# Using the J2103A Power Stage Isolator to Measure Power Supply Open-Loop and Control Loop Gain

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## 1.0 Introduction and Application

In the world of power electronics, the focus is on the power supply, where the challenge is developing an accurate model to use for simulation or measuring the gain to determine the power supply stability and performance. To create an accurate model for the power supply, the open-loop gain (AOL) and closed-loop plant gain of the power supply need to be understood. However, most power supply manufacturers do not provide the AOL characteristics in the datasheet, and the closed-loop gain is a function of the control loop designed around the power supply.

A proper understanding of AOL at DC and over-frequency is crucial to the understanding of closed-loop gain, bandwidth, and stability analysis of the power supply. The power supply's closed-loop gain or power supply rejection ratio (PSRR) is an important parameter for power supplies and voltage references. PSRR is a significant performance concern as even small amounts of high-frequency ripple voltage at the input can significantly degrade the output precision of voltage reference and LDOs and impact downstream circuitry. The output of the power supply is not only a function of the inputs but also of the power supply's control loop and power distribution network (PDN) loading. Therefore, it is important to understand these parameters when designing or simulating a power supply.

The power supply plant, as depicted in Figure 1, needs to receive a feedback signal to determine the control loop adjustment to maintain the output voltage under dynamic load conditions. However, this control loop into the plant provides an additional gain to the overall system. So, if a designer wants to know the gain solely of the plant, the control loop needs to be opened. By opening the control loop, the open-loop gain of the plant can be assessed. Further, if a designer wants to create a State-Space Average VRM model in Keysight PathWave ADS or SPICE, measuring the open-loop gain is critical to determining the power supply slope compensation and Ri terms.

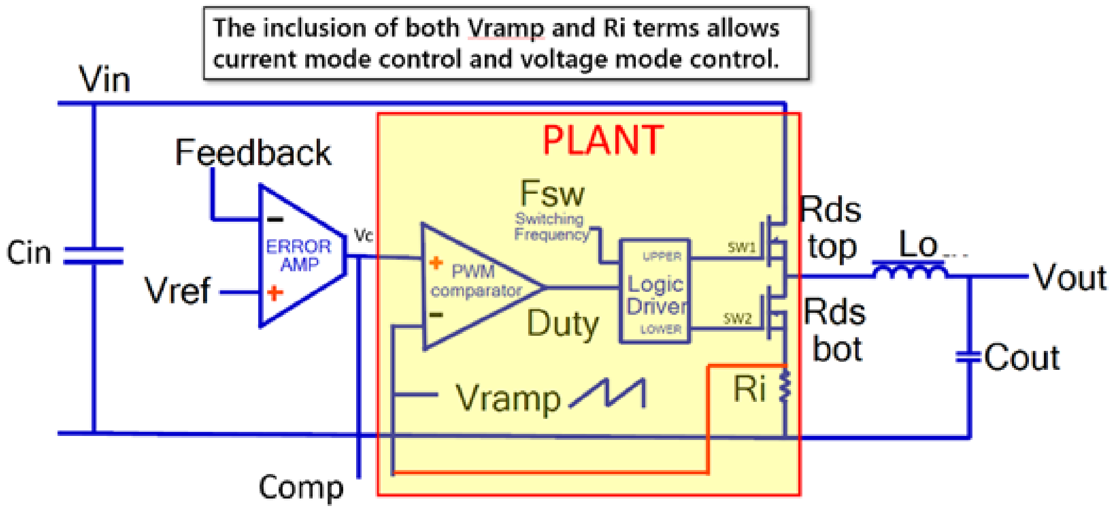



**Figure 1 - Depiction of Power Supply Plant [2].**

With reference to Figure 2, a simple buck regulator diagram is shown, where the loop gain T(s) of this power supply is defined as the product of the transfer function along the closed control loop. Here, three products create the overall transfer function, as shown by EQ(1), where EQ(2) shows the result of the transfer function H(s).

$$H(s) = H_1(s) \cdot H_2(s) \cdot H_3(s) \tag{1}$$

$$H(s) = \frac{V_{comp}}{V_{out}} = \frac{R_1}{R_1+R_2} \cdot g_m \cdot \frac{R_{shunt}}{1+s \cdot R_{shunt} \cdot C_{shunt}} \tag{2}$$

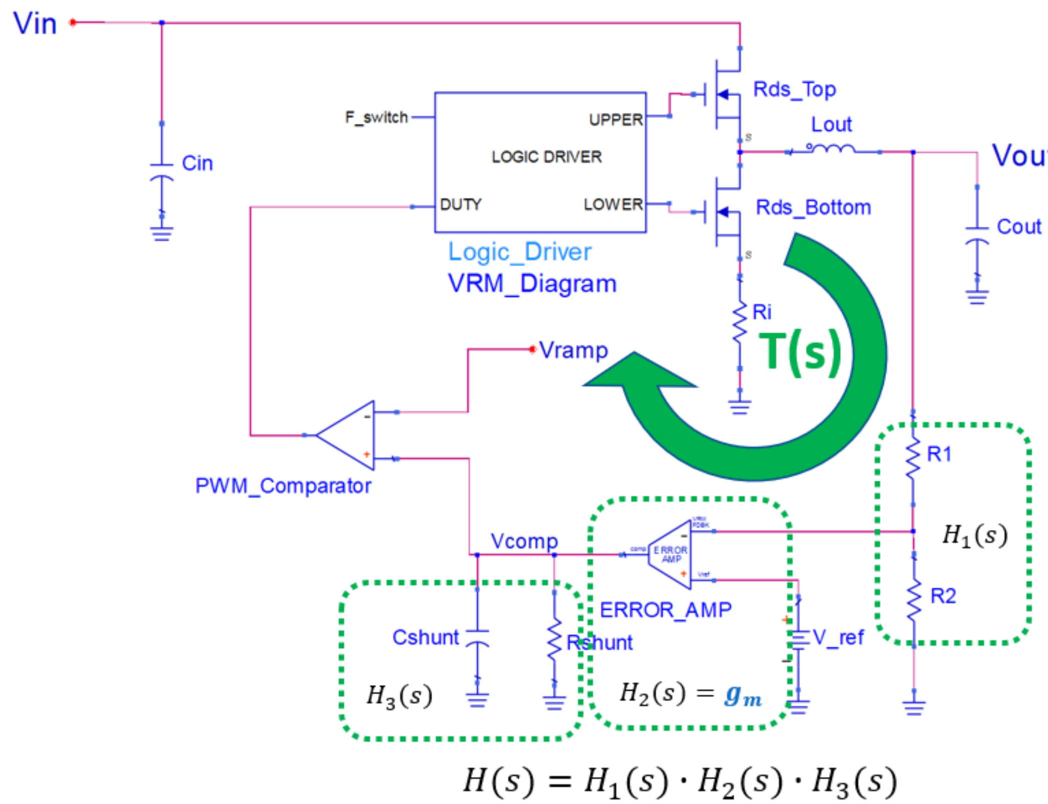



**Figure 2 - Depiction of Buck Regulator Power Supply Closed-Loop Gain.**

Power engineers often struggle to measure the open-loop gain of the power supply. How do you determine the power stage gain on a power supply? This is where the Picotest J2103A power stage isolator, along with a frequency response analyzer (FRA), can help. Measuring the plant's open-loop gain or control loop gain is relatively simple to do if the power supply includes a COMP pin for external compensation.

Frequency response analyzers, such as the OMICRON Lab Bode 100 VNA, are often used to measure power system feedback loop response. It can also be used to measure the characteristics of semiconductor devices, such as the open-loop gain of an operational amplifier.

## 2.0 Measurement Setup for Power Supply Open-Loop Gain with the J2103A

A simple diagram for how to set up the measurement of the power supply open-loop gain with the J2103A and an FRA is depicted in Figure 3. Table 1 provides a more detailed list of the actual test equipment shown in Figure 4. In Figure 4, the DUT is a TPS7H4003 power supply evaluation board from Texas Instruments. The Bode 100 VNA is used for the FRA in the examples below.

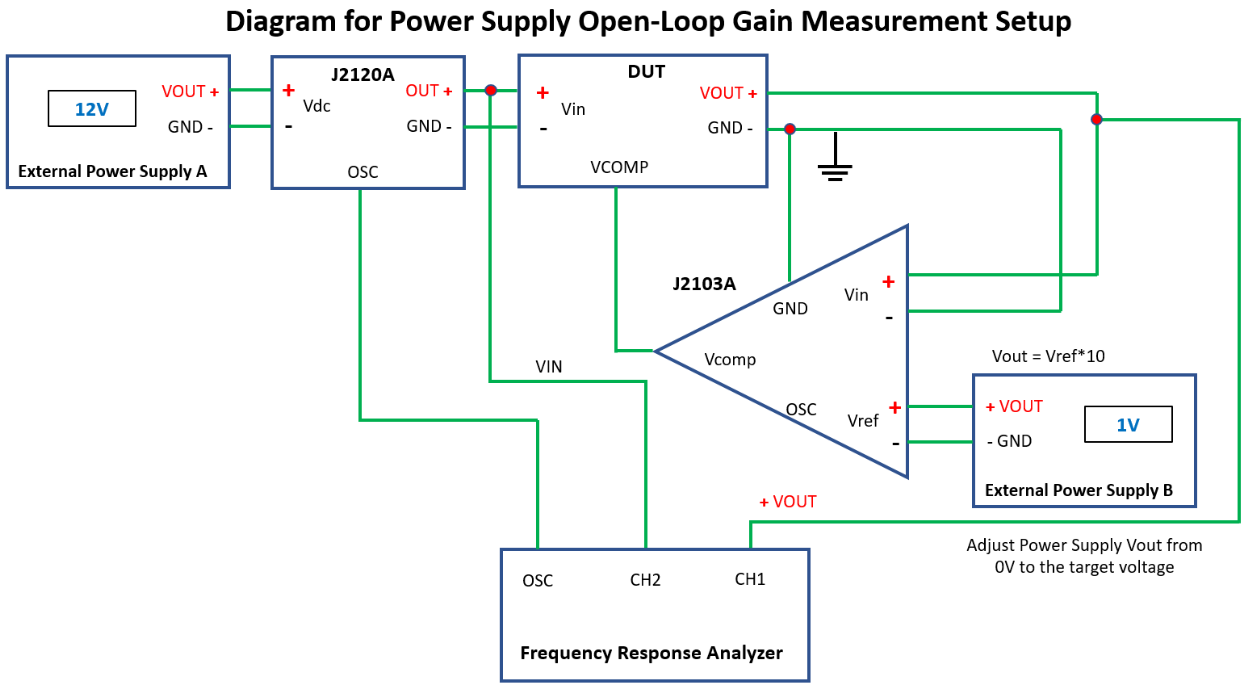



**Figure 3 - Diagram for Power Supply Open-Loop Gain Test Setup with the J2103A and an FRA. In this case, CH1 and CH2 connections are made with the P2104A 1-port probe.**

**Table 1 - Test Equipment List for Measuring Power Supply Open-Loop Gain**

| Description | Model | QTY |
|---|---|---|
| Power Stage Isolator | Picotest J2103A | 1 |
| Power Supply | Picotest P9610A/P9611A or equivalent | 2 |
| Frequency Response Analyzer/VNA | OMICRON Lab Bode 100 | 1 |
| Line Injector | Picotest J2120A | 1 |
| Common Mode Transformer | Picotest J2102B | 1 |
| DC Bias Injector | Picotest J2130A | 1 |
| 1-Port Transmission Line Probe | Picotest P2104A-1X 100mil pitch | 2 |
| PDN Cable® | Picotest PDN Cable 0.25-BNC-BNC | 1 |

**Step-by-Step Instructions for Open-Loop Gain Measurement Using the J2103A**

1. Calibrate the FRA - Please refer to your FRA's manual or the Bode 100 manual
2. Turn off the DC power supply A and B and the J2103A power
3. Set and connect the DUT to the FRA and the J2103A
4. Connect the input terminal (Vin) of the J2103A to the Vout of the DUT
5. Connect the J2103A output terminal to the control loop terminal of the DUT (Vcomp)
6. Connect the J2103A reference terminal (Vref) to DC power supply B
7. Turn on the J2103A and DC power supply B, and set Vref=0V
8. Turn on the DC power supply A, and set the input voltage of the DUT
9. Adjust the Vref voltage until the output voltage of the DUT is equal to the target voltage (Vout=Vref x 10)
10. Use the FRA to measure the power supply's open-loop gain. The J2103A is used to break the control loop of the power supply

**NOTE**: When using the Picotest J2120A line injector, there is a DC drop from Vdc to the output. This DC drop across the J2120A is load current dependent. This drop will be dependent on the input impedance of the DUT (load current drawn). You will need to verify this DC drop is accounted for in the input voltage setting on Power Supply A, as shown in Figure 3 and in Figure 4. More details can be found by referencing the application note titled "Remote Sensing to Remove Non-linear DC Drop Due to Line Injector J2120A" [1].

**NOTE:** The Vref input into the J2103A needs to be set as per EQ(3) below.

$$V_{out} = V_{ref} \times 10 \tag{3}$$

Figure 4 shows an example open-loop setup with the TPS7H4003 buck regulator with the J2103A. This demonstrates the connections between the buck regulator and the J2103A prior to adding the FRA and probes needed for measurement. For the TPS7H4003 buck regulator, a wire is soldered onto the Vcomp pin of the TPS7H4003, the J2103A is connected to this wire, as shown in Figure 4.

As shown by the P9611A power supply display in Figures 4 and 5, the voltage is set to 0.1V, which is input into Vref of the J2103A. This voltage is 1/10th of the 1V Vout from the TPS7H4003 buck regulator on the TI evaluation board.

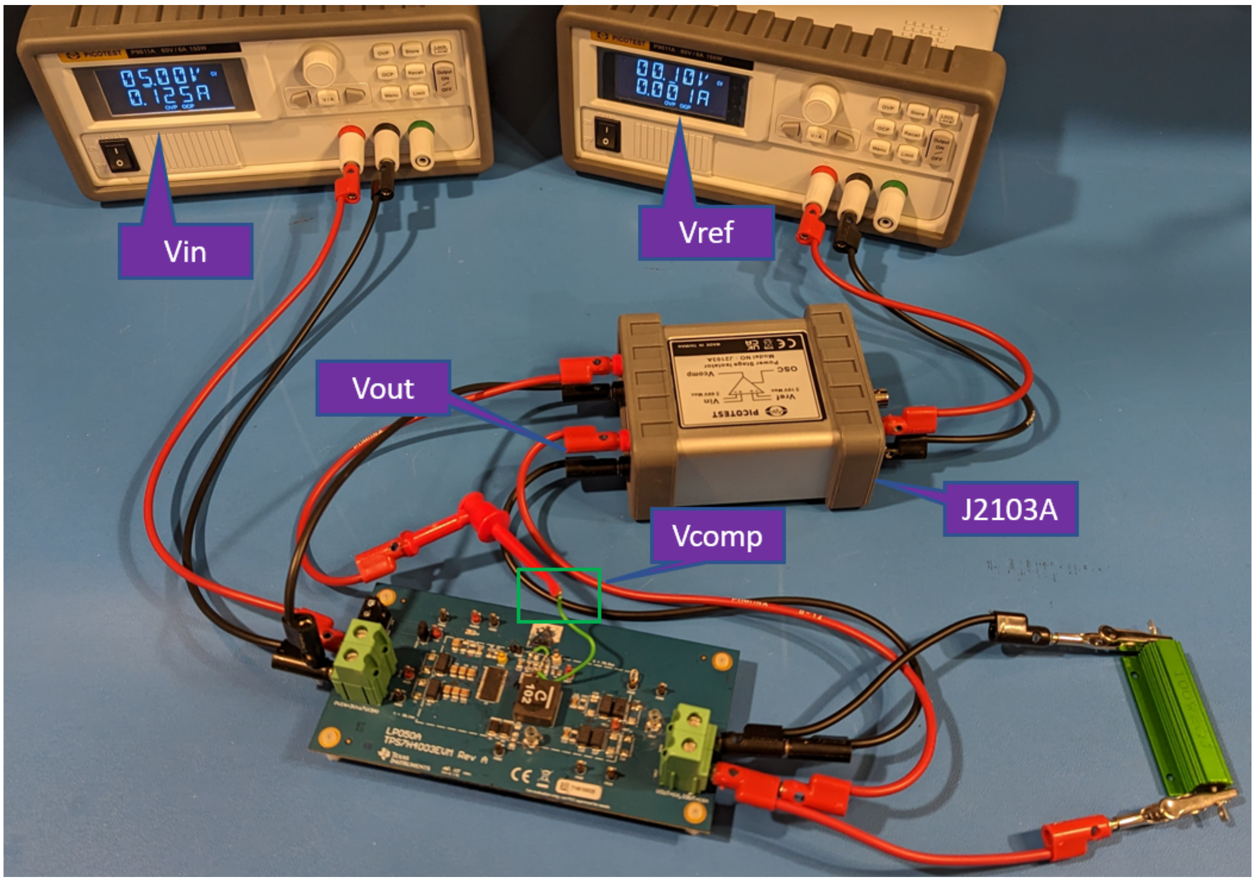
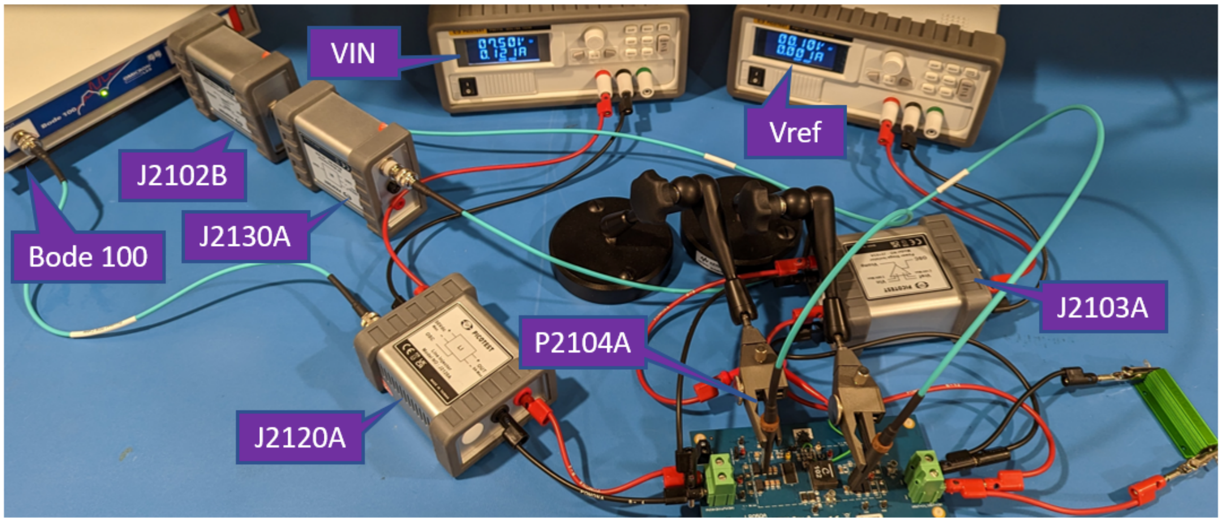



**Figure 4 - TPS7H4003 Power Supply Open-Loop Test Setup with the J2103A.**

In Figure 5, a Picotest J2102B common mode transformer is used to help mitigate the ground loop that exists due to the ground loops created by the FRA connections. This ground loop is present in all FRAs and oscilloscopes with FRA features. So the J2102B is necessary. The J2130A is included on the small signal side of the measurement setup, as a DC block, to isolate the small AC signal going into CH1 of the Bode 100.



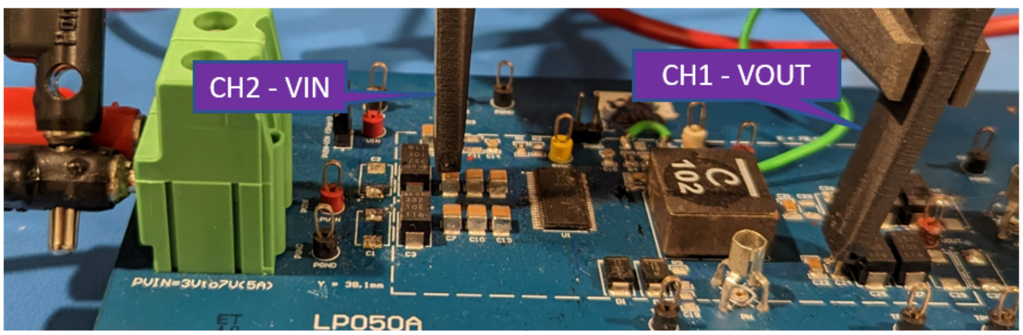




**Figure 5 - TPS7H4003 Power Supply Open-Loop Measurement Setup with the J2103A and the Bode 100 [2]. Two 1-port P2104A probes are shown (below image) connected to the input and output of the DUT.**

The results of the measured open-loop gain and closed-loop PSRR of the TPS7H4003 are shown in Figure 6.

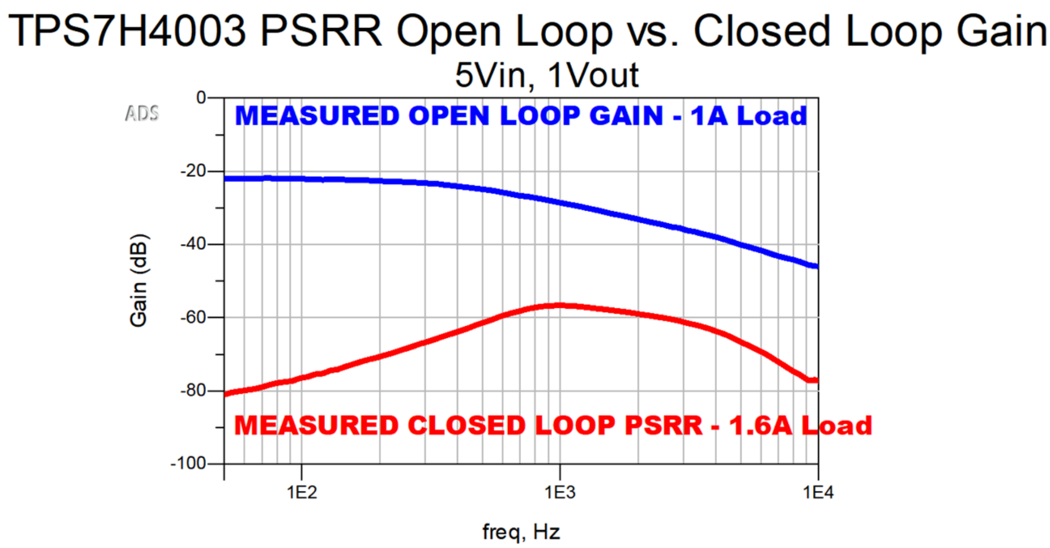



**Figure 6 - TPS7H4003 Open-Loop Gain and PSRR Measurement Result with the J2103A and Bode 100 [2].**

By measuring the open-loop gain of the TPS7H4003 power supply, a designer can use a simulation tool, such as Keysight PathWave ADS, to further tune a State-Space Average VRM model's open-loop gain, to match the measured open-loop gain response. An example of this result is shown in Figure 7. This measurement allows a designer to verify if a power supply's slope compensator and Ri terms, input variables to the power supply open-loop gain, are correct. This data is often not available, any other way, except by direct testing. More details on how to use the J2103A to build the Sandler State-Space Average VRM model version in Keysight PathWave ADS can be found at [2].

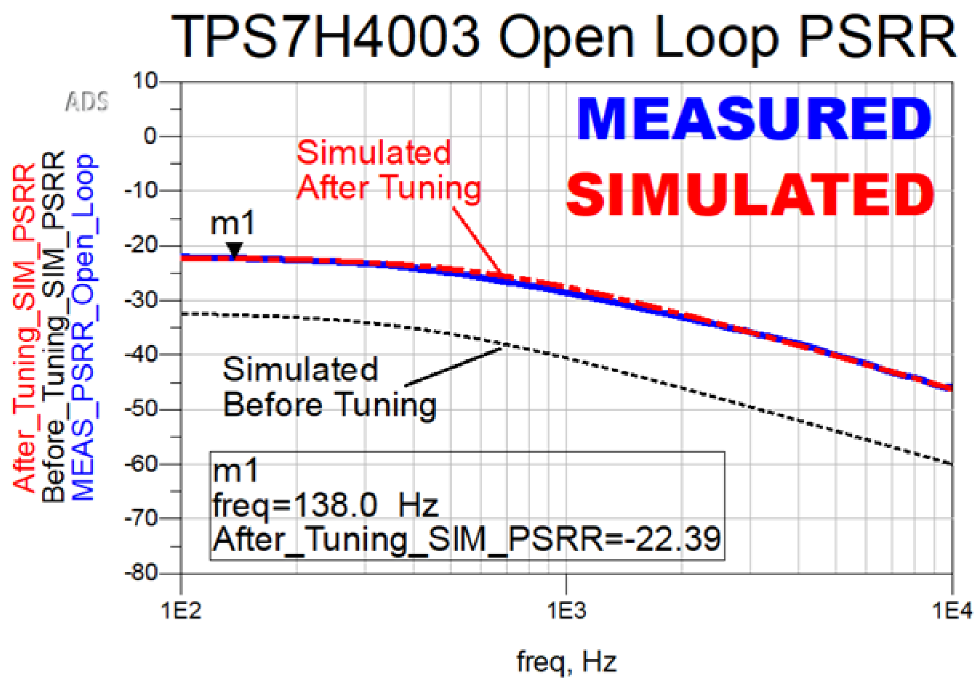



**Figure 7 - Tuning the Simulated TPS7H4003 Open-Loop Gain to Match Measurement [2]. The model uses the Sandler state space average model topology.**

## 3.0 Measurement Setup for Power Supply Control Loop Gain

A simple diagram for how to set up the measurement of the Power Supply Control Loop Gain with the J2103A and an FRA is depicted in Figure 8. Table 2 provides a more detailed list of the measurement setup and test equipment shown in Figure 5. In Figure 8, the DUT, shown in Figure 9, is the Picotest J2103A Power Stage Isolator Demo Board. Figure 10 depicts the actual measurement setup with the J2103A, Bode 100, and P9611A Power Supply.

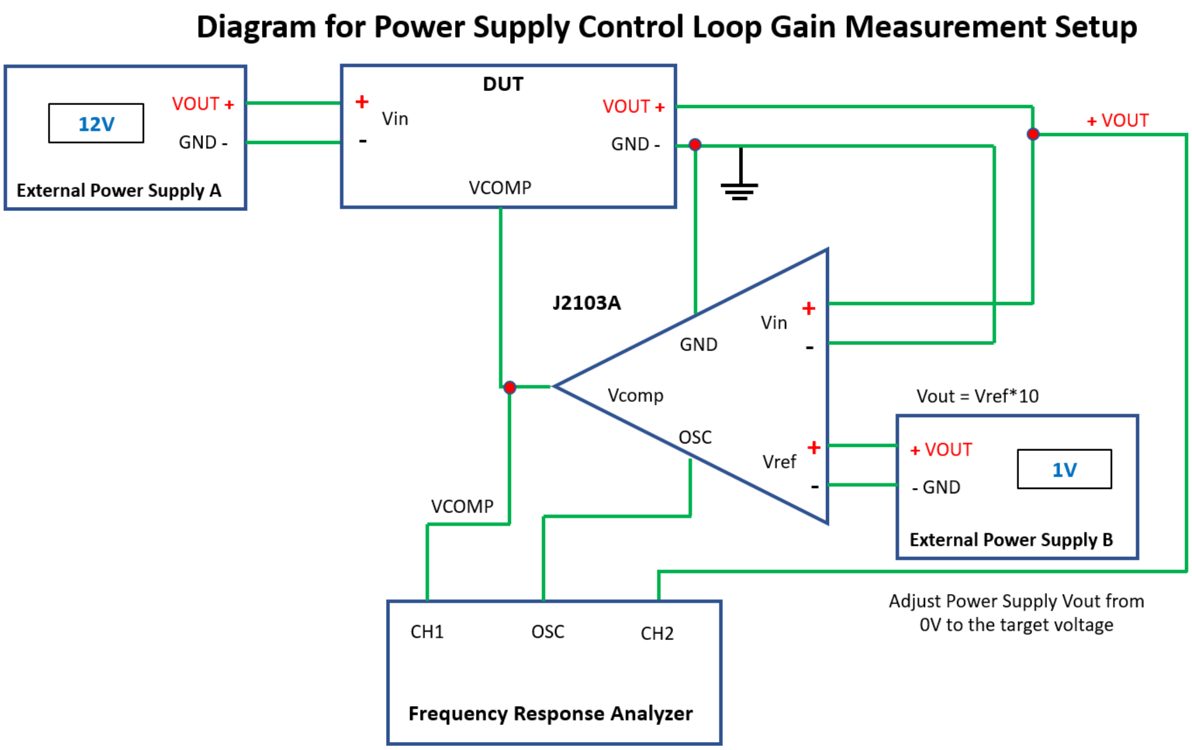



**Figure 8 - Diagram for Power Supply Control Loop Gain Setup with the J2103A and FRA.**

**Table 2 - Test Equipment List for Measuring Power Supply Control Loop Gain**

| Description | Model | QTY |
|---|---|---|
| Power Stage Isolator | Picotest J2103A | 1 |
| Power Supply | Picotest P9610A/P9611A or equivalent | 2 |
| Frequency Response Analyzer/VNA | OMICRON Lab Bode 100 | 1 |
| Common Mode Transformer | Picotest J2102B* | 1 |
| PDN Cable | Picotest PDN Cable 0.25-BNC-BNC* | 3 |
| Picotest Power Stage Isolator Demo Board | Picotest Test Board | 1 |

**NOTE: (*)** In many cases you do need the J2102B and the PDN cable to minimize the ground loop, depending on the magnitude of the PSRR.

**Step-by-Step Instructions for Control Loop Gain Measurement with J2103A**

1. Calibrate the FRA
2. Turn off DC power supply A, B, and the J2103A power
3. Set and connect DUT to the FRA and the J2103A
4. Connect the input terminal (Vin) of the J2103A to the Vout of the DUT
5. Connect the J2103A output terminal to the control loop terminal of the DUT (Vcomp)
6. Connect the J2103A reference terminal (Vref) to DC power supply B
7. Turn on the J2103A and DC power supply B, and set Vref=0V
8. Turn on the DC power supply A, and set the input voltage of the DUT
9. Adjust the Vref voltage until the output voltage of the DUT is equal to the target voltage (Vout=Vref x 10)
10. Use the FRA to measure the Power Supply Control Loop Gain while the small-signal oscillator voltage is injected by the J2103A OSC port into the power supply's control loop

**NOTE: The Vref input into the J2103A needs to be set as per EQ(3).**

After calibration, Figure 10 depicts the measurement setup with the J2103A, Bode 100, and P9611A power supply to measure the control loop of the buck converter with a 3.3V output on the Picotest J2103A Power Stage Isolator Demo Board shown in Figure 9. The J2103A, shown in Figure 10, depicts an early prototype version. The Power Stage Isolator Demo Board contains a Buck converter, a Zeta converter, and a Buck-Boost converter to allow evaluation with the J2103A. As shown by the P9611A power supply display, the voltage is set to 0.33V, which is input into Vref of the J2103A. This voltage is exactly 1/10th of the 3.3V Vout from the buck converter on the evaluation board.

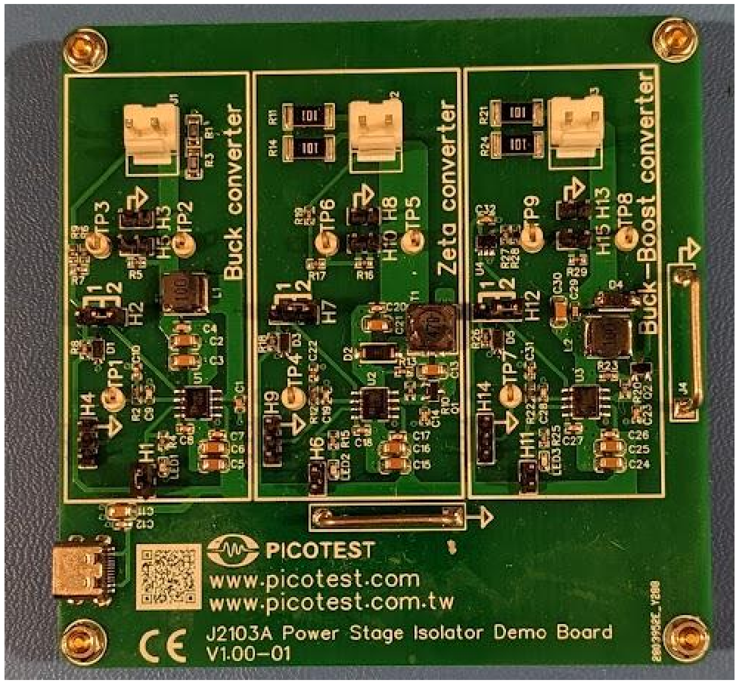



**Figure 9 - Picotest J2103A Power Stage Isolator Demo Board.**

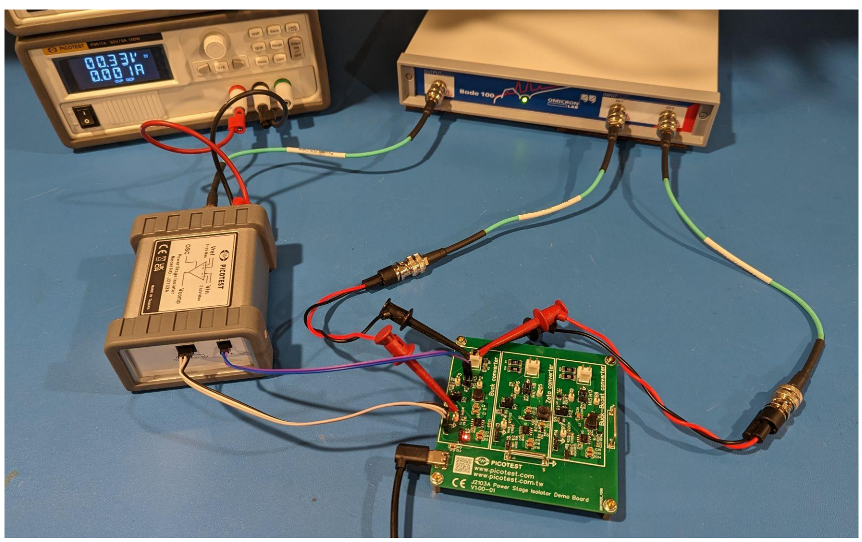



**Figure 10 - Power Supply Control Loop Measurement Setup of the Power Stage Isolator Board Demo Board with the J2103A and Bode 100 FRA/VNA.**

The results of the measured control loop gain and phase of the Picotest evaluation board buck converter are shown in Figure 11.

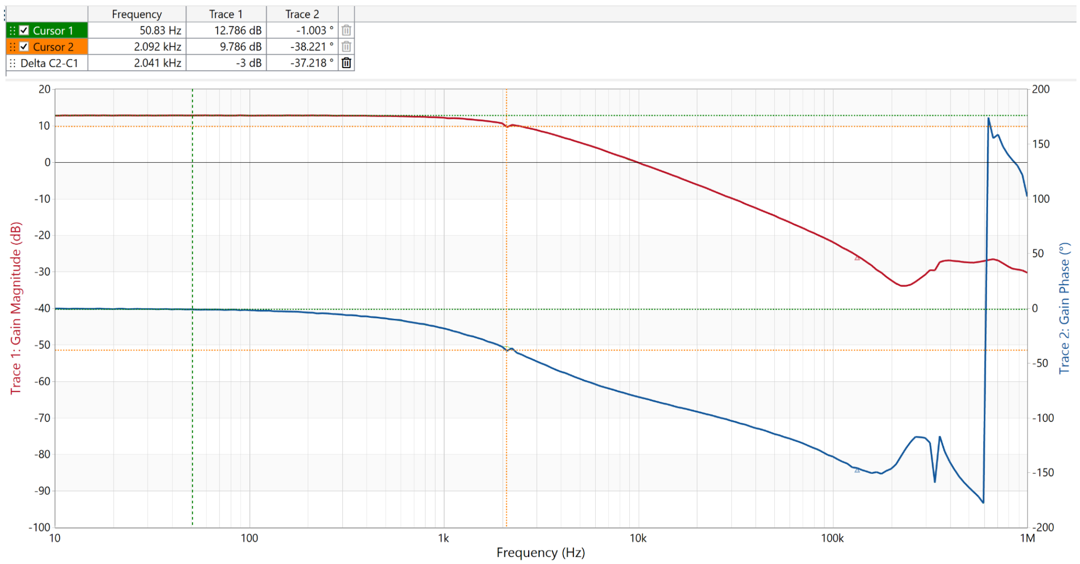



**Figure 11 - Power Supply Control Loop Measurement Setup with the J2103A and Bode 100.**

## 4.0 Measuring Power Supply Open-Loop Gain and Control Loop Gain for Other Power Supply Topologies with the J2103A

The J2103A can be used for measuring power supply open-loop gain and control loop gain for positive and negative power supplies in both negative and positive feedback configurations. Connection diagrams for these other power supply topologies with the J2103A are shown in Figures 12, 13, 14, and 15.

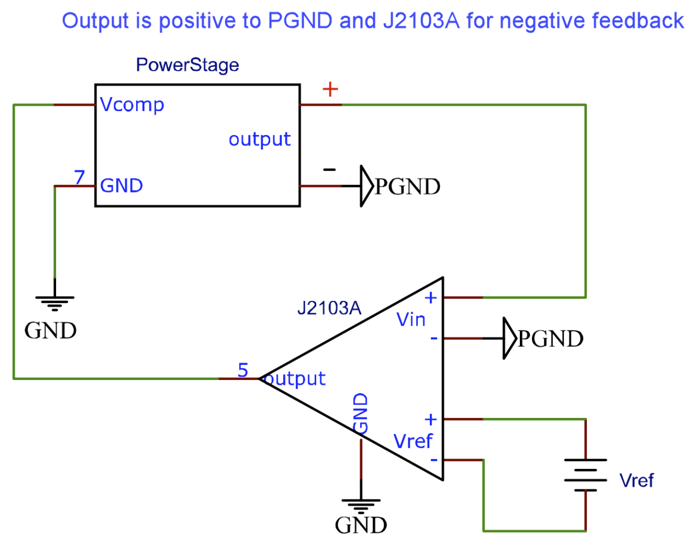



**Figure 12 - Connection Diagram for Positive Power Supply Output with Negative Feedback from the J2103A.**

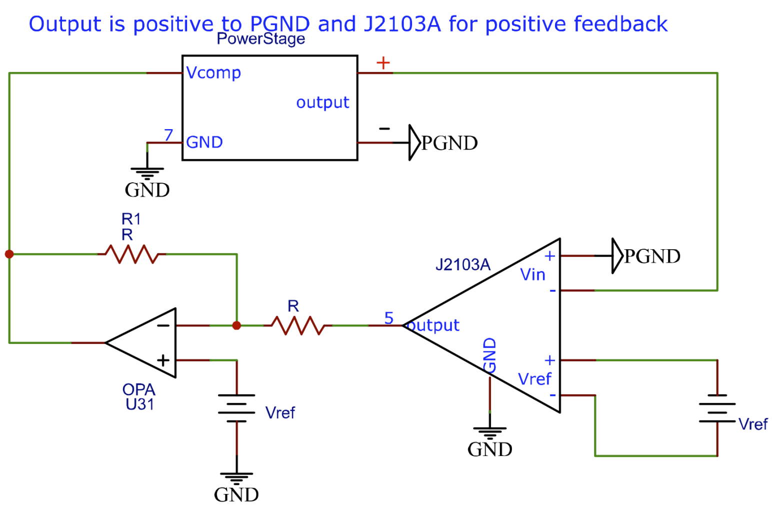



**Figure 13 - Connection Diagram for Positive Power Supply Output with Positive Feedback from the J2103A.**

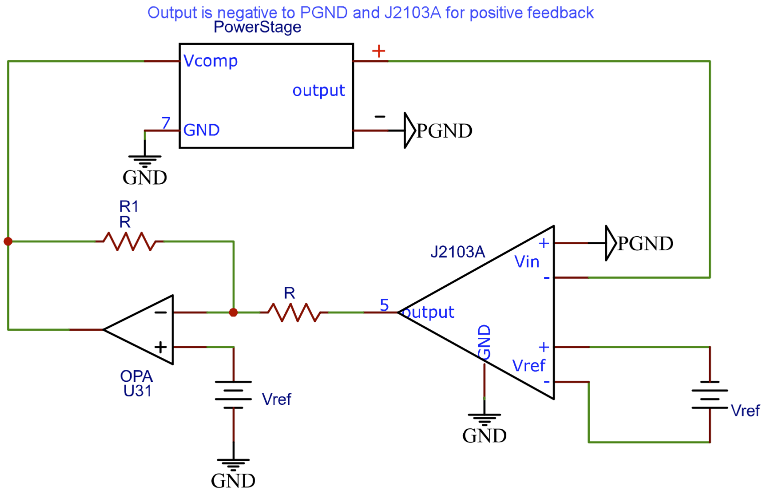



**Figure 14 - Connection Diagram for Negative Power Supply Output with Positive Feedback from the J2103A.**

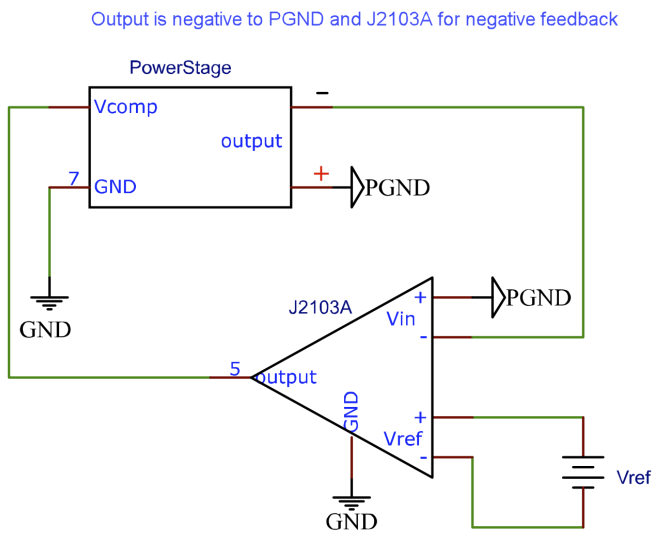



**Figure 15 - Connection Diagram for Negative Power Supply Output with Negative Feedback from the J2103A.**

## 5.0 Conclusion

The plug-and-play J2103A simplifies accurate open-loop and control loop gain parameters quickly and easily while using the Picotest P9611A/P9610A power supply with an FRA, such as the Bode 100. This is a powerful tool for power supply designers to be able to quickly access hidden parameters for their power supply design or to support accurate parameters for state-space average VRM modeling.

## 6.0 References


1. Application Note - Remote Sensing to Remove Non-Linear DC Drop Due to Line Injector J2120A - https://www.picotest.com/images/download/AppNoteRemoteSenseVer05Final.pdf, Also available at https://www.picotestonline.com/forum/welcome-to-the-forum/psrr-testing-with-the-j2120a-line-injector
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