Bluetooth™ Manufacturing Test

April 23, 2002

presented by:

Brian Fetz

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Introduction

- Special Considerations for *Bluetooth*
- Test of Appliances and Radio Modules
- Managers and Manufacturing Test Engineers
- Considerations of Test, Test Plan, vs. Time
- 'Peel the Onion', Cost Sensitive Approach

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This presentation is focused on the manufacturing test requirements for Bluetooth enabled appliances as well as for the Bluetooth modules that may be used for enabling such appliances.

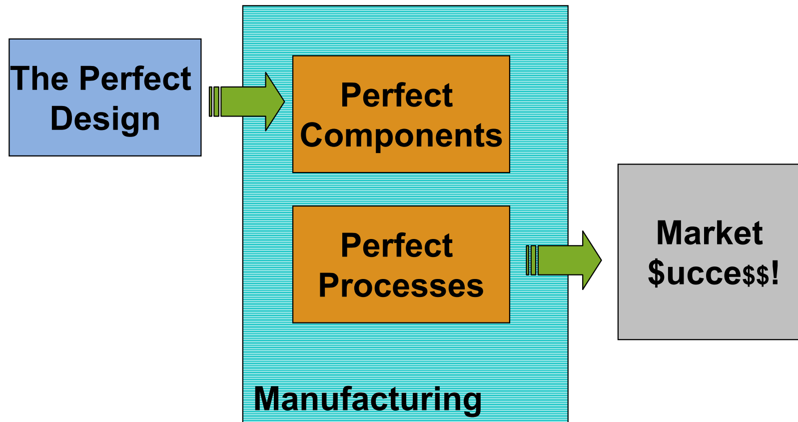
It is of particular interest for manufacturing test engineers and manufacturing managers who have responsibility for such appliances and modules. Though the presentation is focused on manufacturing of the higher level components of Bluetooth enabled products, it will also be of interest to Bluetooth IC vendors as there are many things that are said about them and how they and their products influence the direction one may take.

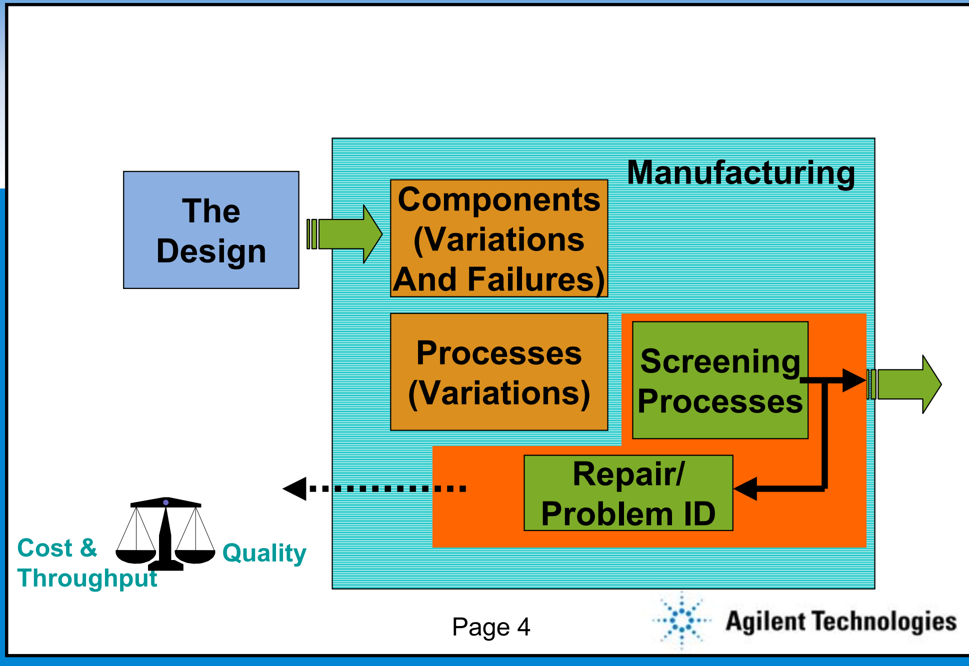
Much has been written about Bluetooth testing and what has falls into largely two categories---detailed write-ups describing particular tests and their equipment needs and those that are fairly superficial that suggest one should test and that one should select tests wisely. Little guidance is given on picking the methodology of a test or even how best to know you should. I aim to deliver on an approach that if followed will go through an exhaustive consideration of test, AND ultimately be sued to synthesize a test plan, and furthermore, show briefly how that test plan may change over time.

Is Bluetooth special? Yes---it is an RF technology and it is supposed to be low cost with low power consumption AND there are a myriad of products and philosophies of those making those products.

The presentation today will be a 'peel the onion' approach to deriving the test plan--- we will start at a fairly high level that most of us will agree upon, and dig down through the many layers that have to be considered---In this approach, one will see that it is a cost sensitive approach which is something most of us are concerned about.

Perfect World




Real World
The Design
Manufacturing
Components (Variations And Failures)
Processes (Variations)
Screening Processes
Repair/ Problem ID
Cost & Throughput
Quality
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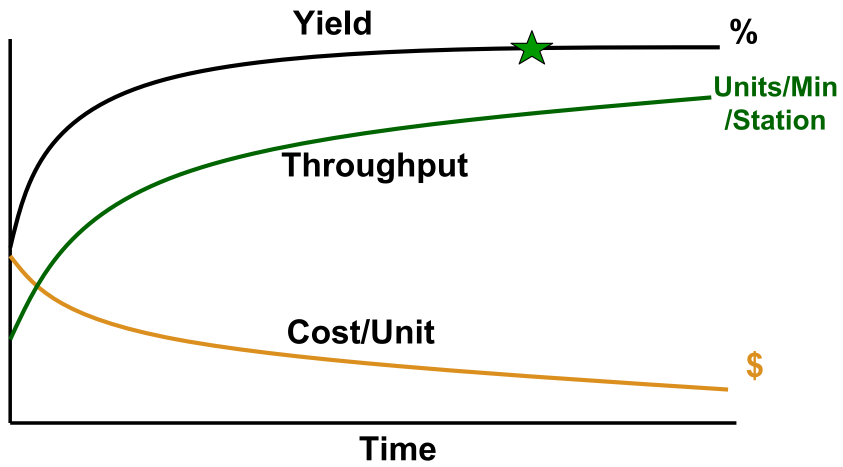
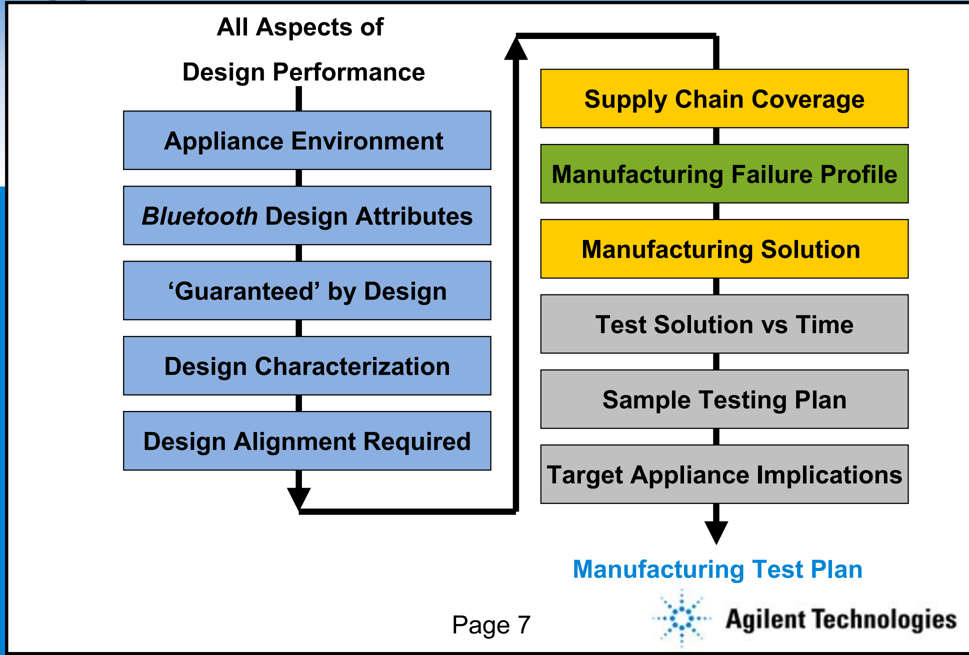
Key Manufacturing Objectives



To Achieve the Objectives

- Understand the Design
- Eliminate Part Failures and Reduce Variations
- Mitigate Process Variations

A comprehensive approach is necessary…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Survey of 'Aspects of Design Performance'

- SW 'Components'
- ✓ The SIG Tests
- ✓ Other Performance Tests
- ✓ Alignments Required
- ✓ Use Case Functionality
- Target Product Functionality

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Survey of ‘Aspects of Design Performance’

- SIG Qualification Tests
  - 9 Transmitter Tests
  - 6 Receiver Tests
  - 1 Regulatory Emissions Test

Meant for Product Qualification: Production Testing to provide confidence that product would pass Specification.

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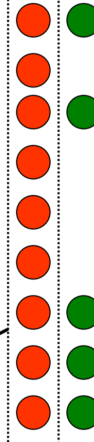
Survey of 'Aspects of Design Performance'

SIG Transmitter Tests

	Spectrum Analyzer	*Bluetooth* Testset
Maximum and Peak Output Power	●	●
Power Density	●	
Power Control	●	●
Output Spectrum: Frequency Range	●	
Output Spectrum: –20 dB Bandwidth	●	
Output Spectrum: Adj Channel Power	●	
Modulation Characteristics	●	●
Initial Carrier Frequency Tolerance	●	●
Carrier Frequency Drift	●	●



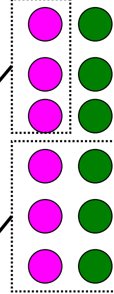
If Test mode LoopBack Mode used… another Radio is Required

Otherwise, Test Mode-Transmit or other proprietary method is required.

Survey of 'Aspects of Design Performance'

SIG Receiver Tests

- Sensitivity with Single Slot Packets
- Sensitivity with Multi-Slot Slot Packets
- Maximum Input Level
- Co&Adj Channel Interference
- Blocking Performance
- Intermodulation Performance



Only with specialized vendor specific Bluetooth Chip SW

Must Work Together

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Survey of 'Aspects of Design Performance'

Other Possible Tests

- Synthesizer Settling:
- Power Ramp:
- Current vs Operational Mode:
- Spectrum Analyzer- Freq Detection Mode
- Spectrum Analyzer - Zero span or RF Detector with Scope, or *Bluetooth* TestSet with Scope
- Battery Emulators

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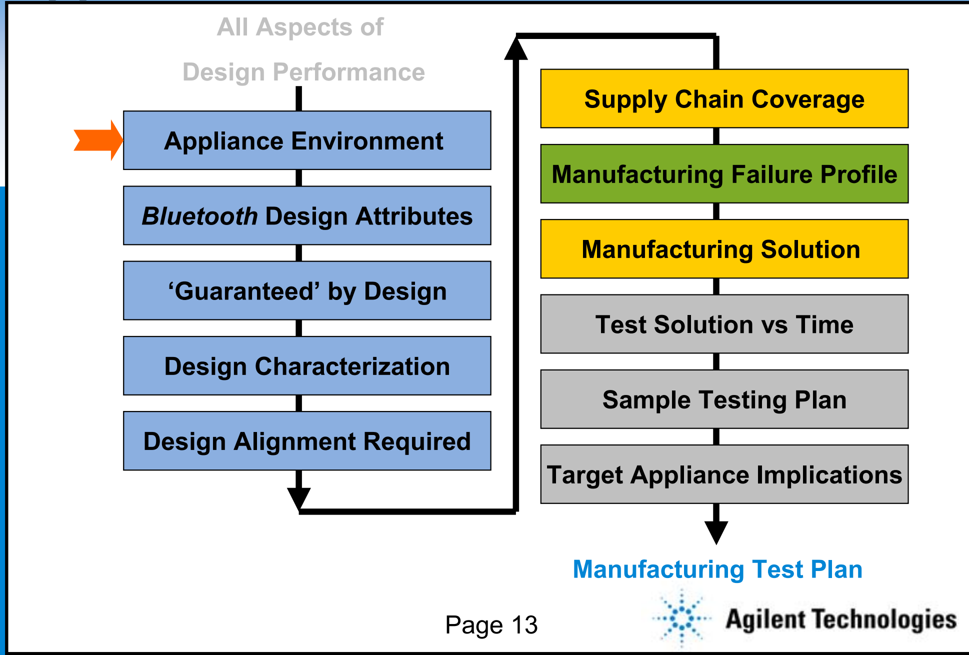
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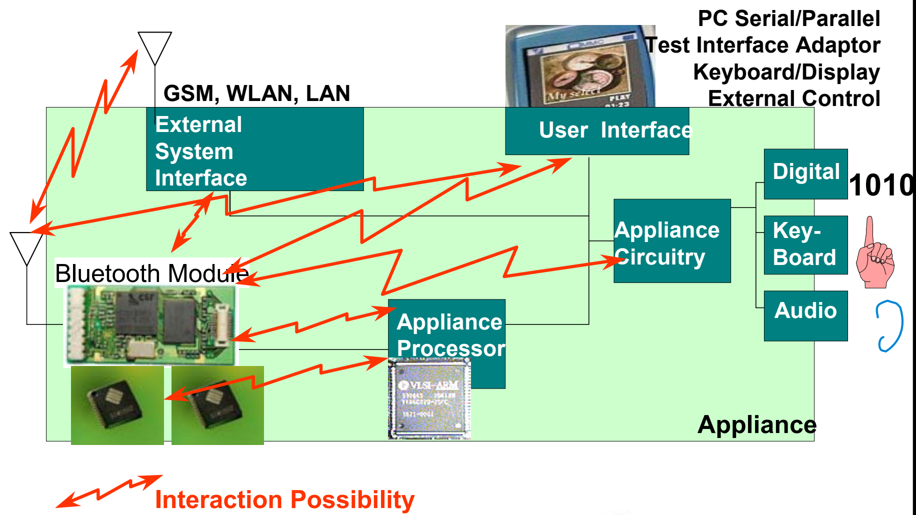
Appliance Environment



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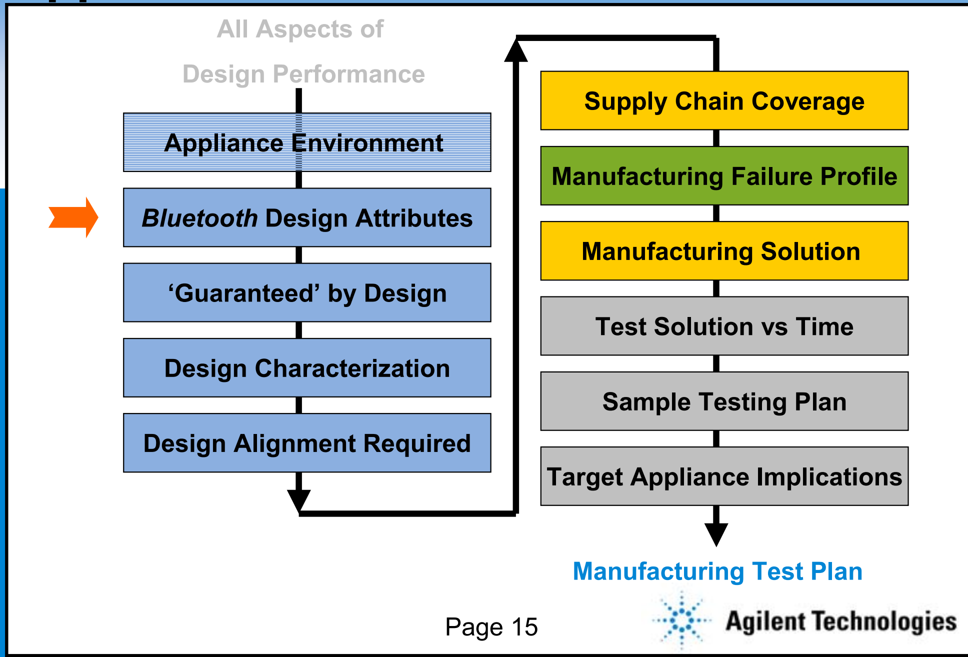

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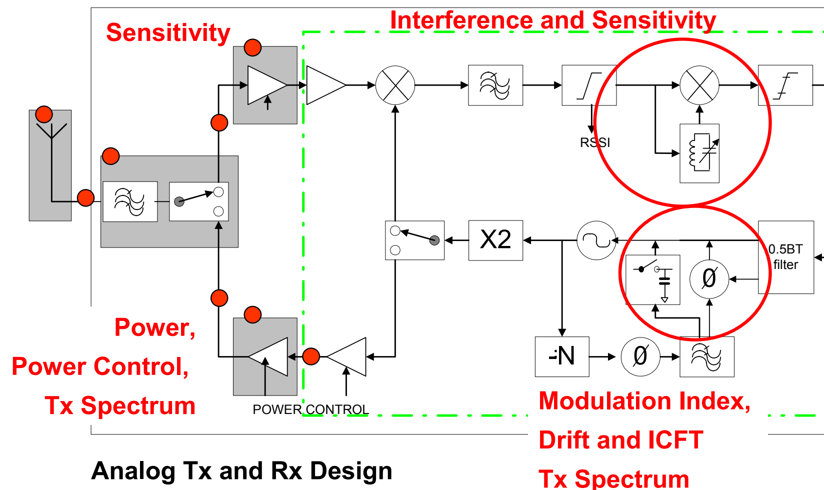
Bluetooth Design Attributes

- **Include Bluetooth Chips and Implementation**



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This diagram shows quite a bit of information, but there are three main areas to focus upon:

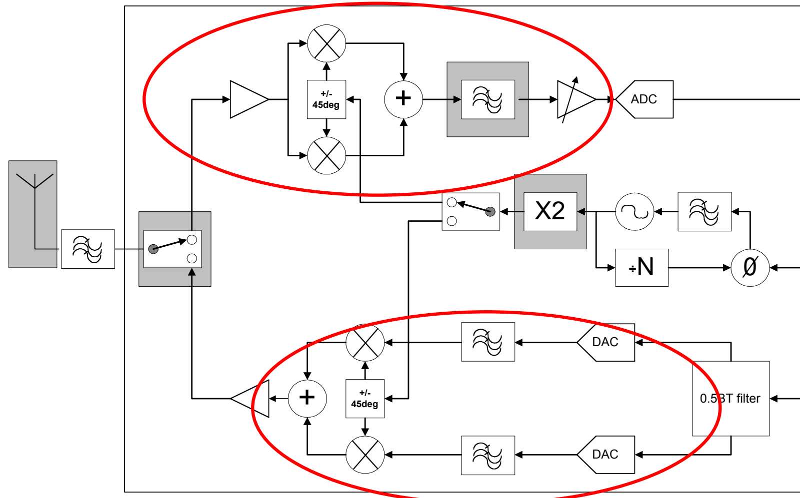
1. **Block Diagram of Design**
2. **Radio Partitioning—multi-ic or not. Locating the boundaries over which the specifications can be made**
3. **Process susceptibilities in the assembly of the radio**

In this diagram we see a direct modulation of a vco for the transmitter. These were probably the original expected implementation and these can have certain tendencies in performance. In those cases where the loop is opened during the transmit cycle, these can drift substantially and may have characteristics that change over frequency.

The red dots indicate issues in partitioning of the design. When different components are used—there are different interfaces which all increase likelihood of failure or extreme variation.

Of particular note that over the partitioning, the various parameters are affected differently. For instance, Sensitivity and Power Out parameters are dependent on absolute levels (in and out). Modulation characteristics are dependent on the Bluetooth transmitter alone (assuming no regulation issues). A Tx Spectrum performance may be split over the Bluetooth transmitter as well as the power amp IC (which may cause distortion)

Bluetooth Design Attributes



IQ TX and Rx Implementation

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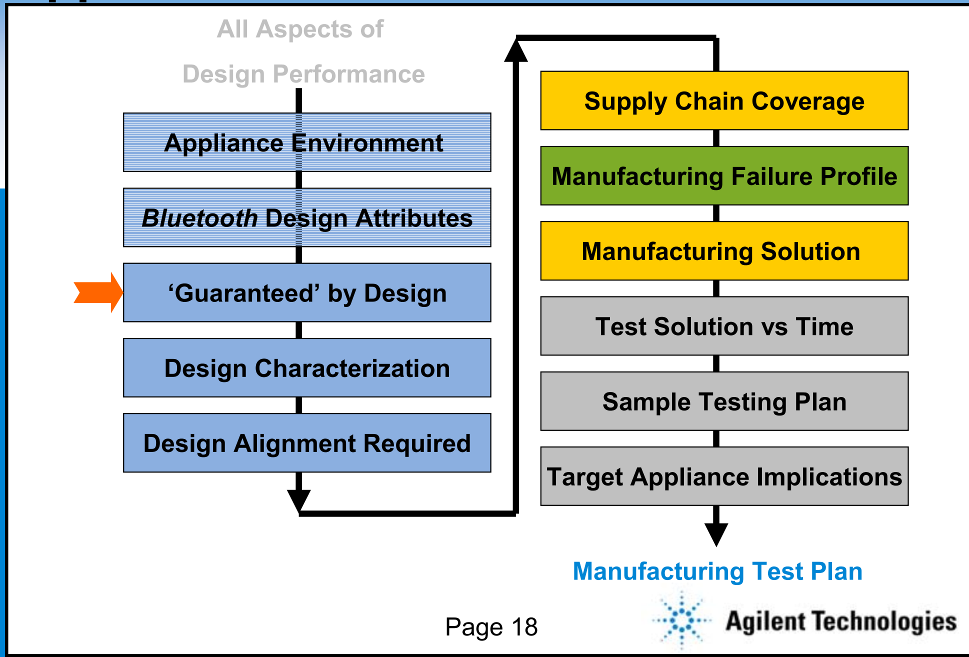
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‘Guaranteed’ by Design

- Nothing is 100%, however, certain assumptions or expectations may be made…
  - Broadband Spurious
  - Transmitter Spectrum
  - Intermodulation Performance
  - Blocking Performance
  - C/I Performance
  - Synthesizer Settling

Device Vendors are Key
May be Final Testing GOAL

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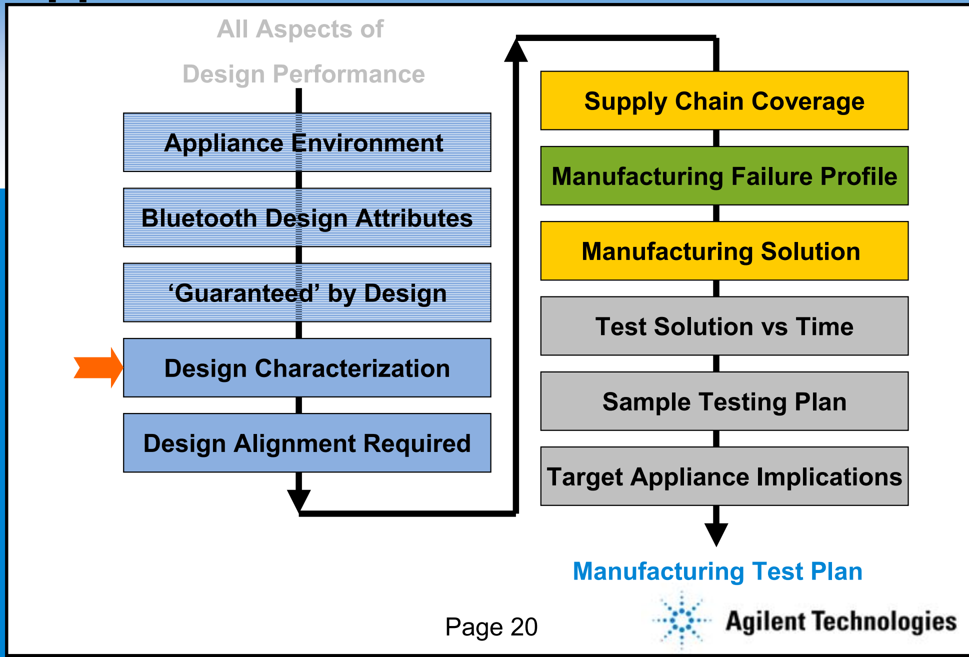

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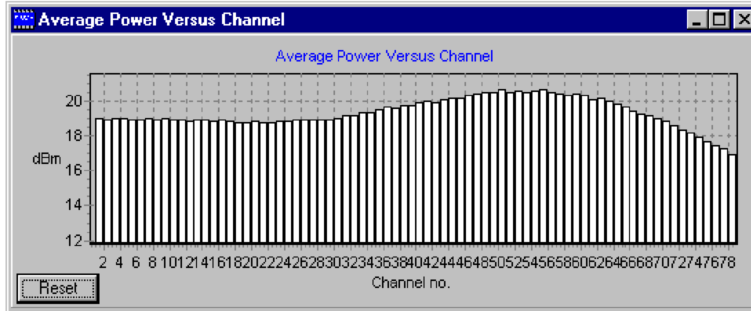
Bluetooth Design Characterization

- **Know What the Design Does!**

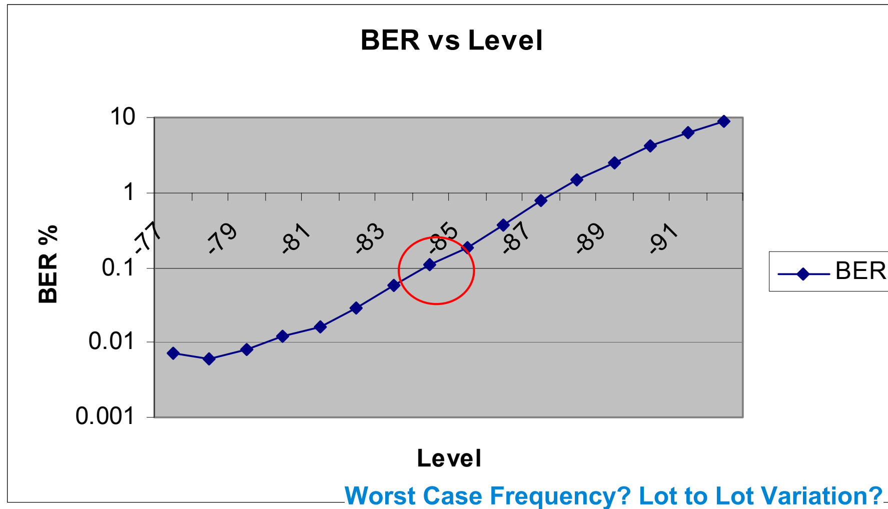
  Power vs Channel



Characteristic Curves Evident?

Bluetooth Design Characterization

Sensitivity vs Level: worst case frequency?



Worst Case Frequency? Lot to Lot Variation?

Bluetooth Design Characterization

- Other Opportunities
  - Modulation Performance vs Frequency
  - Sensitivity vs Impairment
  - Frequency Accuracy/Drift vs Frequency
  - Multi-slot vs Single Slot Sensitivity
  - Transmit Spectrum (–20 dB) vs Frequency
  - Correlations between measurements.
  - Battery emulation characteristics
  - Distributions of performance over lots

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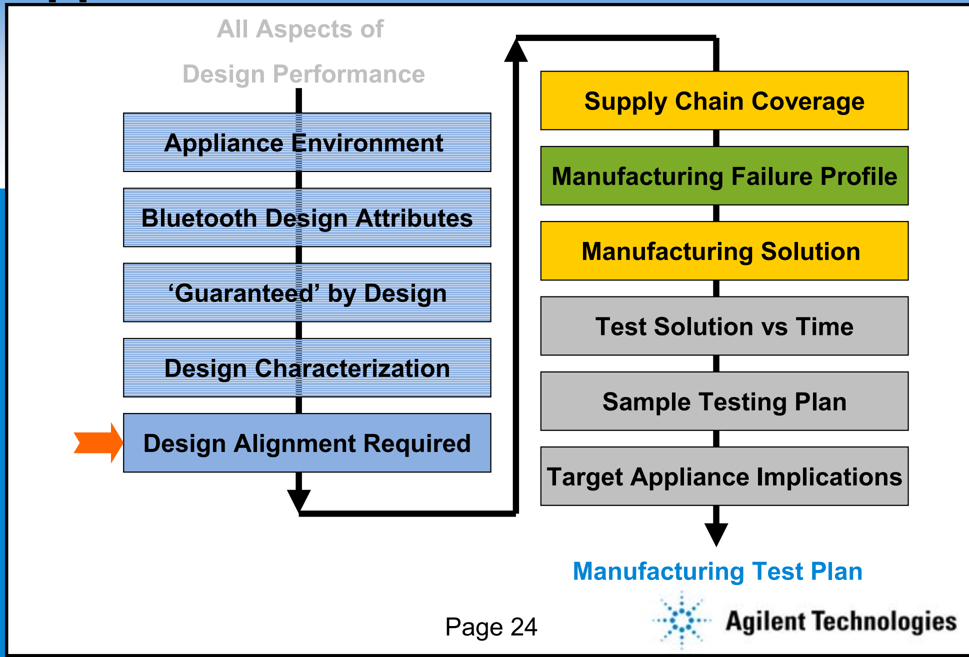
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Bluetooth Design Alignments

- Crystal Trim
- Transmitter
  - Power/Power Step
  - Modulation
- Receiver
  - RSSI
- Use Case and Component Dependent
  - Battery Power

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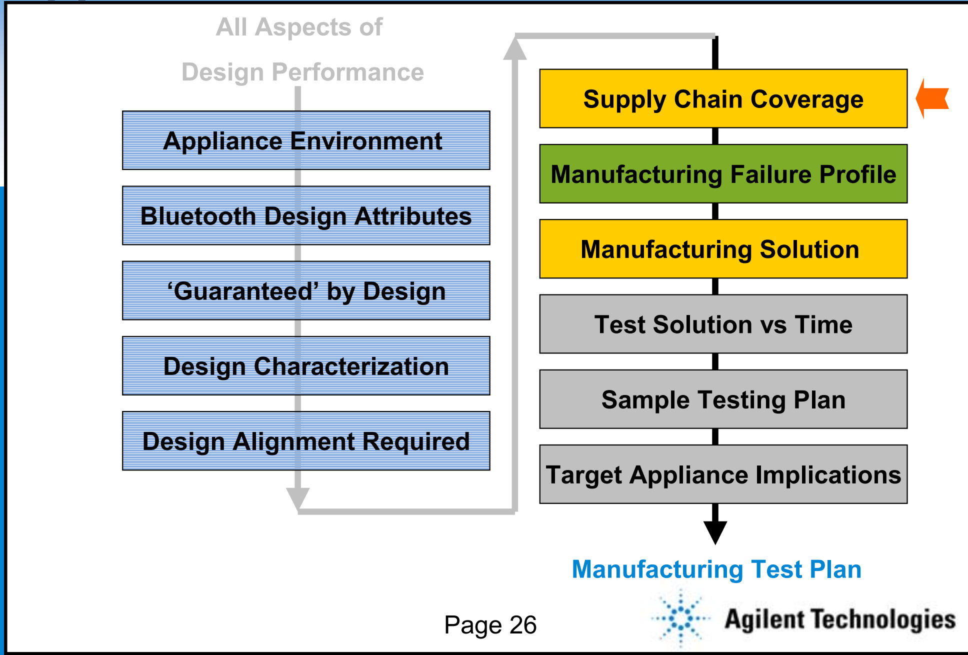
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Supply Chain Test Coverage

- Examine the Test Coverage of *Bluetooth* Vendors IC and Module Vendor (if appropriate).
- Understand Methodology Differences– they are testing physical parameters mostly.
- Discern Correlation with your implementation
- Create a Coverage Table/Matrix

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Supply Chain Test Coverage

Coverage Matrix

- **Strong Correlation**
- **Weak Correlation**
- **Alignment Required**

			Upstream Tests in the Supply Chain															
			IC Test															
		Alignment	Max Output Power vs Freq	Output Power Control	20 dB BW	Spurious Signal Generation:IB	Spurious Signal Generation:OB	FrequencySettling Time	Mod Char:Modulation Index	Mod Char:Initial Frequency Accuracy	Mod Char:Frequency Drift	Rx Intermodulation Distortion	Rx Interference:Blocking	Rx Interference:Co Channel	Rx Interference:Adj Channel	Rx Dynamic Range:Sensitivity	Rx Dynamic Range:Max Input Power	Digital and DC Tests
Alignment Tests																		
	Crystal Tuning	Y																
Performance Tests																		
	Power Output	Y	x															
	Power Control	N		x														
	Modulation Characteristics	Y			x				x									
	Initial Carrier Frequency	N						x		x								
	Carrier Frequency Drift	N									x							
	Sensitivity	N														x		
	RSSI	Y																
	Battery Current vs Operational M	N																x
	Frequency Settling	N						x										
	Pulse Shape	N						x										
	Output Spectrum	N			x													

Supply Chain Test Coverage

Coverage Matrix cont

- Strong Correlation
- Weak Correlation

			Upstream Tests in the Supply Chain															
			IC Test															
		Alignment	Max Output Power vs Freq	Output Power Control	20 dB BW	Spurious Signal Generation:IB	Spurious Signal Generation:OB	FrequencySettling Time	Mod Char:Modulation Index	Mod Char:Initial Frequency Accuracy	Mod Char:Frequency Drift	Rx Intermodulation Distortion	Rx Interference:Blocking	Rx Interference:Co Channel	Rx Interference:Adj Channel	Rx Dynamic Range:Sensitivity	Rx Dynamic Range:Max Input Power	Digital and DC Tests
Other SIG Tests	Maximum Usable Level	N															x	
	Output Spectrum Freq Range	N					x											
	Output Spectrum Adj Ch Power	N				x												
	Out of Band Spurious Emissions	N					x											
	Carrier/Interference Performance	N												x				
	Blocking Performance	N											x					
	Intermodulation Characteristics	N										x			x			
	Power Density	N			x													

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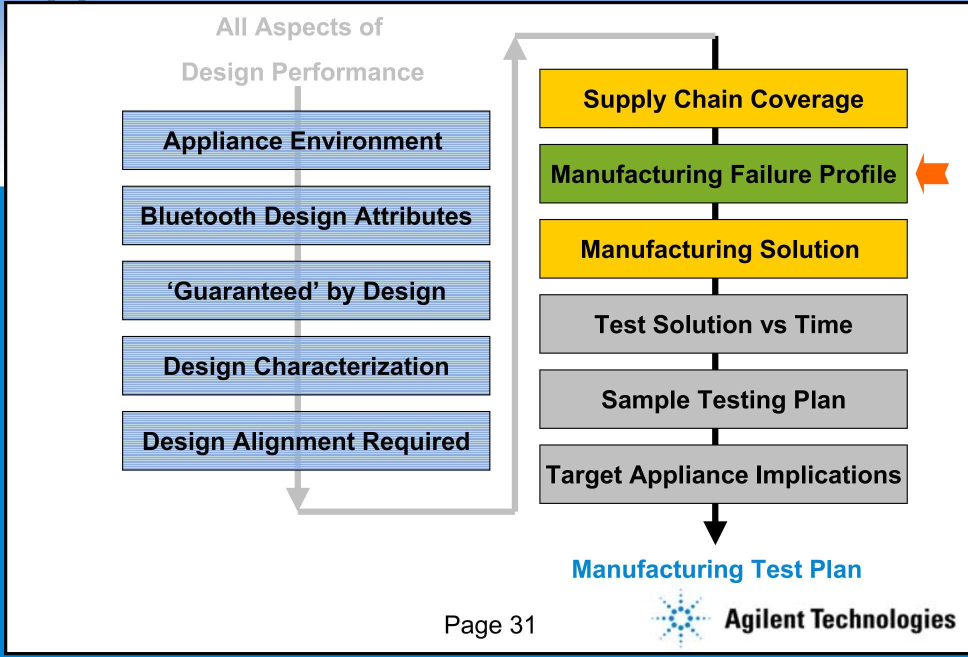
Supply Chain Test Coverage Summary

- When you are done doing this:
  - You have narrowed in on tests you must cover
  - You have begun to Identify candidate tests for reduction
  - Have Established coverage of many tests that you may drop quickly.
- Instrumentation-wise:
  - You have notion of Long Term solution goal
  - You know those tests that, if deleted, get biggest return—capital equipment and test time.



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Manufacturing Failure Profile

- Your assessment of what can go wrong in your manufacturing process.
  - Processes
  - Probabilities
  - Manifestations of Failure to Performance

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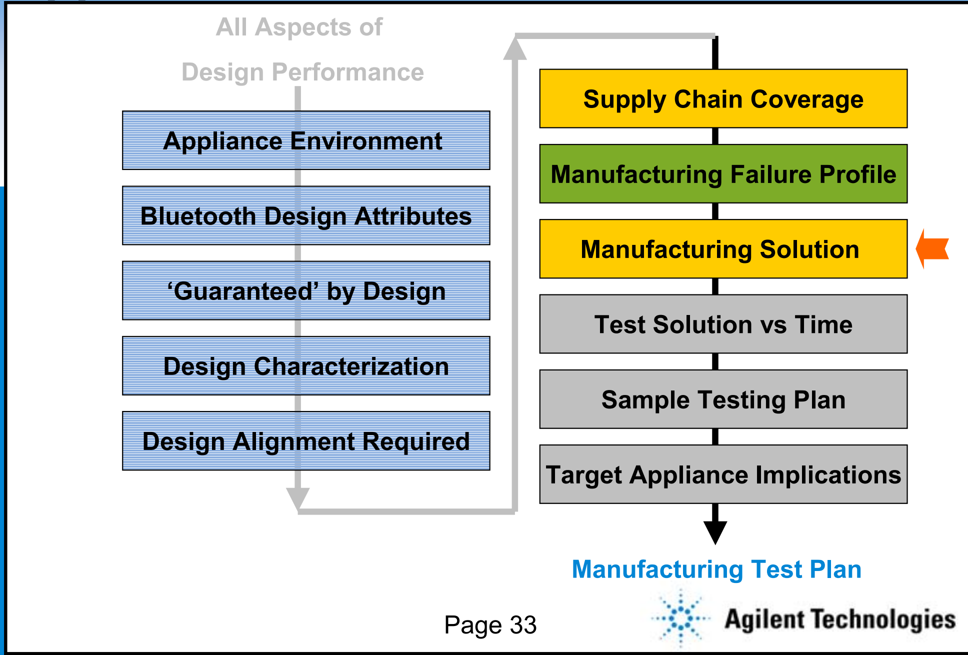
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Manufacturing Solutions

- The SIG Test Regimen is not a production test guideline!
  - Many of the methods are very time consuming.
  - Lack insight into verifying what can go wrong in manufacturing.
- You select methods and conditions that focus on your design and your overall process.

Manufacturing Solutions

- Test Mode—Loopback, Transmit Mode
- Sensitivity–
  - Worst Case frequency
  - Single Slot and Multi-slot?—probably not!
  - 1.6 Million Bits?– don't have to
  - Impairments?–A great process statistic may well be BER Sensitivity with low mod index. (.28)
- Current vs Operational State-
  - Power On-Quiescent
  - Proprietary Low power controls (TX only, RX only, Park)
  - Max Power Transmit

In selecting the tests to do you can use the facilities of the Test mode modes—loopback and transmit modes as well as perhaps proprietary BER Receive modes.

With respect to testing Sensitivity it is very likely that both multi-slot and single slot testing is unnecessary---find the worst case, (multi-slot), and omit the other. Further, the number of bits (1.6 Million) can be adequately done at substantially fewer bits. Testing to a spec of .07% at 30,000 bits or .082 at 100,000 bits.

I feel that in manufacturing impairments as a suite are not particularly useful. Generally, in Manufacturing we want the stimulus to be as pure as possible to keep the margins high. If there is reason to believe that there is an ongoing issue with performance (say a Symbol timing Recovery circuit) that can be a function of silicon and is found only with a special condition then set that condition up---For example, set up the modulation index to be at the low end and the frequency offset to be either at the high or low extreme.

Current draw, as stated earlier, may be an incredibly simple measurement to make that actually yields great benefits in identify things that might go wrong. It may be that a very narrow distribution should exist for any particular operating mode and that a significant deviation from this would indicate poor silicon characteristics, soldering defects, component failure, etc

Manufacturing Solutions

- **Transmitter—**
  - **Max Power:** typical characteristics for min/max
  - **Power Step?:** Verifying the IC…
  - **Center Frequency Drift:** DH5 vs DH1 packets
  - **Initial Center Frequency Tolerance:** a noisy measurement.
  - **Modulation Index:** could be verifying IC, but very quick way to know system, RF/Baseband is working well.
  - **Output Spectrum:** Incremental Cost, Faster methods will need correlation to real performance

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For the transmitter, we can make some simplifications depending on what we have learned through the approach to this point:

Max Power—what are the characteristics vs frequency? Pick only key areas of variability or where spec margin is low.

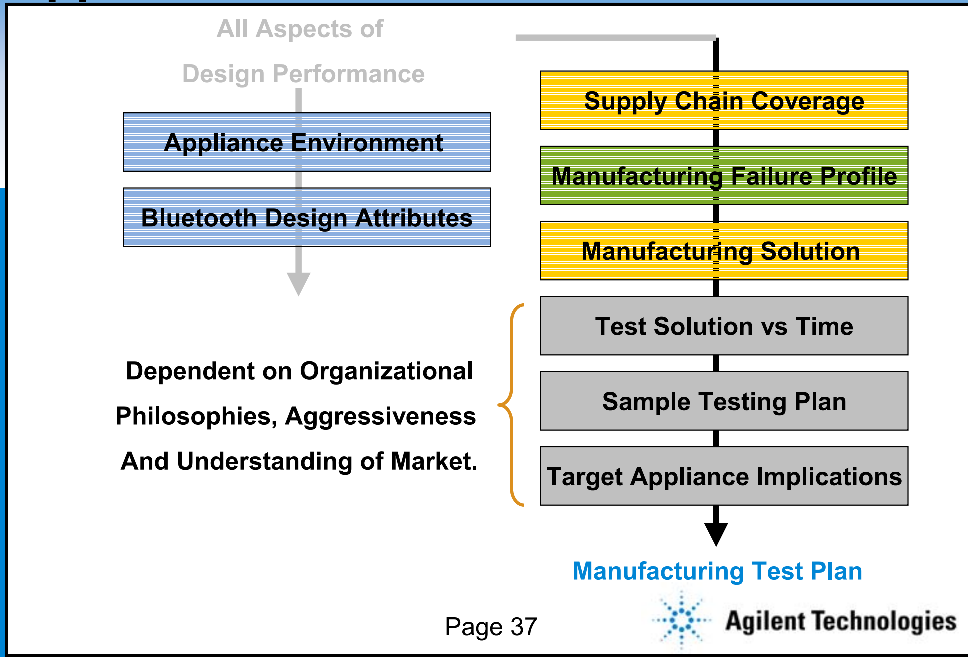
Power Step-if this is not a calibrated parameter—this would be essentially verifying the IC which may well have been done at the IC vendor.

Center Frequency Drift—choose only one packet type, if appropriate.

Initial Frequency Tolerance---realize that this is a noisy measurement.

Modulation Index---realize that you could be verifying the IC—however, is an efficient means to gain confidence in the baseband and RF IC connection.

Output Spectrum: could be a function of environment. If not, may be just testing the IC for physical parameters that the IC vendor may have already determined in their tests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Dependent on Organizational
Philosophies, Aggressiveness
And Understanding of Market.
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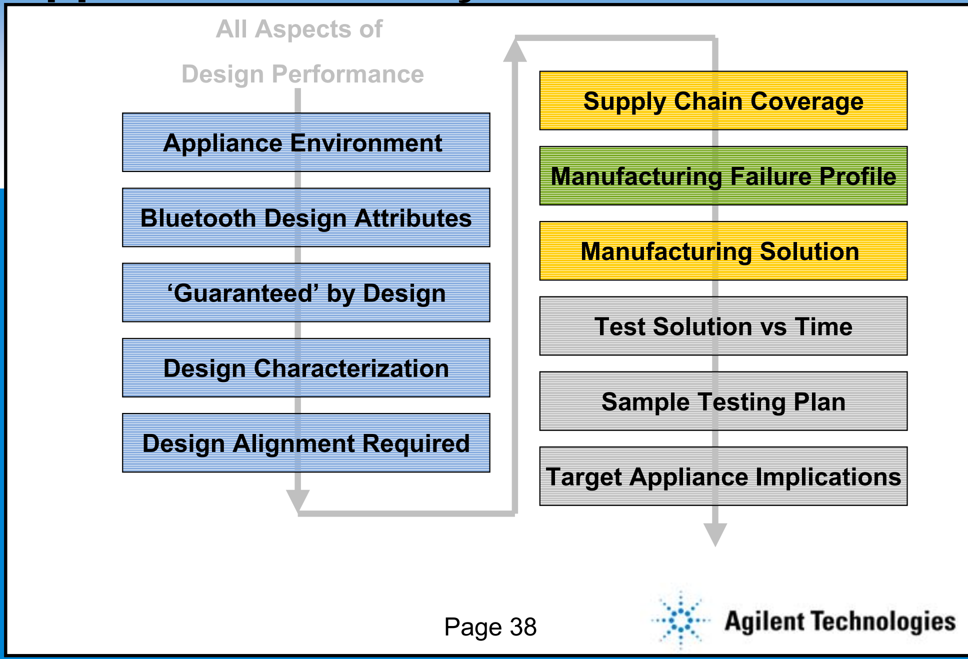

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Approach Summary

Approach Filter Matrix

- Area of Potential Weakness
- Performance 'Guaranteed'
- Alignments Required
- Strong Correlation to IC Test
- Weak Correlation to IC Test

X-Selected for Relationships

A-Always Tested

C-Candidate for Reduction

O-Omit

		Approach Filters									
		Appliance Environment	Bluetooth Design Attributes	Guaranteed Design	Design Characterization	Design AlignmentRequired	Suplly Chain Coverage	Manufacturing Failure Profile	Manufacturing Solution	Test Solution vs Time	Sample Testing Plan
Alignment Tests											
	Crystal Tuning									A	
Performance Tests											
	Power Output				x				x	A	x
	Power Control									C	x
	Modulation Characteristics				x					A	x
	Initial Carrier Frequency									A	x
	Carrier Frequency Drift									C	x
	Sensitivity				x				x	A	x
	RSSI								x	A	
	Battery Current vs Operational M									A	x
	Frequency Settling									O	
	Pulse Shape									O	
	Output Spectrum				x				x	C	x
	Maximum Usable Level				x					C	x
	Output Spectrum Freq Range									O	
	Output Spectrum Adj Ch Power									O	x
	Out of Band Spurious Emissions									O	x
	Carrier/Interference Performance				x					C	x
	Blocking Performance									O	
	Intermodulation Characteristics									O	
	Power Density									O	

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Now that we have moved through all the filters in our approach it is time to summarize our findings. We can do this through another matrix similar to the one introduced for the supply chain. Here we can get an instant view of what form our test plan should take. We note that the bottom half here (in a fictitious Bluetooth IC implementation) almost totally drops out---that is the good news. There are a number of conclusions drawn here which are too detailed to go into right now. But we can see how we should start (with all the A's and C's) and then drive to only the A's. We find that the supply chain column (IC test) provides some excellent coverage in this case.

Recommended Products

- ■ (green) **Direct Access to test**
- ■ (yellow) **Indirect Access/Probing to test**

	Recommended Products							
	E1852B *Bluetooth* Test Set	E4407B ESA Spectrum Analyzer	E4438C ESG-D Signal Generator	66319B Dual-Output DC Source	E4416A EPM Power Meter	53181A Freq Counter	Test Solution vs Time	Sample Testing Plan
Crystal Tuning	Indirect	Indirect				Direct	A	
Power Output	Direct	Direct			Direct		A	x
Power Control	Direct	Direct			Direct		C	x
Modulation Characteristics	Direct	Direct					A	x
Initial Carrier Frequency	Direct	Direct					A	x
Carrier Frequency Drift	Direct	Direct					C	x
Sensitivity	Direct		Direct				A	x
RSSI	Direct		Direct				A	
Battery Current vs Operational Mode				Direct			A	x
Output Spectrum		Direct					C	x
Maximum Usable Level	Direct		Direct				C	x
Output Spectrum Adj Ch Power		Direct					O	x
Out of Band Spurious Emissions		Direct					O	x
Carrier/Interference Performance	Direct *		Direct *				C	x

*** Requires two signal sources to make this measurement**

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Initial *Bluetooth* Test Plan

- Interface Aliveness,FW Download
- Crystal Tuning and Trim
- Battery Current vs Operational Mode
- Received Strength Indicator
- Receiver Sensitivity
- Power Alignment and Verification
- Modulation Characteristics
- Initial Center Frequency Tolerance and Drift
- Carrier/Interference
- Transmit Spectrum
- Maximum Usable Level
- *Bluetooth* Address Download

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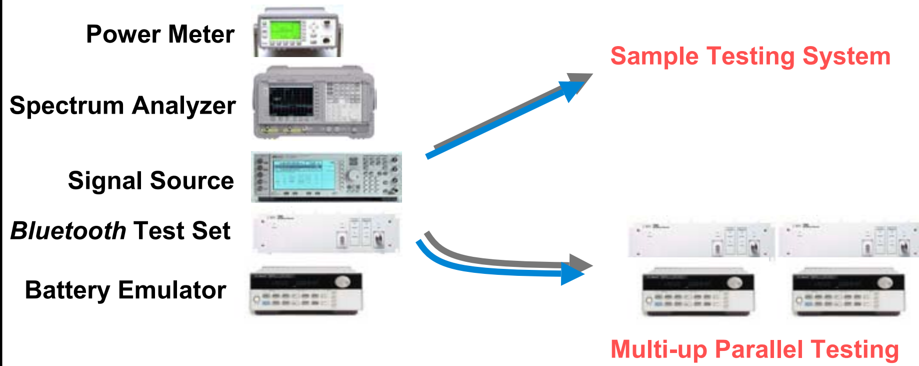
Solutions over Time



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Summary Slide

- We have reviewed Business Objectives that drive Manufacturing test in the Real World.
- Introduced an Approach that methodically considers Design, Components and Processes in an effort to identify an efficient test plan to support these objectives
- Introduced the notion of coverage matrices to help discern the Test Plan.
- Have shown how the Test Equipment(cost) can be reduced over time. And that a Sampling Plan may be a great way to drive this.

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