

Power Analysis Demo Guide

LAB 5: FREQUENCY RESPONSE ANALYSIS

Control Loop Response (Bode Plot) and Power Supply Rejection Ratio (PSRR)



NOTE: Some minor details in the screen shots in this document may differ from the instrument you are using.

NOTE: Always use the latest instrument software for demonstrations. Go to www.tek.com/software and search for "5 Series MSO" software. Follow the installation instructions on the web page.

INTRODUCTION

The stability of a control loop determines the closed loop performance of most key aspects of the power supply.

An unstable power supply can oscillate, resulting in very large ripple, poor step load response, and excessive noise and EMI. A power supply does not have to be fully oscillating to be inadequate. The control loop stability controls PSRR, dynamic response and output impedance. Poor stability means that all these responses will also be poor.

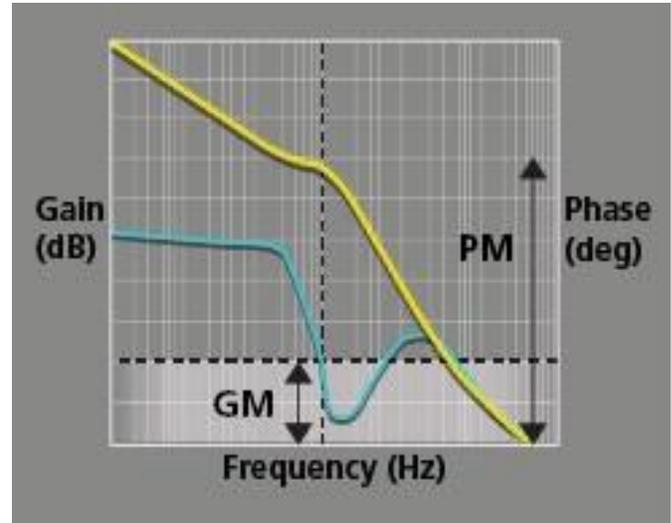
Because the performance is not simply pass or fail, and changes with part tolerances over the life of the power supply, it is extremely important to understand the initial performance.

The Bode plot is the generally accepted method for assessing the stability of a loop. A Frequency Response Analyzer, or FRA, is used to measure the Control Loop Response, popularly known as Bode plot, and the Power Supply Rejection Ratio (PSRR); two key metrics of power supply performance.

The Bode plot is ideally measured with a FRA but now, due to the addition of specialized software, can also be obtained using oscilloscopes, along with a built-in or external function generator.

The control loop response computes and plots gain as $20 \log(V_{out} / V_{in})$. Phase margin is measured at the gain crossover frequency, which occurs at the frequency where the gain plot crosses 0 db. The corresponding point on the phase plot gives the phase margin. The Gain Margin is calculated using the Phase Margin.

In this app note the Picotest VRTS1.5 demo board (adjustable regulator board) is used to demonstrate this test.



An injection transformer is used for connecting the FRA to the circuit being tested for control loop stability measurements. The goal of the transformer is to inject a signal into the control loop being measured, without impacting the performance of the loop. In order to accomplish this to a reasonable degree, the transformer is isolated and, therefore, is capable of floating on a high voltage, such as a Power Factor Corrector (PFC), which is often close to 400VDC.

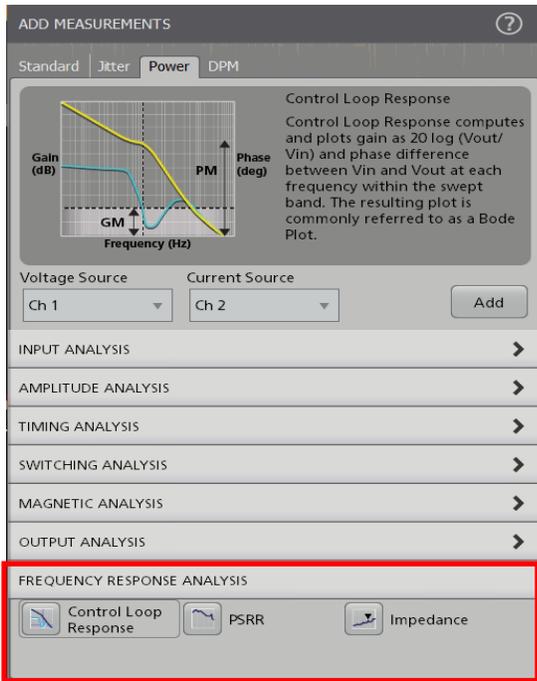
The usable bandwidth of an injection transformer is significantly greater than the 3dB frequency limits. Because the transformer bandwidth itself is outside of the measurement, it leads many to incorrectly believe that the transformer is a non-critical element.

The bandwidth of the transformer is strongly related to the terminating impedance. Most network analyzers provide a 50Ohm oscillator source impedance. Assuming this impedance, the optimal termination resistor is 5 Ohms. This significantly attenuates the injection signal, which is beneficial, as a common error in Bode measurements is using a signal which is too large, and therefore not a small signal measurement. An added benefit of this low value is that it can always be left in circuit, simplifying the connection to the network analyzer or scope without appreciably impacting the output voltage of the circuit being tested.

Picotest supports the oscilloscope stability testing with three injection transformer options for different circuit applications as discussed below.

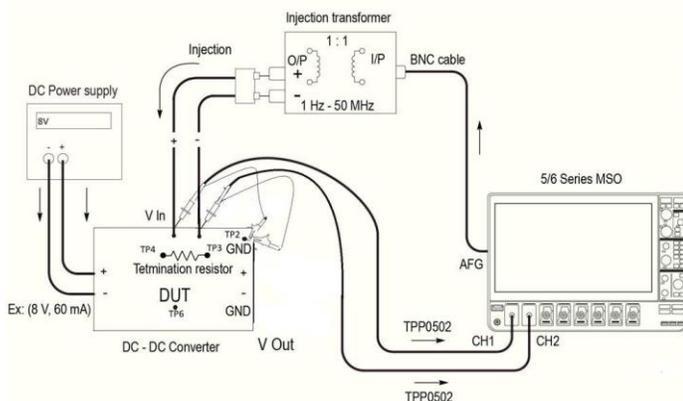
Control Loop Analysis

This guide provides step-by-step instructions and introduces the capabilities of the 5/6Series MSO FRA measurements.



The first step is to set up the test so that the injection signal from the built-in signal generator can be used to inject an AC signal into the control loop. An injection resistor (5-10 ohms) in the feedback path is required. An injection transformer is used to inject the signal across the resistor.

Shown below is the Bode plot measurement test setup.



What You Will Need

- ❑ MSO 54 / MSO 64, 5 series / 6 series MSO Scope
- ❑ 5-PWR /6-PWR Power Measurement and Analysis SW
- ❑ 5 -AFG / 6-AFG Arbitrary / Function Generator
- ❑ Two TPP0502 500 MHz, 2X TekVPI® passive voltage probe
- ❑ Picotest Injection transformer (<https://www.picotest.com/tektronix.html>) to inject signal from the AWG into your control loop through your injection resistor
 - Picotest J2100A 1Hz - 5MHz, supports PFC regulators 5MHz high enough for most supplies, low distortion, 5 Ohm termination for minimum impact to loop
 - Picotest J2101A 10Hz – 45MHz, 10Hz supports off-line power supplies, 45MHz high enough for state-of-the art regulators
 - Picotest J2110A Active Injector DC-45MHz
- ❑ Sample DUT Board: Picotest makes two good training test boards - VRTS1.5 (left) and the VRTS3 (right)



These demonstration boards are self-contained and designed to support a wide range of typical distributed power system measurements including Bode plots and PSRR. Input power is provided via a USB port.

- 1 BNC-BNC Cable
- 2 sets of banana plug to mini-grabber cables
- DC Power supply (Keithley 2230-3-1 or 8V/min)

Objectives

- Obtain a basic understanding of the FRA and PSRR measurements in a power supply.
- Learn how to make FRA measurements with a 5 /6 Series MSO oscilloscope.

CONTROL LOOP MEASUREMENT

This demo setup requires the use of two TPP0502 probes to measure the Bode plot.

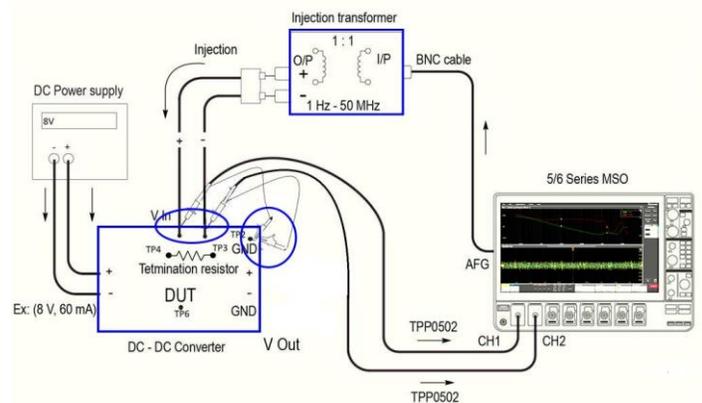
Setting up:

- ❑ Select Measure Menu of the 5 Series Scope and verify the PWR option is available. Under the PWR tab Control Loop Analysis there are three measurements; FRA, PSRR and Impedance.
- ❑ Push the front panel **Default Setup** button of the 5 Series Scope to set the oscilloscope into a known state.
- ❑ Tap the **Add New Measure** button in the upper right corner of the display to launch the Measurement configuration menu.
- ❑ Tap the **Power** tab at the top of the menu.
- ❑ Tap the **Frequency Response Analysis** panel title to display the panel.
- ❑ Tap the **Control Loop Analysis** measurement button.
- ❑ Connect a TPP0502 probe to channel 1 of the oscilloscope and connect the + input of the probe to the **TP4** (1) test point.
- ❑ Connect the - input of the probe to the GND test point at TP6/TP2.
- ❑ Connect the 2nd TPP0502 probe to channel 2 of the oscilloscope and connect the + input of the probe to the **TP3** (2) test point as shown above.
- ❑ Connect the – input of the probe to the TP2/TP6 GND test point at the top of the board.
- ❑ Connect the oscilloscope AFG Out to the input of Picotest J2101A injection transformer using a BNC Cable.
- ❑ Connect the injection transformer output to the Picotest VRTS1.5 test board at the input test points to **TP4** (- Ve) and **TP3** (+ Ve).
- ❑ Connect a DC 7-10V power supply to the board.

Signal	Test points
AFG + J2101A	TP3 (Red lead) and TP4 (Black lead)
TPP0502 to Scope Ch1	TP4 (-Ve) and GND TP2/TP6
TPP0502 to Scope Ch2	TP3 (+Ve) and GND TP2/TP6
DC Power Supply to VRTS1.5	TP1 (+Ve) and GND TP2/TP6

Note: Please make sure switch 1 is on and 2 is off for a successful Bode demo. Use a short lead between J2101A and LDO.

Refer to the below setup diagram and check all these above connections and test points of Picotest LDO board and injection transformer.



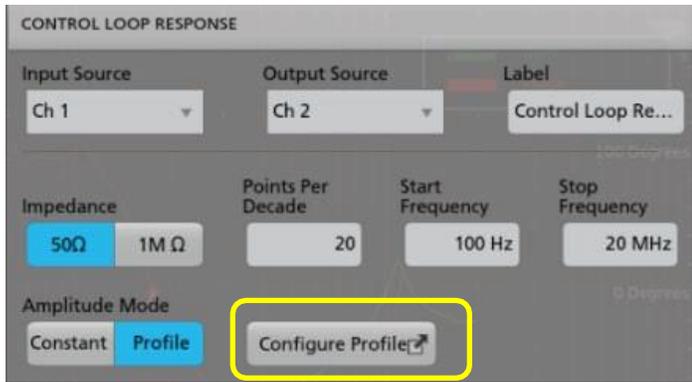
- ❑ Tap the **Add** button.
- ❑ Tap outside the configuration menu to dismiss it.

Actual connection:

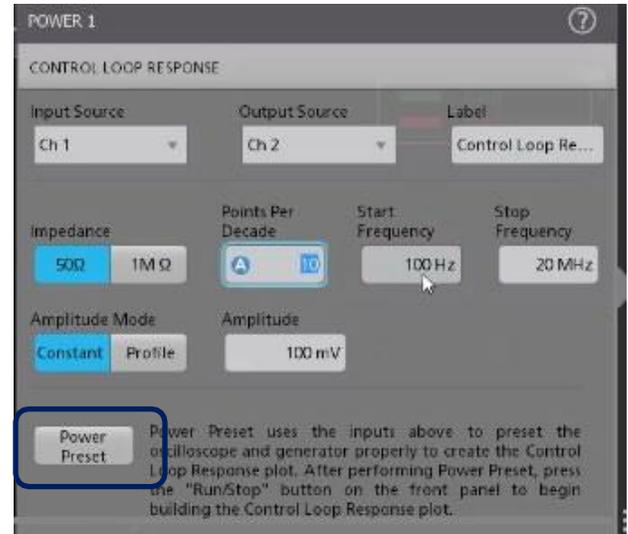


- ❑ Double-tap the Power 1 measurement results badge in the Results Bar to launch the configuration menu.

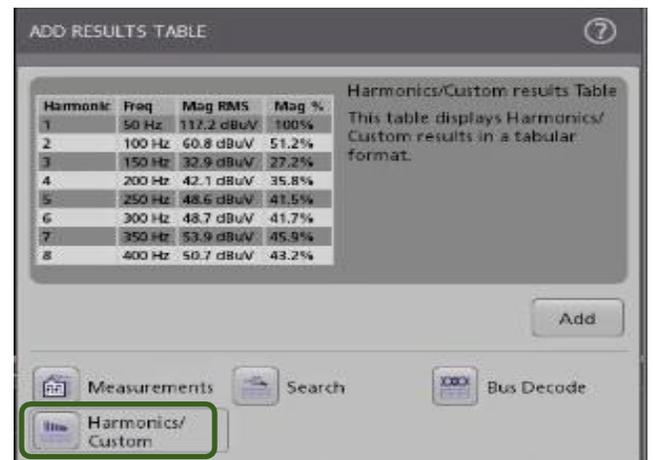
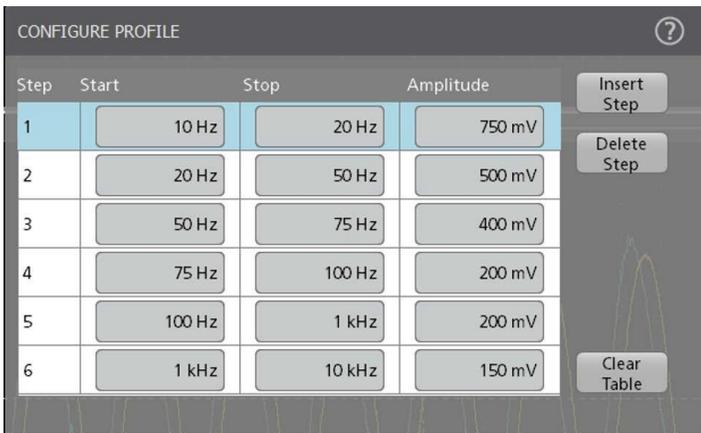
Note: If the software shows the Phase Margin first, please check connections and re-run the test. Note: the voltage reference is connected to the output voltage and not to ground. For this reason, the measurements for both Ch1 and Ch2 are referenced to Vout and not ground. In most of the applications the probes will connect to ground.



- Application supports Constant and Profile Amplitude methods. The constant amplitude means the same amplitude is applied at all injection frequencies. The profile amplitude applies different amplitudes over each frequency band.



- Tap the Result Table and select Harmonics table button.



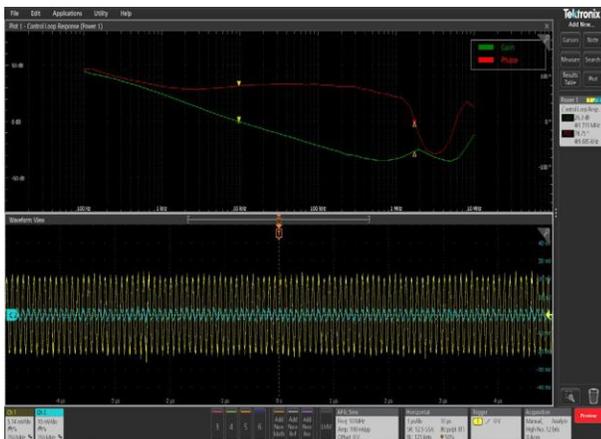
- The start and stop frequency, amplitude, and points-per-decade determine the stimulus the generator will inject into the control loop.
- Amplitude profile configuration enables designers to improve the SNR (Signal to Noise Ratio) by customizing the injection signal amplitudes for each frequency band.
- Users can inject lower amplitudes at frequencies where the DUT is sensitive and inject higher amplitudes where the response is less sensitive to distortion.
- Configure start and stop frequency values and set the amplitude values under Constant profile.

- Click on the Power Preset button to start the measurement.
- Select front panel Run button.
- Preset will automatically enable the profile values on the AFG as set earlier.
- The measurement will start, and the Phase and Gain curves will display on the Scope screen.

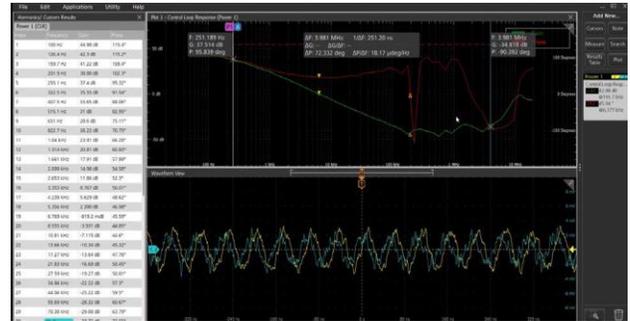


Index	Frequency	Gain	Phase
1	100 Hz	44.98 dB	115.4°
2	126.4 Hz	42.3 dB	115.2°
3	159.7 Hz	41.22 dB	108.4°
4	201.9 Hz	38.88 dB	102.3°
5	255.1 Hz	37.4 dB	95.32°
6	322.5 Hz	35.55 dB	91.54°
7	407.5 Hz	33.65 dB	88.06°
8	515.1 Hz	31 dB	82.95°
9	651 Hz	28.6 dB	75.11°
10	822.7 Hz	26.22 dB	70.75°
11	1.04 kHz	23.91 dB	66.28°
12	1.314 kHz	20.81 dB	60.83°
13	1.661 kHz	17.91 dB	57.99°
14	2.099 kHz	14.98 dB	54.58°
15	2.653 kHz	11.86 dB	52.3°
16	3.353 kHz	8.767 dB	50.01°
17	4.238 kHz	5.629 dB	48.62°
18	5.356 kHz	2.398 dB	46.98°
19	6.769 kHz	-819.2 mdB	45.59°
20	8.555 kHz	-3.931 dB	44.85°
21	10.81 kHz	-7.115 dB	44.6°
22	13.66 kHz	-10.34 dB	45.32°

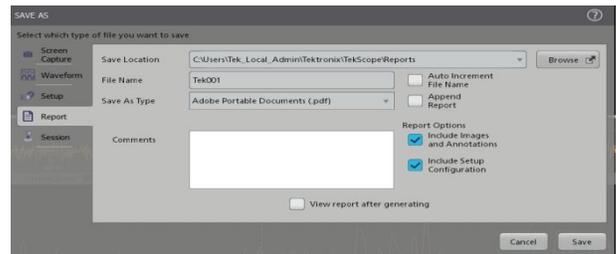
- ❑ Gain curve crosses zero dB, and the Phase Margin is calculated.
- ❑ Phase curve crosses zero-degree and the value of the Gain margin is calculated.



- ❑ Bode plot showing Gain and Phase margin and Table results at various frequencies is shown above.



- ❑ Users can save session files for future reference.

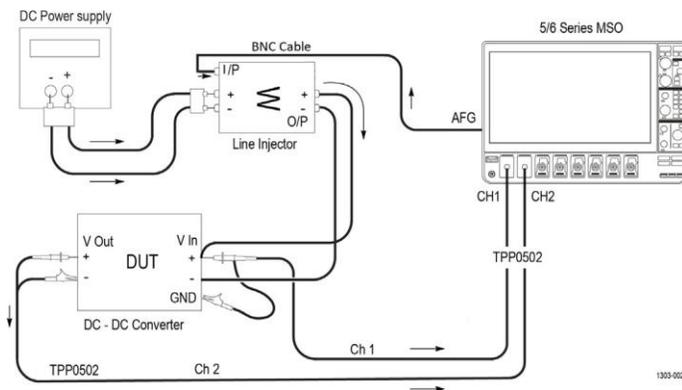


- ❑ Reports can be saved in PDF/mht format as shown.

Power Supply Rejection Ratio

To perform a PSRR test, sinusoidal ripple is summed with the DC input voltage. The frequency of the ripple is swept over a user defined bandwidth. A DC + AC summing device, such as Picotest's J2120A line injector, is required for this measurement.

The scope and associated software measures both the modulated input and output levels and then computes the rejection ratio (gain or attenuation) as $20\log(V_{in}/V_{out})$ at each frequency within the swept band. The diagram shows the PSRR test setup.



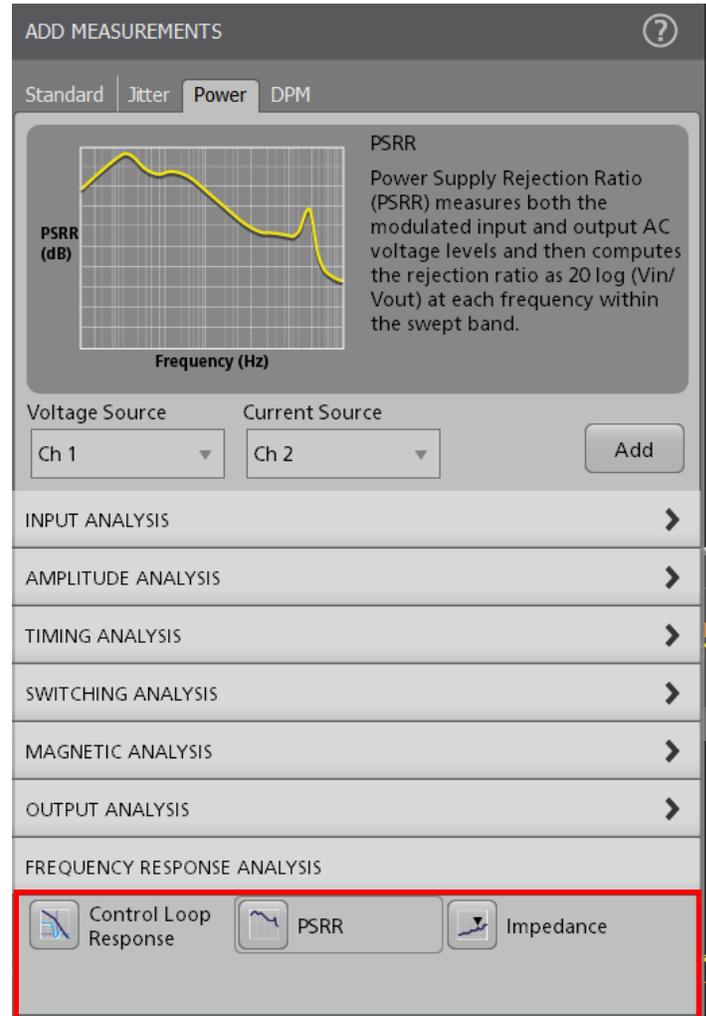
- ❑ A line injector allows the input DC supply voltage to be AC modulated by the signal source signal. It must be capable of modulating over the frequency of interest as well as supporting the DC voltage and DC current requirements of the DUT.

RECOMMENDED SETUPS

- ❑ MSO 54 / MSO 64, 5 series / 6 series MSO Scope
- ❑ 5-PWR /6-PWR Power Measurement and Analysis SW
- ❑ 5 -AFG / 6-AFG Arbitrary / Function Generator
- ❑ Two TPP0502 500 MHz, 2X TekVPI® passive voltage probes
- ❑ Line Injector
 - Picotest J2120A Line Injector – Maximum input voltage 50V/5A, Variable voltage drop 1.5-3.5V, Modulation input impedance 10k Ohms, Usable bandwidth 10-10MHz
 - Picotest J2121A Line Injector – High powered, Maximum input voltage 400V/20A, isolated current monitor, regulated voltage drop 0.75V, Modulation input impedance 50 Ohms, Usable bandwidth 10-1MHz

PSRR MEASUREMENT

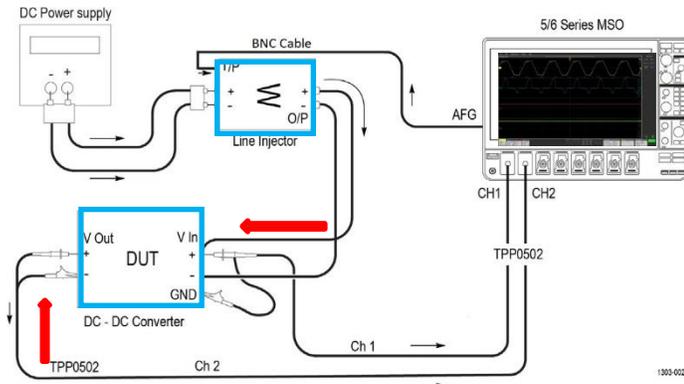
- ❑ Select Measure Menu of the 5 Series Scope and verify the PWR option is available. Under the PWR tab Frequency Response Analysis has three measurements; Control Loop Response (Bode plot), PSRR, and Impedance.



- ❑ Push the front panel **Default Setup** button of the 5 Series Scope to set the oscilloscope into a known state.
- ❑ Tap the **Power** tab at the top of the menu.
- ❑ Tap the **Frequency Response Analysis** panel title to display the panel.
- ❑ Double click the PSRR measurement button.
- ❑ Or select PSRR and tap the **Add** button.
- ❑ Tap the **Add New Measure** button in the upper right corner of the display to launch the Measurement configuration menu.
- ❑ Or right click Power 1 and select Configure Power 1.

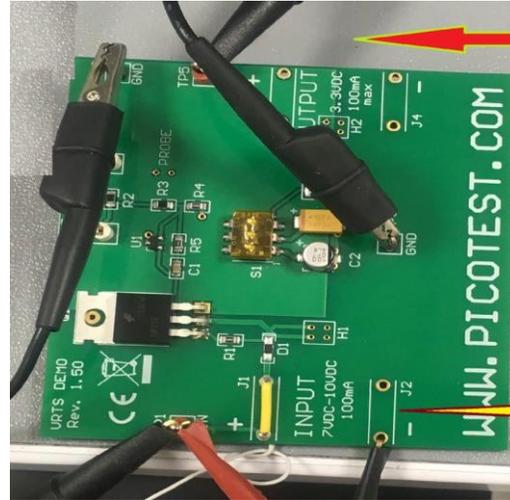
- ❑ Verify that the **Input Source** is set to **Ch 1** and the **Output Source** is set to **Ch 2**.
- ❑ Tap outside the configuration menu to dismiss it.

Refer to the setup diagram below and verify that all the connections and test points for the Picotest VRTS1.5 board and line injector are set as required.

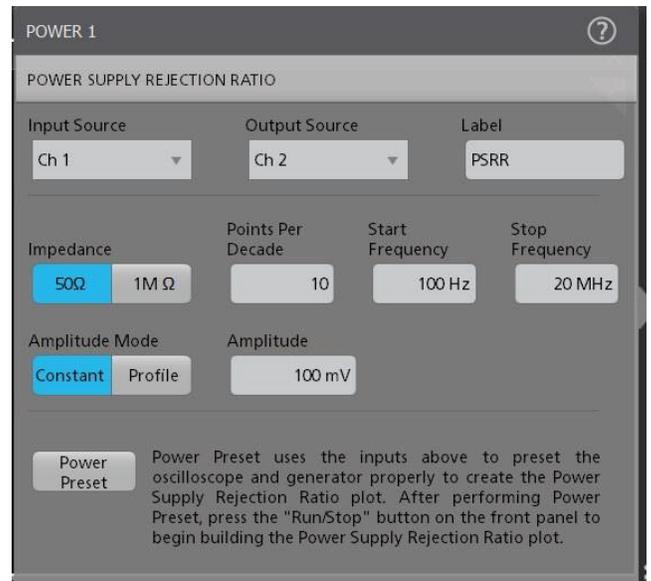


SETTING UP THE DUT FOR PSRR

- ❑ Push the front panel **Default Setup** button of the 5/6 Series Scope to set the oscilloscope into a known state.
- ❑ Connect a TPP0502 probe to channel 1 of the oscilloscope.
- ❑ Connect the + input of the TPP0502 probe to the **+INPUT** test point at **TP1**.
- ❑ Connect the - input of the probe to the **GND** test point.
- ❑ Connect the 2nd TPP0502 probe to channel 2 of the oscilloscope.
- ❑ Connect the + input of the TPP probe to the **+OUTPUT** test point i.e. **TP5** as shown above.
- ❑ Connect the - input of the TPP probe to the **GND** test point at the top of the board.
- ❑ Connect oscilloscope AFG Out to the input of Picotest J2120A line injector using a BNC cable.
- ❑ Connect a DC 7V-10V power supply to the input of the J2120A.
- ❑ Connect the output of the J2120A to the input of the demo board, **Positive to +Vin, Negative to -Vin**.

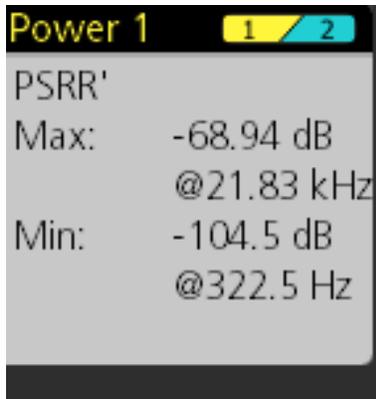


- ❑ Verify that the **Input Source** is set to **Ch 1** and the **Output Source** is set to **Ch 2**.
- ❑ **Application supports constant and profile amplitude methods.** The constant amplitude means the same amplitude is applied at all frequencies. The profile amplitude applies different amplitudes at each frequency band.
- ❑ Configure start and stop frequency values and set the amplitude values under Constant profile.
- ❑ Click on the Power Preset button to start the measurement.
- ❑ Select front panel Run button.
- ❑ Preset will automatically enable the profile values on the AFG as set earlier.

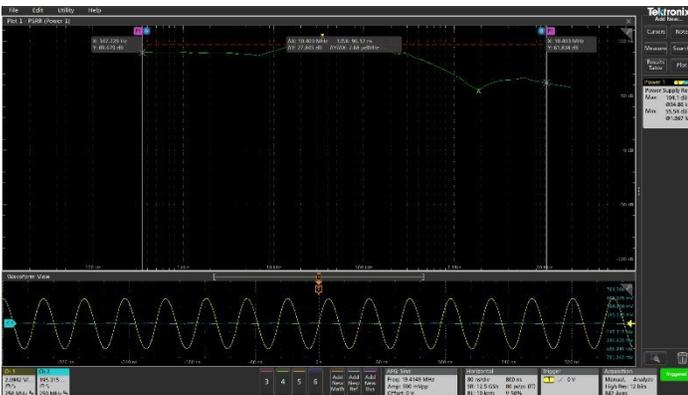


- ❑ The user can choose between two amplitude modes such as constant or profiled amplitude.

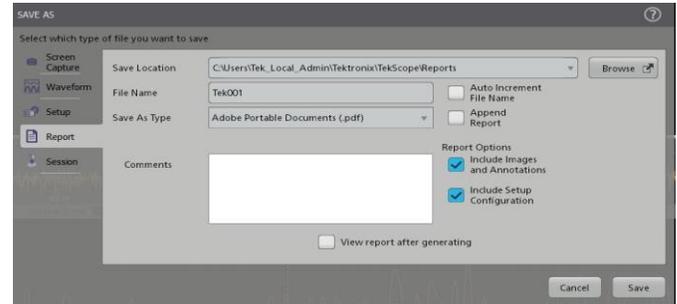
- ❑ The measurement will start, and the curve will display on the Scope screen. The measurement badge shows the Max and Min PSRR values with frequencies.



- ❑ Shown below is a sample PSRR plot using the Picotest VRTS1.5 board.



- ❑ The user can save the session files for future reference.
- ❑ Reports can be saved in PDF/mht format.



- ❑ Report generated in PDF format.

Visit this link to view the Power App note:

<https://www.tek.com/document/application-note/power-supply-measurement-and-analysis-4-5-6-pwr-application-software>

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