

Development of Cost-Effective Wi-Fi 6 SISO/MIMO Vector Signal Generator and Analyzer

Jeng-Kuang Hwang, Chien-Min Chen

Department of Electrical Engineering, Yuan Ze University, Taiwan

eejhwang@saturn.yzu.edu.tw, s1078601@mail.yzu.edu.tw

Abstract—In order to reduce the R&D and testing costs of wireless communication products, this paper proposes a low-cost cross-platform Wi-Fi 6 SISO/MIMO vector signal generator and analyzer, by dismantling the traditional instrument architecture into core software, cross-platform control interface, and radio platforms. We develop the vector signal generation (VSG) software according to the specifications, and design the receiving end analysis algorithm to complete the development of the vector signal analysis (VSA) software. On the other hand, we also develop a cross-platform control interface, so that the core software can be integrated across platforms through this interface. The platforms we have completed integration include low-cost NI universal software radio peripheral (USRP) B/N/X series SDR platform and high-end NI vector signal transceiver (VST). Through this architecture, the radio platform can be flexibly selected according to the user's budget and needs, thereby greatly reducing the R&D and testing budget.

Keywords—VSG/VSA, Wi-Fi 6, Software Defined Radio, MIMO, Cost-effective

I. INTRODUCTION

Vector signal generator (VSG) and vector signal analyzer (VSA) are instruments that widely used to verify and test the designed wireless communication system algorithm or devices at the research and development (R&D) and production test phase. With the increase in testing requirements such as 5G, Wi-Fi 6/6E devices [1], etc., these instruments significantly increase R&D and testing costs. However, the requirements for test instruments vary with different test cases. For example, R&D debugging, testing, and verification require high instrument accuracy, and detailed analysis items and charts are required to verify or clarify problems; for production line testing, it is important to detect whether the device under test passes the specification and generate the test report in a very short period of time.

In this paper, we propose a cost-effective cross-platform Wi-Fi 6 VSG/VSA, which is able to gain the flexibility and make a trade-off between the cost and performance. With the concept of software defined radio (SDR) [2,3], we deconstruct the conventional VSG/VSA architectures into the core VSG/VSA software, cross-platform control interface, and radio platforms parts.

II. ARCHITECTURE OF THE COST-EFFECTIVE VSG/VSA

As mentioned above, the VSG/VSA architecture can be divided into core software, radio hardware, and cross-platform control interface parts as shown in Figure 1, and the development process of each module will be described respectively.

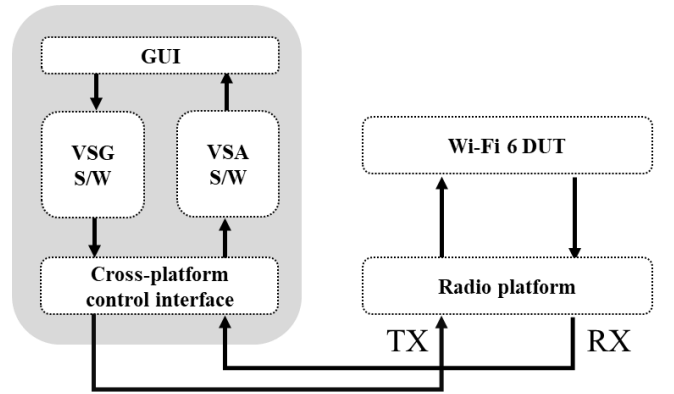


Figure 1. Deconstructed VSG/VSA architecture

A. Core VSG/VSA software

1) **VSG software development:** We first refer to IEEE 802.11ax specification [4] and generate each field of the HE SU PPDU packet with different bandwidth, modulation and coding schemes (MCS) and number of spatial streams. The available settings are listed in Table 1. The generated complex IQ waveform will be verified by the commercial VSA software (Keysight 89600) to ensure that the waveform is correctly generated and the SIGNAL information can be decoded. Figure 2 shows the graphical user interface (GUI) for users to set the parameters and observe the power versus time (PvT), power spectrum density (PSD), and the constellation of the generated waveform.

TABLE 1. AVAILABLE SETTING OF THE VSG

Item	Feature
Packet content	L-STF, L-LTF, L-SIG, RL-SIG, HE-SIG-A, HE-STF, HE-LTF, and HE-Data
Bandwidth	20, 40, 80, 160 MHz
Modulation	BSPK, QPSK, 16QAM, 64QAM,

	256QAM, 1024QAM
MCS	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
Spatial streams	Up to 8 streams

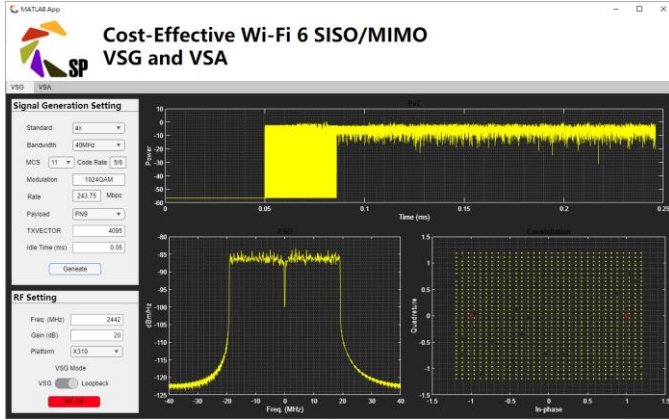


Figure 2. Graphical user interface of core VSG software

2) **VSA software development:** Second, we design the IEEE 802.11ax waveform demodulation and analysis algorithm as illustrated in Figure 3. The received IQ raw data from the radio platform will be feed into demodulation and analysis process. In this process, we will detect the data packet from the input IQ raw data, and then the coarse CFO (carrier frequency offset) estimation will be performed [5] and used to correct the data packet. The L-LTF are employed for fine timing, CFO, IQ gain imbalance and quadrature error estimation before the fast fourier transformation. In the frequency domain, the SISO/MIMO channel are extracted with the HE-LTF and the common phase error and the sampling clock offset are estimated and used to correct the data. Finally, the spectral flatness are measured and the EVM (error vector magnitude) can be calculated from the equalized data.

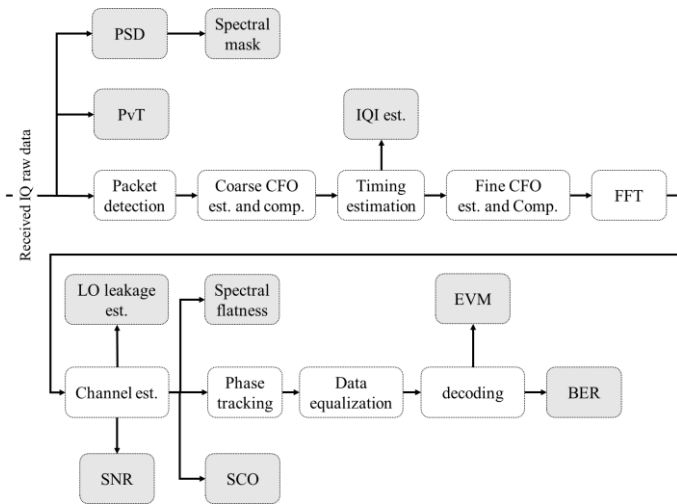


Figure 3. VSA demodulation and analysis process

The demodulation and analysis results include all transmitter test items in the test specification, time/frequency domain plot and MIMO channel parameters, and are listed in Table 2. As in the development in VSG software, we also design the VSA GUI to display all these test results and plots as shown in Figure 4. We also performed a cross-validation comparison of the results for the same IQ waveform with the Keysight 89600 VSA software to confirm the correctness of the analysis.

TABLE 2. WI-FI 6 SIGNAL ANALYSIS ITEMS AND PLOTS

No.	Analysis Items	Unit
1	Transmit power	dBm
2	Spectral mask	Pass/Fail
3	Spectral flatness	Pass/Fail
4	Center frequency offset	Hz
5	Sampling clock offset	ppm
6	LO leakage	dB
7	IQ gain imbalance	dB
8	IQ quadrature error	degree
9	EVM	dB
10	SNR	dB
11	BER	%

No.	Plot
1	Power vs. Time
2	Power spectrum density
3	Constellation
4	EVM vs. Subcarrier
5	EVM vs. Symbol

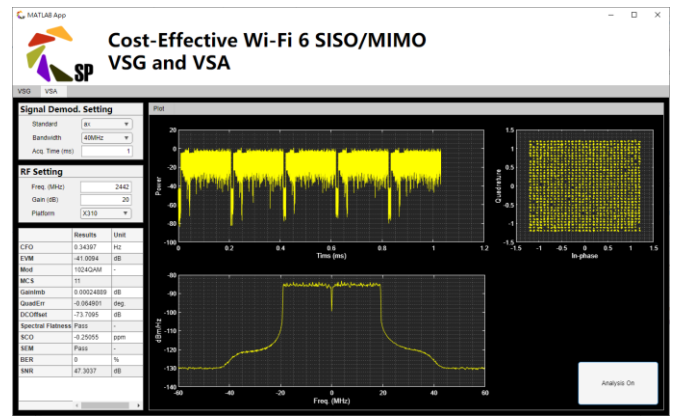


Figure 4. Graphical user interface of core VSA software

B. Cross-platform control interface

Once the core VSG/VSA software design phase is complete, the cross-platform control interface is designed to transfer the RF setting parameters like transmit/receive center frequency, gain, bandwidth, sample rate etc. Besides, the interface has to deliver complex IQ samples generated from VSG software to the radio platform, and also send back the received complex IQ samples to the VSA software for analysis.

C. Radio platform

In order to be able to arbitrarily match different radio platforms according to different usage requirements, we currently integrate various series of NI high-end VST instruments and NI USRP SDRs. The models and the RF specification are listed in Table 3. Since the NI VST aims for high-end test instruments, it's with calibrated power and excellent EVM performance (about -50dB in loopback test). However, USRP is an uncalibrated software defined radio, its power can only be controlled by TX/RX gain settings, but this only changes the relative value of the power magnitude, and its power also varies with frequency band. Therefore, the TX/RX power calibration process must be completed before one can set the TX power or measure the RX power in dBm.

TABLE 3. SPECIFICATION OF RADIO PLATOFRM

Radio platform	Model	Channel	Frequency Range	Bandwidth (Max)
VST ¹	PXIe-5645	1 Tx, 1 Rx	65MHz-6000MHz	80MHz
USRP B-Series	B200	1 Tx, 1 Rx	70-6000MHz	56MHz ¹
	B210	2 Tx, 2 Rx		
USRP N-Series ¹	N210	1 Tx, 1 Rx	10-6000MHz ²	40MHz ³
	N310	4 Tx, 4 Rx	10-6000MHz	100MHz
	N321	2 Tx, 2 Rx	3-6000MHz	200MHz
USRP X-Series ¹	X300	2 Tx, 2 Rx	10-6000MHz ²	160MHz ²
	X310	2 Tx, 2 Rx		

¹: Capable of synch. multi-devices; ²: Using UBX-160 RF daughter board; ³: Using UBX-40 RF daughter board; ⁴: Recommend no greater than 20MHz.

III. EXPERIMENTAL RESULTS

After completing the above work, we conduct cross-validation through commercial instruments as shown in Figure 5. First, we use the self-developed VSG software with the USRP X310 (with UBX-160 RF daughter board) platform to transmit Wi-Fi 6 160MHz bandwidth signals (Figure 6). At the receiving end, we use a Keysight oscilloscope to intercept the RF signal to the Keysight 89600 analyzer software. The results show the signal can be decoded correctly, and the EVM is about -40dB.

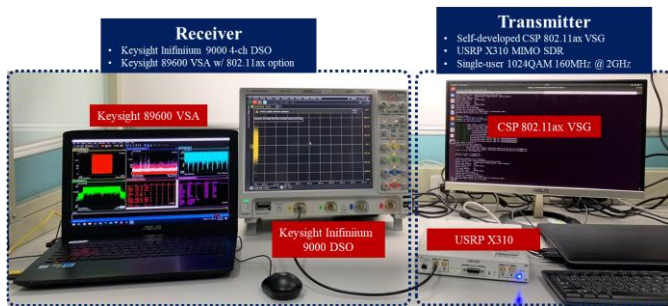


Figure 5. Cross-validation setup

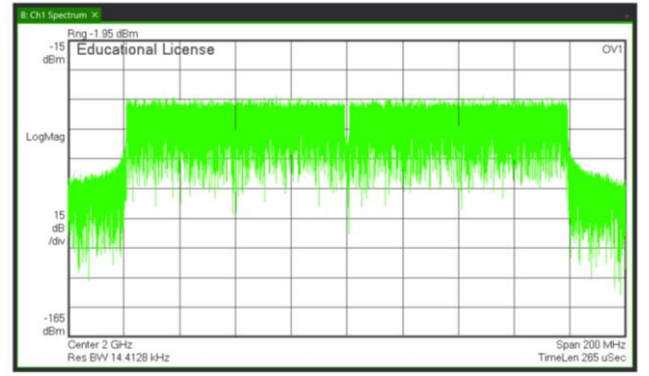


Figure 6. Spectrum of Wi-Fi 6 160MHz signal

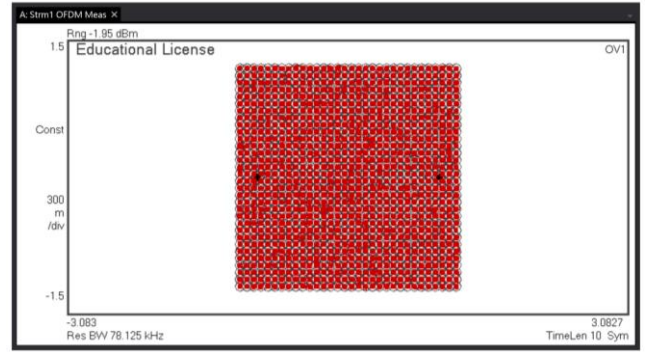


Figure 7. Demodulated constellation of 1024QAM modulated data

IV. CONCLUSIONS

By deconstructing the VSG and VSA architecture into the core VSG/VSA software, cross-platform control interface, and radio platforms parts, we built up a cost-effective, flexible test platform. Since we master the core technology of Wi-Fi 6 VSG and VSA, we can ensure the correctness of the signal generation and try our best to improve the analysis performance. In addition, we can also develop more analysis functions and applications to achieve faster and more accurate measurement. On the other hand, because different radio platforms have different interfaces, specifications and performances, we develop the cross-platform control interface to be able to integrate the core VSG/VSA software and the radio platforms, and built the power calibration process for the USRP SDRs, enabling it can perform power measurement. To sum up, the proposed cost-effective test platform has been tested and verified by the commercial instruments, and can be used in R&D test or the mass production phase. In the future, we will integrate more radio platforms and expected to upgrade the core VSG/VSA software for supporting Wi-Fi 7.

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Jeng-Kuang Hwang (S'87-M'91-SM'18) was born in Taipei, Taiwan, in 1962. He received the graduation degree (Highest Hons.) in electrical engineering from the National Taipei Institute of Technology, Taipei, in 1982, and the Ph.D. degree in electrical engineering from National Tsing Hua University, Hsinchu, Taiwan, in 1991. Since 1991, he has been with the Department of Electrical Engineering and the Department of Communication Engineering, Yuan-Ze University (YZU), Zhongli, Taiwan. In 1997, he had been a Visiting Professor with AT&T Labs/Research, Florham Park, NJ, USA. From 2008 to 2011, he served as the Chairman of the Communication Engineering Department, YZU, where he is currently the Director of the Communication Research Center. He has conducted many research projects in both academia and industry, authored or co-authored over 150 papers and 2 books, and holds 20 patents. His current research interests include communication signal processing, software defined radios, signal measurement and instrumentation, MIMO channel sounding and modeling, and radar systems.



Chien-Min Chen received the B.S. and M.S. degrees in communication engineering from Yuan-Ze University (YZU), Zhongli, Taiwan, in 2012 and 2014, respectively. He joined the YZU Communication Research Center in 2014 and has been involved in 4G LTE SISO/MIMO signal generation/analysis and building cross-platform test/measurement/verification platform. Now, he is working on his Ph.D. degree in Electrical Engineering at YZU. His main research interests include communication signal processing, MIMO systems, IEEE 802.11 family, MIMO channel, and software defined radios.