Essential Test Adapters for Your Network / Impedance Analyzer

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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.

As design consultants, specializing in worst-case analysis for analog circuit applications, we are routinely called in to address design problems arising in RF and power electronics applications. Many of the problems we are asked to resolve can be readily avoided if the proper signal injectors are used. To cover the range of test measurements, many different types of signal injectors are required, each providing a different test function.

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.

This article discusses each of the basic injectors that you should own, as well as, some of the measurements where they are all but essential. A web link is included so that you can obtain application

information for these injectors and also so that you can purchase injectors you may not currently have in your laboratory.

Injection Transformers

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.
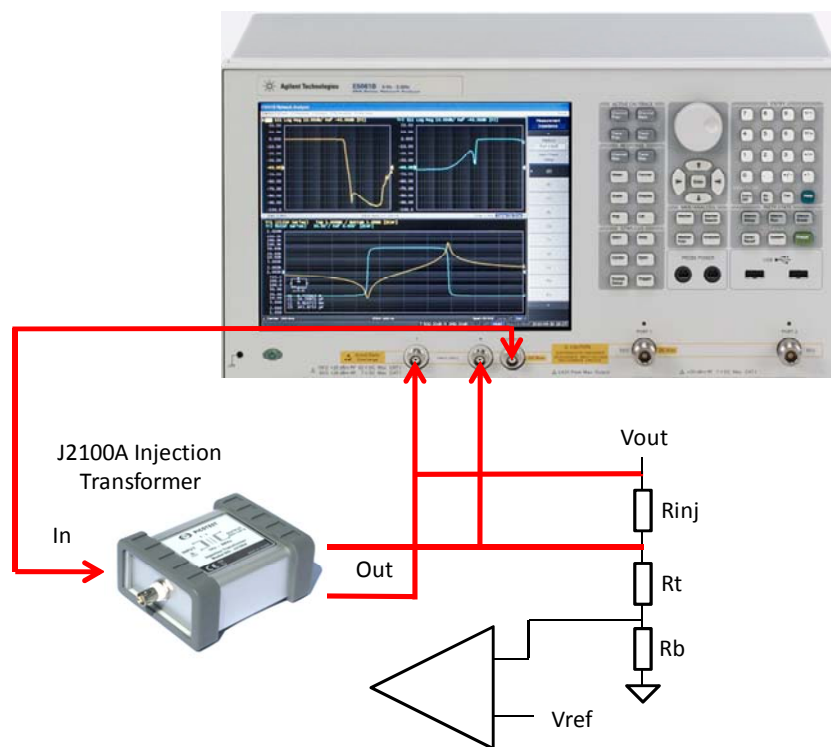
Figure 1 – Sample setup for the injection transformer (J2100A or J2101A) or the solid-state injector (J2110A) used to perform stability measurements, in this case with the Agilent E5061B Network Analyzer.

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

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.

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.

Line Injector

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.

The line injector allows the input DC supply voltage to be modulated by the analyzer source signal, as in the case of measuring PSRR (Figure 2). 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.
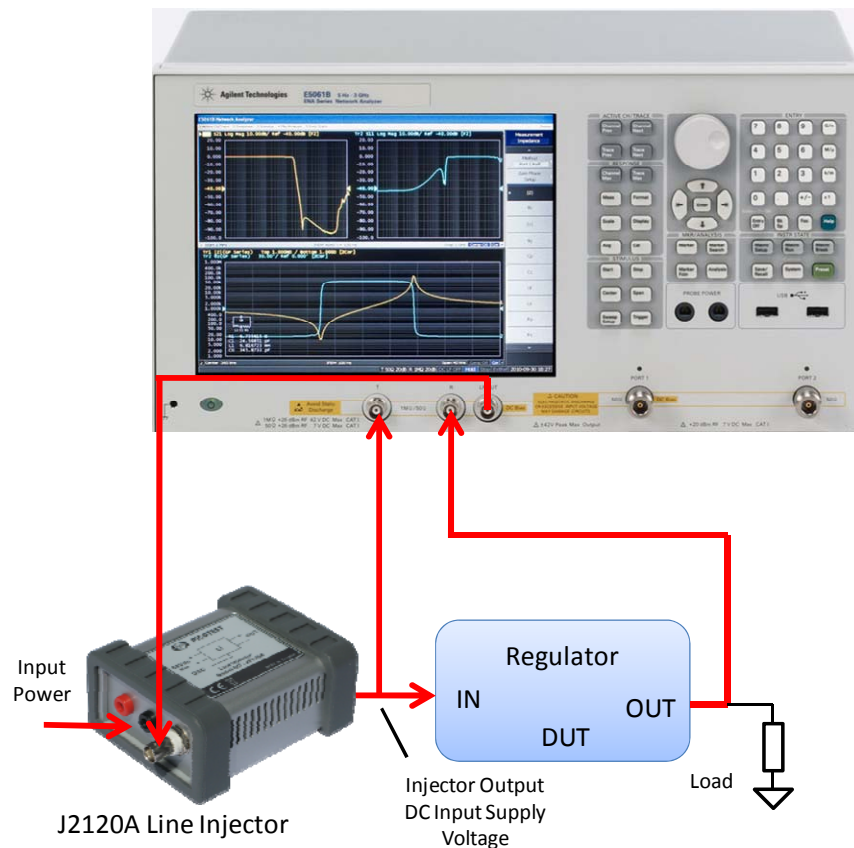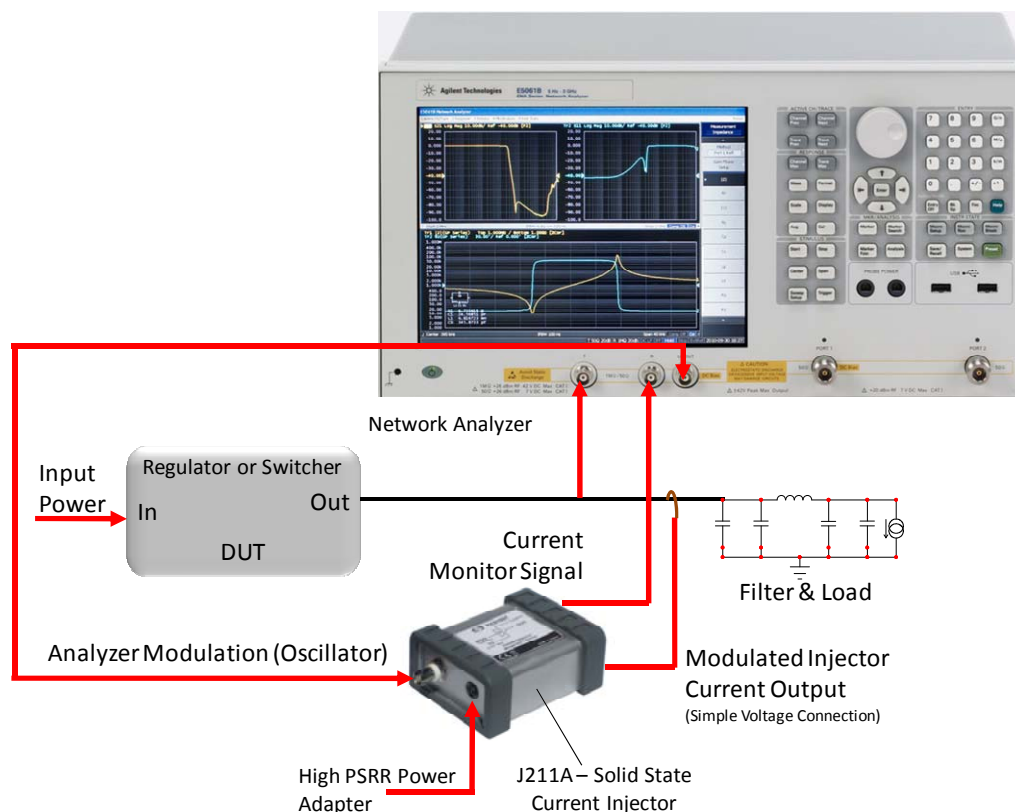

Figure 2 – Sample setup for the Line Injector (J2120A) used to perform a PSRR measurement with the E5061B

The line injector, being in series with the input power to the circuit being tested, must be capable of operating at the input voltage and current levels of the circuit being tested, while minimizing the power dissipation within the injector.

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Solid State Current Injector

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 stability (phase margin) 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.

Attenuators

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 <u>too high</u> 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.

Conclusions

While most of us own a network analyzer, few of us own the necessary Signal Injectors to make accurate and repeatable measurements. It is very easy to obtain incorrect results which can have a serious negative impact on the outcome of your project.

All of the Signal Injectors discussed are available from Picotest (www.Picotest.com) individually and in cost saving bundles. For application examples and more information about these injectors, visit www.Picotest.com.

References

1. "Why Network Analyzer Signal Levels Affect Measurement Results", Steve Sandler, Tom Boehler, Internal White Paper, www.picotest.com