PICOTEST

Signal Injectors

Documentation

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Chapter 1 - Overview

Welcome

Thank you for purchasing Picotest Signal Injectors.

Regulator and SMPS applications today are much more demanding than ever. Today's designs require increases in switching frequency and bandwidth, higher efficiency and lower standby current. A high resolution, high fidelity test setup is more critical than ever to getting the accurate measurements you need.

Picotest Signal Injectors are designed to greatly improve the accuracy of your test results.

Summary of Benefits:

- More accurate voltage regulator and power supply measurements
- Ability to your test systems' stability and step load non-invasively
- Ability to your test systems' stability in the production circuit configuration
- Ability to make high fidelity PSRR measurements
- Ability to test Stability using Output impedance in circuits with the control loop cannot be easily broken.
- Ability to bias components under test
- Greatly reduce distortion in Bode and impedance measurements

What’s Included

Your Picotest Signal Injector set includes one or more of the following:

- **J2100A** Injection Transformer (1Hz-5MHz)
- **J2101A** Injection Transformer (10Hz-45MHz)
- **J2110A** Solid State “Bode Box” voltage injector with low noise high PSRR power adapter *
- **J2111A** Solid State current injector with low noise high PSRR power adapter *
- **J2120A** Line Injector
- **J2130A** DC Bias Injector
- **J2140A** Attenuators
- **J2150A** Calibrator
- **J2160A** Splitter
- **J2170A** High PSRR adapter
- **VRTS01** Voltage Regulator Test Standard kit*

* Note: the low noise, high PSRR power adapter, J2170A, can be used to power either the J2110A or the J2111A. No other power adapter may be used with these injectors. The other adapters do not require external power to be applied. One J2170A is included with each Signal Injector Bundle (set of Signal Injectors). One J2170A will be included with each J2110A or J2111A injector if they are purchased individually.

Documentation and Support

This documentation details the use of various Signal Injectors. Specifications for the individual injectors are also included.

The support section of Picotest’s web contains additional documentation and various publications on testing power supplies regulators and other equipments in the Picotest Signal Injector Set.

Warranty

Every Picotest product you buy from Picotest is backed by a 3 year product manufacturer’s warranty.

Calibration

The Signal Injectors do not require calibration.

Chapter 2 – Introduction to Signal Injectors

Introduction

Signal Injectors, also known as test adapters, or interface adapters are used to inject signals into various circuits so that the circuit's characteristics can be analyzed. Tests include Bode plot control loop analysis, circuit and component impedance measurements and conducted susceptibility measurements.

The network analyzer, sometimes referred to as a Frequency Response Analyzer (FRA) is a common piece of equipment in most of our labs today. Analyzers are used for a variety of tasks including stability analysis, component characterization and of course frequency response measurements. They can vary in features but regardless of the analyzer being used, the analyzer oscillator signal must be injected into the circuit being tested in order for a measurement to be made.

The quality of the test signal injector, or test adapter, and the injection method can have a direct impact on the test results. It is often the case that we see hobby store transformers used to inject signals into the loops of power supplies. In this case, the results are likely to be distorted due to the poor frequency response and impedance matching of the transformer.

It is critical that you understand the bandwidth limitations and the impedance of the test adapter, as well as, the impact of the injection signal magnitude on the measurement if you want to get accurate and repeatable test results.

In order to avoid many of the common test setup and measurement issues, several types of signal injectors are required each providing signal injection for a different type of test. These include injection transformers, solid state signal injectors (current and voltage), line injectors and other coupling elements.

The Picotest Injectors may be used with any network analyzer including those from Omicron, Agilent, Venable, Ridley and others. Please refer to the connection diagrams, shown with each injector, to see how each is interconnected with your test equipment.

Injection Transformers – J2100A & J21101A

The injection transformer is by far the prevalent method for connecting the network analyzer to the circuit being tested, and is primarily used for control loop stability measurements (Figure 1). 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, it is important to pick an injection point that is unaffected by the terminating impedance of the transformer, which is often in the range of 5 to 50 Ohms.

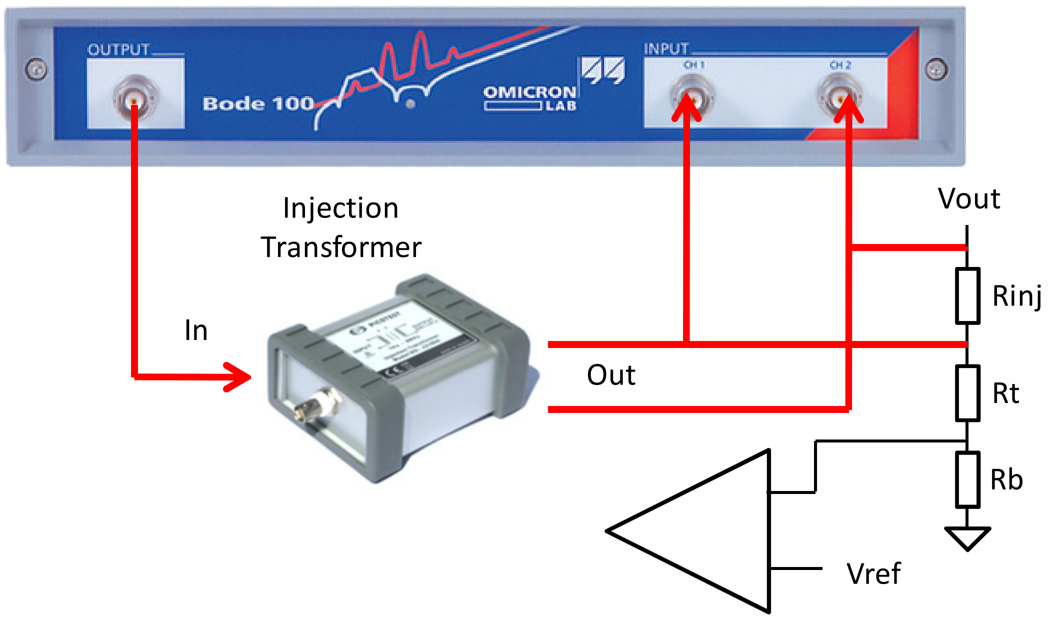


Figure 1: Sample setup for the injection transformer (J2100A or J2101A) used to perform stability measurements.

The transformer itself is outside of the measurement, leading many to incorrectly believe that the transformer is a non-critical element. The frequency range of the injection signal is dependent on the circuit being measured. The measurement of a typical Power Factor Corrector (PFC) control loop generally requires a measurement frequency of 1Hz or lower, as it is common for a PFC to have a control loop bandwidth of less than several Hz. The bandwidth of a high performance linear regulator can be as high as several MHz. While several different transformers can be used to address this range, it is beneficial to use a single transformer or two transformers covering different frequency bands at most, due to the high cost of the transformers.

The design of a transformer that has significant permeability at 1Hz and minimal attenuation at 10MHz or more is difficult to achieve. The core materials are quite expensive and the transformers generally must be hand wound. These issues combined with the relatively small market size dictate the high cost, since the development cost must be amortized over a small number of units. We regularly see engineers using audio transformers or hum eliminators as signal injectors. The result is that many programs suffer due to the incorrect results that are produced from the use of a poor injection transformer.

Solid State Voltage Injector – J2110A

While it is possible to obtain high quality injection transformers with bandwidths as wide as 1Hz to 5MHz or more, in some cases this is still insufficient for some tests. For example a typical heater control loop might have a bandwidth of less than 1Hz while some linear regulators and opamp circuits can have bandwidths of up to 100MHz or in some cases even higher. For these applications, a solid state injector can provide the necessary bandwidth. A solid state injector can perform at DC, while the upper frequency limit is dictated by the components selected and the printed circuit board material and layout. It is possible to obtain a solid state injector with a working range of DC – 200MHz, though above 50MHz the interconnection between the injector and the circuit being tested can become quite critical. It is essential that ripple from the injector power supply does not dramatically degrade the dynamic range or the signal to noise ratio of the measurement. The resulting plots are often much cleaner when using a solid state injector than with an injection transformer.

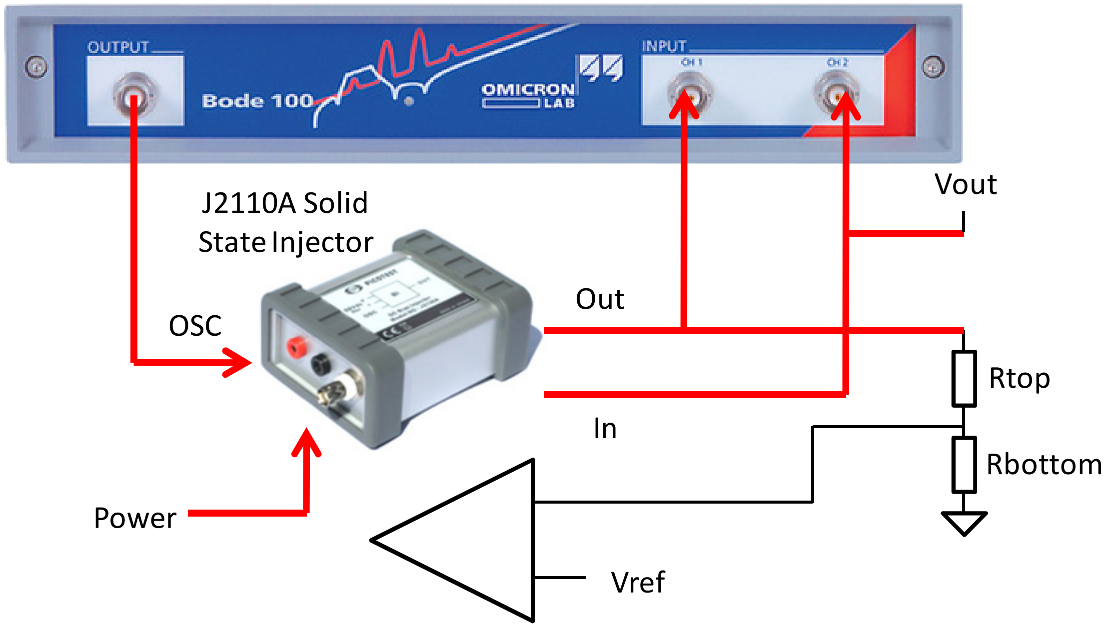


Figure 2: Sample setup for the solid state injector (J2110A) used to perform stability measurements.

The selection of a valid injection point in the circuit is more critical when using a solid state injector than with the transformer injector. The solid state injector presents an infinite impedance between the points of injection. In order to provide correct results one side of the measurement must present a much higher impedance than the other side. In a typical power supply control loop, the voltage sense divider is generally a good injection point, since the output impedance of the power supply is very low compared with the impedance of the voltage sense divider.

The solid state injector has a limitation in the operating voltage, with the majority limited to 10V or 12V. This is not the amplitude of the injection signal, but the DC operating voltage. While it is possible to use higher voltage opamps and precision matched dividers, the performance, including bandwidth suffers. Most applications requiring a solid state injector fall within these operational limits.

Solid State Current Injector – J2111A

The current injector is possibly the most versatile of the Signal Injectors. While it is not designed to replace an electronic load, it is capable of performing a small signal step load at switching speeds and bandwidth that electronic loads cannot. Also, the capacitance of an electronic load is generally too high to not impact the measurement.

Incorporating a 40MHz current monitor, the current injector can also be used to measure output impedance, as well as, the stability of a filter, combined with the negative resistance of a switching converter or power supply. An added benefit is that using a current injector, these measurements can all be made while connected to the system and non-invasively.

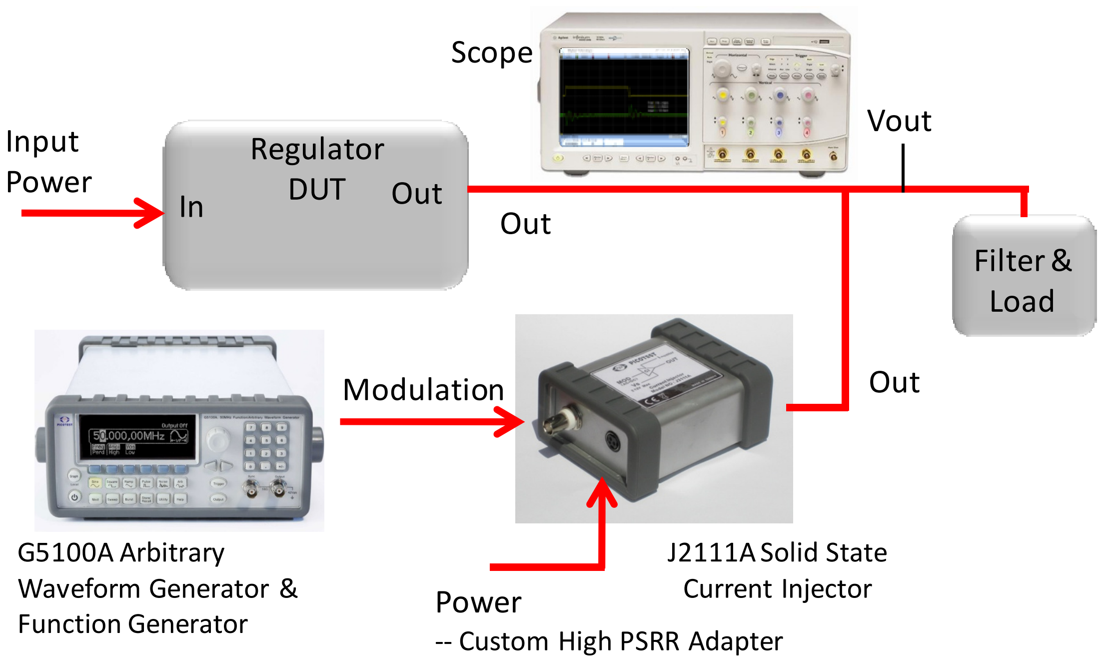


Figure 3: Sample setup for the Solid State Current Injector (J2111A) used to perform a non-invasive load transient measurement.

The current injector is a bilateral device, which works with positive or negative voltages and includes an internal bias for use with a network analyzer. The bias can be disconnected for use with an external waveform or arbitrary waveform generator such as the Picotest G5100A.

Line Injector – J2120A

While the injection transformer is a very wideband adapter, it is not useful for measuring ripple rejection (PSRR) of a power supply or even an opamp. This is because the attributes that make the injection transformer perform so well also result in a transformer that is absolutely intolerant of DC current. Even very small DC currents (5mA or less) can greatly reduce the signal capacity or even totally saturate the transformer. For this reason, the line injector is another essential test adapter.

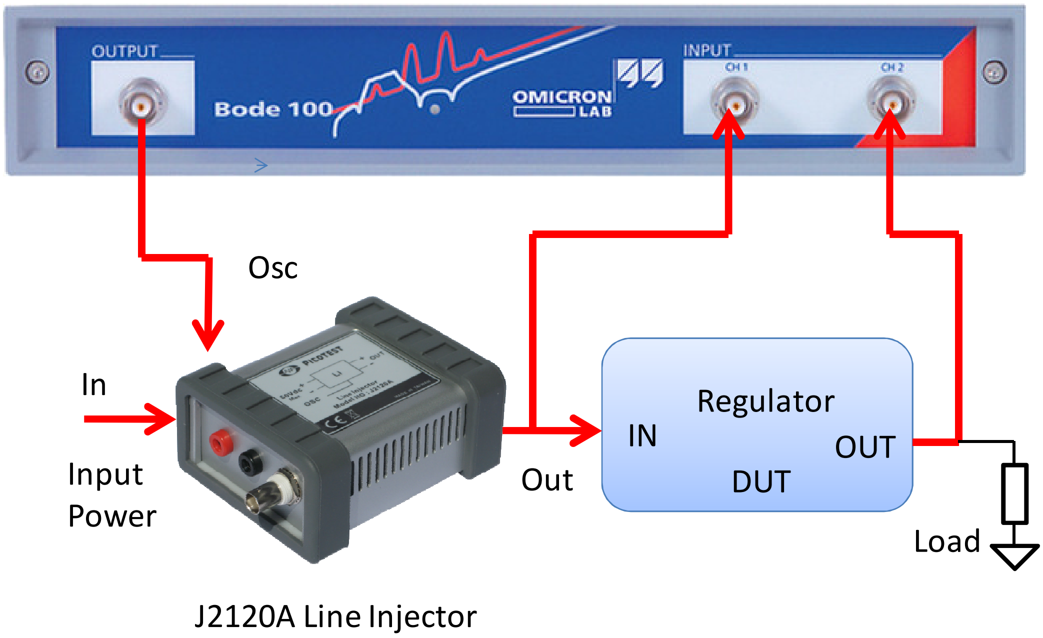


Figure 4: Sample setup for the Line Injector (J2120A) used to perform a PSRR measurement.

Bias Injector – J2130A

When using the network analyzer to measure impedance, such as the capacitance and ESR or a capacitor, or the DCR of an inductor, etc., it is often necessary to provide a voltage bias to the device being tested. This is true of semiconductor junction capacitances, varactors, and some ceramic capacitors (especially X5R). In these cases the impedance is a function of the DC bias on the device. The Picotest DC bias injector (J2130A) is used for this purpose during impedance measurements.

Attenuators – J2140A

There are two common uses for attenuators when used in conjunction with the network analyzer. One is to attenuate the oscillator source signal. While this may seem odd, one of the most common errors in analyzer measurements is using a source signal that is too large. Even though the analyzer allows setting of the signal output amplitude, the lowest setting is often too high to allow an accurate small-signal measurement to be made. The correct amplitude is the smallest amplitude that exceeds the noise floor.

Attenuators are also useful for improving the dynamic range of the measurement. In some cases, as in measuring the open loop gain of an opamp as one example, the low frequency loop gain will be extremely large (100dB or more is not uncommon). Attenuating the output signal increases the effective range of the measurement.

Chapter 3 - Signal Injectors: Measurements and Specifications

Injection Transformers

One of the most common tests performed by a network analyzer is the control loop stability measurement, or Bode plot. The injection transformer is the most prevalent method for connecting a network analyzer to the circuit in order to perform the stability measurements.

There are two different injection transformers, each with different overall bandwidths to support various types of applications.

Main Features

J2100A 1Hz-5MHz Transformer

- 1Hz supports PFC regulators
- 5MHz high enough for most power supplies and regulators
- 23 Octave range
- Low distortion for superior precision
- 5 Ohm termination for minimum impact to loop
- Includes attenuation to assure small signal measurement

J2101A 10Hz-45MHz Transformer

- 10Hz supports off-line power supplies
- 45MHz high enough for even state of the art regulators
- 23 Octave range
- Low distortion for superior precision
- 5 Ohm termination for minimum impact to loop
- Includes attenuation to assure small signal measurement

Description

The goal of the transformer is to inject a signal into the control loop being measured, *without impacting the performance of the loop*. The test is performed by inserting an oscillator signal into the control loop, allowing an OPEN LOOP measurement in a CLOSED LOOP system. The analyzer sweeps the frequency while measuring the voltage at each side of the transformer. One side of the transformer is the input signal while the other side is the output signal. The division of the two results in the loop gain and loop phase, or bode response. The transformer is isolated and, therefore, capable of floating on a high voltage, such as in a Power Factor Corrector (PFC) circuit, which is often close to 400VDC.

The usable bandwidth of an injection transformer is generally significantly greater than its 3dB frequency limits. This is because the transformer itself is outside of the measurement, leading many to incorrectly believe that the transformer is a non-critical element.

The bandwidth of the transformer is strongly related to the terminating impedance (i.e. the impedance of the instrument). The source impedance of the oscillator in the Omicron Bode-100, and most other network analyzers, is 50 Ohms. Assuming this impedance, the recommended termination resistor is 5 Ohms. This significantly attenuates the injection signal, which is generally beneficial, as a common error in Bode measurements is using a signal which is too large, and therefore, resulting in a measurement that is not a "small signal" measurement. This low value termination resistance also improves the low frequency bandwidth of the transformer.

An added benefit of this low value is that it can generally be left in the circuit at all times, simplifying the connection to the network analyzer without appreciably impacting the output voltage of the circuit being tested.

Today's power systems demand better measurements at both higher and lower frequencies. Engineers often use audio transformers or video transformers for signal injection purposes. This is unwise, as the low frequency performance of a video transformer is generally quite poor while both the low and high frequency performance of the audio transformer are quite poor. Many of the transformers sold as injection transformers use ferrite core materials, which are good for high frequency but relatively poor for high frequency.

The design of a transformer that has sufficient permeability at 1Hz and minimal attenuation at 10MHz or more is difficult to achieve. The core materials are specially processed and the transformers generally must be hand wound.

The Picotest injection transformers are capable of an impressive 23 Octave bandwidth. This bandwidth is still not sufficient to support all requirements, and so two transformers have been designed. One is optimized for performance from 1Hz to 10MHz while the other is optimized for 10Hz to 40MHz.

Either transformer is usable for most applications. The lower frequency transformer is usable for PFC measurements, where the bandwidth is generally below 10Hz while the higher frequency transformer is usable for the newest switch-mode converters and LDO's which have bandwidths up to several MHz.

While the injection transformer is a very wideband adapter, it is not useful for measuring ripple rejection (PSRR) of a power supply or even an opamp. This is because the attributes that make the injection transformer perform so well also result in a transformer that is intolerant of DC current. Even very small DC currents (5mA or less) can greatly reduce the signal capacity or even totally saturate the transformer.

Connecting the Injection Transformer: Stability

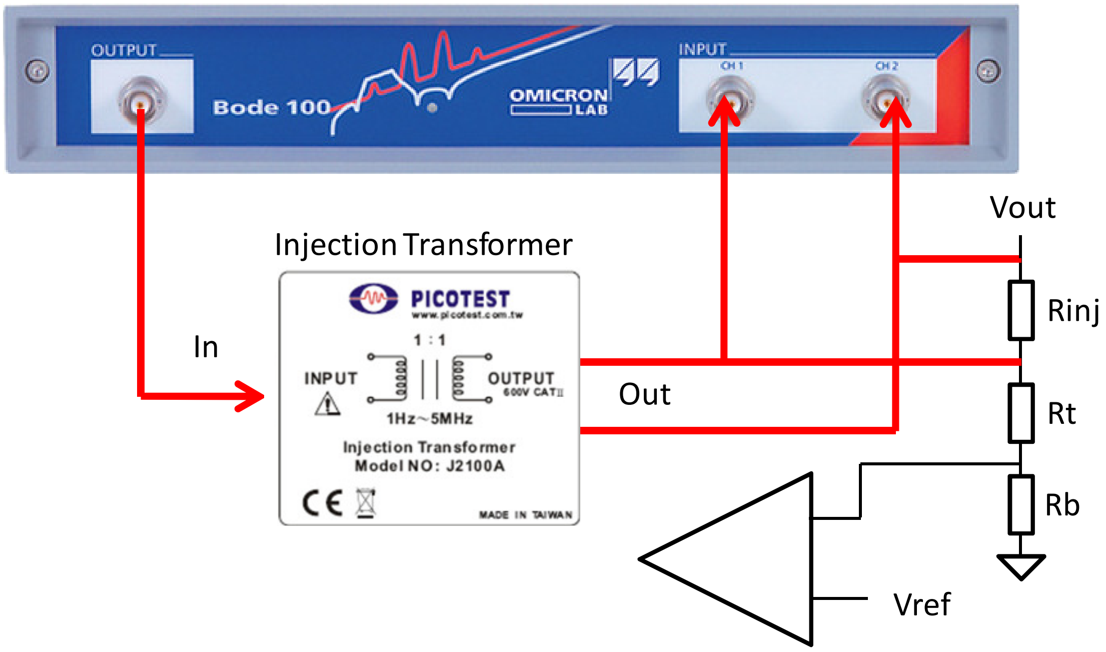
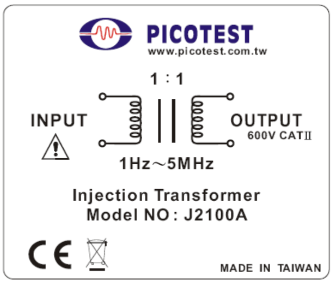


Figure 5: Injection Transformer Connections for stability measurements.

The injection transformer is connected as shown above. The output oscillator of the Bode analyzer is connected via a BNC connector to the input of the transformer. The output of the transformer is connected across the "in-circuit" injection resistor (Rinj). This allows the analyzer oscillator to stimulate the loop while the loop response is recorded.

Technical Specifications: J2100A



Performance at -10dBm input level	
Characteristic	**Rating**
DCR	
Ratio	1:1
Termination Impedance	5 Ohms
Nominal 3dB Bandwidth	1Hz ~ 5MHz
Isolation Voltage	600V
Isolation Capacitance	390pF@1KHz
DC current	10mA
Temperature range	0~50˚C
Maximum Altitude	6000 Ft

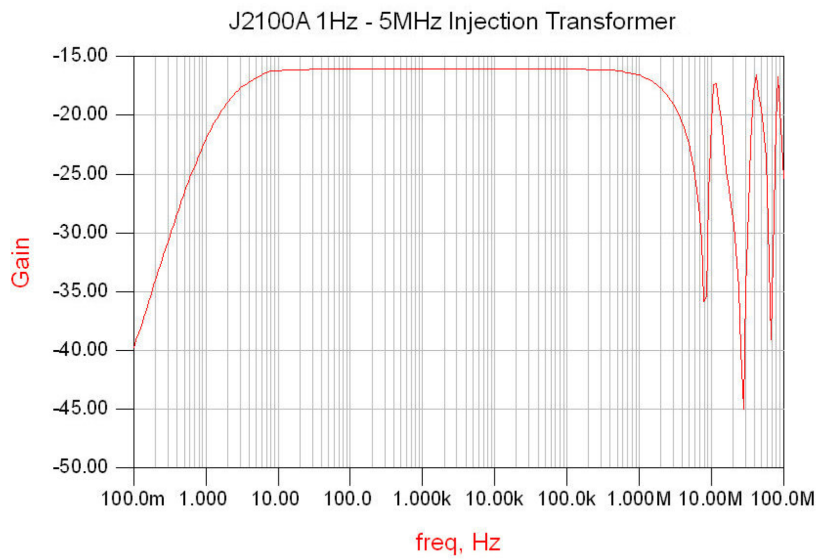
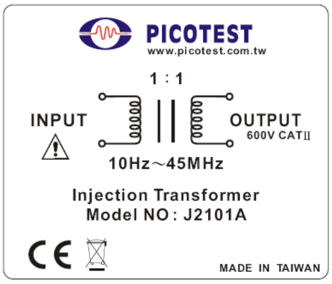


Figure 6: Frequency Response for J2100A injection transformer.

Technical Specifications: J2101A



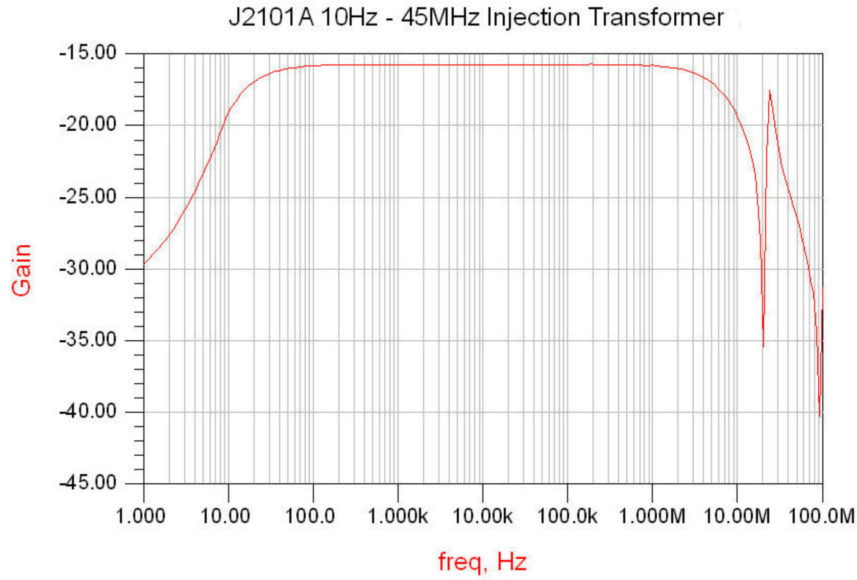


Figure 7: Frequency Response for J2101A injection transformer.

Characteristic	Rating
DCR	
Ratio	1:1
Termination Impedance	5 Ohms
Nominal 3dB Bandwidth	10Hz ~ 45MHz
Isolation Voltage	600V
Isolation Capacitance	150pF@1KHz
DC current	10mA
Temperature range	0~50˚C
Maximum Altitude	6000 Ft

Solid State Voltage Injector

Main Features

J2110A Solid State Bode Box Voltage Injector

- DC-45MHz supports thermal and mechanical controls and highest performance regulators
- Low distortion for superior precision
- 25 Ohm insertion resistance
- 50 Ohm oscillator input
- < 3uA typical bias current
- >2 MΩ typical Input Resistance
- High PSRR Low Noise Regulator with Universal input

Description

The solid state voltage injector or "Bode box" is employed in the same way as the injection transformer. As noted in the introduction section, the J2110A injector has a wider bandwidth. However, the selection of a point in the circuit to insert the injection connection can be more challenging. In order to provide correct results one side of the measurement must present much higher impedance than the other side. A rule of thumb is that one side should have an impedance that is at least 50 to 100 times greater than the other. In a typical power supply control loop, the voltage sense divider is generally a good injection point, since the output impedance of the power supply is very low compared with the impedance of the voltage sense divider.

Connecting the Solid State Injector: : Stability

The solid state injector is connected in much the same way as the injection transformer. The exception, as noted above, is that the impedance on the Vout side must be different from the Rtop side.

No injection resistor is used.

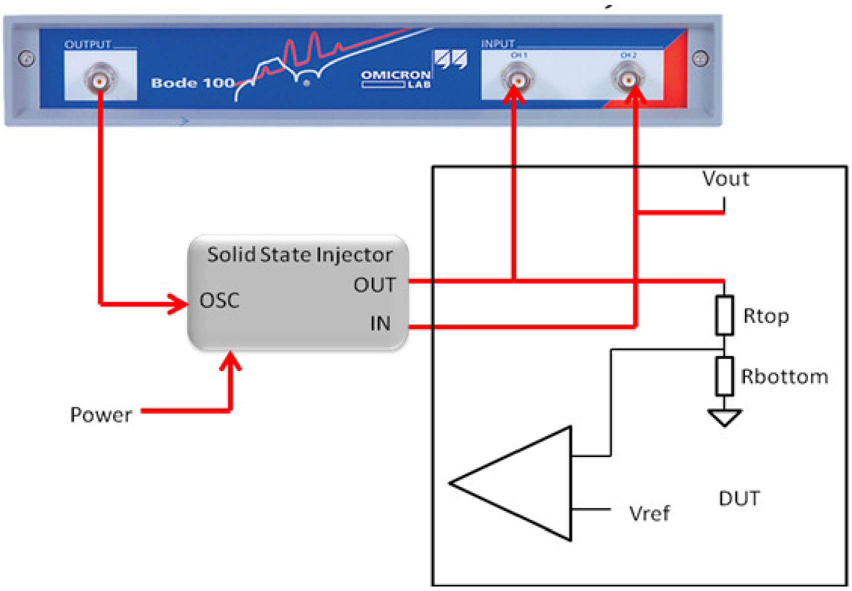
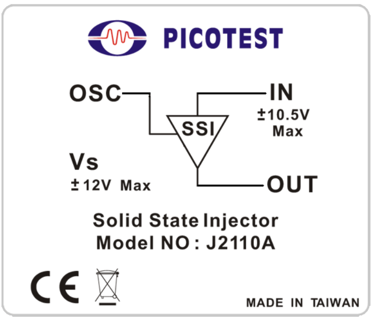


Figure 8: Solid State Injector Connections for stability measurements.

Technical Specifications



Characteristic	Rating
Maximum Vcc	±12V
Maximum Icc	20mA
Maximum input voltage DC+AC	±10.5V
Maximum Output Voltage	±10.5V
Offset Voltage	3mV
Bias Current	8uA
3dB Bandwidth (-10dBm)	DC ~ 40MHz
Temperature range	0~50˚C
Maximum Altitude	6000 Ft

Line Injector

Main Features

J2120A Line Injector

- 10Hz-10MHz usable bandwidth
- Low loss design
- 5 Amps maximum current
- 50VDC max input
- Easily measure input filters and PSRR

Description

The line injector allows the input DC supply voltage to be modulated by the network analyzer source signal, as in the case of a PSRR measurement. The line injector must be capable of a frequency range well below the AC line frequency and at least above the control loop bandwidth of the circuit being tested.

Connecting the Line Injector: PSRR

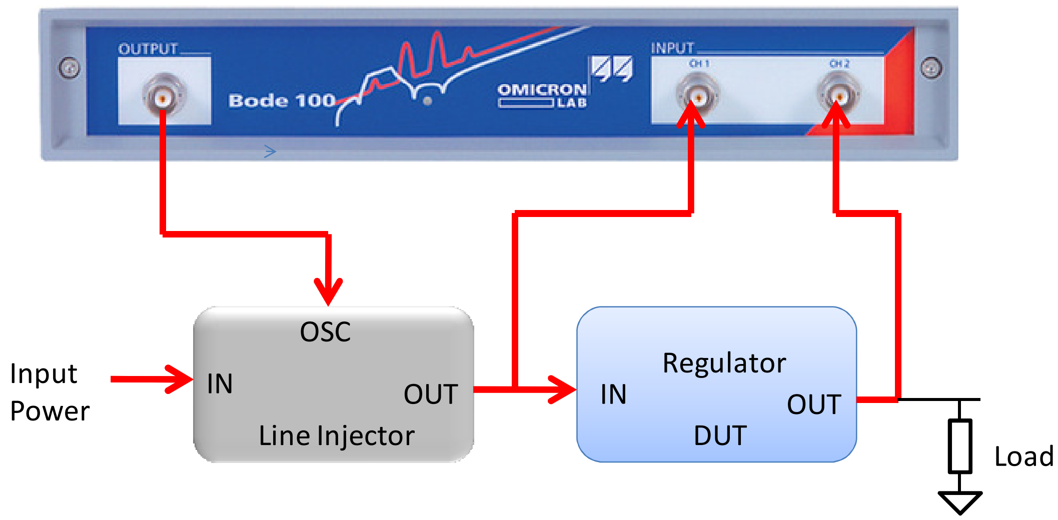


Figure 9: Line Injector Connections for PSRR measurements.

The line injector is only capable of sourcing current, so that the output amplitude can be significantly impacted by the operating current and the total storage capacitance at the load. The Bode-100 network analyzer has a very high selectivity so distortion at the output of the line injector generally does not influence the measurement. Again, this is a small signal injector, so the oscillator signals should be kept as small as possible above the noise floor. As a guide, try to keep the input signal amplitude below 50mVpp (-20dBm). In some cases we want to attenuate the source signal even further, and so we have included the attenuators in the injector kits. Some analyzers, such as the Omicron-Lab Bode-100 allow shaping the injection amplitude as a function of frequency, which helps optimize the signal level.

Measuring Input Impedance

The line injector can also be used in conjunction with a current probe to measure the input impedance of a power supply. The input impedance of a switching power supply or regulator is negative, which is a stability concern when combined with an EMI filter, making the measurement an important part of the design, analysis and verification process. The current probe must be set for 1A/V or the results need to be scaled accordingly for different settings.

Connecting the Line Injector: Input Impedance

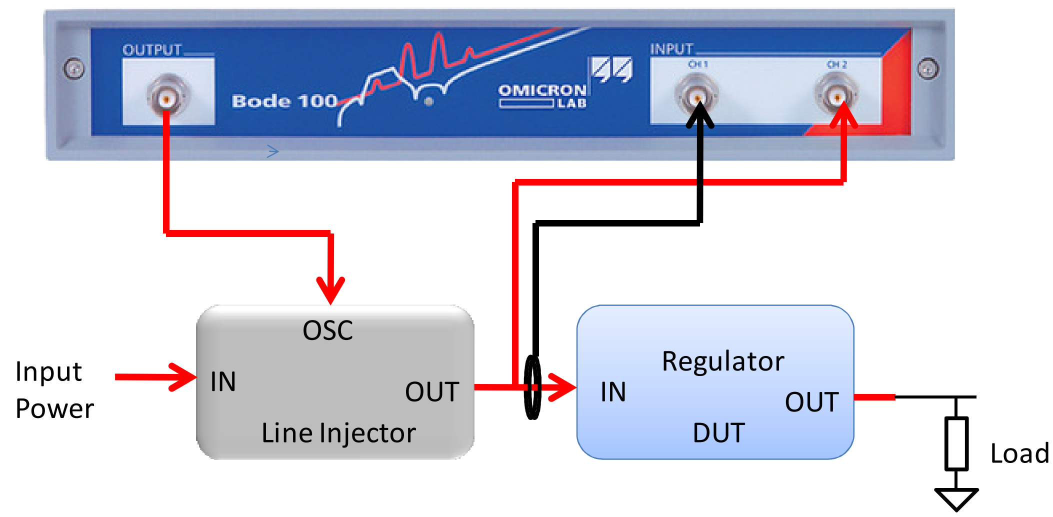
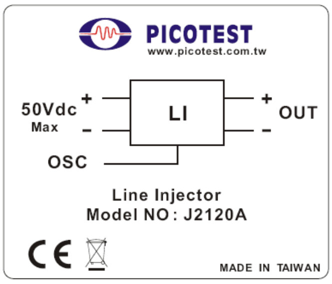


Figure 10: Line Injector Connections for input impedance measurements.

Technical Specifications



Characteristic	Typical
Maximum DC Input Voltage	50VDC
Maximum Continuous Current	5A
Maximum Voltage Drop	3.25VDC
3dB Frequency Response	15Hz~5MHz
Useable frequency response	10Hz~10MHz
Recommended injection signal	-20dBm~10dBm
Temperature range	0~50˚C
Maximum Altitude	6000 Ft

DC Bias Injector

Main Features

J2130A Bias Injector

- 10Hz-10MHz usable bandwidth Low loss design
- Easily measure varactors, junction capacitance
- Measure X5R capacitor voltage sensitivity
- Bias low power transistor amplifiers and diodes for parameter extraction

Description

The Picotest DC bias injector (J2130A) is used for applying a DC voltage bias on components during impedance measurements.

Connecting the DC Bias Injector: Component Bias

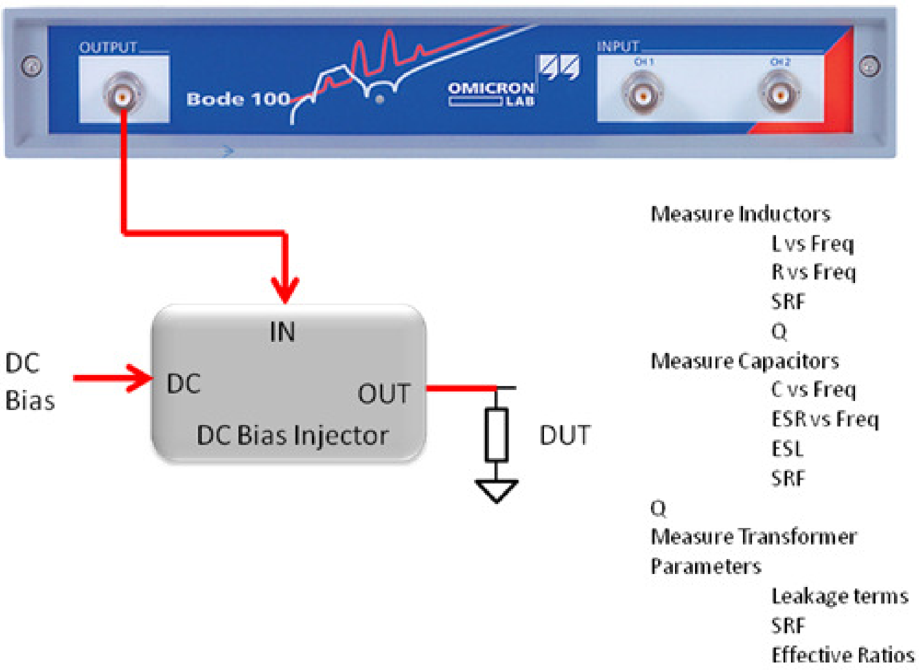
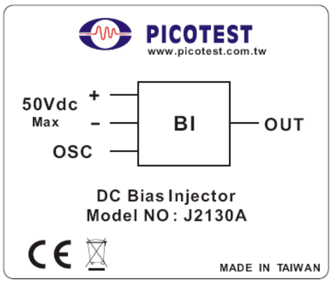


Figure 11: Connections for DC Bias Impedance measurements.

Technical Specifications



Characteristic	Typical
Maximum DC Bias	50VDC
Bias Resistance	10kOhms
Maximum Bias Current	5mA
Frequency Response	15Hz~40MHz
Temperature range	0~50˚C
Maximum Altitude	6000 Ft

Solid State Current Injector

Main Features

J2111A Solid State Current Injector

- High PSRR Low Noise Regulator with Universal input
- 20nSec typical rise and fall time
- DC-40MHz usable range (interconnection dependent)
- Two Quadrant Bipolar operation works with positive or negative source
- Build in offset for use with Network Analyzer
- Precision current monitor with 50 Ohm output
- Works with AWG, Function generator and network analyzer
- Can be used to measure battery impedance

Description

The current injector is one of the most versatile of the injector products. Coupled with the G5100A, or other equivalent function generator, it is capable of performing small signal load steps up to 40MHz, with very fast rising and falling edges. Using the G5100A, also allows the rise and fall times to be controlled, various waveforms or even arbitrary waveforms. This can be used to simulate the effects of many different types of loads, including high speed digital circuit loading, which is often largely dynamic.

The current injector can also be used to measure output impedance of power supplies, voltage regulators, power buses and even batteries. It can be used to non-invasively measure the stability of a combined input filter and the negative resistance of a switching power supply. It also has application in the measurement and extraction of transistor data, including small signal current gain, Ft and many other dynamic performance parameters.

In RF and instrumentation circuits it can be used to provide constant current biasing for class A amplifiers and buffers.

The current injector has two connections for the output, Output and GND. The input is DC+AC and can be connected to either a signal generator or a network analyzer. A built in bias current enables Class A operation for use with a network analyzer. The Current Injector and DC Bias injector can also be used for this purpose.

The output current is reduced 40dB from the input signal, resulting in 10mA/V scaling. The current monitor is designed to be terminated into 50 Ohms and can be used with the network analyzer, an oscilloscope or a DMM to monitor current. When used in conjunction with a voltage probe, the analyzer can measure Voltage/Current, which is the impedance.

Connecting the Current Injector: Output Impedance

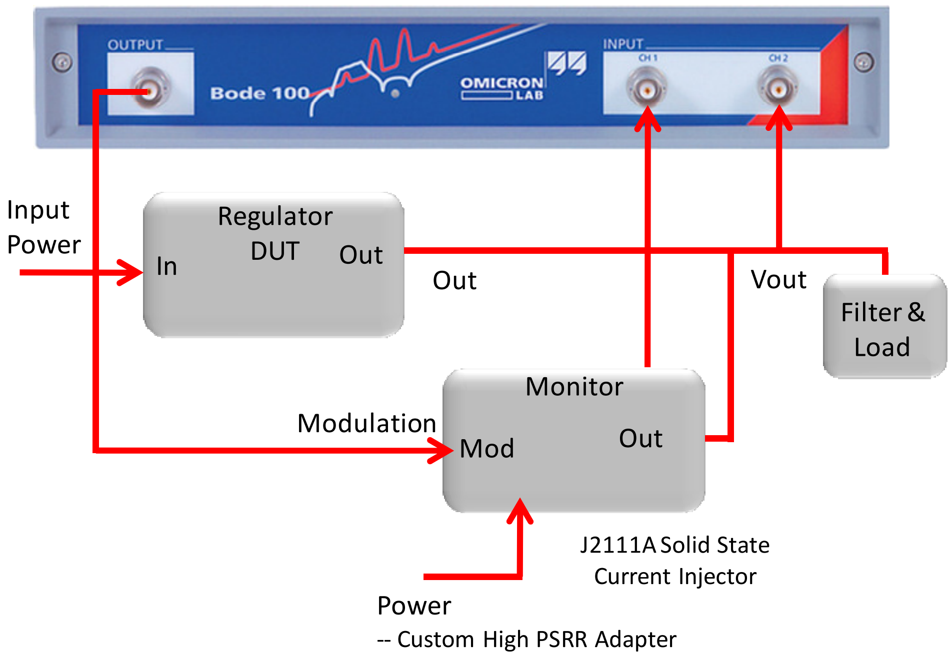


Figure 12: Current Injector Connections for output impedance measurements.

Connecting the Current Injector: Reverse Transfer

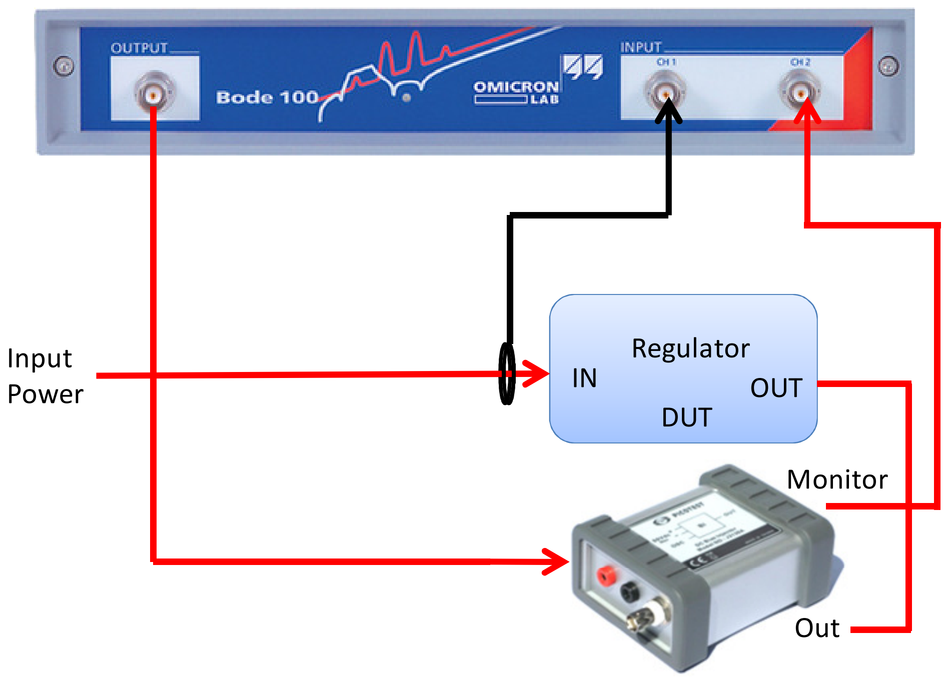
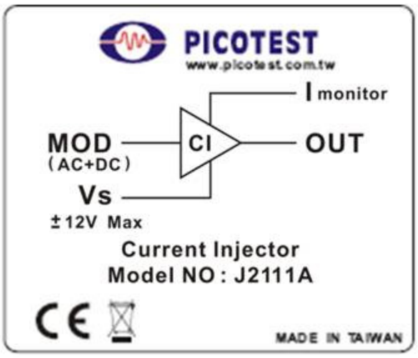


Figure 13: Current injector connections for reverse transfer measurements.

Technical Specifications



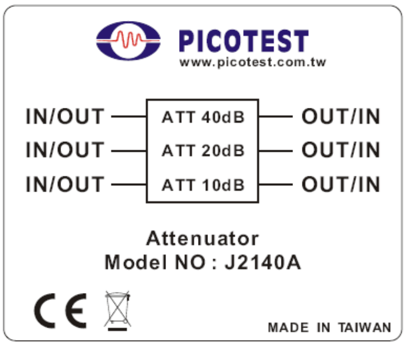
Characteristic	Typical
Max input voltage DC+AC	Vcc-1.5V
Output voltage	Vcc-2V
Current Monitor	1V/A
Modulator Gain	10mA/V
Offset Current (typical)	+/-24mA
Usable Bandwidth	DC~40MHz
Temperature range	0~50˚C
Maximum Altitude	6000 Ft

Attenuators

Main Features

- Integrated unit includes 20dB, 40dB and 60dB
- Cascade for greater attenuation
- Improve noise floor or assure small signal measurement

Technical Specifications



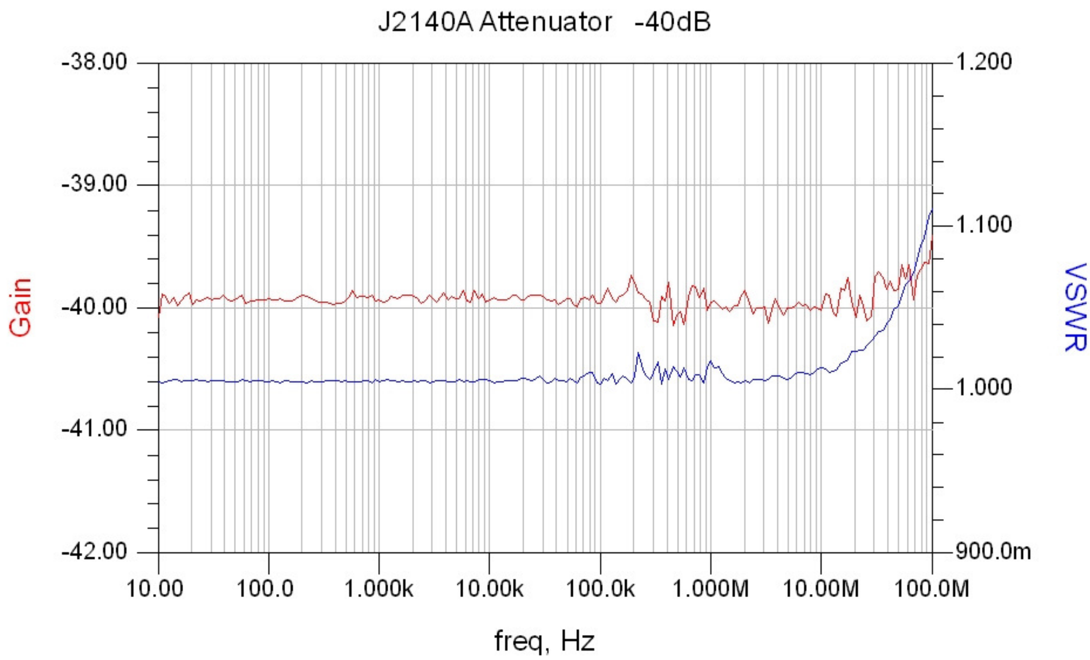


Figure 14: 40dB attenuator frequency response.

Characteristic	Rating
Maximum input Level	+20dBm
3dB Frequency Range	DC~50MHz
Maximum VSWR	1.3
Attenuation Accuracy	0.2dB

Chapter 4 - References

General

1. "Switchmode Power Supply Simulation with PSpice and SPICE 3", by Steven M. Sandler, McGraw-Hill Professional; 1 edition (2006), ISBN: 0071463267

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3. "Power Specialist's App Note Book, Papers on Simulation, Modeling and More", Edited by Charles Hymowitz, http://www.intusoft.com/lit/psbook.zip

4. "Inline equations offer hysteresis switch in PSpice", Christophe Basso, On Semiconductor, EDN, August 16, 2001

5. "SPICE Circuit Handbook", by Steven M. Sandler and Charles E. Hymowitz, McGraw-Hill Professional; 1 edition (2006), ISBN: 0071468579