



Electrical Overstress Failure Analysis- *Mission critical transient voltage suppressor power applications*

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**Wednesday April, 21st 2021
Session #2B Reliability
17:30 – 17:50**

Power Filter Background & Analysis Request

- Power filter assemblies and NHA sub-systems were exposed to an inadvertent over-voltage condition during Integration functional testing
- Process level RCA determined several sub-systems were exposed to this condition as a result of test station misconfiguration during a maintenance / upgrade cycle
- ALL sub-systems were inspected for over-volt stress evidence and were subjected to additional environmental, BIT & functional tests, without failure
- The team & customer wanted verification that the misapplied voltages did not subject any components to over-voltage stress (walking wounded)
- VR1, VR2 (Transient Voltage Suppressors) & R1, R2 (Power Resistors) are critical to transient and OV / OI protection. Several power filter CCA's were sent to the FA Lab. for analysis

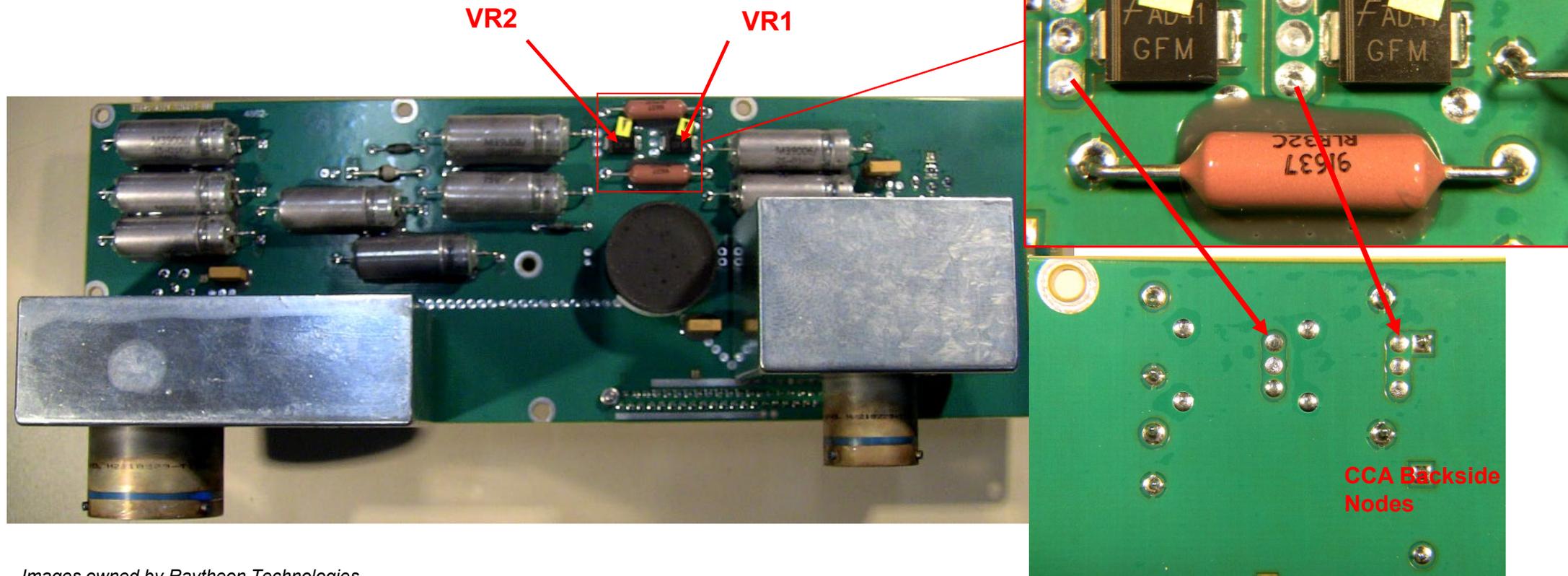
Analysis Goals

- ✓ Determine if the over voltage condition damaged VR1/VR2 & R1/R2
- ✓ Visually inspect, photograph, X-ray VR1/VR2 & R1/R2 for any indication of electrical overstress
- ✓ Perform electrical testing to confirm the functional integrity of the TVS diodes and associated resistors
- ✓ Provide recommendations to ensure the affected sub-systems were not impacted

Power filters are essential in protecting CTF circuits from transients, noise & OV/IV conditions

CCA Visual Inspection- VR1 & VR2, mounted on Filter PWB

VR1 & VR2 in Parallel with R1 / R2 on the input side of the circuit. There are no signs of heat damage on the components or PWB, mask layer discoloration, fractures in encapsulant, disruptions or solder reflow in the associated PWB nodes & lands

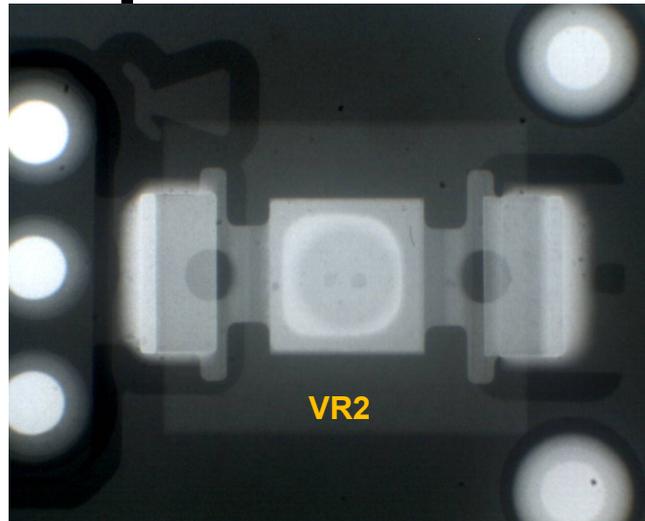


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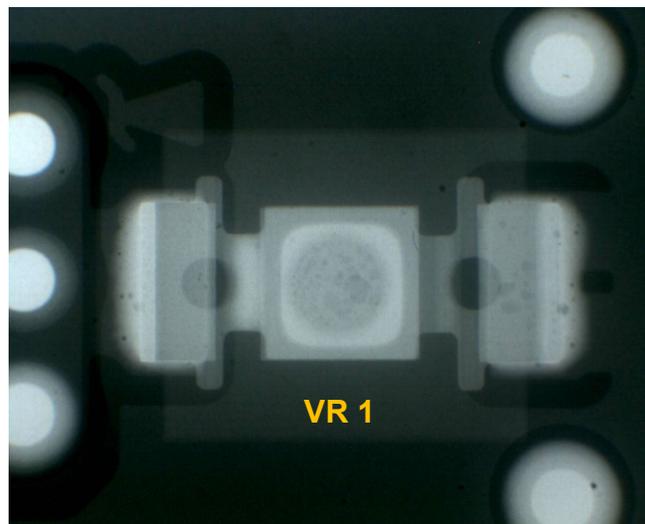
Components, PWB, Connectors & Filter Inspected under Microscope no Anomalies found

CCA Radiographic Inspection-

CCA level x-ray can expose evidence of damage to both the components, associated circuit nodes & copper planes



No damage was observed, related to the Source supply misapplication



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X-rays reveal no damage to the Voltage Input components, PWB artwork or copper structures

Initial Electrical Measurements

DMM measurements of VR1/VR2 using diode & resistance modes.
Diodes & associated resistors appear un-damaged

Test Asset: Fluke 112 True RMS DMM

Sample	V_F	* V_R	Ω_F	Ω_R	** Resistance (II) at 1mA
VR1	0.609V	OL	3.480M Ω	OL	
R1					3.0K Ω
VR2	0.606V	OL	3.368M Ω	OL	
R2					6.0 K Ω

* Voltage @ conduction, Not V_{BR} . Not measureable in this setup

** measured *in circuit* parallel equivalent value

Go / No go check, prior to removal & curve trace analysis

Component Visual Inspection- VR1 & VR2 Removed from CCA

No physical signs of heat damage, discoloration, expansion or encapsulant fractures due to EOS

VR1 Top



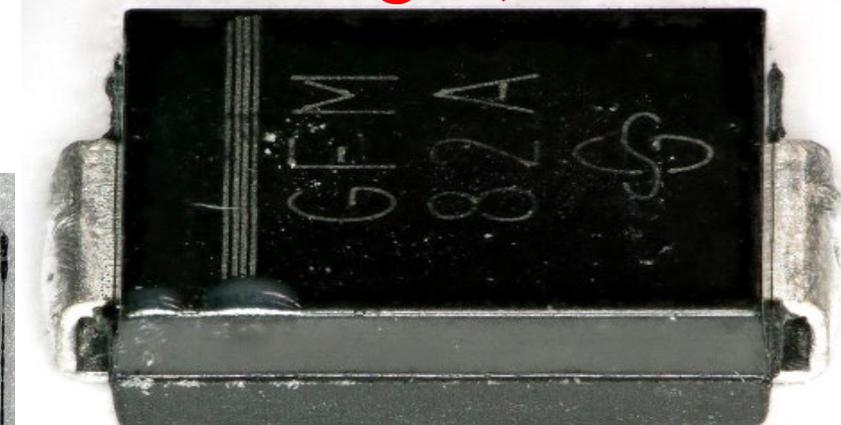
VR1 @ 20x; -62°



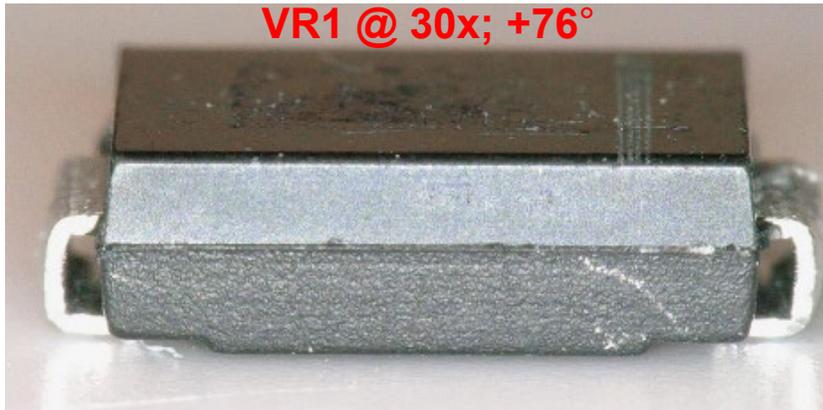
VR2 Top



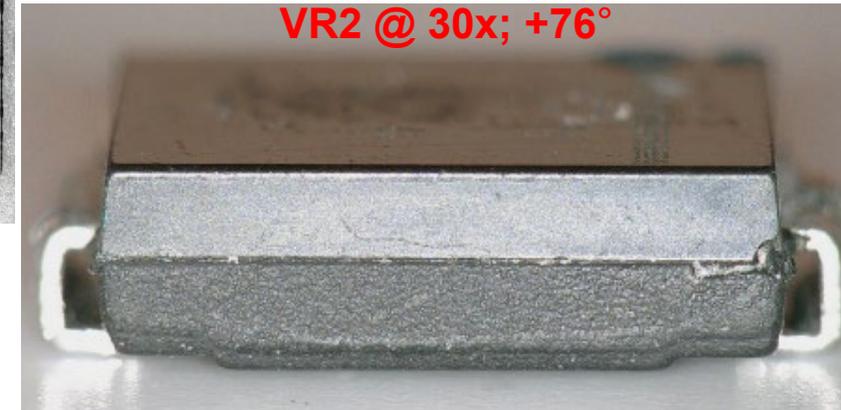
VR2 @ 20x; -50°



VR1 @ 30x; +76°



VR2 @ 30x; +76°



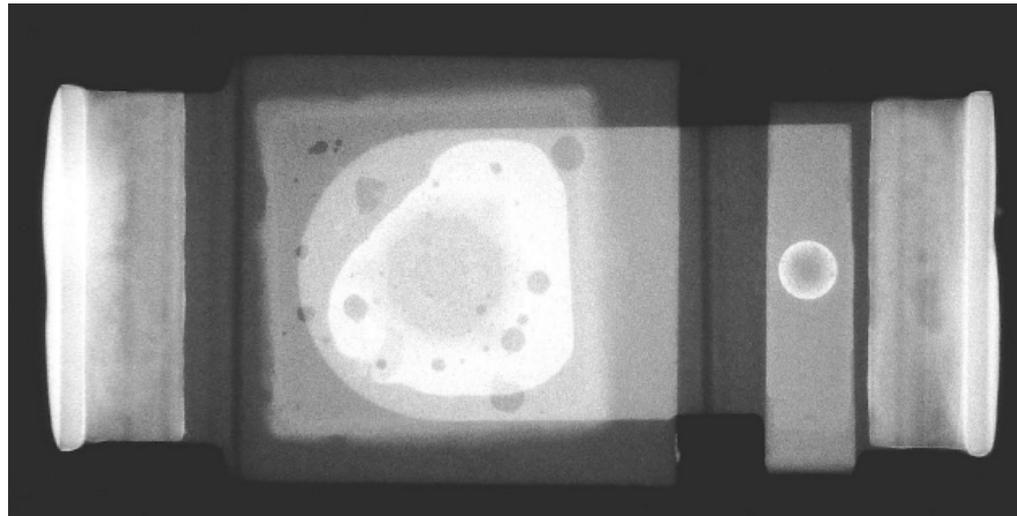
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Vishay Markings Noted, 5 approved COTS TVS suppliers, per Internal Vendor Item Control Drawing (VID)

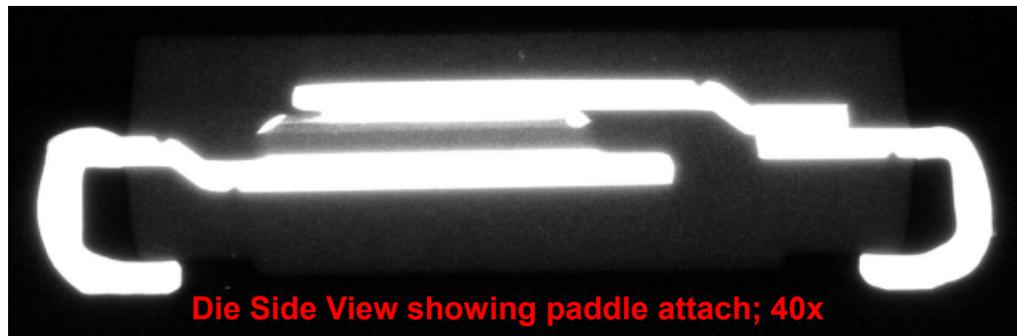
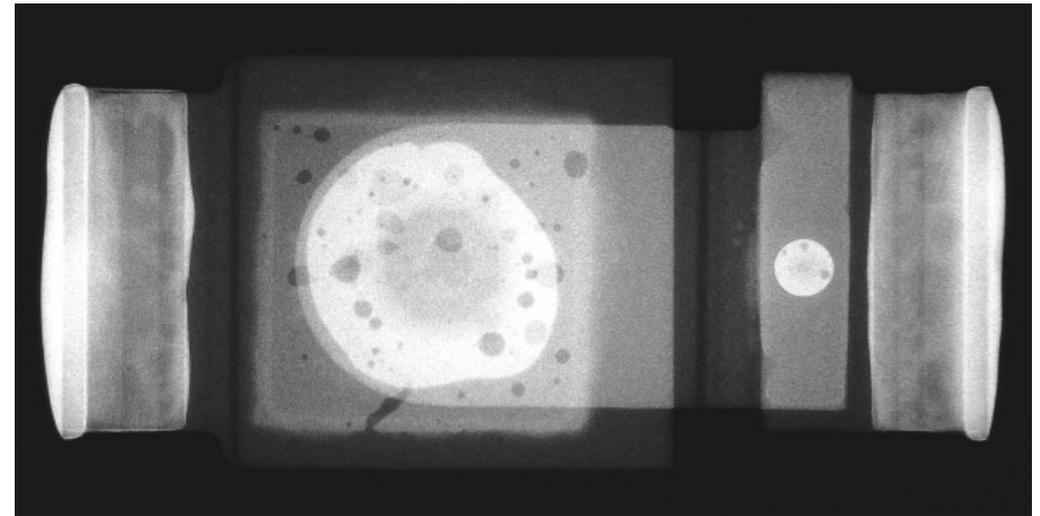
Radiographic Inspection- *Wet film to Digital*

X-ray images of VR1 & VR2 reveal no thermal stress or solder anomalies. Die eutectic voiding is compliant

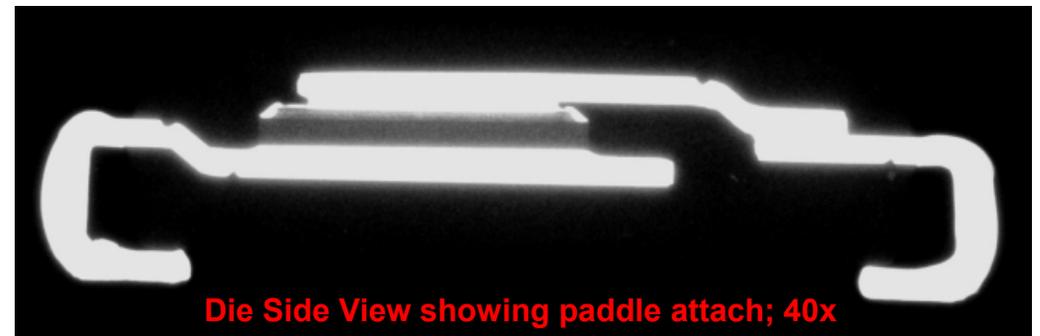
Die Top View; 40x



Die Top View; 40x



Die Side View showing paddle attach; 40x



Die Side View showing paddle attach; 40x

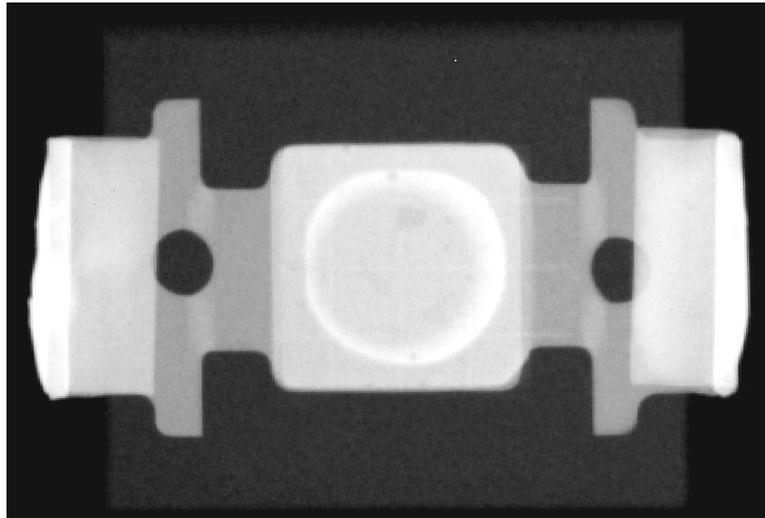
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No separation of lead frame paddles from the die

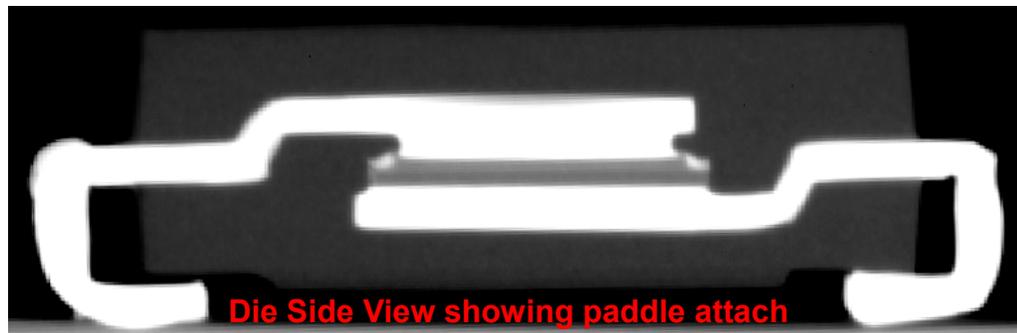
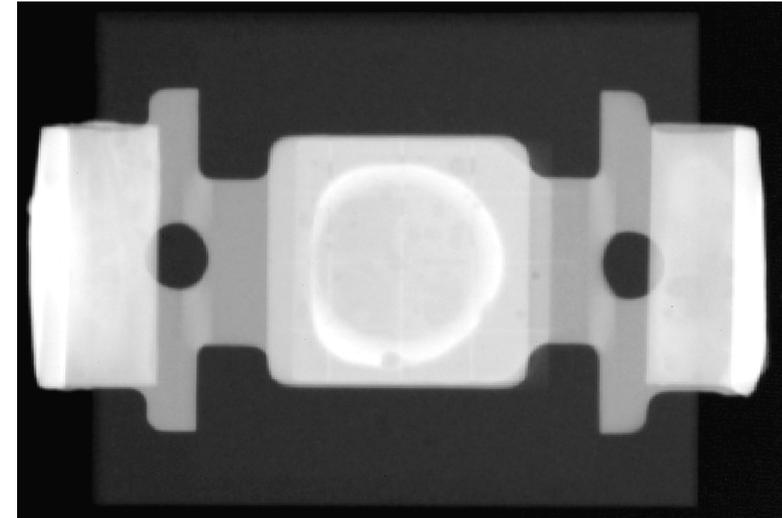
R/T X-Ray Inspection- *Alternate Asset & Supplier*

VR1 & VR2, no thermal stress or solder anomalies. Compliant die eutectic

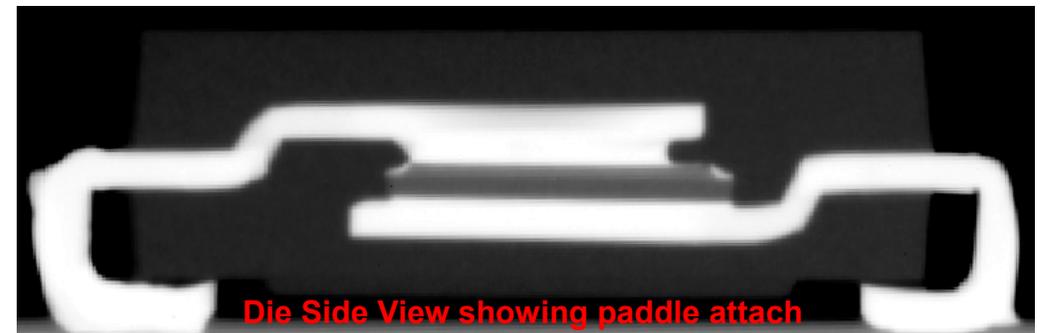
Die Top View



Die Top View



Die Side View showing paddle attach



Die Side View showing paddle attach

Images owned by Raytheon Technologies

NO separation of lead frame paddles from the die

Vishay Datasheet Assessment- *SMCJ33A Key Parameters*



www.vishay.com

SMCJ5.0A thru SMCJ188CA

Vishay General Semiconductor

Surface Mount TRANSZORB[®] Transient Voltage Suppressors



FEATURES

- Low profile package
- Ideal for automated placement
- Glass passivated chip junction
- Available in uni-directional and bi-directional
- Excellent clamping capability



RoHS
COMPLIANT
HALOGEN
FREE
Available

MAXIMUM RATINGS ($T_A = 25\text{ °C}$ unless otherwise noted)

PARAMETER	SYMBOL	VALUE	UNIT
Peak pulse power dissipation with a 10/1000 μs waveform ⁽¹⁾⁽²⁾	P_{PPM}	1500	W
Peak pulse current with a 10/1000 μs waveform ⁽¹⁾	I_{PPM}	See next table	A
Peak forward surge current 8.3 ms single half sine-wave uni-directional only ⁽²⁾	I_{FSM}	200	A
Power dissipation on infinite heatsink, $T_A = 50\text{ °C}$	P_D	6.5	W
Operating junction and storage temperature range	T_J, T_{STG}	-55 to +150	$^{\circ}\text{C}$

Notes

⁽¹⁾ Non-repetitive current pulse, per fig. 3 and derated above $T_A = 25\text{ °C}$ per fig. 2

⁽²⁾ Mounted on 0.31" x 0.31" (8.0 mm x 8.0 mm) copper pads to each terminal

Vishay COTS Unidirectional Device: *Identify V I thresholds which verify proper function*

* Datasheet excerpts used WITH permission from Vishay Semiconductor www.Vishay.com

Vishay Datasheet Assessment- *SMCJ33A Key Parameters*



www.vishay.com

SMCJ5.0A thru SMCJ188CA

Vishay General Semiconductor

ELECTRICAL CHARACTERISTICS (T _A = 25 °C unless otherwise noted)									
DEVICE TYPE MODIFIED "J" BEND LEAD	DEVICE MARKING CODE		BREAKDOWN VOLTAGE V _{BR} AT I _T (1) (V)		TEST CURRENT I _T (mA)	STAND-OFF VOLTAGE V _{WM} (V)	MAXIMUM REVERSE LEAKAGE AT V _{WM} I _D (μA) (3)	MAXIMUM PEAK PULSE SURGE CURRENT I _{PPM} (A) (2)	MAXIMUM CLAMPING VOLTAGE AT I _{PPM} V _C (V)
	UNI	BI	MIN.	MAX.					
(+)SMCJ33A	GFM	BFM	36.7	40.6	1.0	33	1.0	28.1	53.3

Notes

- (1) Pulse test: t_p ≤ 50 ms
- (2) Surge current waveform per fig. 3 and derate per fig. 2
- (3) For bi-directional types having V_{WM} of 10 V and less, the I_D limit is doubled
- (4) All terms and symbols are consistent with ANSI/IEEE C62.35
- (5) For the bi-directional SMCJ5.0CA, the maximum V_{BR} is 7.25 V
- (6) V_F = 3.5 V at I_F = 100 A (uni-directional only)
- (+) Underwriters laboratory recognition for the classification of protectors (QVGQ2) under the UL standard for safety 497B and file number E136766 for both uni-directional and bi-directional devices

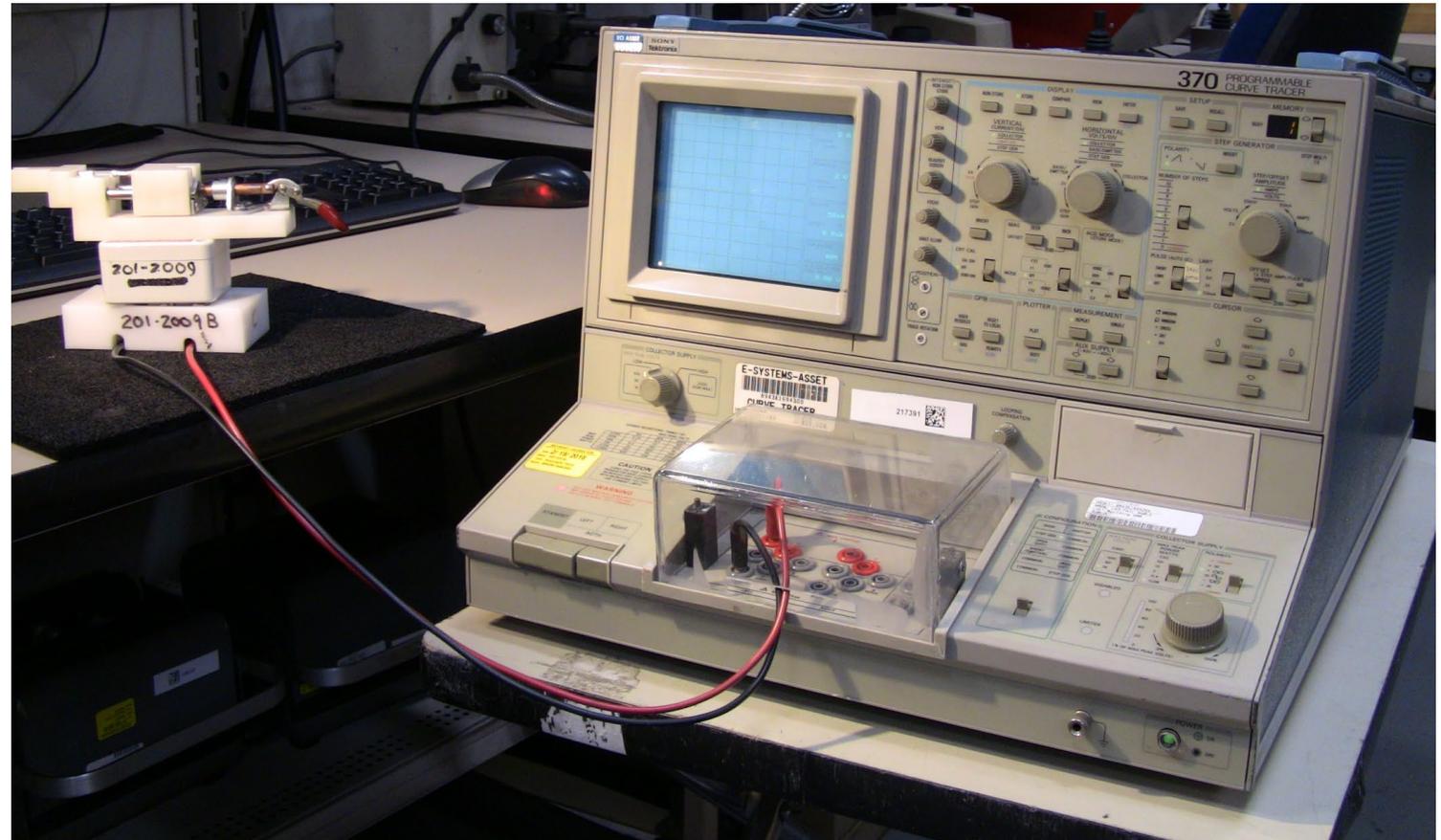
Other parameters (most Si & Ge devices)-
V_f = 410mV – 610mV, Typical (Current dependent)

Vishay COTS Unidirectional Device: Identify V I thresholds which verify proper function

Equipment Selection- *Low Vs. High power assessment*

Tektronix 370 Selected for Evaluation

- Tektronix 371 out for repairs; High power assessment **REQUIRES** solder mounting & specialized fixturing
- Key Parameters in the datasheet required to verify high power diode functionality are low voltage & current

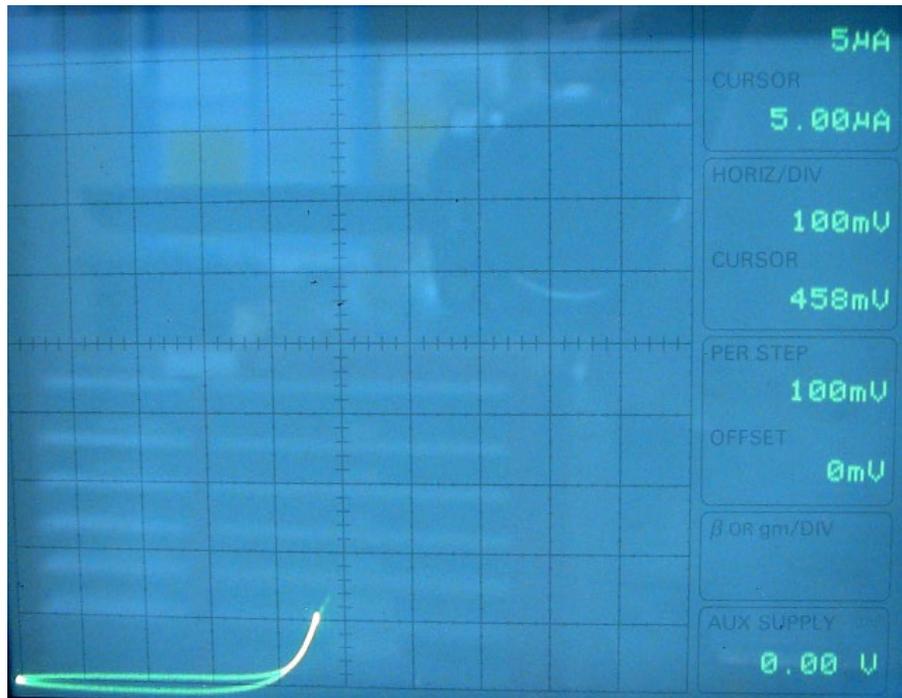


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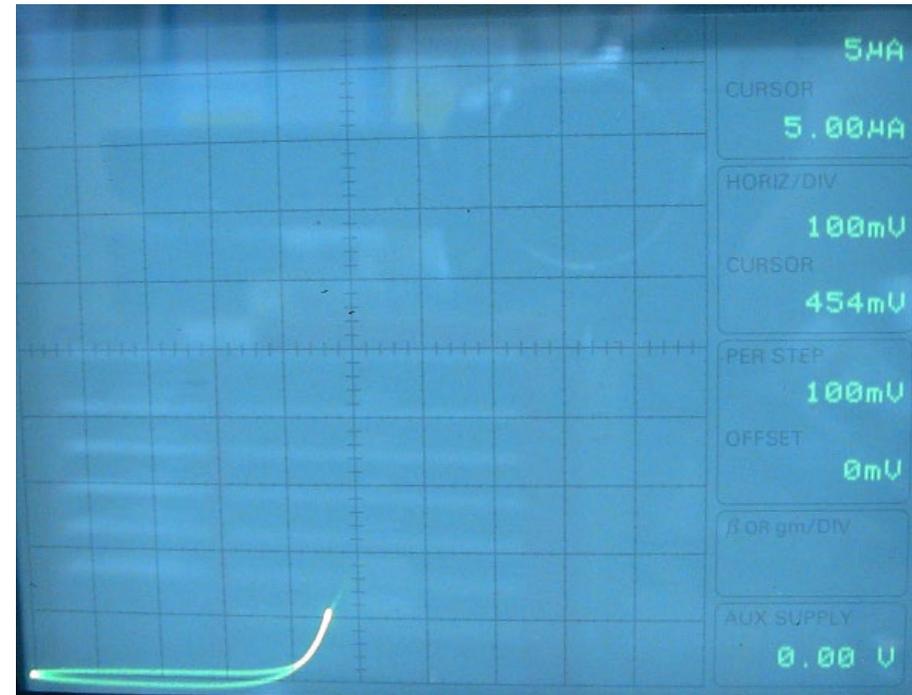
Utilize right equipment to *verify* component functionality, high power testing not required

Electrical Measurements- Forward Voltage

VR1 Forward Voltage (458mV @5 μ A)



VR2 Forward Voltage (454mV @5 μ A)

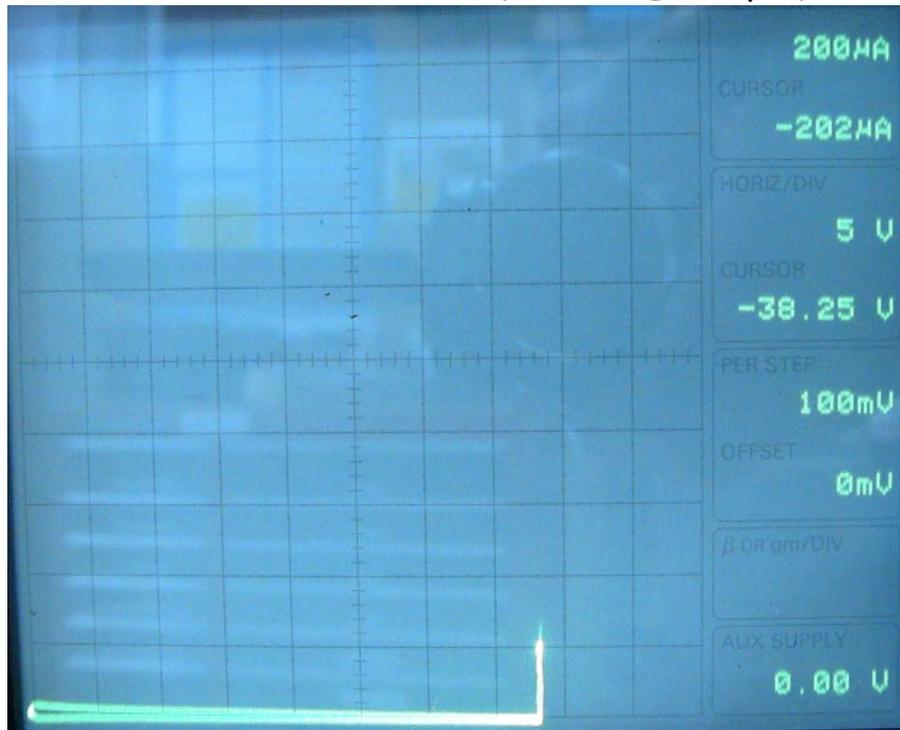


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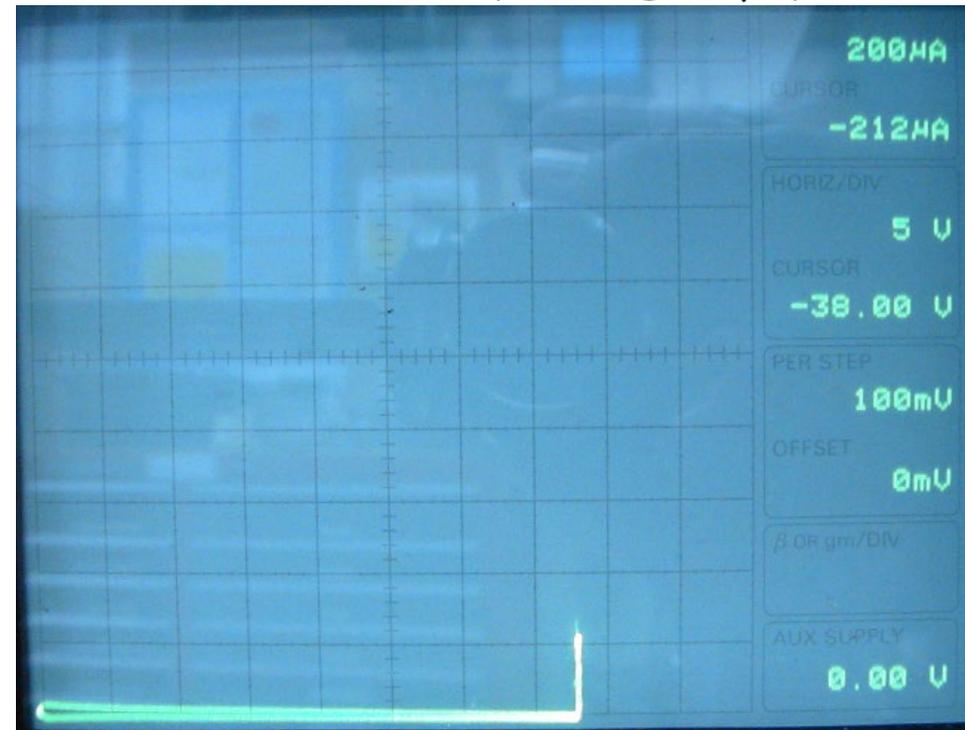
Electrical Parameters- Within typical range, no soft knee or resistive shunt

Reverse Current – Breakdown Voltage

VR1 I_R breakdown (38.25V @ 202μA)



VR2 I_R breakdown (38.00V @ 212μA)

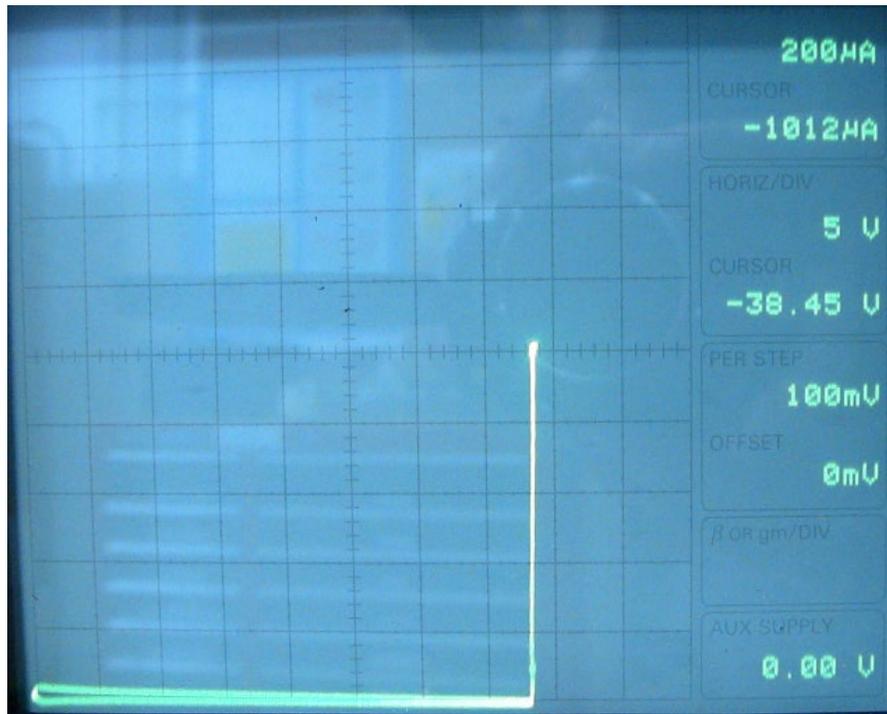


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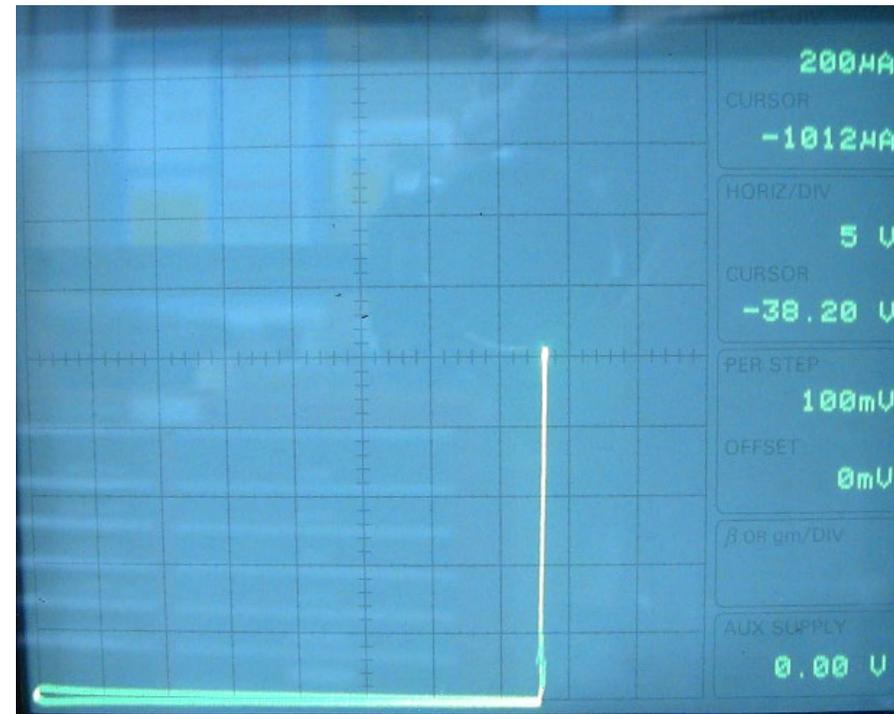
Electrical Parameters- Within Product Specification, no soft knee or resistive shunt

Reverse Current – Breakdown V @ 1mA

VR1 I_R breakdown (38.45V @ 1.012 mA)



VR2 I_R breakdown (38.20V @ 1.012 mA)

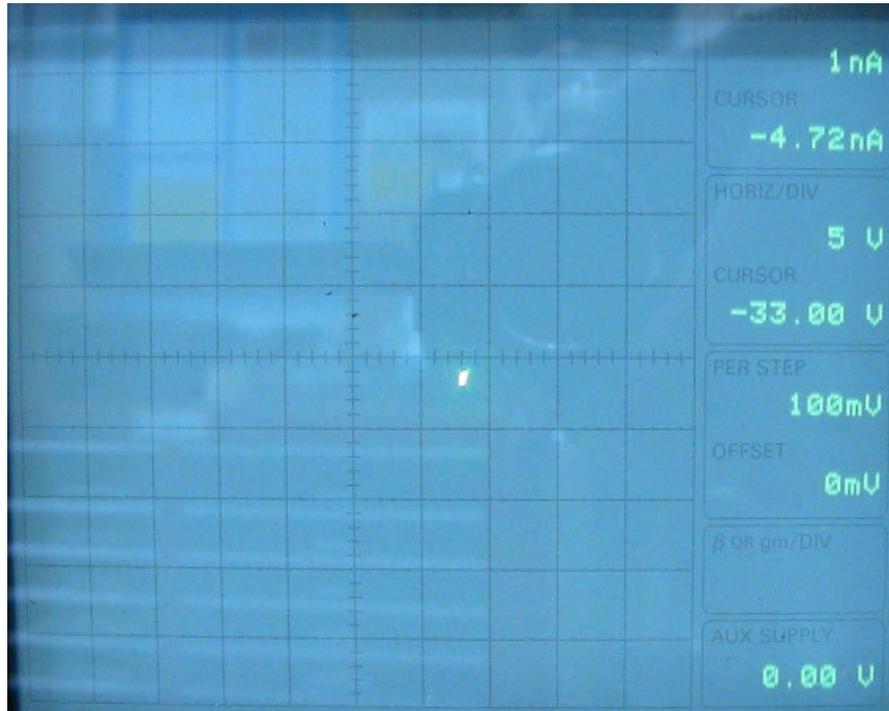


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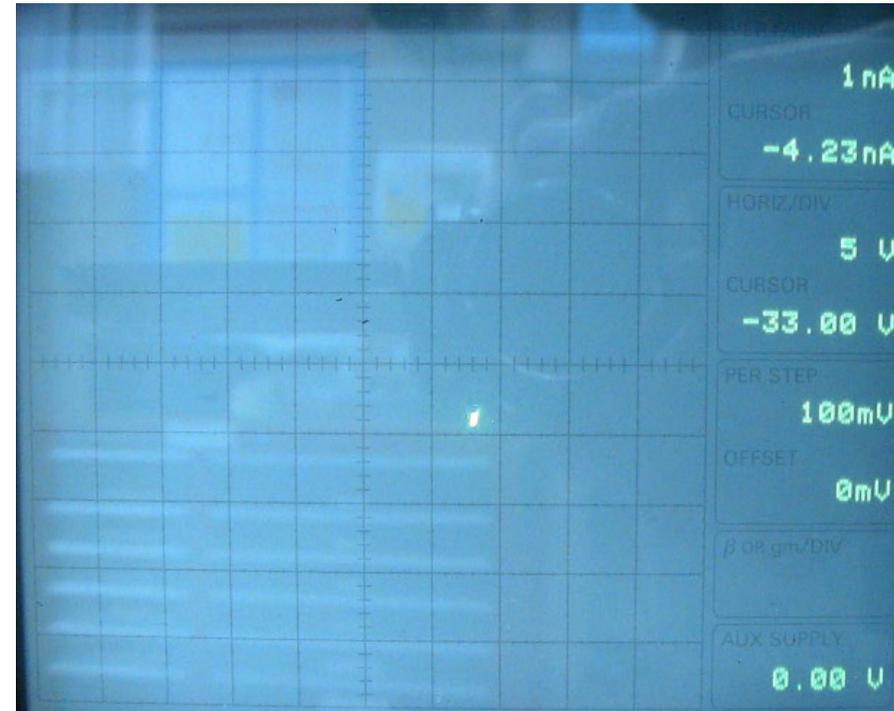
Electrical Parameters- Within Product Specification, no soft knee or resistive shunt

Reverse Leakage- 33 Vdc @ 5 μ A Maximum (*Design Requirement*)

VR1 Reverse Leakage 4.72nA @ 33Vdc(rms)



VR2 Reverse Leakage 4.23nA @ 33Vdc(rms)



Vishay OCM Supplier specifies: 1.0 μ A Max

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Electrical Parameters- *Within Product Specification, leakage WELL below thresholds*

Parametric Measurements- Results Summary, VI Curve Trace

Electrical characterization test results *Tek 370 Curve Tracer (low power)*

Test Asset: Tektronix 370 Curve Tracer

Sample	V_F (450-610mV Typical)	I_R (>35V @ 2-300uA)	$V_{BR(V)}$ @ 1mA (36.7V-40.6V)	*Reverse leakage at V_{RWM} 33v @ 5.0μA max
VR1	458mV @ 5μA	38.25V @ 202μA	38.45V @ 1.012mA	33V @ 4.72nA
VR2	454mV @ 5μA	38.00V @ 212μA	38.20V @ 1.012mA	33V @ 4.23nA

V_{BR} for this design, must be > 36.7 Volts
Reverse leakage @ V_{RWM} = 5.0μA max ; Supplier specifies 1.0μA max

Electrical Parameters- Within Product Specification, leakage WELL below thresholds

Power Filter TVS Analysis- *Results & Conclusions*

1. Visual inspection & X-ray of VR1 and VR2 TVS diodes show ***no physical*** evidence that these were damaged or degraded, due to the misapplied EOS condition
2. Physical & X-ray inspection of the Input Filter CCA and associated I/O connectors did not yield any evidence that electrical / thermal overstress degradation was present
3. Initial and parametric tests per the Vishay supplier datasheet & our internal VID showed that the diodes function as intended; Curve Tracer showed NO signs of EOS degradation
4. Physical Inspection, internal BIT test and additional environmental testing of NHA assemblies proved that the critical function sub-system control circuits & assemblies were shielded from the EOS condition by the TVS diodes & over-volt protection circuitry within the Power Filter CCA
5. Additional power filter assemblies were evaluated, including the removal & characterization of the TVS diodes. In ***ALL*** instances, the diodes power filter CCA's & NHA sub-system control circuitry was not affected

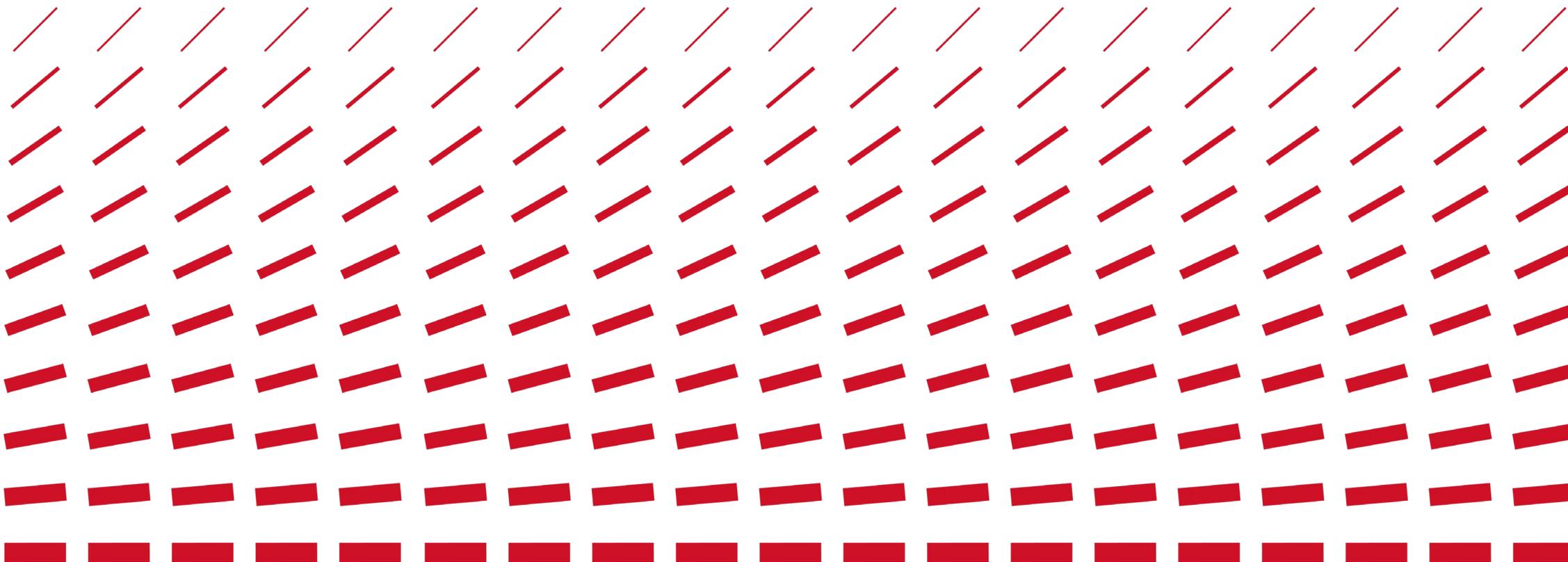
Electrical Parameters- *Within product specification; NO evidence of electrical overstress present*

Power Filter TVS Analysis- *Recommendations, Required Actions*

6. As an additional precautionary measure, all sub-system power filter CCA's were inspected electrically verified and had VR1/VR2 TVS components replaced
7. Removed devices were analyzed for evidence of EOS degradation. There have been ZERO failures / non-conformances
8. Process / Test engineering PM / upgrade process was revised to include both supervisory & QA Inspection of all test system maintenance and repair actions
 - Three peers involved in confirming correct Test station configuration
9. Test station source supply, ground, signal connectors & interposers were updated to use unique keyed connectors to mitigate future test system voltage misapplications

Critical to function systems *REQUIRE* additional actions & analysis to ensure function & reliability!

Thank you!!



Abstract

In mission critical / high reliability uptime power applications, source energy applied to communication, control and navigation circuits must be free of Electro-magnetic Interference (EMI), transients & parasitic noise generated by power supply sources, sub-systems or external events. Power filter CCA's / assemblies use a combination of chokes, power Inductors, capacitors, EMI filters, Transient Voltage Suppressors (TVS) & Logic control to protect critical circuit function. This presentation will review a test process failure, where high voltage was inadvertently applied to several power filter assemblies during system level functional test. We will review how exposed components were analyzed and how the critical systems & power filter assemblies were deemed to be unaffected by these events.

Topics Covered-

1. High power Transient Voltage Suppressor (TVS), Specifications & Application
2. Process event, leading to a failure investigation for mission critical hardware
3. Analysis techniques to assess potential over-voltage exposure condition on control circuits
4. Analysis results and recommendations
5. Follow on preventative / corrective measures to meet and exceed customer's expectations

Presenter's Bio

Aaron DerMarderosian Jr. is a Principal Multi-Discipline engineer in Raytheon Technologies Intelligence & Space business segment, working in the failure analysis laboratory Largo, FL. He has worked in engineering for 30 years focused on: reliability analysis & assessment, failure investigation, product / program FRACA, design verification test, systems & circuit analysis. Investigation activities include counterfeit analysis, detection & avoidance methods, Hardware security assessments and root cause analysis of failed components and electronic assemblies. He is a senior member of the IEEE, member of SMTA & served as IEEE Boston Reliability chapter chair (2006-2008) & AdCom officer for 10 years. Aaron received multiple individual & team achievement awards, Engineering technical honors in 2004 & 2007 and a technical innovation & inventors award in 1991 (Raytheon), leading to a patent. Aaron has presented at several technical conferences & IEEE events, he has a B.S. degree in Engineering from Northeastern University (Boston Ma.)

Contact Information-

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Acronyms, Definitions

BIT: Built In Test, required for high availability

CCA: Circuit Card Assembly

COTS: Commercial Off The Shelf (components, products)

CF: Counterfeit (IE CF Analysis)

CTF: Critical To Function- Circuit, sub-system which is critical to mission success

DLC: Date Lot Code

EOS: Electrical Overstress, Source supply misapplication

FA: Failure Analysis

FCT: Functional Test

IC: Integrated Circuit

ICT: In-Circuit Test

I/O: Input / Output , Bi-directional connectors (power/signal)

ITAR: International Traffic in Arms Regulations

Legacy: Previous generation system (Military / Aerospace)

LRIP: Low Rate, Initial Production

MA: Mission Assurance

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

NHA: Next Higher Assembly- Circuit, sub-system or system

OCM: Original Component Manufacturer

OEM: Original Equipment Manufacturer (Systems)

PCN: Product Change Notice

PM: Preventive Maintenance- Proactive actions to prevent failures and downtime

PLCP: Product Life Cycle Process

Prime: System Design Lead / Provider

QC: Quality Control

QMS: Quality Management Standard

QPL: Quality Parts List

R&R: Remove & Replace (Operations Action)

RCA: Root Cause Analysis

RTX: Raytheon Technologies

R/T X-ray: Real time digital X-ray, vs. wet film

SIA: Semiconductor Industry Association

SME: Subject Matter Expert

SMT: Surface Mount Technology

Supplier: Sub-system component provider, Sub-Contractor

TVS: Transient Voltage Suppressor, Semiconductor

V I: Voltage Vs. Current- Ohm's law relationship

VID: Vendor Item control Drawing- Used to specify approved suppliers, in lieu of a Specification