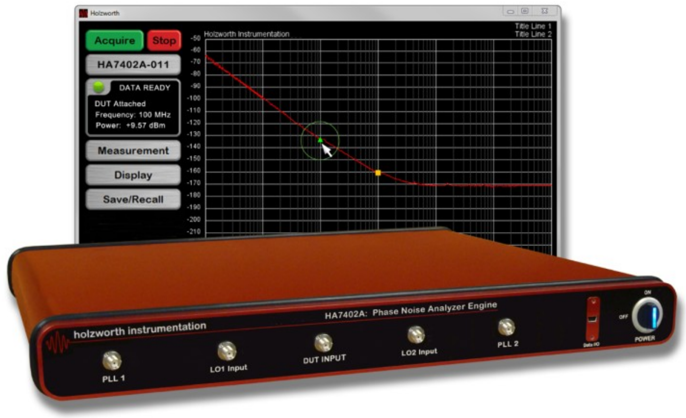
QUICKLY EVALUATE HIGH PERFORMANCE OSCILLATORS

Using the Holzworth HA7062C *Real Time* Phase Noise Analyzer – White Paper

INTRODUCTION

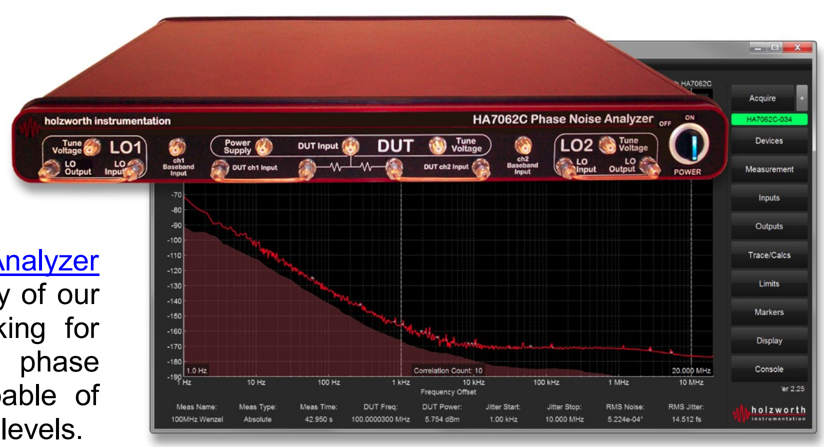
Designers and manufactures of today's high performance OCXOs, CROs, DROs, TCXOs, SAW oscillators, *etc*. are pushing phase noise measurement floor requirements to the theoretical limits. In some cases, even beyond what has historically been considered impossible. Oscillator manufacturers and engineers who are tasked to evaluate the performance of ultra low phase noise oscillators demand a phase noise test system that can accurately measure their devices with the fastest acquisition speeds possible.

In 2010, Holzworth Instrumentation first introduced the model HA7402A. This analyzer was specifically designed for quickly measuring the phase noise of high performance oscillators in both R&D and manufacturing test. The HA7402A was a cross correlation machine that, as an industry first, utilized 2x non-coherent external frequency sources (voltage tunable oscillators) as the system test LOs. Born as an elegantly simple concept, the highly effective *External LO Mode* function has since been adopted by alternate manufactures of phase noise analysis systems.



Utilizing cross correlation for phase noise analysis makes it possible to measure the phase noise of a DUT that has better performance than that of the test system LOs. However, cross correlating to achieve lower measurement floors not only consumes measurement time, but can also result in inaccurate data if not properly implemented. The optimal test system scenario for making fast, accurate phase noise measurements is for the test system LOs to have equal or better phase noise performance than that of the DUT. The straight forward design of the HA7402A Cross Correlation Engine allowed for industry leading measurement speeds, and high accuracy at an extremely reasonable cost of ownership.

Holzworth has moved through several revisions of the design to incorporate higher measurement offsets, an ANSI z540 calibration (for NIST traceable data), real time measurement capability, and more. The current HA7042C and the HA7062C *Real Time* Phase Noise Analyzer both incorporate Holzworth's full history of our premium measurement features, making for the industry's fastest, most accurate phase noise analyzers that are proven capable of measuring to the lowest possible noise levels.



Both the HA7402C and the HA7062C offer *External LO Mode* for implementing user supplied LOs. This feature, coupled with Holzworth's real time cross correlation engine, makes for the flat out fastest measurement speeds available for high performance oscillators. This white paper outlines the setup procedure and measurement examples. If you don't currently own a Holzworth Real Time Phase Noise analyzer, feel free to contact us for a comparative test drive. Holzworth products perform as specified.

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MOTIVATION

All analog, 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 cannot produce as low of phase noise performance as good fixed frequency LO sources at the same relative frequency. RF synthesizers are by nature a compromise between phase noise performance and broadband tuning capability.

For example, in a cross correlation analyzer where only one correlation is made, the phase noise measurement floor will be essentially identical to the phase noise performance of the internal LO synthesizers. Measuring a DUT with better phase noise performance than the internal synthesizers requires the cross correlation engine to go to work and make up the difference. This part of the process can consume an excessive amount of time, especially when noise floors of lower than -170dBc/Hz are necessary. For example, a modern, high end 100MHz OCXOs can perform at levels of better than -190dBc/Hz (offsets > 10kHz), while the close to the carrier phase noise has been demonstrated at levels of below -140dBc/Hz (100Hz offset). 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. In some cases, even with cross correlation, the system hardware is not capable of reaching the required noise levels, resulting in invalid data.

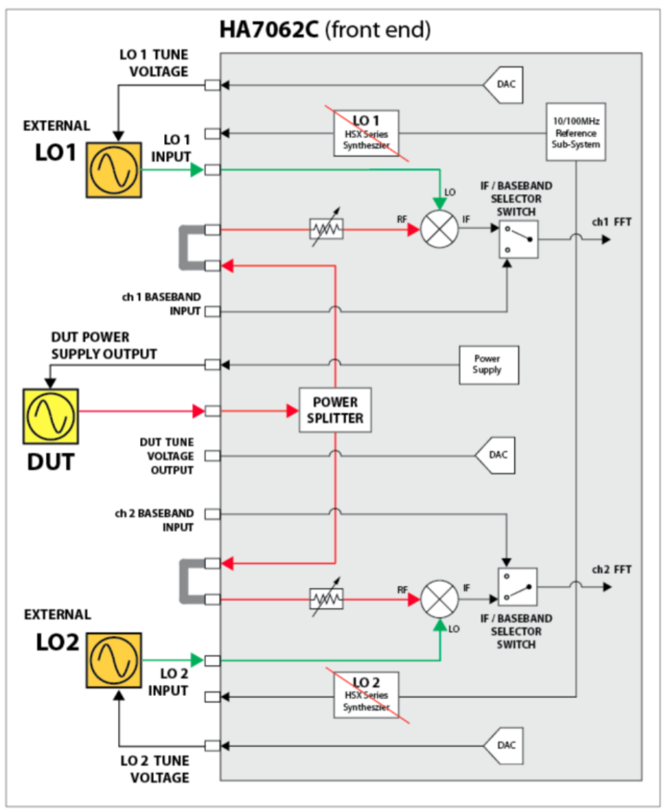
Ultra low phase noise measurements to levels of below -190dBc/Hz, can now be made in a relatively short period of time when using dedicated external LO's that are more optimal for the task at hand. The motivation in an R&D environment is achieving the lowest noise floor possible. In a production environment, the motivating factor is fast throughput for product phase noise performance testing. In both cases, measurement accuracy is imperative.

The HA7062C implements cutting edge hardware and firmware, coupled with intuitive application software (GUI). This enables 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.

CONFIGURATION EXAMPLE

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 HA7062C to test an oscillator in External LO Mode, requires two similar oscillators as the LO sources in addition to the DUT (3 in total). The diagram to the right is a simplified block diagram of the HA7062C front end, configured with a DUT and two user supplied LOs. Each LO is independently monitored and calibrated to phase lock to the DUT via each respective PLL tune port.



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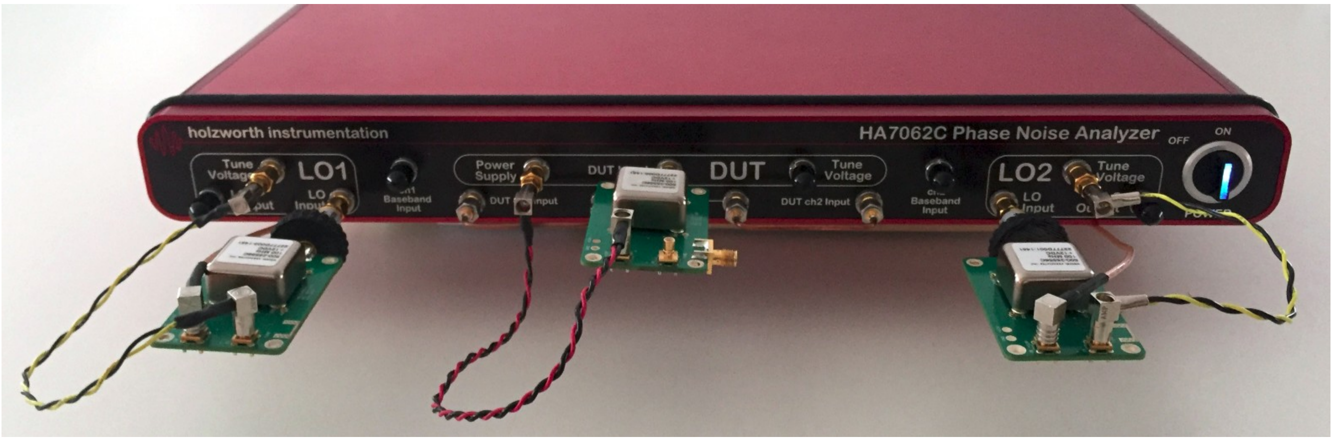
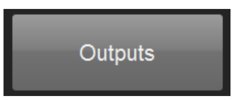
In this example, the *External LO Mode* test setup utilizes 2x Wenzel 100MHz OCXOs as the external LOs. The DUT is also a 100MHz OCXO, having the same performance specifications.



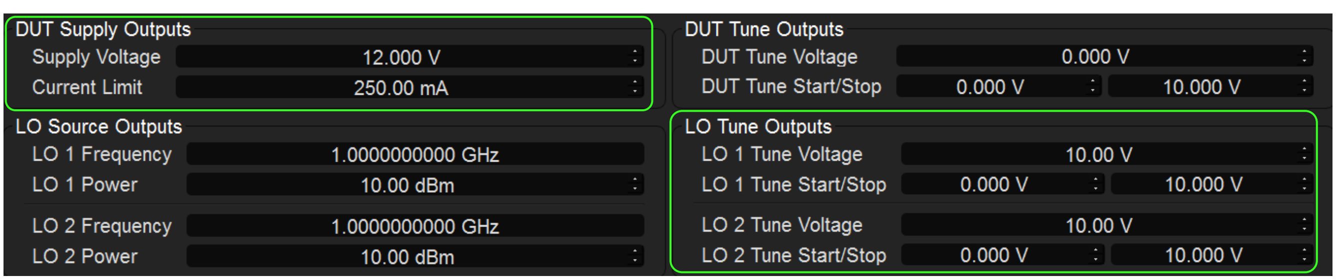
CONNECTING / CALIBRATING THE EXTERNAL LOs:
For operation in *External LO Mode*, the ideal output RF power level for LO1/LO2 is between +7dBm and +12dBm at the LO1/LO2 Input ports on the analyzer. Coaxial attenuators are recommended for achieving optimal power levels, as necessary.

NOTE 1: 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.

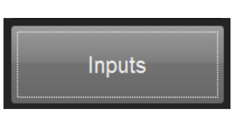


At the right side of the GUI, select the *Outputs* button, which will display the outputs selector menu, below the plot area.

Within the Outputs menu, a user can make adjustments to: *DUT Supply Output*, *DUT Tune Output*, *LO Source Outputs* (for manually controlling the internal synthesized LOs – disregard for this example), and the *LO Tune Outputs*. In this measurement setup, the DUT Supply Output is set to 12.000V and the LO Tune Outputs are each set to 0.000V (start), +10.000V (stop).



The HA7000 Series currently only offers a low noise power supply for the DUT. An additional power supply must be used for both external LOs. Holzworth has found that the cleanest of measurements occur while using batteries. Many users have confirmed that even heavy capacitive filtered bench top power supplies can introduce both unwanted spurious artifacts as well as reduced phase noise performance within the data response curve.



Once the proper DUT supply voltage and LO tune voltage ranges are set, the next step is to select the Inputs button, which will then display the *Inputs* menu, below the plot area.

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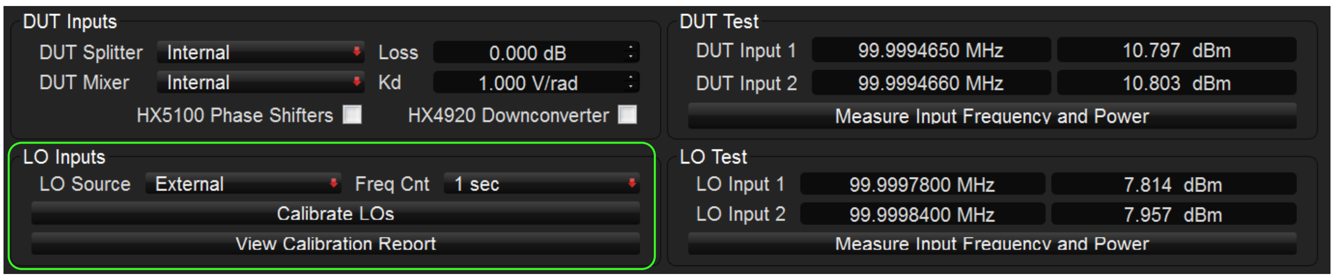
Within the Inputs menu, the user can make selections for *DUT Inputs*, make selections/adjustments for *LO Inputs*, verify the DUT frequency and power level via *DUT Test*, and verify the frequency and power levels of each LO via *LO Test*.

To accommodate varying tune voltage ranges for the external LOs, the HA7062C allows the user to independently set the upper/lower tune voltage limits for each external LO. 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.

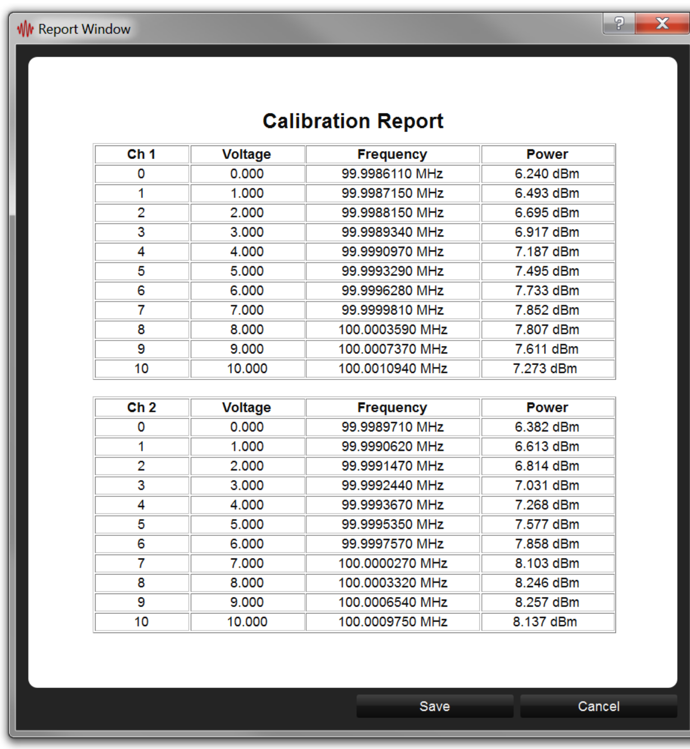
NOTE 2: Allow for enough LO warm up time with the external LOs so that the frequency outputs have fully stabilized. Once the LOs are stable, the user is ready to begin LO calibration and DUT test. Stabilized DUT and LOs can be verified via the *Measure Input Frequency and Power* button, located under *DUT Test* and *LO Test*. This step is not necessary, but is available for verification.



Under *LO Inputs*:

1. Select "External" for the LO source.
2. Select *Calibrate LOs* and the button will then indicate the status of the calibration.
3. Once the calibration is complete, the user can select *View Calibration Report*

The calibration report can be saved for reference and is a useful tool to verify that the calibration lookup table for each external LO has been properly swept and that the voltage levels are as to be expected.



Calibration Report

Ch 1	Voltage	Frequency	Power
0	0.000	99.9986110 MHz	6.240 dBm
1	1.000	99.9987150 MHz	6.493 dBm
2	2.000	99.9988150 MHz	6.695 dBm
3	3.000	99.9989340 MHz	6.917 dBm
4	4.000	99.9990970 MHz	7.187 dBm
5	5.000	99.9993290 MHz	7.495 dBm
6	6.000	99.9996280 MHz	7.733 dBm
7	7.000	99.9999810 MHz	7.852 dBm
8	8.000	100.0003590 MHz	7.807 dBm
9	9.000	100.0007370 MHz	7.611 dBm
10	10.000	100.0010940 MHz	7.273 dBm

Ch 2	Voltage	Frequency	Power
0	0.000	99.9989710 MHz	6.382 dBm
1	1.000	99.9990620 MHz	6.613 dBm
2	2.000	99.9991470 MHz	6.814 dBm
3	3.000	99.9992440 MHz	7.031 dBm
4	4.000	99.9993670 MHz	7.268 dBm
5	5.000	99.9995350 MHz	7.577 dBm
6	6.000	99.9997570 MHz	7.858 dBm
7	7.000	100.0000270 MHz	8.103 dBm
8	8.000	100.0003320 MHz	8.246 dBm
9	9.000	100.0006540 MHz	8.257 dBm
10	10.000	100.0009750 MHz	8.137 dBm

NOTE 3: The calibrated frequency range of both LO1 and LO2 must overlap the frequency of the DUT for a proper phase lock to occur in order for the system to make the phase noise measurement.

The *External LO Mode* calibration process typically takes less than 30 seconds (at 1 second frequency counter interval) 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.

NOTE 4: *Frequency Cnt* (counter) adjustments can be made based on the stability of the LO sources. The default frequency counter interval is 1 second, which is ample for most high performance 100MHz and greater external LO sources.

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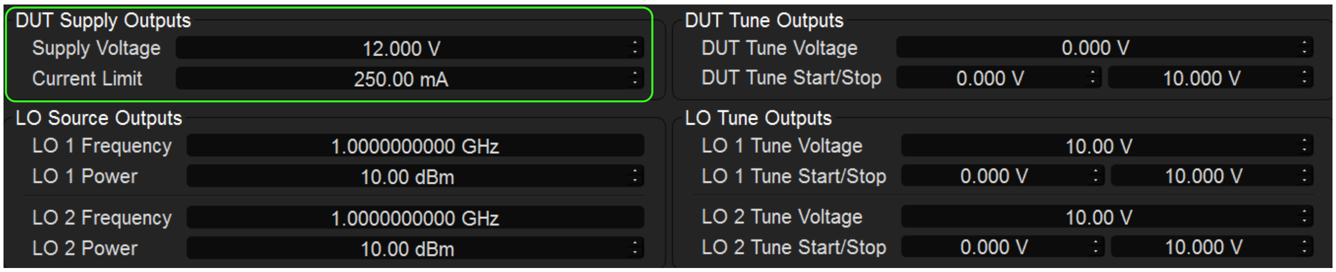
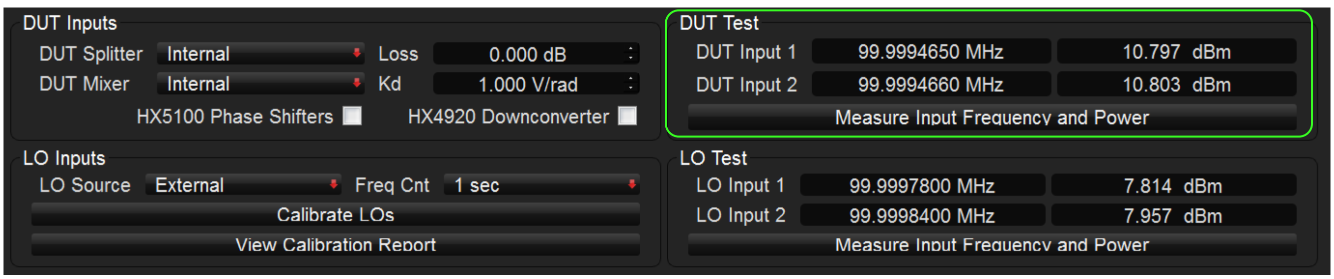
DEVICE UNDER TEST:
The HA7062C will accept a DUT RF power range of -5dBm to +20dBm. A good rule of thumb for measuring the phase noise of high performance sources is the higher the DUT power level, the better. In a 50 ohm system, the noise floor cannot surpass -187dBc/Hz at +10dBm power, -197dBc/Hz at +20dBm input, *etc*.

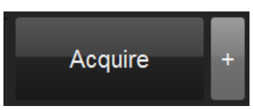


As noted prior, the DUT supply voltage level has been set to 12V (see above) and the power level was verified as "in range" (see below).



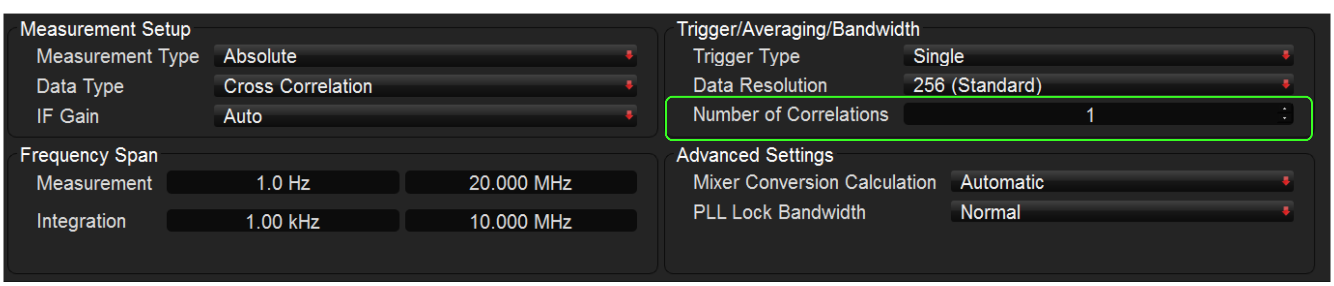
NOTE 5: *DUT Test* displays 2 DUT readouts (DUT Input 1 and DUT Input 2). This feature is for applications that use the splitter bypass function at the front panel (not used for this measurement). There is an independent frequency counter and power meter located at the mixer (phase detector) for each cross correlation channel. The readings will typically be within 1% of each other. Higher differences may indicate a user configuration error or a potential hardware fault.

ACQUIRING DATA:
At this point, the system is ready to go.



Selecting the Acquire button at the top/right of the GUI will begin the process. The analyzer will then perform a final internal calibration step prior to phase locking to the DUT and correlating data.

For this example, the external LOs have essentially the same performance as the DUT, being of the same series and part number. Data on the next page is captured for 1 correlation and 5 correlations via the *Measurement* window.



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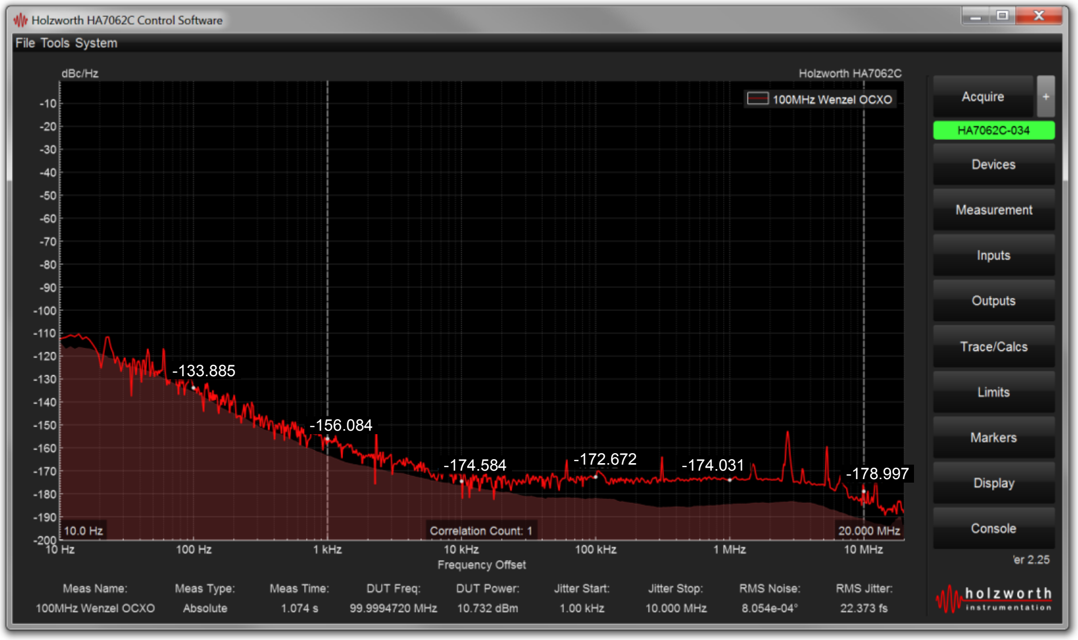
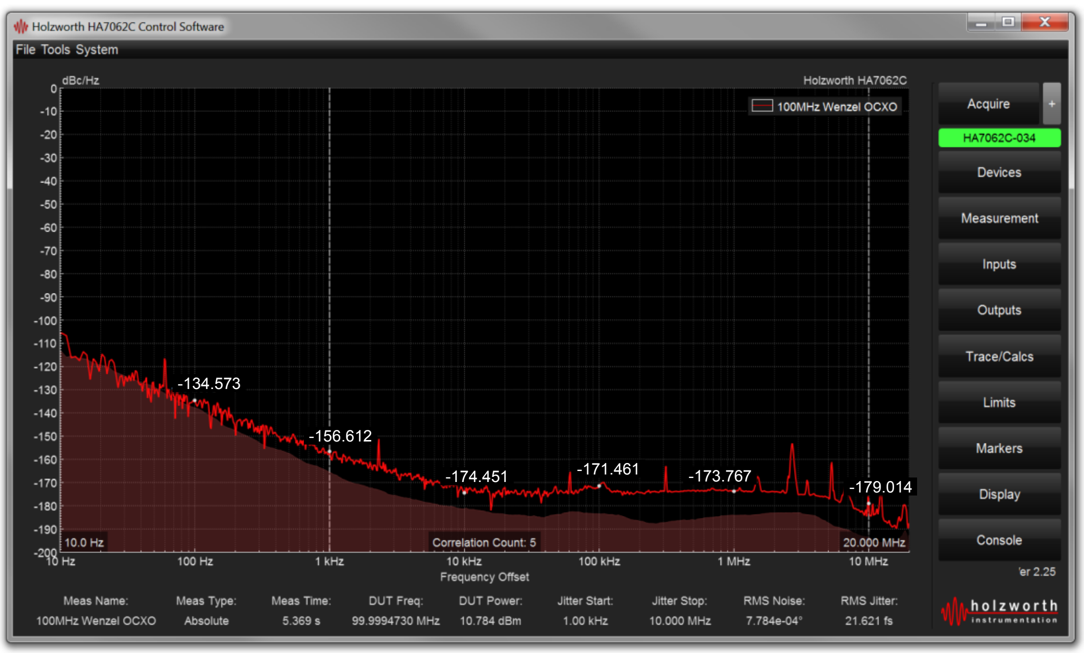
SPEED CHECK

Time is money. The HA7062C is designed to accurately measure phase noise and/or jitter and/or AM noise in the shortest amount of time possible. The pure speed of the HA7062C demonstrated here is in part due to utilizing *External LO Mode*. However, Holzworth's current generation of real time FFT processing hardware has been heavily optimized for enhanced measurement speed.



100MHz OCXO (standard): 1 Correlation = < 1.1 seconds
(No removal of environmental spurious)



100MHz OCXO (standard): 5 Correlations = < 5.4 seconds
(No removal of environmental spurious)

Note that there are no substantial differences between the 2 measurements, demonstrating that fewer correlations are necessary when using test system LOs that have similar performance as the DUT.

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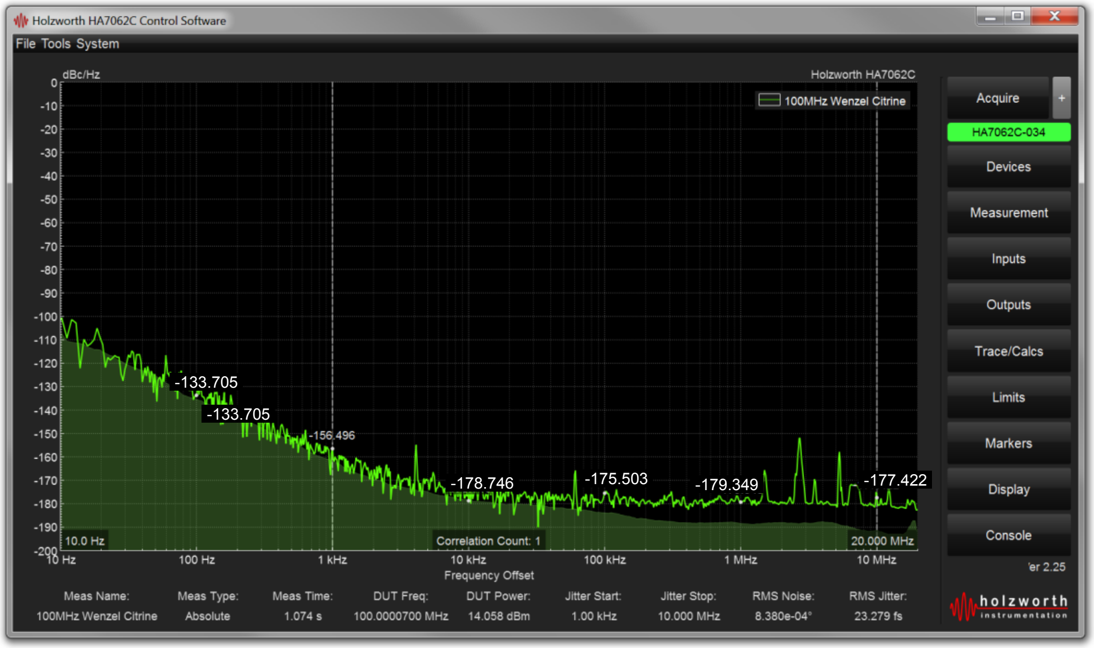
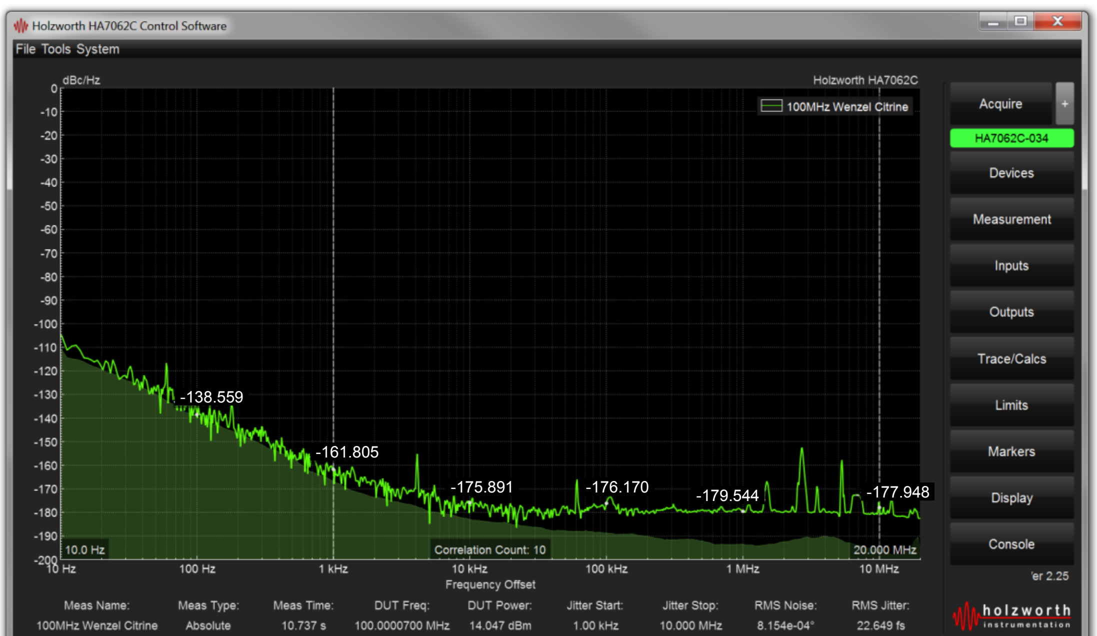
SPEED CHECK (DUT better than LOs)

Additional DUTs that are within the calibrated tune range of the external LOs can now be measured without recalibrating. Simply select *Acquire*.

In this case, a 100MHz OCXO having better phase noise performance than the external LOs is being tested. In this case, increasing the number of correlations is necessary to achieve measurement accuracy at lower frequency offsets, as demonstrated below.



100MHz OCXO (high performance): 1 Correlation = < 1.1 seconds
(No removal of environmental spurious)



100MHz OCXO (high performance): 10 Correlations = < 10.8 seconds
(No removal of environmental spurious)

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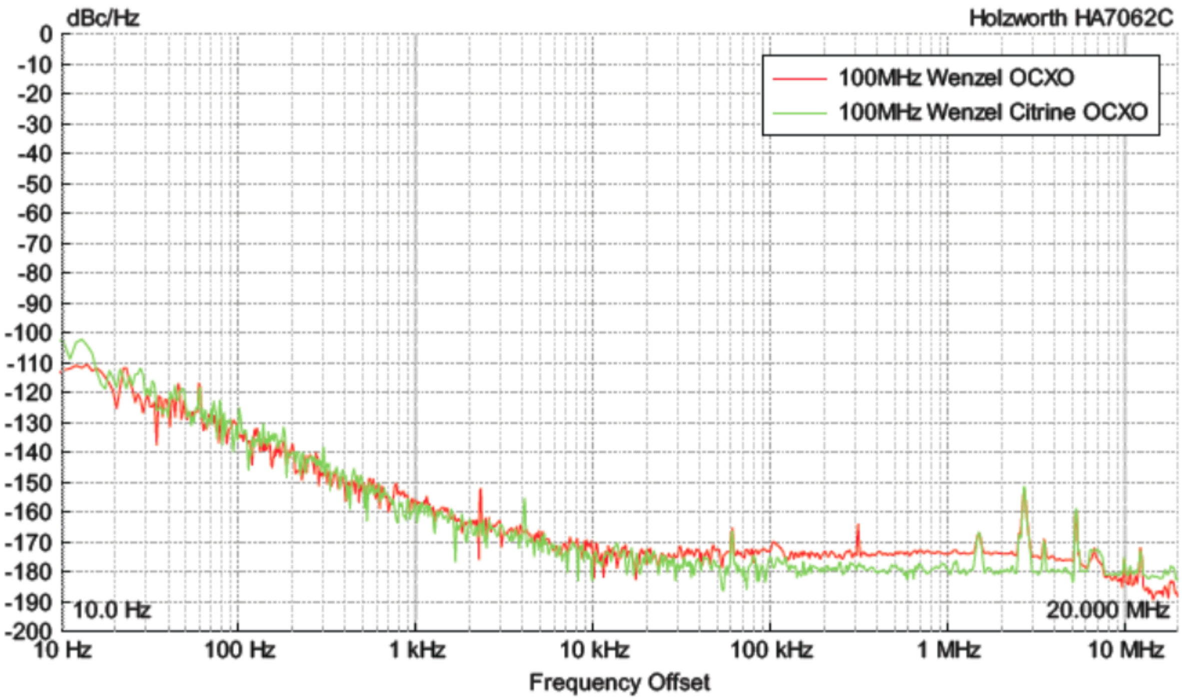
REPORT GENERATION:

Data can be saved as a proprietary .htf file, which will maintain all measurement & display settings for re-importing into the GUI. Raw data can also be saved as a .csv file. Furthermore, the data plot image can be saved as a .png with options to invert background color, change individual trace colors, and more.

A more recent feature that has been incorporated into the GUI is *Generate Report*. The *Generate Report* function allows a user to customize a full report with specific output parameters noted for an unlimited number of traces.



100MHz Wenzel OCXO	DUT Info	Jitter Stats	Marker Freq	Value [dBc/Hz]	Spur Freq	Value [dBc]
S/N:	Freq: 99.9994720	Start: 1.00 kHz	100.0 Hz	-133.88	2.32 kHz	-140.94
HA7062C-034	MHz	Stop: 10.000	1.00 kHz	-156.08	2.716 MHz	-111.59
Type: Absolute	Power: 10.732 dBm	MHz	10.00 kHz	-174.58	5.310 MHz	-115.11
Date: 2017-12-01	Gain: 42 dB	Jitter: 22.373 fs	100.00 kHz	-172.67	12.207 MHz	-121.43
Time: 16:12:15	Acq: 1.074 s	Noise:	1.000 MHz	-174.03		
Temp: 47.28°C	Offset: 10.0 Hz	8.054e-04°	10.000 MHz	-178.98		
Limit Test: None	# Correlations: 1					

100MHz Wenzel Citrine OCXO	DUT Info	Jitter Stats	Marker Freq	Value [dBc/Hz]	Spur Freq	Value [dBc]
S/N:	Freq: 100.0000690	Start: 1.00 kHz	100.0 Hz	-128.36	4.11 kHz	-141.04
HA7062C-034	MHz	Stop: 10.000	1.00 kHz	-158.00	2.686 MHz	-110.32
Type: Absolute	Power: 14.096 dBm	MHz	10.00 kHz	-175.40	5.310 MHz	-114.44
Date: 2017-12-01	Gain: 42 dB	Jitter: 22.765 fs	100.00 kHz	-175.17		
Time: 16:17:34	Acq: 1.074 s	Noise:	1.000 MHz	-179.11		
Temp: 47.24°C	Offset: 10.0 Hz	8.195e-04°	10.000 MHz	-177.61		
Limit Test: None	# Correlations: 1					

The *Generate Report* tool is fully customizable by the user. Modify the layout, reported parameters, colors, company logo, title, *etc.*, allowing for easily loaded templates to use for R&D and/or manufacturing test reports, customer data, and more.

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CONSISTENTLY VALID DATA

The data acquired should fully represent the DUT measurement (no question of artifacts 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 recently revealed issue with many cross correlation phase noise analyzer designs is the affects of AM noise adversely influencing the measured PM (phase noise) response. This phenomenon is referred to as “cross spectral collapse”. Unlike most alternate phase noise analyzer designs, Holzworth phase noise analyzers are designed to be AM immune, at the hardware level. For more information on this cross spectral collapse, visit the following link at the US NIST website: https://www.nist.gov/publications/collapse-cross-spectral-function

Another often 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 HA7000C Series 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.

Finally, the chassis and the power supply of the HA7000C Series 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 power supply. Holzworth engineering has found that at measurement levels of approximately -175dBc/Hz and below, even high end off the shelf power supplies begin to introduce spurious artifacts to the DUT data.

With Holzworth phase noise analysis test systems, what you see is what you get. Noisy artifacts in a data response can often be environmental… electrical and/or mechanical in origin. Holzworth believes the transparency in data generation is extremely valuable to the end user. Start with the cleanest hardware possible and then what you see is what you have measured.

SUPPORT

Holzworth support personnel are available Monday through Friday from 8am to 6pm, mountain standard time (8:00 – 18:00, GMT-7) to provide test system configuration support.

Holzworth Instrumentation Support

Email: support@holzworth.com

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