Vector Signal Analysis – 20 years on!

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Twenty years ago on 21st December 1992 Hewlett-Packard introduced a new test instrument. Like all HP Test Instruments of its time – and all *Agilent Test Instruments today it was identified by a product number. This one was 89410A and it was called a 'Vector Signal Analyzer'. The 89410A was a completely new class of instrument. This paper tells a little of its history but mostly we look at how vector signal analysis has developed throughout 20 years of continuous development.

Except for a few notable exceptions until the early1990s the world according to Test and Measurement was almost entirely analogue. Time and State based logic analyzers always were Digital and the Oscilloscope had already started to become digitalised. Low-frequency and audio instrumentation had played with digital signal processing and FFT analysis, The essential block diagram of almost all RF and Microwave test equipment remained analogue. Including the primary instrument for analysis of RF signals, the Spectrum Analyzer.

The classical block diagram of a Spectrum Analyzer is a heterodyne receiver, using a sweeping local oscillator to down-convert signals from the input into a fixed IF amplifier where the signal of interest is selected in a resolution bandwidth filter before being passed through a logarithmic compression amplifier to an envelope detector. The detected signal is then displayed on a CRT where the x-deflection is driven by the sweep generator. The y-deflection is driven by the instantaneous signal envelope, thereby tracing a graphical spectrum of signal amplitude onto a graphical display. .

No analyzer actually had such a simple block diagram, at least in the last thirty years. From the late 1970's High-end Spectrum Analyzers had been developed with digital control, digital displays, marker functions with state and trace storage. This overlay technology rapidly spread to mid-range and even modest performance RF & microwave spectrum analyzers. Underneath the digital wrapper the block diagram was still largely an analogue instrument, and remained so until relatively recently.

On its introduction the 89410A Vector Signal Analyzer was just a 10 MHz baseband processor. This was followed soon afterwards by the 89440A which added an external RF Down-converter that expanded operation to 1.8 GHz. . Later this was upgraded to the 89441A which operated to 2.65 GHz. Together this made up the 89400 family. The one feature that distinguished the VSA from other digital FFT analyzers of its time was a processing block diagram that maintained the amplitude & phase relationship of the signal from the input all the way through to the display The external precision RF Down-converter made the baseband VSA capable of making measurements on RF Signals.

After conversion to a digital stream the input signal is demodulated against a nominal centre frequency. In the 89400 this functionality was implemented in a digital ASIC which offered significantly better fidelity than ever possible with analogue circuitry. The output of the demodulator contains two streams of digits representing in-phase and quadrature components of the signal each at the signal sampling rate. These samples are then resampled in a decimation filter into the bandwidth of interest. The decimated samples are then passed to a more-or-less conventional Digital Signal Processor which can perform further processing. The signal can then be processed in the time domain or after a complex FFT processes, in the frequency domain. The processed data was then passed to a display processor that enabled the data to be visualized in many different ways on the colour display screen.

The IF processor box included a waveform generator; this could generate some standard test signals and play an arbitrary waveform file. This feature had originally been included as a part of a built-in test function. The down-converter was designed with an optional up-converter to implement some stimulus response testing – a feature that actually was never implemented. However the up-converter channel could be used to replay a signal captured by the analyzer and on the strength of this capability in fact became one of the most ordered optional add-in features.

* *Agilent Technologies spun off from Hewlett Packard in an IPO during 1999.*

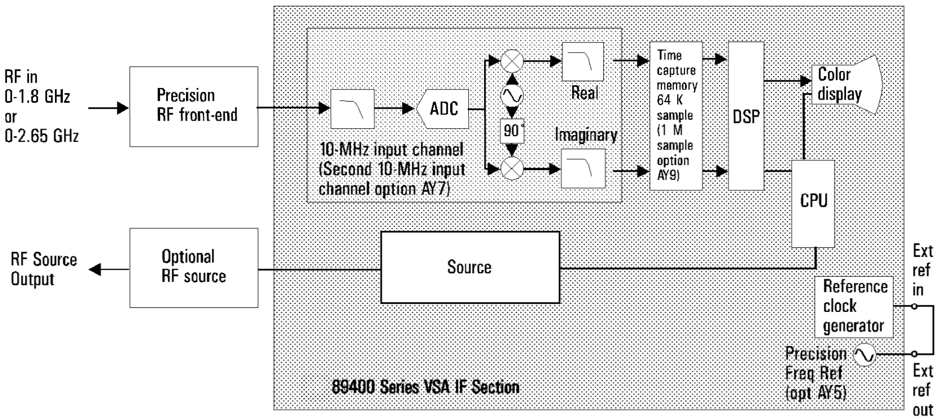

Fig 1: 89400 Vector Signal Analyzer

The VSA cannot be discussed without talking about its flexible digital demodulation capability. Many VSA users encountered the 89400 as an instrument that was used for measuring Error Vector Magnitude (EVM) The demodulator used a technique originally invented for measuring modulation quality of GSM transmitter signals. This technique was extended for QPSK and then generic QAM signals. EVM measurements are based on recovery of data from an input signal stream. The data is then used to re-create a 'perfect' reference signal. The received and reference signals are then compared (aligned and subtracted) to generate a file of error vectors which can be processed to give metrics which can be displayed in various formats. This method has become the standard method on which almost all quality measurements for digital modulation formats are based.

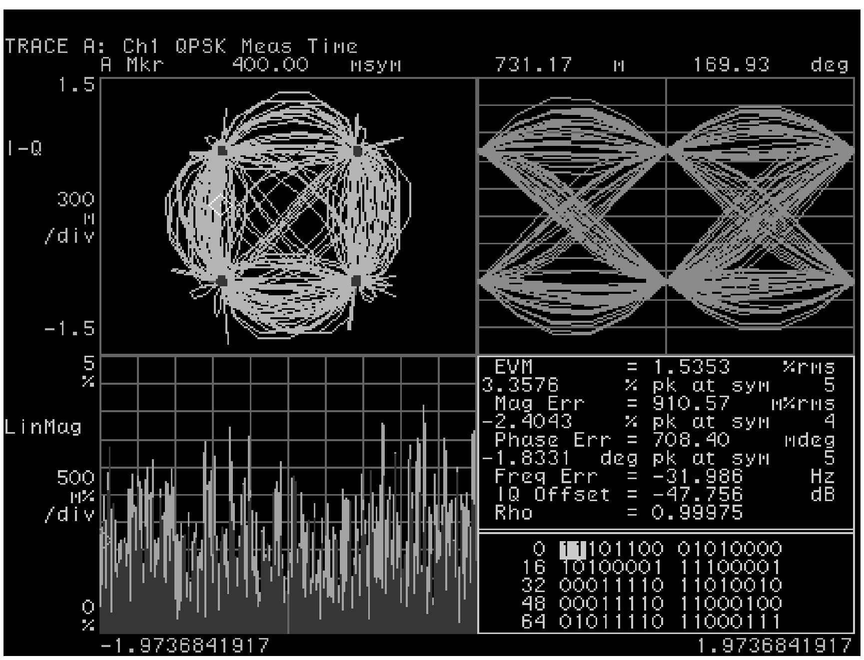

Fig 2. Vector Demodulation of QPSK signal.

By the late 1990's many new demodulation formats had been added. VSB formats were added to support Cable TV standards; OQPSK was added to support development of the North American CDMA_One cellular system. A demodulator was developed for DVB-T, the European Terrestrial Digital TV standard, but was rather complex, so it ran in an attached PC rather than in the VSA itself.

By all measures, the 89400 was a ground breaking product with a very long list of "firsts". It was more than just the first ‘Vector Signal Analyzer’. It was also one of the first instruments designed to connect over a LAN; it was the first we can identify that had a built-in comprehensive ‘on-line’ help; it included a Basic Interpreter and could create its own basic control programs using a mechanism of key-stroke recording; it could capture signals, and then replay them later; It could capture signals and process and display them in a pipelined process, that was effectively a real-time spectrum analyzer (albeit with a rather limited signal bandwidth by today’s standards). An interesting demonstration of this capability was to tune to a HF weather-fax service and to display the captured time-series signal on a ‘spectrogram display’ to reveal a weather map.

The technology developed for the 89400 was reused in other Agilent products. The first, introduced in 1998, was implemented as an application specific instrument designed for making measurements for the manufacturing test of base station transmitters for the Cellular telephone networks This was called the E4406A Transmitter Test set and used signal processing flow similar to the 89441A. The E4406A as in fact a test-bed for the digital IF and baseband processing section of a very high-performance Spectrum Analyzer, the Agilent E4440A PSA introduced in 1991. Agilent’s E4440A PSA Spectrum Analyzer was in the vanguard of the move towards an entirely digital IF processing block diagram. Removing analogue signal processing from the spectrum analyzer block diagram allows the measurement accuracy specification to be dramatically improved. Absolute accuracy signal level measurement with the E4440A is better than ±0.26dB compared with about ± 1.8dB for the 8562EC.

Fig 3(a) E4406A Transmitter Tester **(b) E4440A PSA Spectrum Analyzer**

By the late 1990’s users were demanding more performance from the VSA. What had appeared to be blindingly fast in 1992 had become the norm. The 2.65 GHz upper frequency was limiting in some applications, such as Wireless LAN, and users were demanding wider signal bandwidths. A new product was required and was designed by the same team but using an entirely different physical architecture. The immediate successor for the 89400 was a pile of instrument modules and a PC software package and was called the 89600.

89600 hardware was built using VXI instrument modules. VXI is Instrument Extensions for VME, a modular processing bus system which came into prominence in the 1990’s and has largely been supplanted by the popular PXI format for small format cards and AXI for larger formats. The system uses a combination of generic and specifically designed signal acquisition models. By choosing a modular format the system could be configured flexibly to support RF, IF and baseband inputs. The 89600 used a high performance radio receiver module as a down-converter and 2.7 GHz and 6 GHz versions were available.

The 89400 used a three-processor architecture; a 68030 processor hosted the PSOS operating system (PSOS). A Motorola DSP performed signal processing, a TI graphics processor drove the display screen. 89600 moved all the software into a PC-Windows environment and this gave immediate speed improvements even when running on a modest 300 or 350 MHz PC. Most users opted for a moderately high specification 500MHz processor, still quite a costly choice in the year 2000. Today’s PCs are equipped with dual or quad ‘core’ CPUs, operate with more than an order of magnitude shorter cycles times and cost far less than typical machines from only 12 years ago.

Software based instrumentation can be implemented in many different ways. Choosing the right way to meet a commercial objective is not always easy. One approach might be to develop application focussed test systems with defined test configurations, ready to perform specific customer measurements. Another approach could be to deliver software in the form of a toolkit, or set of drivers, leaving the user free to construct applications that exactly fulfil specific test or measurement needs. This approach provides ultimate flexibility, but often with little 'out-of-the-box' functionality beyond demonstration programs and hardware verification utilities. .

Agilent's goal with the 89601A software was to provide out-of-the-box operation with sufficient flexibility for both manual and remote operation to meet a wide range of user needs. This approach implies the development of a big user interface with control over many different parameters. This was created within the framework of a typical PC/Windows user interface with pull down menu items and toolbar icons organized into groups of functionality. The display was preconfigured for a number of different display formats that allowed simultaneous views of the signal and measurement screens, based on the formats provided in the original 89400 VSA. The 89601A software was not exactly an emulation of the 89400 based hardware, but users of the older product could find their way around the new software with very little learning time.

With this approach the software became the test instrument. Apart from initial hardware configuration the user did not need to understand how to control the hardware itself. Release 3 of the 89601A software was in 2002 and this added support for two other 'front ends'. One was the E4406A VSA Transmitter Test Set, the other a new high-performance Spectrum Analyzer, the E4440A VSA.

Fig 4 89600 VXI based system

Other 'front-ends' were added in subsequent releases. These included several other models of Spectrum Analyzer, a small test-set designed for WLAN manufacturing test and further configurations of VXI cards. Digital Storage Oscilloscopes were added to support wide bandwidth signals to be measured. Some Logic analyzers can capture signals at digital IQ baseband so that signal vectors can be tested in the digital domain. Digital probe implementations have been developed for testing signals on high-speed busses complying with standards such as CPRI used in some cellular base-stations and with the MIPI M-phy interface used in the DigRF standard used in advanced cell-phone chip-sets. Some performance figures for different front end implementations are listed in the table below.

Version	Hardware	Max Bandwidth	Sample Rate	Capture Depth
89400	89410/89440/441A	10 MHz	25.6 Msa/sec	1 Msa
VSA/89600	896xx	36/40 MHz	100MSa/sec``	256 Msa
VSA/89600	N9030A PSA	80 MHz	200 MSa	100Msa
VSA/89601B	93204A Infiniium	33GHz	80 Gsa/s	1GSa

The signal input module does not just need to be hardware. 89601A can be embedded into EEsof ADS and SystemVue designs or within a Simulink™ model. Embedding measurement instrumentation into a system model enables a design engineer to start testing his product before he has completed the design and to continue testing it through physical prototype stages and into production. Using the VSA to make the measurements ensures that the same methodology is used throughout the product design cycle.

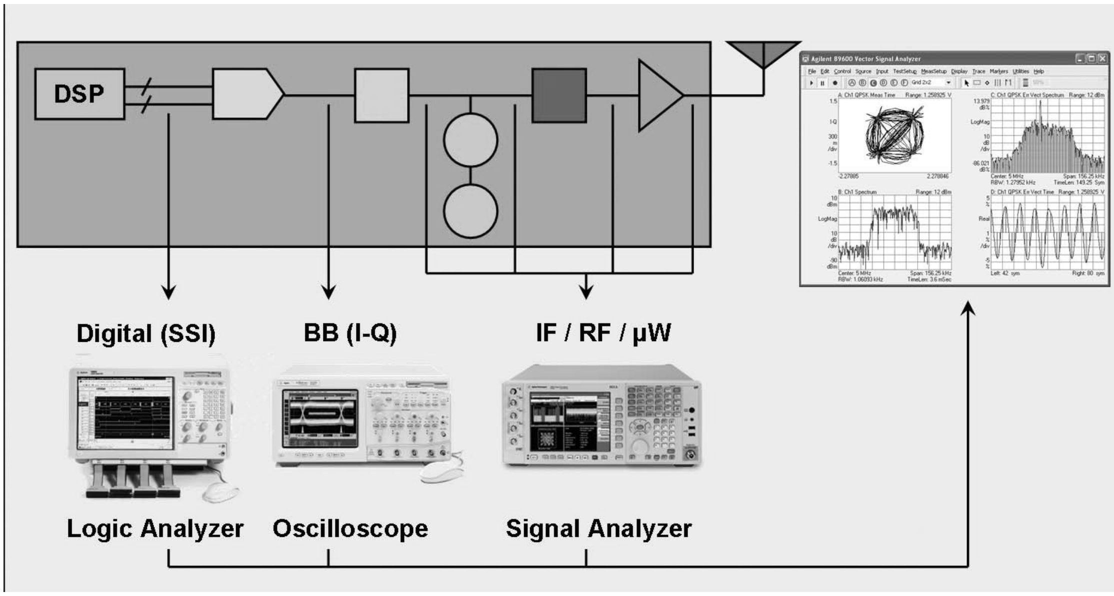

Fig 5 Baseband to RF Analysis

Controlling a software instrument

Whereas the 89400 was a stand-alone instrument and could be controlled like any other instrument with ASCII/SCPI mnemonics the 89600 was a product that ran inside a standard Personal Computer and it was reasonable that users would want to run their control program suite in the same PC. This approach was admirably accommodated in Microsoft Windows with the COM standard that provides a stable and secure program to program communication scheme. .

Programming a COM interface can appear daunting to a novice programmer. The VSA control interface has hundreds of controls, many of which are context sensitive. This complexity poses quite a challenge to test programmers, especially those who have become accustomed to SCPI based interfaces and high-level instrument drivers for even moderately simple instruments. One way that the VSA tackled this challenge was by inclusion of a macro-script recording scheme that enables users to automate their test procedures. 89601A scripts can be created by the user navigating the UI to perform manually the measurement he wants to automate. The macro is recorded as a VBA (Visual Basic for Applications) fragment containing all the calls needed to reproduce those actions within a test program. Smart VSA programmers create macros to automate the functionality they require and then extract the program coding from the recorded macro. Translating the program syntax from VBA to the language of choice is not an issue for a test programmer.

The latest 89601B versions of the software the user can choose between VB.NET or C# as the macro language and record macros in very much the same way. The 'B' version of the software includes another enhancement in the re-inclusion of a SCPI interface. This emulates the actions of the COM or .NET programming model. This has not been added to appease SCPI aficionados but does allow system design choices when it is needed to run the User Software and the VSA in separate PCs. One scenario when this is desirable is when the VSA is hosted inside one of the test instruments in a system. This is a common usage case as many instruments now run versions of Windows as the Instrument's operating system. This is the ideal approach for huge captured time records where there are very wide bandwidth signals and complex modulation and coding schemes.

The VSA software was upgraded to 89601B in October 2010.The B version was introduced to take advantage recent enhancements to the PC Windows operating system. Internals were updated to support Microsoft.NET; it was also re-engineered to operate in a 64-bit system and the graphics displays were rewritten to remove many of the restrictions that had been inherited from its long development legacy. VSA-B allows least 20 user windows to be configured for simultaneous displays.

Measurement marker capability was also upgraded from just one marker and one 'delta' marker per window to having at least 20 markers per window with flexible coupling between different markers in different display windows.

The digital demodulation capability of 89601B has continued to develop and support for many more formats has been added. As wireless standards became ever more complex the VSA team have needed to develop new test methods to test features of these standards and to design new display formats to help visualize the result of these analyses. Agilent's approach for the more complex formats has been to develop and release versions early in the standards development process.

Formats such as the relatively simple 802.11n Wireless LAN standard, as well as the more complex WiMAX and LTE schemes support transmission of multichannel signals using transmit diversity and/or spatial multiplexing of signals, sometimes called MIMO transmission. Demodulation of spatially multiplexed MIMO transmissions needs simultaneous capture of two or more RF transmission streams followed by demodulation and matrix decoding.
In particular LTE supports many different combinations of bandwidths, transmission modes and modulation & coding schemes. Furthermore downlink and uplink signals use using completely different formats.

The 89601A software had a total of 12 major releases over a period of approximately eleven years. 89601B is continuing along the same route The latest release – VSA 15 – takes advantage of the multithreading in Windows 7/64 and allows users to configure multiple measurements and to connect multiple input front ends. Actually of these capabilities were supported in the earlier releases of VSA-B, but in VSA-15 multiple measurements can run simultaneously. This capability does require a high-specification CPU and a machine with enough memory, but does not make and specific demands on the users – other than keeping track of which measurements are connected to which input channels and in which windows the results are displayed.

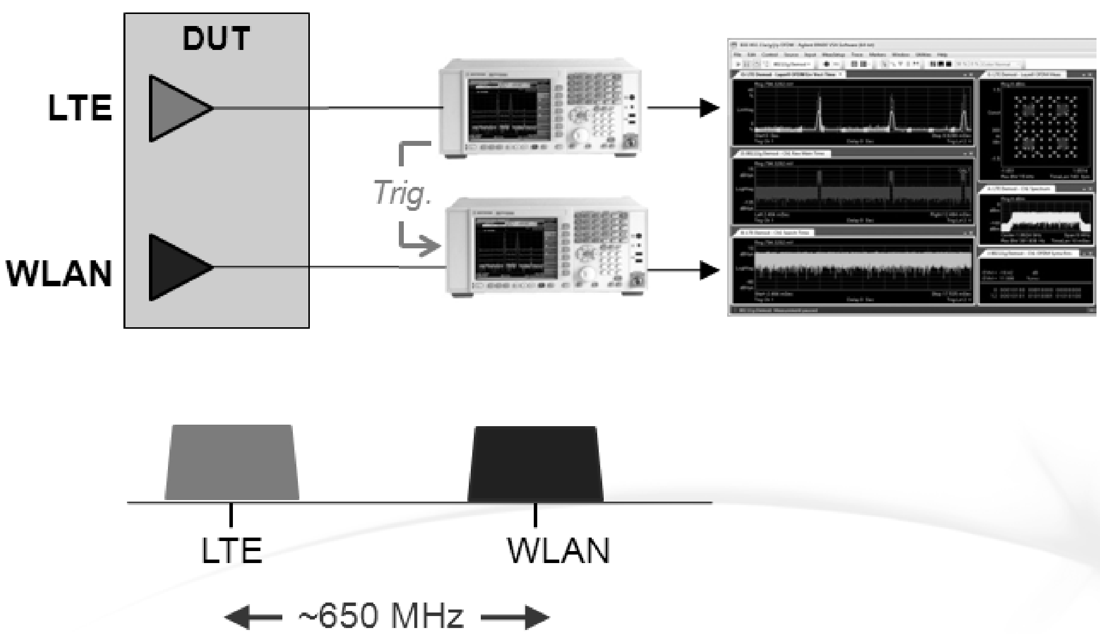

Fig 6: Multiple measurements from multiple signals

Summary

This paper has summarised the continuous development of the Agilent VSA over a twenty year period.   We have looked at how it a standalone measurement ‘box’ has been transformed into a software package able to make measurements with any of a fairly large number of hardware instruments. We have seen how the ability to demodulate single stream digital modulation has spawned the development systems to demodulate analyze and decode multicarrier schemes used for cellular communication schemes such as 3GPP WCDMA and LTE.

Many other Test & Measurement companies offer signal analyzers with capabilities similar to some of those offered in the 89601B VSA. This paper does not attempt to promote the VSA over any of these rival products.   Within Agilent’s own range of Signal and Spectrum Analysers many the standards compliant measurements are available as firmware supported options.   The VSA does not attempt to compete with these options for some of the analogue measurements, such as ACLR or harmonic and spurious emission measurement. The VSA can capture signals and replay them, through a vector signal generator, but does not attempt to compete with specialist off-air signal recording systems. Vector signal analysis can also capture and record signals and then create gapless spectrogram displays from these recordings, but it does not attempt to operate as a wide bandwidth ‘real-time’ spectrum analyzer.

References

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Introduction to Vector Signal Analysis.   Agilent Technologies pub no 5990-7451EN