Raytheon

5.3 Implications of COTS Packaging Modifications in Legacy Systems

Space and Airborne Systems

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April 13, 2017

Agenda- IC Packaging

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I. Evolution in the Commercial IC Supply Chain

II. Revision Impact to Circuit design

III. Review (2) Case Examples

- **Antenna RF Switching CCA**
- **RF Communications CCA**

IV. Conclusions- *Recommended Actions, Preventive Measures*

Integrated Circuit-
Evolution In The Supply Chain

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- Acquisition Reform under Perry Initiative- *March 1996*
  - Departure from Military specs., Utilize COTS products and commercial best practices where possible
  - Exponential growth IC's, demand due to computers & the internet REQUIRED *revolutionary* changes
  - Changes in Engineering, Business, Quality, Product Support, Development Tools, Equipment, Materials & Technology. ***REQUIRED*** to meet demands
  - Improvement in Speed, Performance & Integration of functional blocks required changes in Packaging, Lead frame interconnect technology
- Semiconductor Industry Requirements for Product Release
  - COST reduction, fractions of a penny at high volume is ***Significant!***
  - Increase in yield
  - Novel IP, Increases Market Share
  - Increase in performance

Commercial technology sector *DRIVES* innovation & cost savings changes

IC & Die Revisions-

IMPACT Circuit Designs

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Modifications-

Performance "Intended for New Circuit Designs"

- Die Shrink >> **Increase-** yield per wafer, production throughput. speed, **Reduce-** capacitance / resistance / inductance
- Lower Voltage >> Reduce power consumption
- Die Material >> Increase junction temp., lower V threshold, improved digital / RF characteristics (GaAs, GaN, SiGE, SiC)
- IC Packaging Supplier >> Cost savings, Increased throughput, Quality Performance

Material

- Molding Compound >> Cost Savings, Improved environmental protection, Restricted Substance Compliance
- Lead frame >> Cost Savings, Restricted Substance Compliance
- Bond Wire >> COST SAVINGS Industry migrating away from Gold to Copper

Product Release Impact / Update Mechanisms

- OCM Technical Support >> Product Change (PCN) & End of Life (EOL) notifications
- Engineering Services >> IHS, Silicon Expert, QTec *rely* on timely OCM information!

A multitude of factors influence how IC's perform in legacy designs

Example 1- Broadband IF Driver Amplifier

(2) FA Investigations, RF switching CCA

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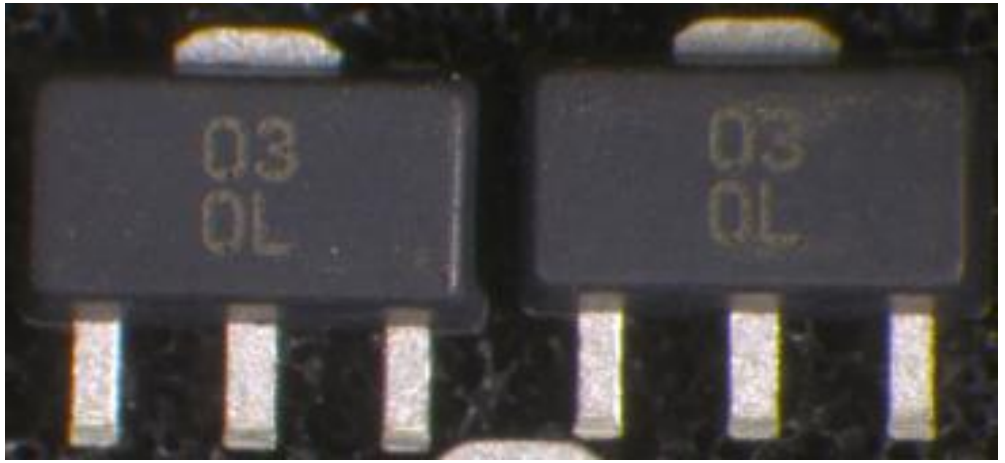
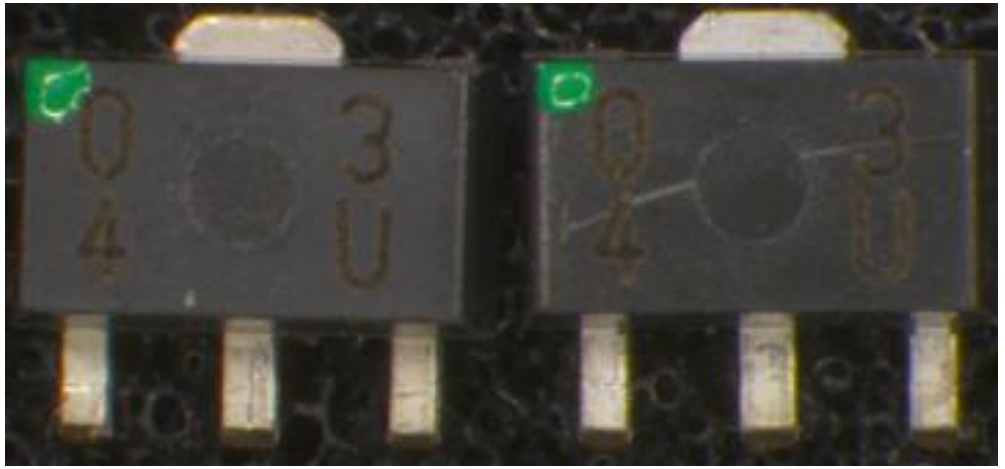
- Components acquired to support a 20 board build for legacy program upgrade >> **Qty.17 per board**
- Obtained from approved ID, previously owned excess inventory
- Updated CF requirements instituted Q notes requiring authenticity & electrical testing
- Passed supplier tests & incoming inspection but failed during CCA functional test (low gain)
- Initially indicted as ***suspect counterfeit*** due to physical differences
- Older 2000 DC components pulled from stores worked, 2004 DC had Low gain, **Part discontinued in 2009, then Transferred**

SOT-89 Visual Inspection



Physical / mechanical differences



Example 1- Broadband IF Driver Amplifier

(2) FA Investigations, RF switching CCA

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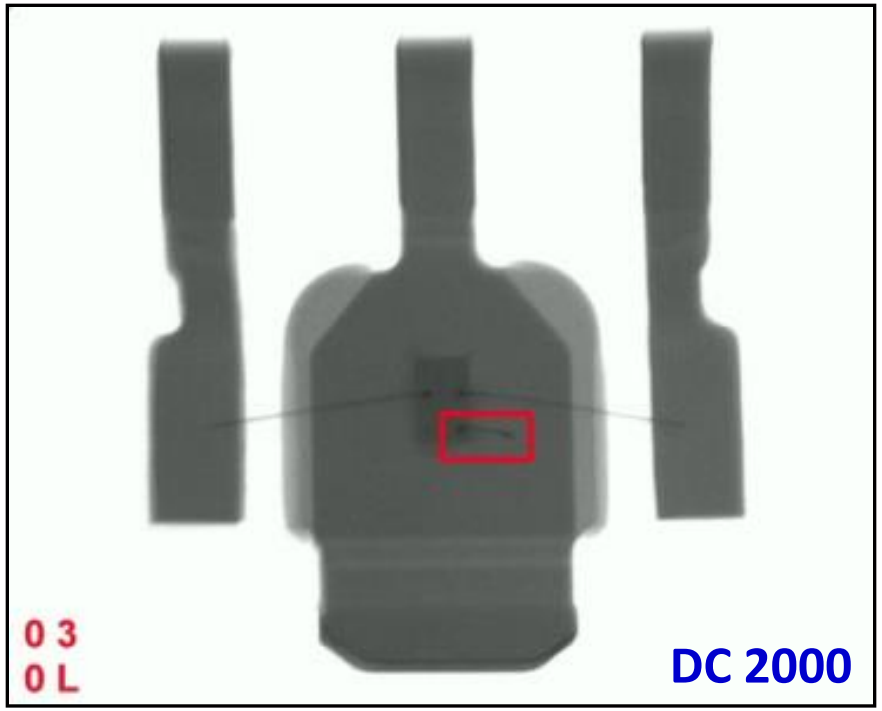
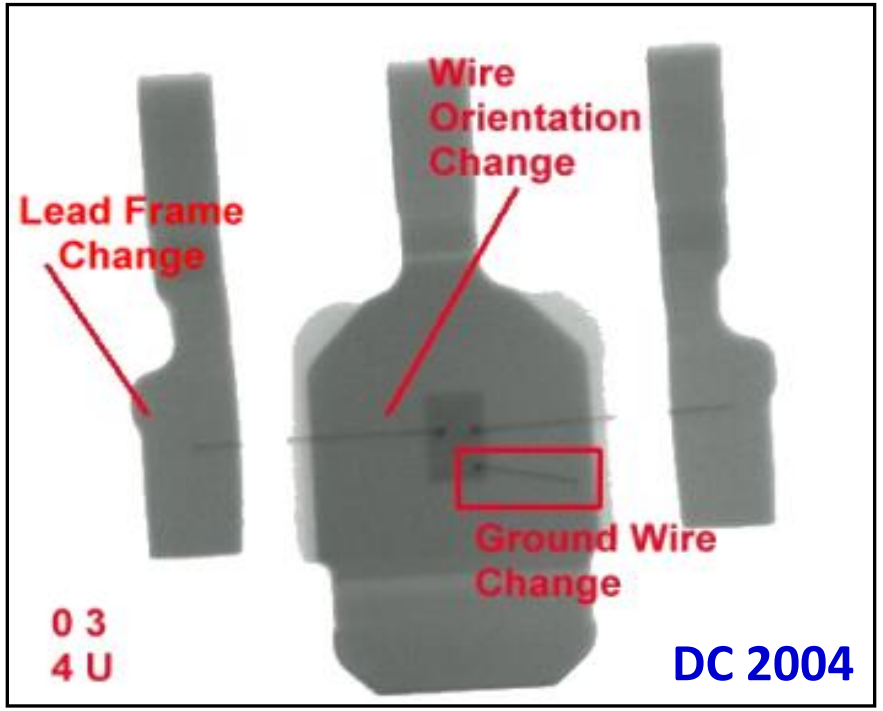


SOT-89 X-Ray:

Leadframe >

Wire Bond Placement >

Extended Gnd. Loop >



- 2004 DC components marginally met dimensional, FAILED lead pitch & paddle width
- X-Rays revealed differences in Lead frame, paddle & wire bond placement
- HIGH volume COTS device used in CATV Industry, mass produced 2000 to 2009
- NO PCN's filed from 2000 to 2008! Feb 2008, PCN: Mold Compound Change & Second Source OCM, Dec 2011: "molding compound will not affect product form, fit, function, or Reliability"

Example 1- Broadband IF Driver Amplifier

(2) FA Investigations, RF switching CCA

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Rev 1 Electrical Specification [1]

Electrical Specifications[1]: T_A = +25°C, Vs = 5 V,Is = 70 mA

Parameter	Test Conditions	Units	Min	Typ	Max
Gain[2]	F = 50-450 MHz	dB		18	
Noise Figure[3]	F = 50-450 MHz	dB		4.4	
Input Return Loss	F = 50-450 MHz	dB		12	
Output Return Loss	F = 50-450 MHz	dB		15	
1dB Compression	F = 50-450 MHz	dBm		22	
Output IP3 [4]	F = 50-450 MHz	dBm		40	
Current	Vs = 5 V	mA		70	

1. All measurements taken in a 50 ohm system unless otherwise specified.
2. Gain varies at –0.008 dB/°C typical.
3. Noise figure varies at 0.007 dB/°C typical
4. OIP3 measured with Pout/Tone = +5 dBm, Tone spacing = 10 MHz

Broadband IF Driver Amplifier
50 - 450 MHz
V 1.00
Advanced

Rev 4 Electrical Specification [2]

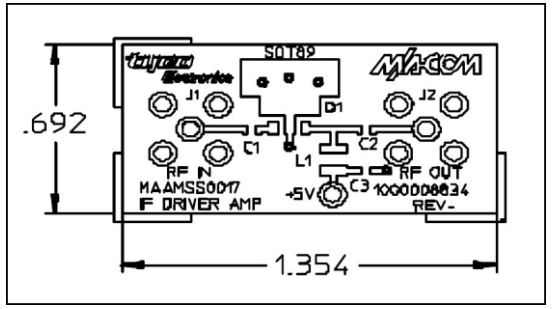
Broadband IF Driver Amplifier
50 - 2500 MHz
MAAMSS0017
V4

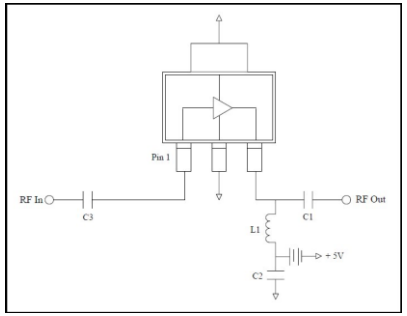
Electrical Specifications: T_A = 25°C, V_{CC} = 5 V, Z_0 = 50 Ω, P_{IN} ≤ -10 dBm

Parameter	Test Conditions	Frequency	Units	Min	Typ	Max
Gain	—	250 MHz	dB	15.5	18	19.5
		50 - 600 MHz	dB	—	17	—
		600 - 1500 MHz	dB	—	12.5	—
		1500 - 2000 MHz	dB	—	10.5	—
		2000 - 2500 MHz	dB	—	8	—
Noise Figure	—	50 - 600 MHz	dB	—	4.8	—
		600 - 1500 MHz	dB	—	5.1	—
		1500 - 2500 MHz	dB	—	5.3	—
Input Return Loss	—	50 - 600 MHz	dB	—	10	—
		600 - 2500 MHz	dB	—	13	—
Output Return Loss	—	50 - 600 MHz	dB	—	10	—
		600 - 1500 MHz	dB	—	13	—
		1500 - 2500 MHz	dB	—	10	—
Output 1dB Compression	—	50 - 600 MHz	dBm	—	20	—
		600 - 2500 MHz	dBm	—	19	—
Output IP3	Two tone, P_{IN} / Tone = -13 dBm, Tone spacing = 10 MHz	250 MHz	dBm	35	38.5	—
		50 - 600 MHz	dBm	—	37	—
		600 - 2500 MHz	dBm	—	34	—
Current	V_{CC} = 5 V	—	mA	—	70	100

- 2000 to 2004: Datasheet revised 4 times to characterize broadband performance
- Revision 4 defined nominal frequency @ 250 MHz & Min/Max parameters, gain, noise figure & return loss
- PCB Test board not available, able to fabricate one
- Effects gain but able to characterize die revisions

Test PCB & Schematic [1]





[1] Broadband IF Driver Amp., MAAMSS0017 V1, DS ref., Datasheet Archive 2017. http://www.datasheetarchive.com/ Searched & Accessed: 3.15.17

[2] Broadband IF Driver Amp., MAAMSS0017 V4, DS ref., 2005. https://octopart.com/search?q=MAAMSS0017 Searched & Accessed: 3.15.17

Example 1- Broadband IF Driver Amplifier

Standalone Component, *characterized on Test PCB*

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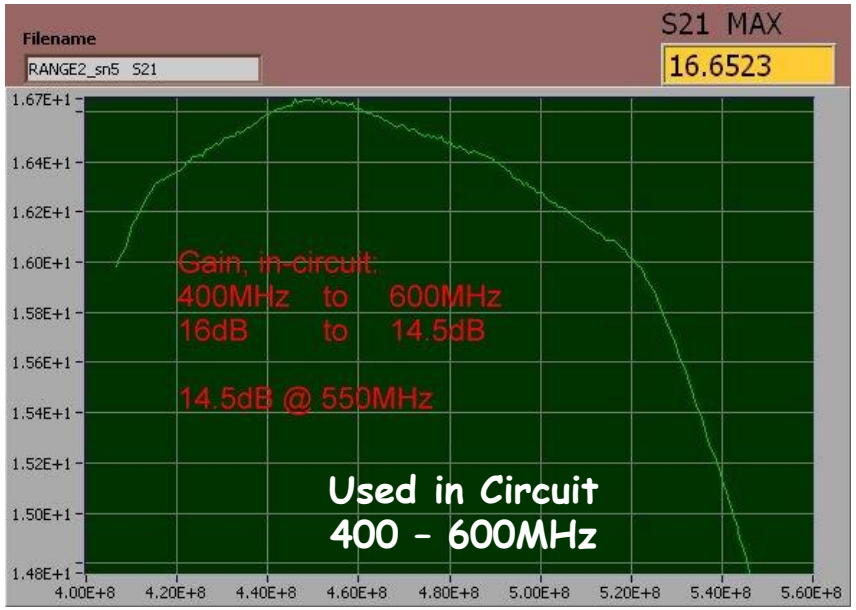
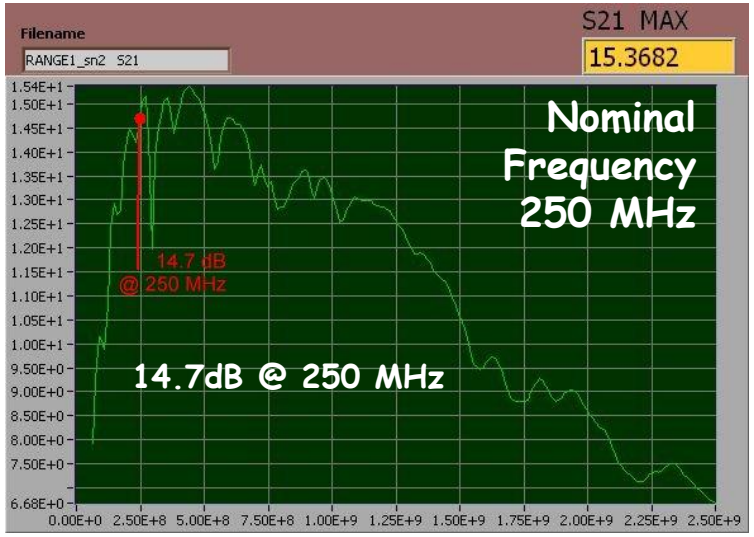
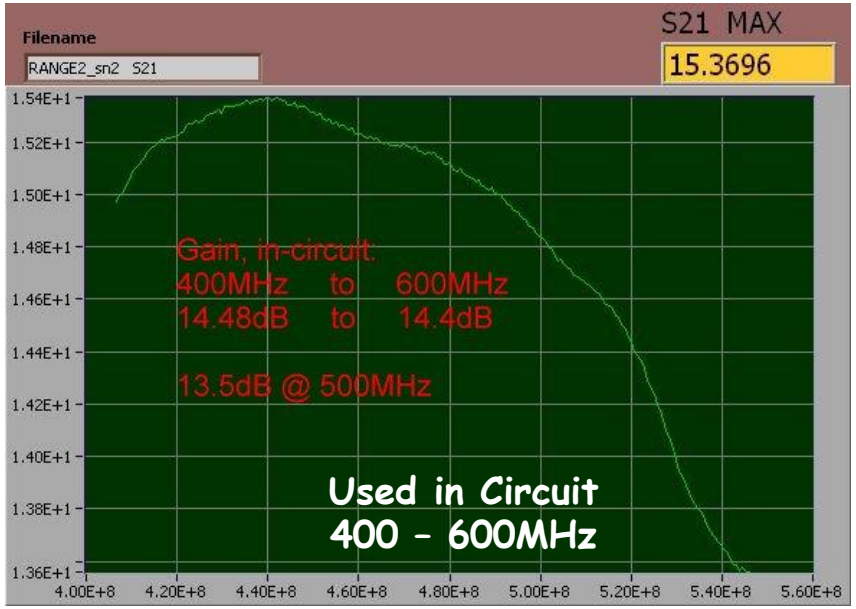
DC 2000 Gain Characteristics: 1+ dB higher across spectrum



DC 2004 Gain Characteristics: -1 dB lower across spectrum





Example 1- Broadband IF Driver Amplifier

(2) FA Investigations, RF switching CCA

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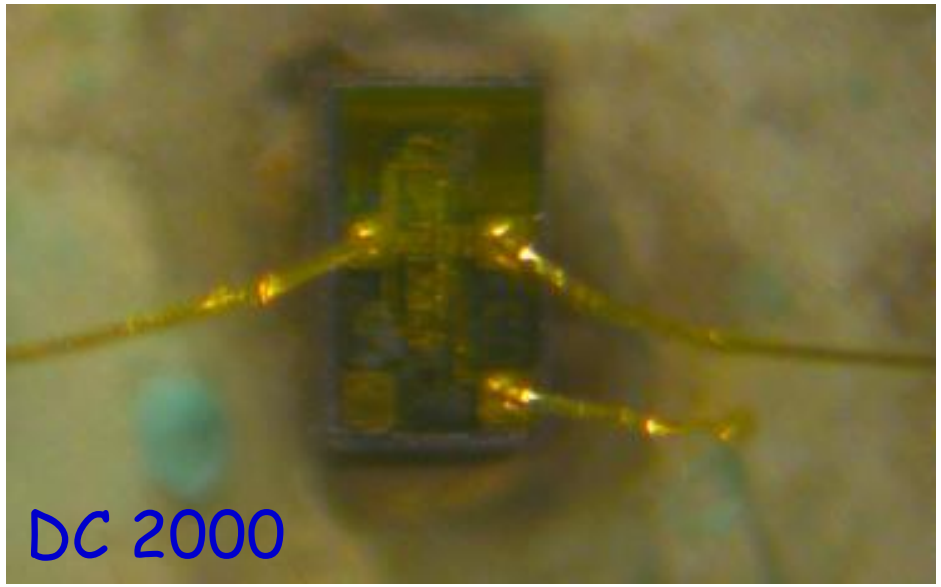
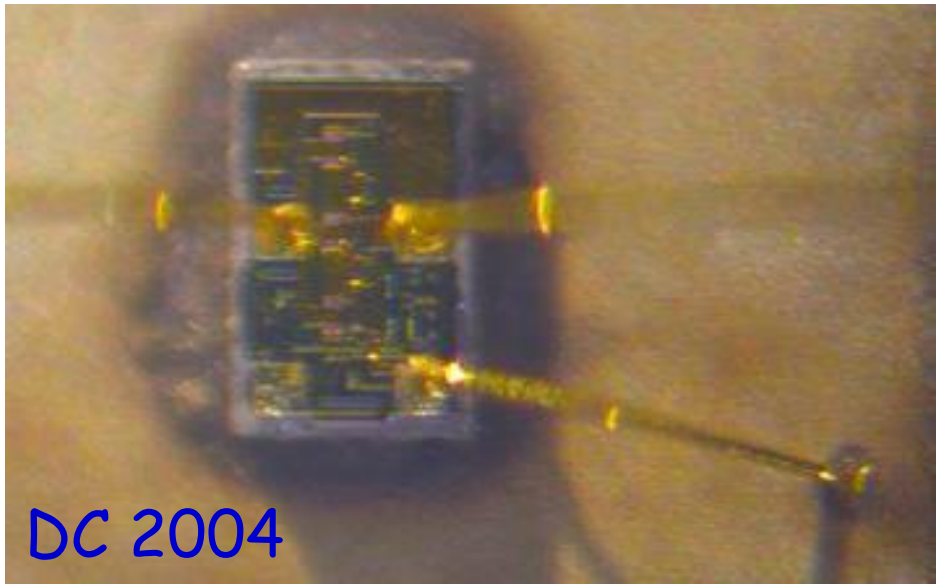
De-capsulation: Shows wire placement Issue





- ✓ OCM supplier changed: **Lead frame, Wire Bonder** (Wire Placement) **& Injection Mold**
- ✓ Likely a result of a change in IC Packaging Supplier
- ✓ OCM design engineering reviewed analysis & data. Confirmed effects of longer ground loop on gain, resulting in dB drop & roll-off **outside** nominal range
- ✓ RF CCA design gain required operation outside nominal range 200-400MHz

Industry "Best Practices"- PCN Release Not Required / Enforced

Example 1- Broadband IF Driver Amplifier

(2) FA Investigations, RF switching CCA

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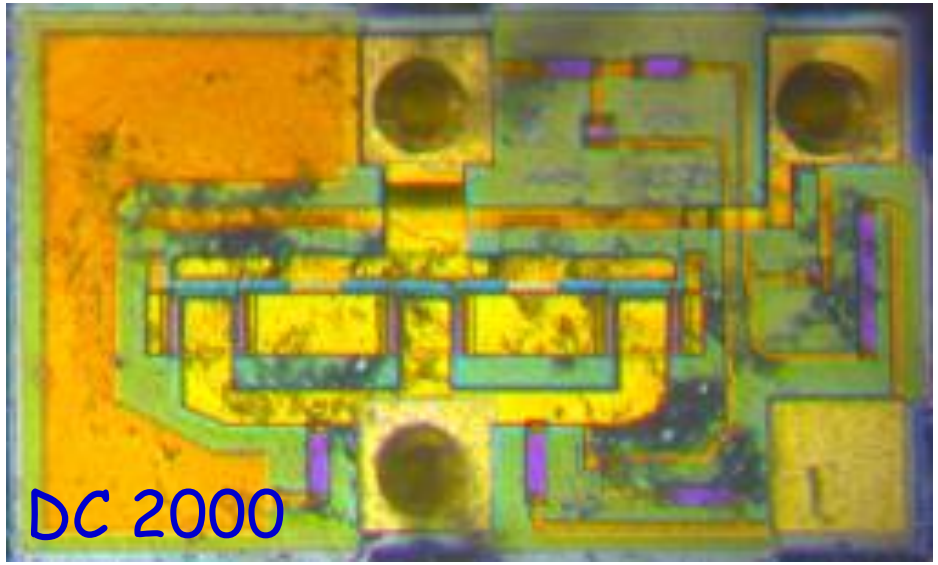
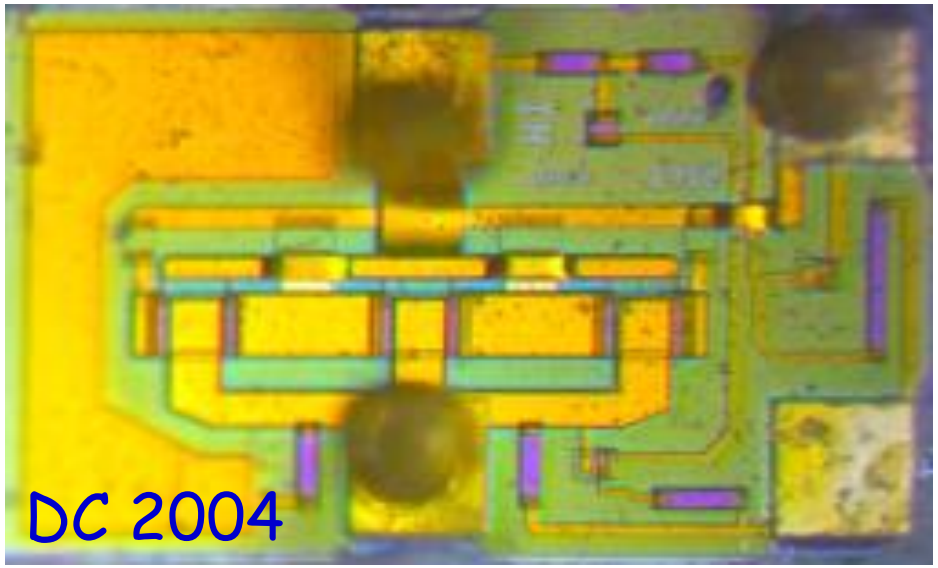
High Mag. Inspection: Die are the **SAME**





- OCM PCN **NOT** released- Effect of ground loop gain changes at frequency ***not captured*** In datasheets
- **Supplier Change**: Impact to Form-Fit-Functionality ***Not*** Properly Assessed!
- **Short Term:** Amps. replaced with legacy components with DC 2000
- **Long Term:** Recommended replacing obsolete MAAMSS0017 with updated equivalent component, with Improved Freq. Characteristics

Driver Amp. is obsolete- *REQUIRES* eventual design change

Example 2- 60V N-Channel MOSFET, 2N7002

(1) FA Investigation, RF Communications CCA

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I. Common switching device; (4) OCM's Identified on the design specification ASL

II. 40-50% yield @ board level test. Q501 Failed FM distortion, decreased output capacitance

III. Supplier mounted IC's (SOT-23) appear significantly different than repair stock. Indicted as suspect CF

IV. Engineering provided spice model & details of the test fixture failure mode as observed

Analysis- "K" date code has less capacitance (D-S, D-G)

Circuit functions as On/Off switch appropriately

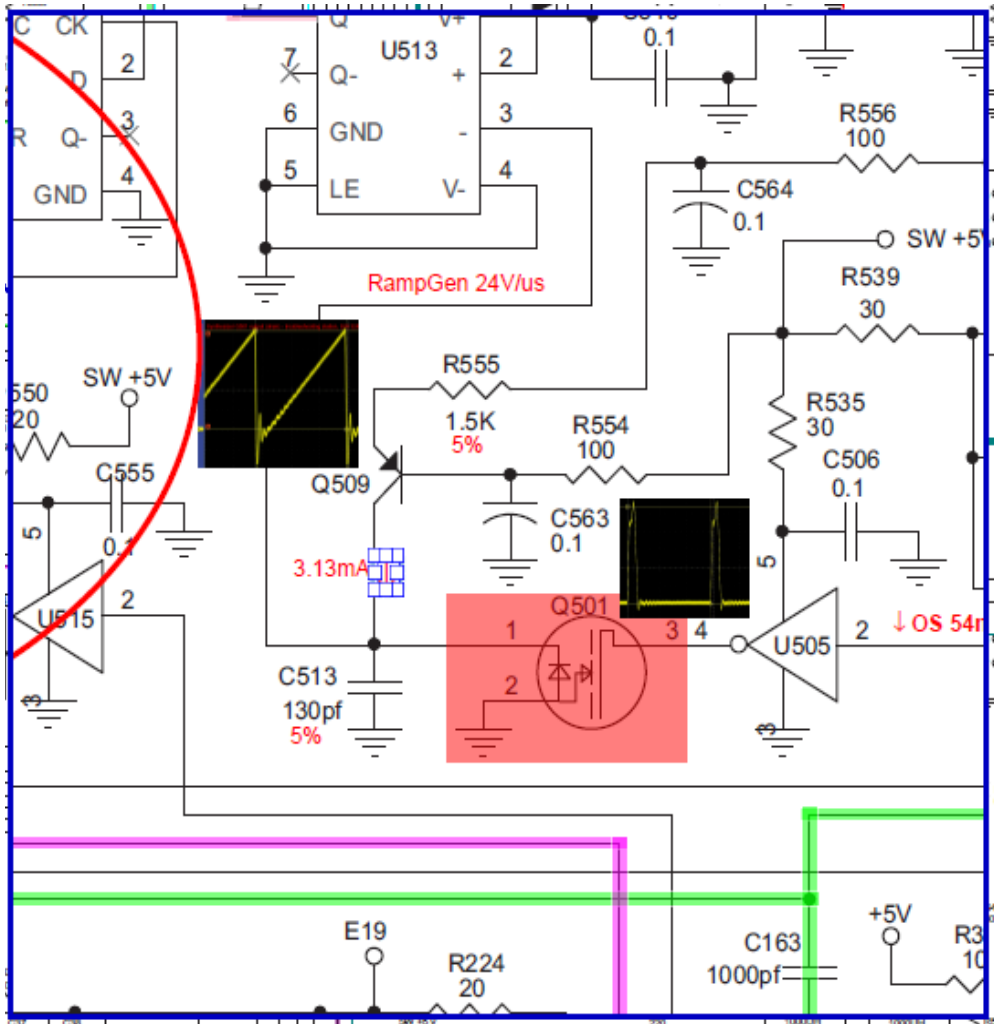
Device OFF: Source charges capacitor at the drain
- Generates saw tooth waveform

Device ON: Capacitor discharges, saw tooth starts near 0V

Steeper saw tooth related to less capacitance

Circuit Function DEPENDENT on MOSFET Timing & Capacitance Attributes!

Spice Model, As applied in Circuit



Example 2- 60V N-Channel MOSFET, 2N7002

(1) FA Investigation, RF Communications CCA

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Research, observation, markings & dimensional analysis determined:

Failing devices = OCM1

DC "K" = Mfg. 2011/13/15

Repair stock ***RESTORES*** circuit performance

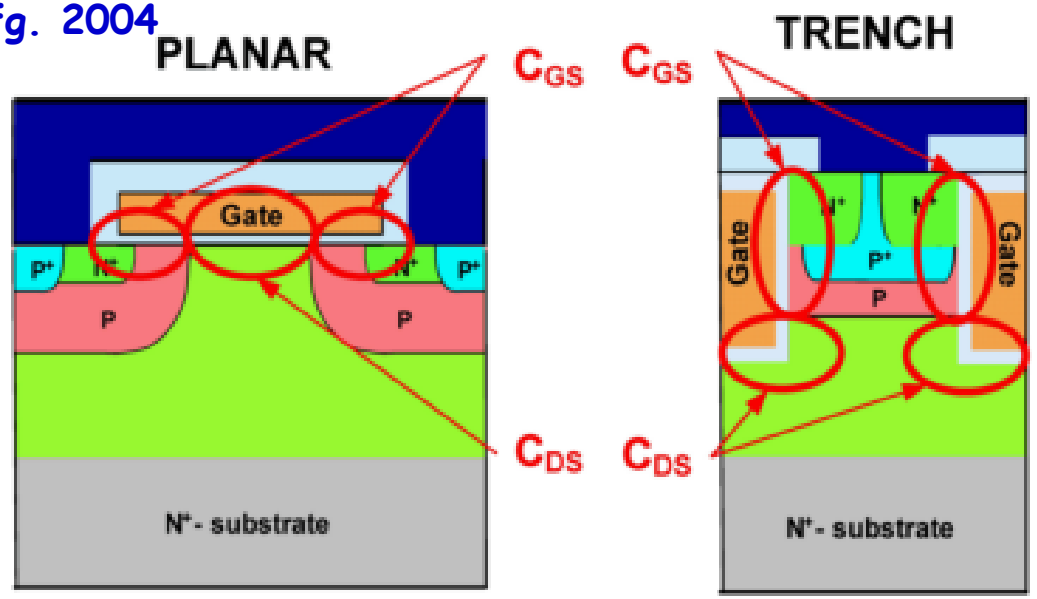
Repair stock = OCM2

DC "E" = Mfg. 2004

✓ ***OCM1*** migrated from Planar to Trench FET architecture in 2009- Die shrink, Larger Yield, Increased switching speed

✓ ***OCM1*** Tests confirm increased switching speed & reduced output capacitance

Improvements for new designs EFFECTS time dependent legacy circuits!



Example 2- 60V N-Channel MOSFET, 2N7002

(1) FA Investigation, I-V Characterization

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Curve Trace Analysis-

FA lab. measurements, BOTH devices function as intended

I-V Characteristics OCM2 (Old) **Vs. OCM1** (New)**-** Different due to OCM1 die level changes

OCM 2 DC 2004 Characteristics

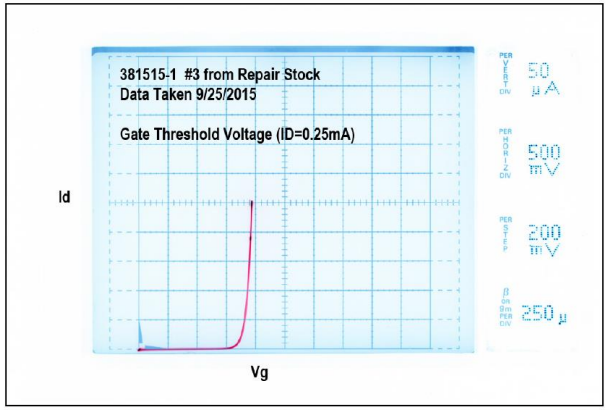

Figure 11 Gate Threshold Voltage at ID=0.25mA. Sample #3 from Repair Stock. the allowed limits of 0.8 v to 2.5 v.

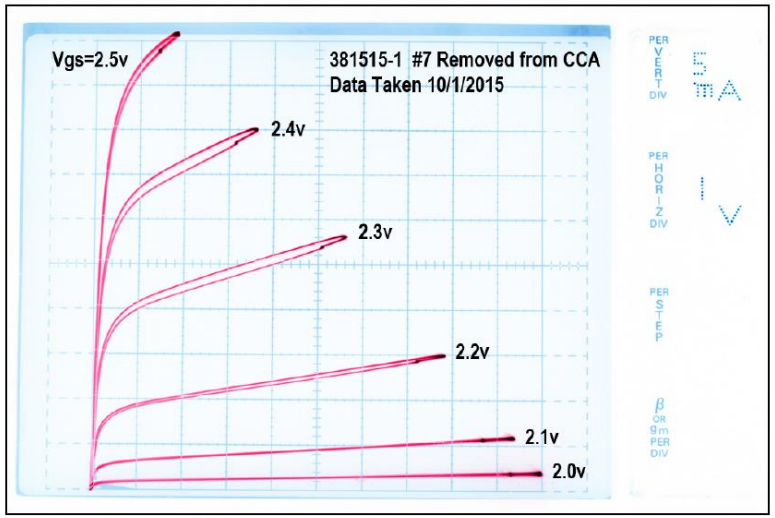

Figure 8 Device (#7) Removed from a CCA. This had the highest "gain".

OCM1 Newer DC 11/13/15 Higher Gain

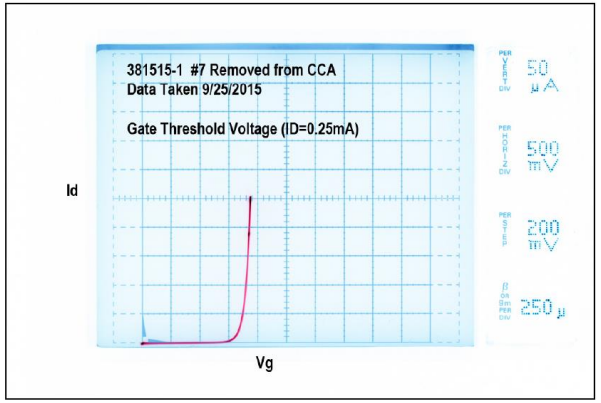

Figure 9 Gate Threshold Voltage at ID=0.25mA. Sample #7 Removed from a CCA. within the allowed limits of 0.8 v to 2.5 v.

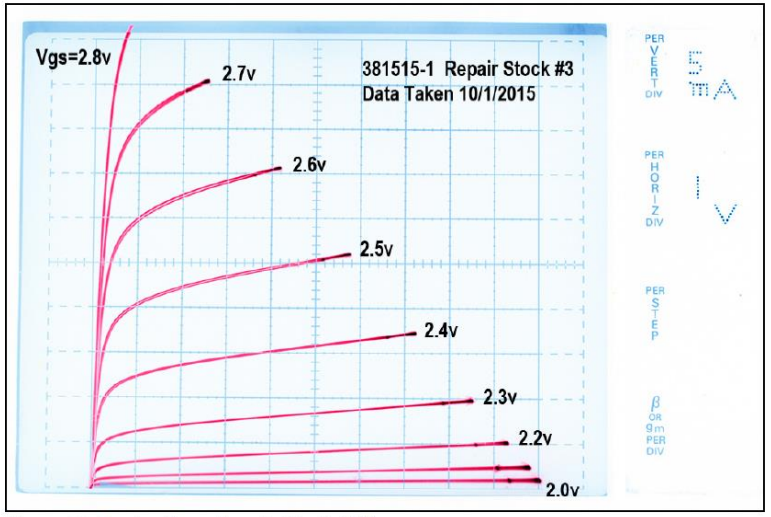

Figure 10 Device from Repair Stock (#3).

Example 2- 60V N-Channel MOSFET, 2N7002

(1) FA Investigation, X-Ray Analysis

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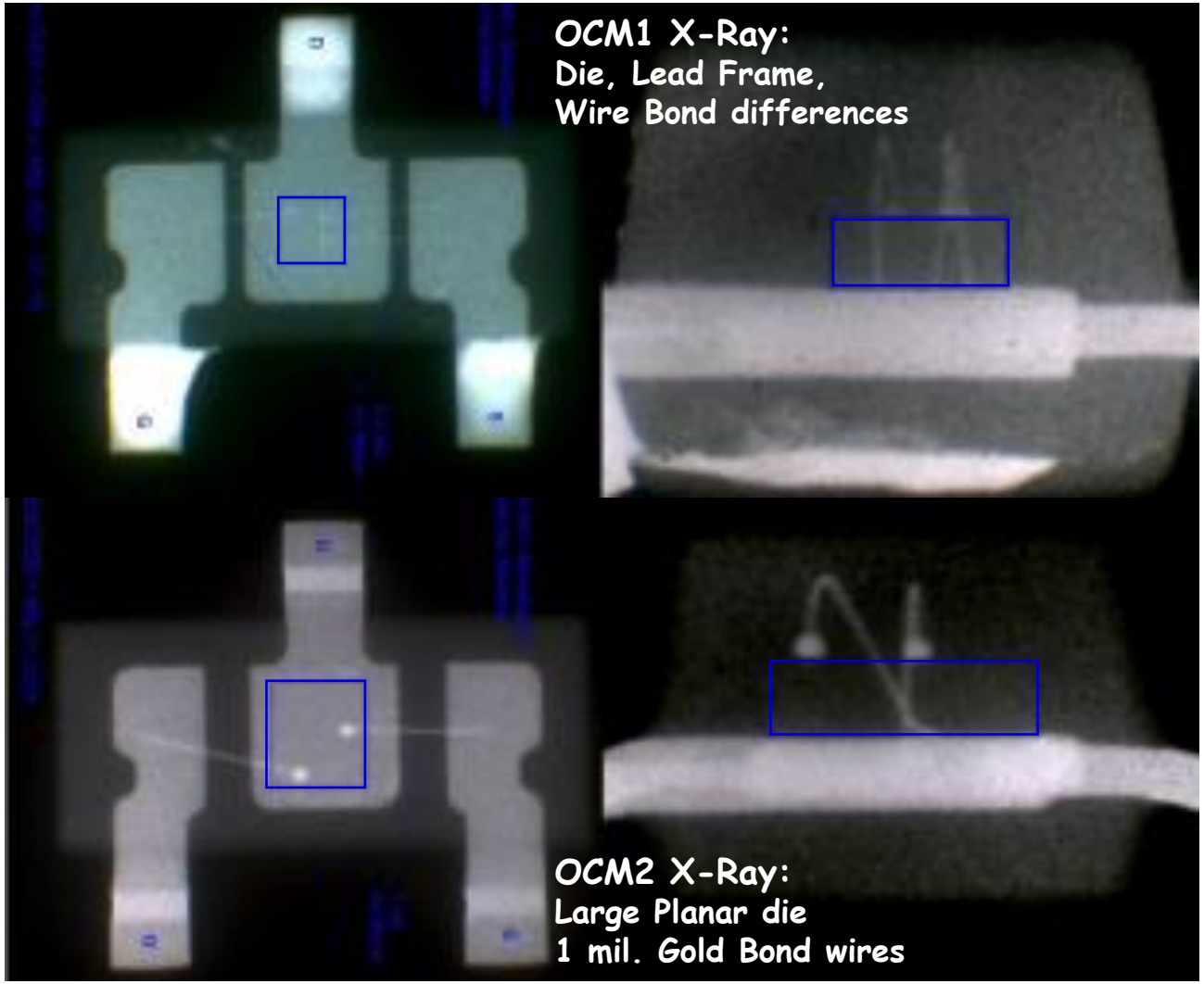
Factors: Effecting function in legacy circuit

1. *OCM1* migrated to copper wire, 0.5 mil with industry wide transition. Double wire bond D-S required,

   DUE to increased bond strike force

2. Bond wire length, orientation, quantity & lead frame differences effect
   - Gain
   - Noise susceptibility

   Results in Increased FM distortion



Technology Migration- Effects Circuit performance!

Example 2- 60V N-Channel MOSFET, 2N7002

(1) FA Investigation, Decapsulation

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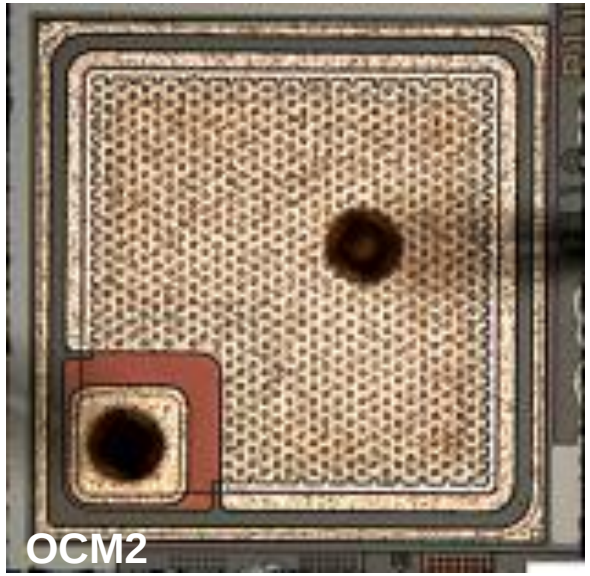
Factors: Effecting function in legacy circuit

3. Reduced C(D-S) & C(G-S) output capacitance effects
   - **State timing in circuit**
   - **Reduced noise tolerance**

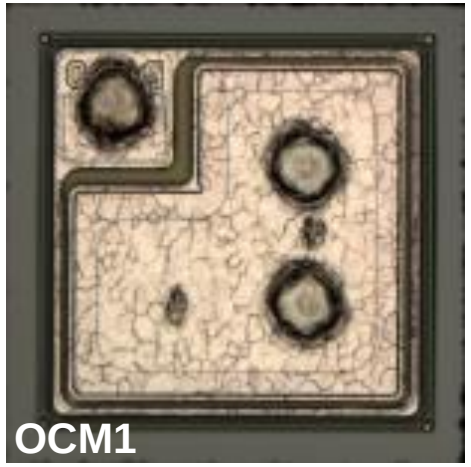
Lab. Recommendation: Reduce FM distortion and modify circuit timing by adding capacitance to accommodate planar & trench FET technology



OCM2 DeCap

Die Area 669 x 671 = 448,899μm²

{Images NOT to scale}



OCM1 DeCap

Die Area 392 x 393 = 154,056μm²

Technology Migration- Effects Circuit performance!

Conclusions-

Recommended Actions, Preventive Measures

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- Commercial OCM's make changes to die & packaging to:
  - REDUCE Cost, Increase yield & throughput, INCREASE market share
  - Improve Function and Performance
- Utilize Industry "Best Practices"
  - Assessments of Form, Fit, Function impact ***VARY***
  - Datasheet Sheet Updates / Releases, Technical Content, PCN / EOL Notices ***VARY***
- For legacy systems
  - Perform review of component availability & PCN's, ***PRIOR*** to build
  - Specify replacement components, as necessary
  - PCN impact assessment may require testing and additional analysis
- Impact of architectural, process or supplier changes
  - REQUIRES analysis from SME's in Materials, Electrical, Components & Failure Analysis

Acronyms, Definitions

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AT&L: Acquisition, Technology & Logistics; DoD undersecretary (OSD)

AD: Authorized Distributor

AOI / AXI: Automated Optical / X-Ray Inspection, Process improvement

ASL / PSL: Approved *or* Preferred Supplier List

BU: Business Unit

CAT: Counterfeit Avoidance Team (Enterprise wide)

CB: Certification Body

CCAT: Counterfeit Component Avoidance Training

COTS: Commercial Off The Shelf (components, products)

CPB: Customs Protection & Borders

CPI/CI: Critical Program Information / Counterintelligence

CTN: Components Technology Network (Enterprise wide)

DFARS: Defense Federal Acquisition Regulation Supplement

DHS: Department of Homeland Security

DI: De-Ionized (Water)

DLA: Defense Logistics Agency

DMS: Diminishing Manufacturing Supply (source)

DoD: Department of Defense (U.S.)

DoJ: Department of Justice (U.S.)

EHS: Environmental Health & Safety

EOL: End Of Life (System Refurbishment / Upgrades)

ERAI: Electronic Resellers Association Incorporated

ESS: Environmental Stress Screening

ETMA: Engineering Technology & Mission Assurance

FA: Failure Analysis

FCT: Functional Test

FD: Franchised Distributor

GAO: Government Accountability Office (U.S.)

GIDEP: Government-Industry Data Exchange Program

IC: Integrated Circuit

ICT: In-Circuit Test

ID: Independent Distributor

IDEA: Independent Distributors of Electronics Association

ITAR: International Traffic in Arms Regulations

Legacy: Previous generation system (Military / Aerospace)

LF: Lead Free

LTB: Last Time Buy

MA: Mission Assurance, Internal Raytheon Function

MDA: Missile Defense Agency

MIL Spec: Military Specifications

MIL-STD: Military Standard (specifications)

MSL: Moisture Sensitivity Level (defined in J-STD-020E)

NC: Non-Conformance, Electronic Components, Hardware, Material or Process

NASA: National Aeronautics and Space Administration (U.S.)

NDAA: National Defense Authorization Act, Implemented Annually

NEPP: NASA Electronics Parts and Packaging program

NFD: Non-Franchised Distributor

NHA: Next Higher Assembly

OCM: Original Component Manufacturer

OEM: Original Equipment Manufacturer (Systems)

OSD: Office of the Secretary of Defense (U.S.)

PCN: Product Change Notice

PLCP: Product Life Cycle Process

POC: Point Of Contact

PPP: Program Protection Plan

Prime: System Design Lead / Provider

QC: Quality Control

QPL: Quality Parts List

RF: Radio Frequency

RTN: Raytheon

SAE: Society of Automotive & Aerospace Engineering

SEM-edx: Scanning Electron Microscopy-energy dispersive x-ray spectroscopy

SASC: Senate Armed Services Committee

SIA: Semiconductor Industry Association

SME: Subject Matter Expert

SMT: Surface Mount Technology

Supplier: Sub-system component provider, Sub-Contractor

SAE: Society of Automotive & Aerospace Engineering

SEM-edx: Scanning Electron Microscopy-energy dispersive x-ray spectroscopy

SASC: Senate Armed Services Committee

SIA: Semiconductor Industry Association

SME: Subject Matter Expert

SMT: Surface Mount Technology

Supplier: Sub-system component provider, Sub-Contractor

Abstract

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Abstract: During the product lifecycle of high volume commercial discrete and Integrated circuit components, subtle and more significant changes are often made in production to increase: Volume, Throughput, Performance and Profit Margins. These changes may or may not appear in PCN (Product Change Notice) releases from the OCM. This is dependent on whether or not the supplier is able to assess impact from the "Form, Fit or Functionality" perspective. Without exhaustive testing in all applications, the impact of these changes are not well understood.

We will review (2) Failure Analysis examples where changes in the IC packaging or die architecture significantly impacted Raytheon programs, resulting in failures and delays in production. Root cause analysis and findings will be shared and what preventative steps should be taken to mitigate the impact of these changes, particularly in legacy designs.

Topics Covered-

1. Overview of Semiconductor Industries best practices and run rules
2. Review an example program circuit level failures attributed to a poorly documented OCM component revision change
3. Review an example of a program circuit level failure attributed to a die architectural change and how this impacts / limits functionality in an existing circuit design
4. Provide best practice recommendations on how to mitigate risks associated with component level changes