# Using SystemVue to Integrate a Flexible R&D Testbed for LTE

Application Note

## Introduction

As wireless communications evolve, the structure of wireless systems is becoming ever more complex. New test signals and measurements are needed to test the performance of these systems according to the quickly evolving wireless standards. Sometimes, however, the required waveforms and measurements are not available on existing hardware instruments. At such times it is valuable to have software in the test system that can generate the new waveforms and perform advanced measurements.

To construct test systems that meet the requirements of new wireless standards, a number of different instruments are used. If we simply connect these instruments one by one and manually configure the test system, the task of getting this system to operate correctly will be difficult and time-consuming. A much more efficient approach is to integrate all the instruments and automate the system-level performance tests using a software tool.

System-level performance tests usually require a golden transmitter and a golden receiver to provide test references. However, during the initial development of a new product, the product's transmitter and receiver are not yet complete. It is useful, therefore, to have a software receiver to test the new product design and early hardware.

This application note describes an integrated solution for testing wireless communication systems based on the quickly evolving LTE standard. Agilent SystemVue is recommended as the core software in this test solution to integrate all test instruments, create new test waveforms, enable advanced measurements, and provide a software reference receiver. An integrated test system configured for LTE base station receiver measurements is used as an example. It is well known that receiver sensitivity is an important measurement for describing LTE receiver performance. To test receiver sensitivity according to the latest 3GPP LTE specifications, Agilent proposes a test system using SystemVue with a built-in reference receiver and certain auto-configuration capabilities. In this configuration, this system can be used to test both frequency division duplex (FDD) and time division duplex (TDD) uplink receivers that are specified in LTE. Receiver performance curves for throughput vs. signal-to-noise ratio and for block-error-rate vs. signal-to-noise ratio are generated quickly, with reasonable test accuracy.

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# Test System Structure and Functions

The basic configuration of the integrated test system, shown in Figure 1, includes the SystemVue software, a device under test (DUT), and instruments such as vector signal generators with deep ARB memory, vector signal analyzers with deep capture memory, and a channel emulator. In this configuration, baseband data is generated by SystemVue and sent to the PXB channel emulator. Faders can be used in the channel emulator to set up single input-single output (SISO) or multiple input-multiple output (MIMO) channels with multipath fading. The signal generators, driven by the channel emulator, generate receiver RF and IF signals that are used for testing the DUT. The signal analyzers capture the received signals from the DUT outputs and send them back to SystemVue. In the SystemVue platform, the software receiver can demodulate, deframe, and decode received signals and provide a measure of receiver performance. In Figure 1, the test data flow is indicated by the red arrows.

SystemVue plays the key role in integrating all the instruments in the test system. The flow of test system control is shown in Figure 1 by the blue arrows. The main functions of SystemVue include the following:

- *Test sequence configuration,* which invokes the operation of all involved instruments and the DUT in the desired order

- *Instrument configuration,* which sets up all hardware instruments properly prior to testing

- *Advanced waveform generation,* which generates baseband waveforms as well as baseband and RF signals through the signal generators by means of specific instrument control protocols such as LAN, GPIB, and USB

- *DUT configuration,* which conditions the device for testing and can also provide FPGA programming capability in applications such as software defined radio (SDR) or cognitive radio

- *DUT output capture,* which is typically performed using a vector signal analyzer by digitizing the DUT output signals and streaming the captured data back to SystemVue for further analysis

- *Advanced measurements,* which may include BER, BLER, or throughput

- *Golden receiver,* which facilitates the advanced measurements.

Next we take a closer look at these SystemVue functions as they are used in the LTE test system.
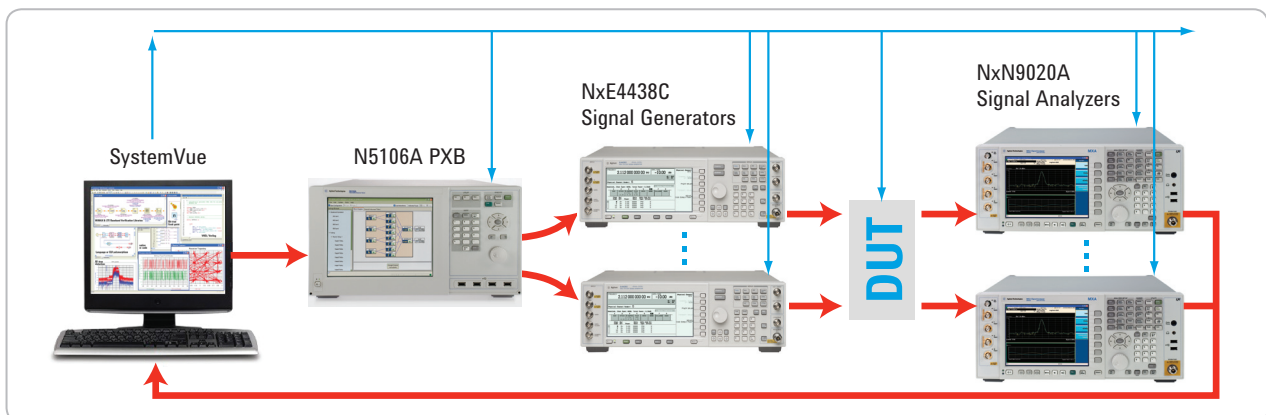


Figure 1. Test system structure

## Managing instrument configuration

SystemVue integrates instrument hardware and software to provide test signals to the DUT and to capture DUT outputs in a synchronized test system. Without integration, each instrument would function on its own; hence it would be impossible to perform complex and challenging tests such as BER, BLER, sensitivity, and throughput.

SystemVue also automatically controls instruments through SCPI commands so that instruments can be programmed to perform operations in the desired order. Stimulus-measurement test sequences can be automated as well as the subsequent post-processing of data.

## Generating standard and custom waveforms

SystemVue can generate test waveforms based on international standards such as 3GPP LTE and WiMAX™. SystemVue also can generate complex waveforms including mixed-mode waveforms, multi-modulation waveforms, waveforms that use specific framed data, or waveforms with special modulation data. Generated waveforms can be automatically downloaded to vector signal generators. Waveform generation also can be sequenced to support flexible and more complex DUT testing.

## Configuring the DUT

SystemVue automatically configures a DUT to its proper test conditions. Since field programmable gated array (FPGA) technology is broadly used in today's hardware design, SystemVue can provide HDL co-simulation. Additionally, SystemVue can convert design control elements into HDL, which can be synthesized to program FPGA inside the DUT, tremendously simplifying the design of SDR and cognitive radio products.

## Acquiring and processing DUT output data

Data captured by vector signal analyzers in the system can be automatically streamed back to SystemVue through either a SystemVue-VSA link or a math language instrument link. Acquired data can be further processed in SystemVue for analysis or for use in advanced measurements.

## Extending the measurement capabilities of instruments

SystemVue performs generic measurements such as BER, BLER, and throughput to extend the measurement capability of the signal analyzers in the system. More specific measurements defined in the standards—for example, reference sensitivity power level, adjacent channel selectivity, and blocking—can also be performed in SystemVue.

## Using SystemVue's "golden" reference receiver

Receiver testing using instruments always requires a "golden" receiver and source. The software golden receiver in SystemVue can be embedded in the test system for troubleshooting and evaluating the performance of receiver designs. This golden receiver can also be used to evaluate and fine tune transmitter design to ensure the transmitter meets critical specifications. Unlike hardware receivers, the software golden receiver in SystemVue can be modified easily to test new standards that overlap existing standards.

## Integrated MIMO test system using SystemVue

The basic structure of the LTE integrated test system described earlier can be used directly for testing SISO designs and can be extended for testing MIMO designs. SystemVue supports MIMO applications by providing MIMO signals via multiple signal generators, including wideband signal generators, and multiple signal analyzers, including logic signal analyzers and multi-channel scopes.

# 3GPP LTE Sensitivity Test

To test 3GPP LTE systems [1-5], SystemVue provides an LTE physical layer (PHY) model library. These PHY models are intended to be a baseline system for designers to understand what nominal or ideal performance can be expected from a system. Use of the PHY models can be extended to evaluate degraded system performance caused by factors such as poorly performing components. Aspects of the LTE physical layer supported in SystemVue's LTE PHY models include the following:

*FDD and TDD modes.* In the 3GPP LTE system, downlink and uplink transmissions are organized into radio frames for the uplink and downlink to support both FDD and TDD modes.

*Downlink physical channels and signals.* For the downlink, the orthogonal frequency domain multiple access (OFDM) waveform is supported. This support includes the LTE downlink physical channels, which correspond to a set of resource elements carrying information originating from higher layers. The downlink physical channels are as follows:

- Physical downlink shared channel (PDSCH)
- Physical broadcast channel (PBCH)
- Physical multicast channel (PMCH)
- Physical control format indicator channel (PCFICH)
- Physical downlink control channel (PDCCH)
- Physical hybrid ARQ indicator channel (PHICH)

The following downlink physical signals are also supported:

- Reference signal
- Synchronization signal

*Uplink physical channels and signals.* Requirements for the LTE uplink differ from downlink requirements in several ways. Power consumption is a key consideration for user equipment (UE) terminals. The high peak-to-average power ratio (PAPR) and related loss of efficiency associated with OFDM signaling are major concerns. As a result, an alternative to OFDM was sought for use in the LTE uplink. Single carrier-frequency domain multiple access (SC-FDMA) is well suited to the LTE uplink requirements. The basic transmitter and receiver architecture is very similar (or nearly identical) to OFDMA architecture, and it offers the same degree of multipath protection. Importantly, because the underlying waveform is essentially single-carrier, the PAPR is lower.

The SystemVue LTE PHY library includes support for uplink physical channels, which are listed below:

- Physical uplink shared channel (PUSCH)
- Physical uplink control channel (PUCCH)
- Physical random access channel (PRACH)

The uplink physical signals are also supported:

- Reference signal
- Sounding reference signal

*Channel coding/decoding.* A channel coding/decoding model set is provided for both the downlink and uplink channel codecs. Models for CRC, convolutional encoding and viterbi decoding, turbo encoding and turbo decoding, a scrambler/de-scrambler, an interleaver/de-interleaver, and HARQ are included.

*Modulation.* A modulation model set includes mappers and de-mappers for QPSK, 16QAM, 64 QAM, OFDM, and SC-FDMA.

*Multiplexing.* The multiplex models provide OFDM and SC-FDMA symbol multiplexing and de-multiplexing, along with downlink and uplink framing and de-framing for the downlink/uplink transceiver.

Additionally, receiver models in the LTE PHY library can be used for constructing both downlink and uplink receivers that implement timing synchronization, frequency synchronization, and channel estimation. Measurement models in the library provide basic measurements including waveform, spectrum, constellation, and EVM measurements. Receiver measurements include BER, BLER, FER, throughput, and reference sensitivity power level.

## Reference sensitivity test based on 3GPP Technical Specification 36.141

In the 3GPP LTE test specification [6], the reference sensitivity power level is defined as the minimum mean power received at the antenna connector at which a throughput of 95% shall be met for a specified reference measurement channel. To set up the test for LTE receiver sensitivity, all system parameters must be set to align with the LTE test specification [6] as defined in Table 1.

*Table 1. Test setup from 3GPP Std FRC Test Parameters (TS 36.141 v8.50, "Base Station Conformance Testing" [6])*

| Reference channel | A1-1 | A1-2 | A1-3 | A1-4 | A1-5 |
|---|---|---|---|---|---|
| Allocated resource blocks | 6 | 15 | 25 | 3 | 9 |
| DFT-OFDM Symbols per subframe | 12 | 12 | 12 | 12 | 12 |
| Modulation | QPSK | QPSK | QPSK | QPSK | QPSK |
| Code rate | 1/3 | 1/3 | 1/3 | 1/3 | 1/3 |
| Payload size (bits) | 600 | 1544 | 2216 | 256 | 936 |
| Transport block CRC (bits) | 24 | 24 | 24 | 24 | 24 |
| Code block CRC size (bits) | 0 | 0 | 0 | 0 | 0 |
| Number of code blocks - C | 1 | 1 | 1 | 1 | 1 |
| Coded block size including 12bits trellis termination (bits) | 1884 | 4716 | 6732 | 852 | 2892 |
| Total number of bits per sub-frame | 1728 | 4320 | 7200 | 864 | 2592 |
| Total symbols per sub-frame | 864 | 2160 | 3600 | 432 | 1296 |

The integrated test system depicted in Figure 1 can be used to make the sensitivity test. Figure 2 shows the setup for the sensitivity test, with SystemVue, the signal generator, and the signal analyzer corresponding directly to those elements in Figure 1. The SystemVue software works as previously described. To emphasize signal flow in Figure 2, we omit the system control arrows that appeared in Figure 1. In Figure 2, the DUT is an LTE base station with RF and digital units as shown.
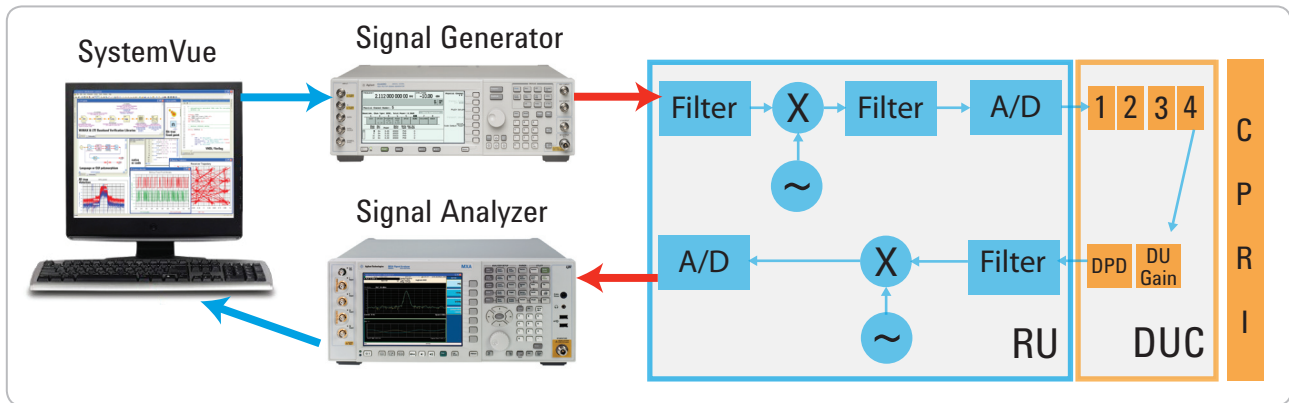


Figure 2. LTE base station receiver test setup

The test procedure performed by SystemVue is described below.
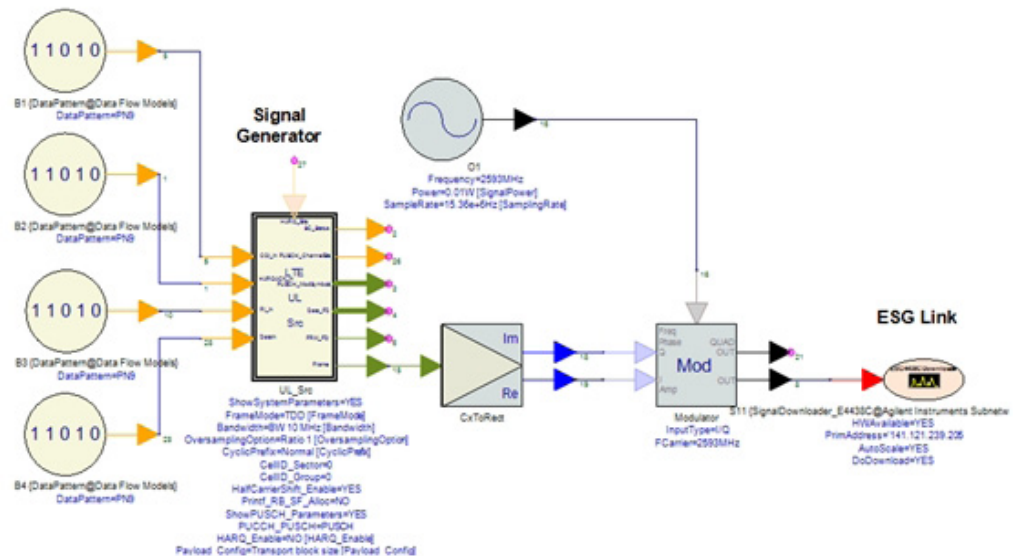


Figure 3.  3GPP LTE FDD or TDD signal generation

To generate the test data, a SystemVue signal generation design is provided as shown in Figure 3. SystemVue drives the signal generator to generate LTE receiver RF test signals for the DUT. The simulated LTE signal is downloaded automatically to the ESG through the link model ESG Link. SystemVue streams back the DUT output signals captured by the test system's vector signal analyzers. The generated LTE TDD (Figure 4a) or LTE FDD (Figure 4b) signal can be measured and verified at the DUT input using an Agilent signal analyzer (EXA, MXA, PXA, or PSA).

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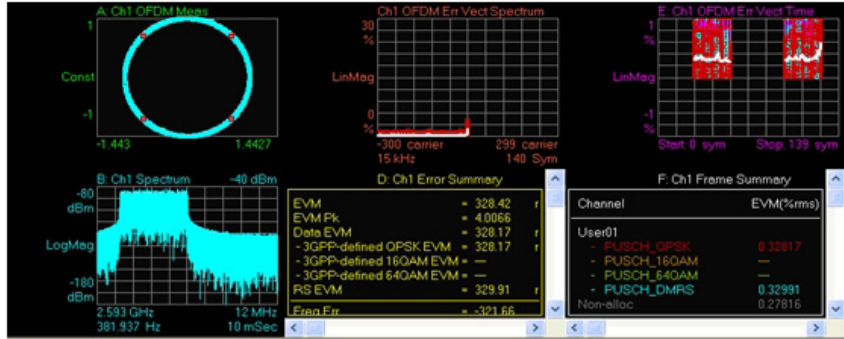
Figure 4a.  LTE TDD data downloaded to ESG and measured by MXA
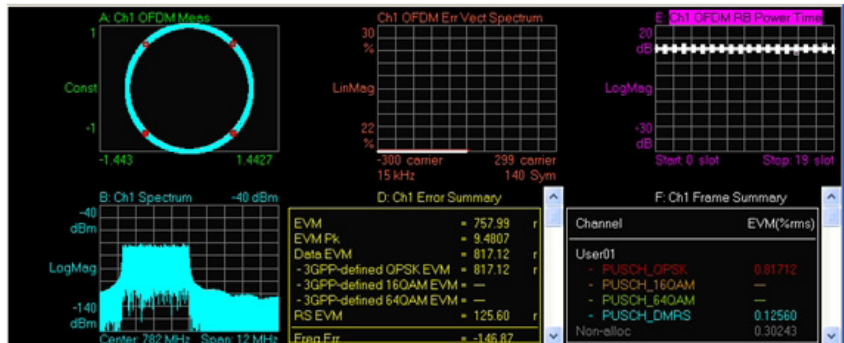


Figure 4b.  LTE FDD data downloaded to ESG and measured by MXA

To analyze the DUT output data, a design is provided in SystemVue, shown in Figure 5. In this design, the VSA Link model acquires the data from the signal analyzer for import to SystemVue for further processing. SystemVue's software receiver can demodulate and decode the SISO signal or MIMO signals and provide receiver performance analysis. As suggested in Figure 5, throughput and BLER can be measured. Curves for throughput vs. SNR and BLER vs. SNR are plotted in Figures 6a and 6b. Receiver sensitivity also can be measured by sweeping the receiver input power level to meet the 95% throughput level. In the test case shown above, the minimum input power level is less than -103 dBm.
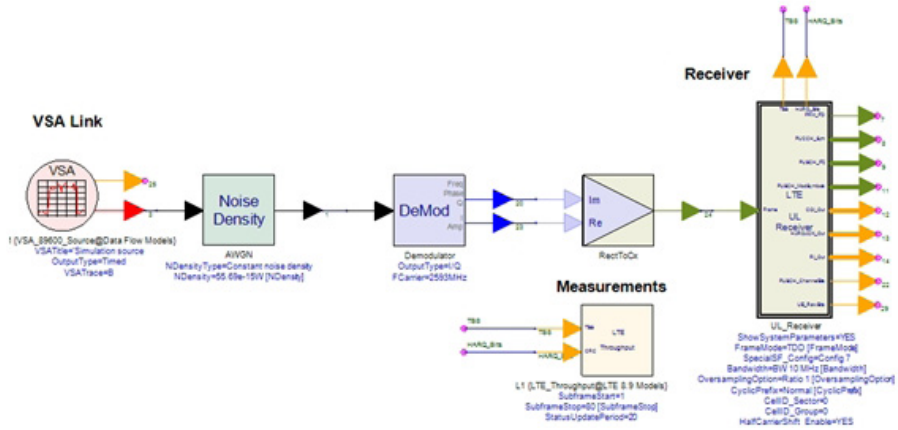


Figure 5.  Vector signal analyzer waveform capture at the DUT output is sent to the SystemVue receiver to recover original data bits and measure sensitivity.
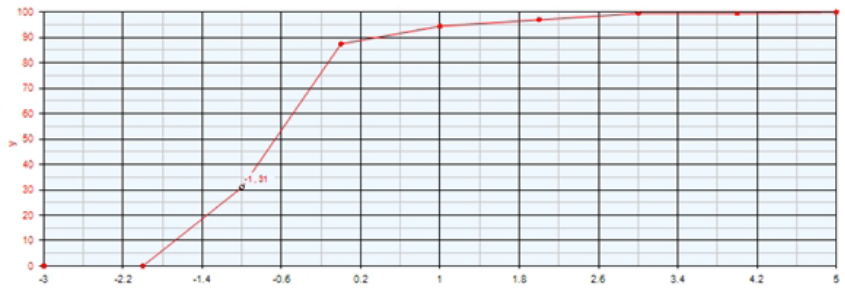
*Figure 6a. Throughput vs. signal noise ratio*
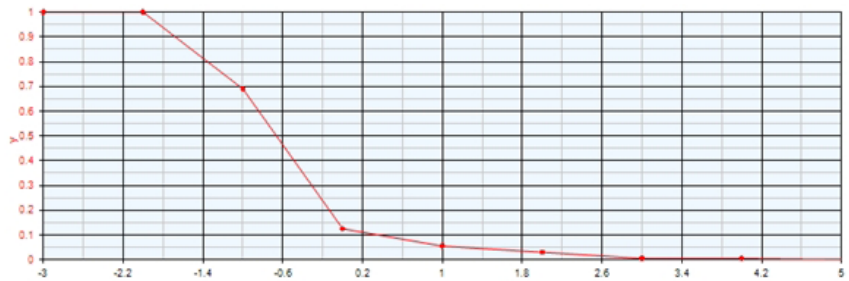


*Figure 6b. BLER vs signal noise ratio*

## Conclusion

Agilent SystemVue integrates and controls test instruments and software to create a test solution with an embedded LTE reference receiver and auto-configuration capability. This solution performs complex LTE measurements that can only be done using an integrated system; at the same time it preserves the power and flexibility that comes from having full-featured test instruments in the system.

In the case study shown above, throughput was characterized with the help of the simulation environment as a bridge.

Normally throughput measurements require a fully implemented radio, which makes these tests difficult to make until the end of a project. Here, SystemVue provided the missing signal processing blocks, reference IP, and test automation to complete a working LTE Physical Layer around an isolated or partially completed component. When combined with models for RF and analog components and propagation and fading, SystemVue can provide R&D engineers and system architects with reliable, ongoing verification of their LTE designs before implementation and throughout the design process. It's no longer necessary to wait until the end of a project to verify system-level performance. SystemVue can integrate the components into a working PHY, regardless of whether portions of the design are algorithmic models, VHDL, or actual hardware; or whether the measured signals are raw data bits, baseband I/Q samples, or modulated RF carriers.

In particular, the LTE PHY libraries for SystemVue provide key measurement models and signal processing blocks that accelerate the LTE PHY design and test process, giving users a head start in developing working LTE eNodeB and UE designs that meet specification requirements the first time.

## References

1. 3GPP TS 36.211 v8.9.0, "Physical Channels and Modulation," December 2009

2. 3GPP TS 36.212 v8.8.0, "Multiplexing and Channel Coding," December 2009

3. 3GPP TS 36.213 v8.8.0, "Physical Layer Procedures," September 2009

4. 3GPP TS 36.101 v8.6.0 "User Equipment (UE) radio transmission and reception," September 2009

5. 3GPP TS 36.104 v8.7.0 "Base Station (BS) radio transmission and reception," September 2009

6. 3GPP TS 36.141 v8.50 "Base Station Conformance Testing," March 2009

## For More Information

Agilent SystemVue
http://www.agilent.com/find/eesof-systemvue

Agilent W1910 LTE Baseband Verification Library
http://www.agilent.com/find/eesof-systemvue-lte-baseband-verification-library