Operational Reliability of RF MEMS

Ohmic-Contact RF MEMS Relay Repeatability, Lifetime, and Environmental Test Methods

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Overview

- **Component Application**
- Test Methods & Data
  - Performance Characterization
  - Environmental Reliability
  - Operational Lifetime
  - Operational Repeatability
- Future Work

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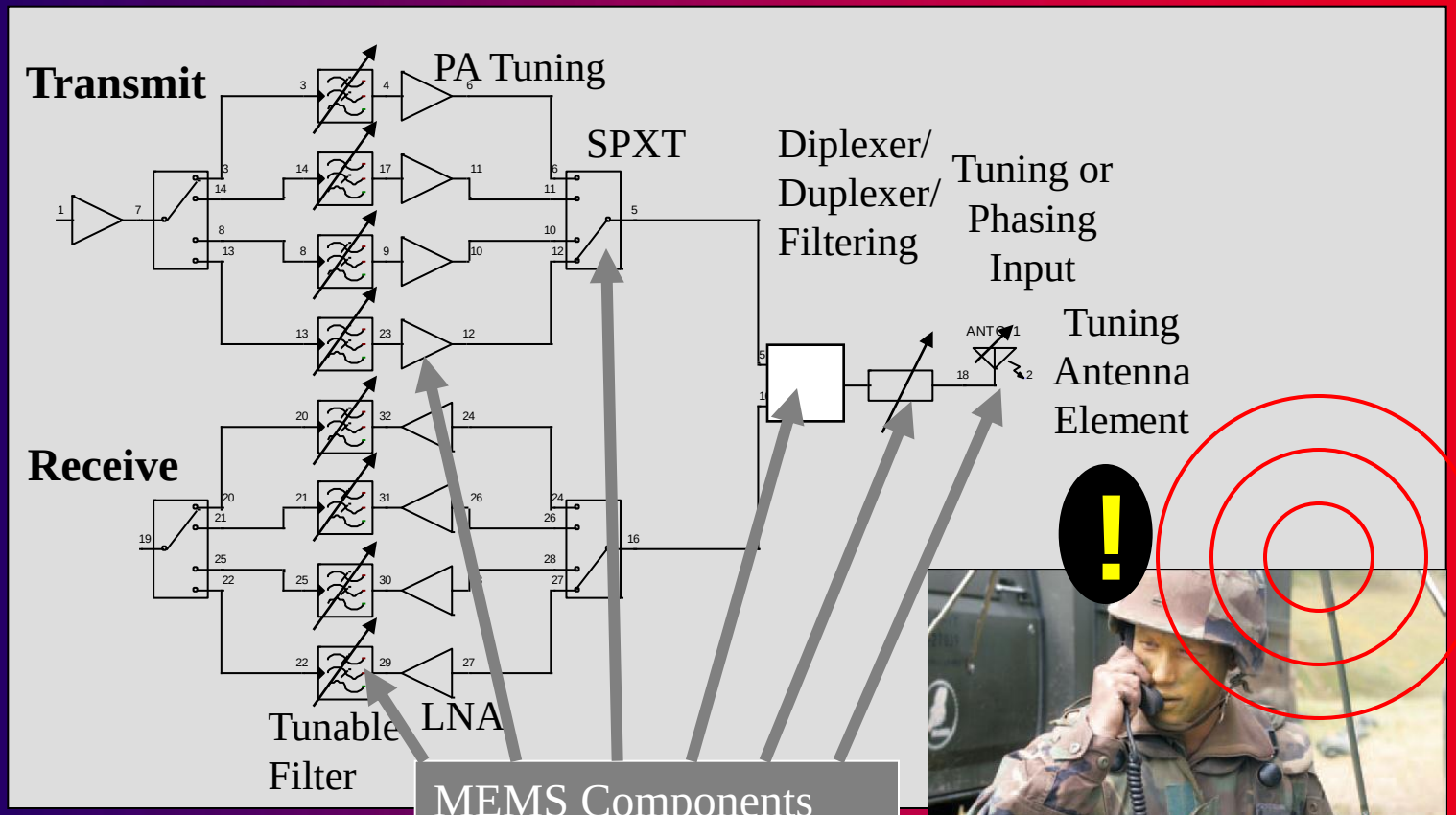
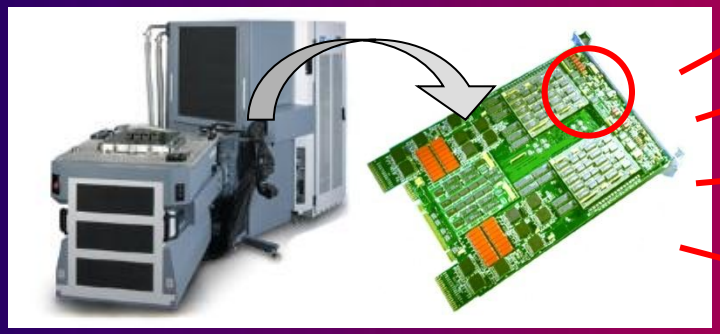
RF MEMS Potential Insertions



MEMS Components
- Compact Integration
- Better Signal Quality
- Power Savings

First Customers – Test Equipment

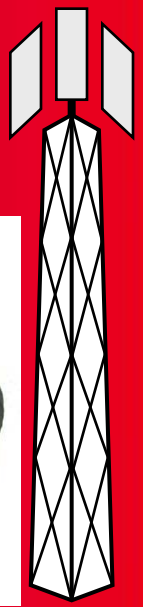
- Nearly all wireless products are rigorously tested
- Conventional test hardware slow and expensive
- Testing costs used to be 6-8%, now at 15-20%
- Industry needs fast, broadband, repeatable relays
- Longer life – larger product runs, adaptable load boards and interface racks



Testing wireless and high speed digital semiconductor products

Teradyne FLEX system example; image used without permission

Need faster and better testing!



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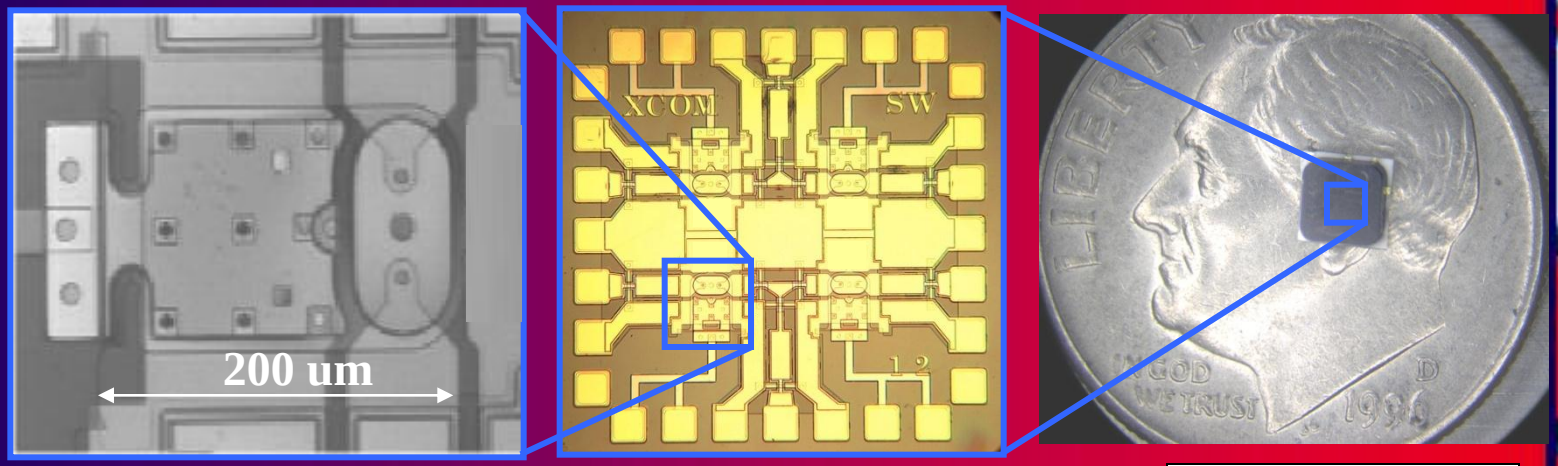
Critical Component Goal

- RF MEMS relays at “attractive” size & cost vs. SAM
- Part must exist; supplier must exist; moderate volumes (100k/mo) must be supported
- Hermetic package for severe environments
- Lifetime must be 100M to compel change/savings
- Otherwise do **everything** “same or better”



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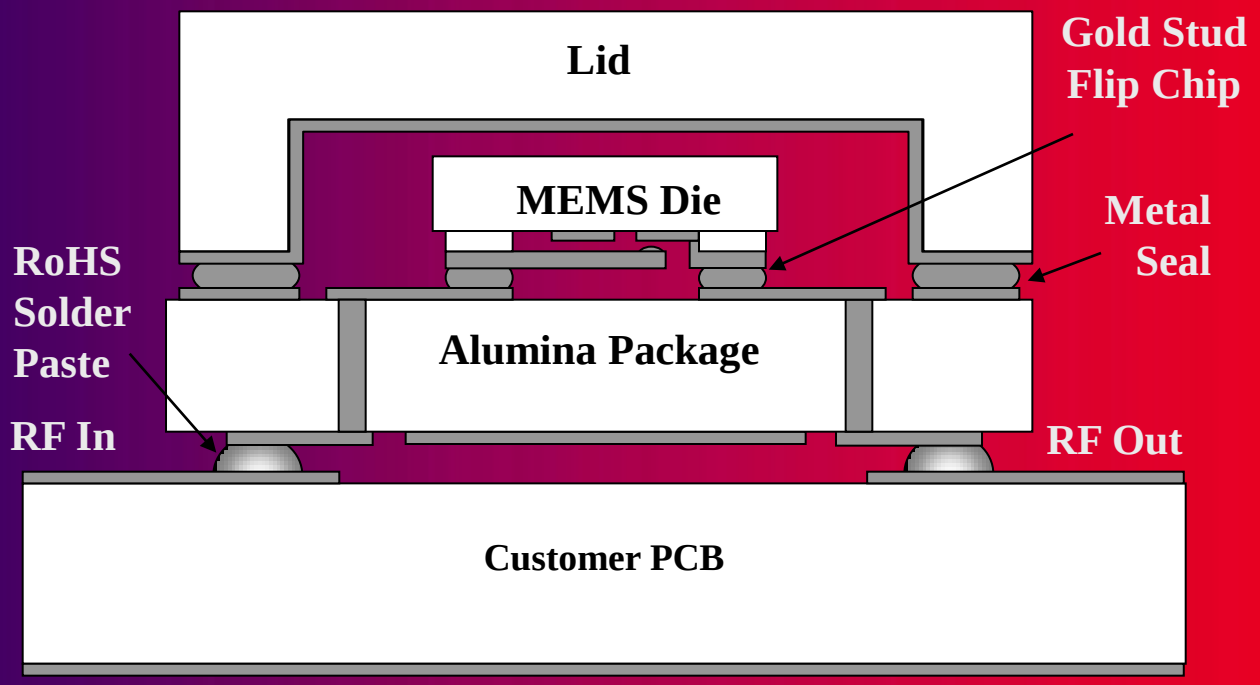
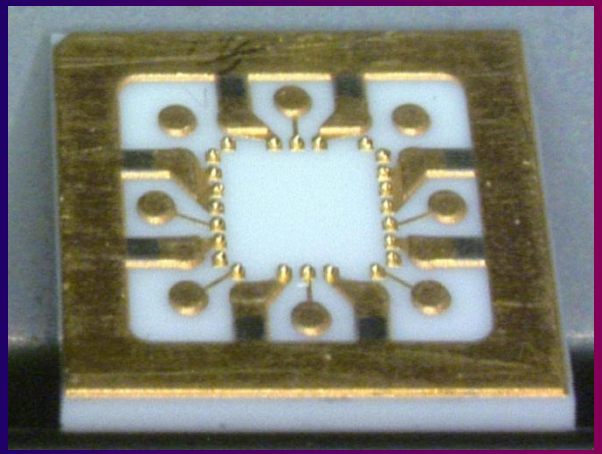
Hybrid Architecture

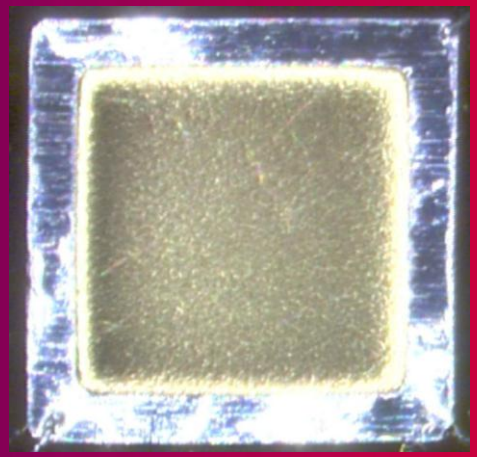
- 1.7 mm Si MEMS die
- 3.8 mm Alumina leadless package w/Cu vias
- 3.7 mm stamped metal lid w/Au coating
- 25 um thick stamped Sn-Cu-Ag seal pre-form

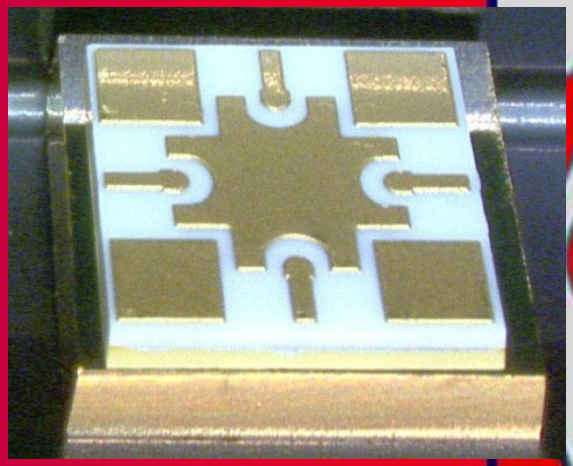


Classic Microelectronic Assembly

- Stud bumped w/semi-auto ball bonder
- Thermosonic flip chip RF MEMS die
- Tack weld preforms to lids
- Align and seal in vac furnace in fixture







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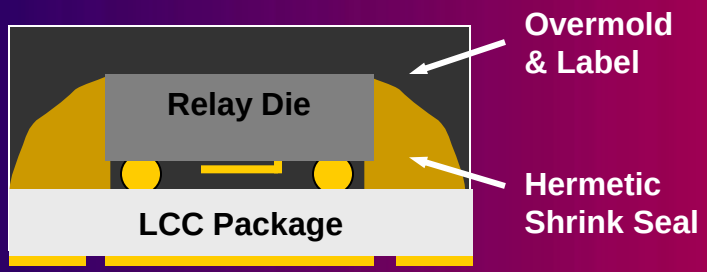
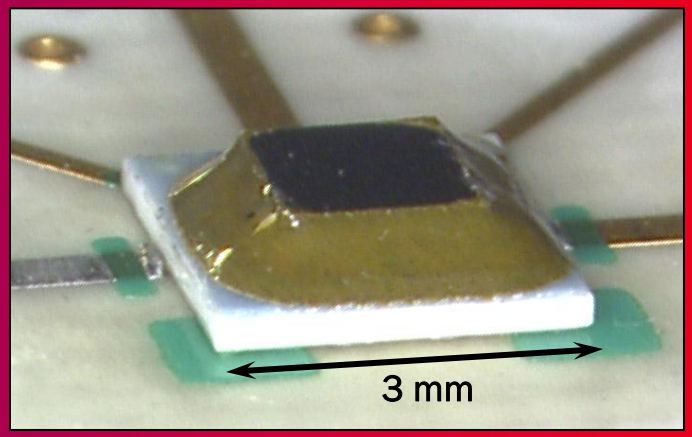
XCOM Industrial Product – 2007

XW3000 SPDT Relay

Device	Process
MEMS	Xipe MEMS die • Surface-micromachined beam • Repeatable gold alloy contacts • Ultra high-repeatability device
Package	MPT QFN-like leadless carrier • Ceramic Substrate • Hermetic metal-filled vias
ASIC	None; future version adds drive and proprietary ESD protection
Seal	Near-Hermetic Glass





Item	Description
Foundry	Innovative Micro Tech (Dedicated MEMS Foundry)
Performance	20 GHz bandwidth Near-perfect linearity
Ruggedness	MIL-STD thermal, vibration JEDEC RoHS solder reflow
Qualified	Q2 2008 (RF only)
Pricing	$50 to $10 ASP; SAM grows as price drops

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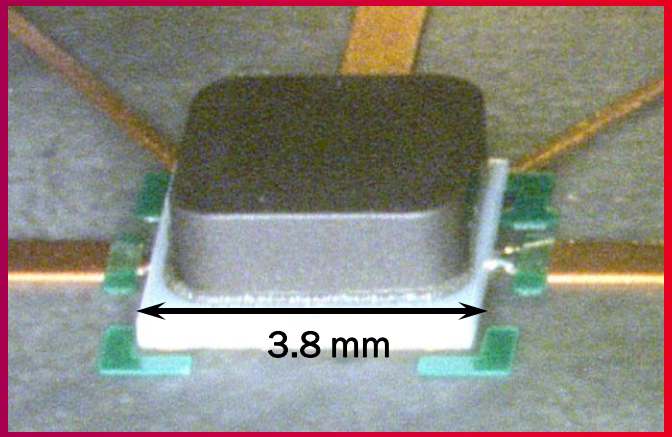
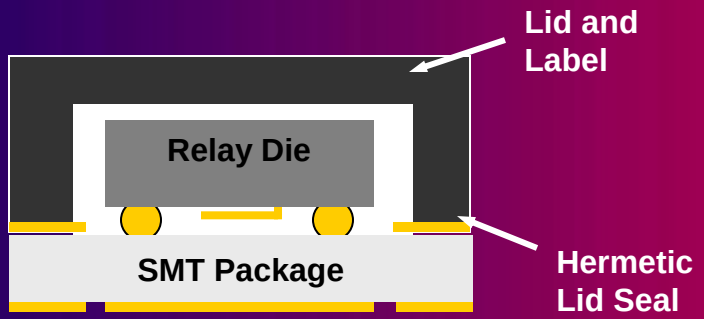
XCOM Industrial Product – 2009

XW3100 SPDT Relay

Device	Process
MEMS	Xipe MEMS die • Surface-micromachined beam • Repeatable gold alloy contacts • Ultra high-repeatability device
Package	New QFN SMT substrate • Proprietary Substrate • Hermetic metal-filled vias
ASIC	None; separate drive circuit
Seal	Hermetic Metal



Item	Description
Foundry	Innovative Micro Tech (Dedicated MEMS Foundry)
Performance	12 GHz bandwidth Near-perfect linearity
Ruggedness	MIL-STD thermal, vibration JEDEC RoHS solder reflow
Qualified	Partial Q2 2009, hot-switch lifetime and ESD weakness!
Pricing	$20 to $3 ASP; SAM grows very rapidly as price drops



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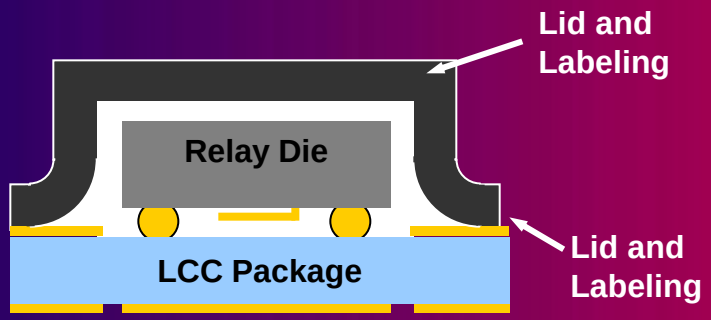
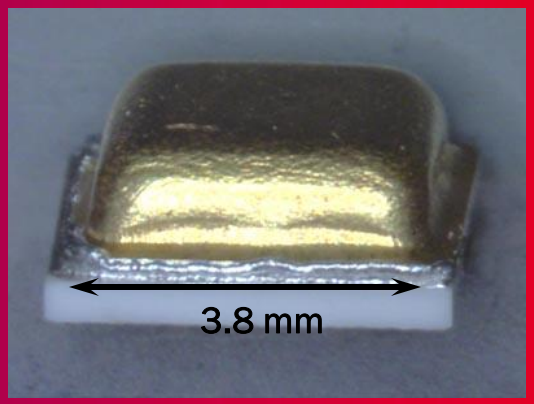
XCOM Industrial Product – Today

XW3200 SPDT Relay

Device	Process
MEMS	Xipe MEMS die • Surface-micromachined beam • Repeatable gold alloy contacts • Ultra high-repeatability device
Package	Variant QFN SMT substrate • Proprietary Substrate • Hermetic metal-filled vias
ASIC	None; future version can add drive and further ESD protection
Seal	Hermetic Metal, cleaner and higher yielding process





Item	Description
Foundry	Innovative Micro Tech (Dedicated MEMS Foundry)
Performance	12 GHz bandwidth Near-perfect linearity
Ruggedness	MIL-STD thermal, vibration JEDEC RoHS solder reflow
Qualified	Q3 2010 Completed hot-switch, cold switch, RF, DC repeatability, ruggedness
Pricing	$20 to $3 ASP

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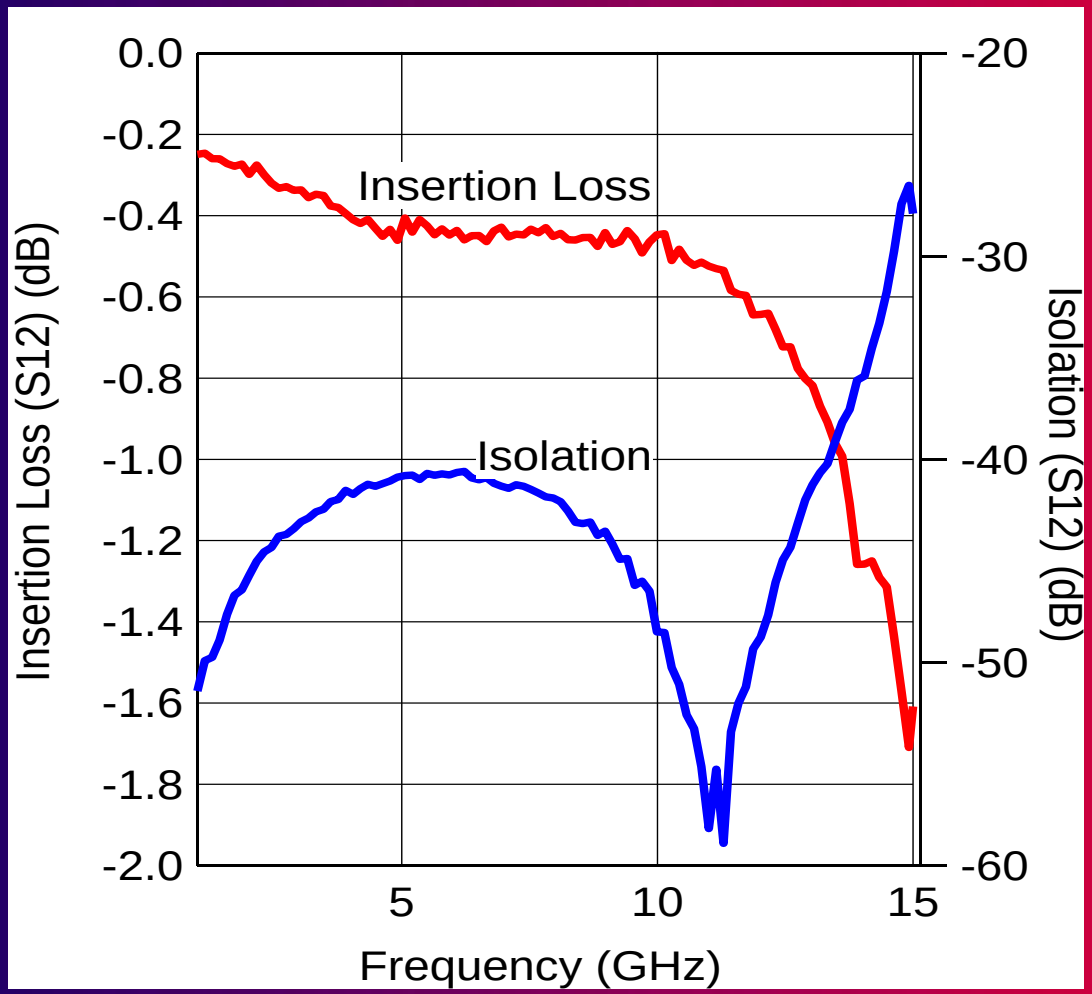
RF MEMS Relay RF Performance



XCOM SPDT relay

As probed on SMT pads with wide CPW

Loss ~0.5 dB through 10 GHz

Input reflection good to 12 GHz

Isolation also good > 40 dB to 13 GHz

5W @50 Ohm rated

25W @50 Ohm, CW 30 MHz survival (limited testing)

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Electromechanical Performance

- Failures of various types identified in 100% DC screening – typically high resistance
- Drive voltage 100V (~70-90V closure)
- Dielectric standoff 120-200V pin-pin
- Power consumption near-zero
- Switching speed
  - Predictive closure speed 6-8 us
  - Reactionary closure speed 30-40 us
  - Open 4V DC standoff ~200 ns
  - Open full RF rated isolation 1-2 us

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Electrostatic Discharge (ESD)

- Do I have to test for ESD sensitivity?
- Yes, if you're trying to assess vs:
  - ISO 10605/TR10605
  - EN 61000-4-2 (European electronics)
  - IEC 61340-3-1/2
  - MIL 883 (Defense)
  - MIL-STD-1512
  - Ford EMC
  - GR-78-CORE
  - RTCA DO 160

ESD Model Basics

- 3 Classifications based on JEDEC 22-A114-B ESD association http://esda.org/
  - Human body model (HBM) 100 pF@1.5 kOhm, ESD STM5.1 – 6 nsec pulse for a short, achieves peak 463 mA through 500 Ohm for 1kV charge
  - Charge device model (CDM) 4 pF/30pF, DS5.3.1 item itself charges up to 2-30 A peak
  - Machine model (MM) 200 pF@0 Ohms, STM5.2 – as if discharged through 500 nH inductor
- Each customer needs to know your ratings, typically HBM is biggest issue, but MM also critical for automated assembly.

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Testing ESD

- Inexpensive simulator circuits available for ESD STM5.1 (HBM), 5.2 (MM), and 5.3.1 (CDM)
- If Defense part, just convert to MIL-STD 1686 section 5.2.1.1 classification, or you could start from MIL-STD-883 Method 3015
- EU uses IEC-61000-4-2 specification
- Most options available in higher end "ESD guns" ESD3000 for about $3-5k or $200 for 1 wk rental
- Overview: http://www.desco.com/PDF/Classifications.pdf
- XCOM relay is a Class 1A. M2, C2 device
- You really should characterize all three models

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Environmental Categories – JAN vs. ER

- JAN tested to MIL-PRF-39016/28776
- ER T^2R tested to Teledyne Established Reliability Program™ requirements (highly regarded relay industrial rating)
- Allowable reliability failure rates (high!)
  - A = T^2R 1.5% per 10,000 unit cycles
  - B = T^2R 0.75% per 10,000 unit cycles
  - L = JAN 3% per 10,000 unit cycles
  - M = JAN 1% per 10,000 unit cycles

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Industrial Relay Testing – Subgroup 1

Inspection Type and Rating	T^2R B 1.5%/10k	T^2R B .75%/10k	JAN L 3%/10k	JAN M 1%/10k
Screening, Internal Moisture (custom Acceptable Quality Level sampling)	Yes	Yes	Yes	Yes
Vibration (Sinusoidal) AQL sampling			Yes	
Vibration (Sinusoidal) 100% test		Yes		Yes
Screening, Burn-In (No semiconductor switching device)	N/A	N/A	N/A	N/A
Screening, Run-In (Room Temp) (1000 cycles @ 1mA)	Yes			
Screening, Run-In (+125 & -65C) 1000 cycles @ 1mA)		Yes	Yes	Yes

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Industrial Relay Testing – Subgroup 2

Inspection Type and Rating	T^2R B 1.5%/10k	T^2R B .75%/10k	JAN L 3%/10k	JAN M 1%/10k
Drive Functionality (Coil Equiv.) (test electrostatic drive open/close)	Yes	Yes	Yes	Yes
Insulation Resistance (>1MOhm drive and load pins)	Yes	Yes	Yes	Yes
Dielectric Withstand Voltage (120 drive pins, 200 V load pins)	Yes	Yes	Yes	Yes
Static Contact Resistance (<2.5 Ohms at 1 mA & 4V comp.)	Yes	Yes	Yes	Yes
Turn-On and Turn-Off Voltage (drive voltage <90V, release >20V)	Yes	Yes	Yes	Yes
Turn-On and Turn-Off Time (DC) (react close <50 usec, open <1 usec)	Yes	Yes	Yes	Yes

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Subgroup 2 - Continued

Inspection Type and Rating	T^2R B 1.5%/10k	T^2R B .75%/10k	JAN L 3%/10k	JAN M 1%/10k
Hold Current (equiv. EMR Voltage) (<1 uA relay, <20 mA driver)	Yes	Yes	Yes	Yes
Contact Repeatability (<0.1 Ohm @ 1mA, 2 Hz, 1k cycles)	Yes	Yes	Yes	Yes
Contact Bounce Window (<50 usec total from drive close)	Yes		Yes	
Contact Stabilization Time (+/-0.040 Ohm, <100 usec total)		Yes		Yes
Set/Reset Time & Voltage, Neutral Screen, Coil Transient Suppression, Diode Integrity, and Break-Before-Make Testing not relevant for MEMS	N/A	N/A	N/A	N/A

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Industrial Relay Testing – Subgroup 3

Inspection Type and Rating	T^2R B 1.5%/10k	T^2R B .75%/10k	JAN L 3%/10k	JAN M 1%/10k
Solderability (2/Lot 30 sec @ 250C)	Yes	Yes	Yes	Yes
Leak Test (2/Lot Fine He Leak)	Yes	Yes	Yes	Yes
Temperature Cycle (2/Lot 1011.9 Cond B –55 to 125C)	Yes	Yes	Yes	Yes
Liquid-Liquid Thermal Shock (2/Lot 1011.9 Cond B –55 to 125C)		Yes		Yes
Constant Acceleration (2/Lot 2001.2 Cond A 5 kG 1 min)		Yes		Yes
Concrete Drop Shock (2/Lot	Yes	Yes	Yes	Yes

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Operational Lifetime

- **Warning: This Takes Time!**
  - Only take data meaningful to customers – pick power levels, duty cycles, speeds etc. carefully
  - Perform parallel testing, 4x, 8x, 16x whatever
  - Automate as much as possible, capture more data than you need if you can glean other value
- Data Collection Process
  - For RF MEMS, we pick 5 mW and 2 W to cover common power levels used
  - Hot switch and cold switch, run to definition of failure (death or exceeding 3 dB from optimal)
  - Stop when Weibull plots converge
  - Get testing with the customer precisely as needed for their application, otherwise you waste time and money

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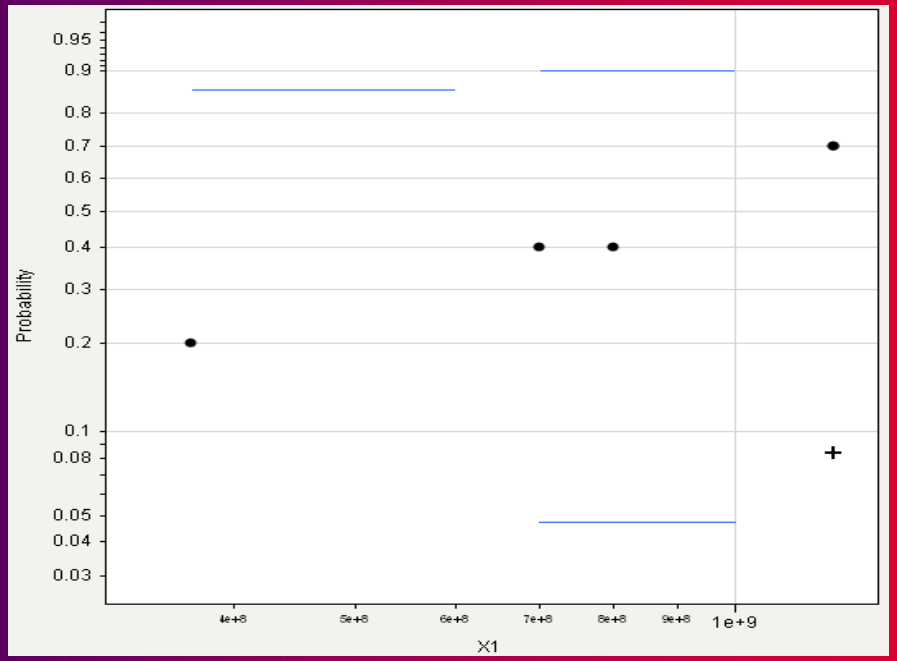
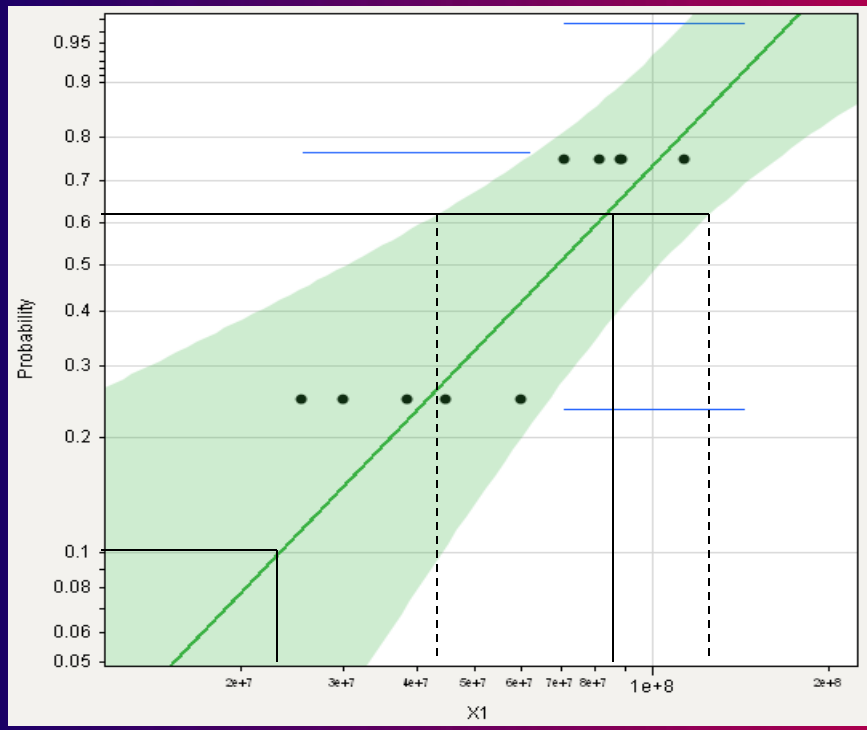
Lifetime – Cold Switch 5 mW

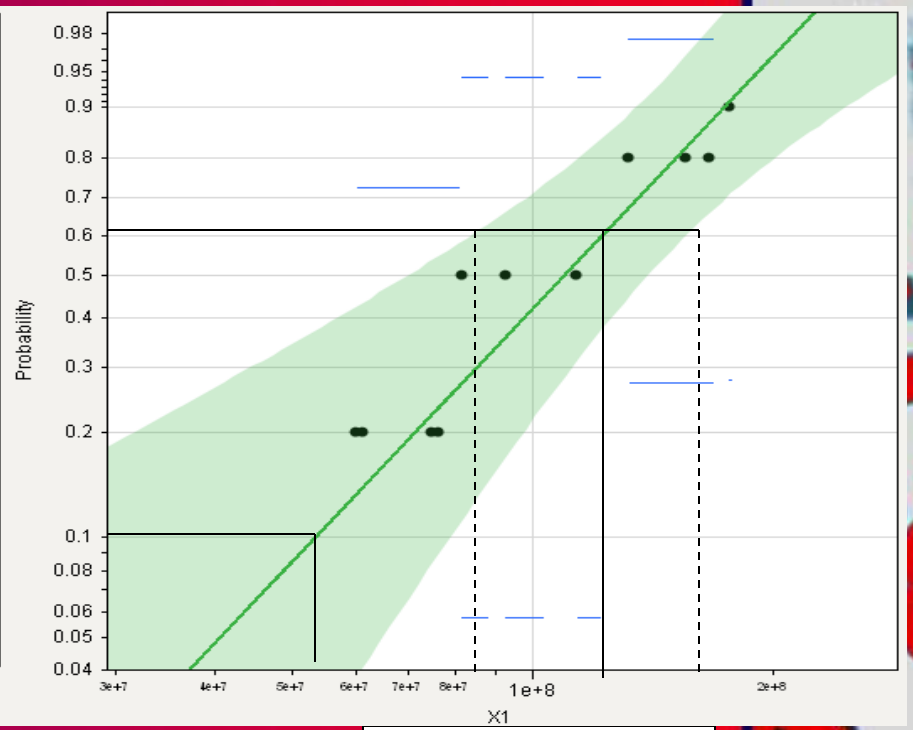
- **Long data sets, no convergence**
  - Baseline many hundreds of millions typical
  - Modified process ran for 1B, single part, no lifetime issue
  - Would like to get converged plot in multi-part test



Lifetime – Cold Switch 2 W

- **2W CW 50 Ohm, 1 kHz, modifications improve**
  - Look for 10% and 62.5% points on 50% confidence line
  - Characteristic life 84M baseline, modified parts 135M!
  - Hit 100M point required by customer, so ready to sample





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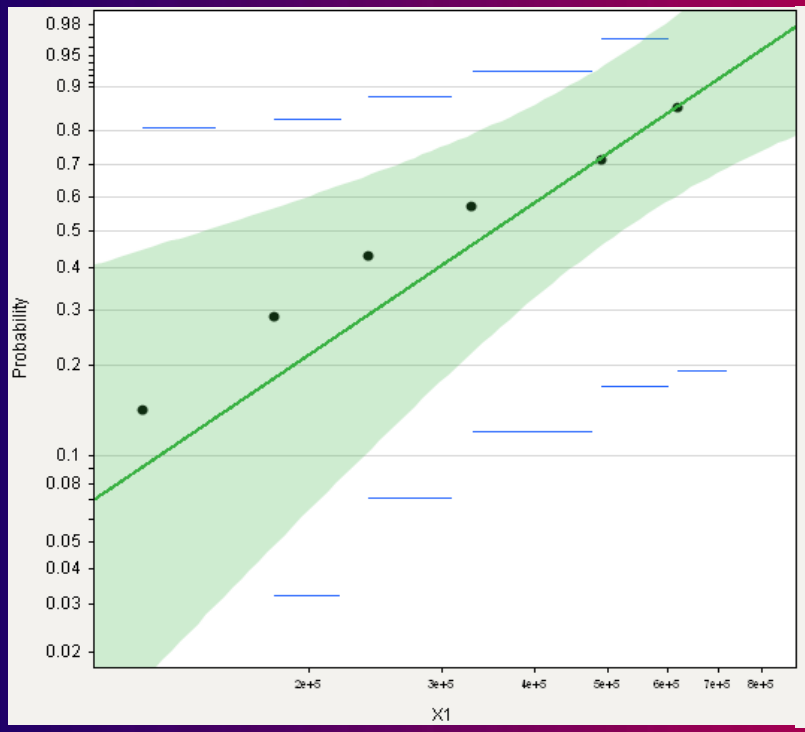
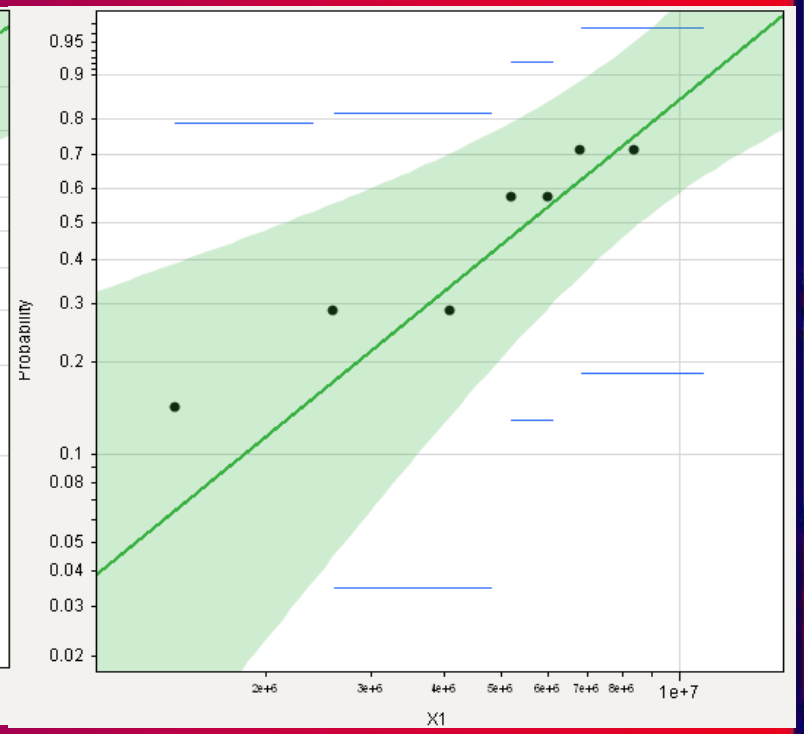
Lifetime – Hot Switch 5 mW

- **5 mW CW 50 Ohm, 1 kHz, modifications improve**
  - Characteristic life 420k baseline
  - Modified process parts 700k, almost a 2x improvement!





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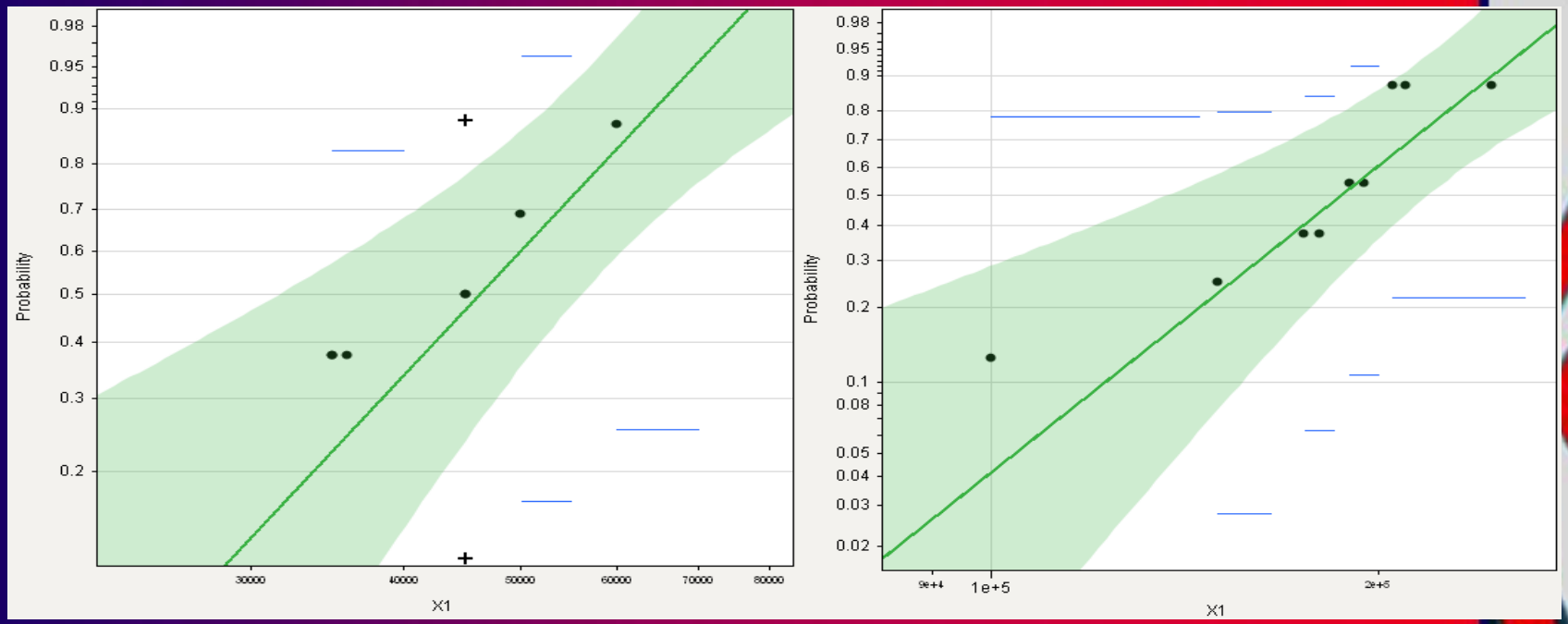
Lifetime – Hot Switch 2 W

- **2W CW 50 Ohm, 1 kHz, mods show significant gain**
  - Characteristic life 51k baseline
  - modified parts 205k, a 4x improvement!



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Repeatability Is Critical!

- Repeatability most challenging ATE specification – **#1 reason for design win failures of MEMS in past**
- Mid/high load repeatability easy to achieve; higher power helps makes a clean contact!
  - Application-specific load, speed, lifetime tests
- Low-load repeatability critical due to importance of low-power testing of wireless systems
  - **Standard 1 mA test from HP 4338 w/20mV @ 2Hz**
  - Cannot have single event >5 Ohms in 1000 cycle screen
  - 100% of all parts must pass
  - Must have 90% DCRT <40 mOhms in 1000 cycle screen
  - 100% of eval boards & test coupons must pass
- Industry already uses many compensation techniques for macro relay weaknesses

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RF Repeatability, 2/Lot Screen

- Full Sweep to 10 GHz, find worst point
  - Plot window min, mean, max, and climb
- Cycle 100x, plot every 10th cycle
  - Must have <0.02 dB window, no climb
- Cycle 1Mx, plot every 100,000th cycle
  - Must have <0.04 dB window, no climb
- Cycle 10Mx, plot every 1Mth cycle
  - Must have <0.08 dB window over life
  - Window climb should also be <0.08 dB

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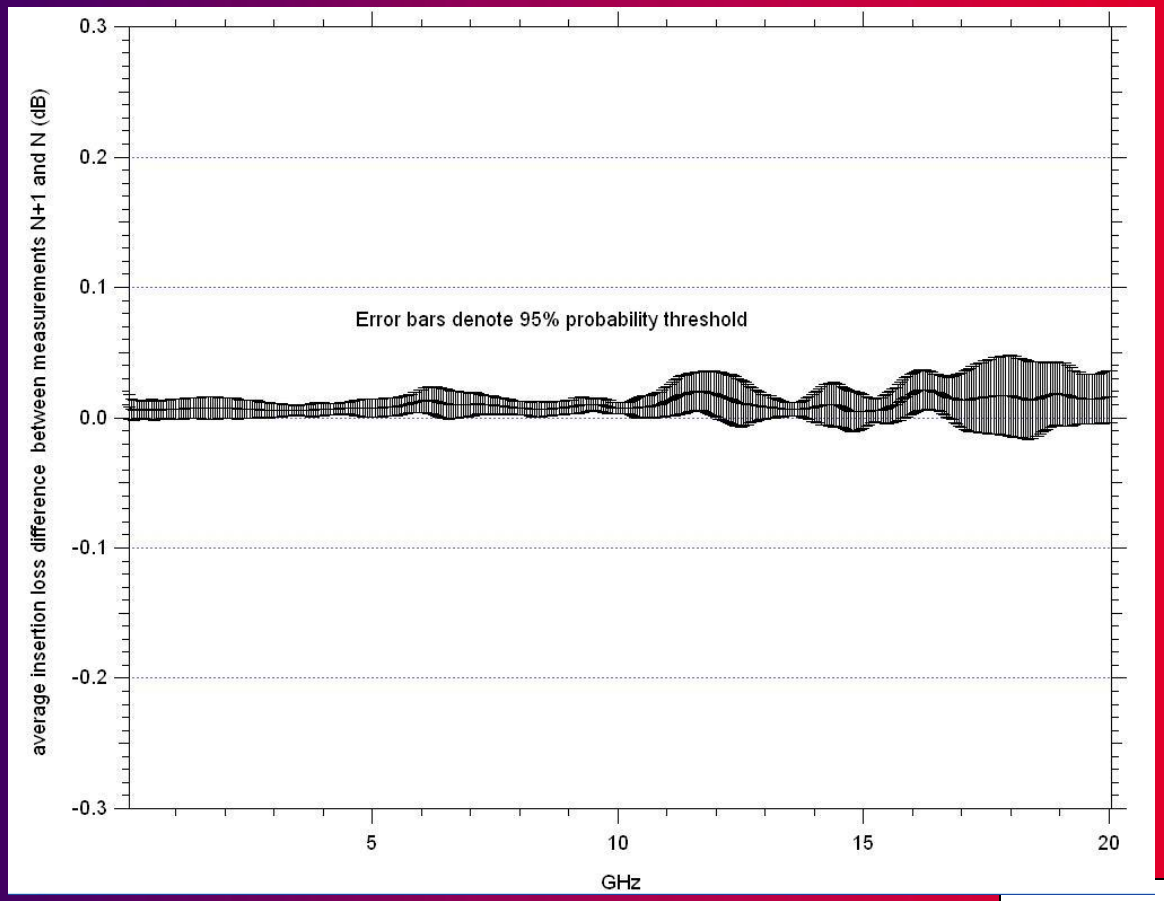
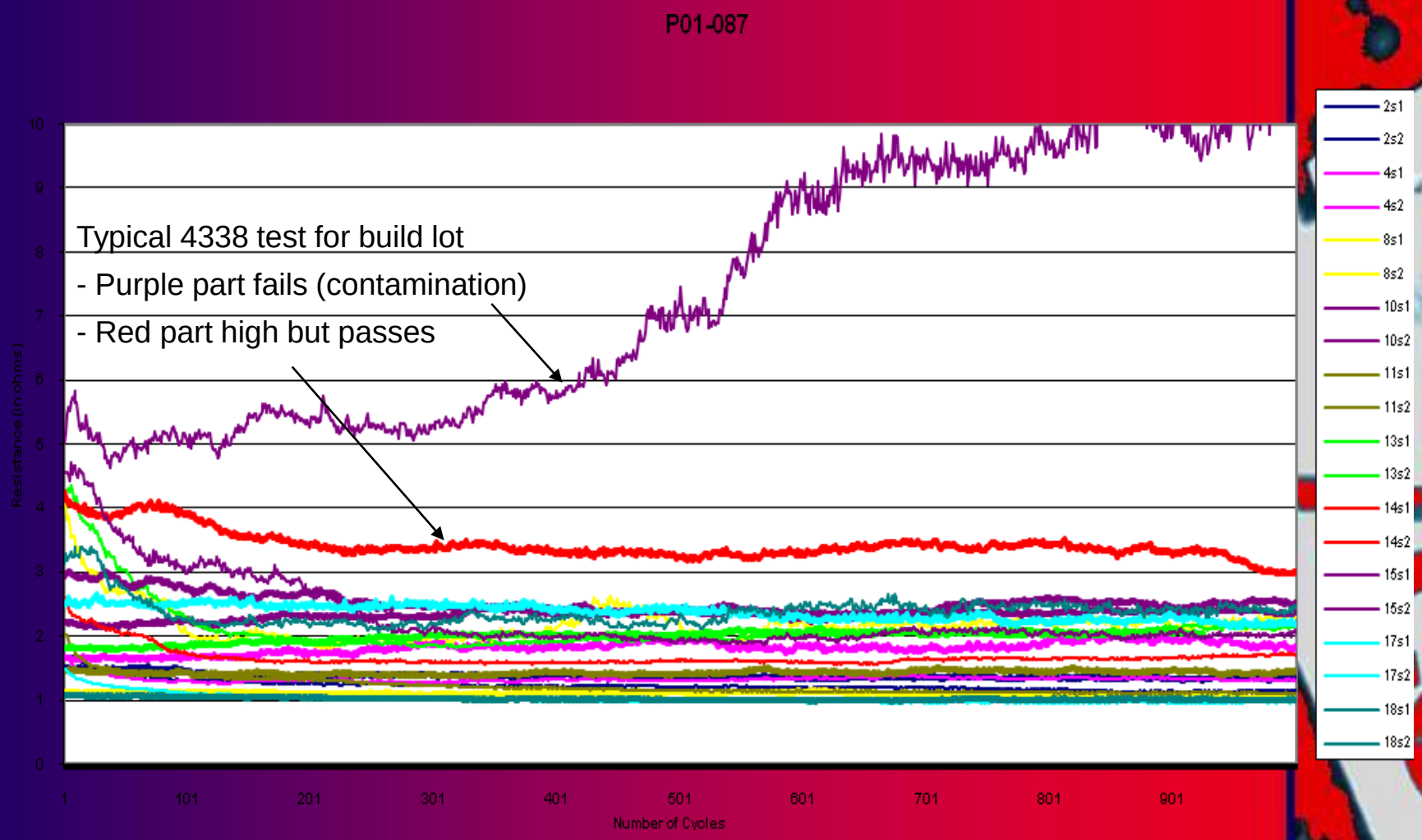
Repeatability - RF

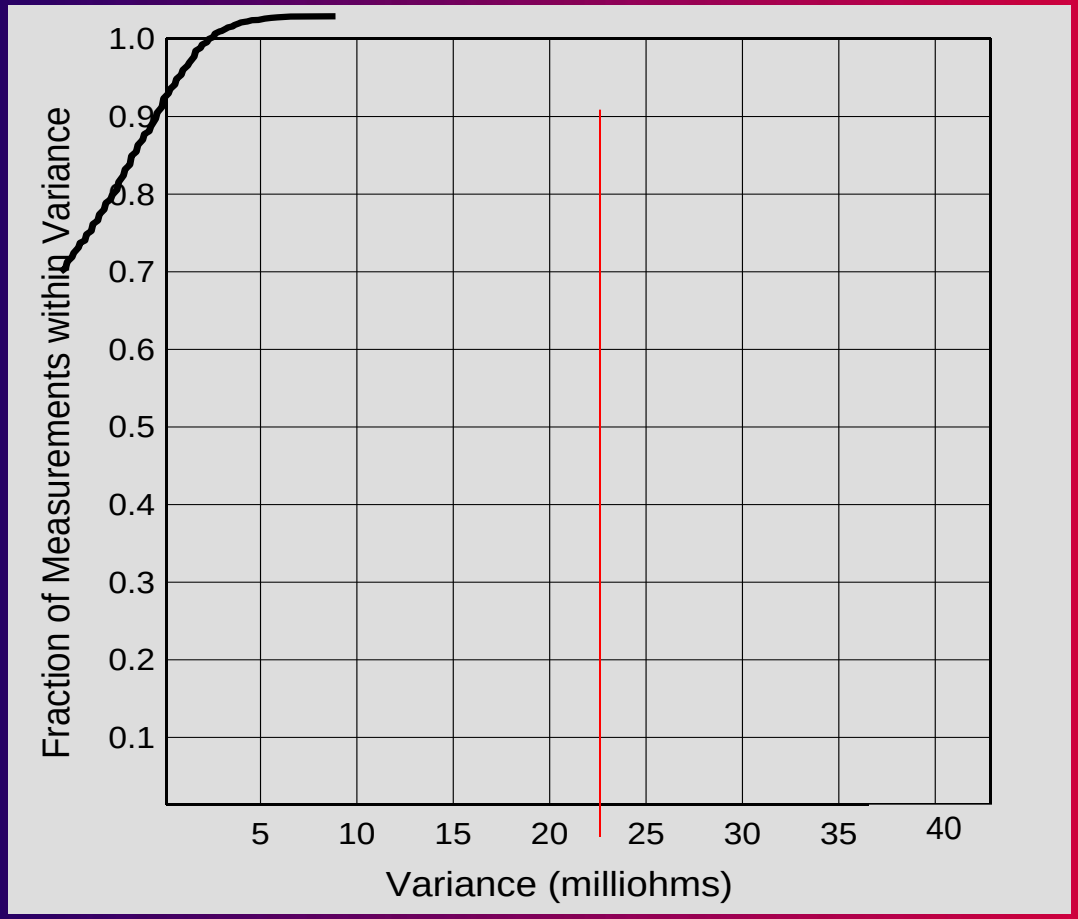
- RF repeatability validated by Teledyne cycle-sweep method
  - As expected, only variance is due to DC resistance evolution



Repeatability – DC (AC) Low Load



Repeatability – 1000 Cycle Variance



XCOM SPDT relay in standard package as tested on 4338

Standard 100% part screen 1000 cycles

Take all data, report only 90% DCRT

Example 22.5 mOhm

If below 40, ship it!

Test is costly, so adds to price, but proves each part good for high sensitivity apps

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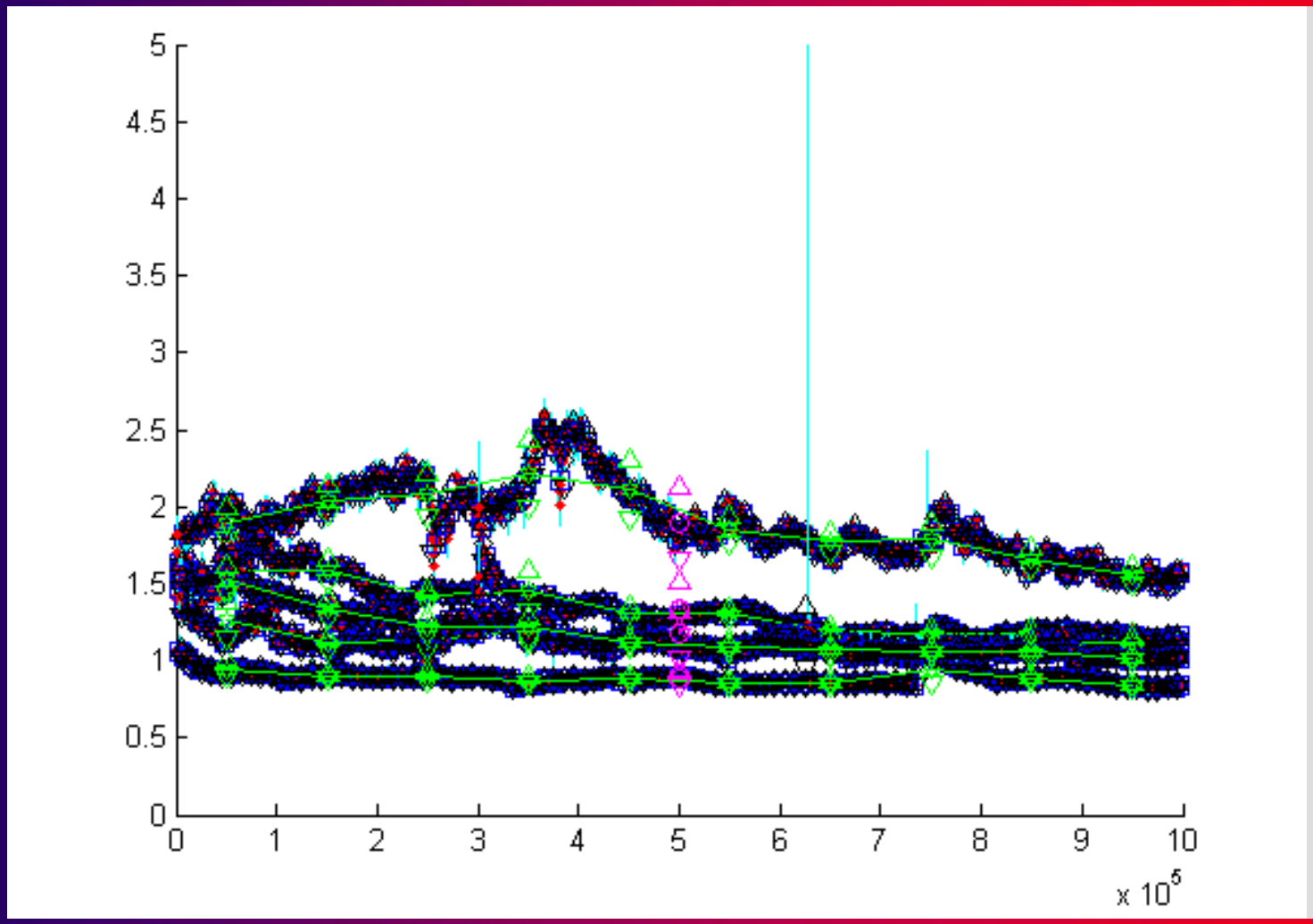
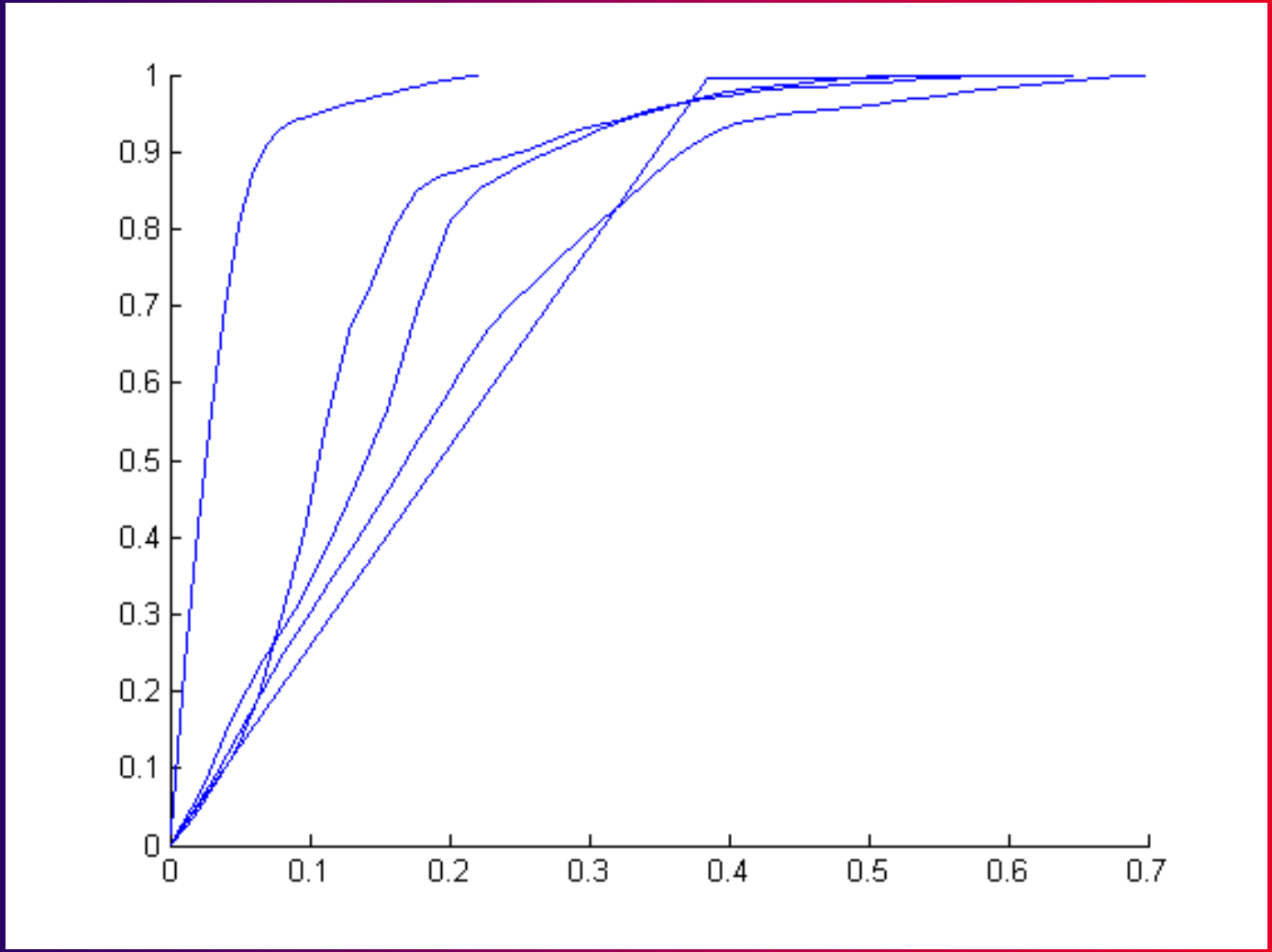
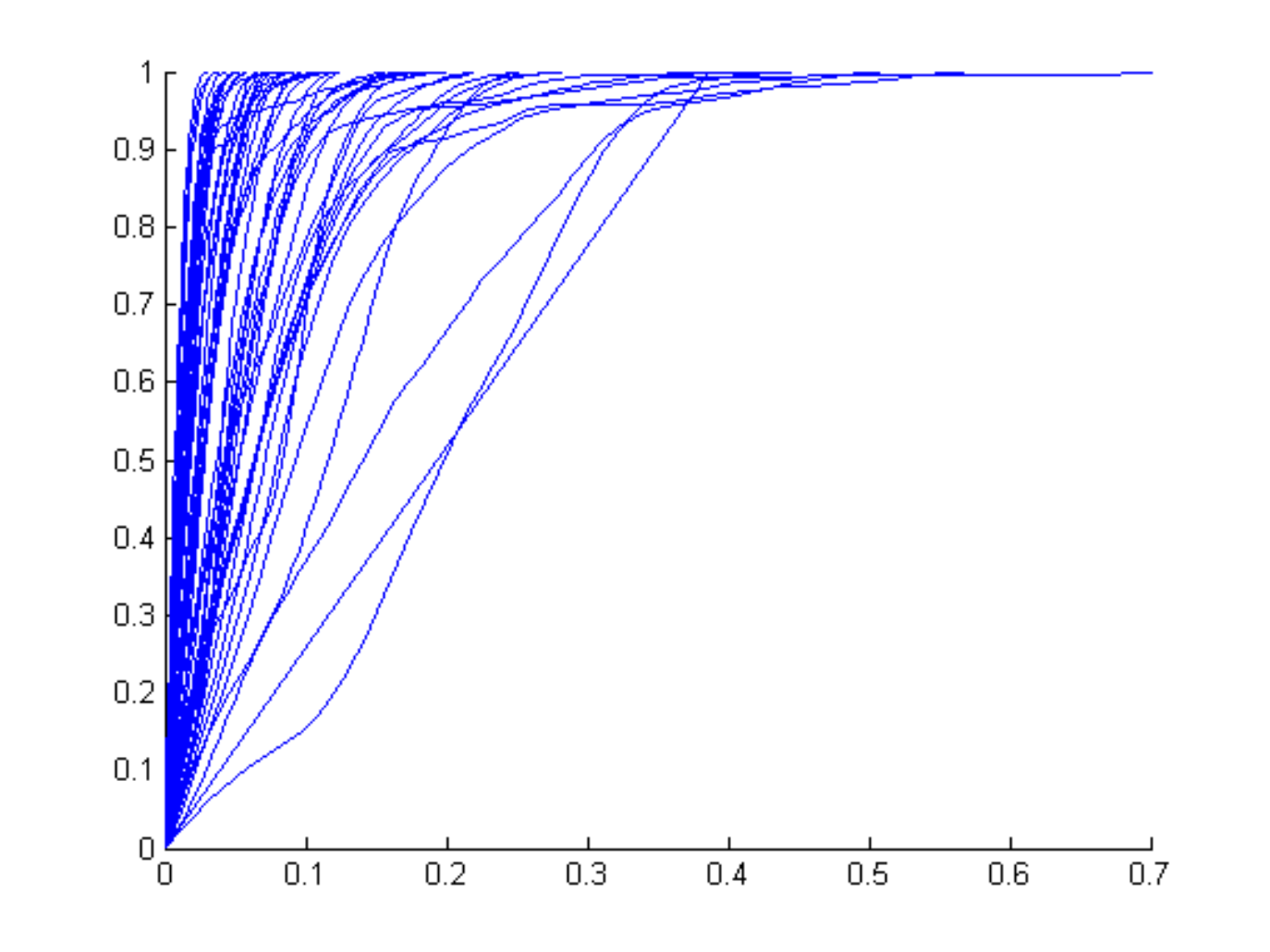
What About Repeatability Over Time?



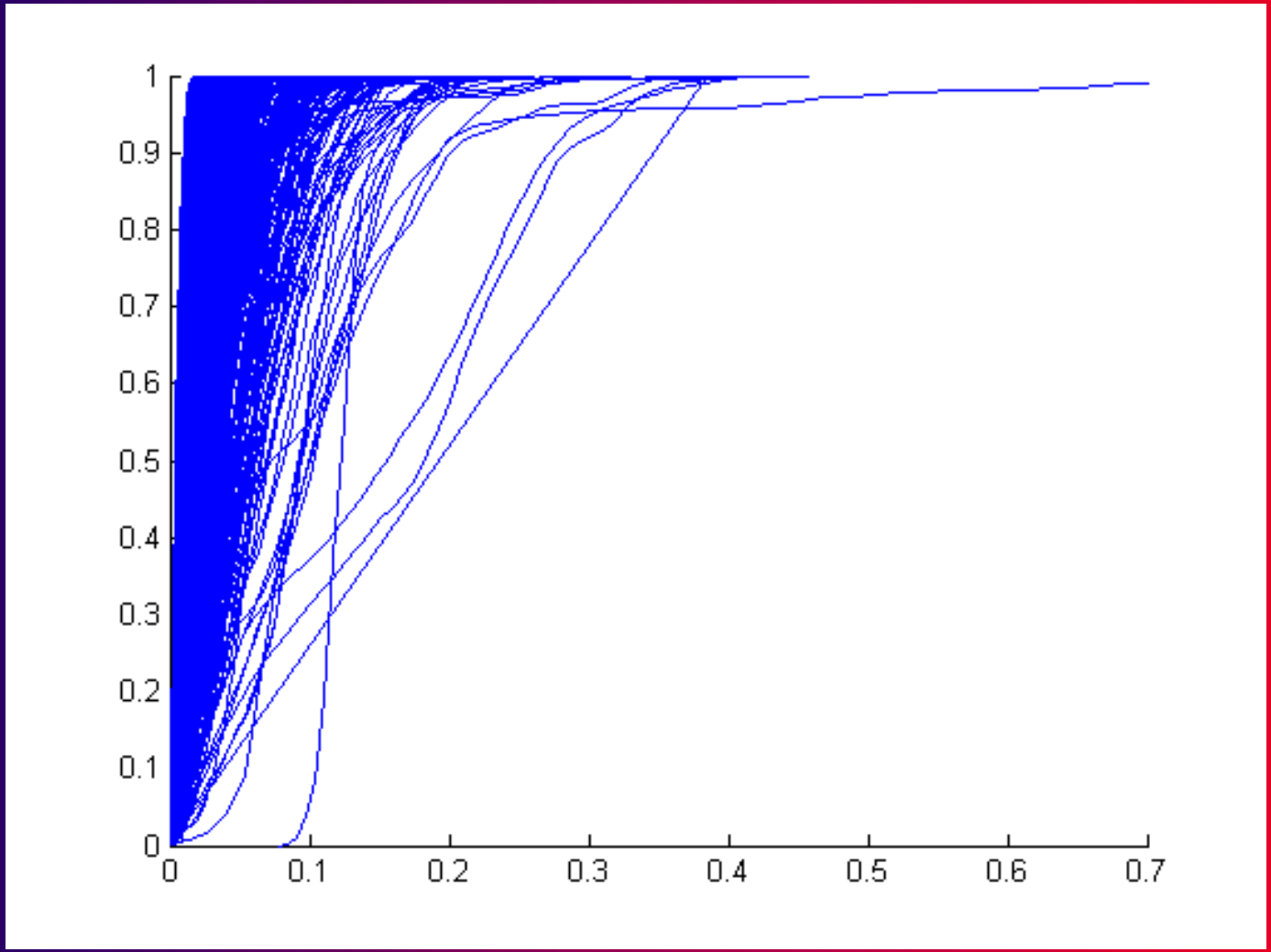
Bin Size 1M Cycles (1 Trace/Part)



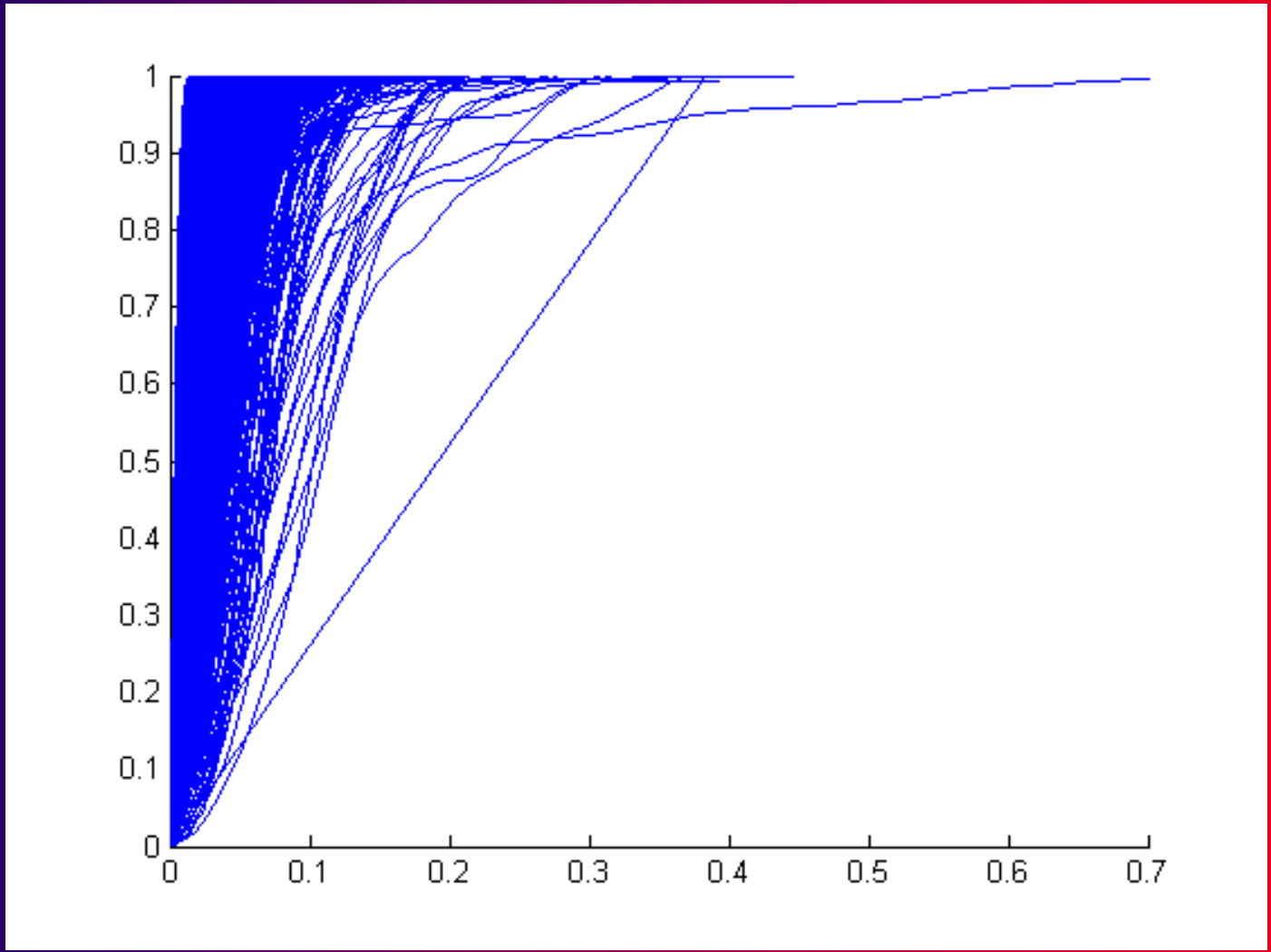
Bin Size 10k Cycles (10 Traces/Part)



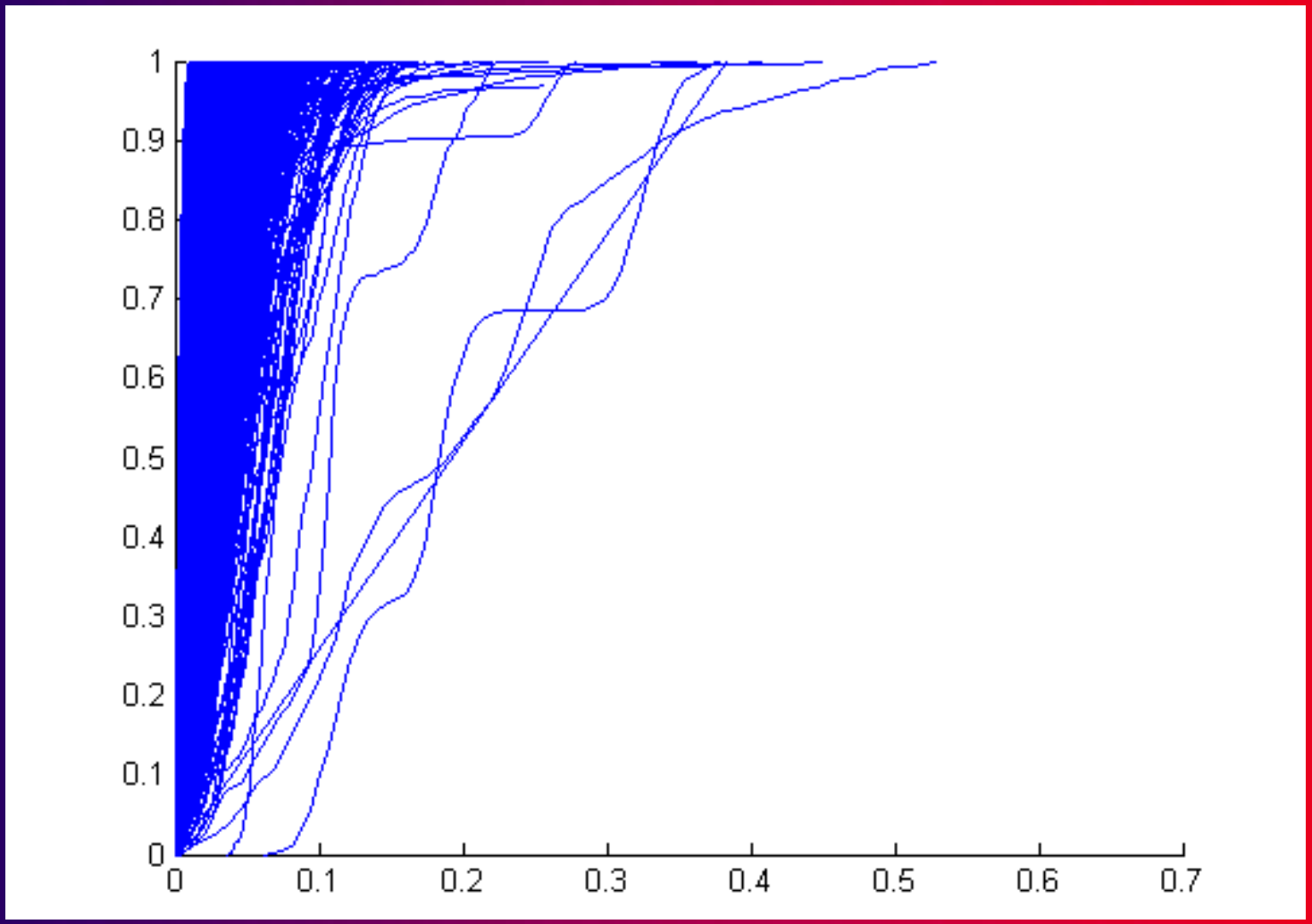
Bin Size 10k Cycles (100 Traces/Part)



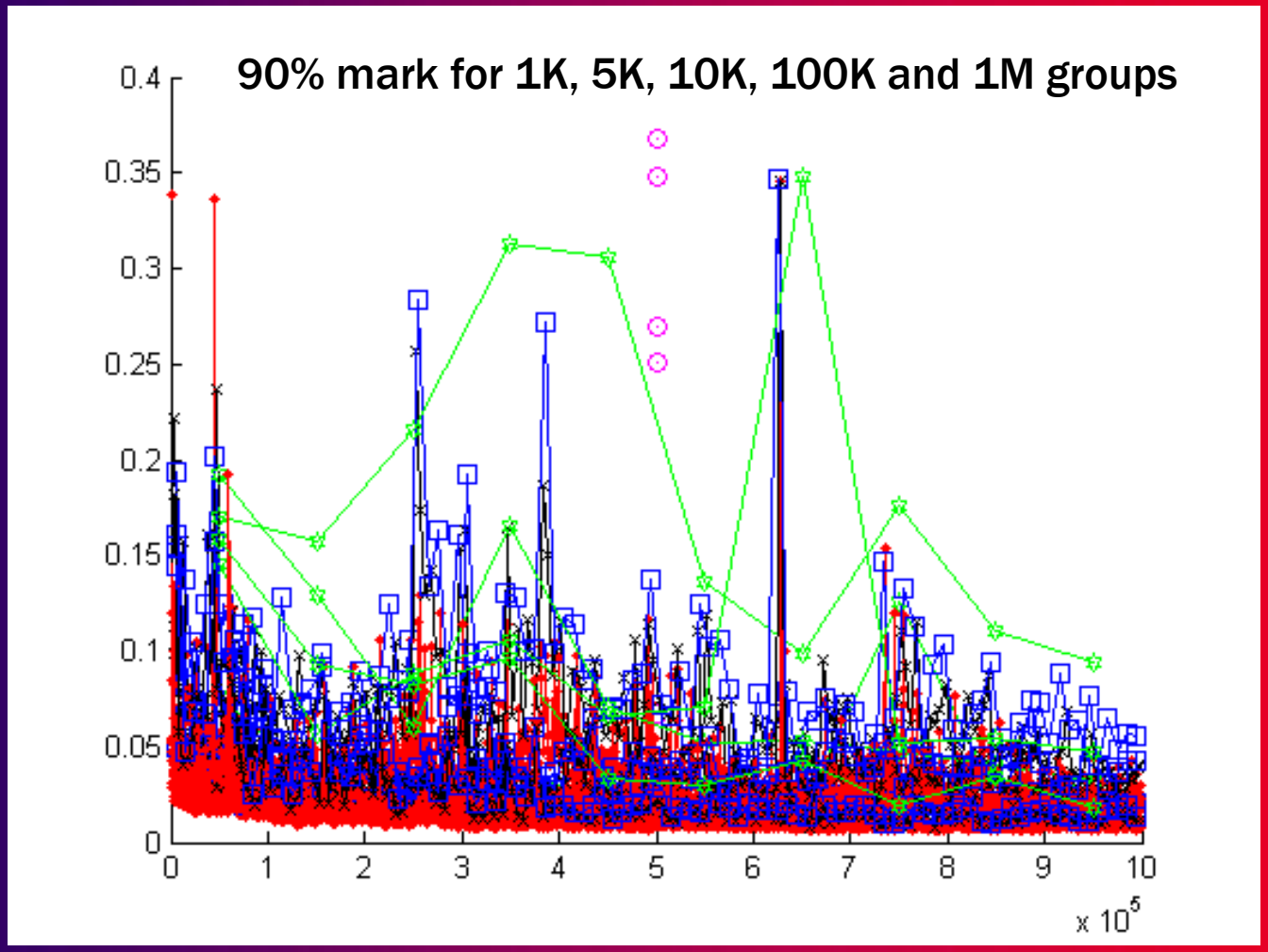
Bin Size 5k Cycles (200 Traces/Part)



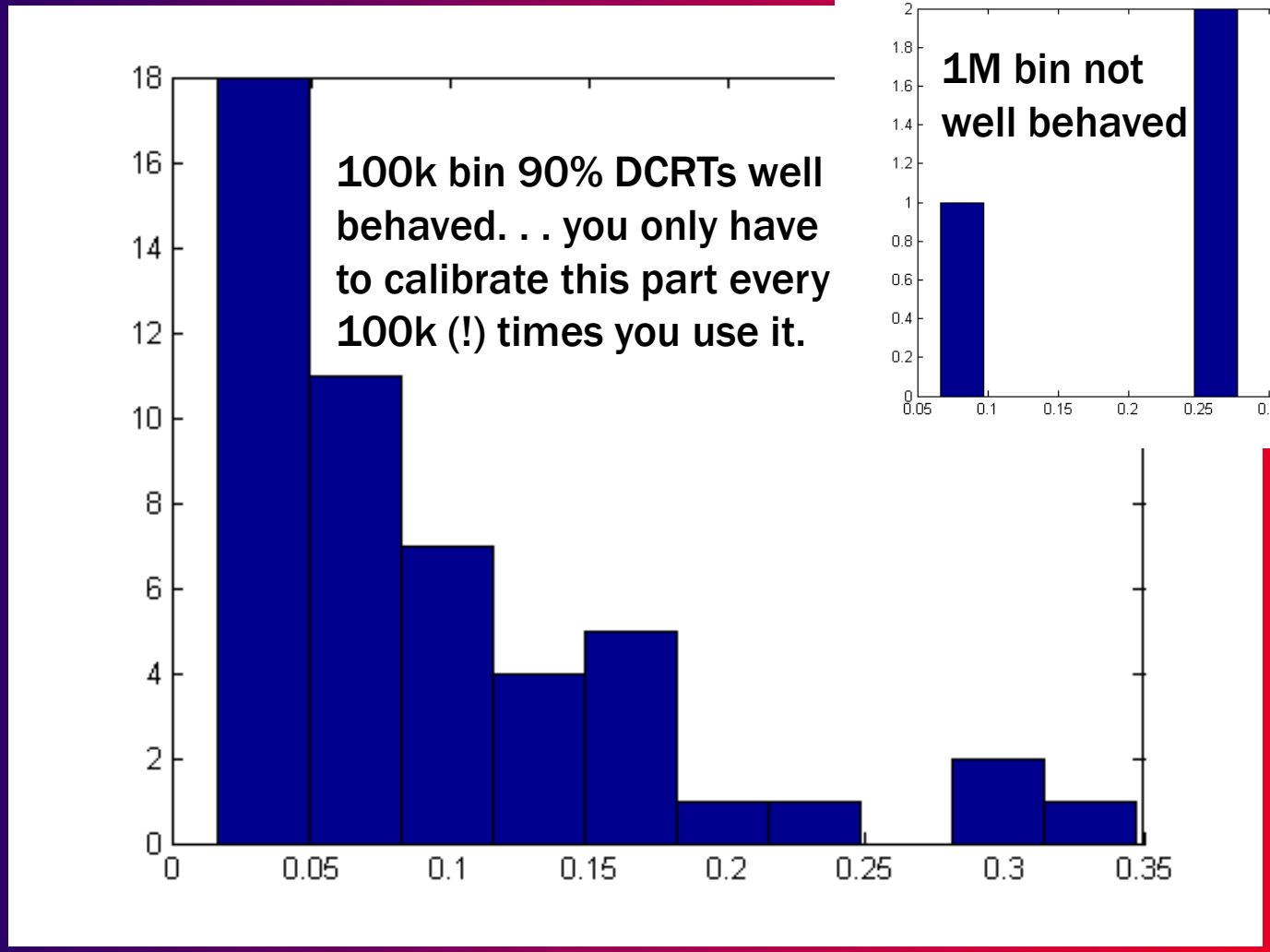
Bin Size 1k Cycles (1,000 Traces/Part)



Oh, We're Not Done Yet . . .



Plot The Bins! NOW It's Characterized



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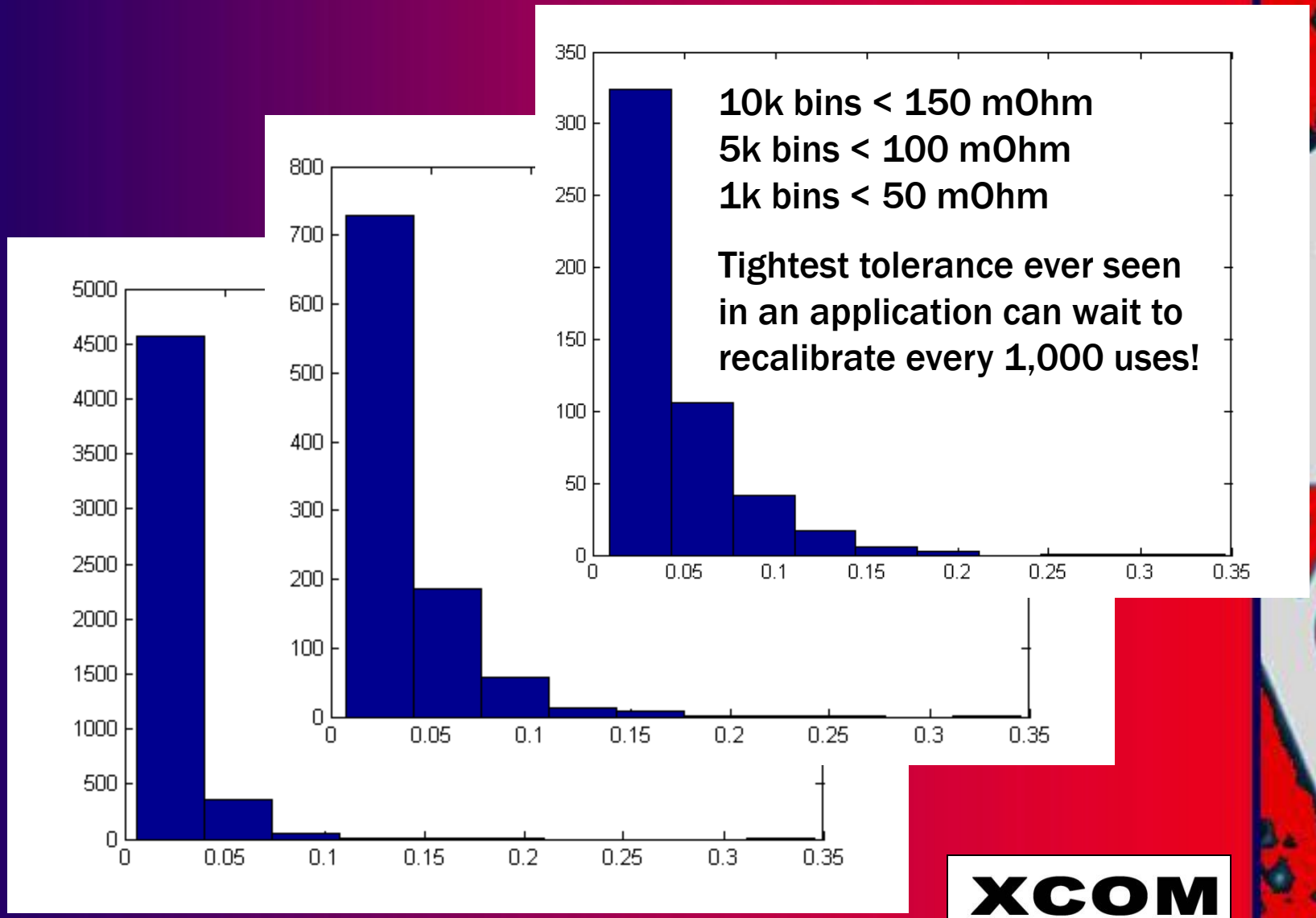
The 10k Bins Look Even Better



Overview

- Component Application
- Test Methods & Data
  - Performance Characterization
  - Environmental Reliability
  - Operational Lifetime
  - Operational Repeatability
- Future Work

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Industrial Relay Readiness

	MRL 1 (Proven Worth)	MRL 2 (Production Intent)	MRL 3 (Production Start)
Technology Level	4-5	6-7	8+
System Insertion	Demonstrated	Well Tested	Fully Tested
Specs Validated	50%	90%	100%
Interface Phy/Elec	50%	90%	100%
Cost Achieve/Plan	CKP1B, 80% CKP2	80% CKP3	At Cost
Manufacturing	Demo	Proven	Ready
Processes	Nearly Complete	Complete	Complete
Equipment	Cost Estimated	Cost/Plan Done	In Place
Reliability & Char.	90% Part	90% System	100% System
Failure @ System	75% / 25%	100% / 75%	100% / 100%
Ops Test/Eval Plan	Considered	Initiated	Complete

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Recap Product History

- Product looked great, but cost was too high
- Solved yield root cause over two years, modified packaging to accommodate
- Established characterization, testing, and screening requirements based on JEDEC, MILSTD, and relay industry standards
- Reliability qualification completed (twice)!
- Manufacturing qualification incomplete
- System-level assessment finally underway

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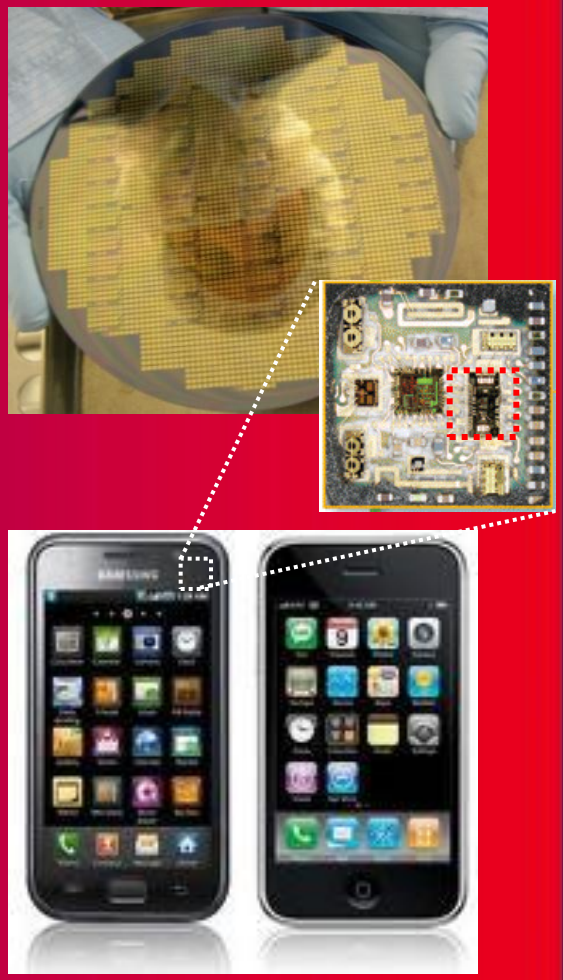
RF MEMS Future

- Ramp Industrial Relays
  - XCOM sampling
  - OMRON starting ramp
  - Radant & others sampling
- High-End Circuit Products
  - Matrix & tuner development
  - Phase shifters qualifying
- Consumer Products?
  - EPCOS, WiSpry, Cavendish
  - New players? Consolidation?
- **Activity & Excitement!**



Simulation; No RF MEMS parts are presently incorporated into RFMD power amplifiers or used in Samsung handsets
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