Faster, Better and Cheaper Ways to Test Today’s Wireless Devices

Agenda

– The World is Connecting: the need for RF test
  – RF testing background
  – Make your testing faster
  – Make your testing better
  – Make your testing less expensive
  – Keysight can help
Wireless Device Market Predictions

• Industry hyperbole are based on cumulative installed base e.g. 50B by 2020, 95B by 2025
• Keysight addressable market linked to yearly hardware shipment volumes – growth still impressive
• Industry volume could double in 5 years, triple in 7 years

Other things

Preliminary data

Smartphones, feature phones, tablets and PCs
Wireless Connectivity for the Internet of Things

A single wireless technology can not accommodate the diverse need of IoT markets

Smart Home
- Security & alarm
- Light control
- HVAC control
- Remote control
- Door control
- Energy efficiency
- Entertainment
- Appliances

Wearables
- Health monitor
- Fitness trackers
- Smart watch
- Smart glasses
- Smart bands
- E-textiles
- Hearing-aid

Smart City
- Traffic management
- Water distribution
- Waste management
- Security
- Lighting
- Environmental monitoring
- Infrastructure
- Parking sensor

Industry Automation
- Smart machine
- Surveillance camera
- Factory automation
- Asset tracking
- Logistics and optimization of supply chain

Smart Energy
- Generation & trading
- Transmission
- Distribution & metering
- Storage
- Services

Connected Car
- V2V / V2X / V2I communications
- eCall
- Infotainment
- Traffic control
- Navigation
- Autonomous vehicles
- Maintenance

Internet of Things
Interference

Popular Frequency Use

<table>
<thead>
<tr>
<th>MHz</th>
<th>54-698</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.56</td>
<td>169</td>
</tr>
<tr>
<td>315</td>
<td>426</td>
</tr>
</tbody>
</table>

- NFC/EMV
- Wireless M-Bus
- China WMRNET
- LoRa
- SIGFOX
- Telensa
- OnRamp
- Wi-SUN
- Zigbee
- Thread
- WirelessHART
- ISA100.11a
- Z-Wave
- EnOcean
- ANT+
- Bluetooth
- 802.11a/b/g/n/ac
- 802.11ah
- 802.11p
- 802.11af
- Positive Train Ctrl
Aspects of the Connected Car

Telematics
• Vehicle Tracking
• Fleet Management
• Navigation
• Diagnostics
• Battery State
• Safety
• V2X
• Eco Driving

Infotainment
• Broadcast Radio
• Digital Radio/TV
• Social Networking
• Web Browsing
• Email
• Bluetooth

Advanced Capabilities
• ADAS (Advanced Driver Assist Systems)
• SDC (Self Driving Cars)
Technologies for IoT and Connected Car

WLAN:
- 802.11p (automotive)
- 802.11ah (low power)
- 802.11ac (high throughput)

Connectivity:
- Bluetooth®
- Zigbee

Cellular:
- cdma2000
- W-CDMA
- TD-SCDMA
- LTE / LTE-Advanced

Match the technology to the need
The Need for RF Test

With \(50B\) of “Things” connecting by 2020, \(95B\) by 2025

- How do we ensure devices play well together?
- How do we ensure devices will work in a wide range of (RF) environments?

- How do we do this quickly and inexpensively given the volumes of products and consumer cost demands?
Agenda

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– RF testing background: Tending to new manufacturing test tech.

– Make your testing faster

– Make your testing better

– Make your testing less expensive

– Keysight can help
Test Occurs Throughout the Product Lifecycle
Each Phase has Unique Test Needs

Product Development

- Design/develop device with desired parameters such as:
  - Leading edge technology features
  - Long battery life
  - Low cost

Ensure device will work in a variety of user environments

Conformance Testing

- In cellular:
  - Ensure device conforms to standards / network requirements
- In WLAN / unlicensed bands:
  - Ensure device will meet applicable FCC/ETSI (or other regulatory authority) standards

Production Test

- Final device calibration, if required
- Verification that no manufacturing defects are present

Design/develop device with desired parameters such as:

- Leading edge technology features
- Long battery life
- Low cost

Ensure device will work in a variety of user environments

Faster Better Cheaper Ways to Test Wireless Devices
Test Occurs Throughout the Product Lifecycle
Test Cost / Test Systems Needed

Product Development → Conformance Testing → Production Test

<table>
<thead>
<tr>
<th>Produce</th>
<th>$</th>
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<tbody>
<tr>
<td>10</td>
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</tr>
<tr>
<td>10,000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Faster Better Cheaper Ways to Test Wireless Devices

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As devices gained in complexity...
Test times, and costs, rocketed higher
New Techniques were needed
To slow and reverse the trend

New manufacturing test techniques
  • Non-signaling
  • Fast-sequenced non-signaling
Signaling => Non-signaling => Fast Sequenced NS
WLAN Sequencer Example—Multiple Packet Sequence

| 5.18GHz 802.11ac 80MHz | 5.28GHz 802.11n 20MHz | 5.18GHz 802.11a 54Mbps |

Sequence Analyzer

Acquisition 1

Step 1 for power

Step 2 for EVM

Acquisition 2

Step 1 for power

Step 2 for EVM

Acquisition 3

Step 1 for power

Step 2 for EVM

Step 1 for power

Step 2 for EVM

Step 1 for power

Step 2 for EVM
Agenda

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– Make your testing faster : *Minimize test equipment idle time*
– Make your testing better
– Make your testing less expensive
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Make Your Testing Faster
What Matters to Test Speed?

- Chipset test Capabilities
- Test equipment Capabilities & Speed
- Test Techniques
- How much you test
Chipset Test Capabilities

What can you do?

– Select chipsets with fast test modes
– Ensure you have access to chipset control modes
Test Equipment Speed

What matters?

- Measurement and analysis speed
- Computer/processor horsepower and the *ability for future upgrades*
- Ensure your test equipment is able to use the fastest chipset test modes (e.g. high speed source and analyzer sequencer capability)
Test Scenario for Single Insertion Multi-format Testing

Connect 1 device per TRX
(1 Tx/Rx & 1 Rx for cellular, 1 Tx/Rx for WiCON, 1 Rx for GNSS)

Faster Better Cheaper Ways to Test Wireless Devices
Test Scenario for Ping-Pong

Summary:
Connect 4 two-antenna DUTs
Test these while connecting 4 additional DUTs
repeat
Improve Test Efficiency with Ping-Pong

Favored Technique when:
Test time $\approx$ load/unload time

Requirements:
Availability of extra calibrated I/O connections
Test Scenario for Pipeline

Serial Test: 2 DUTs

Pipeline: test DUT1 Tx, DUT2 Rx in parallel; then swap

Summary:
DUT1 Rx is tested while DUT2 Tx is tested
I/O is switched then
DUT1 Tx is tested while DUT2 Rx is tested

Faster Better
Cheaper Ways to
Test Wireless
Devices
Improve Test Efficiency with Pipeline

Favored Technique when: Tx test time \(\approx\) Rx test time

Requirements:
- Independent source/receiver operation
- Good port isolation

Serial Test: 2 DUTs

Pipeline: test DUT1 Tx, DUT2 Rx in parallel; then swap

Time saved
Combination: Ping Pong & Pipeline

Connect 16 single antenna DUT, Ping Pong + Pipeline

DUT1/DUT2 Pipeline
DUT3/DUT4 Pipeline

Boot up
WiCon Cal
WiCon Tx
WiCon Rx

TRX1

DUT 1
Boot Cal Tx Rx
Unload / Load

DUT 2
Boot Cal Tx Rx
Unload / Load

DUT 3
Unload / Load Boot Cal Tx Rx

DUT 4
Unload / Load Boot Cal Tx Rx

Faster Better
Cheaper Ways to
Test Wireless
Devices

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Test Scenario for Smart Scheduling Instrument (SSI)

Advanced test efficiency improvement by minimizing the instrument idle time

- Overlap test processes/non-instrument test steps as much as we can
- Dynamically schedule the instrument execution across multi-DUT

Has demonstrated a 30% test time reduction

TRX1 with SSI

Test Time

Test 4 DUTs w/o SSI

Test 4 DUTs w/ SSI

Faster Better
Cheaper Ways to Test Wireless Devices

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Test Multi-DUTs with Single TRX
Test Multi-DUTs with Single TRX

**Ping-Pong**

- **DUT 1**: Boot → Cal → Tx → Rx → Unload / Load → Boot → Cal → Tx → Rx
- **DUT 2**: Unload / Load → Boot → Cal → Tx → Rx → Unload / Load

**WiFi Device as Example**

**Pipeline**

- **DUT1 RFIO3**: Boot-DUT1 → Tx-DUT1 → Rx-DUT1 → Boot/DUT2 → Tx-DUT2 → Rx-DUT2
- **DUT2 RFIO4**: Boot/DUT2 → Rx-DUT2 → Tx-DUT2
- **DUT1 RFIO3**: Boot-DUT1 → Tx-DUT1 → Rx-DUT1
- **DUT2 RFIO4**: Boot/DUT2 → Rx-DUT2 → Tx-DUT2
- **DUT1 RFIO3**: Boot-DUT1 → Tx CAL → Tx-DUT1 → Rx-DUT1
- **DUT2 RFIO4**: Boot/DUT2 → Rx-DUT2 → Tx CAL → Tx-DUT2

*Time saved*

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Test Multi-DUTs with Single TRX

Smart Scheduling Instrument (SSI)

TRX1 with SSI

<table>
<thead>
<tr>
<th>DUT 1</th>
<th>Boot</th>
<th>DUT Config</th>
<th>Inst Exec</th>
<th>DUT Config</th>
<th>Inst Exec</th>
<th>DUT Config</th>
</tr>
</thead>
<tbody>
<tr>
<td>DUT 2</td>
<td>Boot</td>
<td>DUT Config</td>
<td>Inst Exec</td>
<td>DUT Config</td>
<td>Inst Exec</td>
<td>DUT Config</td>
</tr>
<tr>
<td>DUT 3</td>
<td>Boot</td>
<td>DUT Config</td>
<td>Inst Exec</td>
<td>DUT Config</td>
<td>Inst Exec</td>
<td>DUT Config</td>
</tr>
<tr>
<td>DUT 4</td>
<td>Boot</td>
<td>DUT Config</td>
<td>Inst Exec</td>
<td>DUT Config</td>
<td>Inst Exec</td>
<td></td>
</tr>
</tbody>
</table>

Inst. Timeframe
Test techniques for increased throughput

Summary

How much you test:

Chipset Test Capability:
  • Select chipsets with fastest test modes

Test Equipment Capability:
  • Computer/processor horsepower and the ability for future upgrades
  • Ensure your test equipment is capable if utilizing the fastest chipset test modes

Test Techniques:
  • Optimize throughput based on device test needs
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– Make your testing better: Take into account measurement uncertainty
– Make your testing less expensive
– Keysight can help
Are you getting maximum yield?
Can you get more yield by making your test better?

For example:

What do you gain if you can measure your device with an uncertainty of ±0.3 dB instead of ±1.0 dB?

To simplify the example, let’s say you are making a single channel power measurement on your device, and the specified power is –

-5.0 dBm ±2.0 dB

This means your device will pass if it is between -7.0 dBm and -3.0 dBm
What is your yield?

Distribution of devices coming off the production line

Most processes of this type will produce a “normal” distribution across the range of measured performance.

-7 dBm  -5 dBm  -3 dBm

Yield
The opposite of yield is...bad product
Distribution of devices coming off the production line

“Bad product” is what falls outside this range
Impact of Measurement Uncertainty

You must take into account *measurement uncertainty*

A large measurement uncertainty increases the amount of “bad” product. It’s not really bad product, but you don’t know that!

For example:

If your measurement uncertainty is ±1.0dB

Then when you measure -7 dBm the actual device performance could be anywhere from -8 dBm to -6 dBm!

*To ensure your product meets spec, you must add a measurement uncertainty band to your test limit.*
Impact of Measurement Uncertainty

You must take into account *measurement uncertainty*

A large measurement uncertainty increases the amount of “bad” product. It’s not really bad product, but you don’t know that!

-7 dBm  -5 dBm  -3 dBm

Yield

Measurement Uncertainty

Measurement Uncertainty

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Impact of Measurement Uncertainty

You must take into account *measurement uncertainty*

A large measurement uncertainty increases the amount of “bad” product. It’s not really bad product, but you don’t know that!

-7 dBm  -5 dBm  -3 dBm
Make Your Testing Better

What if you reduce your *measurement uncertainty*?

If you can reduce your measurement uncertainty, you can reduce the amount of good product that does not pass.

For example:

If your measurement uncertainty is ±0.3 dB

Then when you measure -7 dBm the actual measurement would be anywhere from -7.3 dBm to -6.7 dBm.
Make Your Testing Better
With a smaller measurement uncertainty...

You pass more *good* product!
Reducing measurement uncertainty = Yield improvement = Less Bad Product

±1.0 dB meas uncertainty

±0.3 dB meas uncertainty

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– Make your testing less expensive : Minimize CoT
– Keysight can help
### Make your testing less expensive

What elements go into the cost of test?

<table>
<thead>
<tr>
<th>Development / Capex costs:</th>
<th>On-going costs:</th>
</tr>
</thead>
<tbody>
<tr>
<td>– Software applications</td>
<td>– Floor space</td>
</tr>
<tr>
<td>– RF test equipment</td>
<td>– Power consumption</td>
</tr>
<tr>
<td>– Other equipment (e.g. computer, power supplies)</td>
<td>– Warranty/support</td>
</tr>
<tr>
<td>– Materials (e.g. racks, switching, cabling)</td>
<td>– Test operator costs</td>
</tr>
<tr>
<td>– Test software development</td>
<td></td>
</tr>
</tbody>
</table>
Make your testing less expensive

But it is not just the *cost* side

\[
\text{Development / Capex costs} + \text{On-going costs} \over \text{Devices tested per hour} = \text{CoT}
\]

You know how to pencil the math –

– If your Development, Capex, and On-going costs are cut in HALF

– AND your Devices tested per hour is also cut in half

– Does Cost of Test (CoT) change?
Make your testing less expensive
What you really want to do is this...

Increase

Devices tested per hour

Decrease or Flat or Smaller

Development / Capex costs

Increase

On-going costs
Make your testing less expensive
Spend your money wisely...

Development / Capex costs:

– Software applications
  • Are the measurements I need included?
  • Am I paying for anything I don’t need?
  • How many equivalent testers will one license cover?

– RF test equipment
  • Are the test equipment specs going to meet my yield needs?
  • Is the equipment easily scalable / expandable as my production needs change?
  • Is the equipment flexible so I can use approaches to speed up testing?
  • Can I use the equipment for testing a variety of formats? i.e. will the equipment reduce future Capex?
Make your testing less expensive
Spend your money wisely...

Development / Capex costs:

– Other equipment (e.g. computer, power supplies)
  • Do you need an external PC or does the RF test set offer a built in PC for testing?

– Materials (e.g. racks, switching, cabling)
  • Can you purchase test equipment that will minimize the other material you need to buy (e.g. built in switching)?

– Test software development
  • Is turnkey test software available?
  • Is test software development assistance available?
Make your testing less expensive

Bottom Line

Understand your company’s needs and trade-offs so that you can minimize your Cost of Test

\[
\text{Development / Capex costs } + \text{ On-going costs } = \text{ CoT}
\]

\[
\frac{\text{Devices tested per hour}}{\text{Devices tested per hour}}
\]
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– Keysight can help : Hardware + Software + People
Vector Signal Analysis and Generation

**Benchtop**
- X-Series SA
- X-Series SG

**Modular**
- M9421A VXT

**One-Box Tester (OBT)**
- E6640A EXM

**Today’s Focus**

**Low Cost SA/SS:** N9320B/22C SA N9310A SS

**Automation software**
- SCPI

**Signal Studio**

**X-Series Applications**

**89600 VSA Software**
E6640A EXM Wireless Test Set
Solve today, evolve tomorrow

Ramp up rapidly & optimize full volume production
Solve Today, Evolve Tomorrow
Ramp up rapidly & optimize full-volume manufacturing

Ultimate Scalability & Port Density
Multi-TRX, multi-port OBT
Up to 6 GHz, 160 MHz BW

Brodest Multi-Format Coverage
LTE-Advanced
802.11ac WLAN
MIMO & more

Highest Throughput & Yield
Fastest, most accurate parallel Multi-DUT test

In sync with the latest chipsets and backed by expert manufacturing test integration engineers
E6640A EXM Wireless Test Set

Tailor your TRX’s frequency range

<table>
<thead>
<tr>
<th>Option</th>
<th>Frequency Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellular Bands (Opt 504)</td>
<td>380 MHz - 3.8 GHz</td>
</tr>
<tr>
<td>WiCon Bands (Opt 5WC)</td>
<td>1.1-1.8 GHz, 2.3-2.6 GHz, 4.8-6 GHz</td>
</tr>
<tr>
<td>Cellular &amp; WiCon Bands (Opt 506)</td>
<td>380 MHz - 6 GHz</td>
</tr>
</tbody>
</table>

Tailor your TRX’s measurement bandwidth

<table>
<thead>
<tr>
<th>Option</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>40 MHz</td>
</tr>
<tr>
<td>Opt B85</td>
<td>80 MHz</td>
</tr>
<tr>
<td>Opt B1X</td>
<td>160 MHz</td>
</tr>
</tbody>
</table>

Frequency range and bandwidth are license-key field upgradable
Ultimate Scalability & Port Density
Platform overview

Up to 4 independent TRX in compact 4U space
- Each is a fully calibrated VSA/VSG with self-contained RFIO
- 2 full-duplex, 2 half-duplex or 4 full-duplex ports
- Up to 6 GHz with 160-MHz bandwidth on each TRX
- Rugged N-Type RF connectors designed for mfg. environment

Add additional TRX (up to 4 per mainframe) when you need to expand production.
E6640A EXM Wireless Test Set

- Ultimate Scalability and Port Density
- Broadest Multi-Format Coverage
- Highest Throughput and Yield

**Cellular**
- LTE-Advanced FDD/TDD, LTE FDD/TDD, CAT-0
- HSPA+, W-CDMA
- 1xEV-DO, cdma2000
- GSM/EDGE/EDGE Evo
- TD-SCDMA/TD-HSPA
- DECT, PHS

**Wireless Connectivity**
- WLAN 802.11a/b/g/n/j/p/ac/ah/af
- Bluetooth 1.0 to 4.2, Bluetooth Low Energy (BLE)
- ZigBee, Z-Wave
- Multi-Satellite GNSS: GPS, Galileo, GLONASS, Beidou, SBAS, QZSS
- Mobile WiMAX
- Digital video, FM

**FAST**
- SAMM, SSI, High Speed Sequencer

**ACCURATE**
- Best in class amplitude accuracy
- Best in class EVM

**MIMO (2x2, 3x3, 4x4) & carrier aggregation**
- Switched MIMO for manufacturing test
- True MIMO (multi-TRX) for design validation
- LTE-A CA Inter- and intra-band
Bluetooth Test Solution

Basic Rate

N9081A Tx Demodulation

Low Energy

Up to 255 Octets (2040 bits)

N7606B Rx Signal
ZigBee/Z-Wave/Thread/WiSUN Test

N9064A Tx Demodulation

N7610B Rx Signal
802.11a/b/g/n/ac/p/ah Test Solution

N9077B Tx Demodulation

N7617B Rx Signal
EXM Reference Solution for “massive parallelism”

- 1 E6640A/EXM with 4 TRX modules
- Each TRX module connects to up to 4 devices
- Each PC runs automation with 1 TRX module to test up to 4 devices
Questions?

Thank you!

Faster Better Cheaper Ways to Test Wireless Devices