Scope graph, which sets the amplitude and time captured is on the left, showing a 22 Hz injection signal with 11 mV peak amplitude. The signal generator control panel shows a base frequency of 7.6 Hz, doing a log sweep with 20 steps/decade to 200 kHz. The output amplitude is 50 mV pk-pk, which is attenuated x 0.1 by the 20 dB attenuator, and then x 0.5 as the 50 ohm signal generator impedance is driving into a 50 ohm load on the EVM. The resultant peak voltage is measured as about 11 mV pk. The signal information shows the amplitude and frequency of the excitation.

Excitation - 11 mV pk, Frequency = 22.8 Hz, EVM not powered.

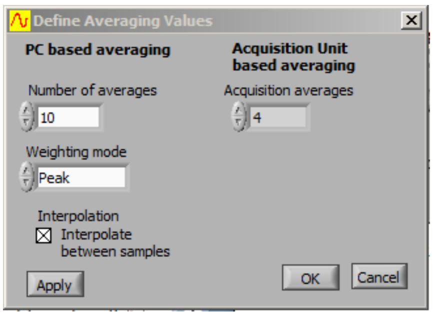


Spectrum settings:



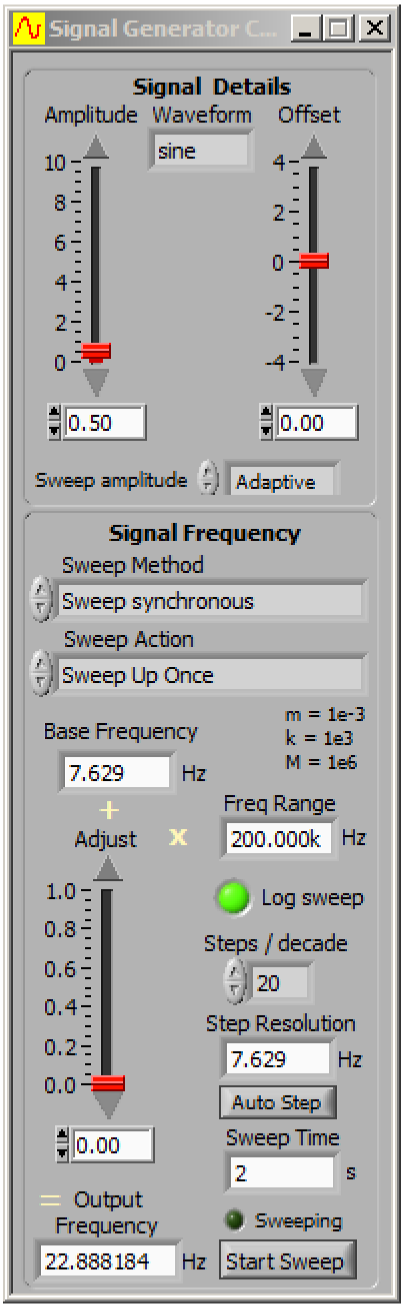
A Hanning window was used for minimum response lobe wiudth and maximum sine wave accuracy.

Averaging Settings



Peak averaging was used, with interpolation between signal generator frequency levels.

Signal Generator Settings



The Signal Generator is set to sweep the signal range with a log sweep. It uses 20 steps per decade.

After setting the spectrum display as required, click the 'Auto Step' button to set the Signal Generator step sized to be quantized to the Spectrum display frequency bins. This achieves maximum accuracy.

The frequency range is base frequency (7,6 Hz) to 200 kHz.

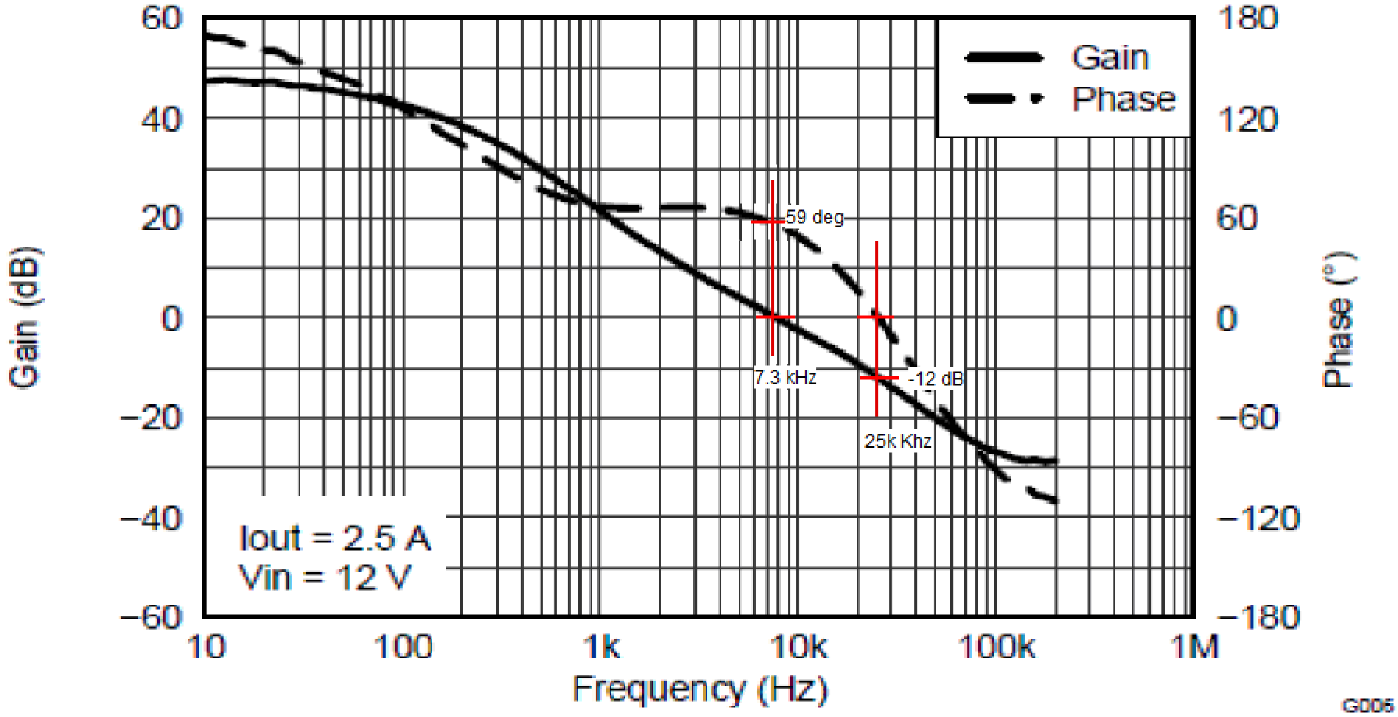
The Sweep Method is synchronous, meaning the Signal Generator steps between captures, leading to maximum frequency accuracy.

The Sweep Amplitude was set to Adaptive. This means that the output amplitude is increased without frequency stepping if the measure coherency Figure of Merit (FRA FOM as displayed in the Spectrum Display top right information entry) is less than 0.2. Values of 0.2 to 10 are good.

In this way the switch mode high gain at low frequencies is compensated for by increasing the output amplitude.

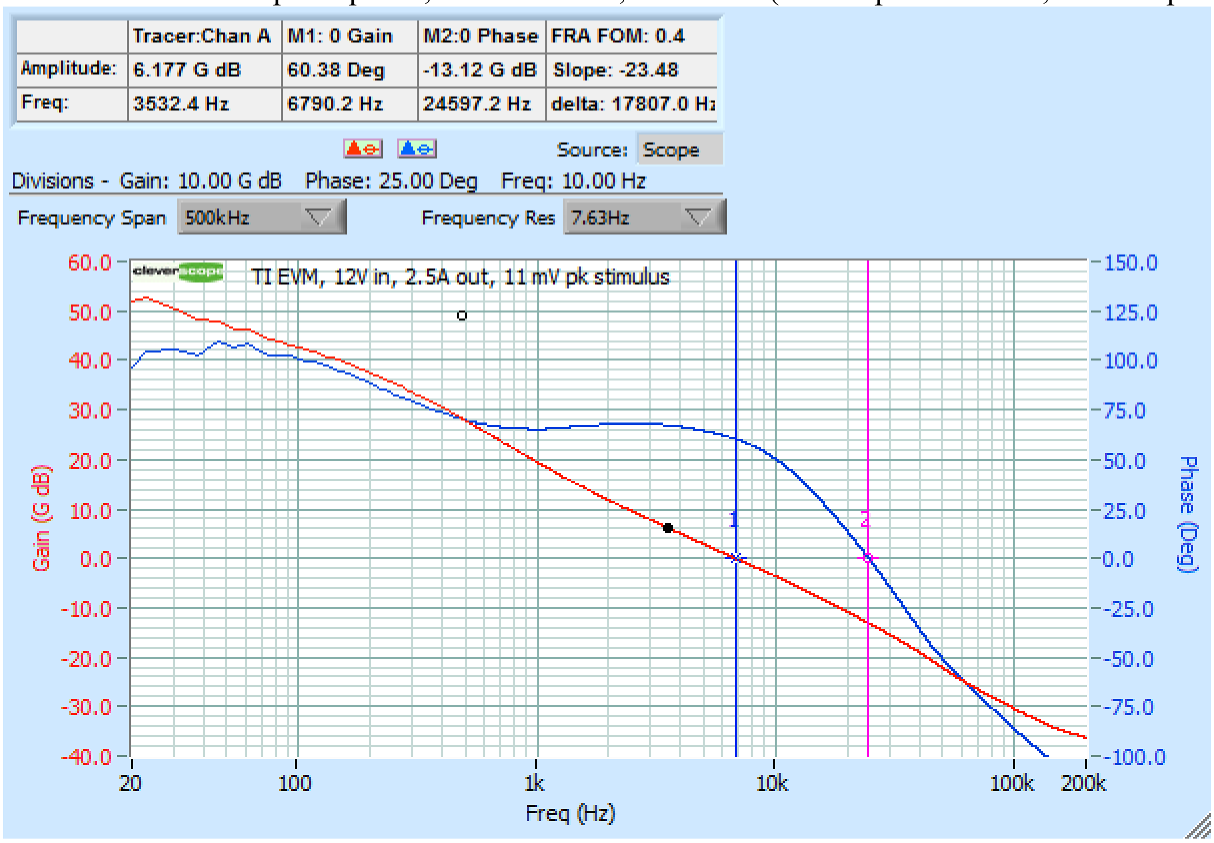
Results

The benchmark is the response shown in the TI TPS55340 EVM description document. This response was at an input voltage of 12V, and an output current of 2.5A. The stimulus is not shown:



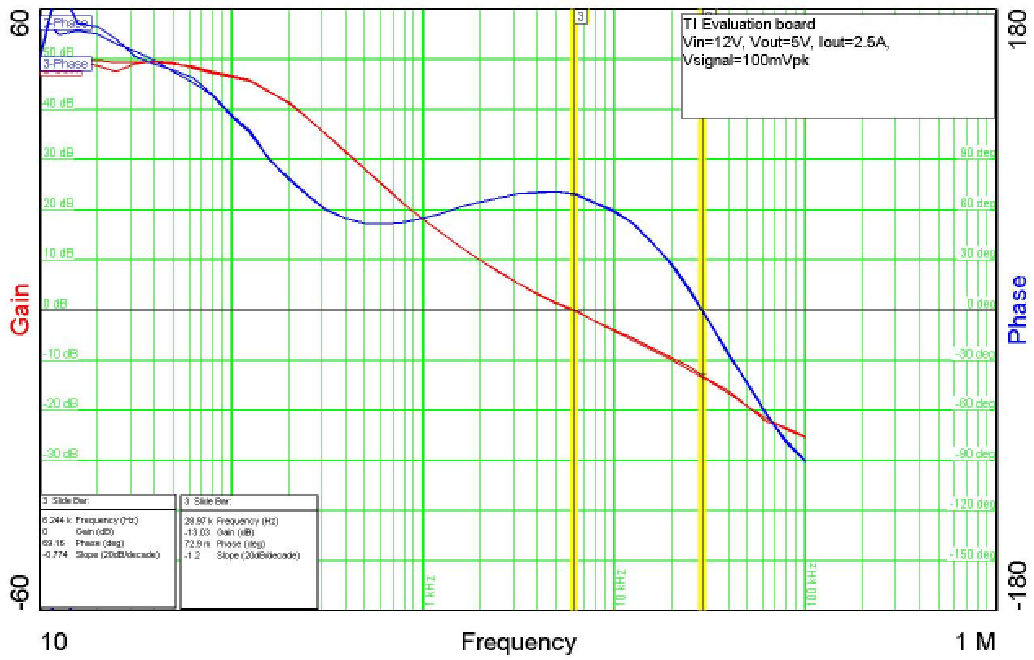
Here we estimate 0 dB gain at 7.2 kHz (59 deg phase) and 0 deg phase at 25 kHz (-12 dB gain).

Here is the Cleverscope response, also at 12V in, 2.5A load (11 mV pk excitation, with adaptive boost):



The Cleverscope 0dB gain is 6.8 kHz (60 deg phase phase) and 25.6 kHz phase (-13.1 dB gain margin). These results, and the shape of the graph are very close to that of the TI network analyser.

The Venable (http://www.venable.biz/4315analyzertemp.php) results for the same load, and 100 mVpk through a 10:1 transformer are:



We see 0db gain at 6.2kHz (69 deg phase margin) and 0 deg phase at 30 kHz (-13 dB gain margin). These are similar results to both the Cleverscope and TI network analyser results. (If anything the Cleverscope results are closer).

Conclusion

The Cleverscope FRA responses match the TI network analyser results well. In general the 0dB and 0 deg crossing points match pretty well between the Venables and Cleverscope responses.

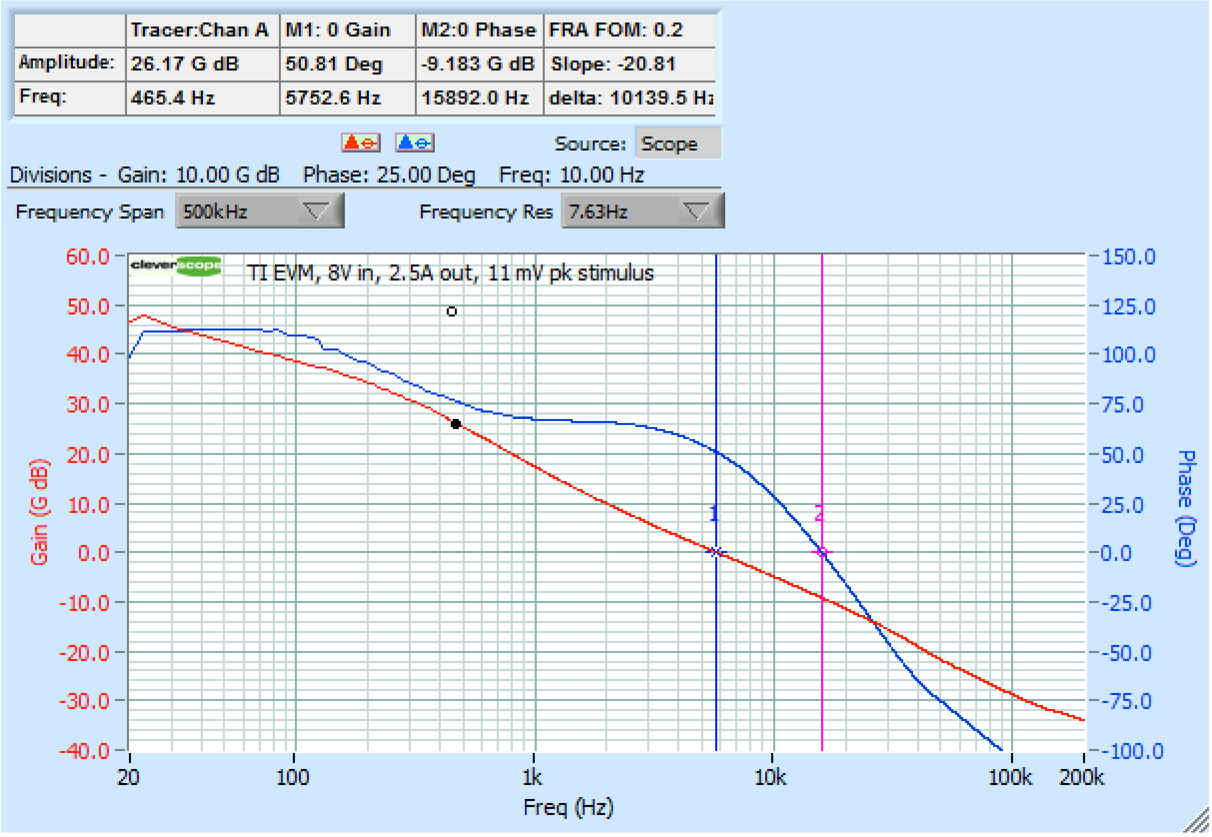
The Cleverscope low frequency boost is adaptive and only just enough to get good coherence. It may well be that the Venables low frequency boost is quite a bit higher, and leads to the low frequency characteristic of the quite pronounced change in phase slope between 100 Hz and 1 khz. We also see the gain flattening off below 100 Hz in each Venables graph. We don't see this phase change, or much gain flattening in either the TI or Cleverscope plots.

I did try and reproduce this behaviour by varying the drive level, but could not get a similar phase variation. Perhaps it has something to do with the isolation transformer.

We compared the Venables results with the Cleverscope results at these additional data conditions:

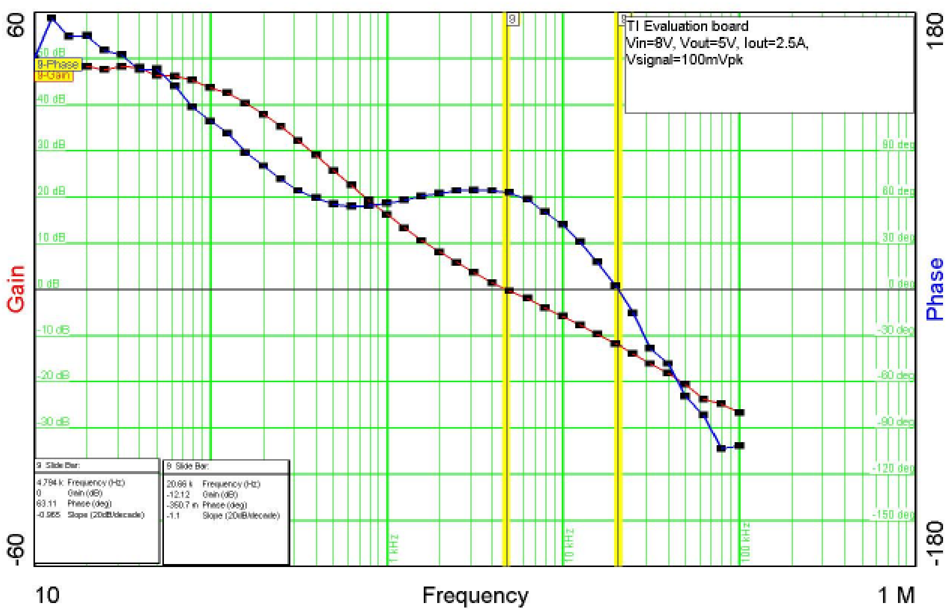
Low line - Vin = 8V, Iout = 2.5A

Cleverscope:



0 dB gain at 5.7 kHz (50.8 deg) and 0 deg phase at 15.8 kHz (gain is -9.2 dB).

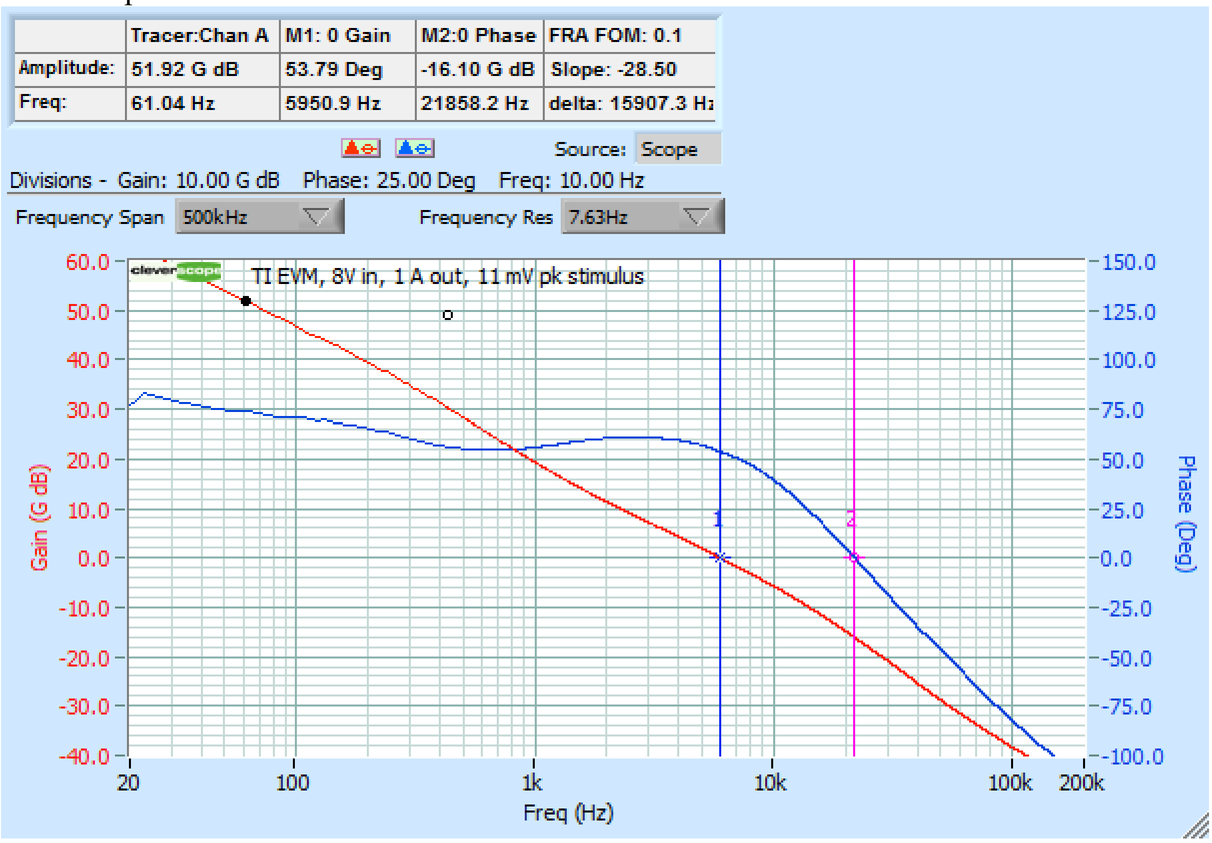
Venables:



Venable plot at Low-line at load of 2.5 A, Vsignal = 100 mVpK. The Venable injection transformer has a 10 to 1 turns ratio so the real injection voltage is 10 mV peak. Crossover or bandwidth is 4.79 KHz with a PM of 63.1 deg while GM = -12.12 dB

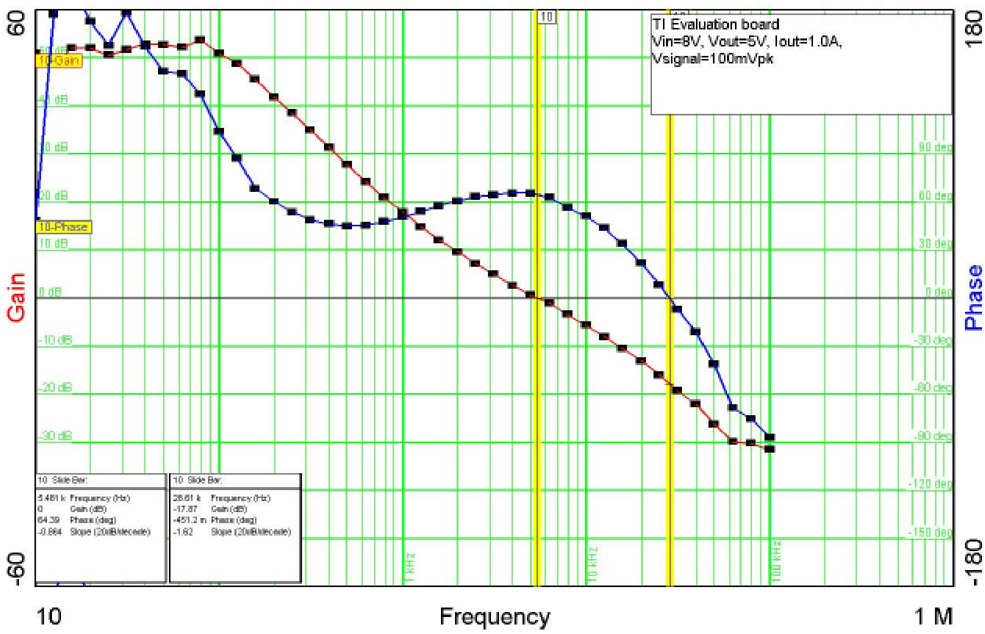
Low line - Vin = 8V, Iout = 1A

Cleverscope:



0 dB gain at 5.9 kHz (54 deg) and 0 deg phase at 21.8 kHz (gain is -16.1 dB).

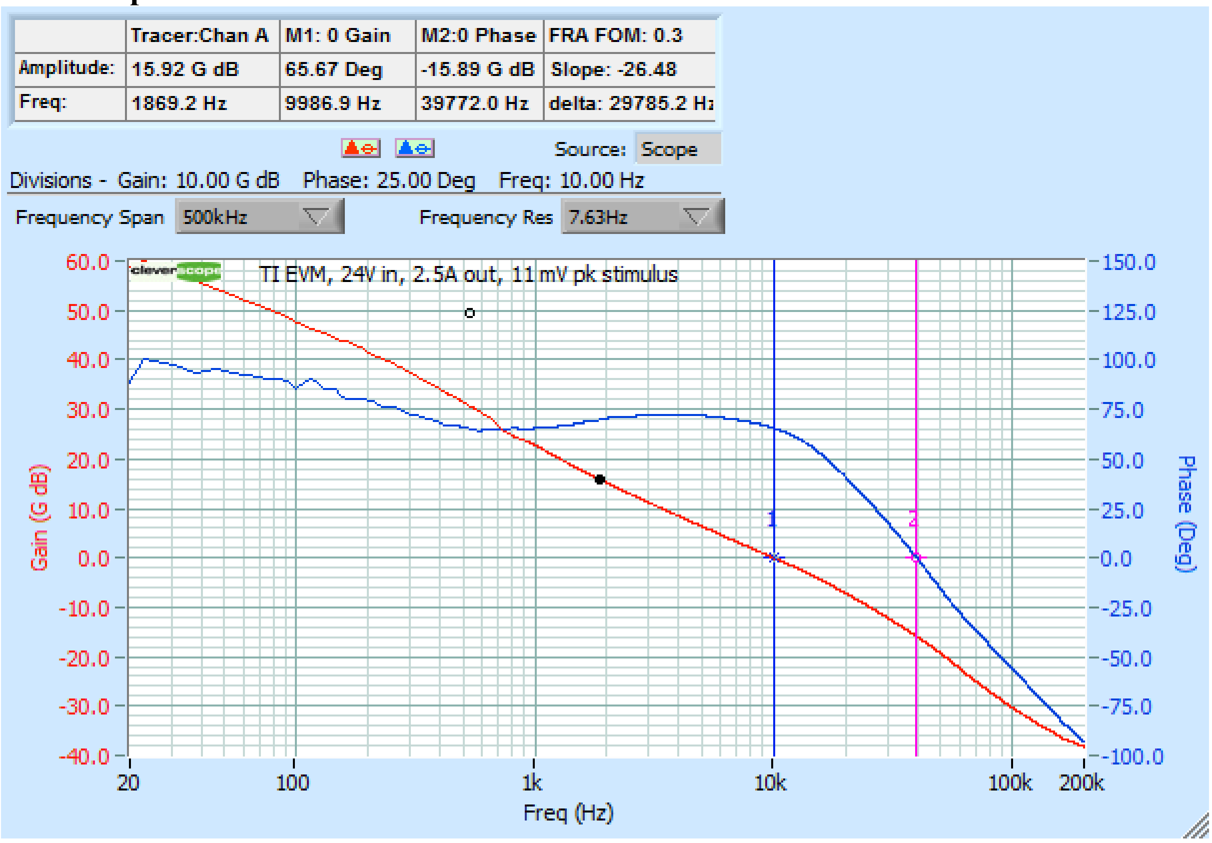
Venables:



Venable plot at Low-line at load of 1.0 A, Vsignal = 100 mVpK. The Venable injection transformer has a 10 to 1 turns ratio so the real injection voltage is 10 mV pk. Crossover or bandwidth is 5.48 KHz with a PM of 64.3 deg while GM = -17.87 dB

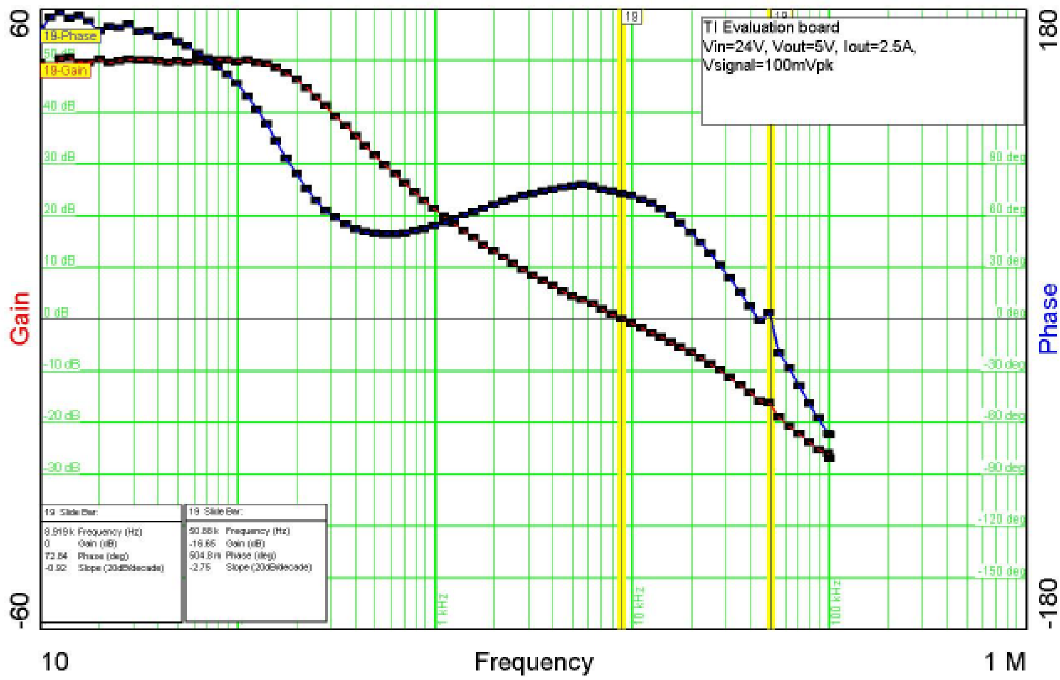
High line - Vin = 24V, Iout = 2.5A

Cleverscope:



0 dB gain at 10 kHz (66 deg) and 0 deg phase at 39.7 kHz (gain is -15.9 dB).

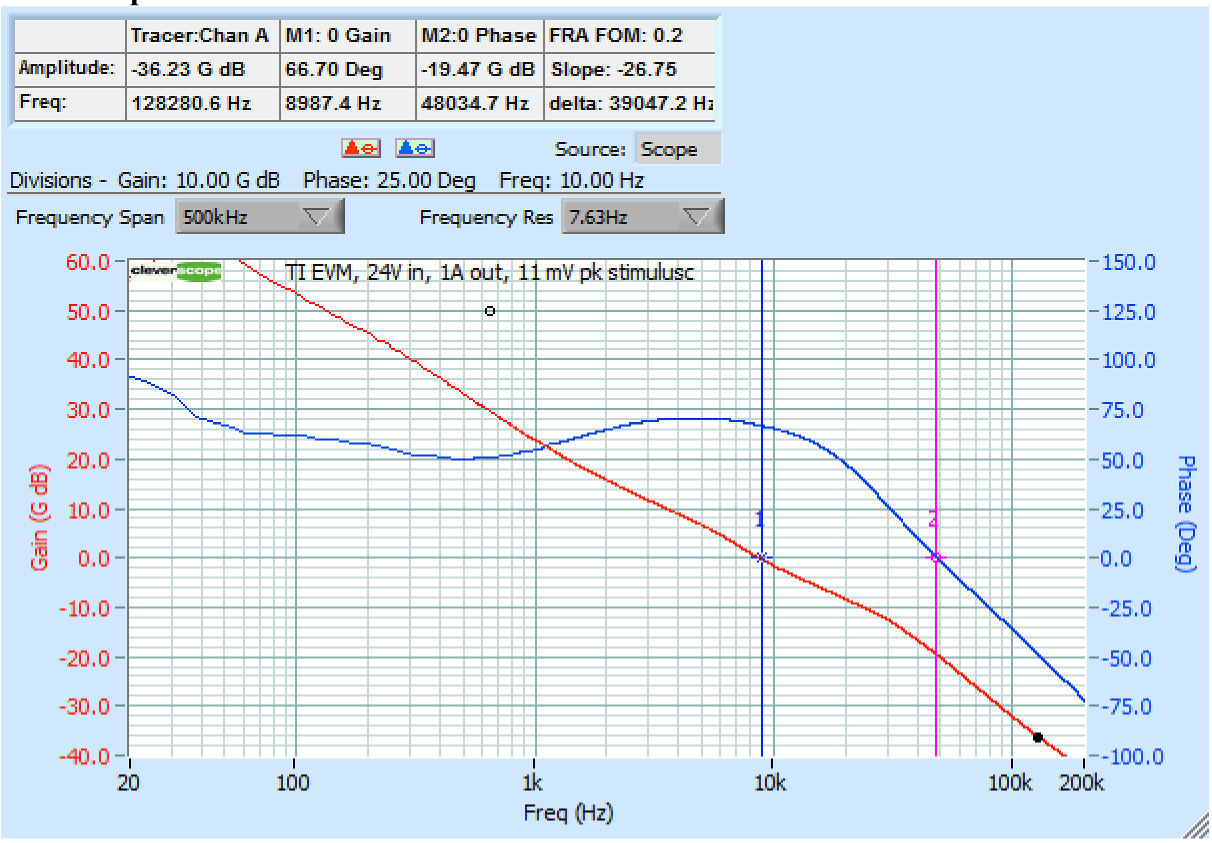
Venables:



Venable plot at High-line at load of 2.5 A, Vsignal = 100 mVpK. The Venable injection transformer has a 10 to 1 turns ratio so the real injection voltage is 10 mV peak. 0 dB gain at 8.9 kHz (phase = 72.8 deg), 0 deg phase at 50.9 kHz (-16.6 dB gain).

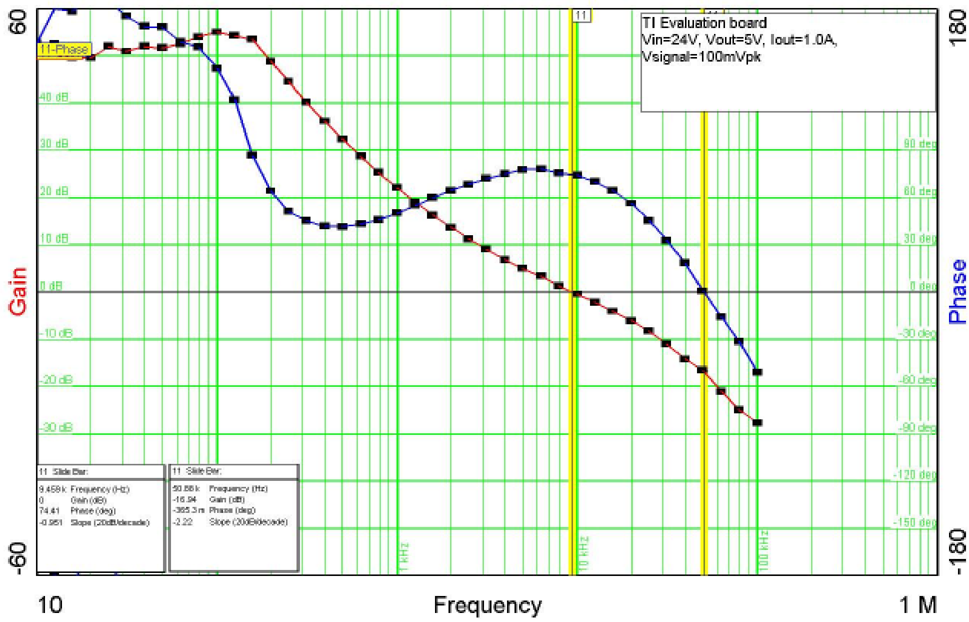
High line - Vin = 24V, Iout = 1A

Cleverscope:



0 dB gain at 8.9 kHz (67 deg) and 0 deg phase at 48 kHz (gain is -19 dB).

Venables:



Venable plot at High-line at load of 1.0 A, Vsignal = 100 mVpK. The Venable injection transformer has a 10 to 1 turns ratio so the real injection voltage is 10 mV peak. Crossover or bandwidth is 9.45 KHz with a PM of 74.4 deg while GM = -16.94 dB