2009 Session 5

ARCHIVE 2009

A SALMAGUNDI OF SOCKET SCIENCE

Performance Studies on Space Transformer Structures

Roger Weiss—Paricon Technologies Corporation

Design & Test of Very High Bandwidth QFN/QFP Sockets

James Zhou, Ila Pal, Dr. James Forster, Jiachun (Frank) Zhou, Steve Davis,
Dima Alzoubaidi—Antares Advanced Test Technologies

Improving Your Test System Performance in High Frequency Applications

Jeff Sherry—Johnstech International Corporation
Michael Voo—Avago Technologies

Wafer-Level Burn-In of Hall-Effect Sensors

Steve Steps—Aehr Test Systems
Jochen Seidler—Micronas GmbH

Performance Studies on Space Transformer Structures

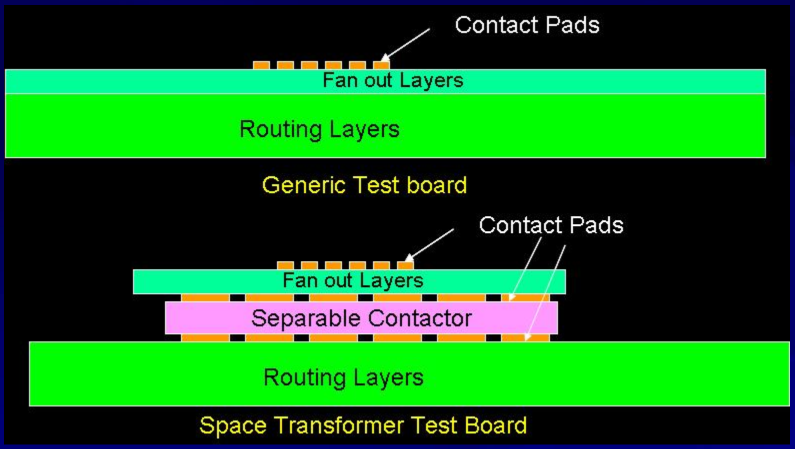
Roger Weiss, PhD
Paricon Technologies Corp.

2009 BiTS Workshop
March 8 - 11, 2009

Presentation Goals

- What are Space Transformers
- Why are they Needed
- Paricon Space Transformer Technology
- Lab Data
- Field Experience
- Intellectual Property

What are Space Transformers?



Why are they Needed?

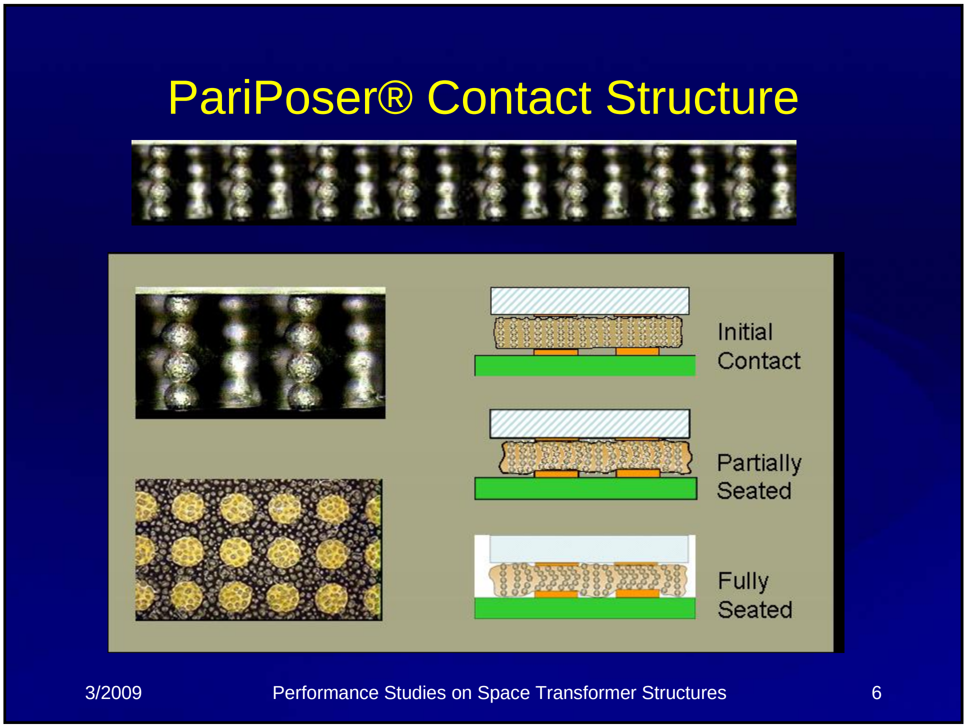
Fine Pitch Devices Key Driver

- Drilling Aspect Ratio Increased
- Plating Aspect Ratio Increased
- Test Board Yield Reduced (1-2 per panel)
- Needed Designs Cannot be Constructed
- Board Prices Increased Dramatically

Why are they Needed?

Space Transformers Solve Problems

- Drilling and Plating Aspect Ratio Decreased
- Technology Challenge Moved to Small Board
    - 50 Boards per Panel
- Increased Design Flexibility
    - Family Test Board Design
- Board Prices Decrease
    - $10k per Setup in at Least 1 Case



PariPoser® Contact Structure

Initial Contact

Partially Seated

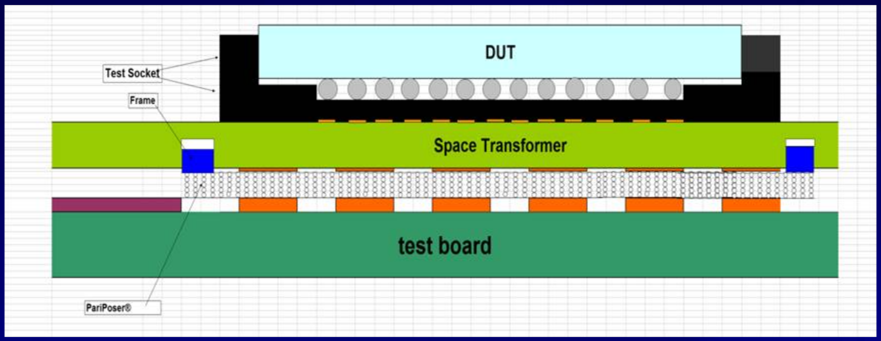
Fully Seated

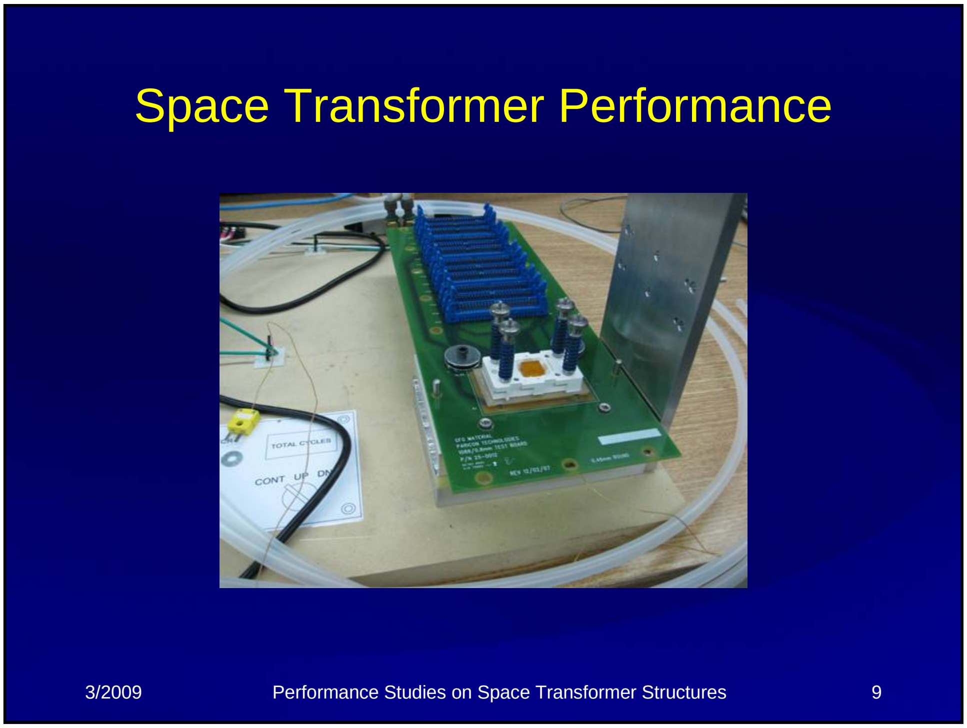
PariPoser® Contact Structure

Structure

- Thickness Under 0.010”
- Less Than 1dB loss at 60 GHz
- Approximates Board Layer Performance

Space Transformer Performance





Space Transformer Performance

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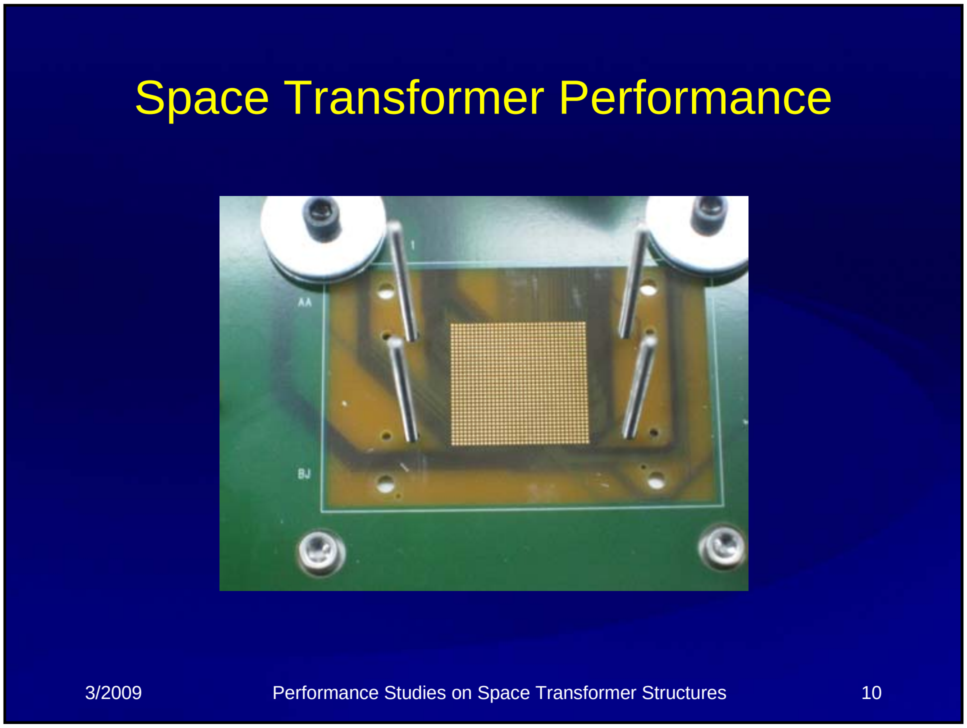

Space Transformer Performance

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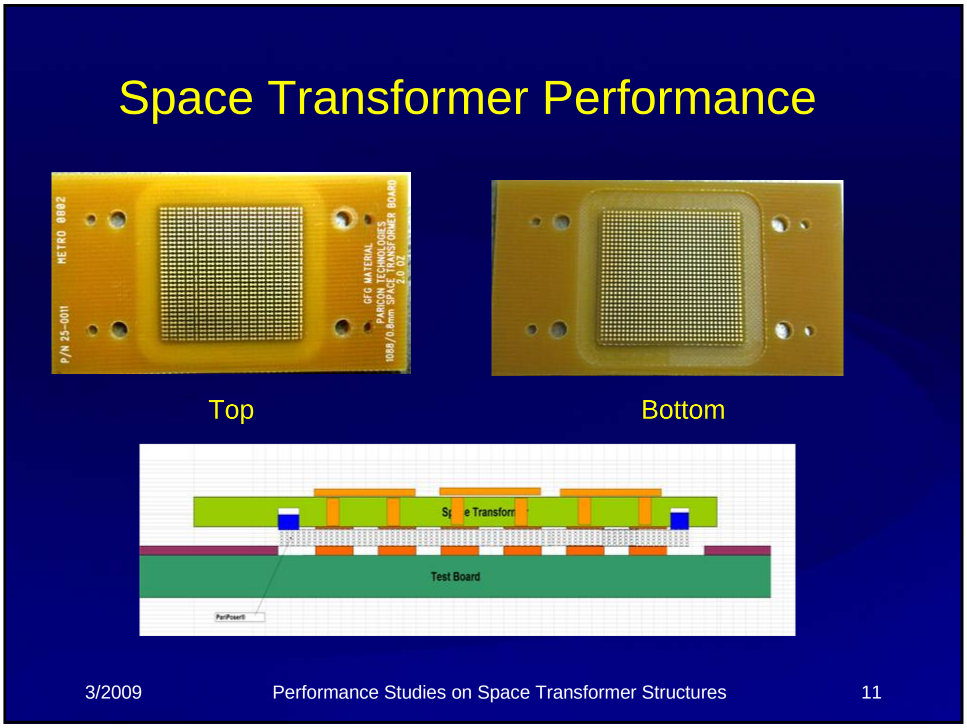

Space Transformer Performance

Top

Bottom

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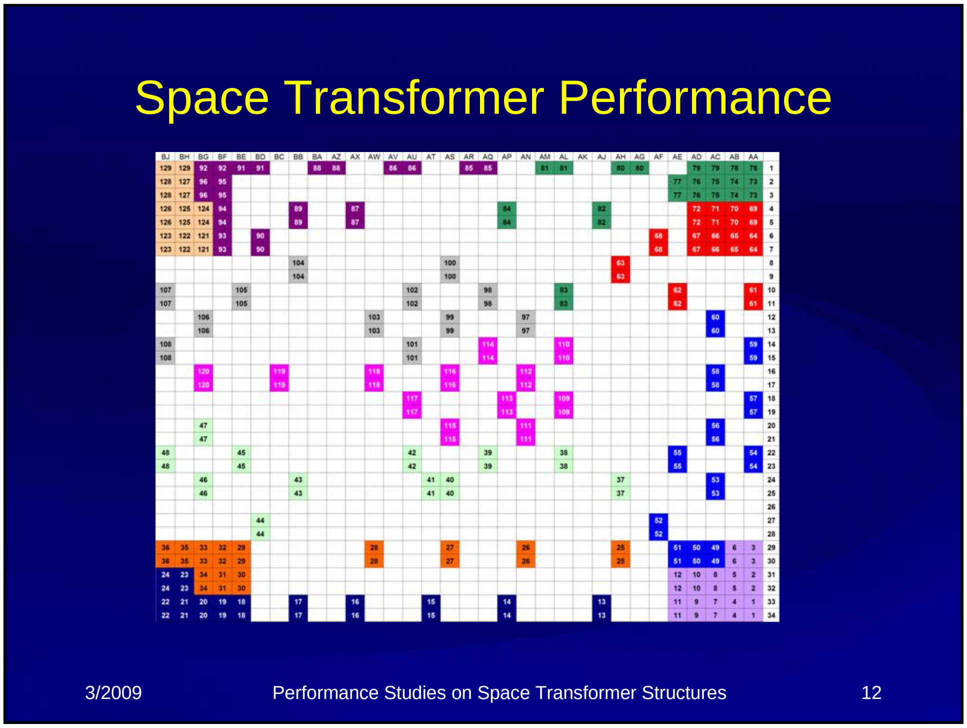

Space Transformer Performance

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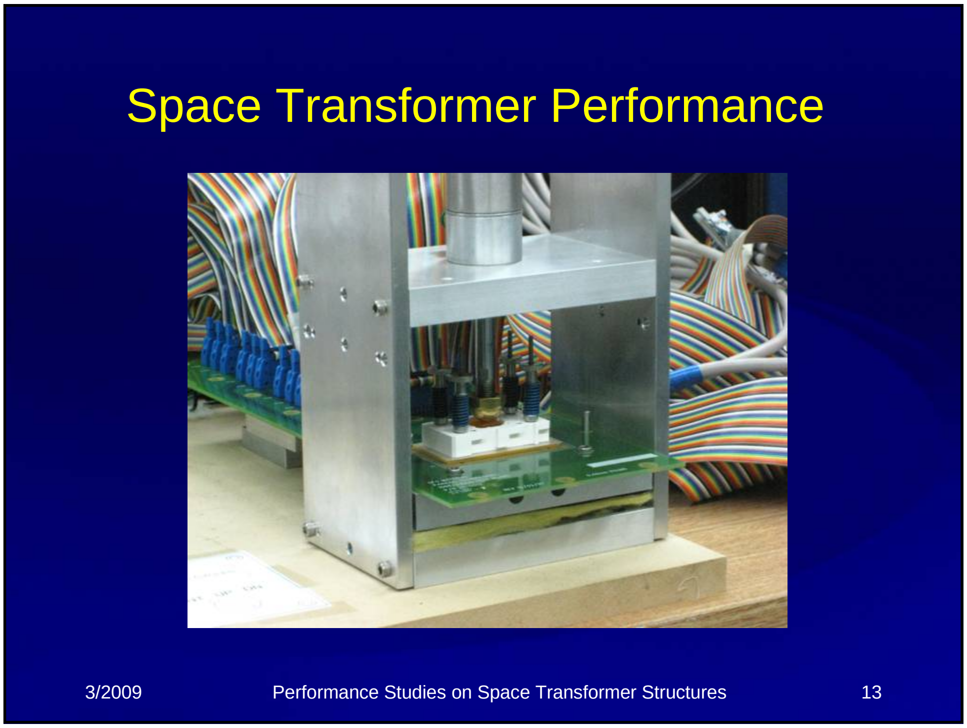

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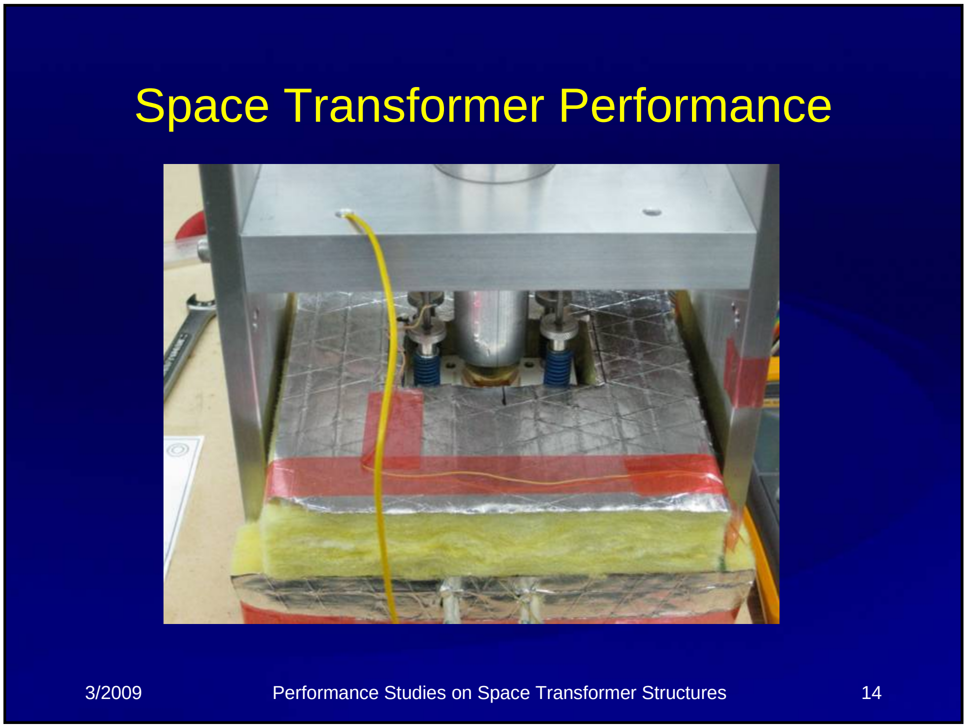

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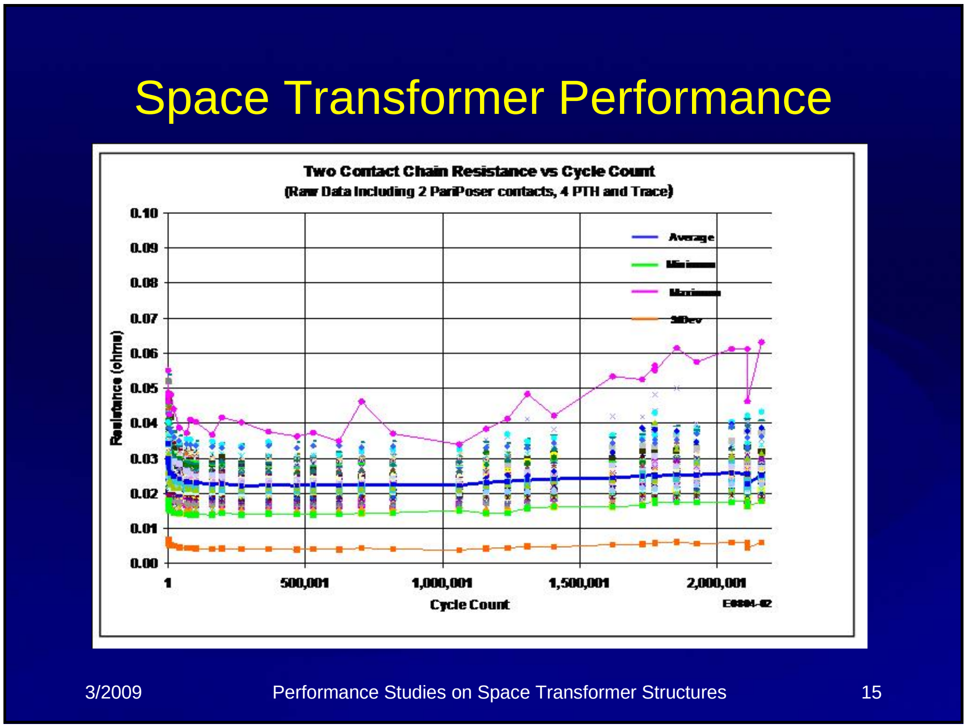

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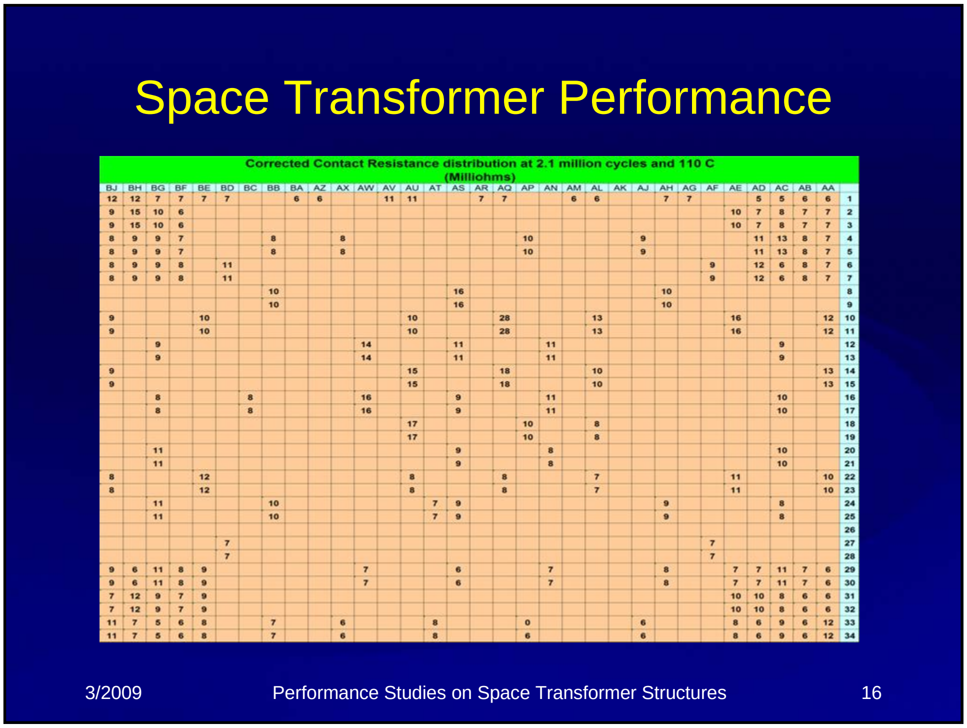

Space Transformer Performance

Corrected Contact Resistance distribution at 2.1 million cycles and 110 C (Milliohms)

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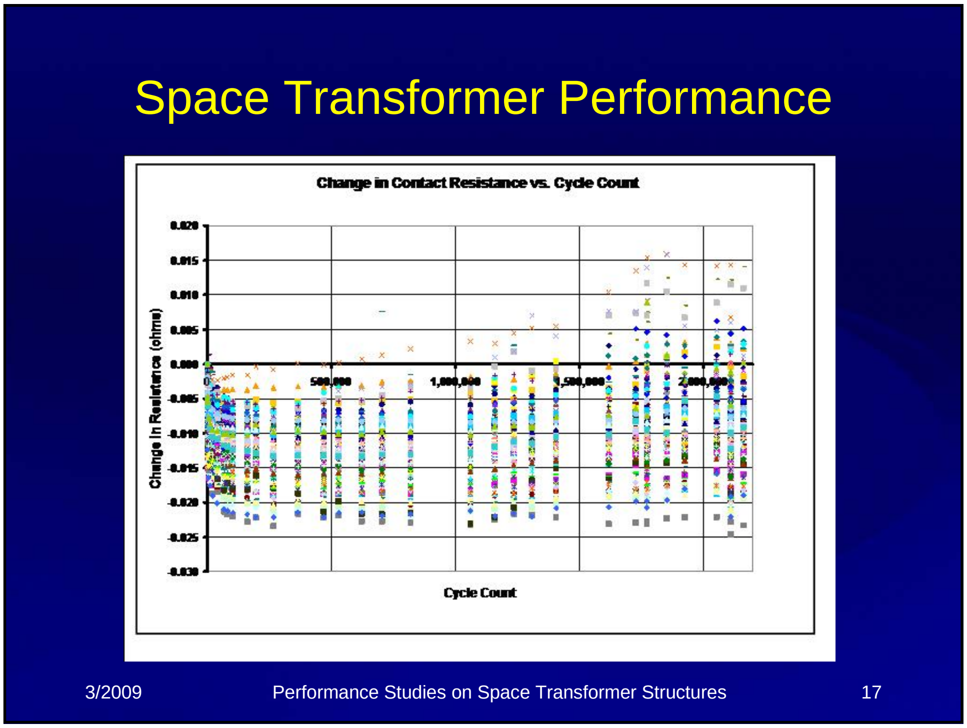
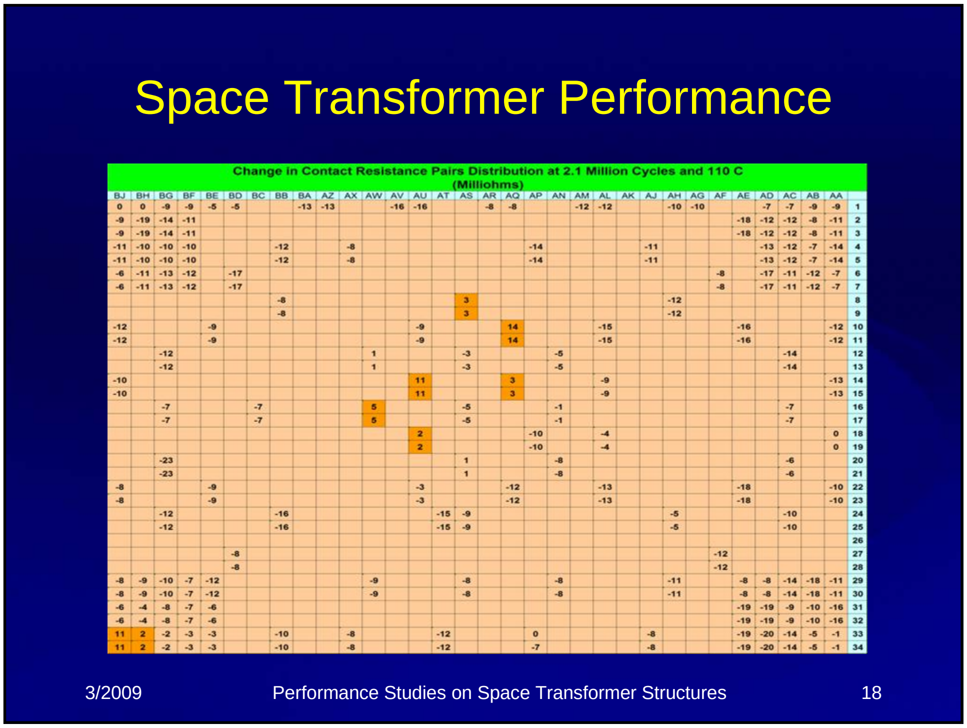


Space Transformer Performance



Space Transformer Performance

Change in Contact Resistance Pairs Distribution at 2.1 Million Cycles and 110 C (Milliohms)

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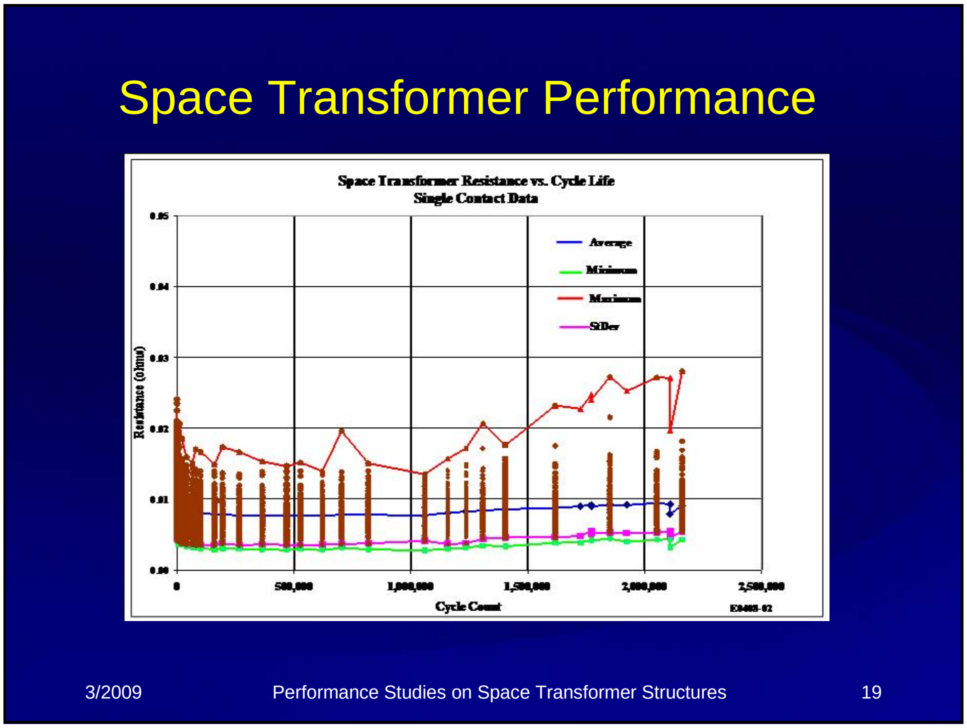
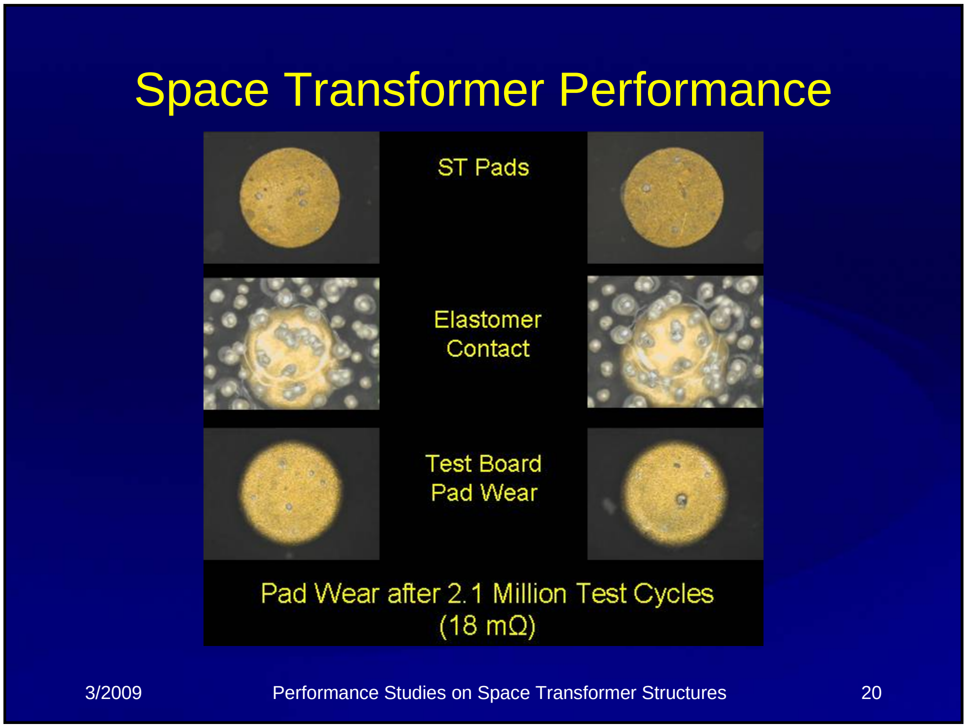


Space Transformer Performance



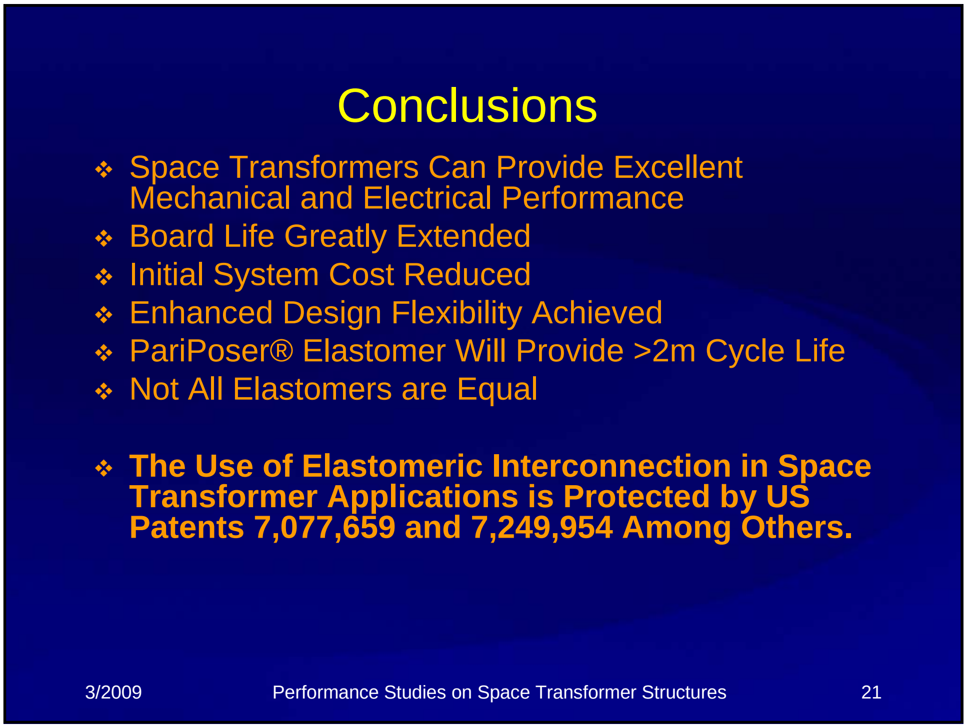
Space Transformer Performance

ST Pads

Elastomer Contact

Test Board Pad Wear

Pad Wear after 2.1 Million Test Cycles (18 mΩ)



Conclusions

- Space Transformers Can Provide Excellent Mechanical and Electrical Performance
- Board Life Greatly Extended
- Initial System Cost Reduced
- Enhanced Design Flexibility Achieved
- PariPoser® Elastomer Will Provide >2m Cycle Life
- Not All Elastomers are Equal

- **The Use of Elastomeric Interconnection in Space Transformer Applications is Protected by US Patents 7,077,659 and 7,249,954 Among Others.**

Contact Information

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Design & Test of Very High Bandwidth QFN/QFP Sockets

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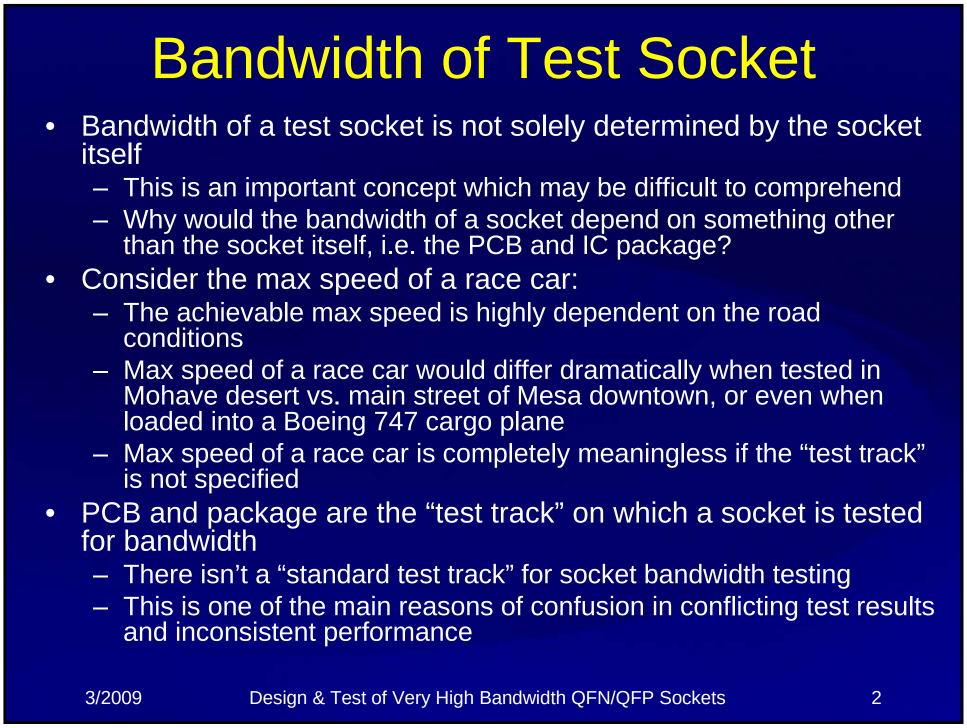
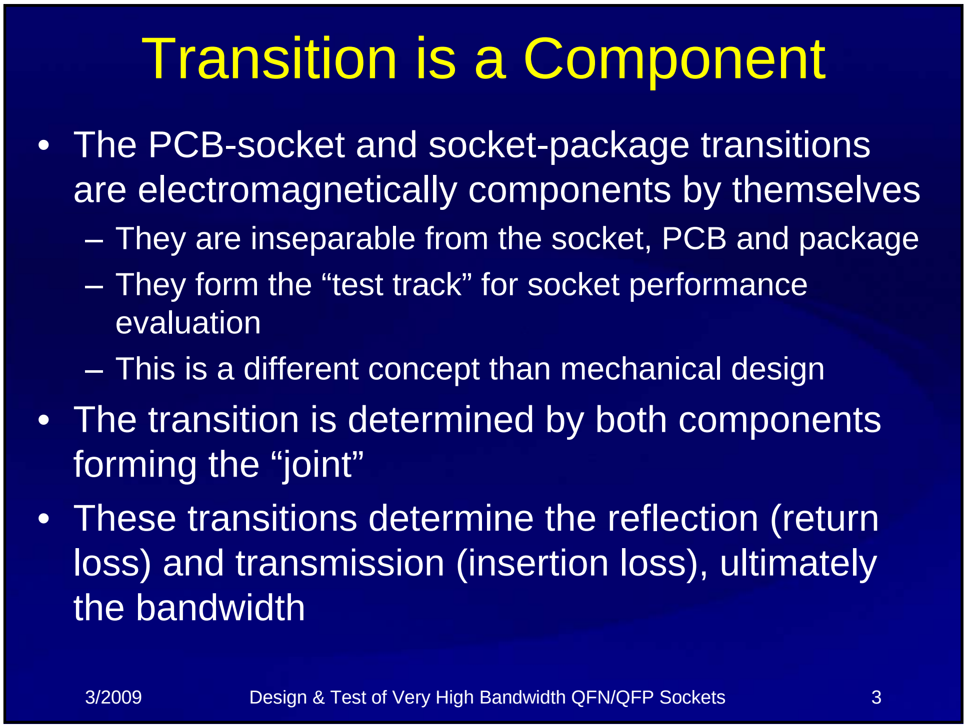


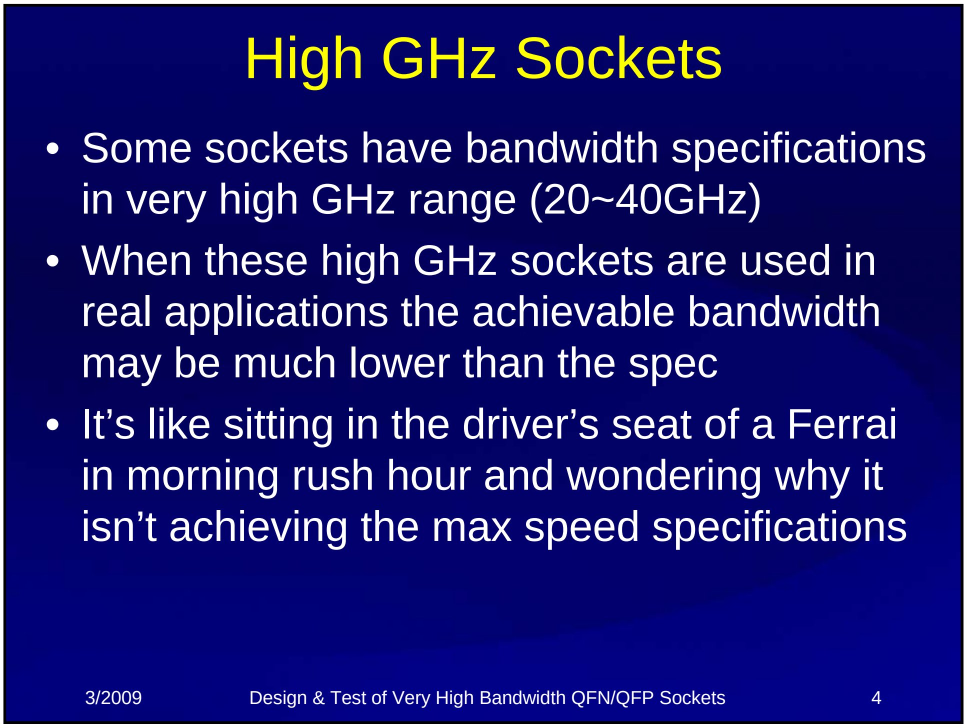
Bandwidth of Test Socket

- Bandwidth of a test socket is not solely determined by the socket itself
  - This is an important concept which may be difficult to comprehend
  - Why would the bandwidth of a socket depend on something other than the socket itself, i.e. the PCB and IC package?
- Consider the max speed of a race car:
  - The achievable max speed is highly dependent on the road conditions
  - Max speed of a race car would differ dramatically when tested in Mohave desert vs. main street of Mesa downtown, or even when loaded into a Boeing 747 cargo plane
  - Max speed of a race car is completely meaningless if the "test track" is not specified
- PCB and package are the "test track" on which a socket is tested for bandwidth
  - There isn't a "standard test track" for socket bandwidth testing
  - This is one of the main reasons of confusion in conflicting test results and inconsistent performance



Transition is a Component

- The PCB-socket and socket-package transitions are electromagnetically components by themselves
  - They are inseparable from the socket, PCB and package
  - They form the “test track” for socket performance evaluation
  - This is a different concept than mechanical design
- The transition is determined by both components forming the “joint”
- These transitions determine the reflection (return loss) and transmission (insertion loss), ultimately the bandwidth

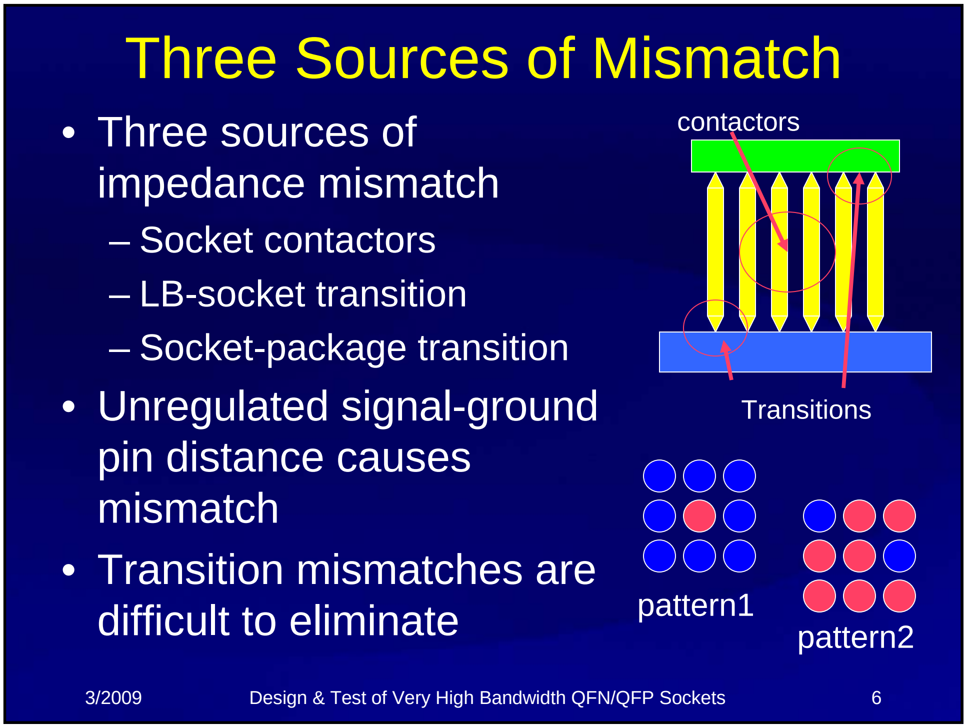


High GHz Sockets

- Some sockets have bandwidth specifications in very high GHz range (20~40GHz)
- When these high GHz sockets are used in real applications the achievable bandwidth may be much lower than the spec
- It’s like sitting in the driver’s seat of a Ferrai in morning rush hour and wondering why it isn’t achieving the max speed specifications

Bandwidth Degradation

- Bandwidth of a test socket may quickly degrade when PCB and package design deviate from ideal conditions used to generate the spec
- Two main sources of bandwidth degradation:
  - PCB-socket transition mismatch
  - Socket-package transition mismatch
- Most socket bandwidth specifications do not include information on PCB and package transitions which have significant impact



Three Sources of Mismatch

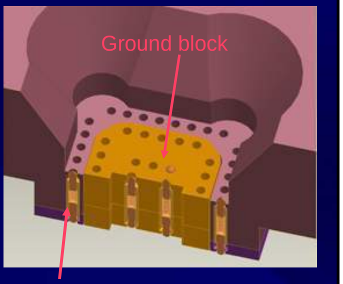
- Three sources of impedance mismatch
  - Socket contactors
  - LB-socket transition
  - Socket-package transition
- Unregulated signal-ground pin distance causes mismatch
- Transition mismatches are difficult to eliminate

Design Approach

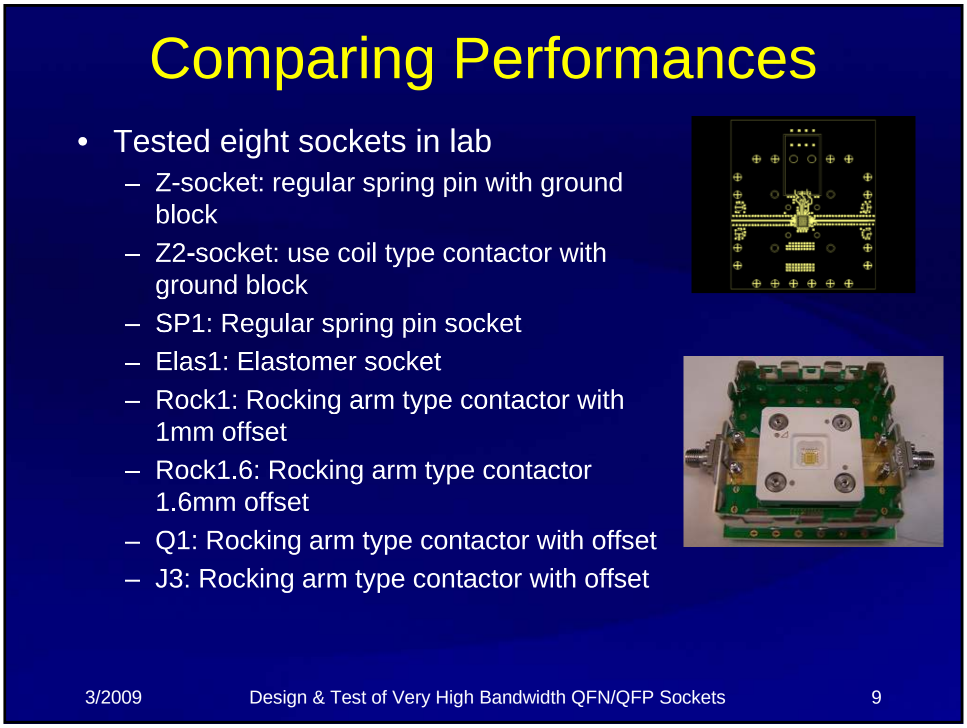
- Key to achieve high bandwidth is to reduce mismatch (reflection) in entire signal path, including the PCB and package in design considerations
  - (1) Reduce mismatch at PCB-socket transition
    - PCB dependent
  - (2) Reduce mismatch inside socket
    - Only depending on socket
  - (3) Reduce mismatch at socket-package transition
    - Package dependent

Z-socket

- Impedance-controlled socket for RF and high-speed QFN/QFP applications
- Ground block serve as return path to help regulate impedance
- Able to tune impedance to close to 50ohm by adjusting pin diameter and pin-to-ground gap
- “uniform transmission line” along spring pin section
- Embedded spring pins in ground block help to make good contact
  - resilient to contamination
  - Provide compliance



Signal & ground pins (GSG, GSSG, SSSS)

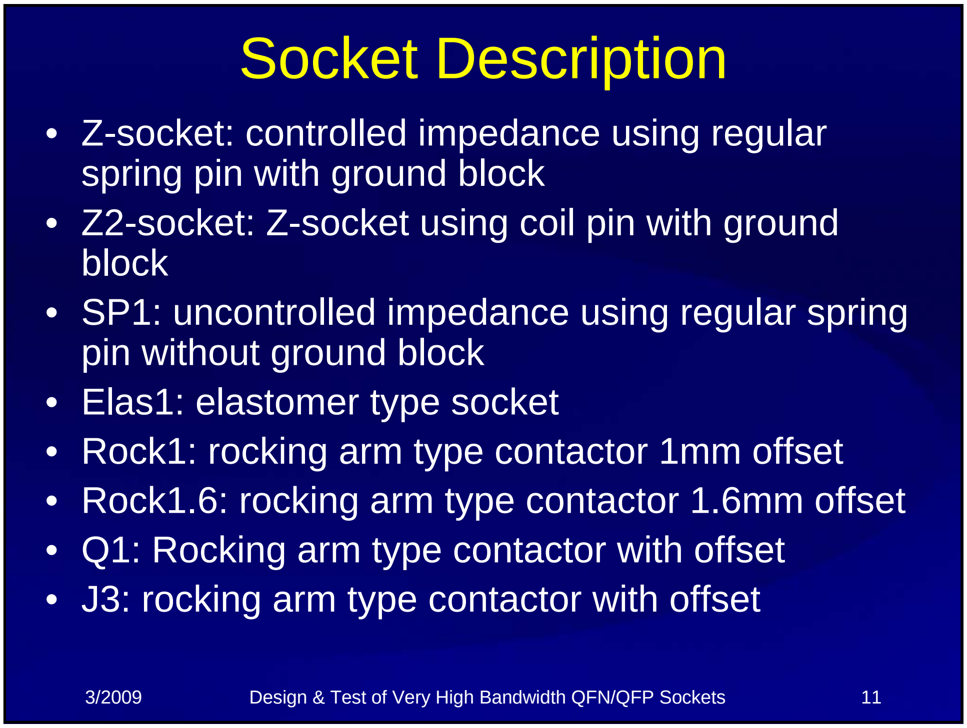


Comparing Performances

- Tested eight sockets in lab
  - Z-socket: regular spring pin with ground block
  - Z2-socket: use coil type contactor with ground block
  - SP1: Regular spring pin socket
  - Elas1: Elastomer socket
  - Rock1: Rocking arm type contactor with 1mm offset
  - Rock1.6: Rocking arm type contactor 1.6mm offset
  - Q1: Rocking arm type contactor with offset
  - J3: Rocking arm type contactor with offset

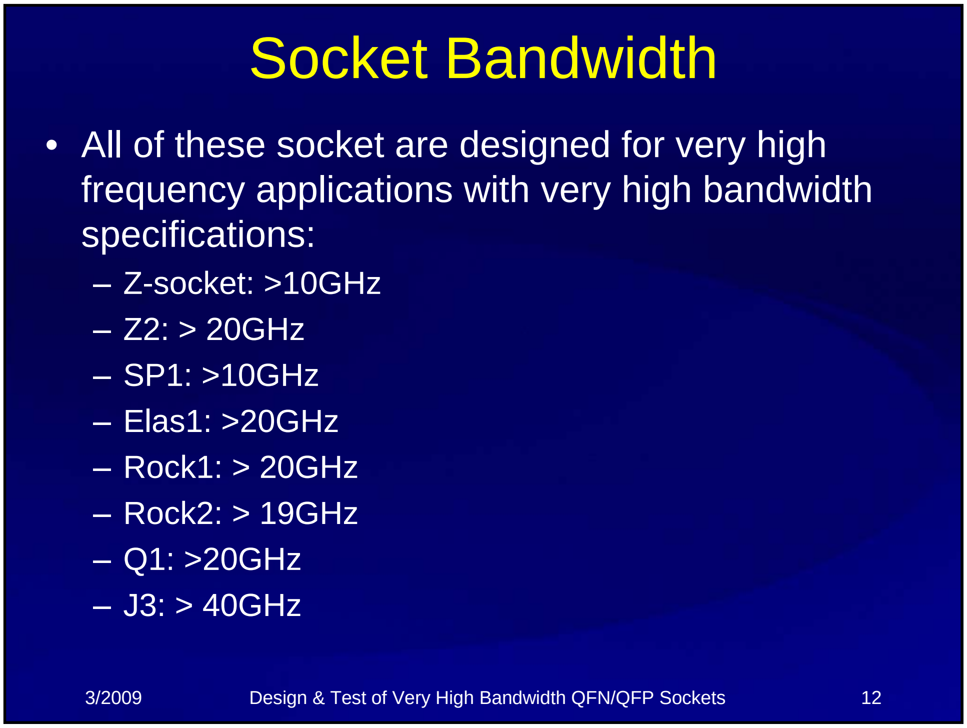
Device Under Test

- Use 32 QFN microwave amplifier 6-18 GHz as device
- This is a real world amplifier testing, different from those tests focusing on pin performance only
- Lab tests focusing only on pins often fails to re-produce the PCB-socket transition and socket-package transition, yielding results that may not be applicable to any real world testing applications
- All test boards have similar layout as recommended by device manufacturer



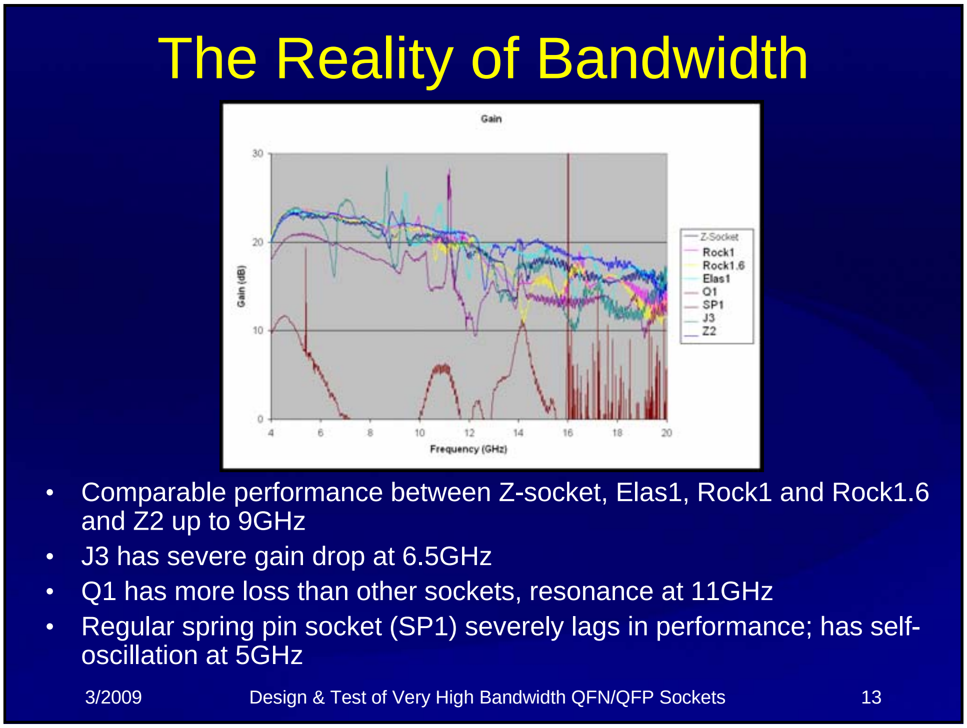
Socket Description

- Z-socket: controlled impedance using regular spring pin with ground block
- Z2-socket: Z-socket using coil pin with ground block
- SP1: uncontrolled impedance using regular spring pin without ground block
- Elas1: elastomer type socket
- Rock1: rocking arm type contactor 1mm offset
- Rock1.6: rocking arm type contactor 1.6mm offset
- Q1: Rocking arm type contactor with offset
- J3: rocking arm type contactor with offset



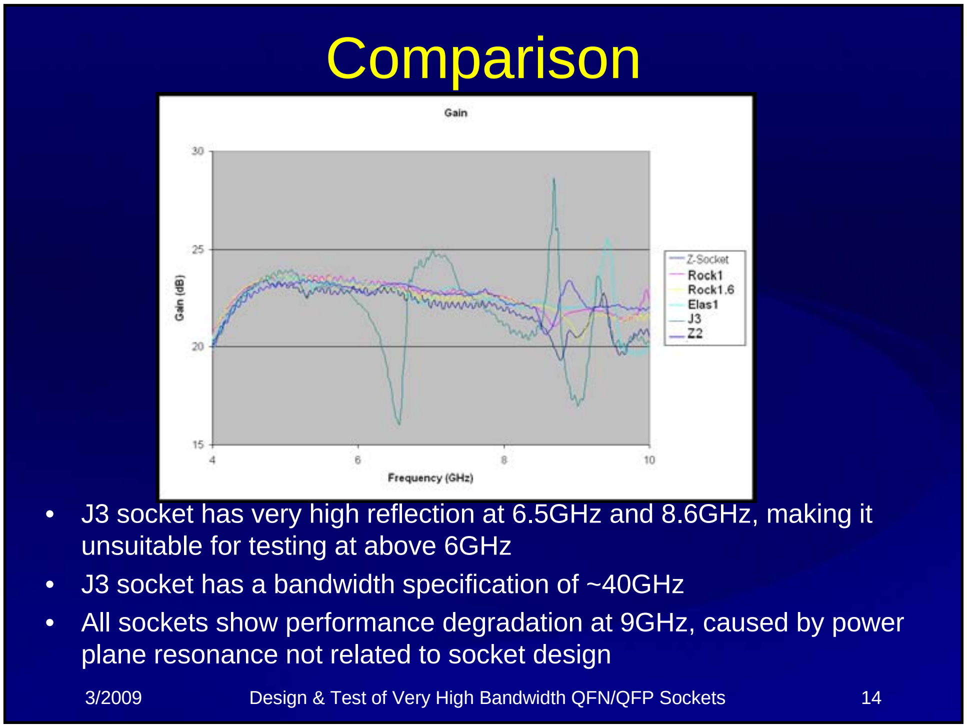
Socket Bandwidth

- All of these socket are designed for very high frequency applications with very high bandwidth specifications:
  - Z-socket: >10GHz
  - Z2: > 20GHz
  - SP1: >10GHz
  - Elas1: >20GHz
  - Rock1: > 20GHz
  - Rock2: > 19GHz
  - Q1: >20GHz
  - J3: > 40GHz



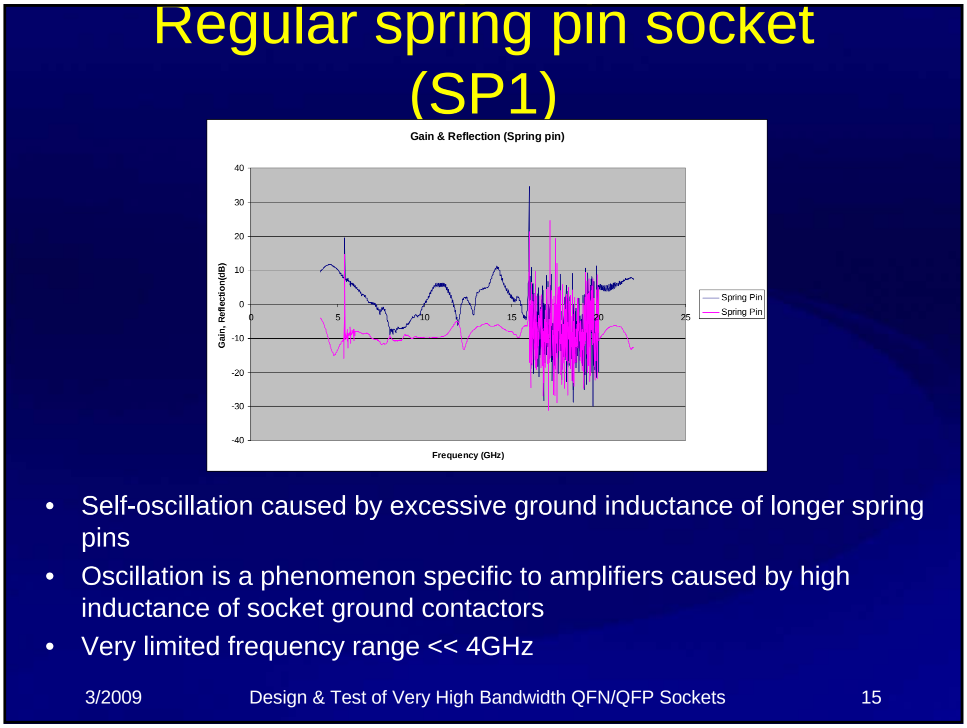
The Reality of Bandwidth

- Comparable performance between Z-socket, Elas1, Rock1 and Rock1.6 and Z2 up to 9GHz
- J3 has severe gain drop at 6.5GHz
- Q1 has more loss than other sockets, resonance at 11GHz
- Regular spring pin socket (SP1) severely lags in performance; has self-oscillation at 5GHz



Comparison

- J3 socket has very high reflection at 6.5GHz and 8.6GHz, making it unsuitable for testing at above 6GHz
- J3 socket has a bandwidth specification of ~40GHz
- All sockets show performance degradation at 9GHz, caused by power plane resonance not related to socket design



Regular spring pin socket (SP1)

- Self-oscillation caused by excessive ground inductance of longer spring pins
- Oscillation is a phenomenon specific to amplifiers caused by high inductance of socket ground contactors
- Very limited frequency range << 4GHz

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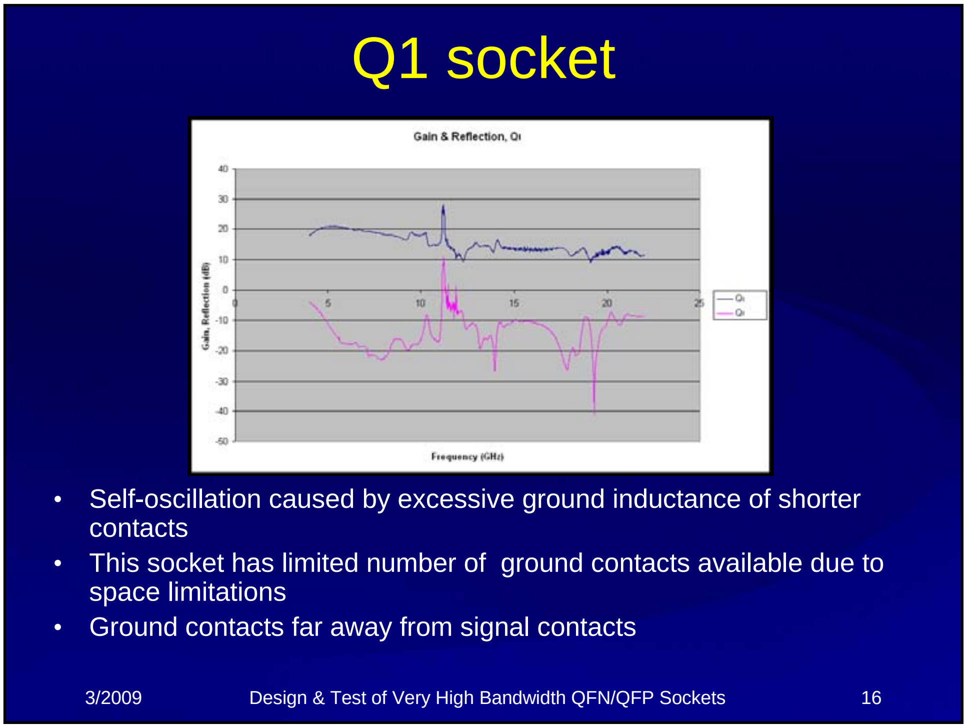
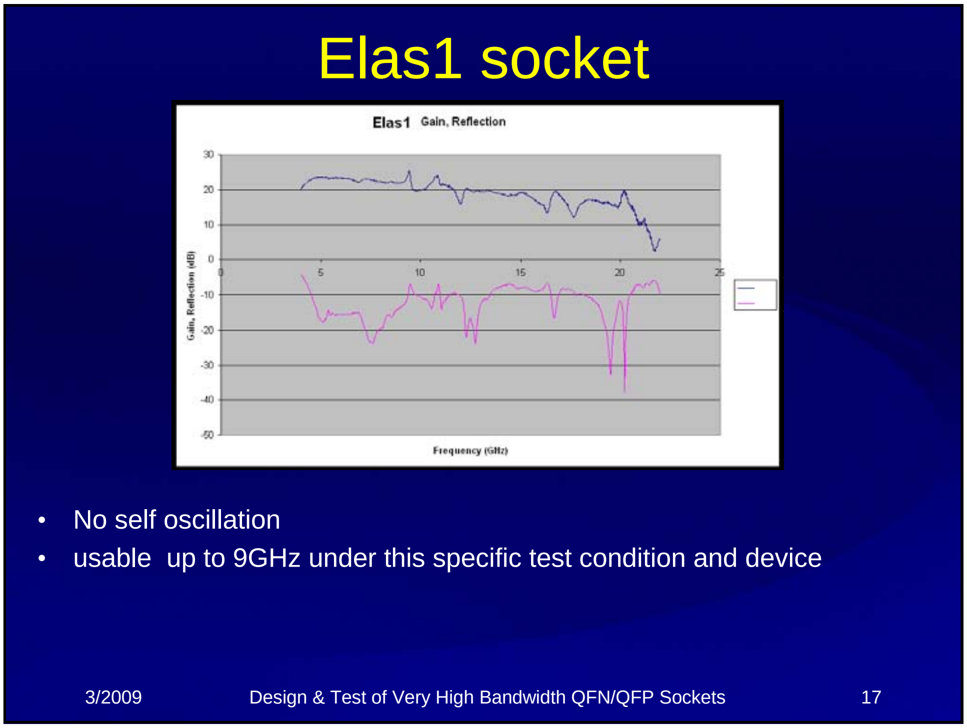


Q1 socket

- Self-oscillation caused by excessive ground inductance of shorter contacts
- This socket has limited number of ground contacts available due to space limitations
- Ground contacts far away from signal contacts

3/2009 Design & Test of Very High Bandwidth QFN/QFP Sockets 16



Elas1 socket

- No self oscillation
- usable up to 9GHz under this specific test condition and device

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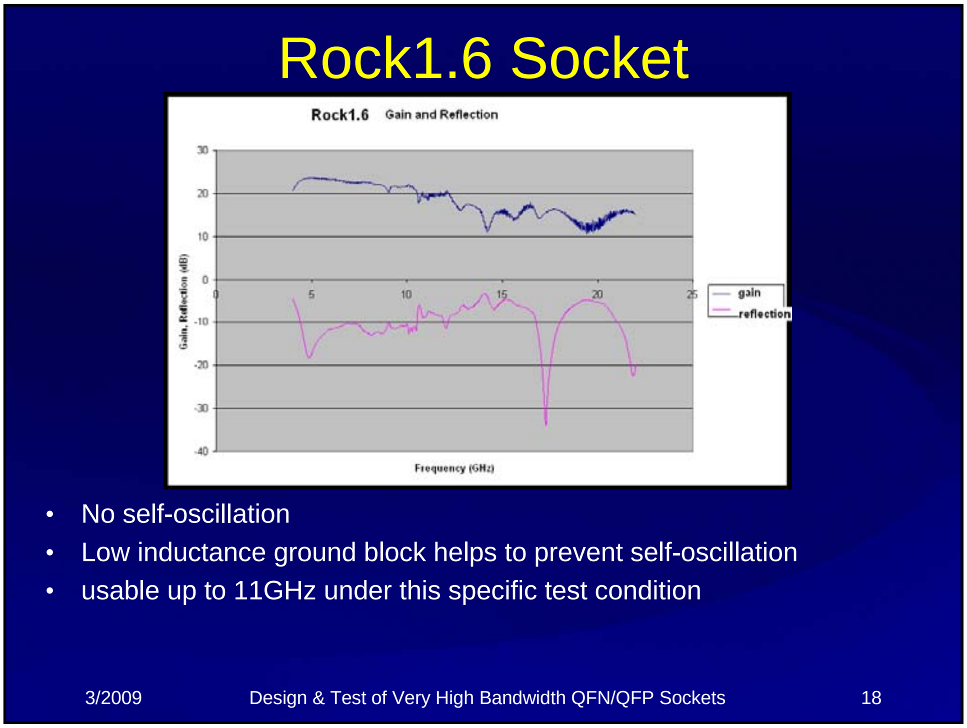

Rock1.6 Socket

- No self-oscillation
- Low inductance ground block helps to prevent self-oscillation
- usable up to 11GHz under this specific test condition

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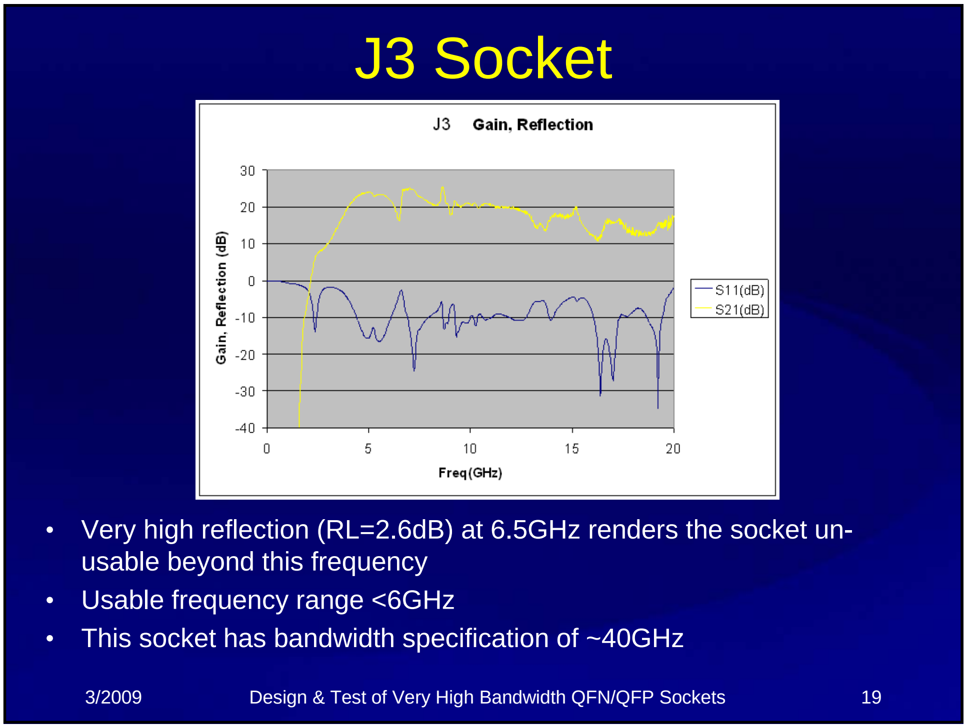

J3 Socket

- Very high reflection (RL=2.6dB) at 6.5GHz renders the socket un-usable beyond this frequency
- Usable frequency range <6GHz
- This socket has bandwidth specification of ~40GHz

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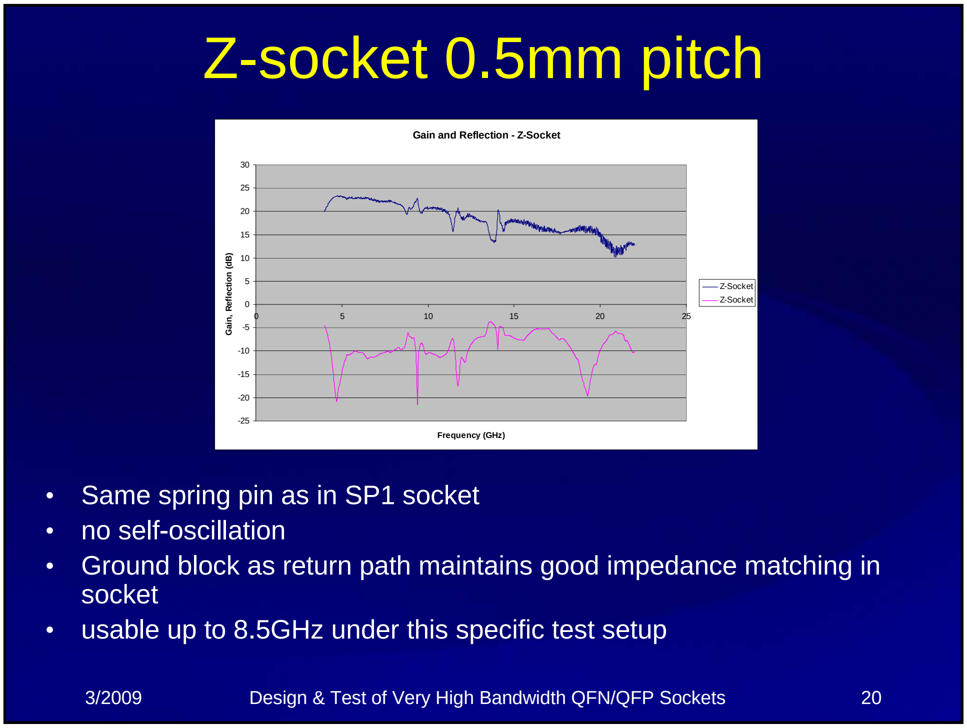

Z-socket 0.5mm pitch

- Same spring pin as in SP1 socket
- no self-oscillation
- Ground block as return path maintains good impedance matching in socket
- usable up to 8.5GHz under this specific test setup

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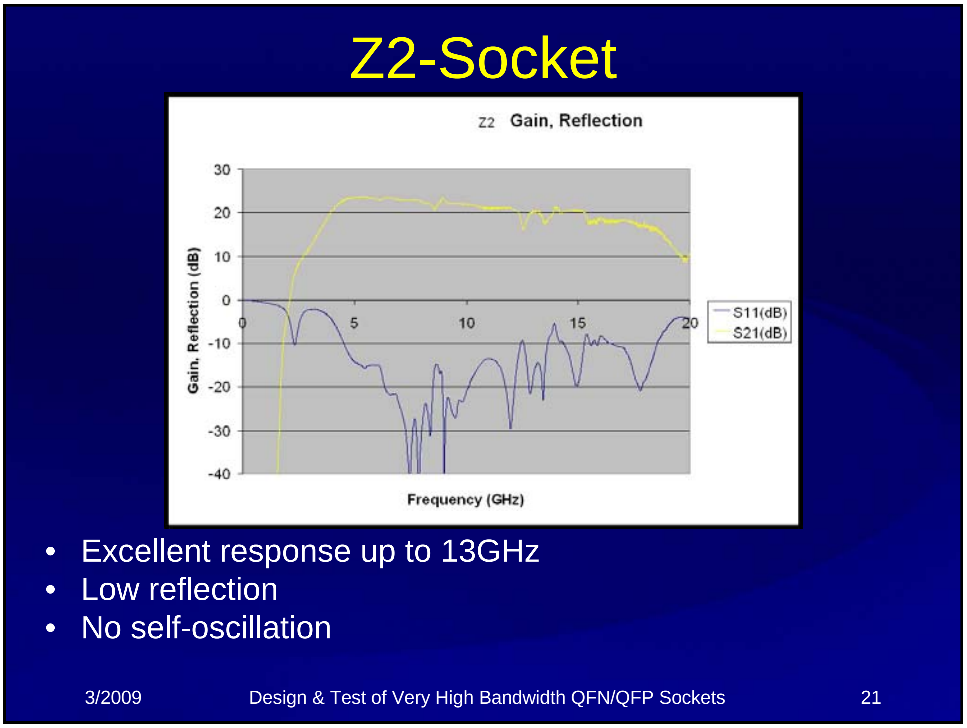
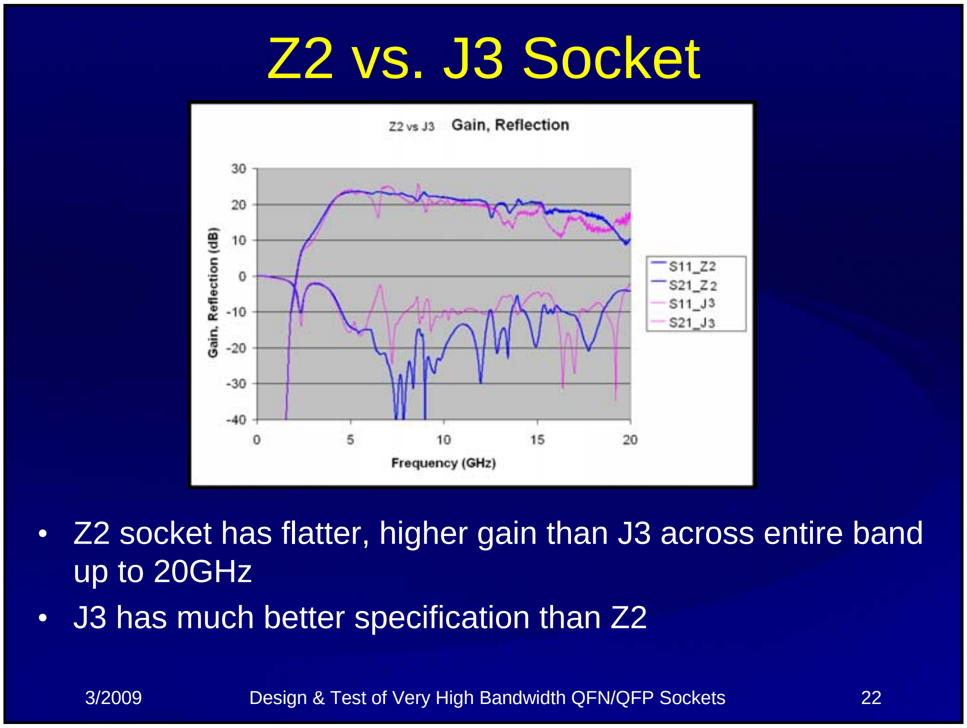


Z2-Socket

- Excellent response up to 13GHz
- Low reflection
- No self-oscillation



Z2 vs. J3 Socket

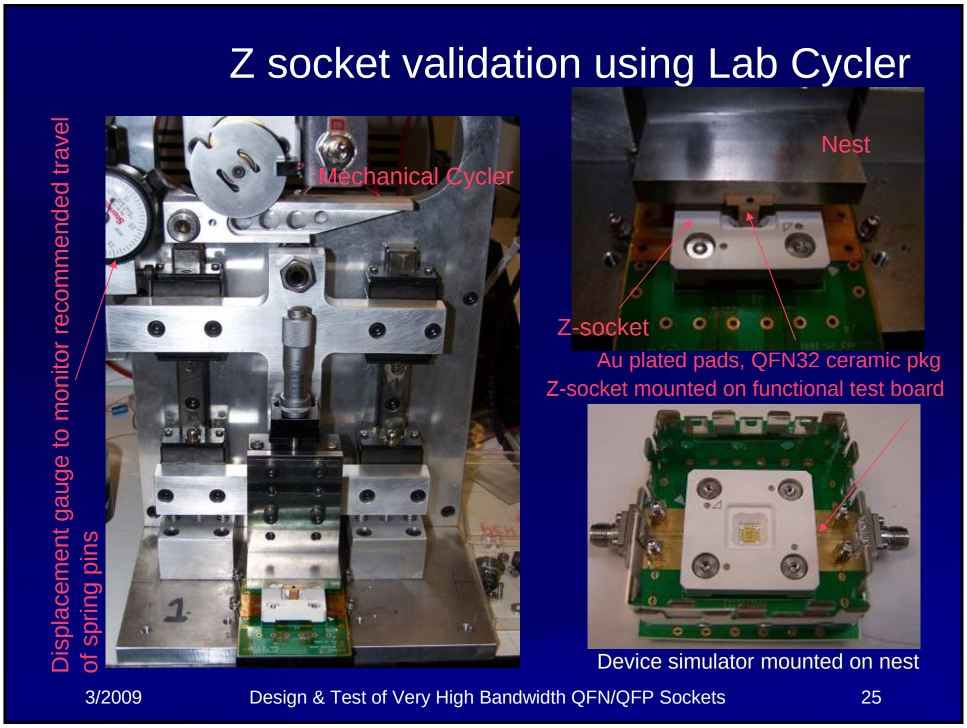
- Z2 socket has flatter, higher gain than J3 across entire band up to 20GHz
- J3 has much better specification than Z2

Real vs. Ideal Testing

- Z-socket comparison testing are conducted under “real conditions” using microwave amplifier
  - It cannot and should not be compared with specifications obtained using “ideal conditions”
- Some socket specifications have very high GHz numbers without specifying the test conditions
  - These specifications are most likely un-achievable in real test conditions

Ideal Condition Testing

- Using coaxial input/output ports
- Highly optimized test fixture
- Unknown test conditions
- Results obtained from ideal or unknown testing configurations cannot be applied to real test conditions
- Results is only applicable and comparable when test conditions are the same



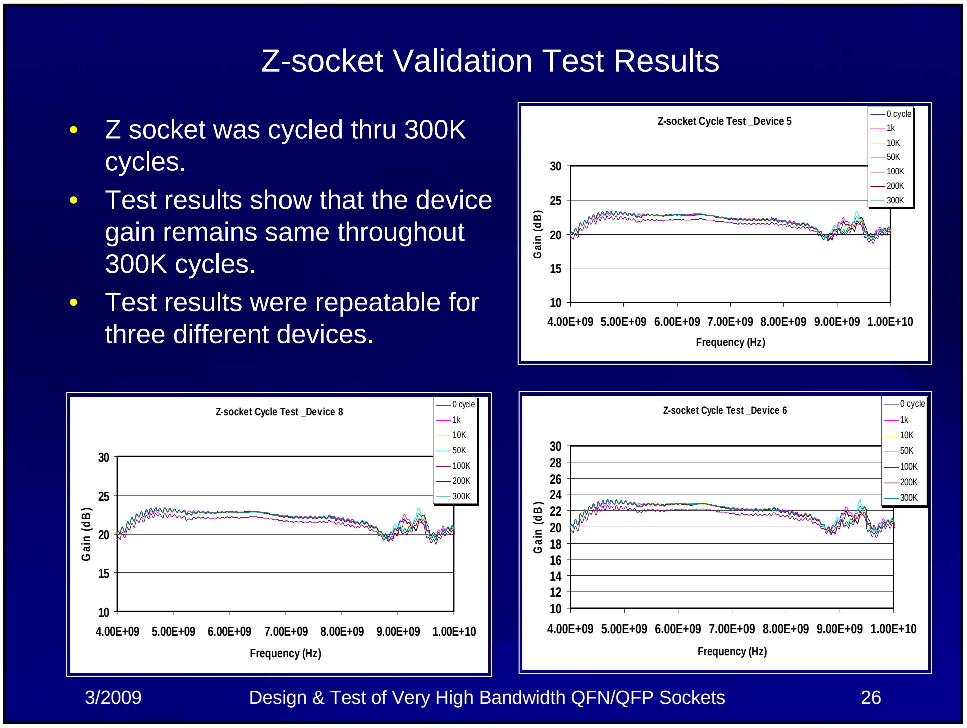
Z socket validation using Lab Cycler

Displacement gauge to monitor recommended travel of spring pins

Au plated pads, QFN32 ceramic pkg

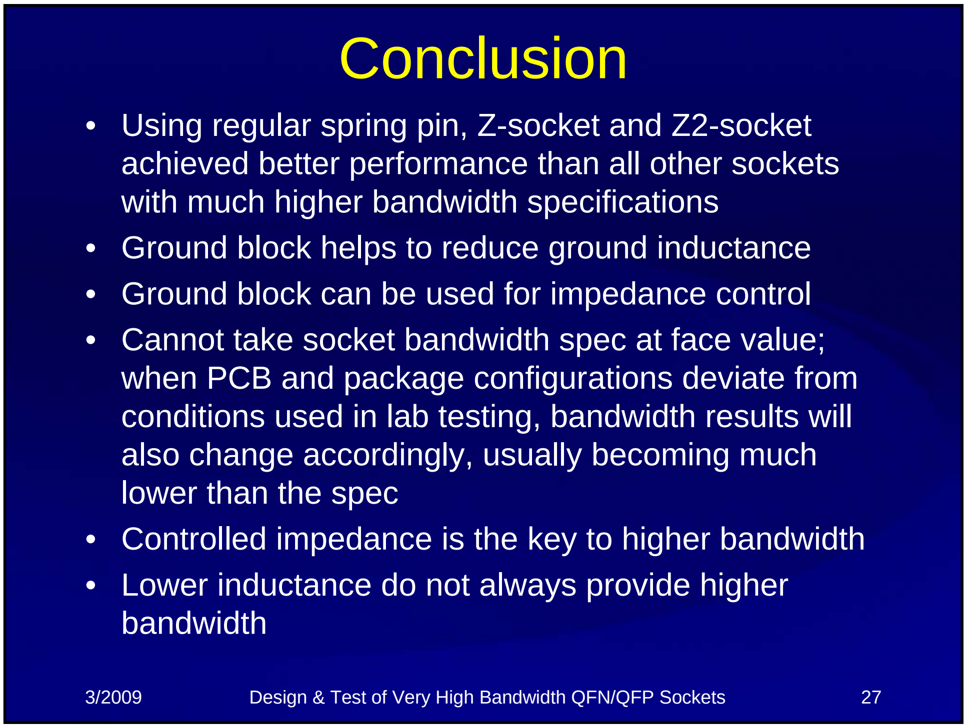
Z-socket mounted on functional test board

Device simulator mounted on nest



Z-socket Validation Test Results

- Z socket was cycled thru 300K cycles.
- Test results show that the device gain remains same throughout 300K cycles.
- Test results were repeatable for three different devices.



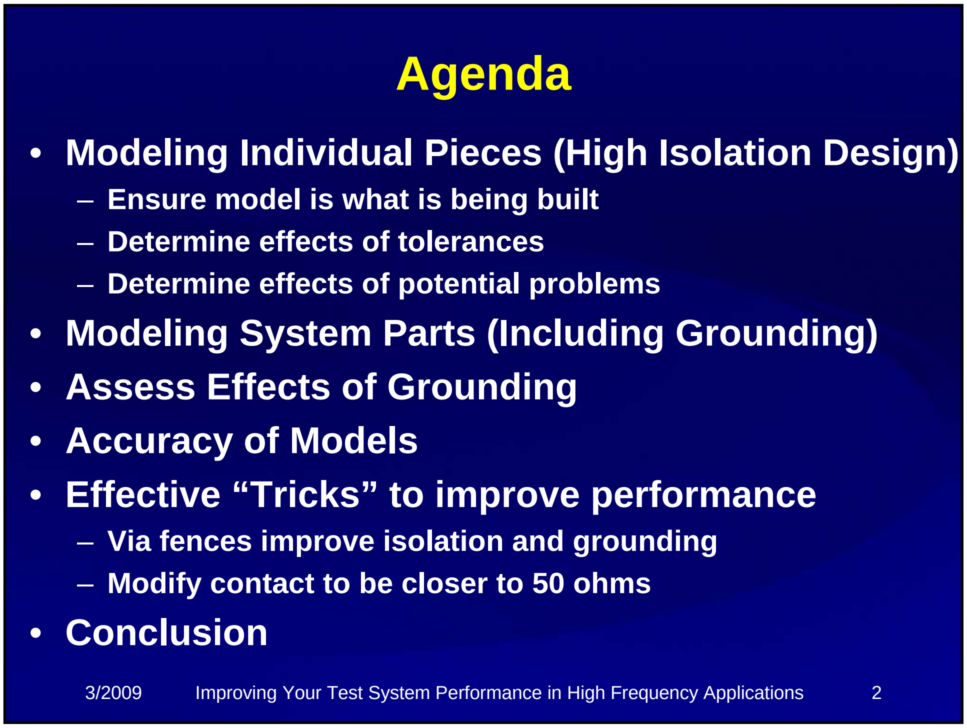
Conclusion

- Using regular spring pin, Z-socket and Z2-socket achieved better performance than all other sockets with much higher bandwidth specifications
- Ground block helps to reduce ground inductance
- Ground block can be used for impedance control
- Cannot take socket bandwidth spec at face value; when PCB and package configurations deviate from conditions used in lab testing, bandwidth results will also change accordingly, usually becoming much lower than the spec
- Controlled impedance is the key to higher bandwidth
- Lower inductance do not always provide higher bandwidth

Improving Your Test System Performance in High Frequency Applications

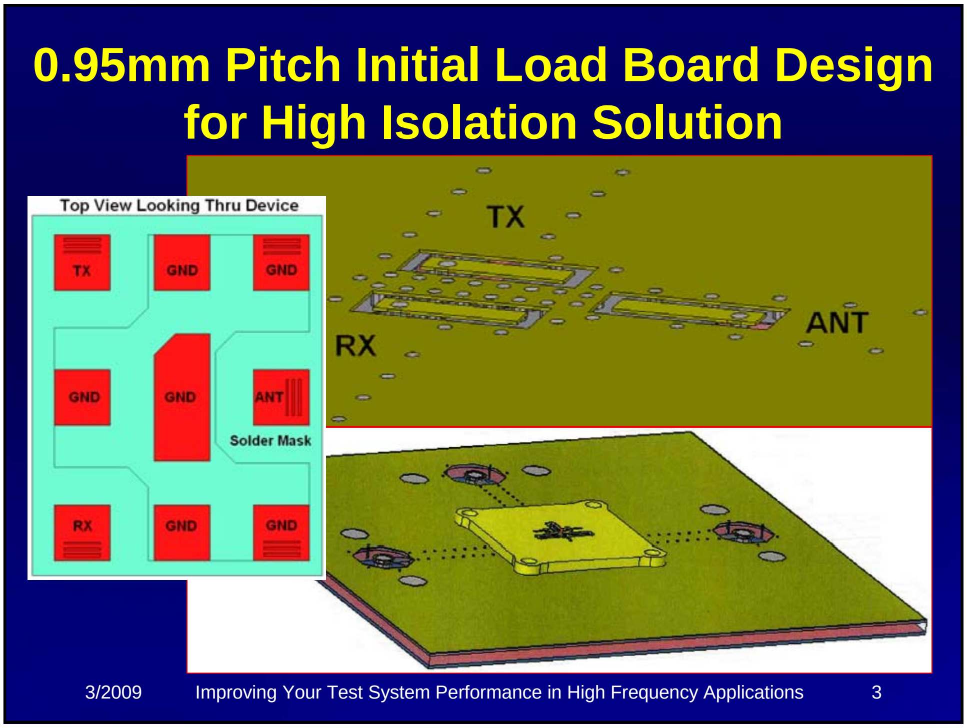
Jeff Sherry, Johnstech International
Michael Voo, Avago Technologies

2009 BiTS Workshop
March 8 - 11, 2009

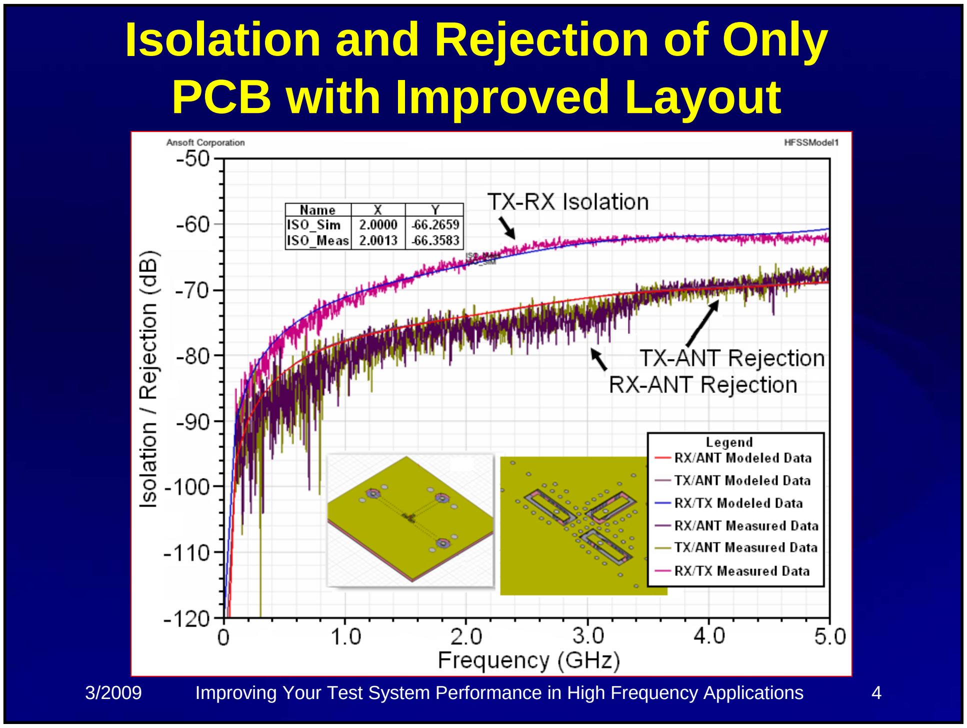


Agenda

- Modeling Individual Pieces (High Isolation Design)
  - Ensure model is what is being built
  - Determine effects of tolerances
  - Determine effects of potential problems
- Modeling System Parts (Including Grounding)
- Assess Effects of Grounding
- Accuracy of Models
- Effective “Tricks” to improve performance
  - Via fences improve isolation and grounding
  - Modify contact to be closer to 50 ohms
- Conclusion

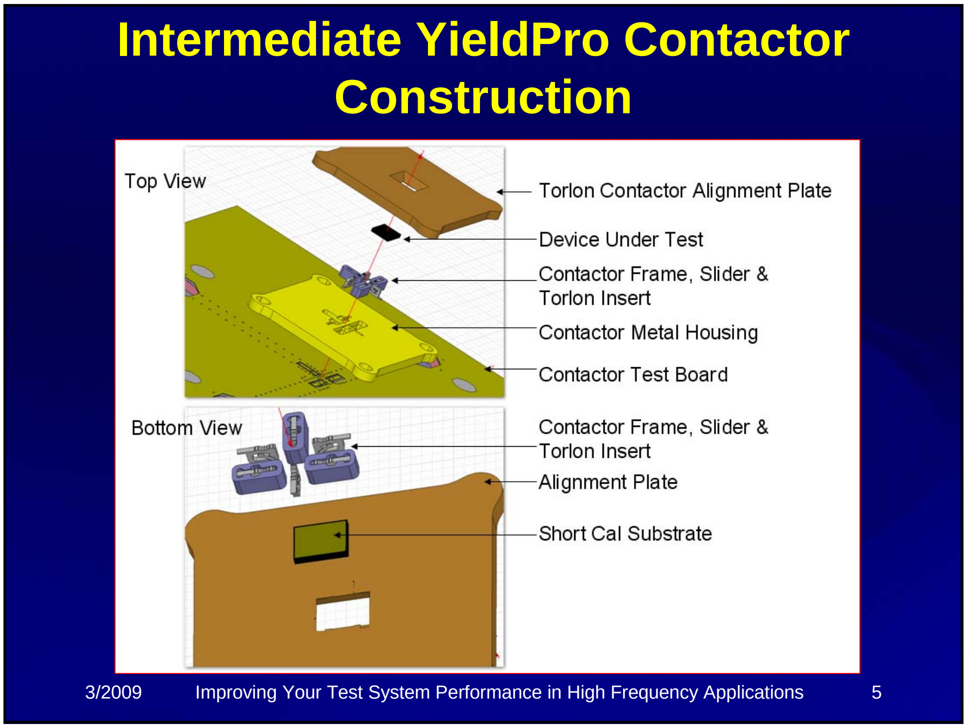


0.95mm Pitch Initial Load Board Design for High Isolation Solution



Isolation and Rejection of Only PCB with Improved Layout

Name	X	Y
ISO_Sim	2.0000	-66.2659
ISO_Meas	2.0013	-66.3583



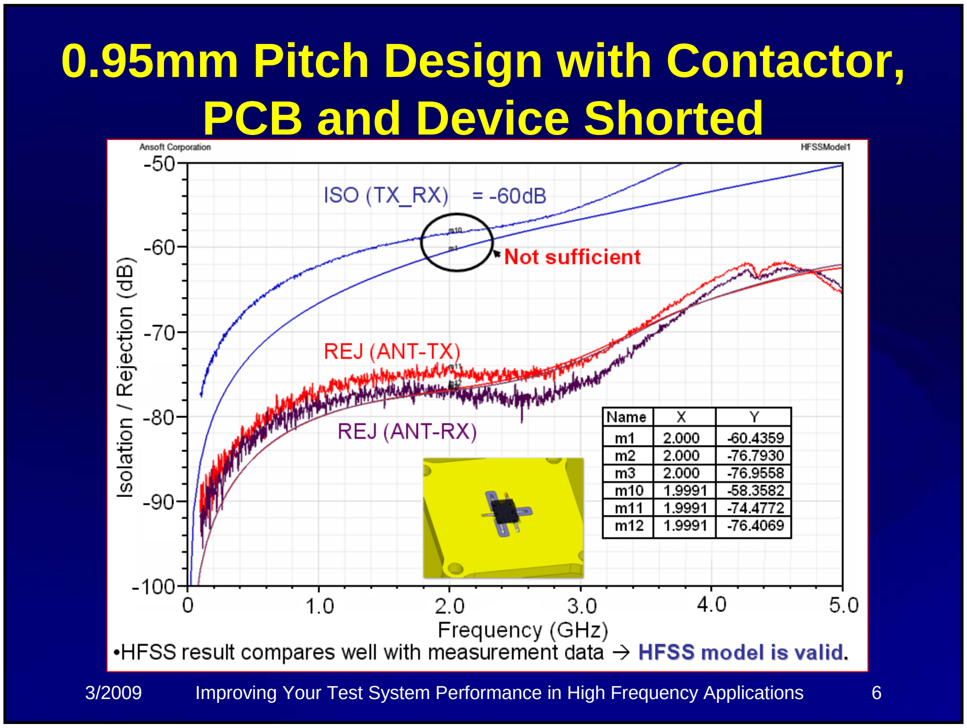
Intermediate YieldPro Contactor Construction

Top View

- Torlon Contactor Alignment Plate
- Device Under Test
- Contactor Frame, Slider & Torlon Insert
- Contactor Metal Housing
- Contactor Test Board

Bottom View

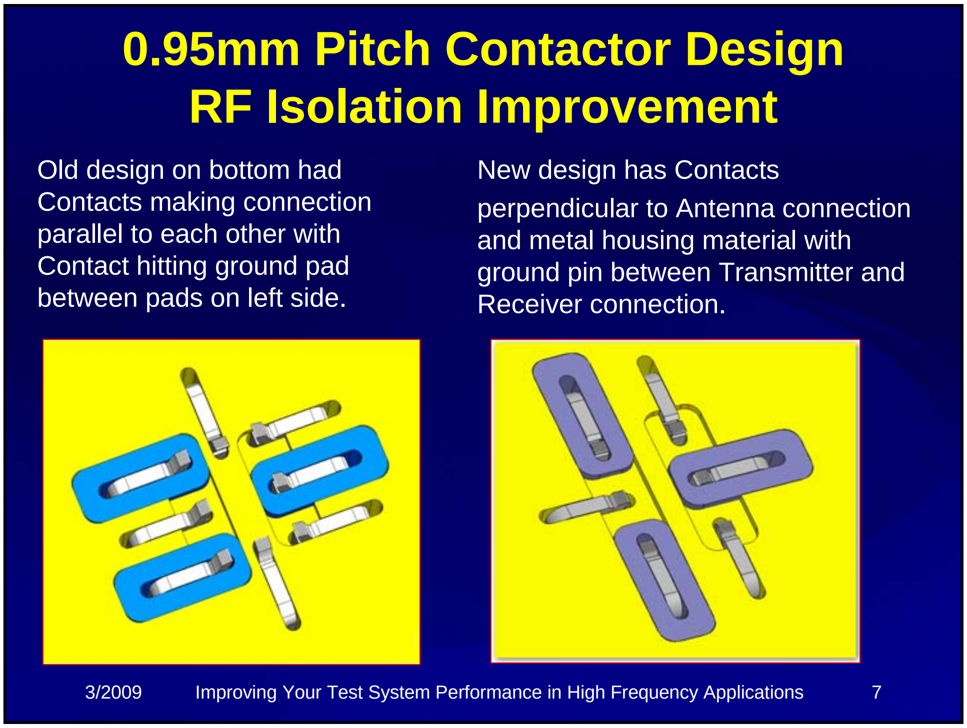
- Contactor Frame, Slider & Torlon Insert
- Alignment Plate
- Short Cal Substrate



0.95mm Pitch Design with Contactor, PCB and Device Shorted

Name	X	Y
m1	2.000	-60.4359
m2	2.000	-76.7930
m3	2.000	-76.9558
m10	1.9991	-58.3582
m11	1.9991	-74.4772
m12	1.9991	-76.4069

- HFSS result compares well with measurement data → **HFSS model is valid.**



0.95mm Pitch Contactor Design RF Isolation Improvement

Old design on bottom had Contacts making connection parallel to each other with Contact hitting ground pad between pads on left side.

New design has Contacts perpendicular to Antenna connection and metal housing material with ground pin between Transmitter and Receiver connection.

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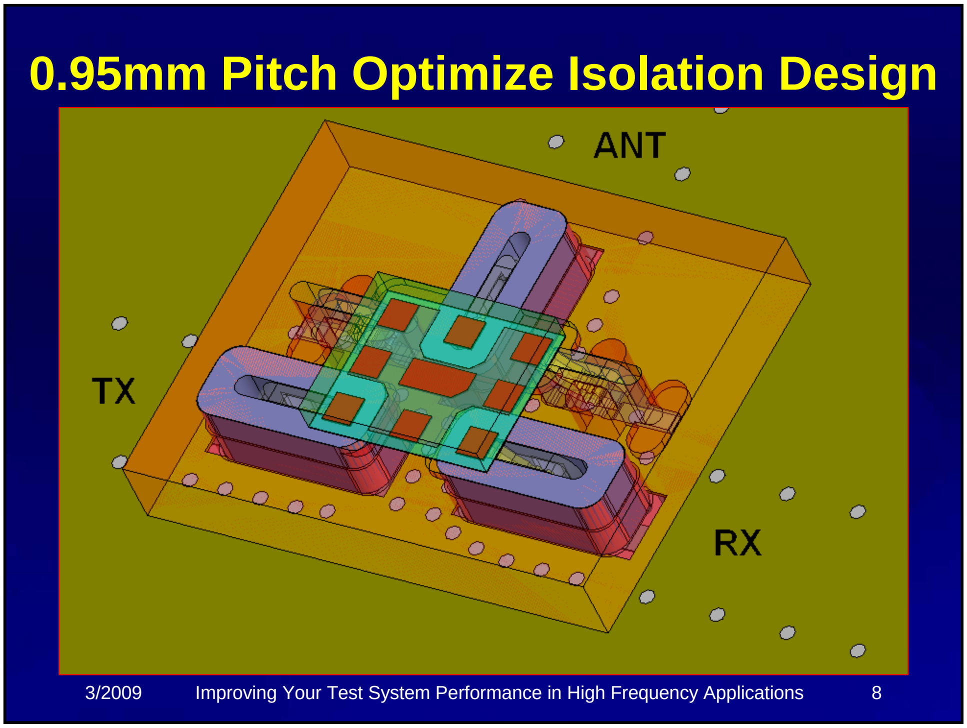

0.95mm Pitch Optimize Isolation Design

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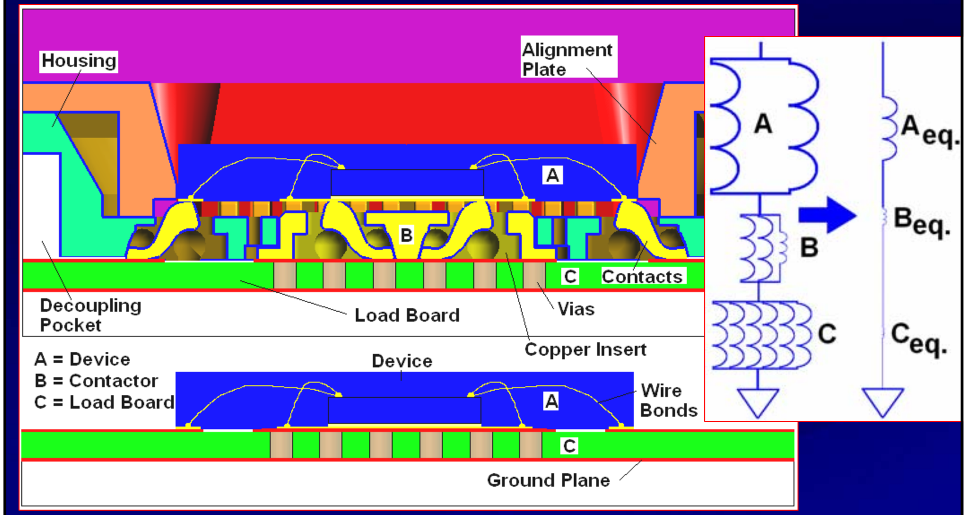
Accuracy and Design Margin Effects on Test Time

- Times are using a 40 GHz Agilent Network Analyzer set up to measure 201 points from 0 to 5 GHz. Digital BW Analyzers are faster

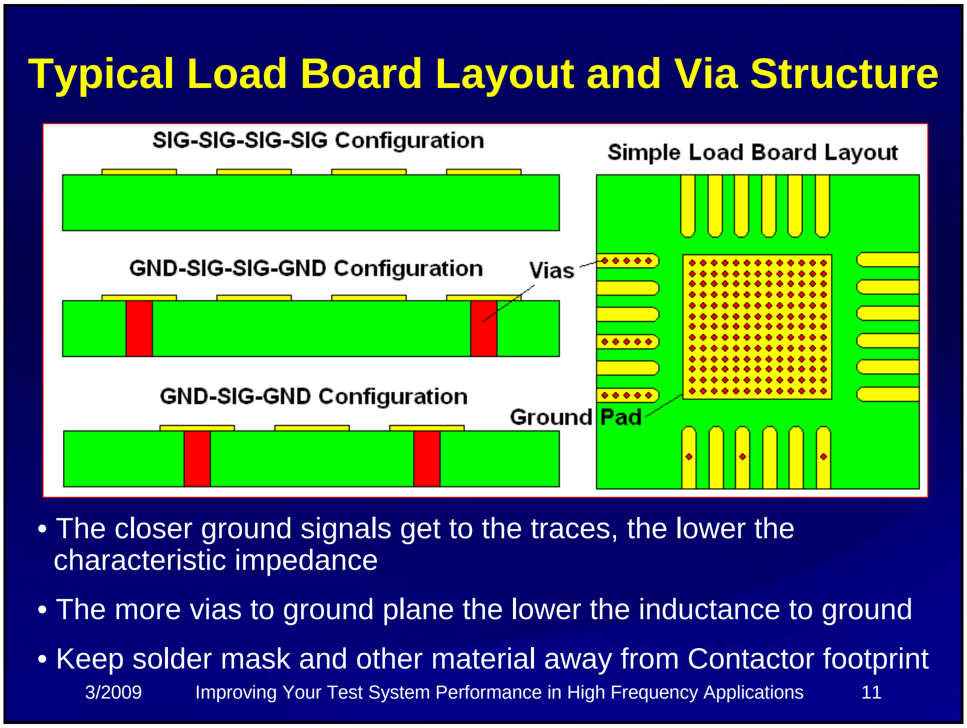
Network Analyzer Settings

IF BW	Test Time	Max. Noise
3000 Hz	100 ms	Reference
1000 Hz	225 ms	-4.78 dB
300 Hz	676 ms	-6.38 dB
100 Hz	1.976 s	-12.36 dB
30 Hz	6.526 s	-15.87 dB
10 Hz	20.826 s	-19.61 dB

Ground Inductance Paths

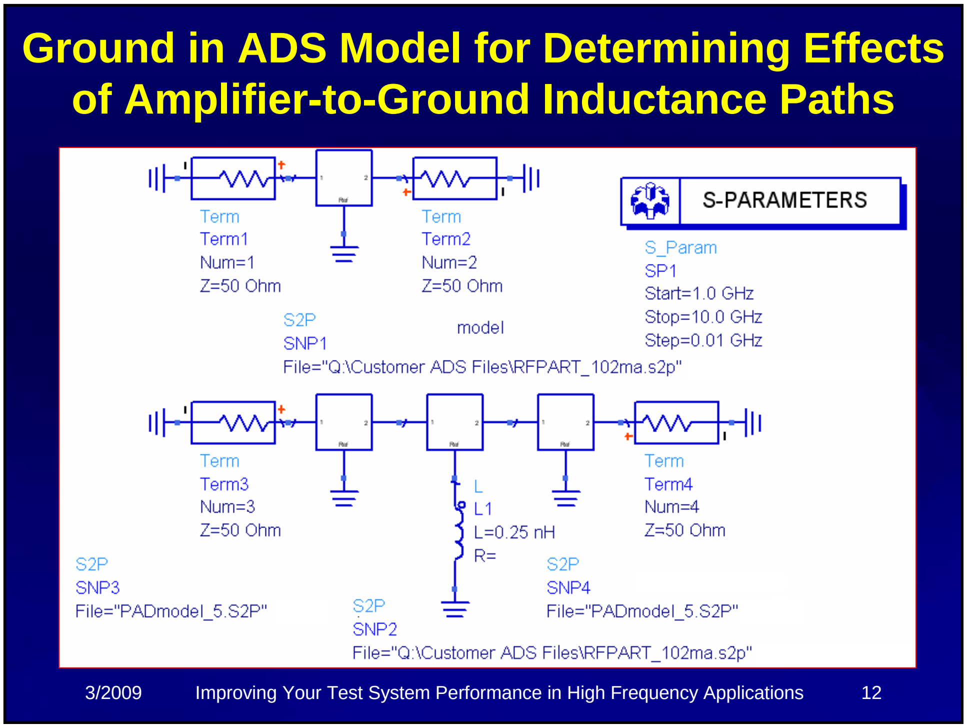


A = Device
B = Contactor
C = Load Board



Typical Load Board Layout and Via Structure

- The closer ground signals get to the traces, the lower the characteristic impedance
- The more vias to ground plane the lower the inductance to ground
- Keep solder mask and other material away from Contactor footprint



Ground in ADS Model for Determining Effects of Amplifier-to-Ground Inductance Paths

Term
Term1
Num=1
Z=50 Ohm

Term
Term2
Num=2
Z=50 Ohm

S_Param
SP1
Start=1.0 GHz
Stop=10.0 GHz
Step=0.01 GHz

S2P
SNP1
File="Q:\Customer ADS Files\RFPART_102ma.s2p"

Term
Term3
Num=3
Z=50 Ohm

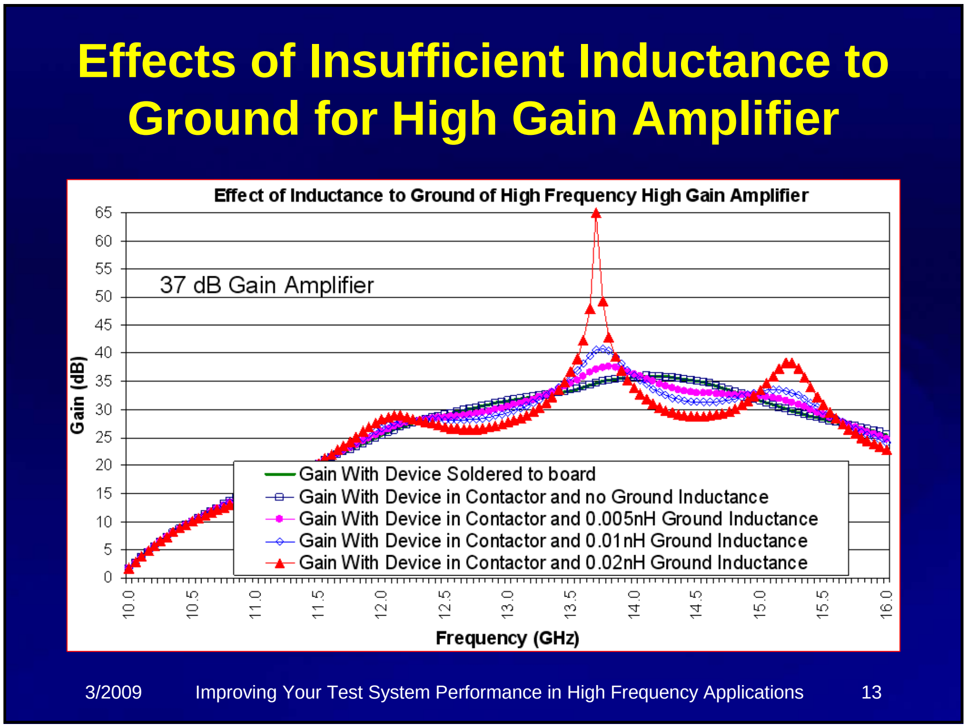
L
L1
L=0.25 nH
R=

Term
Term4
Num=4
Z=50 Ohm

S2P
SNP3
File="PADmodel_5.S2P"

S2P
SNP4
File="PADmodel_5.S2P"

S2P
SNP2
File="Q:\Customer ADS Files\RFPART_102ma.s2p"



Effects of Insufficient Inductance to Ground for High Gain Amplifier

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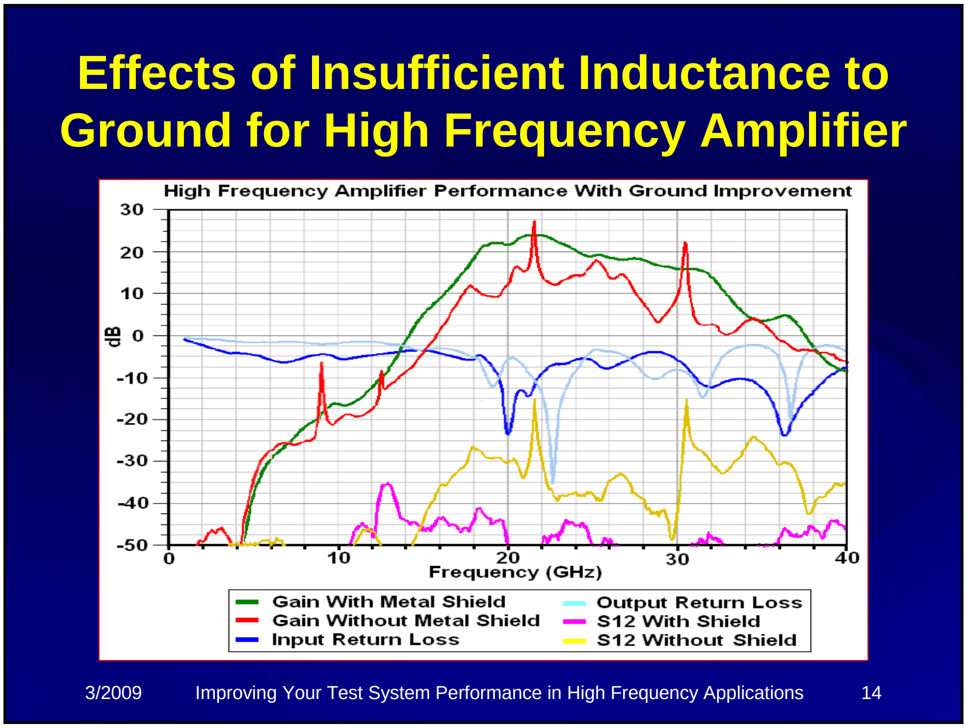

Effects of Insufficient Inductance to Ground for High Frequency Amplifier

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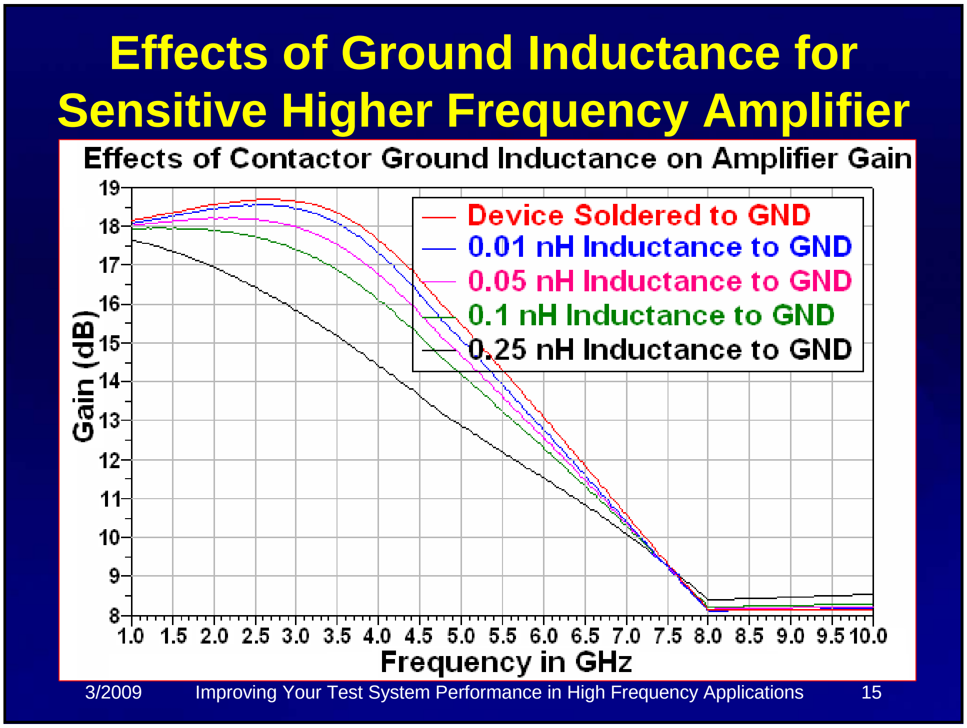

Effects of Ground Inductance for Sensitive Higher Frequency Amplifier

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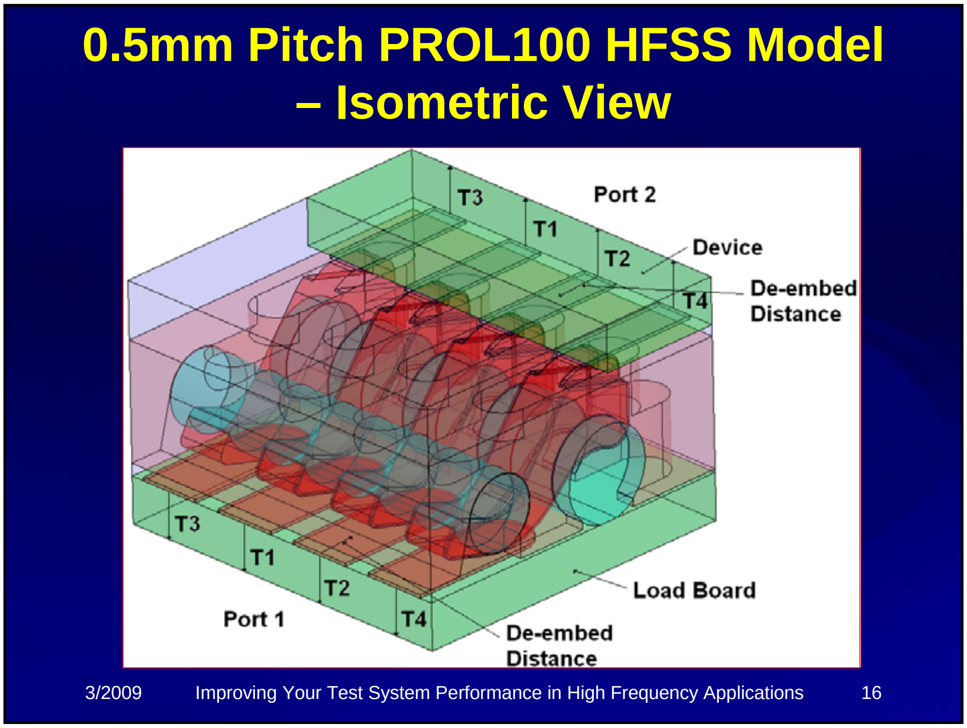

0.5mm Pitch PROL100 HFSS Model – Isometric View

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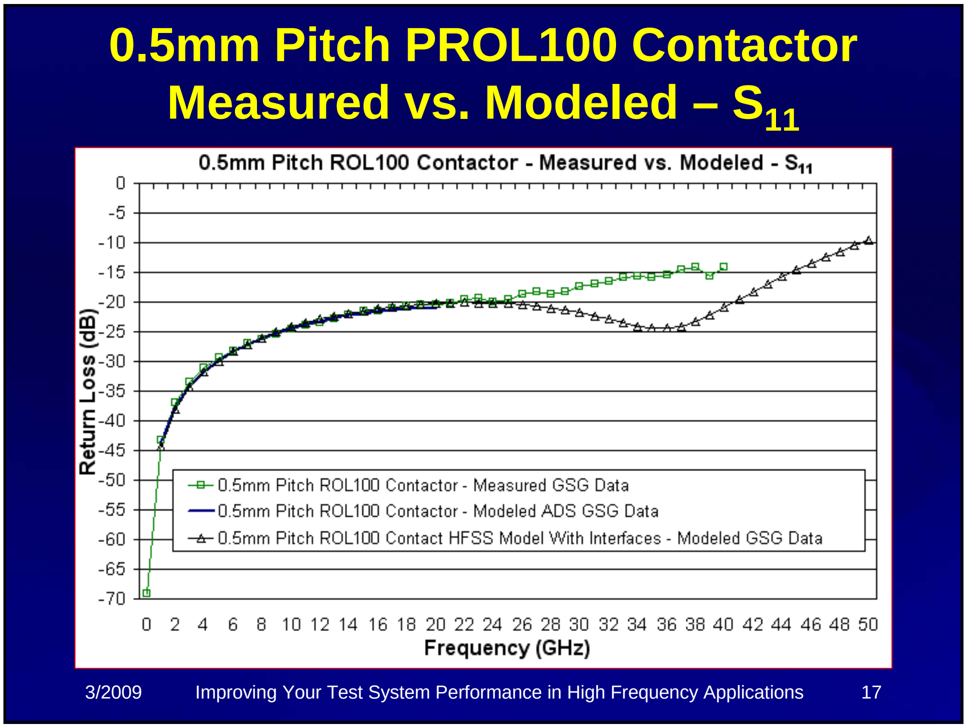
Paper #3



0.5mm Pitch PROL100 Contactor Measured vs. Modeled – S_{11}

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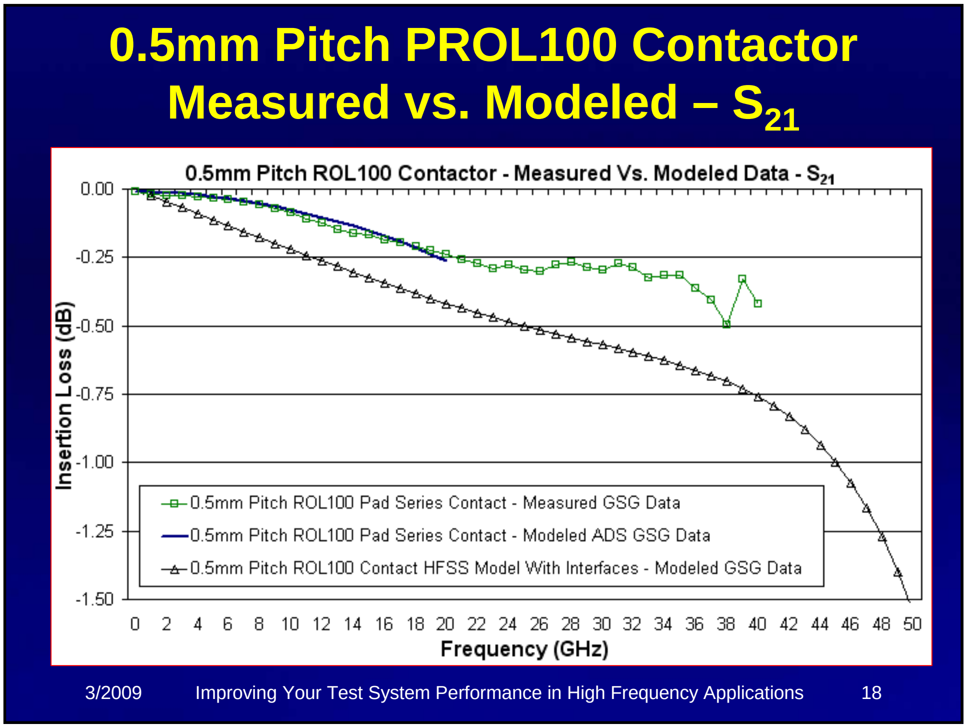

0.5mm Pitch PROL100 Contactor Measured vs. Modeled – S_{21}

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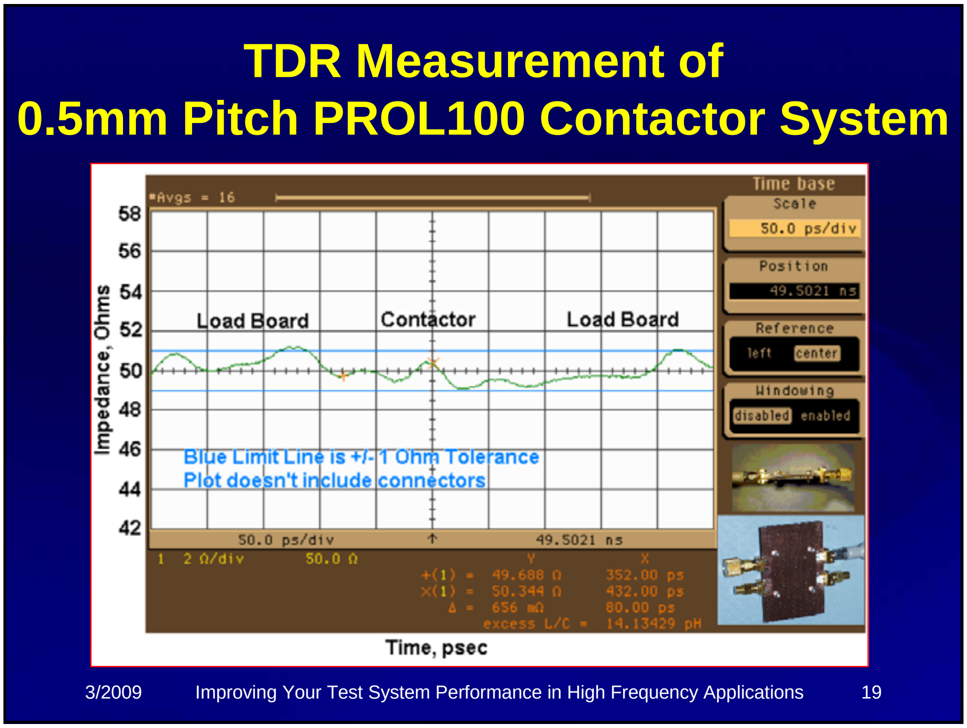


TDR Measurement of 0.5mm Pitch PROL100 Contactor System

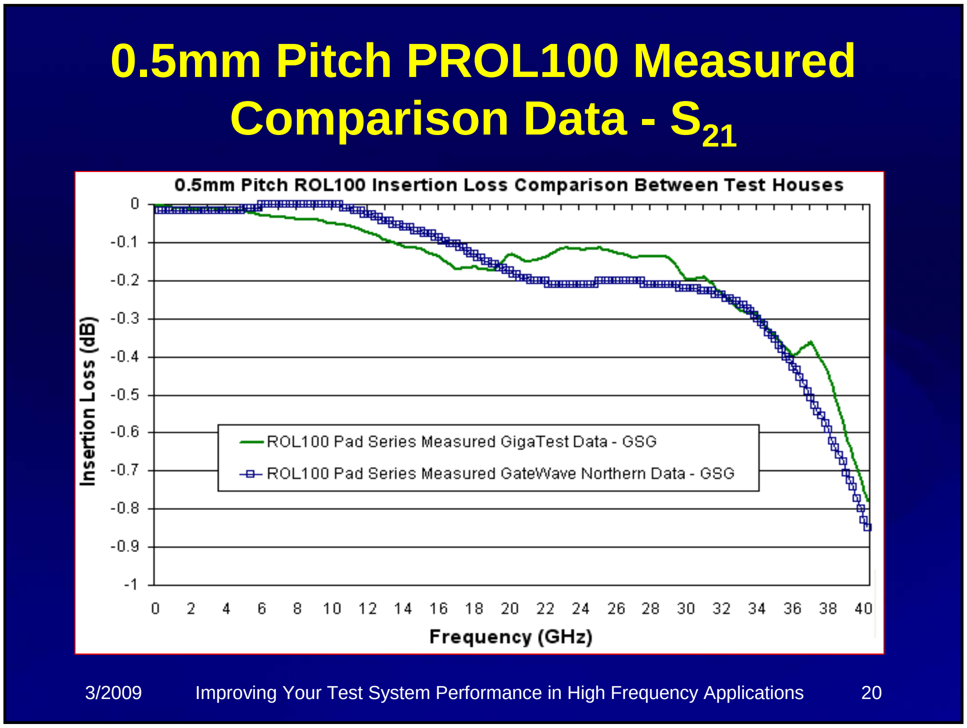
Scale 50.0 ps/div

Position 49.5021 ns

Blue Limit Line is +/-1 Ohm Tolerance

Plot doesn't include connectors

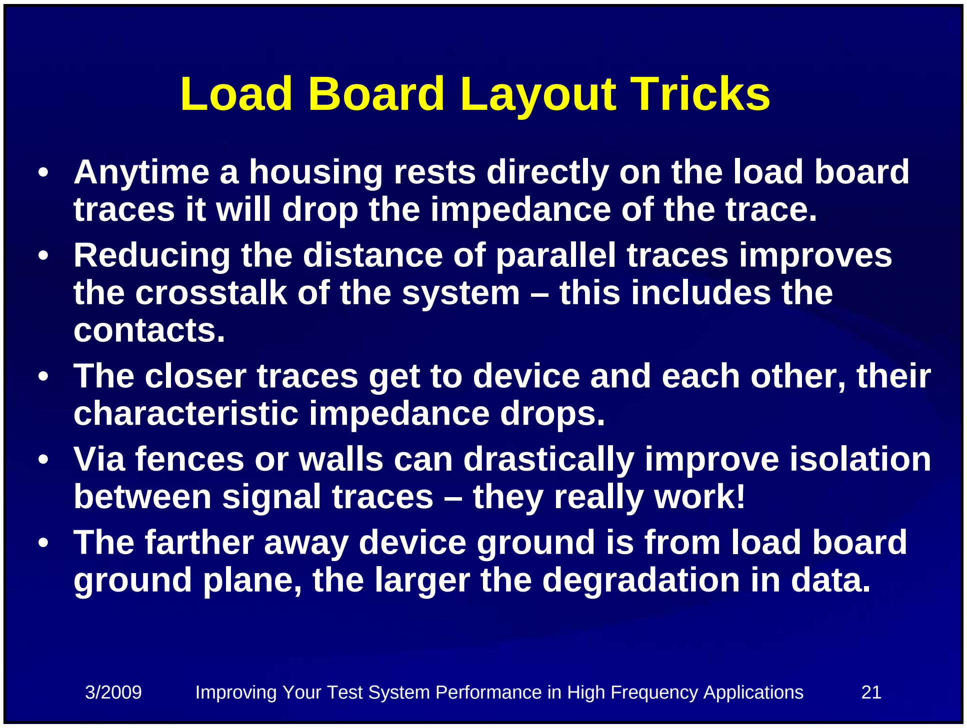
```
1  2 Ω/div       50.0 Ω
                         Y            X
             +(1) =  49.688 Ω     352.00 ps
             ×(1) =  50.344 Ω     432.00 ps
                Δ =  656 mΩ       80.00 ps
                  excess L/C =    14.13429 pH
```



0.5mm Pitch PROL100 Measured Comparison Data - S_{21}

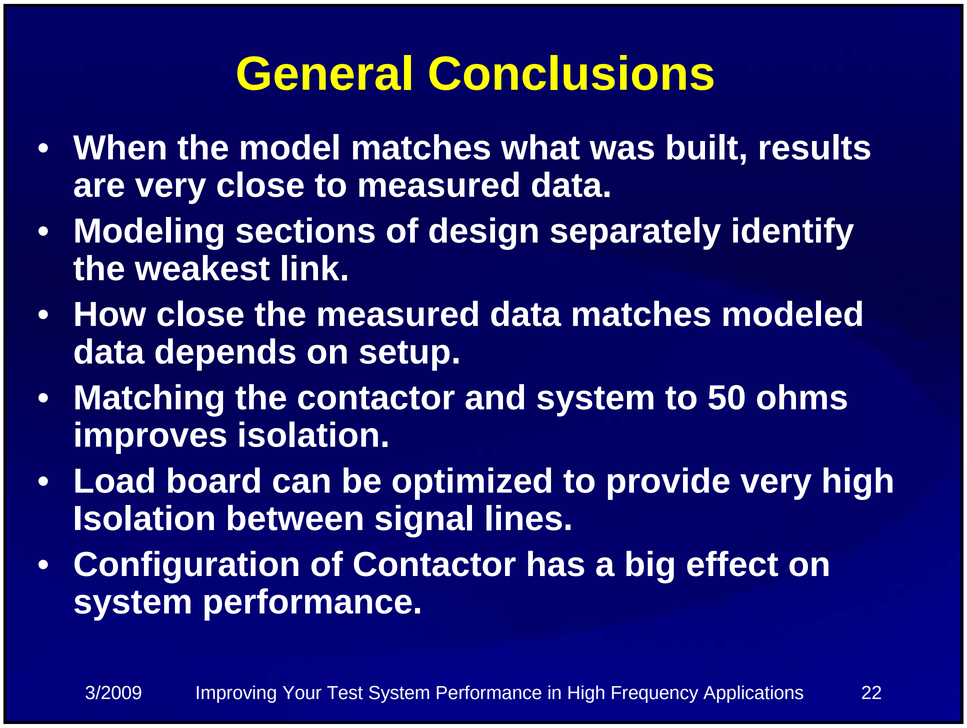
0.5mm Pitch ROL100 Insertion Loss Comparison Between Test Houses

Paper #3



Load Board Layout Tricks

- Anytime a housing rests directly on the load board traces it will drop the impedance of the trace.
- Reducing the distance of parallel traces improves the crosstalk of the system – this includes the contacts.
- The closer traces get to device and each other, their characteristic impedance drops.
- Via fences or walls can drastically improve isolation between signal traces – they really work!
- The farther away device ground is from load board ground plane, the larger the degradation in data.



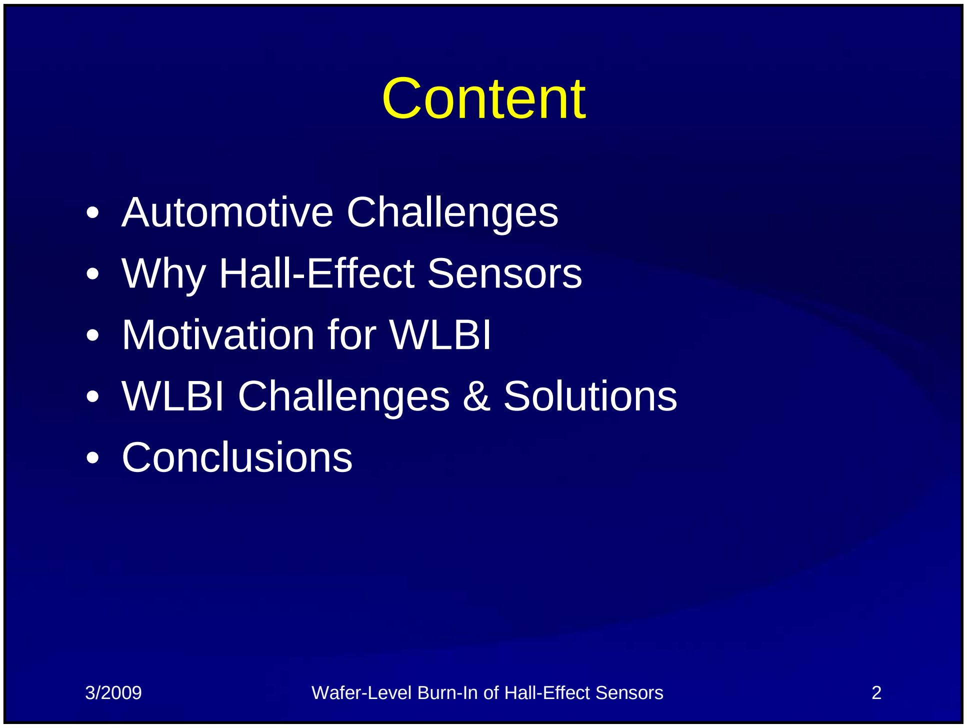
General Conclusions

- When the model matches what was built, results are very close to measured data.
- Modeling sections of design separately identify the weakest link.
- How close the measured data matches modeled data depends on setup.
- Matching the contactor and system to 50 ohms improves isolation.
- Load board can be optimized to provide very high Isolation between signal lines.
- Configuration of Contactor has a big effect on system performance.

Wafer-Level Burn-In of Hall-Effect Sensors

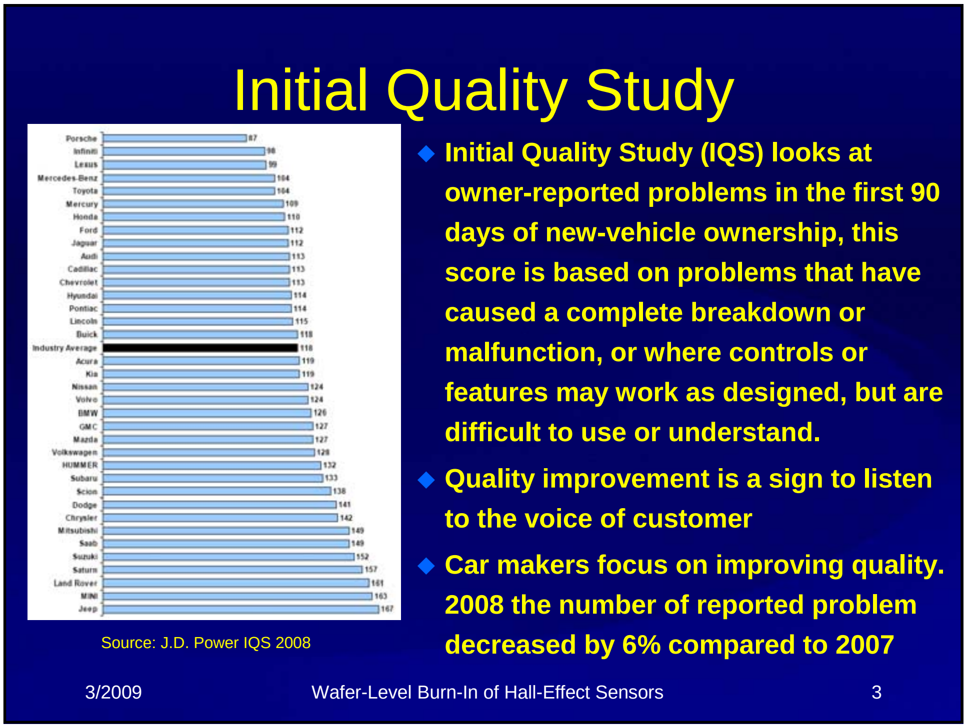
Steve Steps, Aehr Test Systems
Jochen Seidler, Micronas GmbH

2009 BiTS Workshop
March 8 - 11, 2009



Content

- Automotive Challenges
- Why Hall-Effect Sensors
- Motivation for WLBI
- WLBI Challenges & Solutions
- Conclusions



Initial Quality Study

Source: J.D. Power IQS 2008

- **Initial Quality Study (IQS) looks at owner-reported problems in the first 90 days of new-vehicle ownership, this score is based on problems that have caused a complete breakdown or malfunction, or where controls or features may work as designed, but are difficult to use or understand.**
- **Quality improvement is a sign to listen to the voice of customer**
- **Car makers focus on improving quality. 2008 the number of reported problem decreased by 6% compared to 2007**

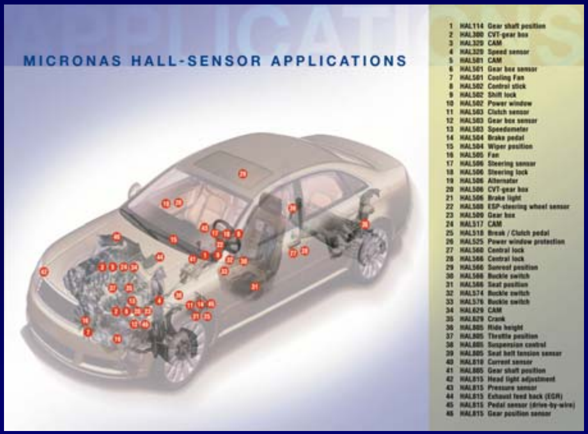
Automotive Environment

- Temperature extremes
  - Closed car in summer sunshine
  - Empty car at night in Northern climates
- Vibration
- Abrasive dirt & dust
- Solvents (oil, gasoline, etc.)
- High humidity, Moisture

Hall-Effect Sensors

- Provide sensing of
  - – Contact (like a switch)
  - – Position (like a potentiometer)
- Sealed
- No abrasive wear
- Simple, highly reliable

Hall-Effect Sensor Applications



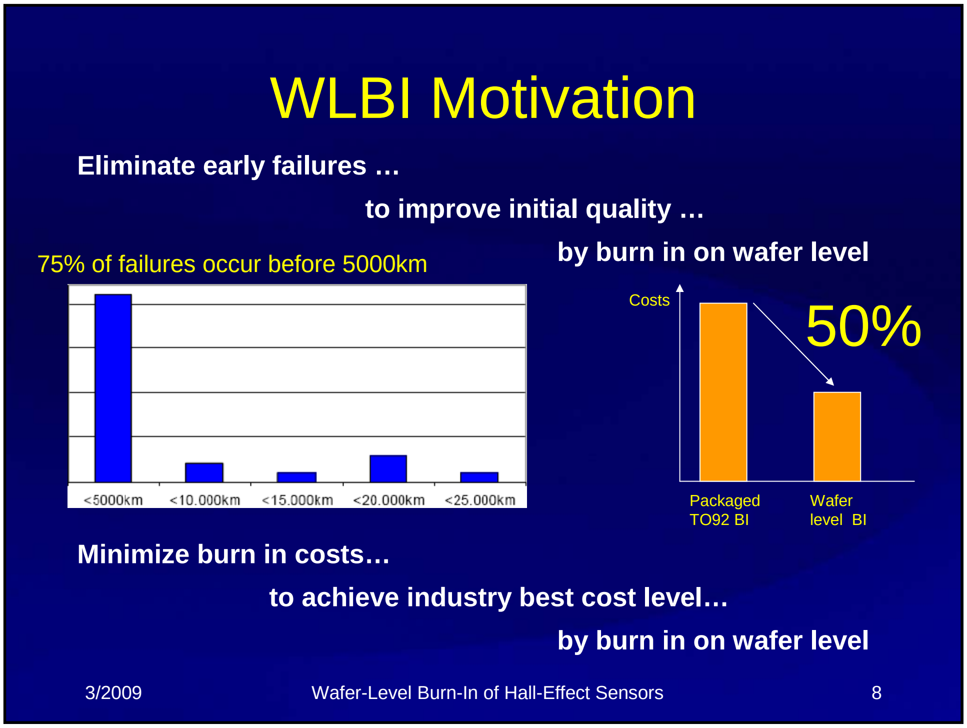
1	HAL114	Gear shaft position
2	HAL300	CVT-gear box
3	HAL320	CAM
4	HAL320	Speed sensor
5	HAL501	CAM
6	HAL501	Gear box sensor
7	HAL501	Cooling Fan
8	HAL502	Control stick
9	HAL502	Shift lock
10	HAL502	Power window
11	HAL503	Clutch sensor
12	HAL503	Gear box sensor
13	HAL503	Speedometer
14	HAL504	Brake pedal
15	HAL504	Wiper position
16	HAL505	Fan
17	HAL506	Steering sensor
18	HAL506	Steering lock
19	HAL506	Alternator
20	HAL506	CVT-gear box
21	HAL506	Brake light
22	HAL508	ESP-steering wheel sensor
23	HAL509	Gear box
24	HAL517	CAM
25	HAL518	Break / Clutch pedal
26	HAL525	Power window protection
27	HAL560	Central lock
28	HAL566	Central lock
29	HAL566	Sunroof position
30	HAL566	Buckle switch
31	HAL566	Seat position
32	HAL574	Buckle switch
33	HAL576	Buckle switch
34	HAL629	CAM
35	HAL629	Crank
36	HAL805	Ride height
37	HAL805	Throttle position
38	HAL805	Suspension control
39	HAL805	Seat belt tension sensor
40	HAL810	Current sensor
41	HAL805	Gear shaft position
42	HAL815	Head light adjustment
43	HAL815	Pressure sensor
44	HAL815	Exhaust feed back (EGR)
45	HAL815	Pedal sensor (drive-by-wire)
46	HAL815	Gear position sensor

- **Hall-Sensors used in dozens of switch and position applications**
- **Critical: brake switch, speedometer, cooling fan, etc.**
- **Convenience: ride height, suspension control, seat position, etc.**

WLBI Motivation

Micronas zero ppm program

- Targets:
  - No failures on customer side
  - Satisfy automotive quality requirements
  - Improve continuously
    - Products
    - Production
    - Personnel
    - Processes



WLBI Motivation

Eliminate early failures …

to improve initial quality …

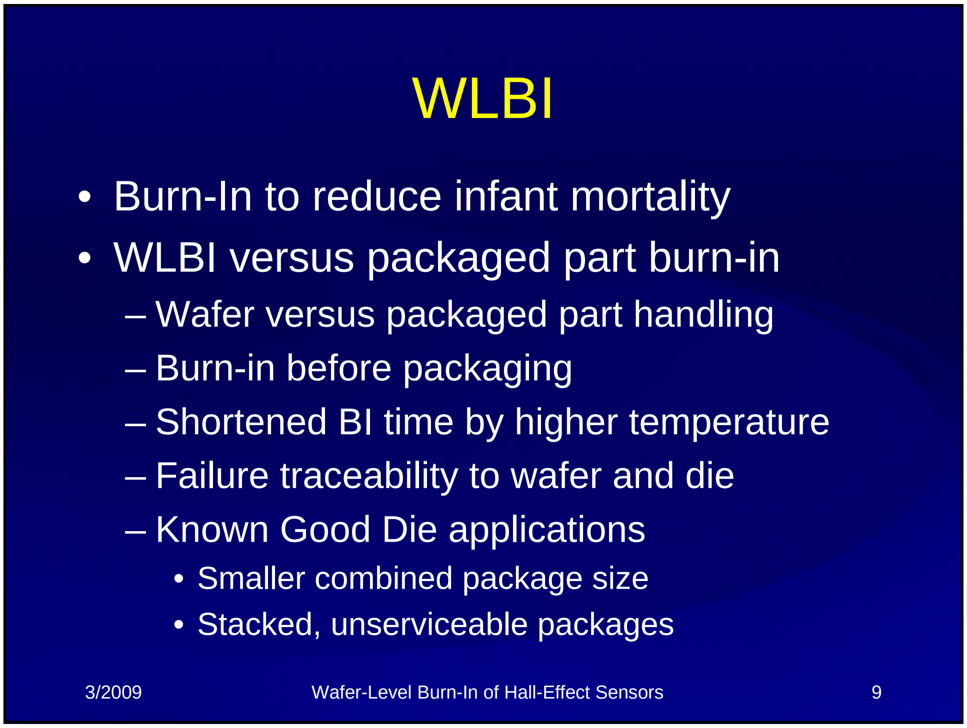
by burn in on wafer level

75% of failures occur before 5000km

Minimize burn in costs…

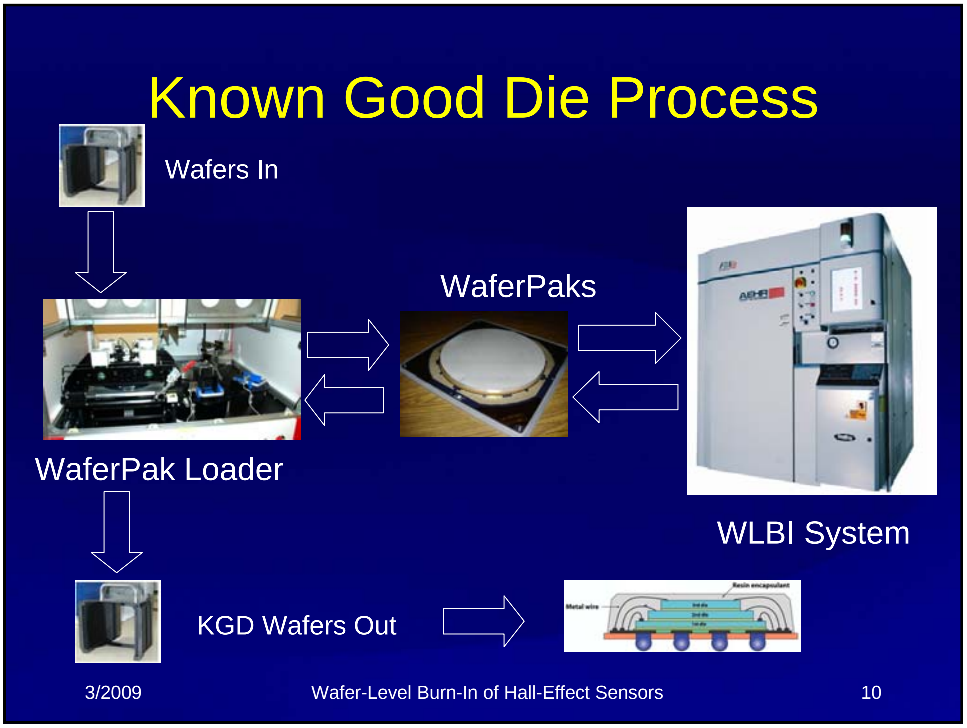
to achieve industry best cost level…

by burn in on wafer level

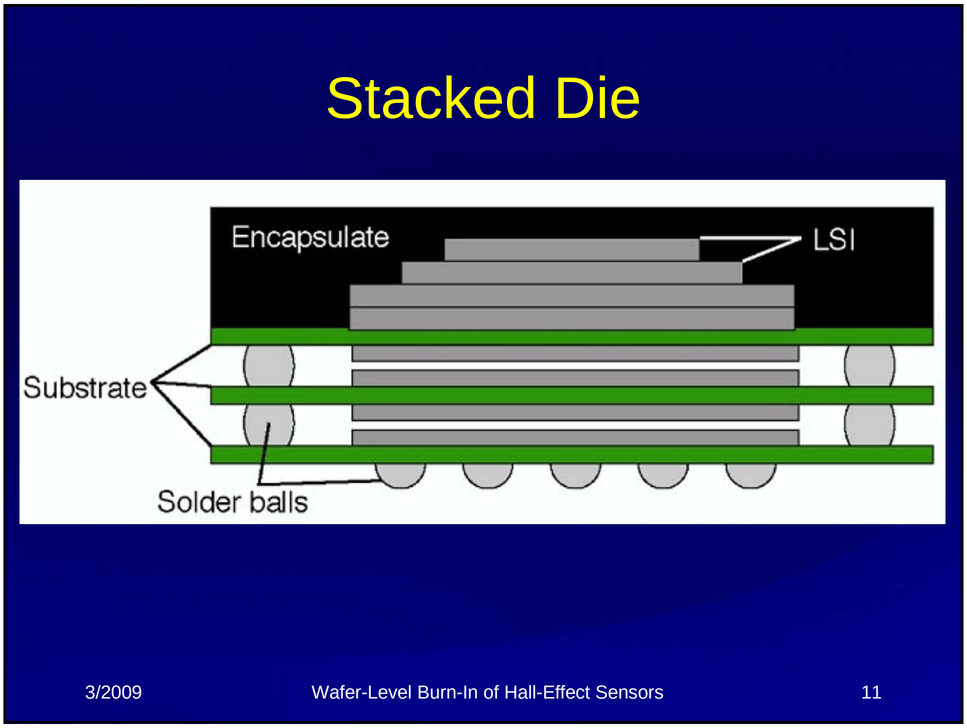


WLBI

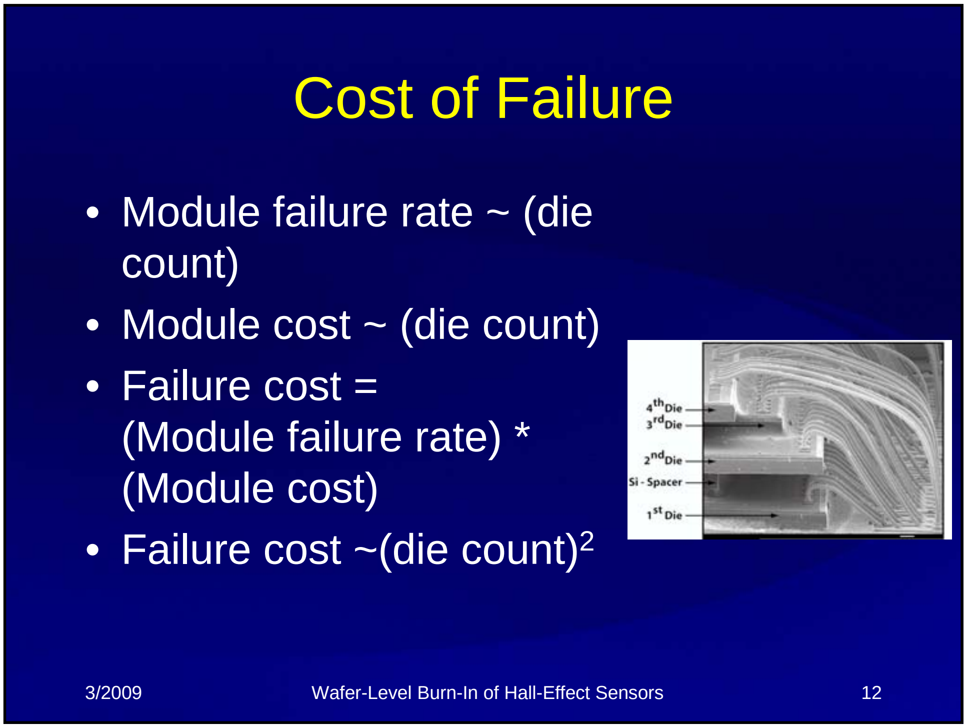
- Burn-In to reduce infant mortality
- WLBI versus packaged part burn-in
  - – Wafer versus packaged part handling
  - – Burn-in before packaging
  - – Shortened BI time by higher temperature
  - – Failure traceability to wafer and die
  - – Known Good Die applications
    - Smaller combined package size
    - Stacked, unserviceable packages



Known Good Die Process

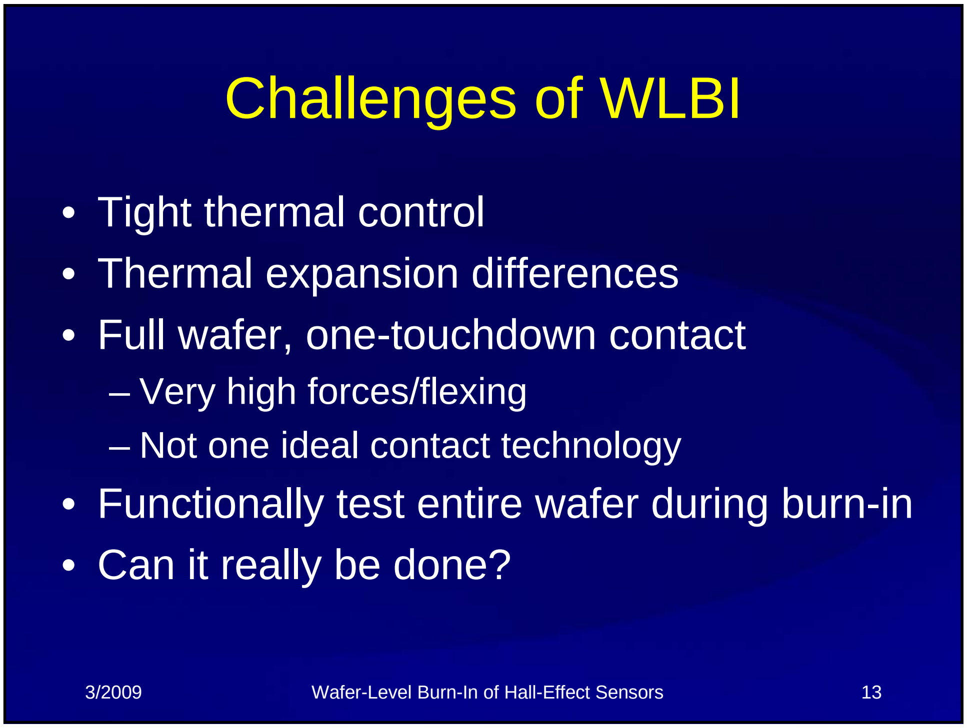


Stacked Die



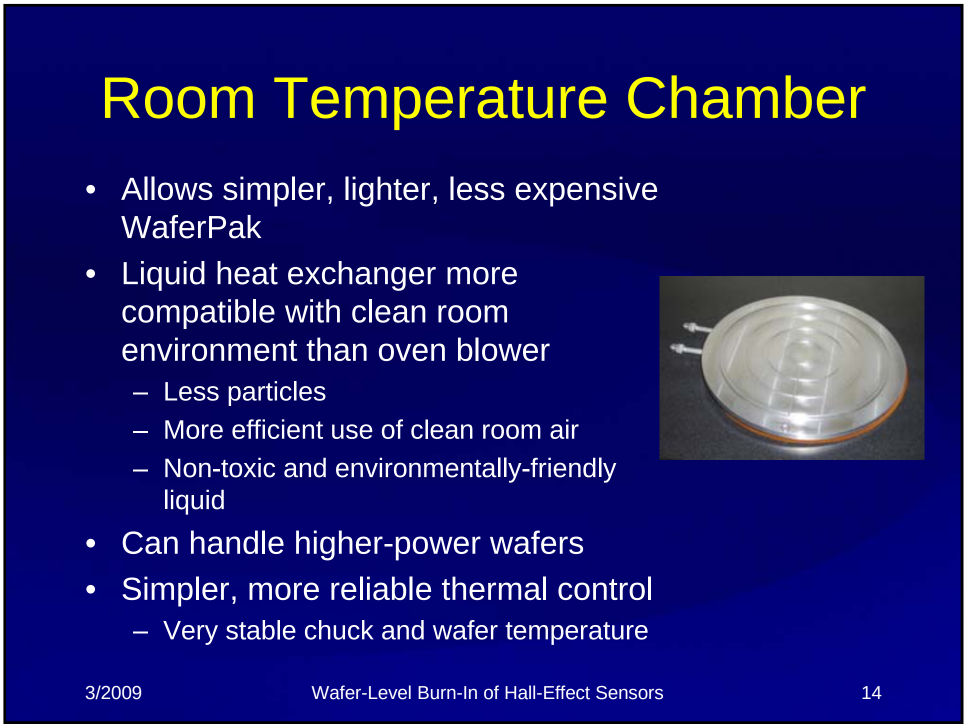
Cost of Failure

- Module failure rate ~ (die count)
- Module cost ~ (die count)
- Failure cost = (Module failure rate) * (Module cost)
- Failure cost ~(die count)^2



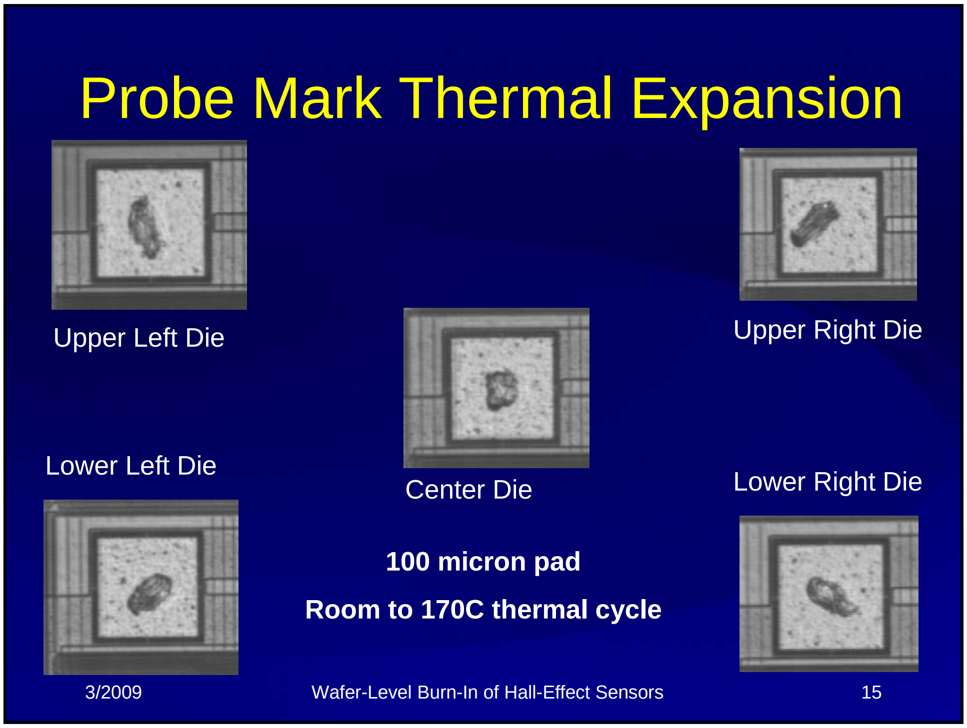
Challenges of WLBI

- Tight thermal control
- Thermal expansion differences
- Full wafer, one-touchdown contact
  - Very high forces/flexing
  - Not one ideal contact technology
- Functionally test entire wafer during burn-in
- Can it really be done?



Room Temperature Chamber

- Allows simpler, lighter, less expensive WaferPak
- Liquid heat exchanger more compatible with clean room environment than oven blower
  - Less particles
  - More efficient use of clean room air
  - Non-toxic and environmentally-friendly liquid
- Can handle higher-power wafers
- Simpler, more reliable thermal control
  - Very stable chuck and wafer temperature



Probe Mark Thermal Expansion

Upper Left Die

Upper Right Die

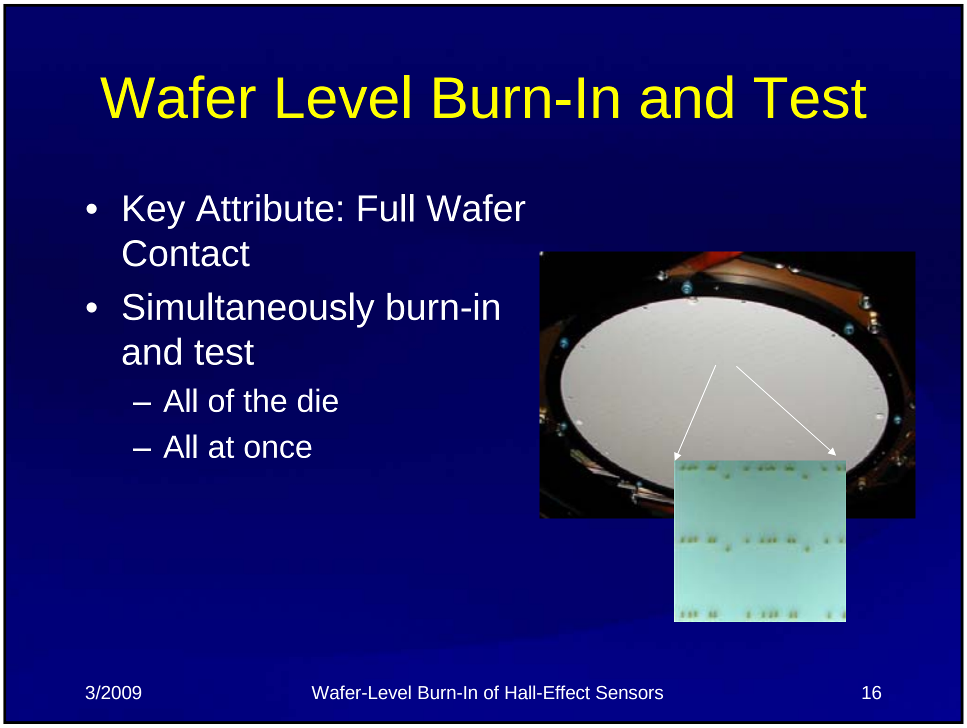
Center Die

Lower Left Die

Lower Right Die

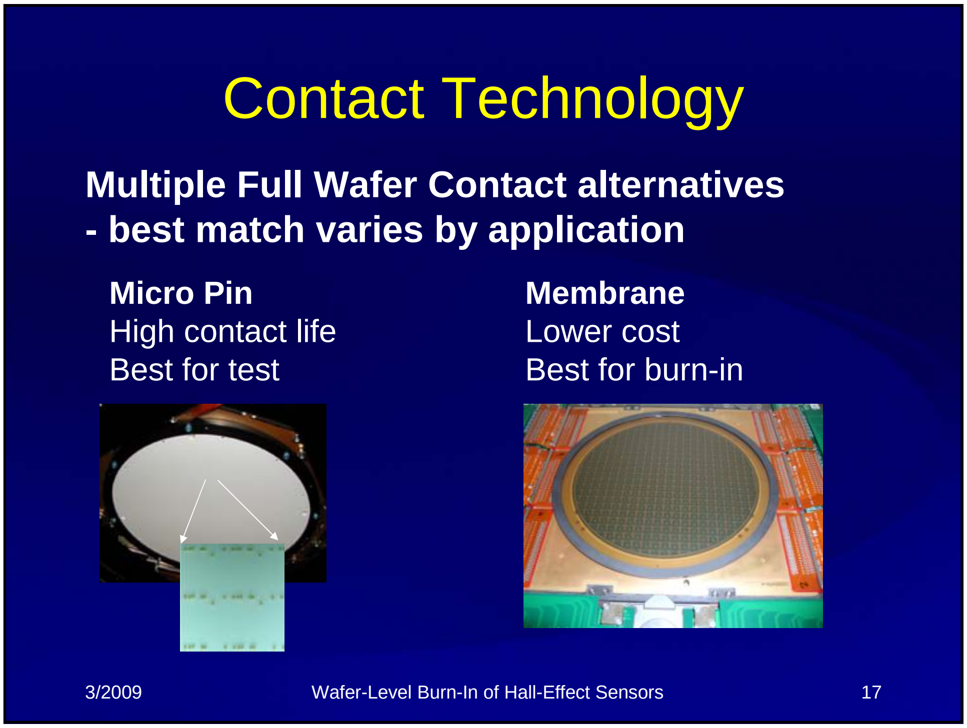
100 micron pad

Room to 170C thermal cycle



Wafer Level Burn-In and Test

- Key Attribute: Full Wafer Contact
- Simultaneously burn-in and test
  - All of the die
  - All at once

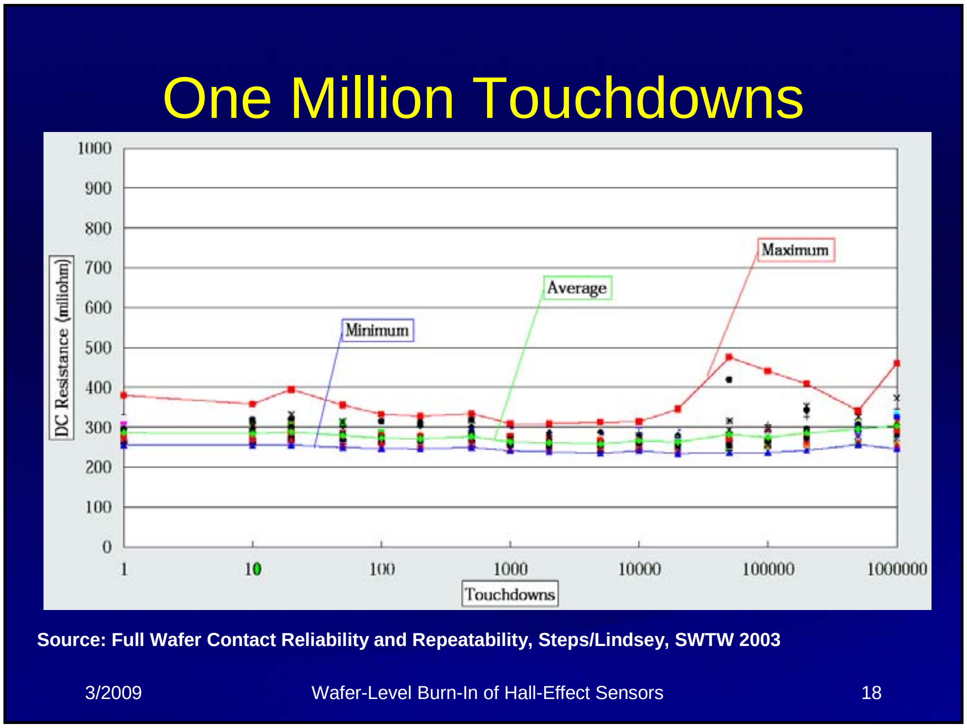


Contact Technology

Multiple Full Wafer Contact alternatives
- best match varies by application

Micro Pin	**Membrane**
High contact life	Lower cost
Best for test	Best for burn-in

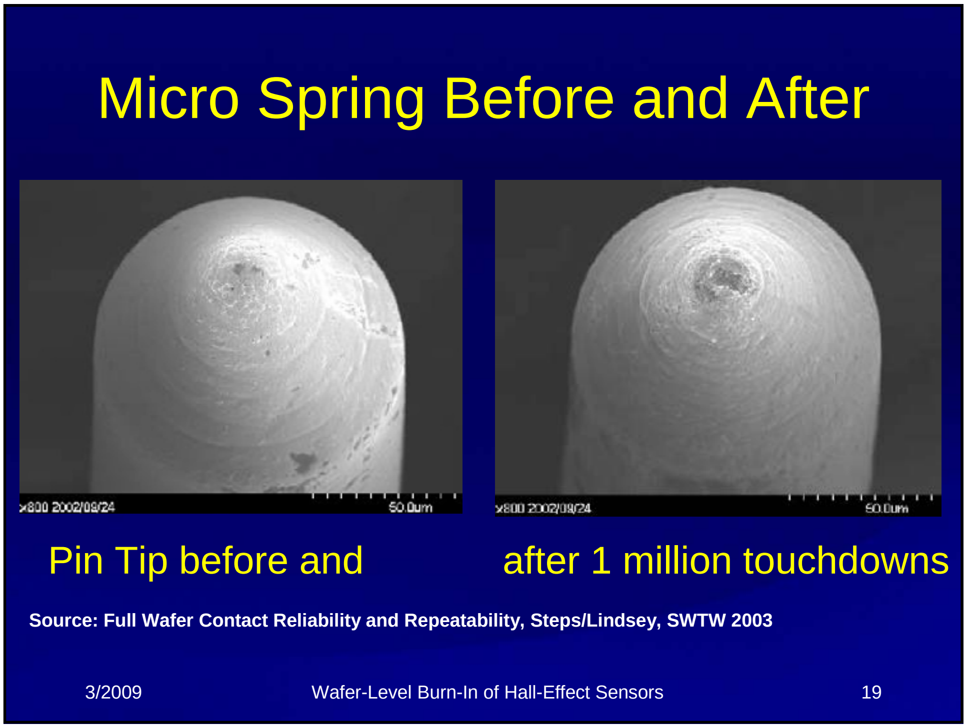
3/2009 Wafer-Level Burn-In of Hall-Effect Sensors 17



One Million Touchdowns

Source: Full Wafer Contact Reliability and Repeatability, Steps/Lindsey, SWTW 2003

3/2009 Wafer-Level Burn-In of Hall-Effect Sensors 18

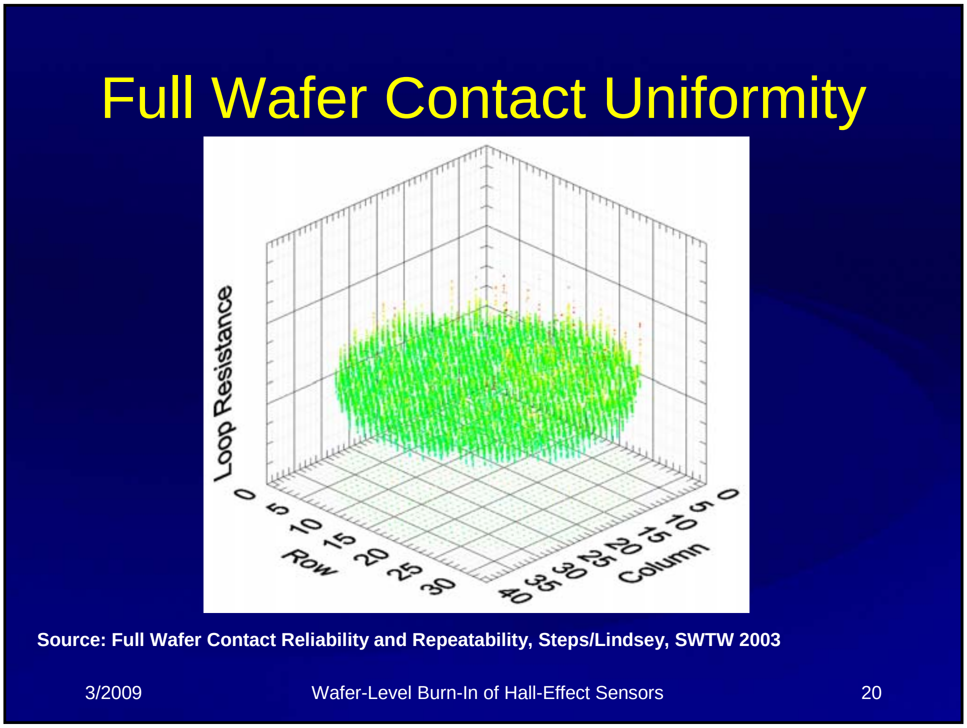


Micro Spring Before and After

Pin Tip before and after 1 million touchdowns

Source: Full Wafer Contact Reliability and Repeatability, Steps/Lindsey, SWTW 2003

3/2009 Wafer-Level Burn-In of Hall-Effect Sensors 19



Full Wafer Contact Uniformity

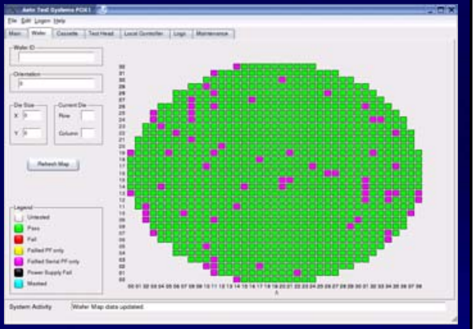
Source: Full Wafer Contact Reliability and Repeatability, Steps/Lindsey, SWTW 2003

3/2009 Wafer-Level Burn-In of Hall-Effect Sensors 20

Test During Burn-In

High Correlation (Typically > 99%) of:

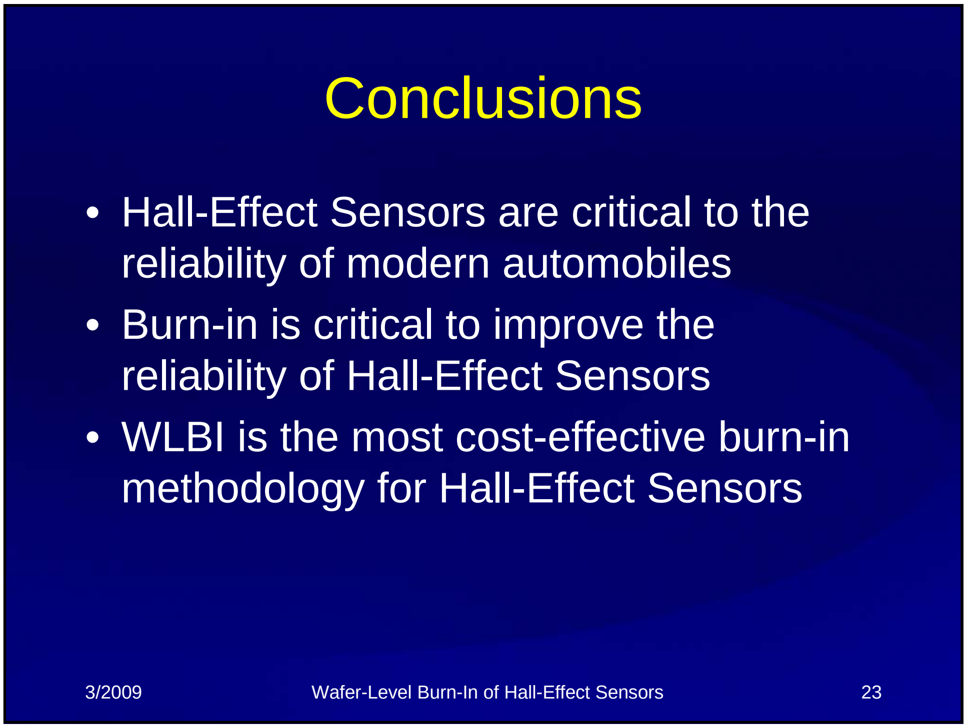
-WLBT
-Normal prober approach



System Activity: Wafer Map data updated

WLBI Production Systems

- Combine single touchdown, full wafer test with burn-in
- Wafer in/wafer out production flow
- Low volume WLBI can be done with 2 wafer system
- Full production can use 15 wafer system



Conclusions

- Hall-Effect Sensors are critical to the reliability of modern automobiles
- Burn-in is critical to improve the reliability of Hall-Effect Sensors
- WLBI is the most cost-effective burn-in methodology for Hall-Effect Sensors