RF Lecture Series
Modulation Fundamentals 4

Introduction to 802.11n Modulation Standard

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Editor's Note

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1. Introduction

The IEEE 802.11n is a wireless local area network specification. The objective of IEEE 802.11n specification is to increase the throughput beyond 100 Mbps as well as extending the effective range from previous 802.11a/b/g standards. At the time of writing, 802.11n itself has not been ratified by IEEE. However many aspect of the protocols have been set.

The purpose of this article is to introduce the basics of the 802.11n standard, and give some of the fundamentals about how to perform some advanced 802.11n tests on Verigy's V93000. This article describes the fundamentals of the 802.11n frame structure, then goes on to discuss the spectrum, and spectral mask requirements. Finally, the EVM test for the 802.11n standard on the V93000 is described.

2. Frame Structure

The 802.11 specify the 3 communication layers, Media Access control (MAC), Physical Layer Convergence Protocol (PLCP) & Physical Medium Dependent (PMD). For modulation purpose, we are concerned mainly with the physical layer, physical medium dependent (PMD) signals, which contain the physical layer convergence procedure (PLCP) Preamble (long and short), PLCP Header, and the data.

The PMD sub layer is the physical layer, which provides the transmission of the signal over the air interface. The PMD layer provides the framing, scrambling, and modulation of the signal. Measurements that can be made on the physical layer signal include standards-based measurements and measurements that can be used as troubleshooting tools in design and development, such as spectral measurements.

In the 802.11n system, PLCP (Physical Layer Convergence Protocol) can have the following formats: the HT (high throughput) Green Field format, the non-HT (Legacy) format, the HT-Mixed format and a legacy duplicate format that duplicates the 20 MHz legacy packet into two 20 MHz spectra to form a 40 MHz channel.

- **Legacy / non-HT Mode**: This allows full compatibility with legacy 802.11 devices. When operating in this mode, the frames are all in legacy format. The device also works in SISO (Single-In-Single-Out) mode. Non-HT mode cannot be used with 40 MHz channels. See Figure 1 for the frame structure.

- **HT Mixed Mode**: This mode is for networks with an 802.11n router and a mixed environment of 802.11n clients as well as legacy 802.11a/b/g clients. There is a full legacy preamble, followed by the option to be either HT or legacy format. The preamble allows legacy clients to detect the transmission, acquire the carrier frequency and timing synchronization. The Legacy signal field (L-SIG) allows them to estimate the length of the transmission. For communication with legacy devices, all transmissions are kept in the legacy 20 MHz channel. For communication in 802.11n at higher throughput, this is done at the 40 MHz channel. The 40 MHz channel is created by using two adjacent 20 MHz channels together. However, the broadcast and other control frames are sent in legacy 20 MHz channels to allow the legacy device to inter-operate as well. See Figure 2 for the frame structure

- **Greenfield Mode**: This is for a network with only 802.11n clients connecting to the 802.11n router. In this mode, there is no provision to allow a legacy device to understand the full transmission. Nevertheless, the first part of the preamble is a legacy short training sequence (define as HT-G-STF in IEEE 802.11n Draft 2.0, and shown in Figure 3). In this way, devices including legacy devices will be able to sense that there is 802.11n equipment in the vicinity. Figure 4 shows an example of the time domain.

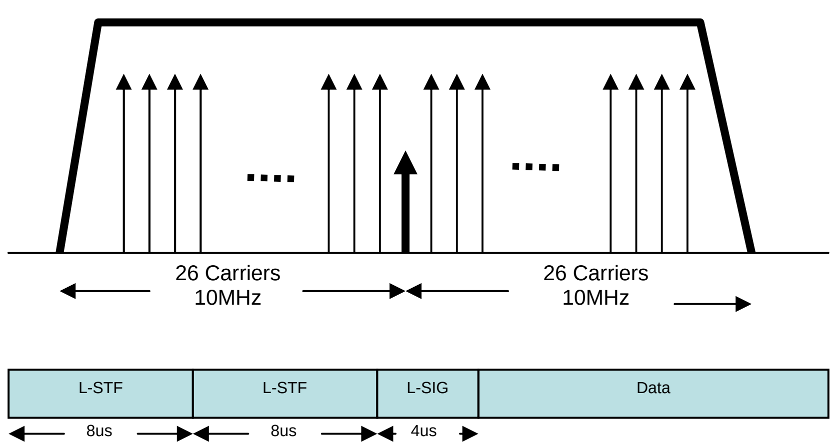

Figure 1: Legacy / Non-HT Mode Frame Structure & Carrier

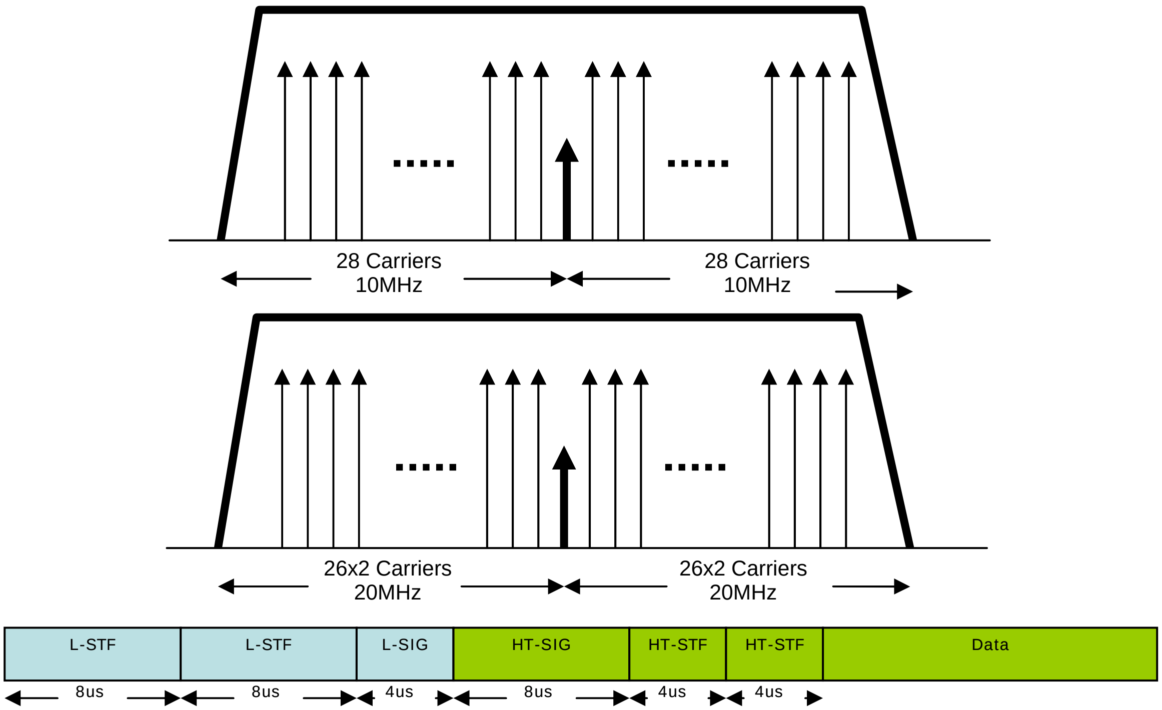

Figure 2: Mixed-HT Mode Frame Structure with 20 MHz Channel and 40 MHz Channel

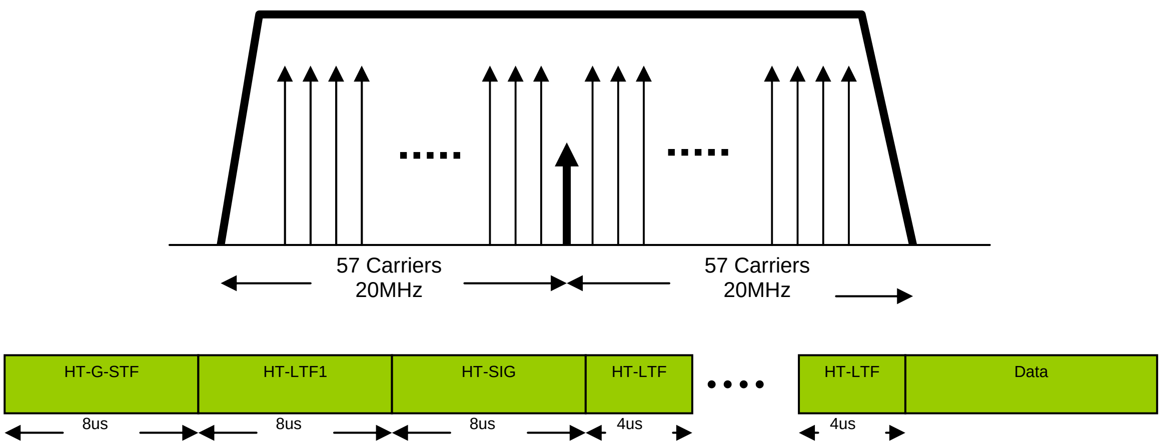

Figure 3: Greenfield Mode Frame Structure & Carrier

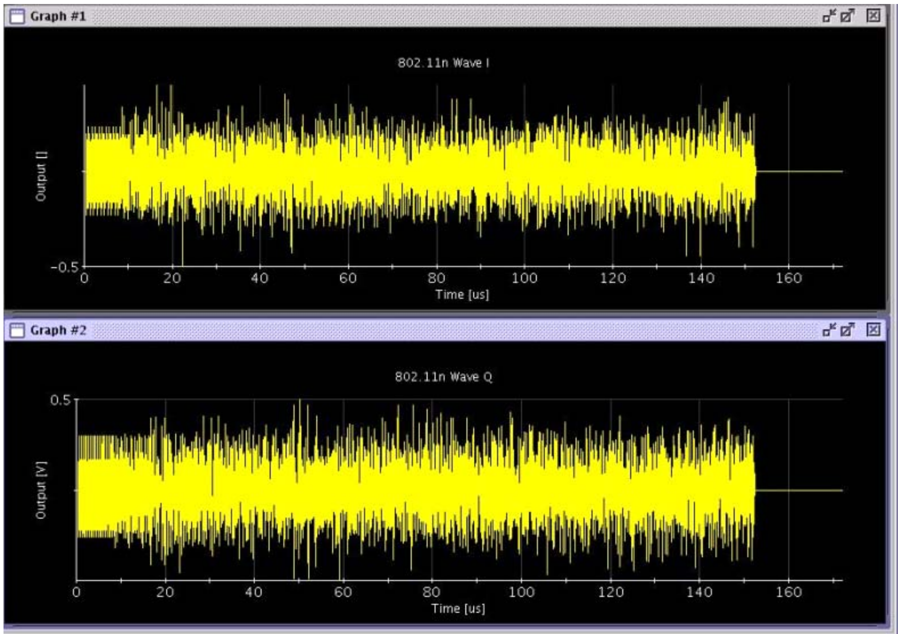

Figure 4: Greenfield Mode Time Domain signal

Let's look more closely at the different field described in Figures 1-4 above.

Legacy Short Training Field (L-STF)

This is the same as the 802.11a short training OFDM symbol. The L-STF is 6Mbps using BPSK modulation. It contains no channel coding, and is not scrambled. The L-STF takes 8 µs to complete. In the 20 MHz transmission mode, the short training field uses sub-carriers: -24, -20, -16, -12, -8, -4, 4, 8, 12, 16, 20, 24 for the OFDM symbols. The 40 MHz transmission mode, it uses sub-carriers -58 to -2 and 2 to 58. The upper sub-channels (sub-carriers 6-58) are phase rotated by +90º. The 90º rotation helps keep the PAPR of the short training field in 40 MHz comparable to that in 20 MHz.

Legacy Long Training Field (L-LTF)

This is the same as the 802.11a long training OFDM symbol. The L-STF is 6 Mbps using BPSK modulation. It contains no channel coding, and is not scrambled. The 20 MHz transmission mode uses sub-carriers –26 to –1 and 1 to 26.The 40 MHz transmission mode uses sub-carriers –58 to –2 and 2 to 58. For the same reason as STF, the tones in the upper sub-channel (sub-carriers 6-58) are phase rotated by +90º. The sub-carriers at ±32 in 40 MHz, which are the DC sub-carriers for the legacy 20 MHz transmission, are both nulled in the L-LTF. Such an arrangement also allows proper synchronization of the 20 MHz legacy device.

High Throughput Signal Field (H-SIG)

HT-SIG consists of two OFDM symbols. It is interleaved and mapped. The HT-SIG is not scrambled. In the 20 MHz transmission mode, the sub-carriers uses -28 to 1 and 1 to 28, and have pilot inserted in sub-carriers –21, –7, 7 and 21. In the 40 MHz transmission mode, the sub-carriers used are -58 to -2 and 2 to 58, and have pilot inserted in sub-carriers –53, –25, –11, 11, 25, 53.

Data Field (Data) & Modulation Schemes

For the 802.11n, a continuous decision-making process is used, based on the feedback from the receiver about the channel conditions to adjust the transmit modulation. Given the conditions, the system will change the modulation rate to provide the best compromise between data rate and error rate for the payload.

In Legacy mode, the 802.11a/g modulation scheme will be used. However, the 802.11n provides many more combinations to allow for transmission using multiple streams and coding. The complexity of 802.11n rate adaptation gives rise to the concept of Modulation Coding Scheme (MCS). MCS includes variables such as the number of spatial streams, modulation, and the data rate on each stream. During communication, the optimum MCS will be constantly negotiated based on channel conditions. There are more than 70 MCS specified in the IEEE P802.11n draft 2.0. Table 1 show the modulation scheme used in the MCS when using single spatial stream is used.

MCS Index	Modulation	Coding rate	Number of Data Sub-Carriers		Number of coded bits per single carrier		Data Rate[Mbps] Guard Interval 800ns		Data Rate[Mbps] Guard Interval 400ns	
			20MHz	40MHz	20MHz	40MHz	20MHz	40MHz	20MHz	40MHz
0	BPSK	1/2	52	108	52	108	6.5	13.5	7 2/9	15
1	QPSK	1/2	52	108	104	216	13	27	14 4/9	30
2	QPSK	3/4	52	108	104	216	19.5	40.5	21 2/3	45
3	16-QAM	1/2	52	108	208	432	26	54	28 8/9	60
4	16-QAM	3/4	52	108	208	432	39	81	43 1/3	90
5	64-QAM	2/3	52	108	312	648	52	108	57 7/9	120
6	64-QAM	3/4	52	108	312	648	58.5	121.5	65	135
7	64-QAM	5/6	52	108	312	648	65	135	72 2/9	157.5
32	BPSK	1/2		48		48		6		6.67

Table 1: MCS related to 1 Spatial Stream

3. Spectrum Analysis

The OFDM modulation used in 802.11n is similar as 802.11a. The spectrum is very flat at the top, and the side lobes are part of the modulation. Most contributors to these side lobes are the sub-carriers located at the extremes. The spectrum shown in Figure 5 is that of the 802.11n in HT format at 40 MHz. It is not obvious by the spectrum, but the 802.11n spectrum is much more dense than in 802.11a, as more carriers are allocated in the same bandwidth. Due to the higher density of the carriers, low phase noise and low distortion requirements are needed to avoid inter-channel interference issues. These requirements are much higher compared to 802.11a, due to the closer spacing of the sub-carriers.

To avoid carrier feed-through issues, the center carrier is not used. One of the tests for 802.11n is the spectral mask test. Figures 6 and 7 illustrate the spectrum mask requirement In order to measure this mask correctly, it is important to ensure that the frequency response of the measuring equipment is flat throughout the measurement span.

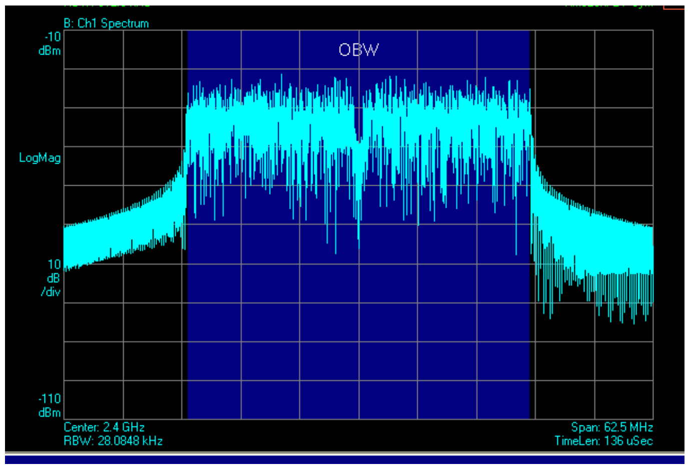

Figure 5: HT-mode 40 MHz Channel Spectrum

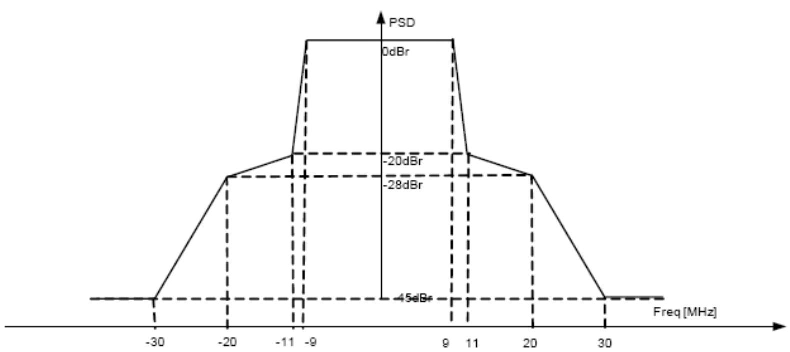

Figure 6: 20 MHz Channel Spectrum Mask Requirement[1]

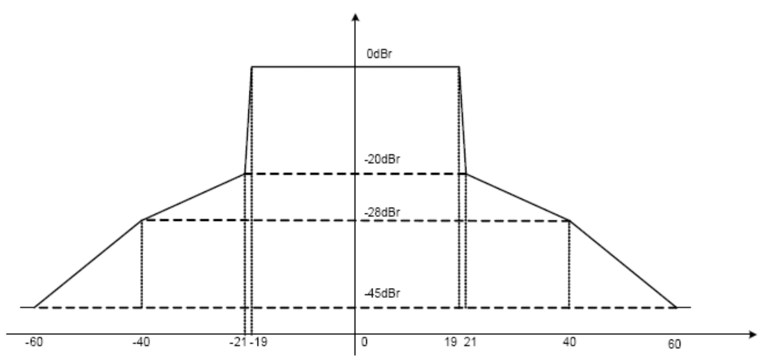

Figure 7: 40 MHz Channel Spectrum Mask Requirement[1]

4. Demodulation & EVM

This section presents the demodulation used in the Verigy V93000 software and demonstrates how to demodulate an 802.11n waveform.

The first thing which is needed before demonstrating and referencing a demodulation procedure is an appropriate waveform to start with. There are a couple of ways of creating a waveform: The recommended method is to use software products for bench equipment such as Agilent’s Signal Studio to create a waveform with exactly the features the user wants it to exhibit. Alternatively, custom waveforms from the DUT design department can also be used directly.

For TX tests, the modulated waveform is applied to the baseband inputs of the DUT, and the resultant RF output waveform is captured by the V93000 RF subsystem. The captured data are then fed into the V93000 demodulation engine which outputs multiple results such as mean rms EVM value over all symbols, mean EVM value over the data symbols, respective peak EVM values, IQ data for constellation plots, etc. The demodulation engine in the V93000 software has been extensively tested for optimal correlation between the V93000 tester and standard bench equipment.

The demodulation engine used in the V93000 is extremely flexible to handle multiple facets of 802.11n modulation. Crucial for a successful application of the demodulation engine are the correct parameter settings which need to be applied to the demodulation engine before it is started. Table 2 below lists and explains the most important parameters for the demodulation of 802.11n waveforms.

Parameter Name	Setting	Description
fofdmSmpFreq	160000000	Sampling frequency
fofdmEqTraining	0	Equalizer training: using data part to help to obtain more accurate channel estimation.
Ofdm11nFFTLen	128	The IEEE 802.11n standard defines 20 MHz and 40 MHz modes of operation. Only values of 64 and 128 are valid. A value of 128 specifies the "40 MHz" mode, which uses 117 sub-carriers and an FFT length of 128. A value of 64 specifies the "20 MHz" mode, which uses 57 sub-carriers and an FFT length of 64. .
fofdmGuardInt	0.25	The IEEE 802.11n standard specifies guard intervals of either 1/4 or 1/8.
fofdmMeasInt	40	This parameter specifies the measurement interval (length), in symbol times, of the portion of the pulse that will be analyzed. Value of 40 used here for HT-Mode
fofdmTrkAmp	TRUE	Uses Pilot to track the amplitude. Useful for longer bursts if there is any amplitude droop.
fofdmTrkPhase	TRUE	Uses Pilot to track the phase. Setting this to FALSE is generally useful only when debugging an incorrect input signal.
fofdmTrkTiming	TRUE	Uses Pilot to track the timing.

Table 2: Key Parameters for Demodulating 802.11n

For complex tests like EVM, effective debugging tools are critical in helping to reduce the development time and the time to market. The demodulation engine in the V93000 software provides useful results to allow the engineer to debug better. Figure 8 shows some of the results generated by the V93000’s demodulation engine for debug purpose.

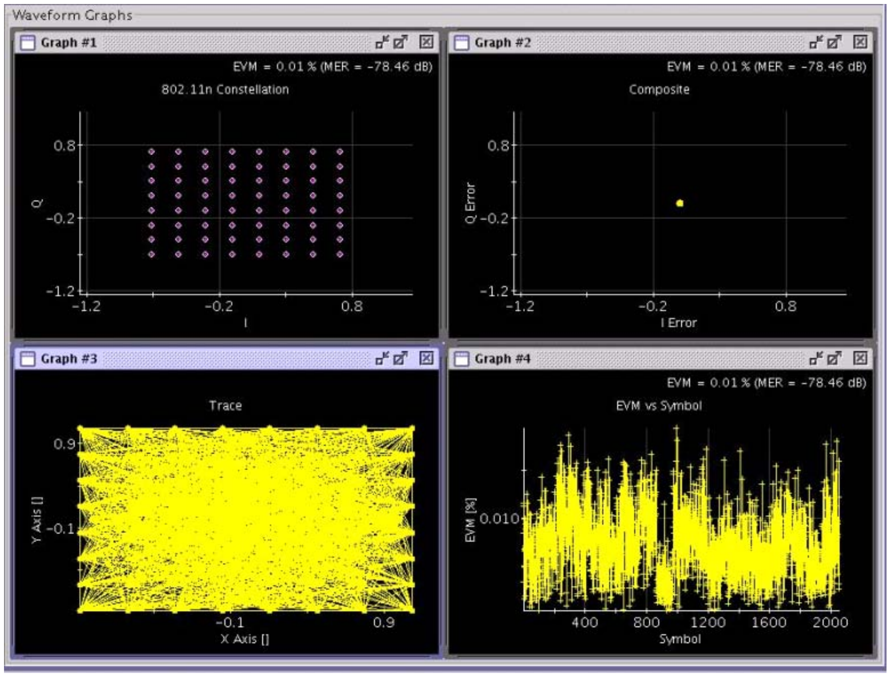

Figure 8: Graphical outputs from V93000 demodulation engine.

6. Conclusion

There are a lot of challenges to measuring EVM for 802.11n. Having the right tools to make the measurements is crucial. This paper has attempted to show the basics of 802.11n Modulation and how these tests are implemented on the V93000. Signal Studio can be used to generate the waveforms to be applied to the DUT (Device Under Test), and the built-in demodulation engine of V93000 can be used to analyze EVM from DUT outputs. Time domain and spectrum and EVM plots are shown to give a better understanding of the whole signal structure.

7. References

[1] IEEE STD 802.11n/D2.00: Draft Standards for Information Technology -- Telecommunications and Information Exchange between Systems -- Local and Metropolitan Area Network – Specific Requirements -- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.

[2] Agilent Signal Studio for WLAN N7617B Manual, release May 2008.

[3] Aruba Networks white paper, "Design for Speed: Network infrastructure in an 802.11n world", Peter Thornycroft, 2008.

[4] Agilent Application Note, "MIMO Wireless LAN PHY Layer [RF] Operation & Measurement," Part Number 5989-3443 (2008).