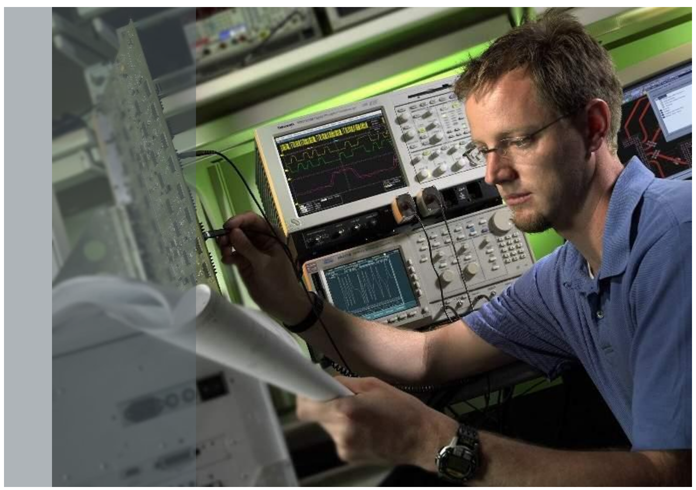
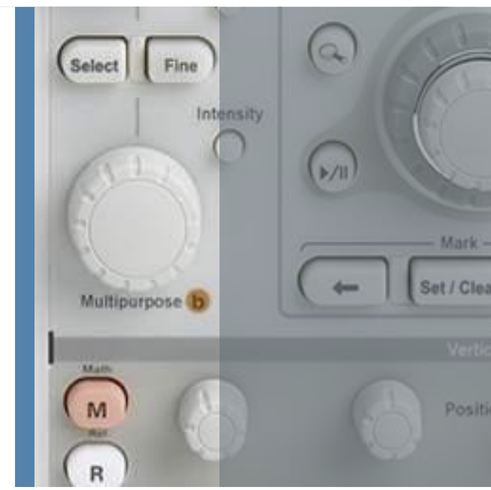
Testing & Troubleshooting for 802.11 standards





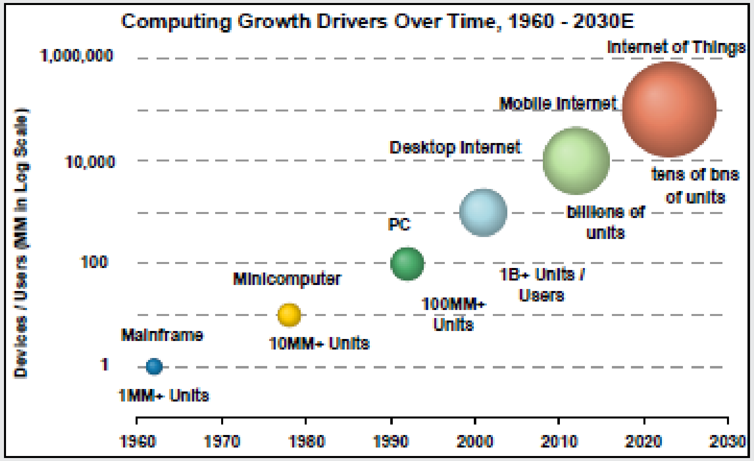
Saliou Dieye
RF Business Development
Tektronix, FRANCE

Agenda

- **Introduction**
  - **WLAN standards**
  - WiFi Standards transmitter measurements
- **Basic Compliance Overview**
  - Standards
  - Regulatory
- **Pre-Compliance Testing**
  - What do we need
  - What can we do
- **Review**
  - Case Studies
  - On-Line Resources

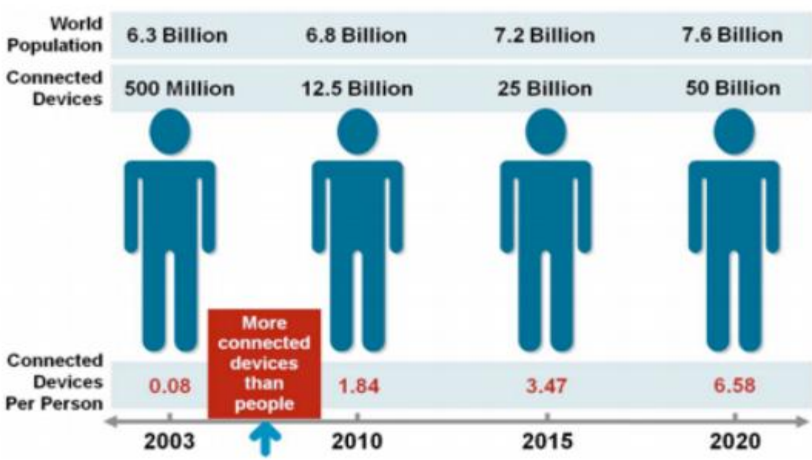
Internet Of Things

The Internet of Things: the opportunity is potentially huge



Source: Company Data, Thomson Reuters, Morgan Stanley Research

Figure 1. The Internet of Things Was "Born" Between 2008 and 2009



Source: Cisco IBSG, April 2011

Exhibit 1

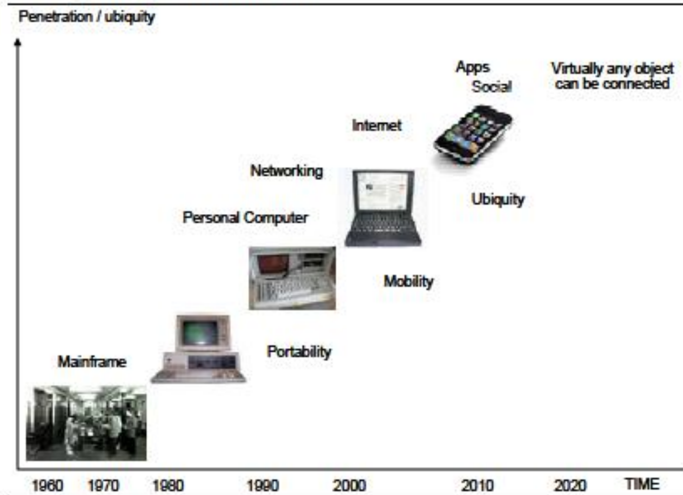
The Internet of Things is now

Fitbit Ultra, Google Glass, Nest Diamond Thermostat

Source: Wikimedia Commons

Exhibit 2

Internet of Things is the next step in Personal Computing's evolution



Source: Morgan Stanley Research

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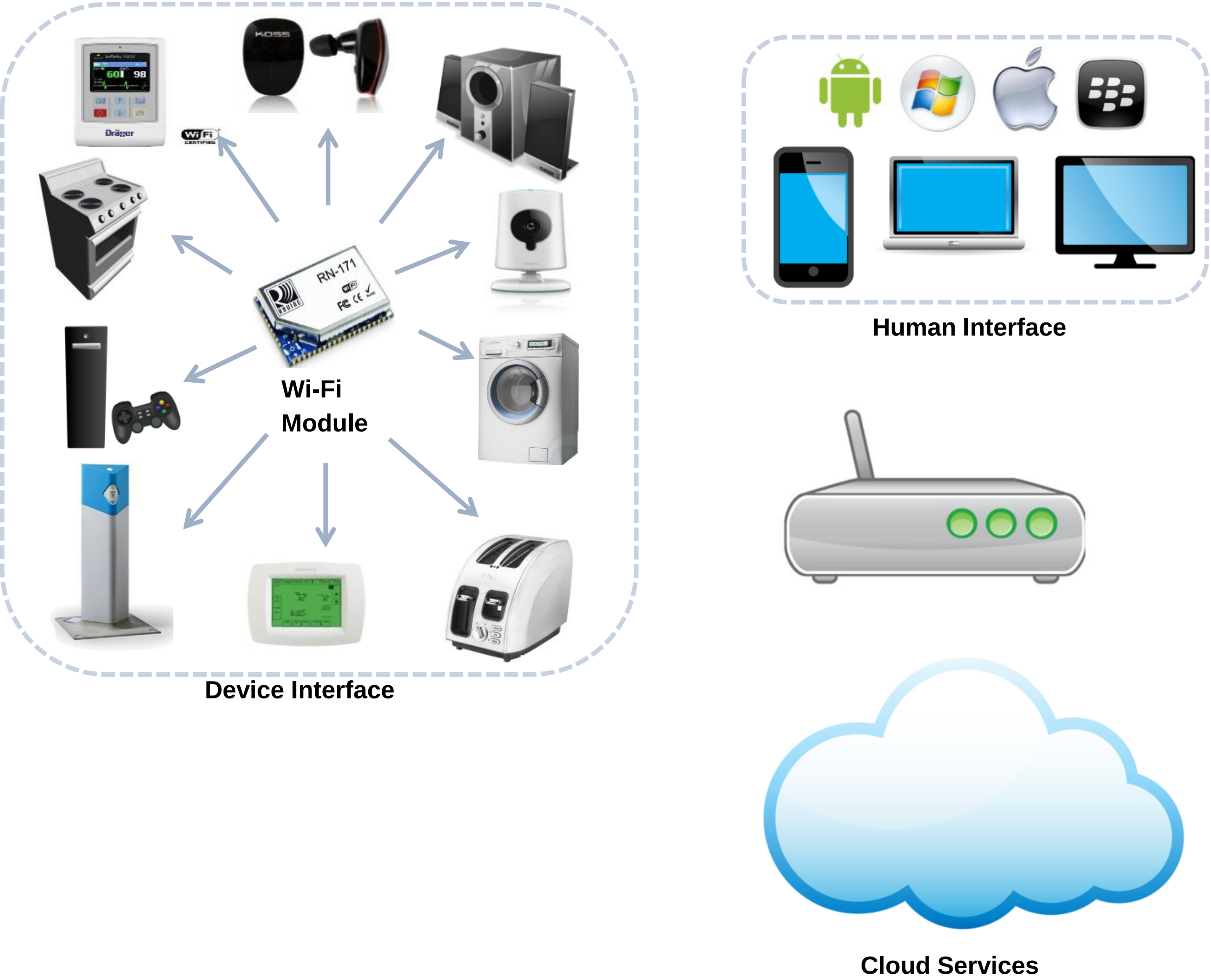
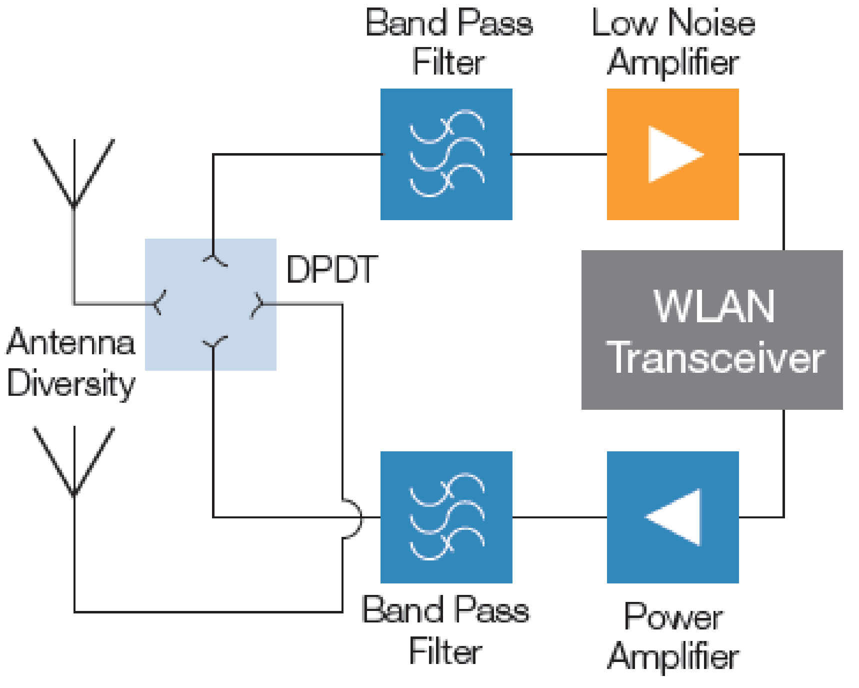
Internet Of Things

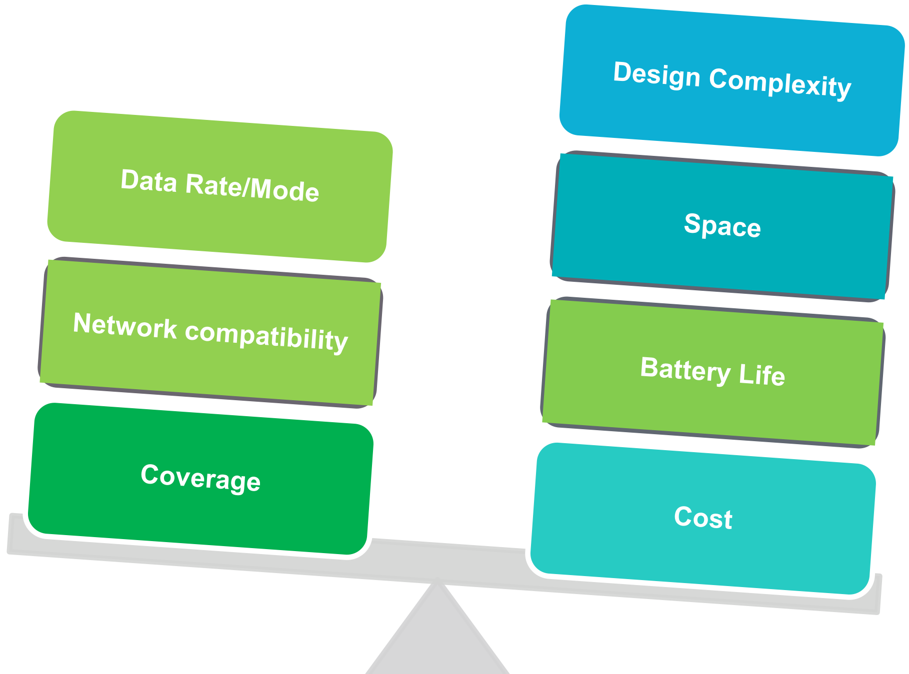


Internet Everywhere = WLAN = 802.11a,b,g,n,ac,ad

- IEEE 802.11 created to provide wireless Ethernet
- Standard has evolved over the years
- Many “drop-in” solutions available
- 802.11 radio modules are now a commodity



Which Module Should I Use ?



Weigh All Your Options !

802.11 Decoder Page

Nickname	Std PHY Name	Freq Band(s)	Signal	BW (max)	Std section
"b"	DSSS HR/DSSS	2.4 GHz	DSSS/CCK 1-11 Mbps	20 MHz	16 & 17
"b/g"	ERP	2.4 GHz	DSSS/CCK/ PBCC (*) 1-33 Mbps	20 MHz	16,17,19
"a/g/j/p"	OFDM	5 GHz 2.4 & 5 GHz	OFDM 64 ≤ 54 Mbps	20 MHz	18 19
"n"	HT	2.4 & 5 GHz	OFDM 64,128	40 MHz	20
"ac"	VHT	5 GHz	OFDM 64-512	160 MHz	(22)
"ad"	DMG	60 GHz	SC/QAM OFDM 512	2200 MHz	(21)

DSSS = Direct-sequence spread spectrum; **CCK** = Complementary Code Keying;
HR/DSSS = High Rate DSSS; **PBCC** = Packet Binary Convolutional Coding
OFDM = Orthogonal Frequency- Division Multiplexing
ERP = Extended Rate Physical; **HT**= High Throughput; **VHT**= Very High Throughput
DMG = Directional Multi-Gigabit
(*) PBCC: Obsolete or Deprecated Format

Radio 101: Packets

- WIFI signals share a basic structure
  - Data is packetized and sent in a “burst transmission”
- Each burst will contain:
  - Preamble & Header
    - Preamble allows receiver to obtain time & frequency sync
    - Header provides information about the packet configuration
    - Simple modulation (BPSK)
  - Payload Data
    - The user’s data being transported
    - Complex modulation (QPSK,OFDM)
- Each burst can have different payload modulation based on QOS

Radio 101: Frequency Bands

Nickname	Band	802.11
2.4 GHz	2.4 – 2.483 GHz	b/g/n
3.6 GHz	3.65 – 3.7 GHz	y **
4.9 GHz	4.94 - 4.99 GHz	y **
5.8 GHz	5.15 – 5.725 GHz	a/h/j/n/ac
5.9 GHz	5.85 – 5.9 GHz	p

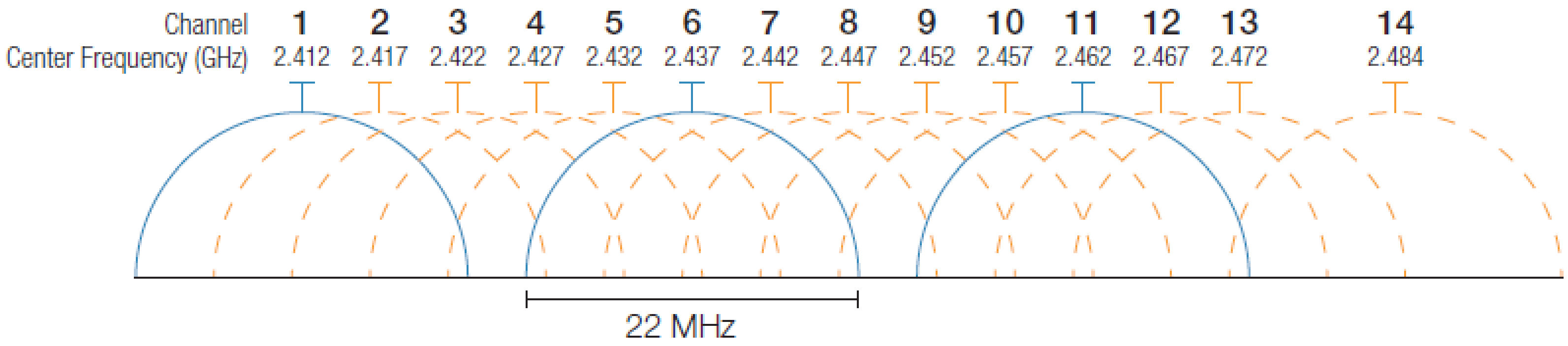
** lightly licensed

Device is not supposed to cause interference

Device gets no protection from other services

Radio 101: 2.4 GHz Channels

- 2.4GHz ISM Band WIFI Channel Assignments
  - Not all countries support all channels
  - Frequency band is shared with other services



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Wi-Fi standard Transmitter Measurements

Type of Measurement	Measurement	DSSS	"b"	"a"	"g"	"n"	"ac"	IEEE Standard Limit
Transmit Power Measurements	Transmit power	YES	YES	YES	YES	YES		country dependent
	Transmit Power On/Off Ramp	YES	YES					(10%-90%) 2 usec
Transmit Spectral Measurements	Transmit Spectrum mask	YES	YES	YES	YES	YES	YES	Std mask
	RF Carrier suppression	YES	YES					-15dB
	Center frequency leakage			YES		20MHz		-15 dBc or +2 dB w.r.t. average subcarrier power
						40MHz		-20 dBc or 0 dB w.r.t. average subcarrier power
	Transmit Spectral flatness			YES		YES	YES	+/- 4 dB, +4/-6 dB (various BWs, 20-160 MHz)
	Transmission spurious			YES				country dependent
	Out-of-band spurious emission	YES	YES	YES	YES			country dependent
Transmit Frequency Measurements	Transmit Center frequency tolerance	YES	YES		YES			+/-25 ppm (DSSS,b,g)
				YES				+/-20 ppm (20 MHz and 10 MHz), +/-10 ppm (5 MHz)
						YES	YES	+/-20 ppm (5 GHz band), +/-25 ppm (2.4 GHz band)
	Symbol clock frequency tolerance	YES	YES	YES	YES	YES	YES	same specs as above
Transmit Modulation Measurements	Transmit Modulation accuracy	YES						Peak EVM < 0.35%
			YES					Peak EVM < 0.36%
	Transmitter Constellation Error							

Transmitter Constellation Error (Transmit Modulation Measurements)

Modulation Type	Coding rate	Limits in dB: "a"	"g"	"n"	"ac"
BPSK	1/2	-5		–5	-5
BPSK	3/4	-8			
QPSK	1/2	-10		–10	-10
QPSK	3/4	-13		–13	-13
16-QAM	1/2	-16		–16	-16
16-QAM	3/4	-19		–19	-19
64-QAM	2/3	-22		–22	-22
64-QAM	3/4	-25		–25	-25
64-QAM	5/6			–27	-27
256-QAM	3/4				-30
256-QAM	5/6				-32

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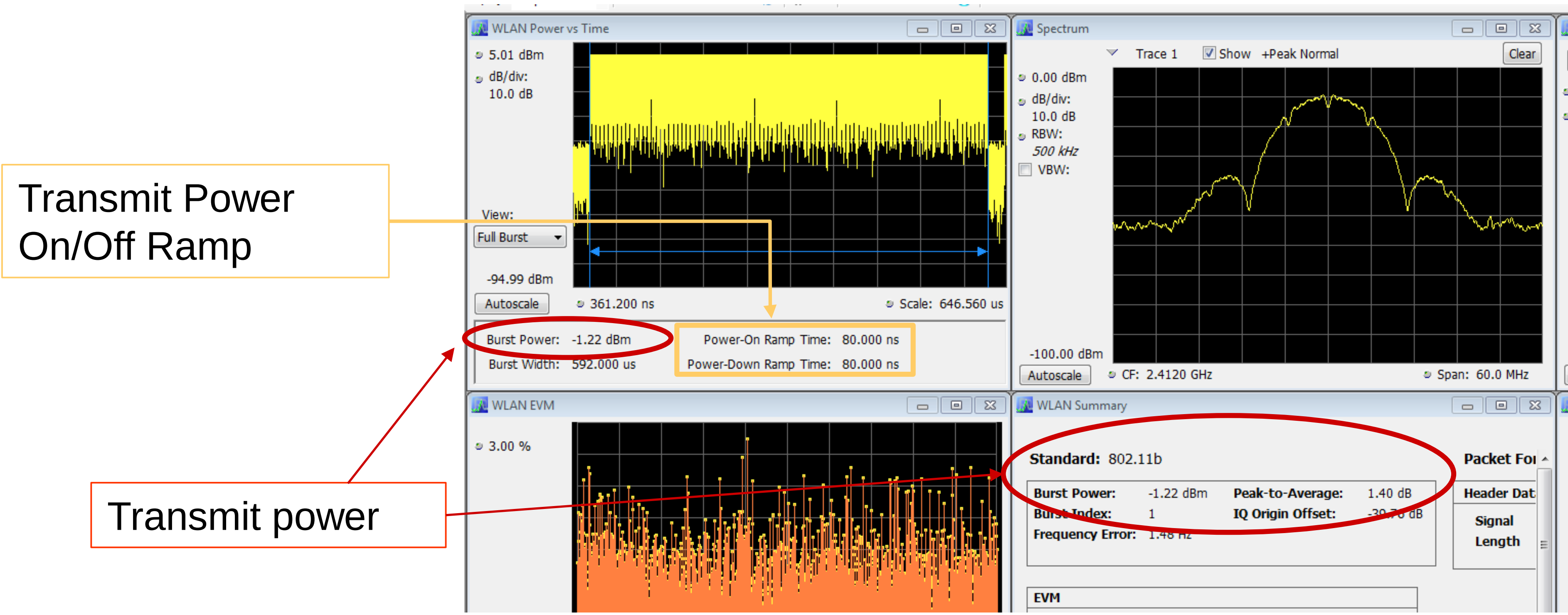
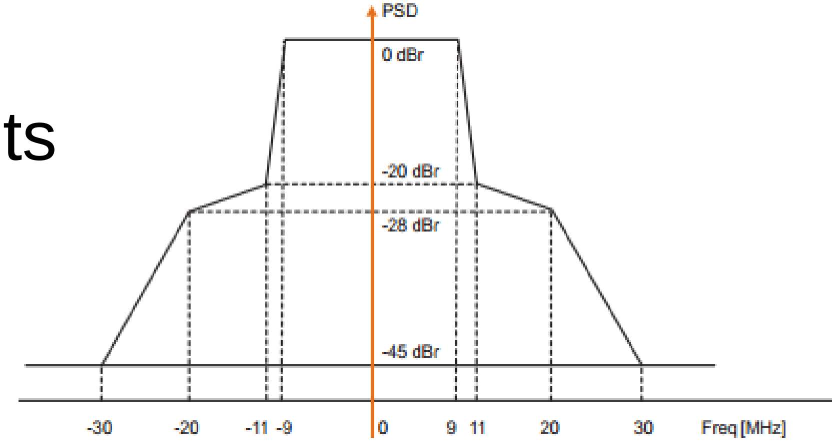
Transmitter Power Measurements

- The objective of these tests is to verify the transmit power level.
  - If too low, performance in a noisy environment is affected;
  - if too high, battery life is compromised and interference issues may arise.
  - Also, must be kept within the limit specified by each country regulations
  - Power variations can compromise the quality of the transmission.



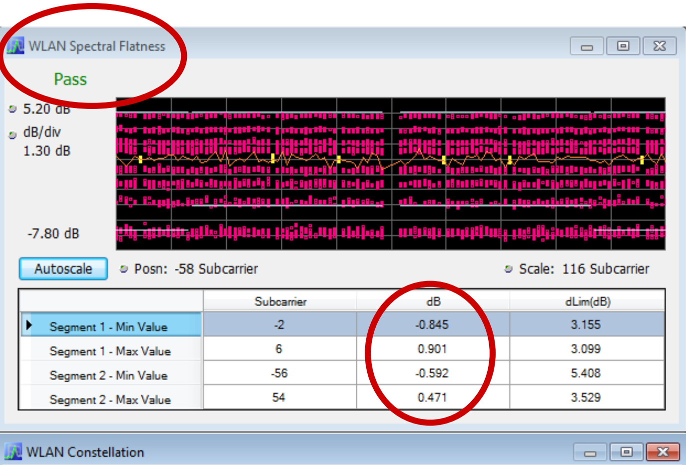
Transmit Spectral Measurements

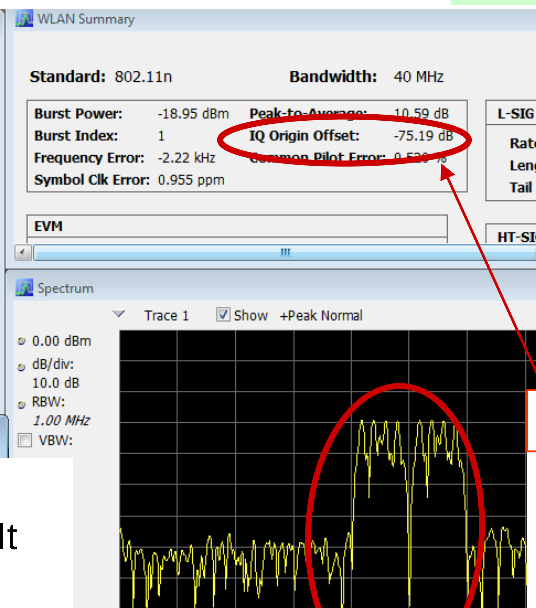
- These measurements verify conformity of the distribution of signal power to the specification as well as compliance to regulatory limits. In addition, they provide information on common types of distortions that can affect the signal.
- **SEM (Spectral Emission Mask):** The permitted distribution of signal power is defined for each 802.11 standard via a mask that needs to be compared to.

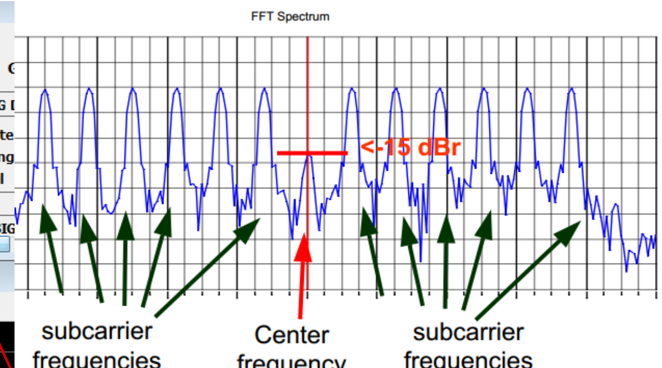


IEEE 802.11 Spectral mask for 802.11 20MHz channel

17.3.9.6.1 Transmit Center Frequency Leakage
<-15 dB relative to overall transmitted power
e.g. 23 dBm transmitted power, 8 dBm center leakage power





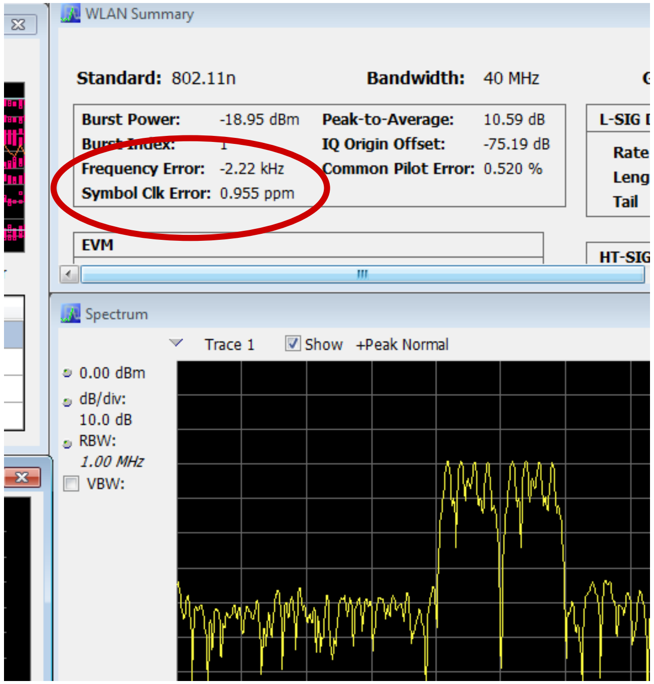


Spectral Flatness is a measure of the deviation in power in all spectral bands. It ensures that power is spread out evenly over the channel, which could be compromised by the output filter performance.

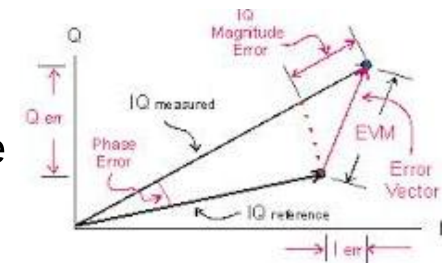
Transmit Center Frequency Leakage: DC offset can affect certain transmitter implementations in the up-converter path, and usually causes carrier leakage. Such leakage manifests itself in a receiver as energy in the transmit center frequency, hence the name Transmit Center Frequency Leakage.

Transmit Frequency Measurements

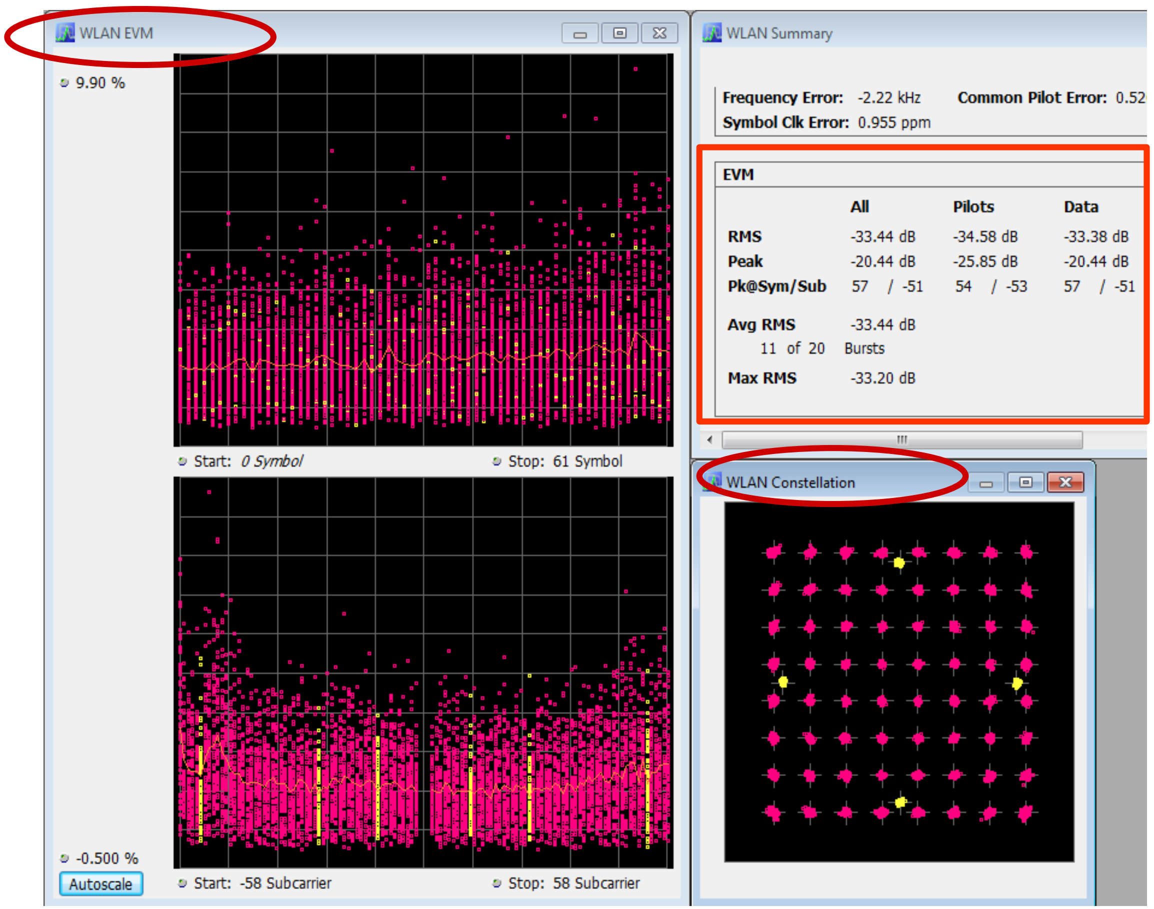
- These tests verify frequency accuracy of the transmitter. This is critical; it ensures that the receiver is able to recover the information contained in it. In addition, precise frequency accuracy minimizes interference in multi-user systems.
- Transmit Center frequency tolerance: A Frequency Error measures the difference (misalignment) between the carrier frequency generated by the reference oscillators at the transmitter and the expected carrier frequency.
- Symbol clock frequency tolerance: A Clock Error is the sampling clock difference at the transmitter and receiver. IEEE requires that the transmit center frequency and the symbol clock frequency for all transmit antennas shall be derived from the same reference oscillator, hence, the specifications for the Clock Error and for the Transmit Center Frequency Tolerance are the same.



Transmit Modulation Measurements



- These tests provide critical information on the types of distortion in the entire transmit chain that can affect the signal quality
- Some common types of corruption are I/Q gain and phase mismatch, symbol clock error, group delay, phase noise, and compression



The EVM (Error Vector Magnitude) is a measure of the deviation of the actual constellation points from the ideal error-free locations in the constellation diagram (in % RMS or dB). Also known as Transmit Constellation Error, the RMS error is averaged over subcarriers, OFDM frames, and packets.

The Constellation Diagram is a representation of a signal modulated by a digital modulation scheme.

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Agenda

- **Introduction**
  - WLAN standards
  - WLAN transmitter measurements
- **Basic Compliance Overview**
  - Standards
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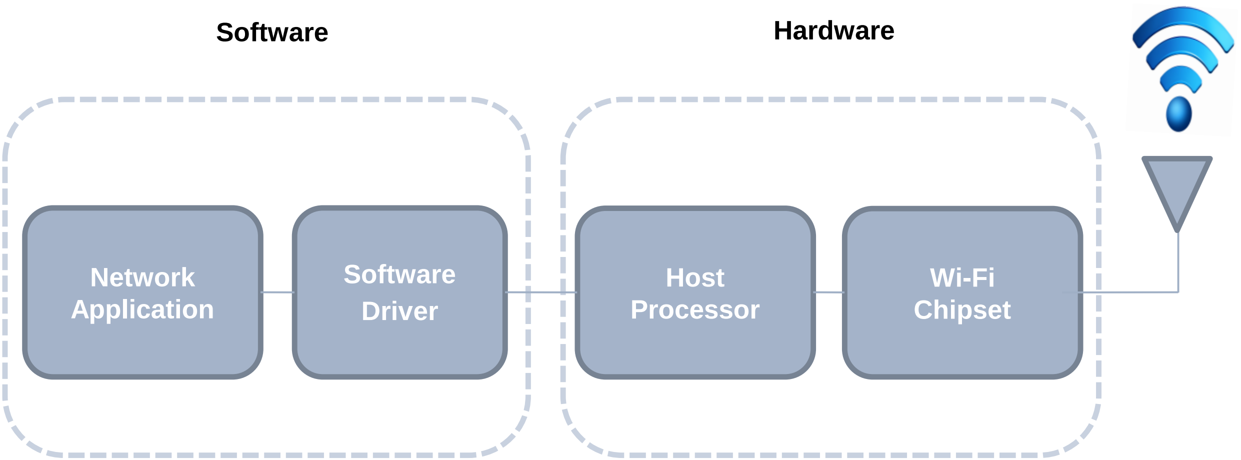
- **Review**
  - Case Studies
  - On-Line Resources

Do You Need Compliance Testing ?

- Many modules available that are “pre-certified”
  - Emissions or Protocol ?
- Are you using a reference design or module ?
- Did you make any changes to the RF path ?
- Compliance has multiple levels of test



Typical Wi-Fi Enabled Device

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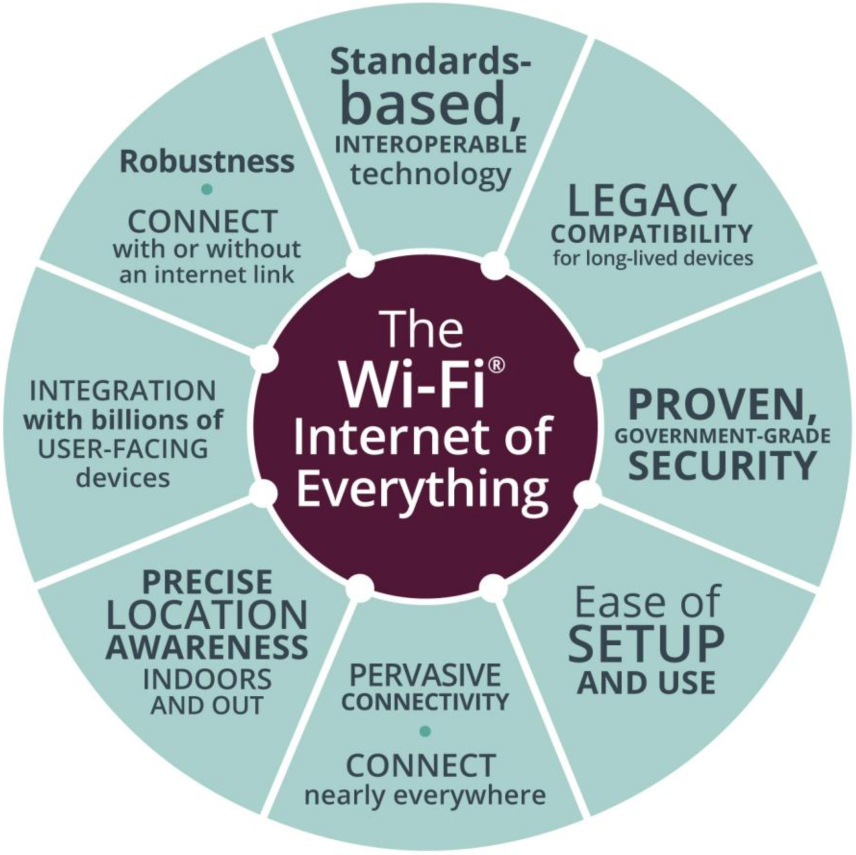
Standards Compliance

- Testing prescribed WI-FI Alliance
- Protocol conformance
  - Connectivity
  - Security
  - Access
  - Applications & Services
  - Inter-operability
- Certified test houses
- http://www.wi-fi.org/



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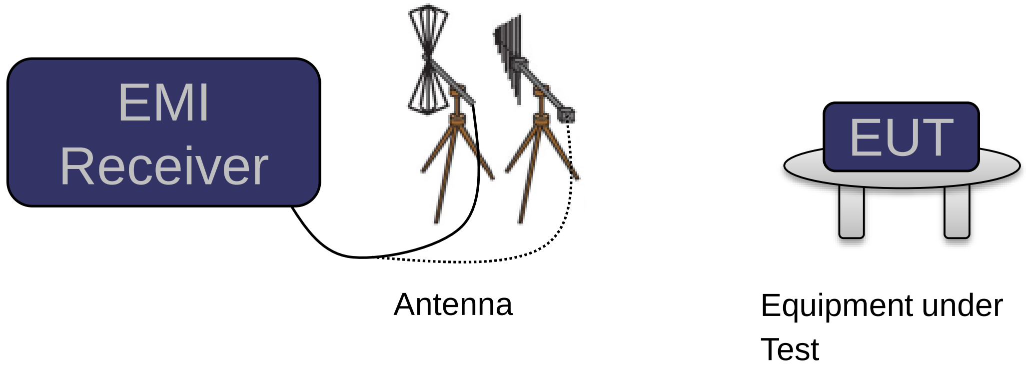
Regulatory Compliance

- Un-intentional radiated emissions
  - Unwanted signals
  - 360 view
- Conducted emissions
  - Unwanted signals coupled to AC
  - Class of service
  - 9kHz – 30MHz
- Intentional radiated emissions
  - Frequency band dependent
  - Class of service

Country	Approval Regulatory standards
United States	Federal Communications Commission (FCC)
Canada	Industry Canada (IC)
Europe	European Telecommunications Standards Institute (ETSI)
Japan	Ministry of Internal Affairs and Communications (MIC)
China	Ministry of Industry and Information Technology (MIIT)
Korea	Korea Communications Commission (KCC)

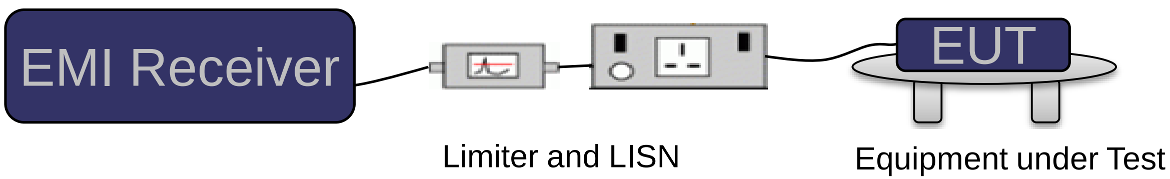
Radiated Emissions

- Performed in RF isolated chamber
- Far field measurements (3m or 10m)
- EUT is placed on a turn-table, idle state
- Fully calibrated setup
  - Chamber
  - Receiver
  - Antenna's



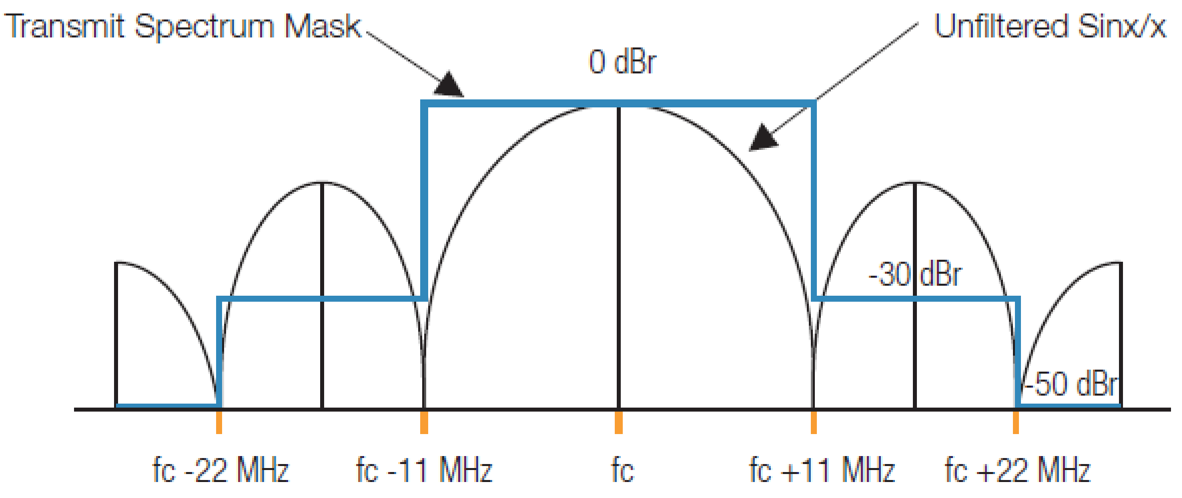
Conducted Emissions

- For devices which connect to power grid
- Characterize energy conducted to AC grid
- Line Impedance Stabilization Network
  - Connected Rx between AC and EUT
- EUT is in operational state



Intentional Radiated Emissions

- For devices which transmit RF energy
- Measure EUT directly connected to spectrum analyzer
  - No antenna !
- EUT is in operational state
  - Must be able to check all modes of operation
  - Low, mid, and highest channel of operation



Regulatory Compliance

- Compliance Measurements → **Test House**
  - Complex measurement setup
  - Chamber time = cost
  - Will report a failure, but not what you can do about it

- Pre-Compliance Measurement → **In House**
  - Test for regulatory issues throughout the design process
  - Test more often
  - **You still need to go to a test house**

Pre-compliance testing will save time/money by identifying problem areas before they become expensive re-design issues

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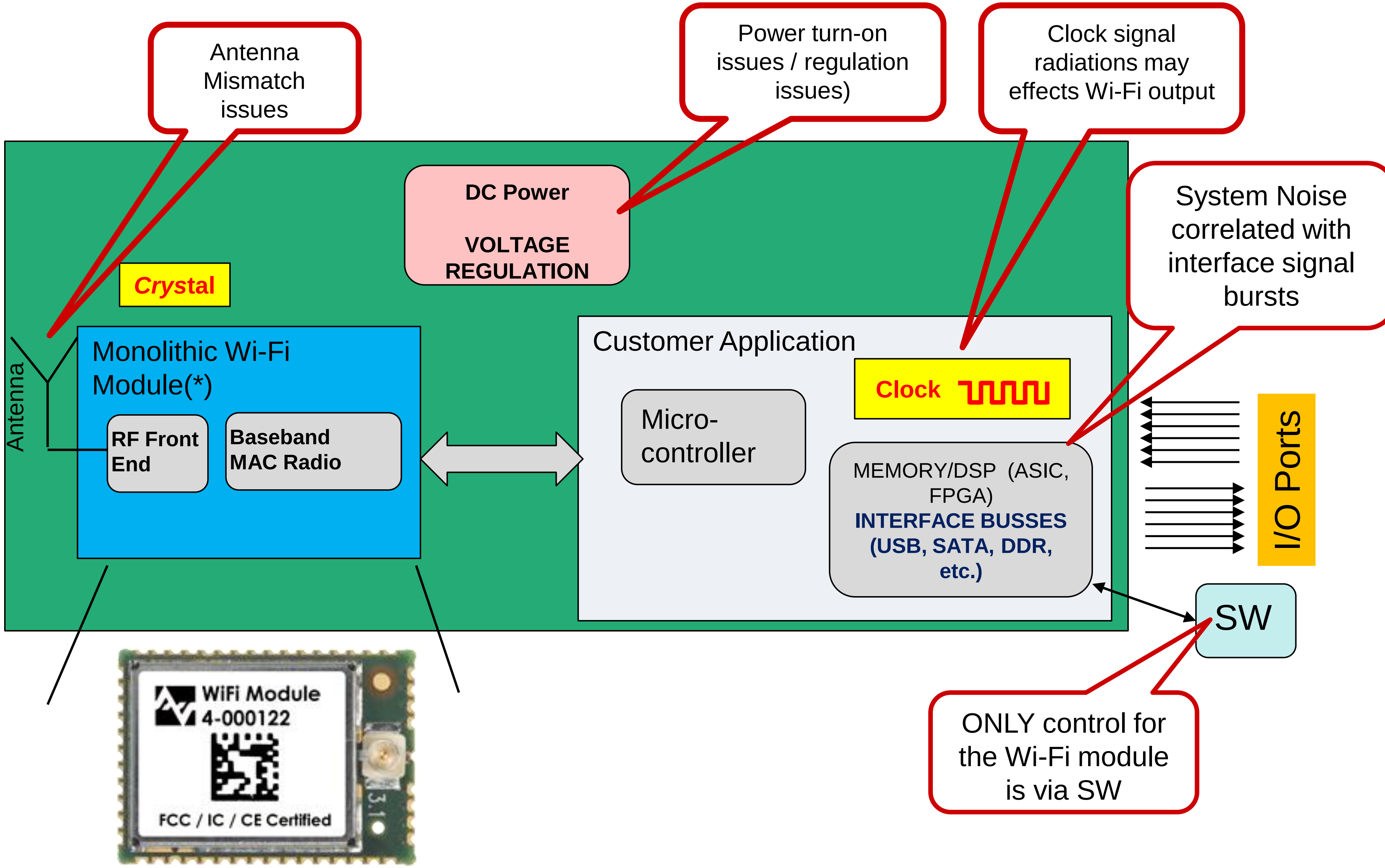
Module Integration Challenges



(*) Certified Module doesn't = Certified End-Product

Wi-Fi Module System Integrator

Background

- **Joe** has a BS in Electrical Engineering, held engineering positions at various commercial product companies throughout his career.
- He is currently employed as a hardware EE for a printer company, designing various printer modules.
- Joe knows about power supplies and motor driven devices**, but not 802.11 or spectrum analyzers**.

Goals

- Obtain pre-compliance test data to determine Pass/Fail RF/wireless printer capabilities.
- Establish repeatable 802.11 printer pre-certification process.
- Collect and analyze test data remotely using a wired or wireless LAN connection.
- To quickly/easily obtain 802.11 Pass/Fail pre-compliance data.
- **Failing Compliance can cause more than $10,000**

Concerns

- **'Not sure what I'm doing. I have to deliver this RF stuff that's new to me.'**
- Getting commercial products 802.11 certified in a quick and easy manner.

Design Cycle for Joe

1. Decide they want Wi-Fi in an existing product
2. Choose Wi-Fi chipset or module for integration
   a) Chipset chosen based on size/power/cost constraints
   b) Module chosen for expediency
3. Hire RF design consultant
4. Integrate Wi-Fi into design – demonstrate initial operability with power on – tweak as necessary
5. Select / integrate antenna and optimize as necessary
6. Begin FCC & WLAN pre-compliance checks – adjust amplification in firmware
   a) Go back to steps 4 and 5
7. FCC & WLAN Compliance Test – YIKES! ($2K/day) – final firmware adjustment
   a) If fail, fire RF consultant and return to step 3.
      Costs of compliance test can increase very quickly and go beyond $10,000
8. Lock down design and ship

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Wi-Fi Integration issues found in steps 4, 5,6,7

- Losing packets (causes losing lip synch, video image freezing…for the more advanced application)
  - Most applicable to customers looking for reliability in the Wi-Fi Link
- Bad data throughput – is not what was spec'ed in the Module datasheet
  - Most applicable to customers looking for performance out of their Wi-Fi Link
- Failing FCC and WLAN Compliance Test
  - Applicable to all types of customers

Ask the customer what their fears and issues are?

WHY?

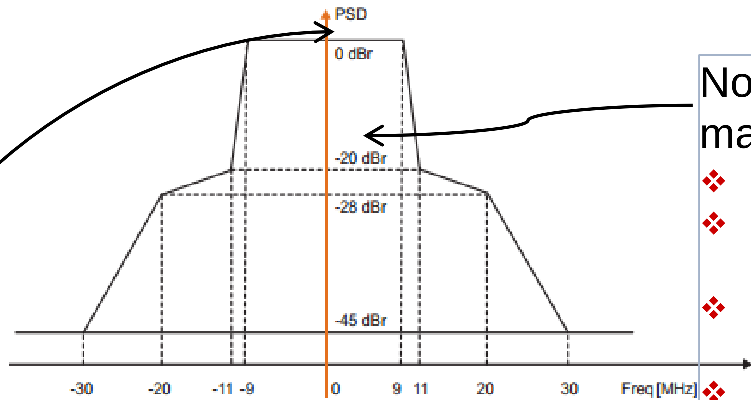
- Power Analysis
  - Switching supplies
  - Regulation
  - Turn-on
- System Clock Harmonics
- Noise via power lines
- Interferences from other RF links
- Antenna mismatch

Troubleshoot with Oscilloscope or a low-end Spectrum Analyzer

Or

An MDO4000

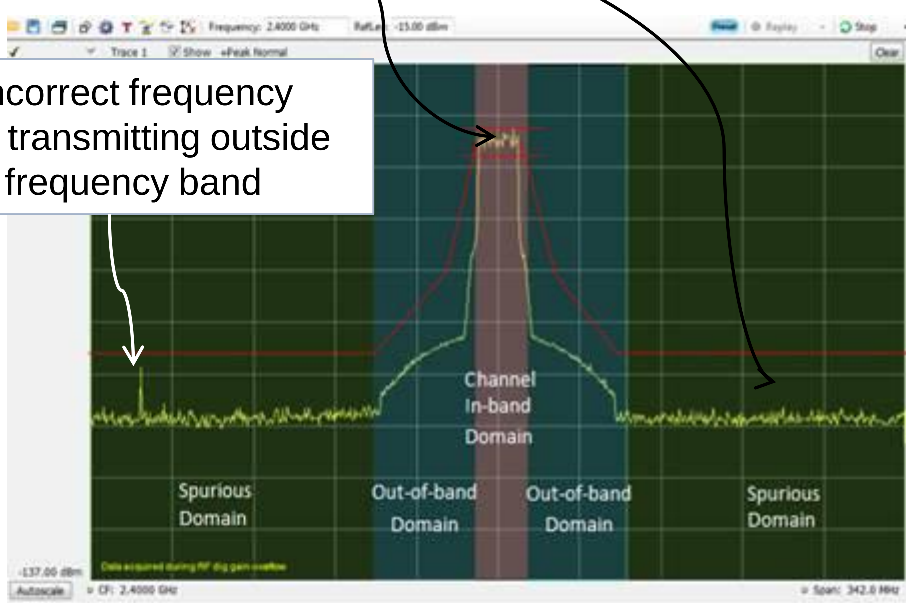
Reasons for failing FCC and WLAN Compliance Test



IEEE 802.11 Spectral mask for 802.11 20MHz channel

Above maximum allowed power

Incorrect frequency e.g. transmitting outside frequency band



Non-conformance to spectrum emission mask

- Transient power peaks within a burst
- Interference from non-RF portions of system
  - (e.g., turning on a motor)
- Interference from other RF portions
  - (e.g., turning on Bluetooth function)
- Coupling from other parts of the system
  - (e.g., microprocessor couples to power supply)
- Power amplifier issues
  - (e.g., power supply, filtering)
- Mismatch issues from transmitter to antenna
- Malfunction of RF switches
  - (e.g., TX/RX switch)

To troubleshoot these issues, **you need an insight in all the pieces of the system**!

(Motor control, microprocessor, Bluetooth, power supply, filtering, antenna, TX/RX switch….)

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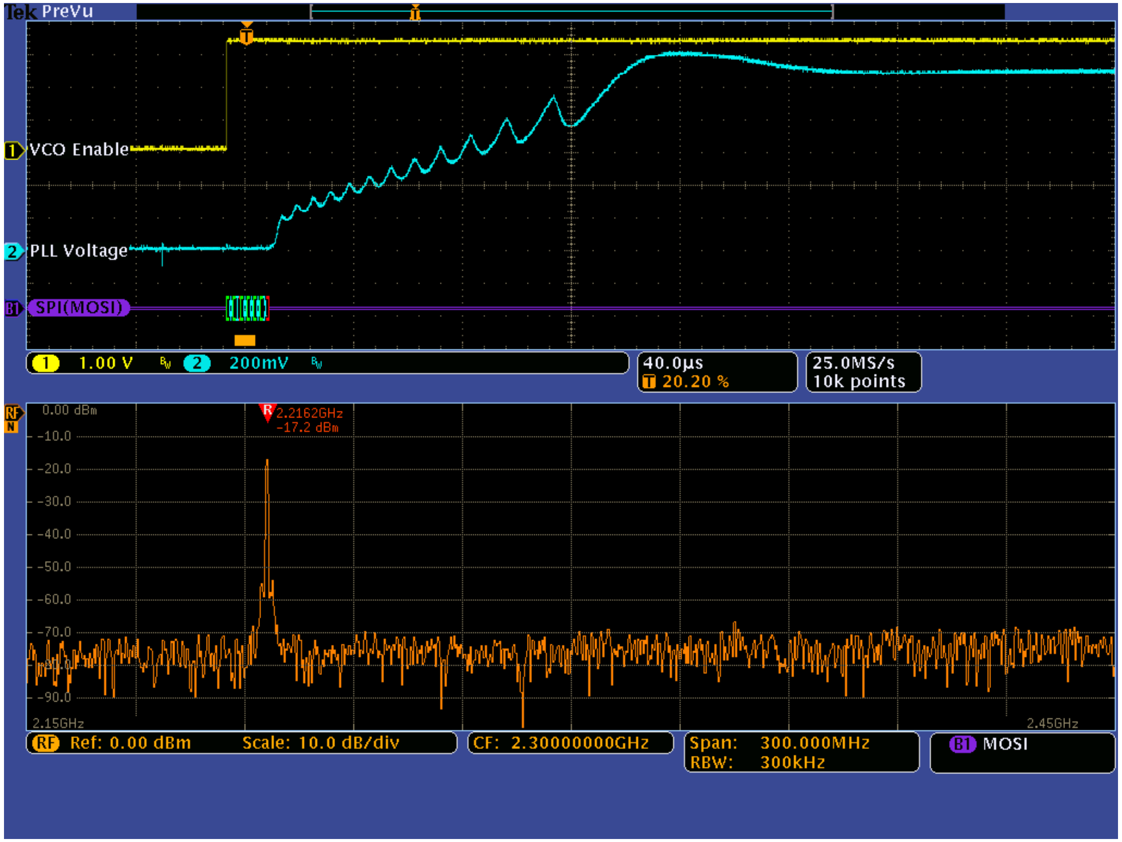
Troubleshooting turn-on of the system

VCO example - one can look at the time and the frequency domain at the same time. See as the PLL voltage reaches its programmed voltage, the oscillator tunes to the 2.4GHz. Check turn-on behavior of the system at the RF level

Tektronix MDO can show how digital and analog signal issues may turn into RF problems

Test Setup:

- Analog Ch-1: VCO Enable
- Analog Ch-2: PLL Voltage
- Digital channels 0-2: SPI command bus – command signal to tune the VCO to 2.4GHz
- RF channel: VCO output signal



Tektronix MDO4000 Series

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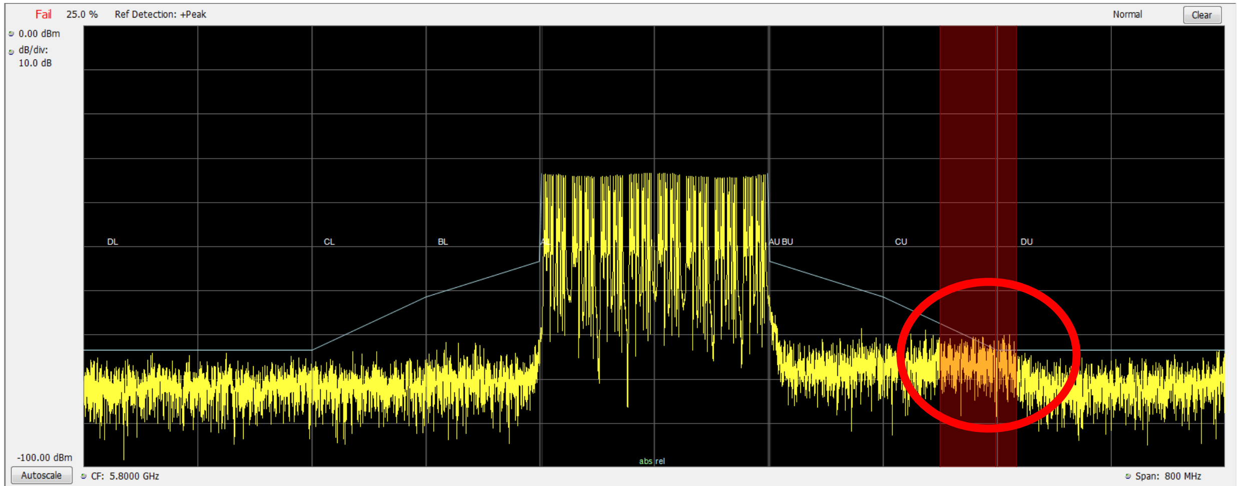
Troubleshooting a WLAN Spectrum Emission Failure



Ref: Peak

-33.37 dBm

Row	Offset	Start Freq	Stop Freq	Peak Abs	Margin Abs	Peak Rel	Margin Rel	@Freq	Integ Abs	Integ Rel
6	BU	81.000 MHz	160.000 MHz	-63.71 dBm	-- dB	-30.34 dB	-10.31 dB	81.307692 MHz	-46.73 dBm	-13.36 dB
7	CU	160.000 MHz	240.000 MHz	-61.80 dBm	-- dB	-28.44 dB	5.56 dB	200.000000 MHz	-47.39 dBm	-14.02 dB
8	DU	240.000 MHz	400.000 MHz	-69.97 dBm	-- dB	-36.60 dB	3.40 dB	248.846154 MHz	-48.77 dBm	-15.40 dB

- Observe the mask failure in SignalVu-PC
- Use spectrum to correlate mask violations to system transients
- Use cursors in SignalVu-PC to capture when event happened
  - If necessary, use EVM versus symbol and correlate violations
- Cross reference to MDO RF and use oscilloscope functionality to troubleshoot system transients on the digital/analog side

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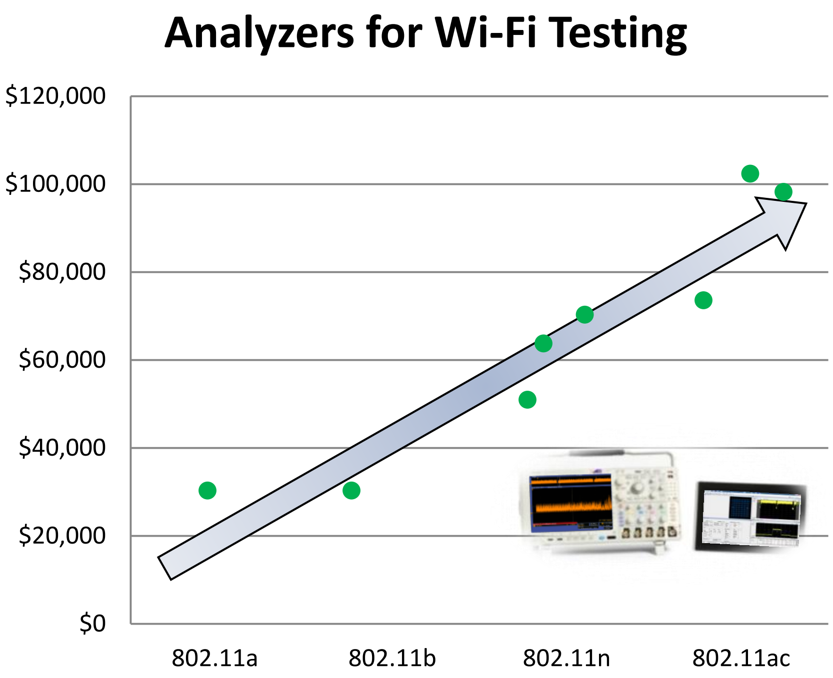
Wi-Fi Test Solutions requirements

- Wi-Fi system integrators don't have an easy path to integration
  - Requires RF know-how
  - Requires WLAN Pre-compliance
  - Requires new T&M purchase
- Cost of test equipment is high
  - RF performance drives price, e.g. bandwidth, phase noise, dynamic range
- T&M suppliers don't offer a Wi-Fi testing cost effective solution
- T&M suppliers don't offer a Wi-Fi testing that is simple to use for scope users



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Simple and Affordable WLAN Pre-Compliance Solution

- Industry’s best price point
- Multiple instruments in 1 box
  - Oscilloscope, Logic Analyzer, Spectrum Analyzer, extensible to Vector Signal Analyzer
- Complete WLAN pre-compliance spectrum emission mask coverage (ease of use)
- If you know time domain, you can operate an MDO (ease of use)
- System-level troubleshooting capabilities (ease of use)
  - Time correlated spectrum analyzer, oscilloscope and logic analyzer
  - Time correlated vector measurements
- Portability for taking instrument onsite to regulatory test lab and to customers for demonstration (portability / footprint)

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Online Resources

- WiFi PHY Transmitter measurements
  http://www.cnrood.com/public/docs/WiFi_Physical_Layer_and_Transm_Meas.pdf
- Current 802.11 standard definition: IEEE Std 802.11-2012
  - Includes amendments a – z (but NOT ac or ad!)
    - http://standards.ieee.org/getieee802/download/802.11-2012.pdf
  - 802.11ac in final approval stages: IEEE P802.11ac/D6.0
    - Draft document currently only available to WG committee members
    - Scheduled for final approval in February 2014
- 802.11ad amendment approved 12/2012: IEEE Std 802.12ad-2012
  - http://standards.ieee.org/getieee802/download/802.11ad-2012.pdf