APPLICATION NOTE

Low-Cost Power Sources Meet ADC and VCO Characterization Requirements

Keysight B2961A/B2962A 6.5 Digit Low Noise Power Source

Introduction

Finding a cost-effective power source for precision measurement applications can be a challenging task. Analog-to-digital (ADC) converter circuits often require power sources with at least 20 bits of resolution. Voltage controlled oscillator (VCO) applications can require noise floors of 10 µV rms or less. While there are existing instruments and measurement techniques that can perform these measurements, the cost of the solutions can often run into tens of thousands of dollars. In addition, many low-frequency (10 kHz or less) applications often need voltages and currents greater than typical signal generators can source. Finally, it can be very cumbersome to use a PC to control instruments in a benchtop lab environment, so a self-contained solution with a small profile, interactive GUI and built-in graphing capability is highly desirable.

KEYSIGHT TECHNOLOGIES

Product Overview

The B2961A (1-channel) and B2962A (2-channel) 6.5 Digit Low Noise Power Source are low- noise precision power sources that can meet these measurement challenges in addition to providing other useful capabilities. Pictures of both the front and rear of these instruments are shown below.

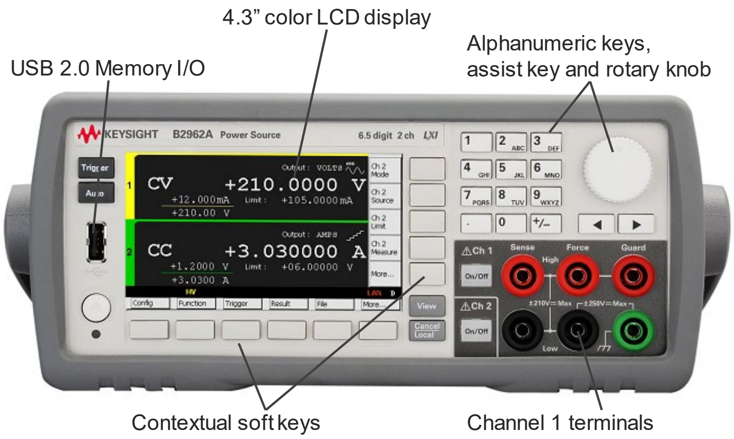


Figure 1. Front view of the B2962A Power Source.

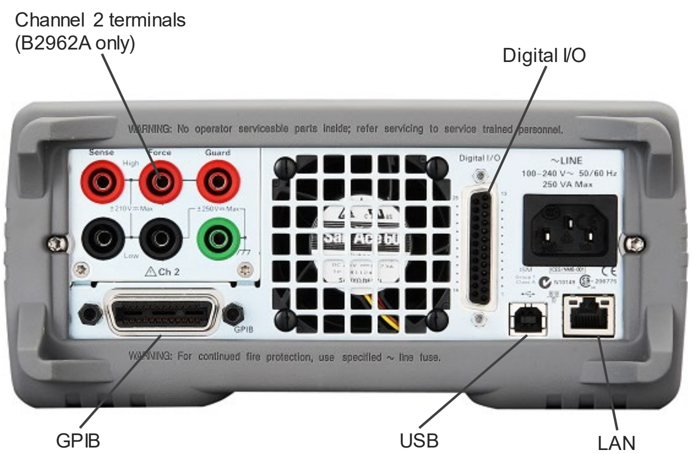


Figure 2. Rear view of the B2962A Power Source.

The B2961A and B2962A can be programmed to act as either ideal voltage or ideal current sources over a very wide range of voltages and currents. The B2961A and B2962A can supply up to ±210 V of voltage, up to ±3 A of current (DC) and up to ±10.5 A of current (pulsed). Moreover, they can source these voltages and currents with 100 nV and 10 fA resolution. A graph showing the voltage and current sourcing capabilities of these products across all voltage and current ranges is shown below:

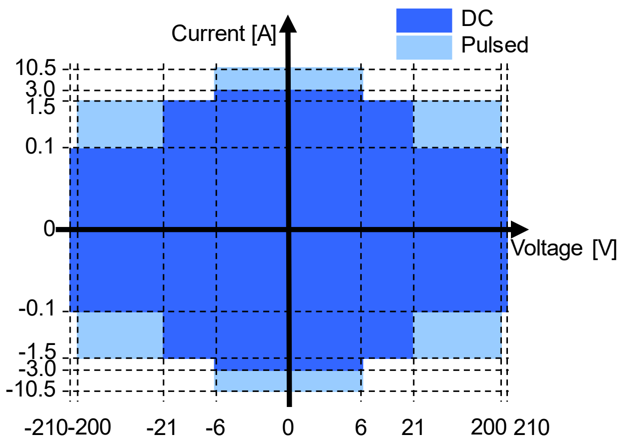


Figure 3. B2961A and B2962A voltage and current sourcing capabilities.

Besides their 6.5 digit precision sourcing capabilities, the B2961A and B2962A also have 4.5 digit measurement capabilities. The ability of a source to also measure is invaluable, since it can eliminate the need for additional equipment (such as a DVM) in many measurement situations.

The B2961A and B2962A have both source and sense outputs that support 4-wire (Kelvin) measurements. Details of the B2961A and B2962A channel outputs are shown below.

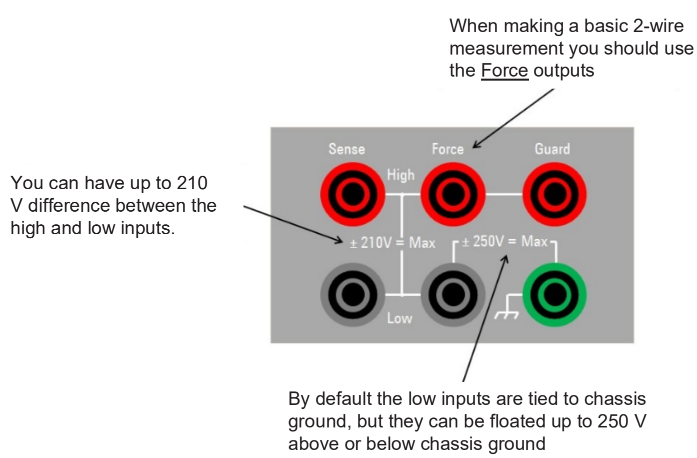


Figure 4. Detail of the B2961A and B2962A channel outputs.

A 4-wire sourcing configuration is typically used when a resistance being evaluated has a value that is comparable to the resistance of the measurement cables being used. By separating the lines that source current from those that measure voltage, the true resistance of the DUT can be accurately measured. The following diagram illustrates this principle:

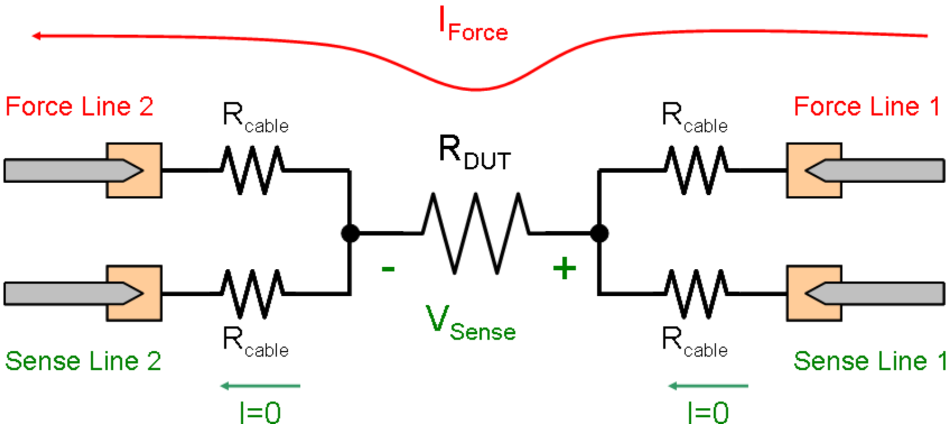


Figure 5. Diagram showing how a 4-wire (Kelvin) measurement eliminates cable resistance.

In addition to simple DC voltage and current sourcing capability, the B2961A and B2962A also can generate a wide variety of arbitrary waveforms in either voltage or current from 1 mHz up to 10 kHz. For applications that do not require high frequency but do require higher power, the B2961A and B2962A can be low-cost alternatives to more expensive function and signal generators. Supported waveforms include sine, ramp, square, triangle, trapezoid and exponential, as well as user-defined waveforms of up to 100,000 points in length. You can specify exactly how many cycles of any given waveform you wish to apply, or specify an infinite number to generate a continuous signal. Moreover, unlike other voltage and current sources that offer waveform generation capability, the B2961A and B2962A provide extremely clean waveforms. For example, the waveforms from many conventional power sources exhibit a “ragged” appearance upon magnification as well as showing discontinuities at their zero crossings as shown below:

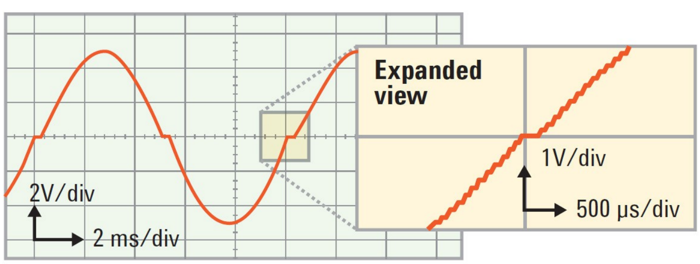


Figure 6. Illustration of zero-crossing discontinuities typical of many function and signal generators.

In contrast, the waveforms output by the B2961A and B2962A have a very clean appearance with no zero crossing discontinuities.

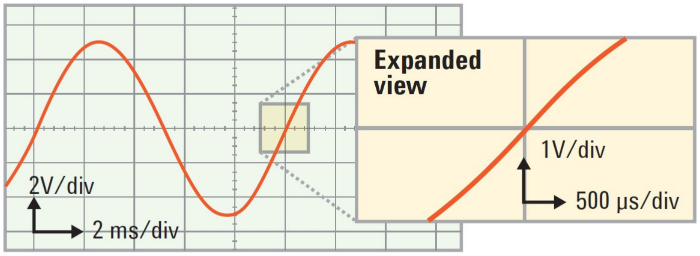


Figure 7. Illustration of clean zero-crossing waveforms produced by the B2961A and B2962A.

Finally, the B2961A and B2962A also have a preview mode that allows for visual verification of a voltage or current waveform before use. By allowing the user to inspect waveforms prior to applying them to the DUT, this feature can prevent accidental device damage.

The B2961A and B2962A possess a pulsed measurement capability that can be used in conjunction with either their DC or arbitrary waveform output modes. In pulsed measurement mode the instruments apply their specified output voltage or current only during a pulse of user-specified duration, and then maintain a base value of voltage or current (also user- specified) during the remainder of the pulse period. There are two main reasons to use the pulsed measurement mode. The first reason is to prevent device self-heating effects from distorting measurement results. By keeping the duty cycle (the ratio of pulse measurement width to total pulse period) small, the device under test (DUT) gets time to cool down between measurement pulses which prevents the device from heating up. The second reason to use pulsed measurement mode has to do with the output power sourcing capabilities of the B2961A and B2962A. The B2961 and B2962A can output more current (up to 10.5 A) in pulsed mode than they can in DC mode, so if currents greater than the DC current limit of 3 A are required then pulsed measurement mode must be used. Since the same sourcing and measurement accuracy is maintained in both DC and pulsed modes, making a measurement in pulsed mode has no disadvantages other than possibly taking slightly longer to make than an equivalent DC measurement. The waveform timings for a pulsed measurement are shown below.

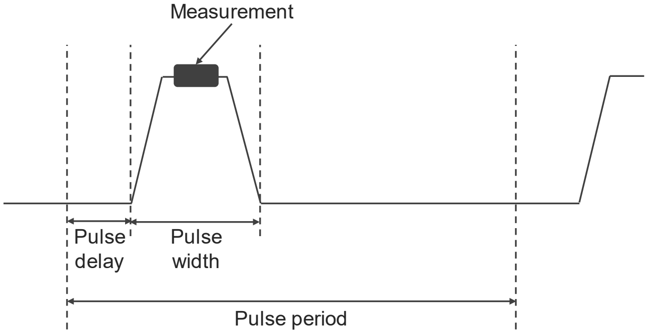
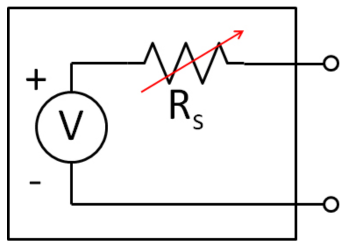
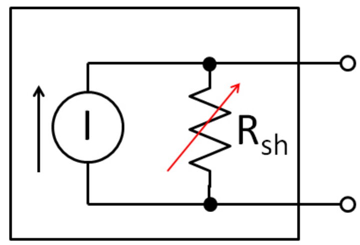


Figure 8. Generic timing diagram illustrating pulsed measurement waveforms.

In DC mode the B2961A and B2962A have a unique programmable output resistance feature that is best understood by considering the Thevenin and Norton equivalent circuits:



Thevenin equivalent circuit



Norton equivalent circuit

Figure 9. The B2961A and B2962A possess a programmable output resistance feature that can have both positive and negative values.

In each of these two cases (voltage source and current source, respectively) the resistance shown can be programmed by the user to both positive and negative values. The limits on the programmable resistance depend primarily upon the output range and are shown in the following table.

Source Mode	Limits Relative to Output Load Resistance	Programmable Resistance Limits	
		Resistance Limit	Current Range
Series Resistance (V Source)	$-(R_{load}/2) \le R_S \le R_{load}$	$R_S \le 25\ \Omega$	$1.5\ A < I \le 3\ A$
		$R_S \le 100\ \Omega$	$100\ mA < I \le 1.5\ A$
		$R_S \le 1\ k\Omega$	$10\ mA < I \le 100\ mA$
		$R_S \le 10\ k\Omega$	$I \le 10\ mA$
Shunt Resistance (I Source)	$R_{load} \le R_{Sh} \le 2\ G\Omega$	$1\ M\Omega \le R_{Sh}$	$100\ nA < I \le 3\ A$
		$10\ M\Omega \le R_{Sh}$	$I \le 100\ nA$

Figure 10. The limits of the programmable output resistance function (Note: Capacitive loading can also affect the resistance limits).

One potential application of this feature is the cancellation of cable resistance when a 4-wire measurement is not possible (due to cabling or fixturing limitations). Since the B2961A and B2962A can program a negative resistance value, it is possible use this feature to zero out cable resistance without employing a 4-wire measurement configuration.

The B2961A's and B2962A's programmable output resistance capability also has one other important feature: the ability to emulate any arbitrary voltage versus current waveform. The B2961A and B2962A can be programmed with up to 16 voltage/current points (entered in a tabular format), and in this mode the B2961A and B2962A will respond with an interpolated V-I characteristic. One application of this feature is the simulation of active devices such as solar cells, as the following figure illustrates:

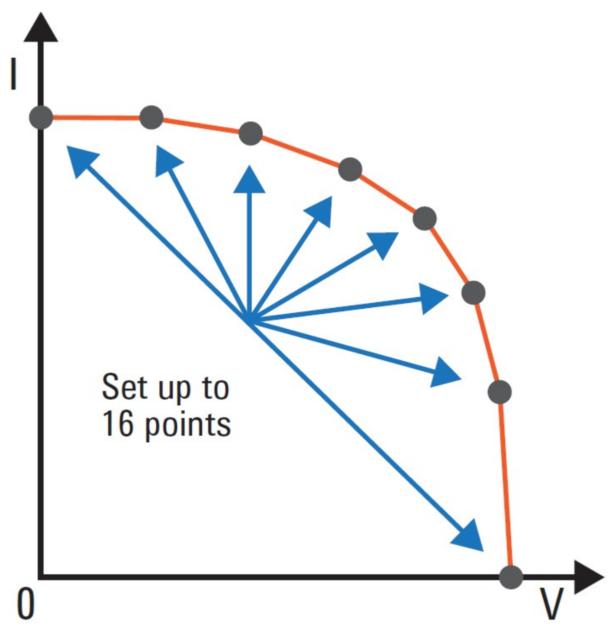


Figure 11. Emulation of a solar cell characteristic using the IV emulation feature of the B2961A and B2962A.

Another potential application of this feature is the simulation of the "corner cases" of an active or passive device. Note: Although not specified for non-DC signals, the B2961A and B2962A can respond with this programmed characteristic curve to signals of up to approximately 100 Hz in frequency.

Low Noise Filter (LNF) Option and Applications

The basic noise floor of the B2961A and B2962A is approximately 3 mV (RMS). A low-noise filter (LNF) option is available that can be connected to a given channel and lower the noise floor of that channel to 350 μV (RMS). When used with the LNF the B2961A and B2962A can still output up to ±210 V of voltage and up to ±3 A of current, but the noise floor is comparable to that of linear power supplies. In addition, the LNF outputs maintain the banana jack 4-wire (Kelvin) configuration, which permits the elimination of residual cable resistance from measurements.

Thus, the combination of the B2961A or B2962A with the LNF provides medium-level low-noise sourcing capability for a modest price.

Figure 12. B2961A shown with low-noise filter (LNF) option.

One application of the B2961A or B2962A with the LNF is the characterization of an analog-to- digital converter (ADC). The servo loop-based testing method is one of the most commonly used means to characterize an ADC's differential and integral non-linearity (DNL/INL), and this is illustrated below:

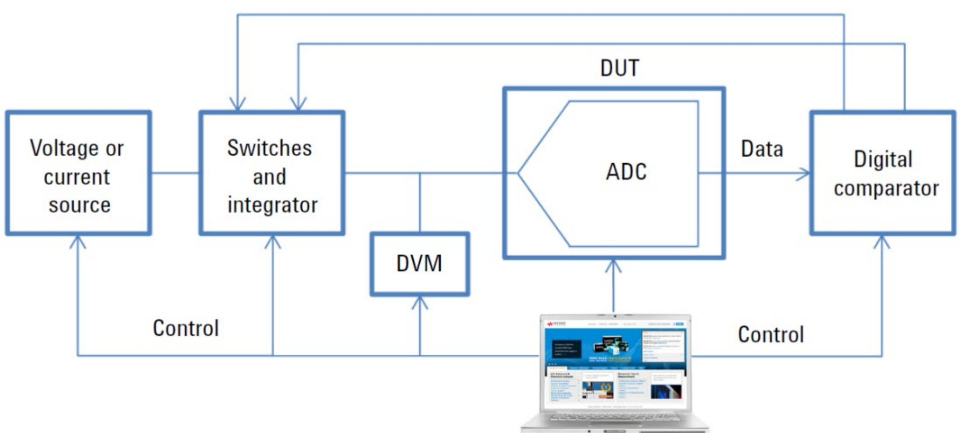


Figure 13. Block diagram of servo loop test method.

Unfortunately, the servo loop ADC test method has several drawbacks:

1. This test method requires many different components, such as a voltage/current source, DVM, servo circuitry, etc. It also requires a complicated program to control and synchronize everything.
2. Conventional voltage/current sources used in the servo-loop test require significant averaging to eliminate noise as well as frequent PC communication, creating lots of test overhead time.
3. The histogram testing method is the most desirable technique due to its simplicity and efficiency; however, most conventional instrumentation does not have the required resolution, noise floor and linearity to test high bit ADCs.

The B2961A or B2962A used with the LNF can greatly simplify this type of ADC testing. A diagram of the improved solution is shown below:

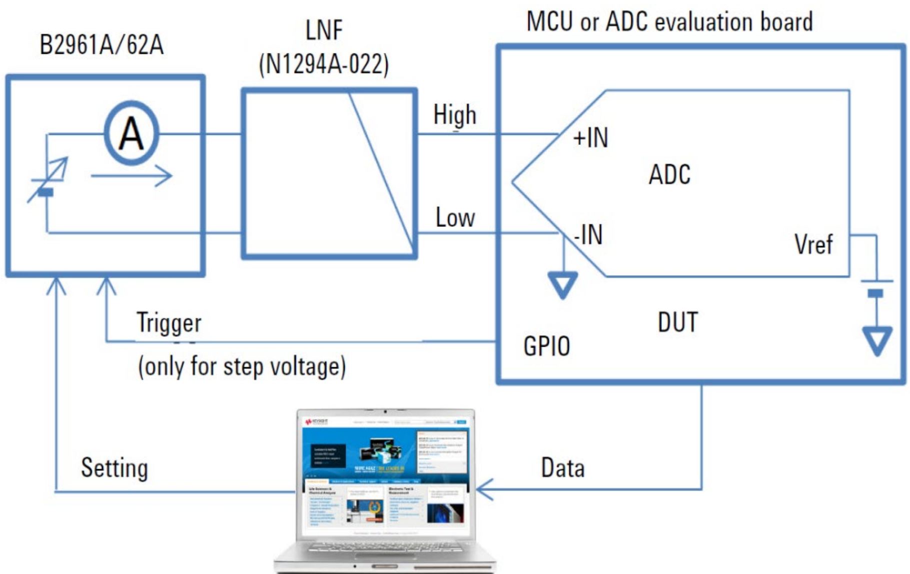


Figure 14. Testing an ADC using the B2961A/B2962A with the LNF option.

This solution has several advantages over the servo loop ADC test method:

1. The B2961A/62A with its low noise filter (LNF) has superior source resolution that does not require external monitoring by a DVM. This improves and simplifies ADC testing.
2. The superior noise performance of the B2961A/62A with its LNF reduces averaging times. In addition, its external trigger input and 100k point wave form memory reduce PC communication frequency. The net result is improved ADC testing efficiency.
3. The B2961A/62A’s excellent arbitrary waveform generation function linearity supports ramp voltage histogram evaluation of 14bit ADC DNL/INL.

Ultra-Low Noise Filter (ULNF) Option and Applications

For applications requiring an even lower noise floor, a high current ultra-low noise filter (HC-ULNF) and an ultra-low noise filter (ULNF) option for the B2961A and B2962A are also available. When connected to a B2961A or B2962A channel, the HC-ULNF and ULNF reduce the noise level to at least 10 μV (RMS). While the HC-ULNF limits the maximum voltage and current outputs to 21 V and 500 mA and the ULNF limits the maximum voltage and current outputs to 42 V and 105 mA (respectively), this is usually not an issue since applications requiring low-noise typically do not require high-power.

Figure 15. B2961A shown with ultra-low noise filter (ULNF) option.

To facilitate determination of the RMS noise voltage at various frequencies, the noise density function of the B2961A and B2962A used with the ULNF option is shown below:

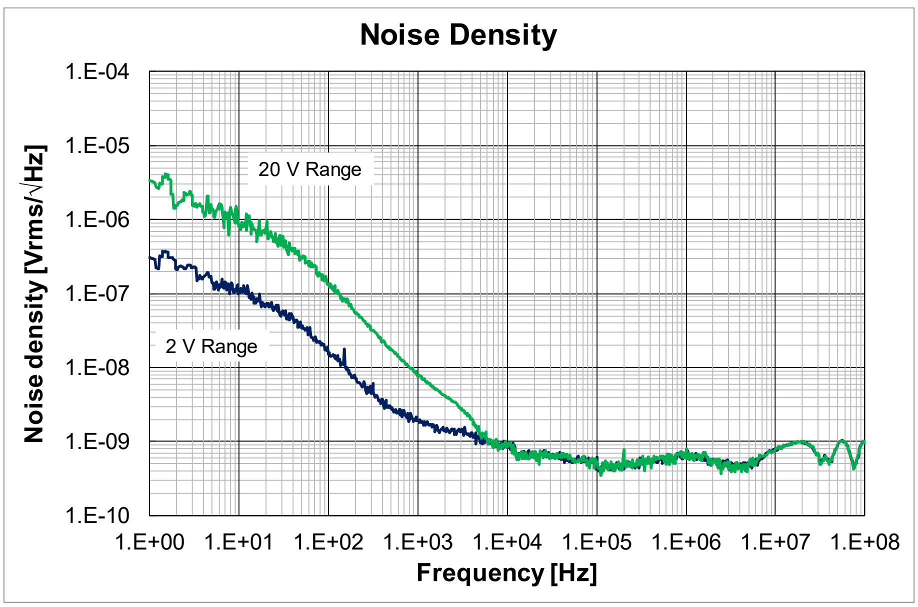


Figure 16. Noise density characteristics of B2961A and B2962A with ULNF.

A noise density (ND) function is specified in units of volts per square root of frequency, and to determine the actual RMS (root-mean-square) voltage at a specific frequency (f_0), the following equation is used:

$$V_{RMS}(f_0) = \sqrt{\int_0^{f_0} [ND(f)]^2 \, df}$$

However, in most cases this calculation does not need to be performed exactly but instead can be approximated by noting that the noise density plot is shown on a log scale. This means that the portion of the graph showing downward sloping behavior has much less effect on the above calculation than you might first think from looking at the graph. In fact, when looking at frequencies in the flat portion of the curve it is often an acceptable approximation to draw a horizontal line from the frequency point at which you wish to know the RMS voltage over to the vertical axis, and then use this constant value to calculate the area under the curve. For example, in the case of the B2961A and B2962A at 10 kHz this yields the following value for the RMS voltage:

$$V_{RMS}(10\ kHz) \approx \sqrt{\left[1\ nV_{RMS}/\sqrt{Hz}\right]^2 \times 10^4\ Hz}$$

$$V_{RMS}(10\ kHz) \approx 100\ nV$$

Of course, the actual noise floor at 10 kHz will be higher than this value. In the case of the B2961A and B2962A with the ULNF, Keysight can guarantee a noise floor of at least 10 µV (RMS) for frequencies up to 20 MHz.

One application of this low-noise sourcing capability is voltage controlled oscillator (VCO) characterization. A typical VCO has three ports: a DC power supply port, a tuning (DC control voltage) port and a signal output port. The B2962A has two independent output channels, so when both of these channels are fitted with the ULNF option it can supply the two required low- noise DC sources. Moreover, since the B2962A can also monitor the voltage and current it is sourcing, it can easily verify the tuning voltage and current consumption.

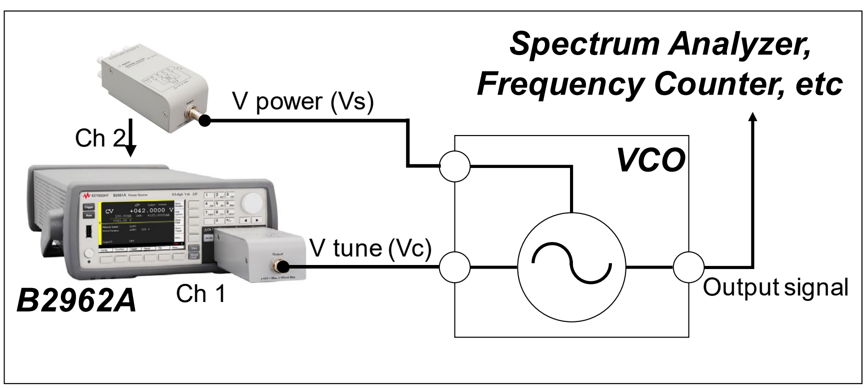


Figure 17. VCO characterization using the B2962A with two ULNF options.

Using this scheme, a VCO phase noise measurement was made for a 791 MHz carrier frequency using the B2962A to supply voltage to the DC power and tuning inputs of the VCO. The results of this measurement are shown below:

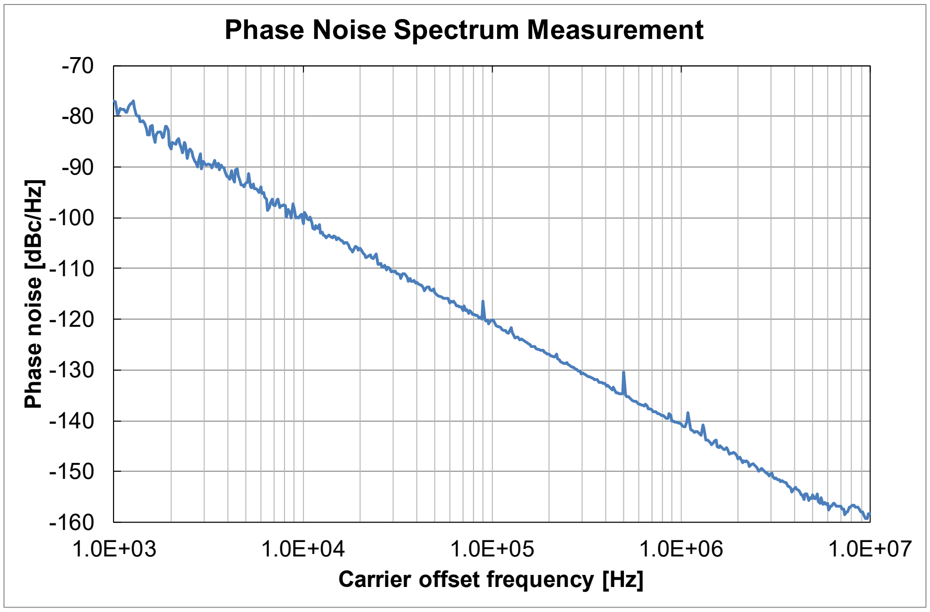


Figure 18. VCO phase noise measurement result using the B2962A with ULNF option on both channels.

Filter Option	Voltage Noise		Maximum Output				Source		Maximum Capacitive Load
	0.1 Hz to 10 Hz	10 Hz to 20 MHz	Power	Voltage	DC Current	Pulsed Current	Minimum Measurement Resolution		
							Voltage	Current	
None	< 5 µVpp	3 mVrms	31.8 W	± 210 V	± 3.03 A	± 10.5 A	100 nV	0.01 pA	0.01 µF (50 µF in high cap. mode)
Low Noise	< 5 µVpp	350 µVrms	31.8 W	± 210 V	± 3.03 A	± 3.03 A	100 nV	10 pA	1 mF
Ultra Low Noise	< 5 µVpp	10 µVrms	4.4 W	± 42 V	± 105 mA	± 0.1 A	100 nV	10 pA	50 µF
High Current Ultra Low Noise	< 5 µVpp	10 µVrms	10.5 W	± 21 V	± 500 mA	± 0.5 A	100 nV	1 nA	50 µF

Figure 19. Table summarizing sourcing capabilities of B2961A (1 ch) and B2962A (2 ch) low-noise power sources.

Summary

This technical overview has outlined some of the capabilities and applications of the B2961A and B2962A low-noise power sources. Their 6.5 digit sourcing resolution and wide bipolar output range give them great versatility as general purpose benchtop power sources. Their ability to source a variety of voltage and current waveforms in either DC or pulsed mode allows them to be used in many applications that cannot be covered by conventional DC power supplies. Their programmable output resistance and V-I emulation capabilities further enhance their usefulness as general purpose debugging tools. Finally, their LNF, ULNF and HC-ULNF options give them the ability to help with the tough measurement challenges presented by ADC and VCO evaluation.

The B2961A and B2962A can provide measurement performance that was previously only available from much more expensive instrumentation. The following table summarizes the B2961A/B2962A and their key accessories.

Product Number	Description
B2961A	6.5 Digit Low-Noise Power Source, 1 channel
B2962A	6.5 Digit Low-Noise Power Source, 2 channel
N1294A-001	2-wire (non-Kelvin) banana to triaxial adapter
N1294A-002	4-wire (Kelvin) banana to triaxial adapter
N1294A-020	High Current Ultra Low Noise Filter (21 V/ 500 mA) for B2961A/B2962A
N1294A-021	Ultra Low Noise Filter (42 V/105 mA) for B2961A/B2962A
N1294A-022	Low Noise Filter (210 V/ 3 A) for B2961A/B2962A