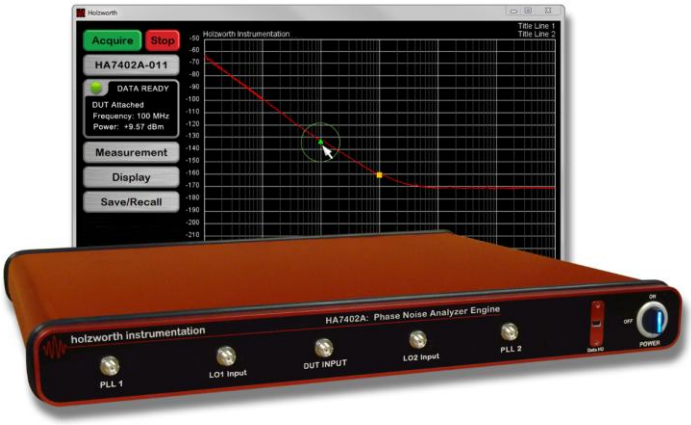
QUICKLY EVALUATE HIGH PERFORMANCE OSCILLATORS
Using the Holzworth HA7402A Phase Noise Analyzer – White Paper

INTRODUCTION
Oscillator manufacturers and engineers who frequently need to evaluate the performance of ultra low phase noise oscillators, at some point, recognize that their phase noise test systems could be primarily improved in three aspects:

1. Reduction of measurement time
2. Lower measurement noise floor capability
3. Reliability and repeatability of test data

There are some very capable general purpose phase noise test systems available on the market. With the growing demand for phase noise test requirements, more and more companies are introducing general purpose phase noise analysis tools. In contrast, Holzworth Instrumentation's HA7402A, was specifically designed for measuring the phase noise of high performance OCXOs, TCXOs, SAW oscillators, frequency standards, *etc*.

The HA7402A is a unique phase noise measurement instrument in that it combines the ease of use of a self contained, cross correlation phase noise analyzer with the ability to use external LOs (local oscillators) as the system references. User supplied LOs can greatly reduce measurement times to achieve low noise floors, while also reducing the list price of the analyzer.



Integrating Holzworth's fully automated LO control system, allows the HA7402A to fully calibrate and independently tune the external LOs for a hassle free test setup. Flawless phase locking to the DUT is as easy as a touch of one button.

MOTIVATION
All tunable phase noise analyzers are essentially affected by the same limitation: the internal synthesizers. The internal synthesizers that are used as the tunable LO sources have worse phase noise performance than good fixed frequency LO sources. RF synthesizers are by nature a compromise between phase noise performance and broadband tuning capability.

For example, in a cross correlation analyzer (also referred to as a "dual core" system) where only one correlation is made, the phase noise measurement floor is identical to the phase noise performance of the internal LO synthesizers. Measuring a DUT with better phase noise performance than the internal synthesizers now requires the cross correlation engine to go to work. This part of the process can consume an excessive amount of time, especially when noise floors of lower than -170dBc/Hz$^{1/2}$ are necessary. The amount of time required for an accurate measurement is dependent on how far the test system (synthesized) noise floor needs to be reduced in order to make a valid measurement.

Ultra low phase noise measurements, in the range of -180dBc/Hz$^{1/2}$ to -190dBc/Hz$^{1/2}$, can be made in relatively short period of time when using dedicated external LO's that are more optimal for the task at hand. The motivation in an R&D environment is achieving the lowest noise floor possible. In a production environment, the motivating factor is fast throughput for product phase noise performance testing.

The focused design of the HA7402A implements specific hardware, firmware and software to enable fully automated LO calibration and DUT locking so that he user needs no additional test equipment to setup a system for making solid, repeatable measurements. There are alternate test systems that allow for use of external LOs, but the manual calibration process is extremely tedious and prone to error.

CONFIGURATION
The cross correlation engine essentially determines what noise is common to the DUT and only displays the

result. Additional information on cross correlation is available in the February 2011 Microwave Journal Technical Feature: *Cross Correlation in Phase Noise Analysis*.

Using the HA7402A to test an oscillator, requires two similar oscillators as the LO sources in addition to the DUT (3 in total). Figure 1 is a simplified block diagram of the HA7402A front end, which shows a DUT and two user supplied LOs. Each LO is independently monitored and calibrated to phase lock to the DUT via the respective PLL tune port.

LO CALIBRATION:
The power levels of LO1 and LO2 need to be between +7dBm and +10dBm going into the analyzer. NOTE: The use of two independent LO sources is fundamental. Splitting the signal from a single LO source (phase coherent signals) will not allow the cross correlation engine to reduce the system noise floor.

For the auto-calibration routine of the HA7402A to properly function, both LO1 and LO2 must have a tunable bandwidth that covers the test frequency of the DUT.

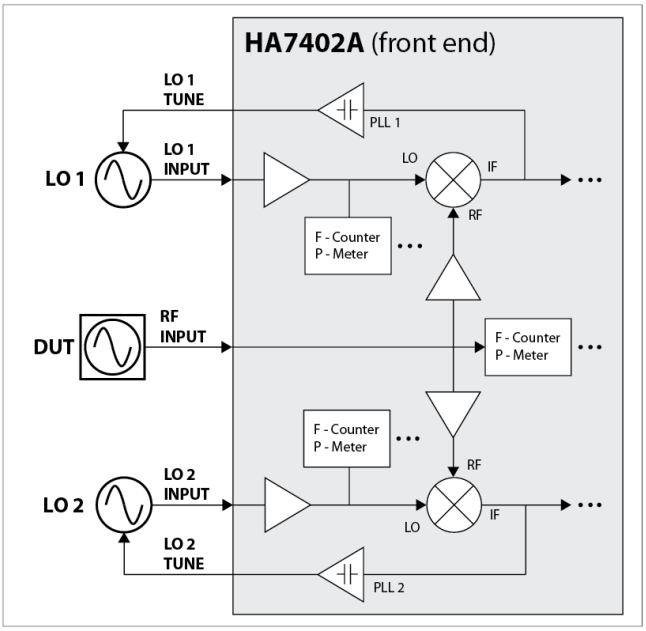


Figure 1: Auto-Calibrating Front End

All LOs have slightly different tuning ranges, -5V to +5V, 0V to +10V, and 0V to 5V are very common. The HA7402A allows the user to independently set the tune voltage limits of each LO as well as any DC offset. Whether the LO tune voltage is a positive or negative slope is a non-factor to the analyzer as it will determine this for each LO during calibration.

Once each external LO has been connected to their respective [PLL] tune port and signal input port, there will be a warm up time associated with full stabilization of the LO sources. The warm up period can be monitored based on the current draw of the LO. Once the LOs are stable, the analyzer is ready to begin calibration and test.

The LO calibration routine is initiated by selecting the *MEASUREMENT* button in the Holzworth software GUI, which will initiate the *Measurement Settings Window*. Inside this window, the tune port voltage range is selected for each LO to establish the calibration limits. Next select *CALIBRATE*. Each PLL tune port will sweep across the respective tune voltage range and the analyzer will create a calibration lookup table for each LO using the frequency counters and power meters. Figure 2 shows an example of the Calibration Table output from two LOs that happen to have opposite tuning slopes.

Calibration Table

LO1

Tune Voltages	Frequency	Power
0	100.000 434 0 MHz	7.4
1	100.000 310 0 MHz	7.4
2	100.000 186 0 MHz	7.4
3	100.000 064 0 MHz	7.4
4	99.999 942 0 MHz	7.4
5	99.999 822 0 MHz	7.4
6	99.999 704 0 MHz	7.4
7	99.999 588 0 MHz	7.4
8	99.999 474 0 MHz	7.4
9	99.999 366 0 MHz	7.4
10	99.999 262 0 MHz	7.4

LO2

Tune Voltages	Frequency	Power
-5	99.999 446 0 MHz	8.2
-4	99.999 538 0 MHz	8.2
-3	99.999 634 0 MHz	8.2
-2	99.999 736 0 MHz	8.2
-1	99.999 842 0 MHz	8.2
0	99.999 950 0 MHz	8.2
1	100.000 064 0 MHz	8.2
2	100.000 180 0 MHz	8.2
3	100.000 300 0 MHz	8.2
4	100.000 422 0 MHz	8.2
5	100.000 546 0 MHz	8.3

Figure 2: Calibration Table Output for two OCXOs used as LO1 & LO2

The calibration step typically takes about 20-40 seconds and only needs to be run one time for a pair of LOs. Once the tune voltage range of the LOs has been established, the phase locking bandwidth is automatically determined and the analyzer is ready to measure a DUT.

DEVICE UNDER TEST:
The HA7402A will accept a DUT RF power range of 0dBm to +15dBm. The test frequency of the DUT must be within the calibrated frequency lock range (overlapping tune range) of the two LOs. Select *ACQUIRE*, and the analyzer will then count the frequency of the DUT and measure the RF power. If the DUT is within range, the analyzer will then perform a final calibration step for the internal measurement and then go into phase locking mode. The two LOs will phase lock to the DUT and the analyzer will begin correlating data.

Additional DUTs that are within the range of the LOs can now be measured without recalibrating. Simply select *ACQUIRE*. This aspect of this instrument is a great advantage for manufacturing test applications.

NOTE: the *Auto-Cal Verification Mode* is a useful function that determines whether either LO has drifted outside of the calibration range prior to a DUT test. If the LO sources are known to be highly stable, this function can be disabled to increase DUT throughput.

SAVING & IMPORTING DATA:
The data is saved as a tabular raw text file in a .CSV format. Saving the DUT data will also automatically store an image of the data plot (including headers) to be defined by the user as either a .PDF, .PNG, *etc*. The software GUI can also import data for comparison, *etc.* Imported data can come from prior saved HA7402A data or any other brand analyzer that can save data in an ASCII format. Refer to the HA7402A User's Manual for more information.

SPEED CHECK

Time is money. The HA7402A is designed to measure phase noise in a relatively short amount of time in comparison to other phase noise analyzers available on the market. In phase noise measurement comparison tests, the HA7402A has demonstrated the ability to measure DUTs with noise floors of -185dBc/Hz$^{1/2}$ at speeds that are up to 100x faster than other leading test solutions. The pure speed of the HA7402A is related to the use of external LOs. However, Holzworth's new generation of FFT hardware has been heavily optimized for enhanced measurement speed. The following example demonstrates the acquisition speed of the HA7062A cross correlation engine.

EXAMPLE:
Two 100MHz OCXOs were selected as the LOs for this test. Figures 3 and 4 show the phase noise performance of each LO source (OCXO). The noise floor of each LO source is approximately -165dBc/Hz$^{1/2}$.

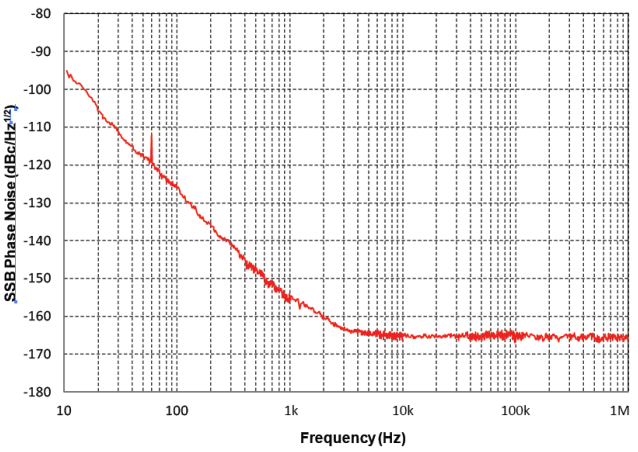


Figure 3: LO1 – 100MHz OCXO

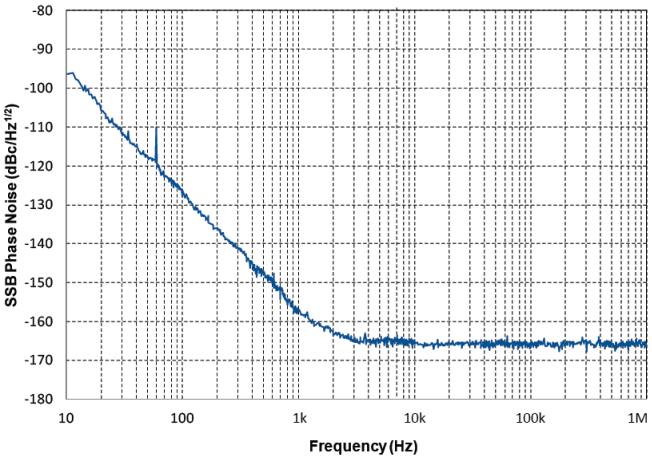


Figure 4: LO2 – 100MHz OCXO

The DUT in this test is also a 100MHz precision OCXO. The performance of the DUT was also verified using a competing signal source analyzer, which took 14 hours to acquire valid data. The data shown in Figure 5 was measured with the HA7402A, which was finished in less than 2 minutes.

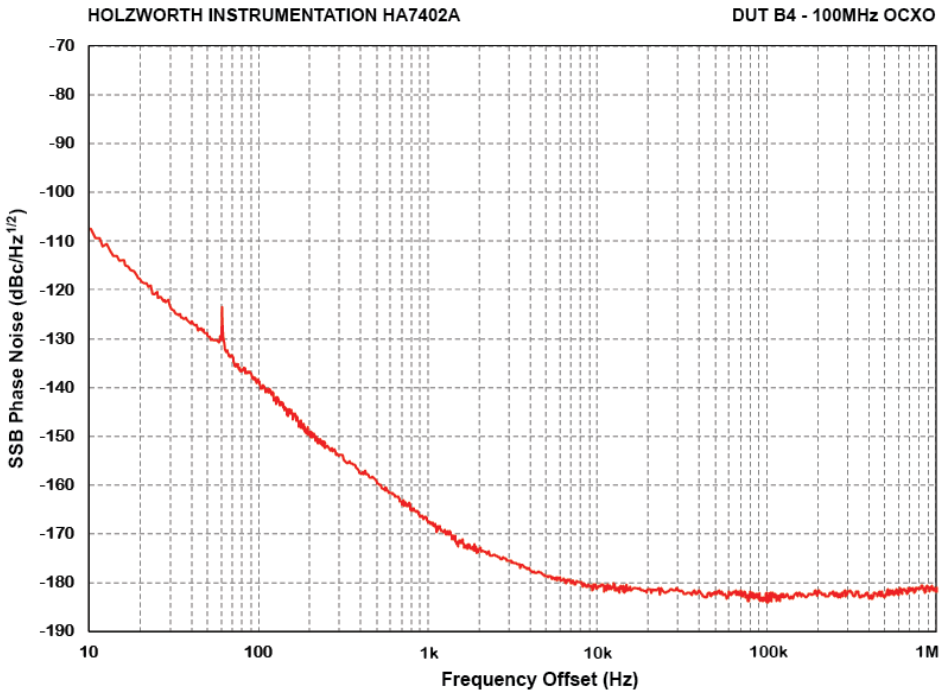


Figure 5: 100MHz OCXO Measurement (-182dBc/Hz$^{1/2}$ noise floor)

In order to acquire the data included in Figure 5, the HA7402A had to cross correlate from the -165dBc/Hz$^{1/2}$ level of the LO sources (Figures 3 & 4) down to a level of -182dBc/Hz$^{1/2}$. The first 10dB noise floor improvement (reaching -175dBc/Hz$^{1/2}$) was achieved in 20 seconds. An additional 10dB improvement in the phase noise floor (to reach -185dBc/Hz$^{1/2}$) would have taken a full 200 seconds, but was not necessary to measure this DUT.

INTERNAL TIMING

Although the HA7402A does not have integrated synthesized LOs like its big brother (the HA7062A), the HA7402A does include an internal, highly stable 10MHz OXCO. The internal 10MHz reference is used as a time base for the integrated frequency counters, which are capable of directly measuring any frequency between 5MHz to 6.7GHz at 1Hz resolution over a 1 second interval without any pre-scaling which causes a loss of resolution. The measurement interval can be software optimized for speed or resolution. As pointed out in the configuration section, the internal frequency counters eliminate the need to use a spectrum analyzer for setting up a measurement. The internal 10MHz reference can also be phase locked to an external 10MHz lab standard for the most demanding applications.

CONSISTENTLY VALID DATA

The data acquired should be all DUT (no question of if artifacts are being caused by the analyzer). Although the GUI has been intentionally simplified to reduce the LO calibration and DUT test functions down to the touch of one button, the internal hardware has also been architected to help prevent some common issues that arise with phase noise test.

A major (sometimes unknown) issue with phase noise measurements is injection locking. Injection locking occurs due to poor port-port isolation at the internal phase detectors (mixers). When a DUT falls subject to injection locking, it is difficult to detect unless the phase noise characteristics of the DUT are already well

understood. Injection locking can distort data by ±3dB to ±30dB or even more. The degree of injection locking can vary and may affect some or all measured frequency offset bands. The bottom line is that data taken under an injection locked condition is not valid. The HA7402A addresses injection locking by optimizing the port-port isolation and match at the phase detectors so that the potential for injection locking is virtually eliminated.

Furthermore, the chassis and the power supply of the HA7402A have been designed to help eliminate non-DUT spurious artifacts. The chassis and internal subsystems are conductive metal-metal hard mounted modules that are double shielded to prevent troublesome ground loops and susceptibility to external signals. The analyzer was also designed for the lowest power consumption possible (<50W), which eliminates the need for cooling fans (a source of microphonics/spurs) and the potential of rapid thermal variations within test system electronics. The rugged/portable chassis is made complete with a proprietary magnetically shielded, toroidal linear power supply… Holzworth engineering has found that at measurement levels of approximately -175dBc/$Hz^{1/2}$ and below, even high end off the shelf power supplies begin to introduce spurious artifacts to the DUT data.

SUPPORT

Inevitably, difficulties can arise with phase noise measurements. The HA7402A includes an option that logs all the step-by-step information being sent to and from the instrument. The log file from a measurement session can be sent to Holzworth support for timely troubleshooting so that any issues can be resolved in the least amount of down time. Holzworth support personnel are available Monday through Friday from 8am to 6pm, mountain standard time (8:00 – 18:00, GMT-7).

Holzworth Instrumentation Support

Email: support@holzworth.com

Phone: +1.303.325.32473 (option 2)

When emailing a session log file, please include the product model number and the serial number, along with your phone number.

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