WHITE PAPER

The Future is Now: 5G NR ATE and Field Test Systems Utilize Teledyne e2v's Quad ADCs to Revolutionize Auto-Calibrated Test Measurements.

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TELEDYNE e2v | Semiconductors
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ABSTRACT

As mobile wireless technology continues its rapid generational development over the last twenty years from 3G to 4G, and now onto 5G NR networks, one technological problem has been consistent throughout; automatic/calibrated testing of required high frequency components.

The most difficult testing challenge for RF ATE and Field Test Systems is simply calibration, repeatability, and correlation of measured performance results in order to verify that they meet required specification limits. Now, as the future of wireless technology transitions to 5G NR components, Teledyne e2v's monolithic quad-channel, multi-port input ADCs utilizing unparalleled on-chip high frequency cross point switch input circuit technology, allows for auto-calibration and measurement techniques in either RF ATE and/or Field-Testing environments.

Teledyne e2v's EV12AQ605 and EV10AQ190 (12 and 10 bit quad-channel ADCs with cross point switch input circuit technology) enable RF ATE and Field-Tester developments to focus on auto-calibrated test measurements for both single channel and multi-port 5G NR devices.

INTER-GENERATIONAL ISSUES

5G is the telecommunication industry's fifth generation technology standard for cellular networks, which began worldwide deployment in 2019. 5G is the planned successor to current 4G networks which provide connectivity to most cellphones and will have greater bandwidth giving higher download speeds eventually up to 10 Gbit/s. Due to this increased bandwidth, current 4G cellphones will not be able to use the new networks, which will require 5G enabled wireless devices. Conversely, 5G will also have to accommodate all 4G network requirements in regards to bandwidth, etc. Therefore, in order to ensure wide service, 5G networks will operate within three frequency bands: low, medium, and high.

Low-band 5G (also called sub-1 GHz) uses a similar frequency range as 4G (600 -700 MHz) which yields download speeds slightly higher than 4G (30-250 Mbit/s).

The medium-band 5G (also called sub-6 GHz) frequency range is 2.5-3.7 GHz (download speeds of 100-900 Mbit/s). This level of service should be available in most metropolitan areas in 2020.

High-band 5G (also called millimeter-wave or mmWave) currently uses frequencies of 26, 28 or 39 GHz. The aforementioned 5G frequency bands have been tested in 2020, and new frequency medium bands (sub-6 GHz) are expected to be implemented in the upcoming months and years (i.e. currently there are more than fifty 5G NR medium band frequencies in use worldwide).

In 2018, an industry consortium setting standards for 5G (3rd Generation Partnership Project (3GPP)) defined any system using 5G NR (5G New Radio) software as 5G. 5G will ultimately support an estimated 1M devices/km^2 while 4G currently supports approximately 100K devices/km^2. Of course, 5G wireless devices will also have 4G LTE capability, due to the fact that the new 5G network will use existing 4G networks for initially establishing the connections with the cell. The bottom line is future 5G components must not only cover the ever-expanding performance demands of the 5G network requirements, but they must also cover previous generations: 2G/3G/4G/5G (GSM/EDGE/CDMA/UMTS/WCDMA/LTE/LTE-A/TD-SCDMA/TD-LTE, etc.).

Therefore, future 5G NR ATE systems will need the ability to test components over a broad range of frequencies in a reliable, repeatable way that can be auto-calibrated and measured in order to ensure results that correlate while also reducing test errors.

THE TROUBLE WITH ERRORS

Characterizing the multitude of uncertainties/errors external to the DUT (Device Under Test) within an RF ATE measurement environment, requires test configurations that will increase confidence in taking measurements that ensure accurate and reliable characterization of the DUT/product performance. Characterizing and quantifying measurement uncertainty is critical in order to achieve desired results.

Generally speaking, the accuracy of a measured result is always questionable simply because all measurements are influenced by physical and electrical environment(s) and are limited by the capability of the source/measuring device/instrument(s) used. Therefore, the measured value is never exactly equal to the true value of the DUT/performance being tested. The difference between the measured and true performance value is simply called error. Depending on how errors originate (external to the DUT), they can be broadly categorized as random or systematic errors. Random errors are just that, random. They are caused by unpredictable temporal or spatial variations during test set-up and test measurement. Generally, random errors are extremely difficult to trace or quantify in regards to how they affect the DUT measurement result. Random errors mainly arise due to changes in the RF ATE environment; such as temperature, connectivity, instrument noise and distortion that also include repeatable errors in connections and cables.

Systematic errors are repeatable and can usually be resolved, but not entirely. Systematic errors can only be minimized to a certain degree. The concept of calibration is simply to estimate the systematic errors in a RF ATE test environment and correct for them. Usually in order to successfully remove systematic errors, calibration standards or reference units are required. A standard or reference unit should represent or reproduce a known unit of measurements to a very high degree of accuracy. Calibration is then carried out by measuring/testing the standard/reference unit, with the measurement system, and that measurement result is then stored as raw data. The raw data result is then used to calculate the systematic errors that occurred during the measurement by comparing the raw data measurement of the standard/reference unit with their known values. This then gives the error result. The systematic error result is then used to correct the measurement result. Unfortunately, for 5G NR ATE testers, including the DIB (Device Interface Boards, Probe Cards, Cables and Connectivity, etc.) over a variety of high frequencies and test conditions, using standards/reference units, becomes problematic. Another way to view calibration is to simply define a reference plane. A reference plane is accomplished by estimating the systematic errors in the test system environment and correcting for them. Unfortunately, random errors cannot be corrected within a reference plane environment. What is increasingly needed, within a RF/5G NR ATE and Field Test Systems environment, is an ability to create a reference plane for each DUT utilizing automatic/calibration and measurement techniques.

TIME FOR INDIVIDUAL COMPONENT AUTO-CALIBRATION AND TEST MEASUREMENT

Creating a reference plane for each DIB (Device Interface Board)/DUT within an RF ATE environment, requires defining a calibration process (Figures 1a & 1b). Typically, standard(s) are used for calibration. Ideally, standard(s) utilize a "gold reference unit" DIB/DUT that would have less than one half to one quarter of the accumulated errors/measurement (Step1) compared to a regular DIB/DUT measurement (Step 2). If this error is achieved (in Step 1), the accumulated measurements utilizing the standard(s) is considered to be sufficient when the actual DIB/DUT is tested (Step 2). Consistently maintaining minimum "gold standard/reference unit" measurement errors within an RF ATE environment, over a wide range of frequencies, noise and voltage levels, and gains is very difficult, time consuming, and costly. Of course, there are inter-connect and component variations that will significantly influence calibrating a reference plane between the standard(s) and the DIB/DUT during calibration (i.e. including multiple Device Interface Board (DIB) anomalies, DIB/DUT contacts/component variations, cables/connectors impedances, source/measurement instrument variations, etc.) Bottom line, given all the above, is calibration methods for 5G NR devices can involve a combination of manual testing that utilize standard(s) in order to establish a reference plane (which introduce significant random errors) followed by auto-testing which hopefully removes the systematic error sources.

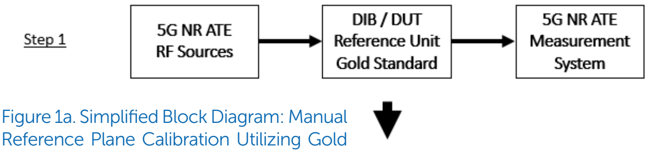


Figure 1a. Simplified Block Diagram: Manual Reference Plane Calibration Utilizing Gold Standard Reference Unit

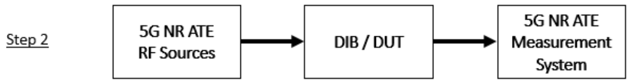


Figure 1b. Simplified Block Diagram: Auto-Measurement of DIB/DUT

Figure 2 represents a generic 6-pin (surface mount package) 5G NR Low Noise Amplifier (LNA) product/DUT (w/o external components). This LNA example would need to be tested within an RF ATE environment that requires calibration prior to testing in order to establish a reference plane. Typical RF ATE tests that would be required for an LNA include:

- Operating Frequency Range (there are 50+ 5G NR network frequency bands)
- Gain/Insertion Loss
- Gain Flatness (over frequency range(s))
- Noise Figure
- Input/Output Return Loss
- Input IP3
- Output IP3

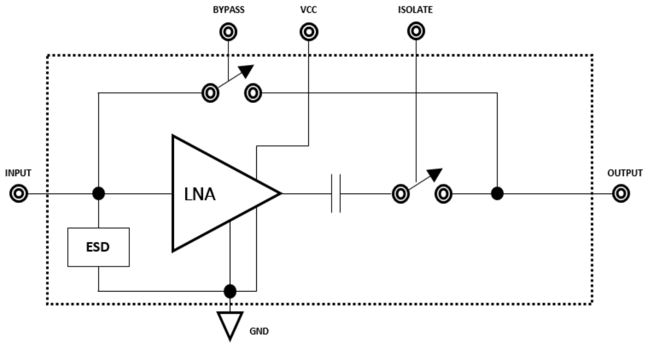


Figure 2. Generic 6-Pin 5G NR LNA DUT w/o external components

Of course, besides testing this particular LNA device, an actual RF ATE environment also needs to have the capability to test other types of 5G NR type devices (Couplers, Attenuators, Filters, VGAs, etc., etc.). Tests may involve individual components, and/or at a sub-system level with multiple devices in cascade (i.e. Coupler + Attenuator + LNA + VGA + Filter, etc.). Therefore, multi-ports could also need to be tested as well.

Figure 3 represents the same generic 6-pin (surface mount package) 5G NR Low Noise Amplifier (LNA) product/DUT with simplified/required external components necessary for operation. These components would be mounted to the DIB as close to the handler contacts as possible. Practically speaking, Figure 3 under high frequency stimulus, is significantly more complex than Figure 2 for both measurement and calibration. Anomalies between the DUT and the DIB/Handler include:

- Attenuator mismatches and loss errors (required for impedance matching and to scale DUT input/output levels)
- Variations of inductor performance(s) between the input and output
- Changes in the interaction between the control line and gate driver
- Ground loops
- Cable/Connection impedances
- Impedance differences in tightening the connectors to the test system with every test module connection required

As mentioned before, the calibration problems increase as the DUT size increases to multiple devices in the signal chain. As the variations increase, calibration and auto-test errors exponentially increase.

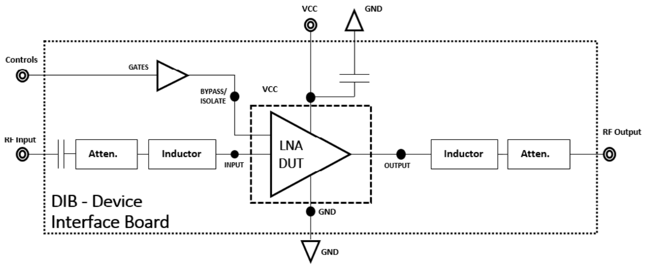
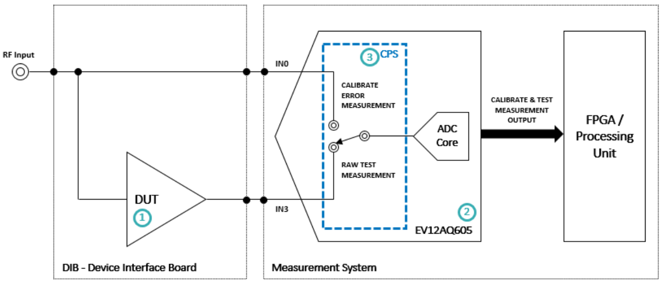


Figure 3. Generic 6-Pin 5G NR LNA DUT/DIB with external components

So, what is needed for future 5G NR ATE systems, and testing field installed telecom equipment, is the ability to test over a broad range of frequencies, specifications, and conditions in a way that is reliable, repeatable, and will correlate (given the previously mentioned errors). It also needs to be auto-calibrated without introducing manual calibration techniques that rely on standards in order to create a reference plane. Figure 4 represents a simplified/conceptual block diagram for an auto-calibrated 5G NR RF ATE measurement system for any DIB/DUT (single or multi-port) irrespective of additional required external components.



① **Device Under Test or Gold/Standard Unit**
② **EV12AQ605 Analog-to-Digital Converter**
③ **CrossPoint Switch integrated in EV12AQ605**

Figure 4. Conceptual Block Diagram: Auto-Calibrated 5G NR RF ATE Measurement/Test System

In order to make accurate, reliable and repeatable measurements within an RF ATE system, test engineers have to bridge the gap between the high-quality connectors that are mounted on the front panels of expensive rack-mounted source and receiver/measurement instruments, and the real-world interface for their DIB/DUT. The contact electrical interface to the DUT (whether a probe card or package/handler contact interface card) is usually integrated within the DIB which is rarely fitted with the same type of high-quality connecters. The cascade of multiple cables/connections between the source (to the DUT) and receiver/measurement instruments (from the DUT), including the DIB, will introduce substantial random and systematic errors. In order to compensate for these errors, the simplified RF ATE test configuration (Figure 4) allows for auto-calibration and measurement at the DUT ports without requiring manual calibration techniques in order to establish a reference plane for each individual DIB/DUT. Figure 4 simply automates the calibration/test measurement by directly measuring the test configuration errors and correcting for them in the final DUT measurement (Raw Test Measurement – Calibration Error Measurement = Final DUT measurement.) This can be accomplished by initially (automatically) switching the internal cross point switch (CPS) to "Calibrate Error Measurement" mode, and then allowing the ADC to make an RF Throughput measurement inclusive of error contributors:

- Direct RF Antennae/source noise and distortion
- Input return loss/attenuator errors to the DUT
- Power supply issues
- Ground issues
- Ancillary source/driver issues (such as the example control port above)
- Connector and Cable errors/variations

This measurement is stored as the Calibration Error Measurement. The CPS is then automatically switched to "Raw Test Measurement" mode, the ADC makes the same measurement inclusive of the DUT (with required external components), and this data is stored as the Raw Test Measurement. The resulting data from the two measurements are conditioned in software in order to produce an auto-calibrated/corrected final test measurement result. The internal CPS enables the RF ATE engineer to automatically reconfigure a DIB/DUT, through a battery of tests, without the requirement of manual intervention and recalibration. Of course, if the DIB/DUT consists of multiple devices in cascade, in the same manner as above, multi-ports can also be measured and auto-calibrated/corrected utilizing the quad ADC with the quad input cross point switch (CPS) which will be explained later.

5G NR ATE DUT AUTO-CALIBRATION AND TEST MEASUREMENT

Figures 5 & 6 depict automated (2-state) solution(s) for a 5G NR ATE auto-calibrated and test measurement system which uses Teledyne e2v's matched quad-channel, multi-port input ADCs utilizing unparalleled on-chip high frequency cross point switch (CPS). Teledyne e2v's EV12AQ605 and EV10AQ190 (12 and 10 bit quad-channel ADCs with cross point switch) enable 5G NR ATE and Field-Tester developments the ability to focus on auto-calibrated test measurements for both single channel (Figures 5, 6 and 7) as well as multi-port 5G NR devices (shown in the next section). The CPS operates within 4 distinct modes (that can be automatically enabled/controlled through the SPI):

- 1-ch mode IN0 input: Quad ADCs, interleaved, maximum sample rate of 6.4 GSPS (4 X 1.6 GSPS)
- 1-ch mode IN3 input: Same as above)
- 2-ch mode IN0 input connected to both A & B ADCs; IN3 connected to both C & D ADCs with maximum sample rates of 3.2 GSPS (2 X 1.6 GSPS) for each channel
- 4-ch mode IN0-IN3 inputs individually connected to A, B, C, D, ADCs respectively; with maximum sample rates of 1.6 GSPS for each separate channel

Also, with an extended input bandwidth above 6 GHz (EFPBW), the EV12AQ605 allows the sampling of signals directly in the C-band (4-8 GHz) without the need to translate the signal to baseband through a down conversion stage (Direct RF Sampling).

Figure 5 depicts the simplified block diagram for taking an auto-calibrated measurement. The CPS is set to 1-ch (IN0 input) mode with the ADCs (A, B, C, D) measuring the RF Throughput port of the DIB/DUT with the DIB/DUT RF Output disconnected (by the CPS). This "Calibration Error Measurement" samples the combined errors of the DIB/DUT(Input):

- Direct RF Antennae/source noise and distortion
- Input return loss/attenuator/filter errors to the DUT
- Power and Ground Issues
- Input/Return Loss/Contact Issues from the DUT
- Ancillary source/driver/component issues contained on the DIB that are required by the DUT
- Connector and Cable errors/variations, etc.

This measurement from the ADCs is stored as the "Calibration Error Measurement".

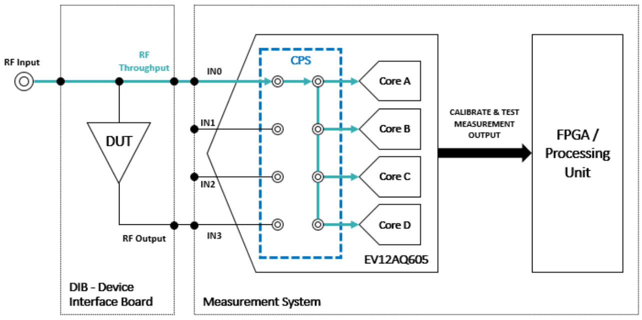


Figure 5. Simplified Block Diagram: Auto-Calibrated Error Measurement

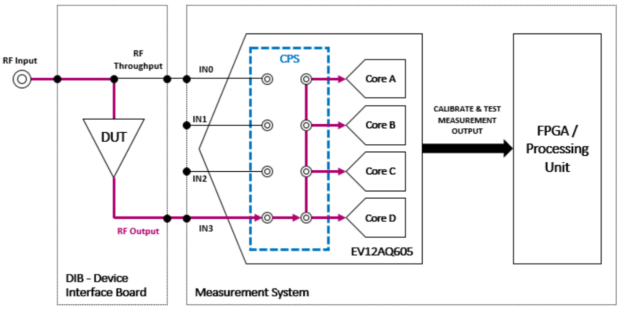


Figure 6. Simplified Block Diagram: Auto-Calibrated Raw Test Measurement

Figure 6 depicts the simplified block diagram for taking a raw test measurement. After the calibration error measurement is taken, the CPS is then set to 1-ch (IN3 input) mode with ADC's (A, B, C, D) measuring the RF Output port of the DIB/DUT with the DIB/DUT RF Throughput port disconnected (by the CPS). This "Raw Test Measurement" samples the combined performance/errors of the DIB/DUT(Input)/DUT(Output) such as:

- The same errors (previously mentioned in the Calibration Error Measurement)
- Plus, the DUT RF Output performance

This measurement from the ADCs is stored as the "Raw Test Measurement." The final DUT measurement is then calculated by taking the Raw Test Measurement – Calibration Error Measurement = Final DUT measurement.

Figure 7 depicts the simplified block diagram for taking both a calibration error measurement and raw test measurement simultaneously. The CPS is set to 2-ch mode (IN0 input connected to both A & B and IN3 input connected to both C & D ADCs). In 2-ch mode ADCs (A, B) measure the RF Throughput port of the DIB/DUT with the DIB/DUT RF Output also being measured by ADCs (C, D). This configuration of simultaneously measuring the "Calibration Error Measurement" and the "Raw Test Measurement" is accomplished utilizing a maximum sample rate of 3.2 GSPS. Again, the final DUT measurement is then calculated by taking the Raw Test Measurement – Calibration Error Measurement = Final DUT measurement.

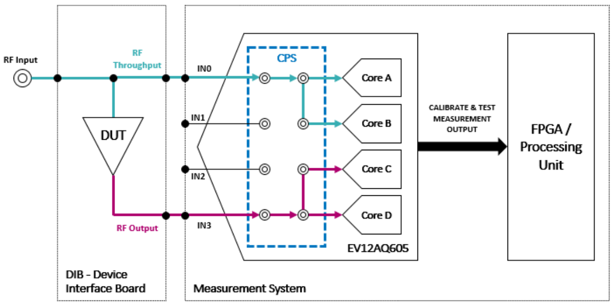


Figure 7. Simplified Block Diagram: Simultaneous Auto-Calibrated Error Measurement and Raw Test Measurements

5G NR ATE SYSTEMS/FIELD-TESTING OF INSTALLED TELECOM EQUIPMENT AUTO-CALIBRATION AND TEST MEASUREMENT

Figure 8 depicts the simplified block diagram for simultaneously measuring multi-port DIB/DUT input/outputs in order to auto-calibrate the measurement system including taking the raw test measurement. The CPS is set to 4-ch mode where each independent sampling ADC channel can operate at a maximum sample rate of 1.6 GSPS. In this configuration, the multi-port DIB/DUT can also be represented as required test/measurement points for an installed field telecommunications system. In 4-ch mode ADCs (A, B, C, D) simultaneously measures the RF Throughput port, Port 1, Port 2, and the RF Output port of the DIB/DUT or Field Test System. Again, this configuration simultaneously measures each port and the data can be utilized as either "Calibration Error Measurement" and/or "Raw Test Measurement" performance. Final test measurement calculations are then accomplished by subtracting any ports calibration errors from any raw test measurements.

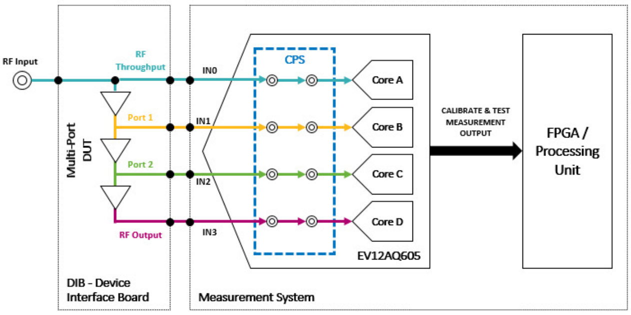


Figure 8. Simplified Block Diagram: Simultaneous Multi-Port Auto-Calibrated Error Measurement(s) and Raw Test Measurement

In addition, the EV12AQ605 includes a "multiple ADC chained synchronization feature" which adds to the design flexibility of these multi-port test measurements. The ADC chained synchronization feature of the 4 ADC cores (clock tree and digital reset) enables automatic/multiple ADC time/phase sampling adjustments and re-alignment techniques that allow for measurement corrections in real-time. This ADC chained synchronization feature also enables the system to be scaled beyond 4-channels to potential 8, 12, 16, etc., channel multi-system implementations.

UNIQUE QUAD ADCS W/CPS (EV12AQ605 & EV10AQ190) ENABLE AUTO-CALIBRATION AND TEST MEASUREMENT FOR 5G NR ATE SYSTEMS AND FIELD TESTING OF TELECOM EQUIPMENT

Specifically, the EV12AQ605 is a quad channel 12-bit 1.6 GSPS

ADC. The built-in Cross Point Switch (CPS) allows multi-mode operation with the capability to interleave the four independent cores in order to reach higher sampling rates. In 4-channel operating mode, the four cores can sample, in phase, four independent inputs at 1.6 GSPS. In 2-channel operating mode, the cores are interleaved by 2 in order to reach 3.2 GSPS sampling rate on each of the two inputs. In 1-channel operating mode, a single input is propagated to each of the four cores which are interleaved by 4 in order to reach a sampling rate of 6.4 GSPS. This high flexibility enables digitization of RF (and IF) signals with up to 3.2 GHz of instantaneous bandwidth. With an extended input bandwidth above 6 GHz (EFPBW) the EV12AQ605 allows the sampling of signals directly in the C-band (4-8 GHz) without the need to translate the signal to baseband through a down-conversion stage. The ADC includes a multiple ADC chained synchronization feature to enable design of multi-channel systems. The device is built in a non-hermetic flip-chip package using HiTCE glass ceramic material in order to reach optimized RF performance and higher pin density.

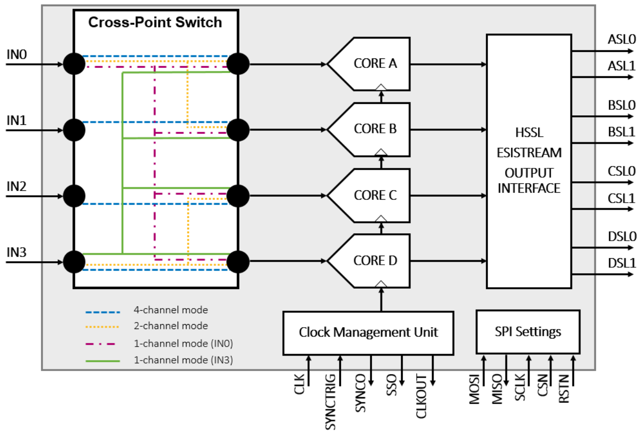


Figure 9: EV12AQ605 block diagram

An important performance point necessary to support the concept introduced in this paper is channel-to-channel isolation or crosstalk. Large crosstalk would add additional error generated inside the ADC and skew the result. These could be corrected within the auto-calibration process similarly to the other source of noise, however the state of the art crosstalk performance of the EV12AQ605 shown in Figure 10 proves that this additional noise would not be an issue when using this ADC.

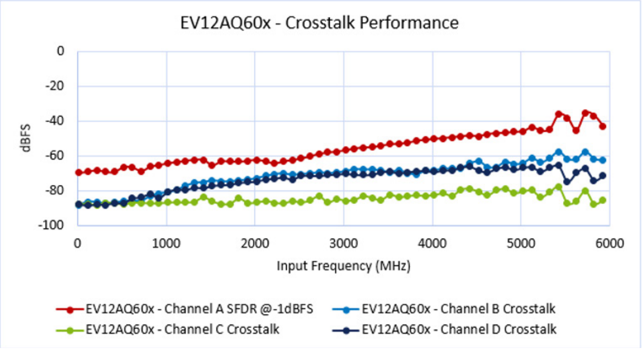


Figure 10: EV12AQ605 crosstalk performance

The EV10AQ190 is an earlier 10b version of a similar ADC with integrated cross point switch. An overview of both is shown in the table below:

	EV12AQ605	EV10AQ190
Sampling Speed	1.6 / 3.2 / 6.4 GSps	1.25 / 2.5 / 5 GSps
Channel number	4 / 2 / 1	4 / 2 / 1
Resolution	12	10
Analog input bandwidth (-3dB)	6.5 GHz (C-band)	3.2 GHz (S-band)
ENOB	8.1b @ 5.3GHz	7.7b @ 1.2GHz
Data output	ESIstream 8 HSSL	LVDS DMUX 1:4
Power consumption	6.6 W	5.6 W
Temperature range	0°C to +90°C -40°C to +110°C	0°C to +90°C -40°C to +110°C
Package	CBGA323 (HITCE) 16x16 mm	EBGA380 31x31 mm

CONCLUSION

As mobile wireless technology deploys 5G NR networks worldwide, automatic/calibrated high-speed testing of required high frequency components is essential. With calibration, repeatability, and correlation of measured performance being the utmost challenge for 5G NR ATE and Field Test Systems; these issues also directly connect to overall test speed and throughput in order to approach an ideal price performance ratio for test developers. Teledyne e2v's monolithic quad-channel, multi-port input ADCs utilizing unparalleled on-chip high frequency cross point switch input circuit technology, enable auto-calibration and measurement techniques for each component (single or multi-port) tested in either 5G NR ATE and/or Field-Testing environments. ■

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