Foundations (Part 1.B) - Frequency Response Measurement of the Plant, Compensator and Loop of our Switch Mode Power Supply

tags: compensator, plant, loop, frequency response measurement

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Introduction

In the last article we discussed Bode plots and how we can use the information displayed on a Bode plot in order to make an assessment of the stability of a power supply. At the end of that article we showed a Bode plot displaying real measurement data of the loop of a power supply.

In this article we are going to discuss how to physically make this measurement, what you will need to do to your power supply, the hardware required and how to connect it to your power supply. We will also cover how to measure the plant and compensator individually.

A typical power supply is shown in Figure 1. The power supply consists of a plant, which in turn can be sub-divided into a power stage, the PWM stage and a compensator. The output voltage is fed into our compensator, which is implemented using an op-amp and the appropriate selection of capacitors and resistors (much more on compensator design in later articles). The output of our compensator is fed into a comparator which generates our new value of duty cycle thus closing the loop. Of course the comparator and compensator op-amp are usually implemented inside our controller IC.

Measuring the loop response

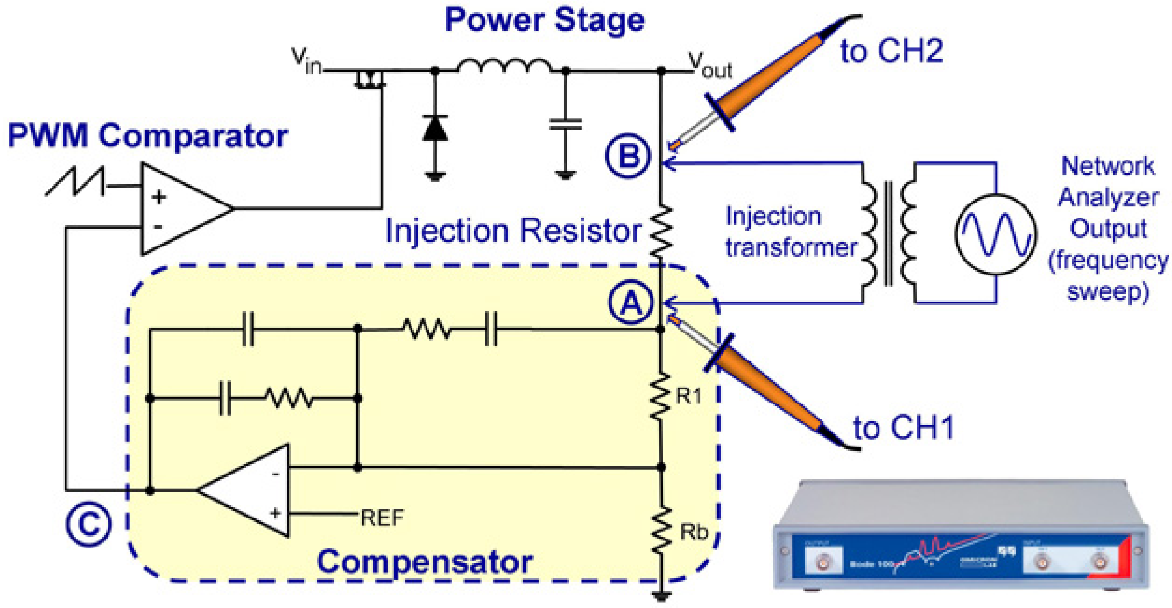

Figure 1. Set up of a typical switched mode power supply showing the injection resistor and measurement points, A, B and C.

As we discussed in the first article, in order to measure the loop, all we have to do is inject a sinusoidal signal into our system and measure how this signal changes as it passes through the system. In order to do this, we will break the loop by inserting an injection resistor into the feedback path of our output voltage. Figure 1 shows the location of the injection resistor. The location is chosen such that it will not affect the overall operation of the loop. The most common location for the injection resistor is on the top of the compensator's potential divider. The value of the injection resistor should be small compared to those of the potential divider so that it does not impact the correct operation of our compensator - typically it is around 20Ω. Across the injection resistor, we will inject a sinusoidal signal of varying frequencies using a network analyser. In our case we used a Bode 100 vector network analyser from OMICRON Lab.

We cannot connect the Bode 100 directly across the injection resistor as the potential at the bottom of the injection resistor is not the same as our ground; therefore we must use an injection transformer as shown in Figure 1. Then, we connect channel 1 of the Bode 100 to point A and channel 2 to point B as shown. Channel 1 will measure the input signal, i.e. the injected sinusoid. Channel 2 will measure the sinusoid as it appears on the output voltage of our converter - i.e. after it has passed through the loop. Using this configuration we will be able to measure the open loop response of our power supply.

An easy way of working out what we are measuring is to simply put your finger in the position of channel 1 and then follow its path through our circuit until you get to channel 2. For example in Figure 1 we can see that we will first go through the compensator, then the PWM and then the power stage; so we are measuring the entire loop.

We will show later in the article how this measurement can be imported in into our automated power supply design software (Biricha WDS)

Measuring the plant

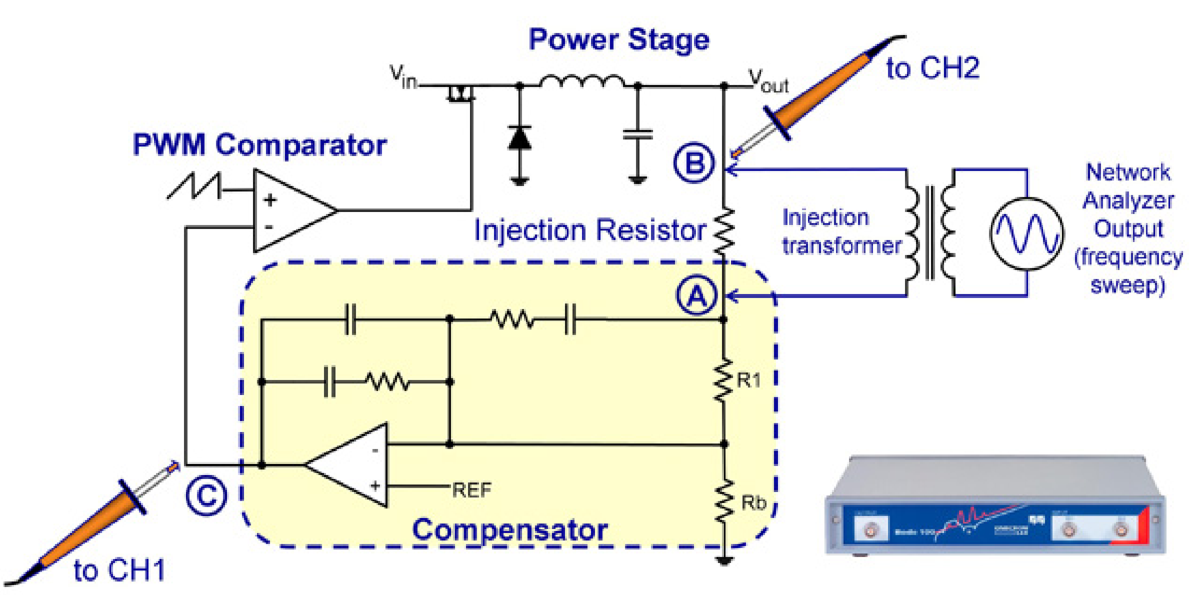

Figure 2 - Measuring the frequency response of the plant.

It is always prudent to measure the plant to make sure that our transfer function (much more on this in later articles) is correct and the same as the real power supply. We can easily superimpose our measurement with our calculated transfer function using Biricha WDS. In order to measure the plant, all we have to do is move the location of our Bode 100’s channel 1 probe to point C as shown in Figure 2. The injection resistor and signal that we are injecting remain the same. If we now put our finger on channel 1 and follow it path to channel 2, we will see that the signal goes through the PWM stage followed by the power stage i.e. we are measuring our plant. The Bode 100 will now compare these two signals and the resulting Bode plot will be the measurement of the plant of our system.

Measuring the compensator

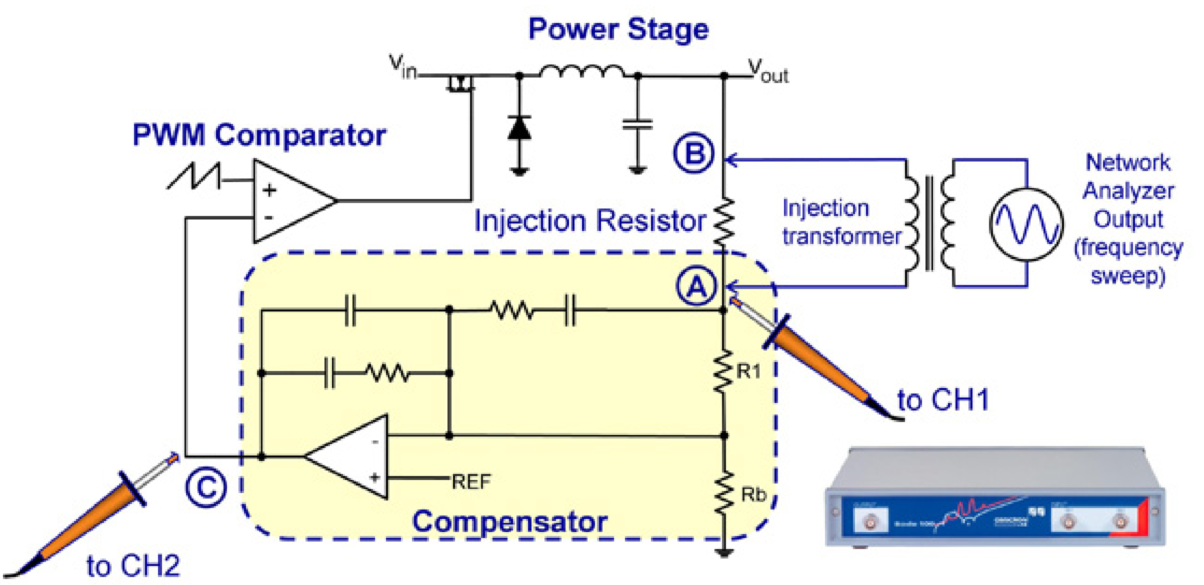

Figure 3 - Measuring the frequency response of the compensator.

It is always important to also measure the frequency response of our compensator to make sure that we have not made any mistakes in our calculations and are not trying to operate the IC's op-amp beyond its capabilities. To measure the compensator we are interested in seeing how the signal changes as it passes from point B in our diagram to point C. Therefore, we should connect Channel 1 to point B and Channel 2 to point C. This measurement will be the frequency response of the compensator within our system and again can be imported into Biricha WDS so that a direct comparison can be made with the calculated results.

Real Life Measurement

As a real life example we will now measure the loop of an analog voltage mode controlled Buck converter. This EVM is used during our Analog Power Supply design workshop [1] and all attendees get hands-on practice of measuring the loop, compensator and plant of this EVM and others during the workshop.

By connecting the Bode 100 vector network analyzer to the Buck converter as described in the loop measurement section, we are able to obtain the real measurement data. This data can then be imported into Biricha WDS for comparison with our calculated results. This is shown in Figure 4.

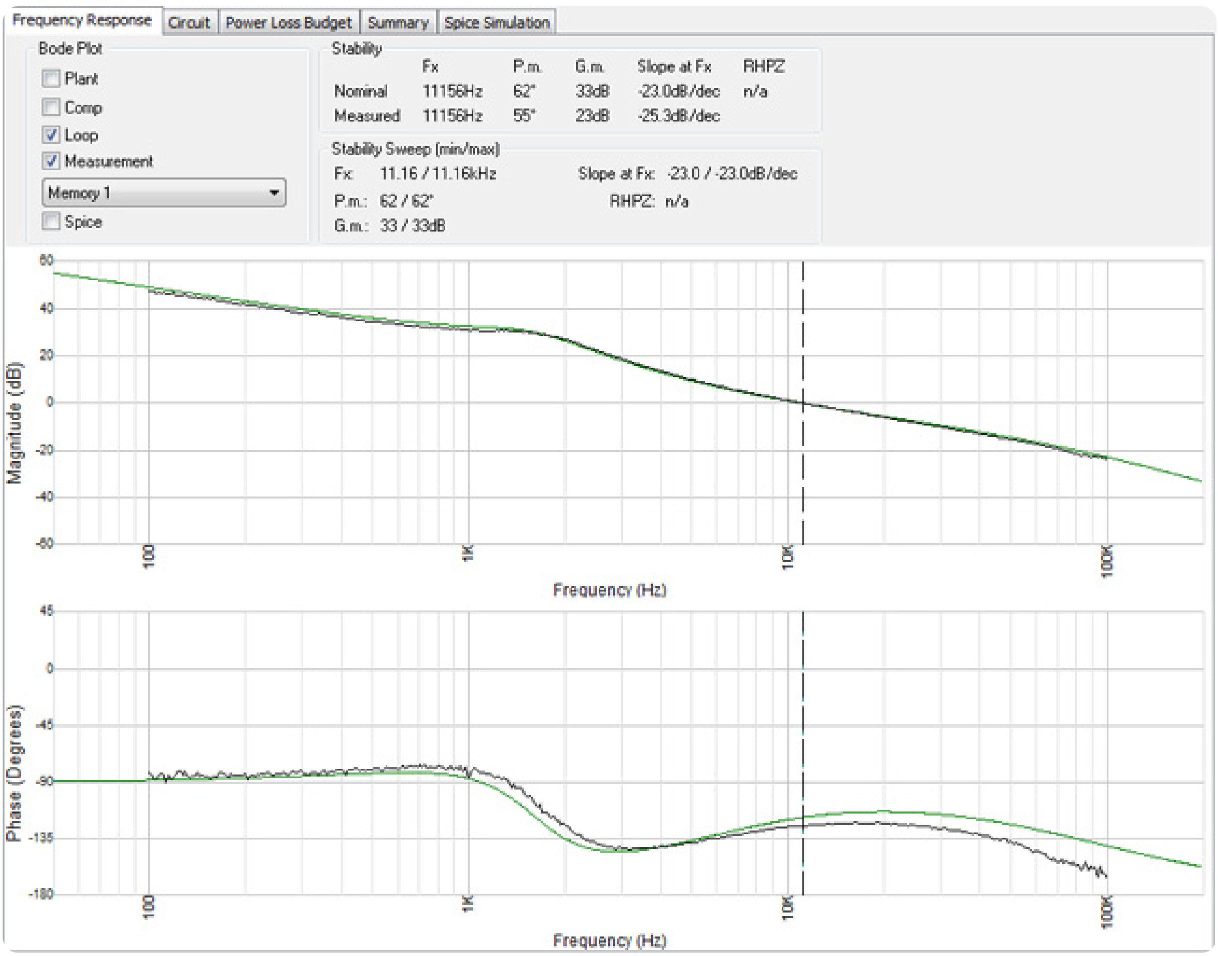

Figure 4 - Real measurement data of the loop (black trace) imported into WDS and compared with the simulated loop (green trace)

The black trace in Figure 4 is the measured result from the Bode 100 and the green trace is the result calculated by WDS. You can see that we have an almost perfect match. There are also almost perfect matches between the calculated and measured results of the plant and the compensator, but we have not shown them here due to the shortage of space.

In the previous article we discussed what to look for in a Bode plot in order to assess stability. In short we are interested in the cross-over frequency, phase margin, gain margin and the slope of the gain plot at cross-over (please see previous article). We can clearly see these from the Bode plot of Figure 4. However WDS also displays these automatically in its “Stability Box”; this is shown in Figure 5.

Stability

	Fx	P.m.	G.m.	Slope at Fx	RHPZ
Nominal	11156Hz	62°	33dB	-23.0dB/dec	n/a
Measured	11156Hz	55°	23dB	-25.3dB/dec	

Figure 5 - Stability of WDS simulated (nominal) loop and real measured loop

You see from the above figure that not only WDS has designed a very robust and stable power supply, in fact the real measurement is a very close match with the designed value.

Concluding Remarks

In this article we have explained how to measure the loop, compensator and plant of your power supply using a vector network analyzer. The measurements were made by injecting a sinusoidal of varying frequency into the loop and measuring how this signal changed as it passed through the system.

The connection setup for the loop, the plant and the compensator were shown in Figures 1 to 3 respectively.

In the next article, we will be discussing transfer functions from first principles and how you can use them to analytically design a compensator for a power supply in order to meet the stability criteria.

Things to Try

1 – Visit OMICRON Lab’s website for more information about Bode 100 (http://www.omicron-lab.com/bode-100/product-description.html)

2 – Try out a trial version of Biricha WDS (http://www.biricha.com/wds)

3 -Check out our videos explaining loop/plant/compensator measurements below:

Foundations (Part 1.B) - Loop Gain Measurement of our Switch ...

Dr. Ali Shirsavar from Biricha Digital Power Ltd describes how to measure the loop of a power supply, defining the injection points and measurement points, in order to determine the crossover frequency, phase margin and gain margin.

Foundations (Part 1.B) - Compensator Frequency Response Mea...

Dr. Ali Shirsavar from Biricha Digital Power Ltd describes how to measure the frequency response of the compensator in your SMPS.

Foundations (Part 1.B) - Plant Frequency Response Measurement

Dr. Ali Shirsavar from Biricha Digital Power Ltd describes how to measure the frequency response of the plant (power stage) of your power supply.

Bibliography

[1] Biricha Digital's Analog Power Supply Design Workshop Manual

[2] Omicron Lab Website (http://www.omicron-lab.com/bode-100/product-description.html)