DESIGN, MANUFACTURE AND TEST TECHNIQUES FOR MULTIPACTOR FREE RF DEVICES

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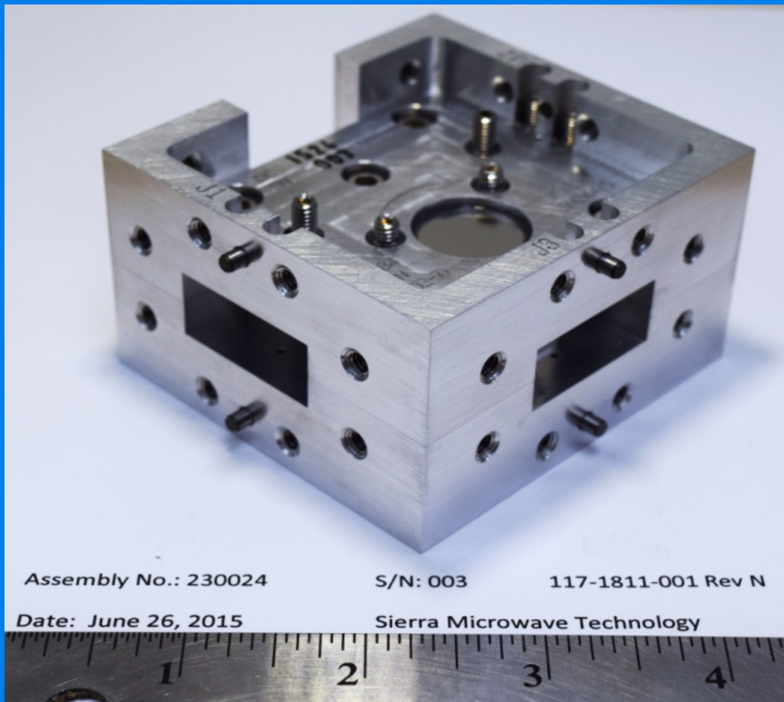
INTRODUCTION

Examples of high power RF devices that were designed and successfully tested for multipaction at Sierra Microwave will be presented, Including:

- A WR112 waveguide circulator in X-band tested to 3000 Watts peak
- A VHF lumped element band pass filter tested to 80 Watts peak
- An L-band coaxial isolator-combiner tested to a combined output power of 2000 Watts peak

The design approach, multipaction mitigation methods, test methods and test results for each of these parts will be presented and discussed

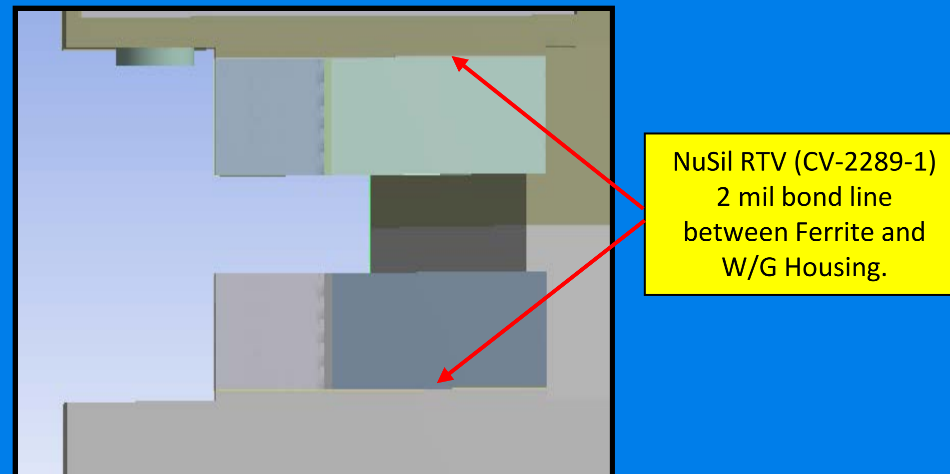
WR112 High Power Circulator



High power waveguide circulator covering 7-9 GHz

Power handling requirement : 1000 Watts peak (500 Watts average)

Device tested for multipaction with 3000 Watts peak (600 Watts average)



Teflon spacer between Ferrites for matching

Gaps between waveguide, Ferrites and Teflon Insert filled with RTV to prevent Multipaction

CIRCULATOR MULTIPACTION ANALYSIS

Multipaction Analysis Performed Using SPARK3D[1]

Electro Magnetic Field Distribution Obtained by HFSS

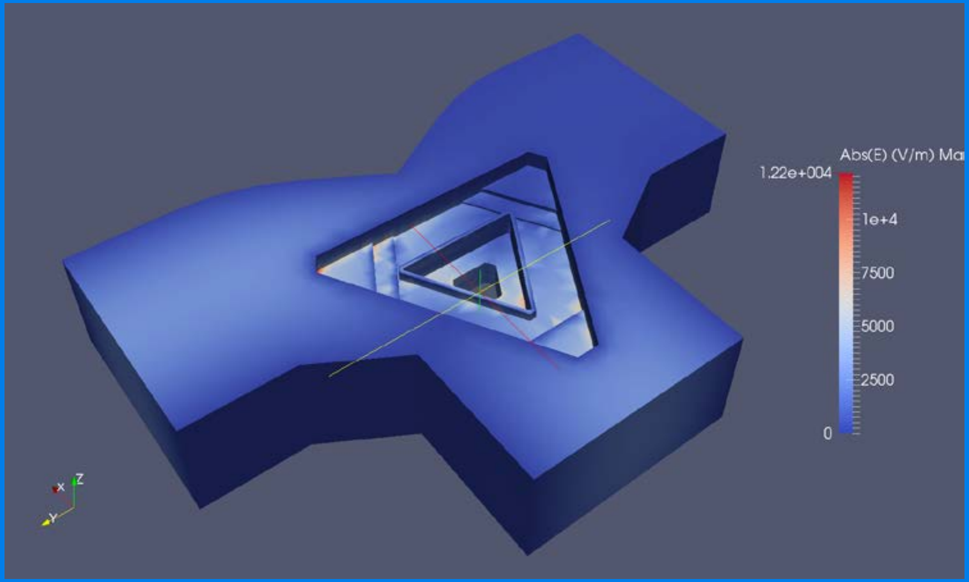
Uniform DC Magnetic Field Used in Circulator Operation Included in the Analysis

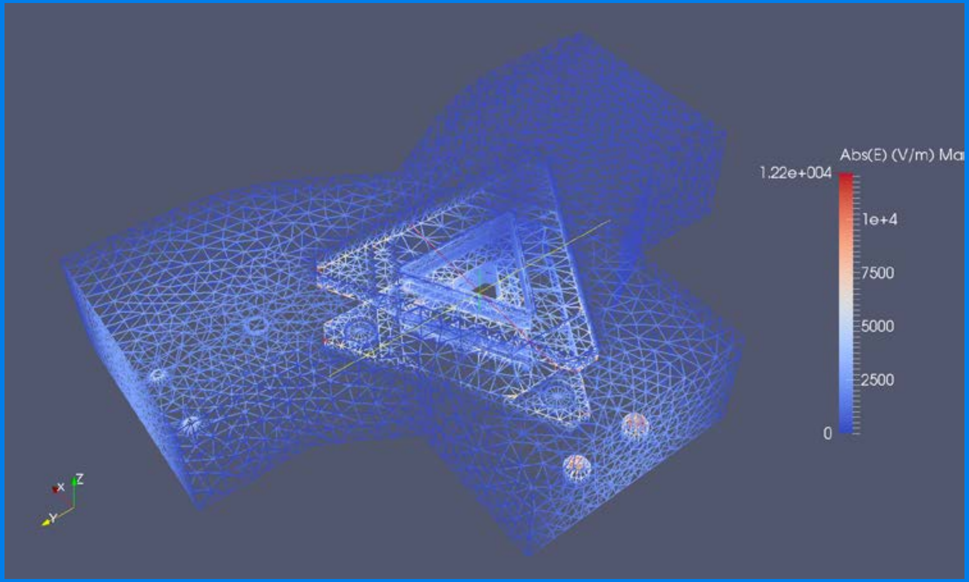
The Presence of Magnetic Field Significantly Reduces Multipaction Threshold

It has been shown[2] by analysis and verified by testing that parallel magnetic fields inhibit electron diffusion which results in lower breakdown voltage and lower Multipaction threshold

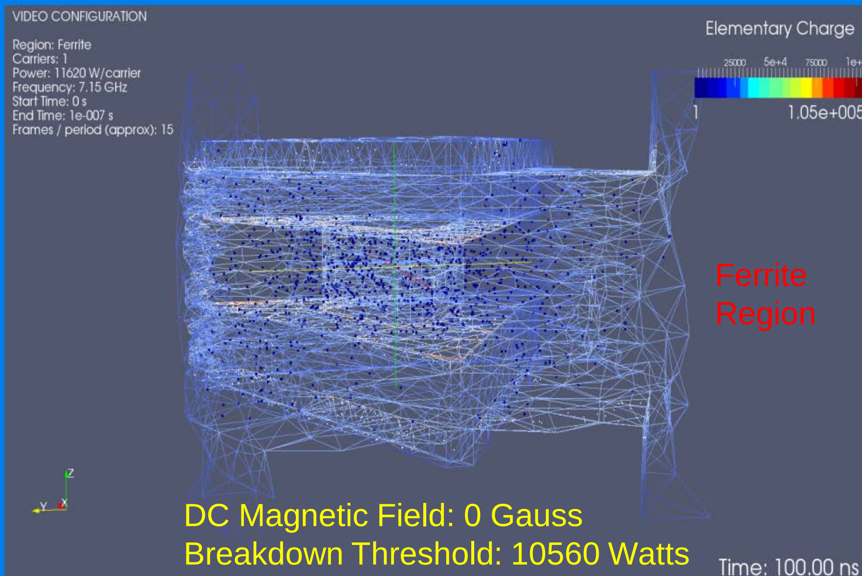
[1] SPARK3D is a SW Developed by Aurorasat
[2] A.A. Hubble et al, Diffusion-Limited Resonant Electron RF Breakdown, MULCOPIM 2014

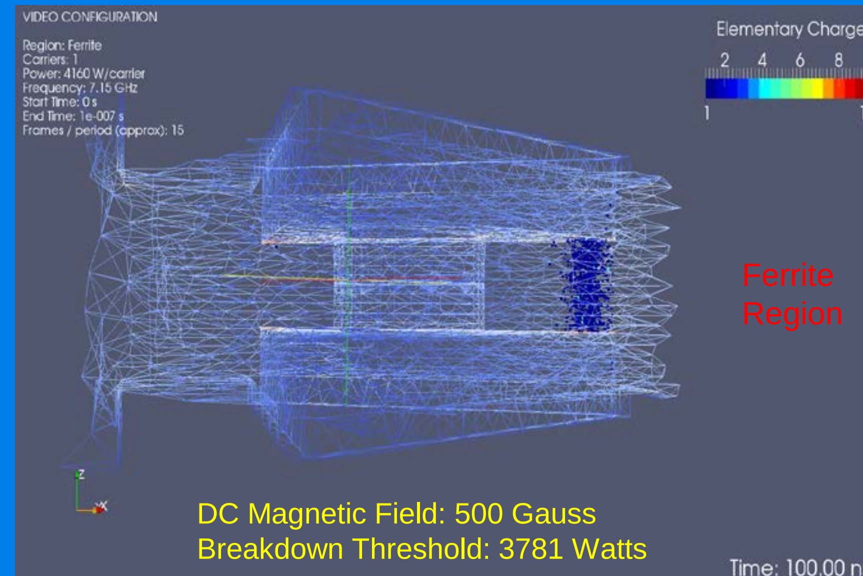
Circulator 3-D Model used in Multipaction Analysis with SPARK3D

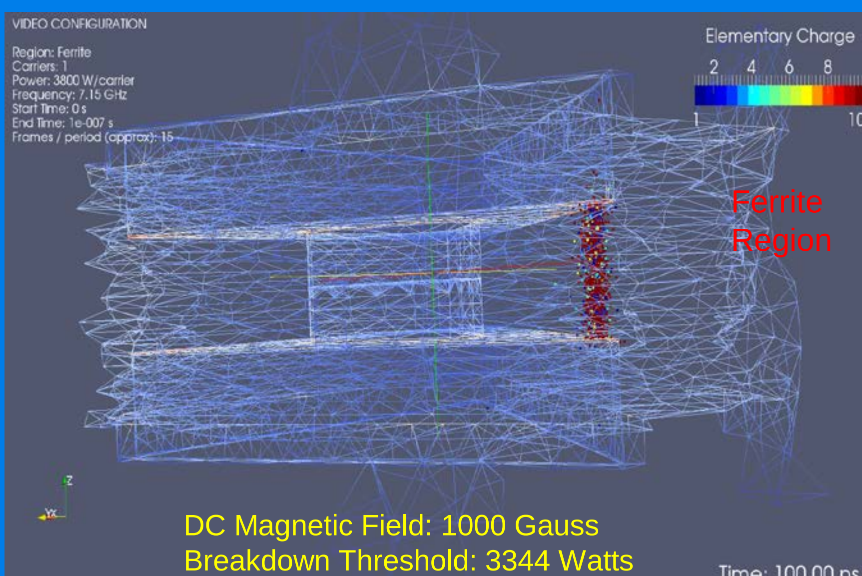


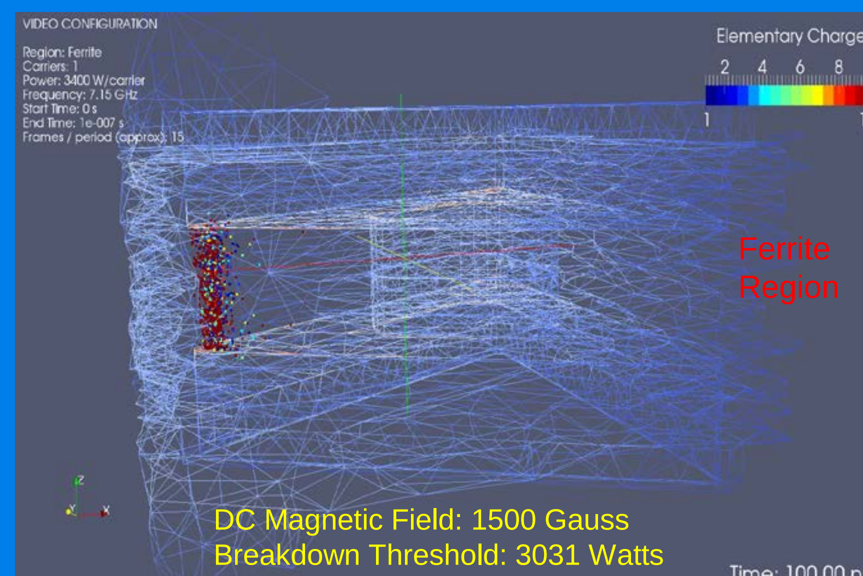


Multipaction Analysis of the Ferrite Region - DC Magnetic Field Included

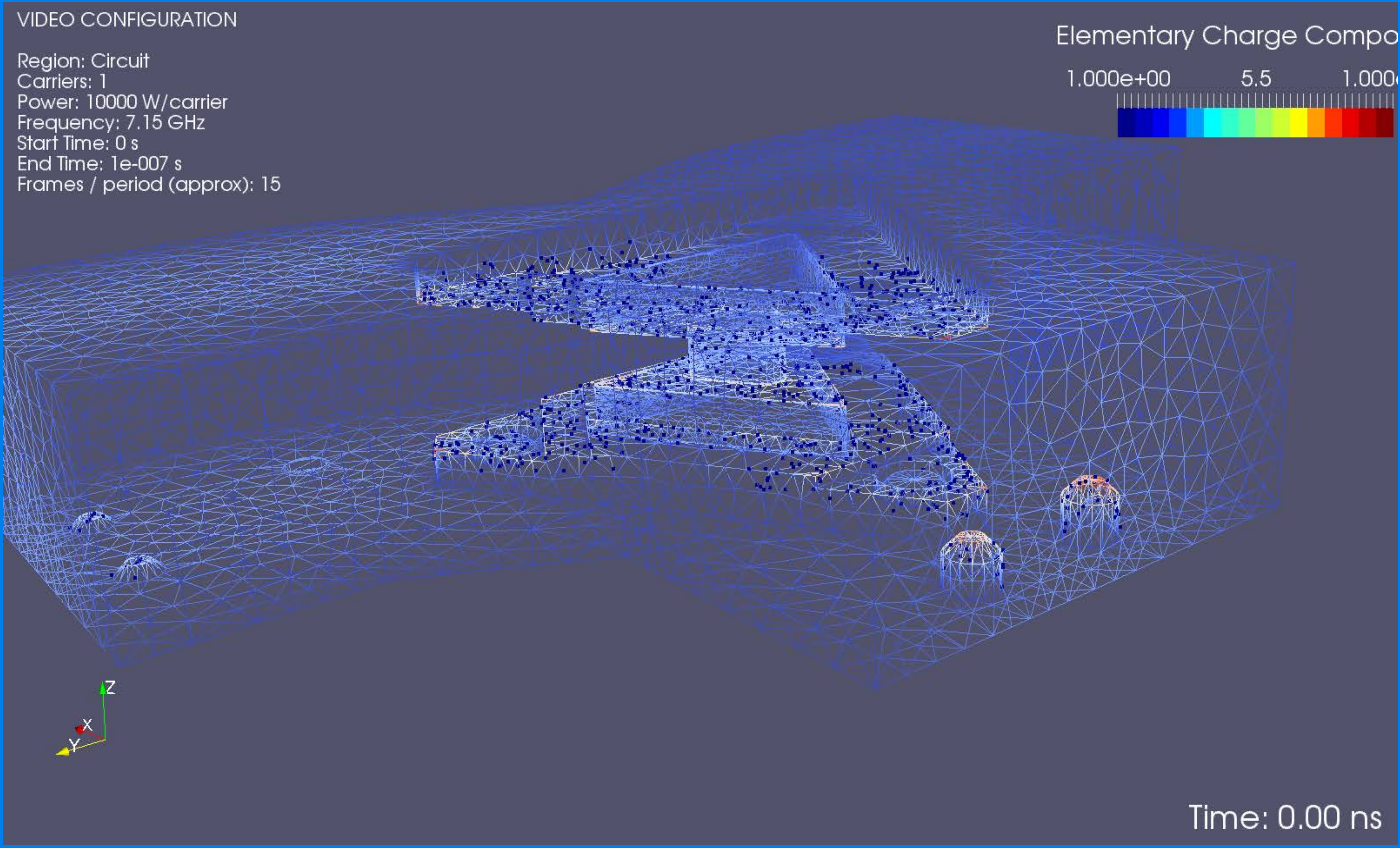






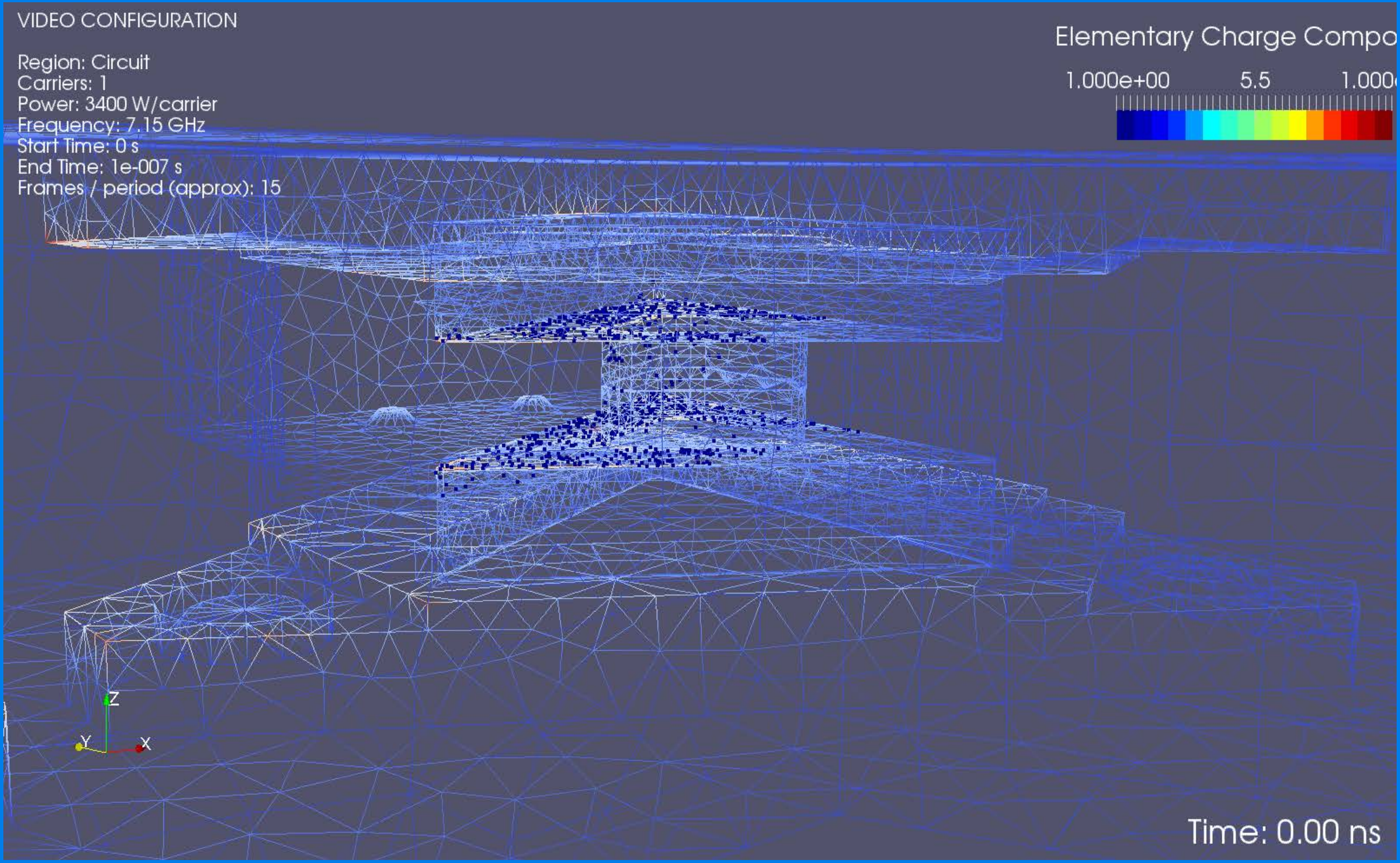


Multipaction Analysis of the Ferrite Region - DC Magnetic Field Included



DC Magnetic Field: 0 Gauss
Breakdown Threshold: 10562 Watts

Multipaction Analysis of the Ferrite Region - DC Magnetic Field Included



DC Magnetic Field: 1500 Gauss
Breakdown Threshold: 3031 Watts

The Presence of Magnetic Field Significantly Reduces Multipaction Threshold

DC Magnetic Field (Gauss)	Multipaction Threshold (Watts)
0	10560
500	3781
1000	3344
1500	3031

The operating point of DC Magnetic Field between the Ferrites is approximately 1500 Gauss

CIRCULATOR MULTIPACTION TESTING

Test Parameters

Parameter	Setting	Notes
Frequency	7.00 GHz	
Power	3000 W peak	600 W average (150W+450W CW)
Pulse Width	100 µs, 5% duty factor	
Pressure	<1.0e-5 Torr.	
Temperature	-10 and +23 Deg. C	
Electron Source	Cs—137 Source,	3 sources, 10 µc each
Sample Rate	50 KHz	
Detection Methods	Input Return Loss, Through Power	Instant Change in any two parameter and/or anomaly in Pico ammeters
	Input/Output Third Harmonic	
	Current Probes (all ports)	
# of Samples Tested	20	

CIRCULATOR MULTIPACTION TESTING

Test Conditions

Test Set-up calibrated prior to Multipaction testing

Multipaction standard used to verify the test set-up

Power level ramped from 1600 Watts peak, 315 Watts average to 3000 Watts peak, 600 Watts average, in 200 Watts intervals with 5 minutes dwell at each level. 30 minutes dwell at maximum power of 3000 Watts peak, 600 Watts average

Forward , reflected and output powers continuously monitored and recorded

Third harmonic signals at input and output continuously monitored and recorded

Current Probes (Pico ammeters) placed at all ports through the vent holes to detect possible anomalies

Several thermocouples placed on DUT and base plate to continuously monitor and record the temperature.

Thermal vacuum chamber pressure continuously monitored

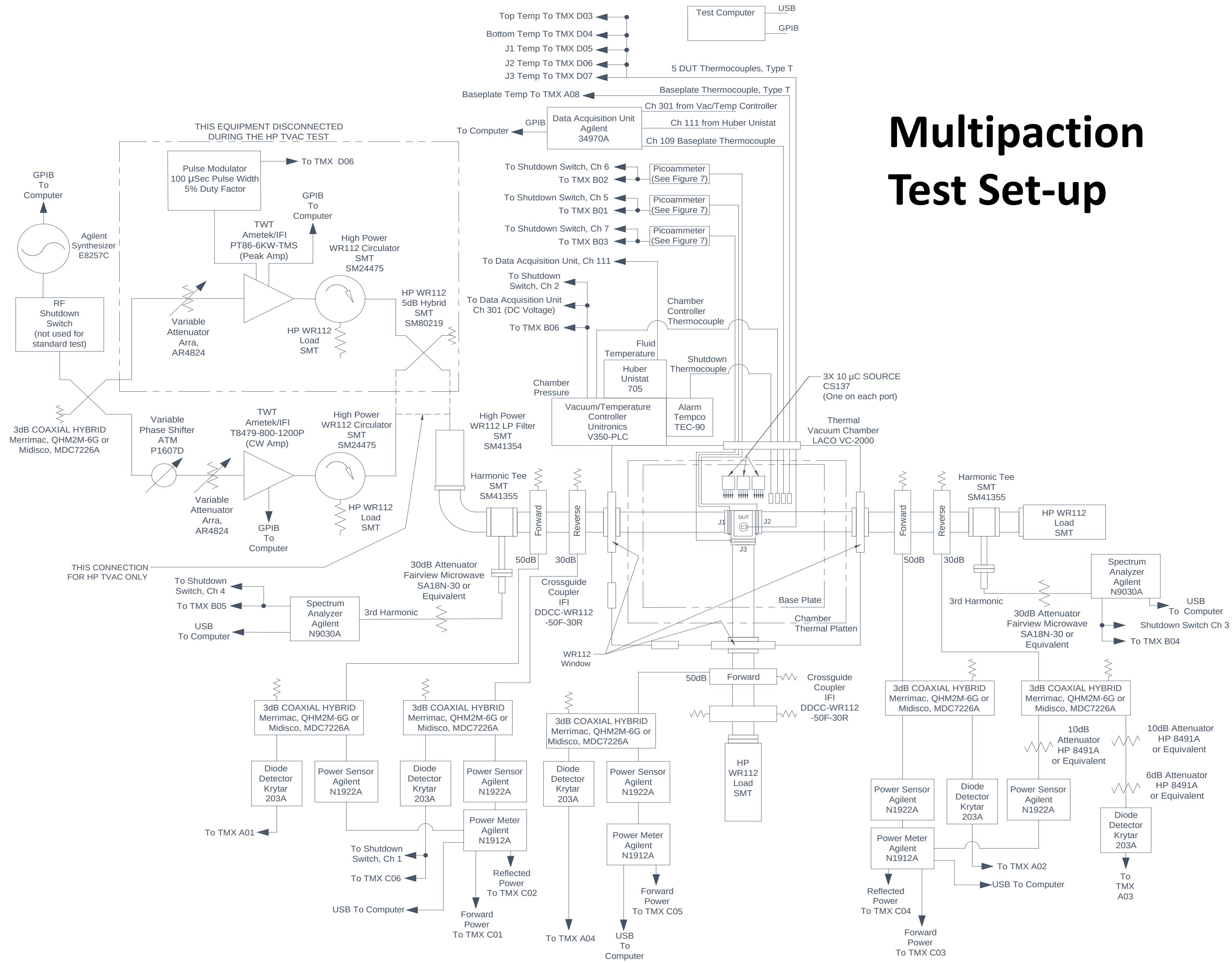
Visual Inspection after multipaction testing using a microscope at 10x magnification and RF test according to the test plan

a HEICO company

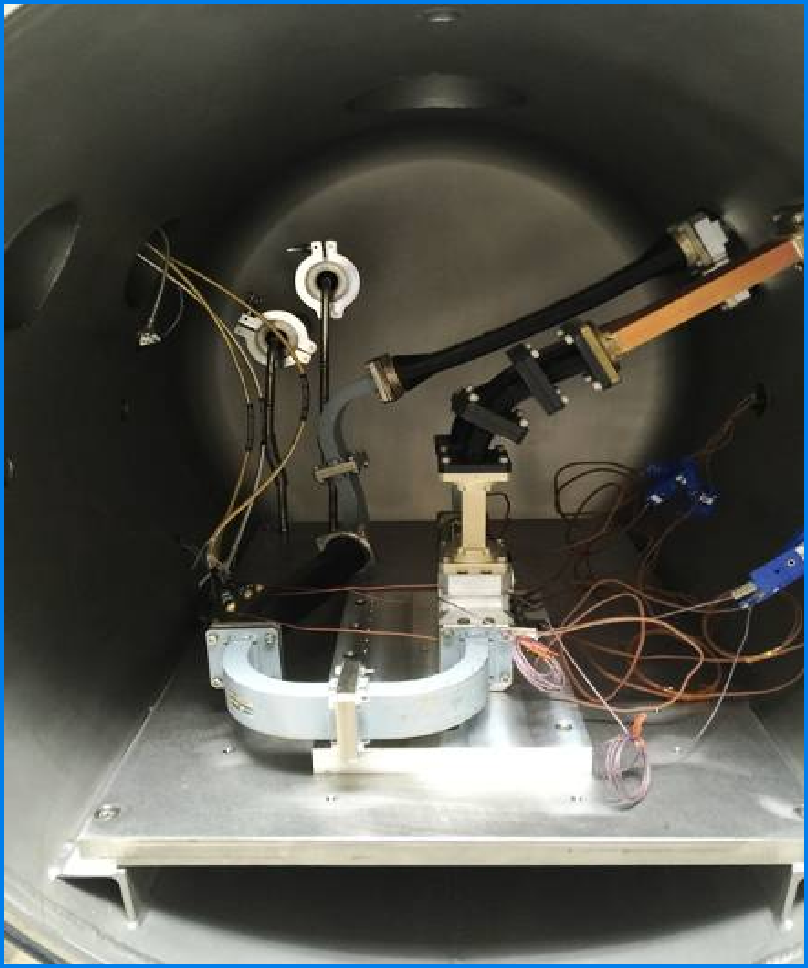
space passive component days
12 - 14 october 2016
European Space Agency

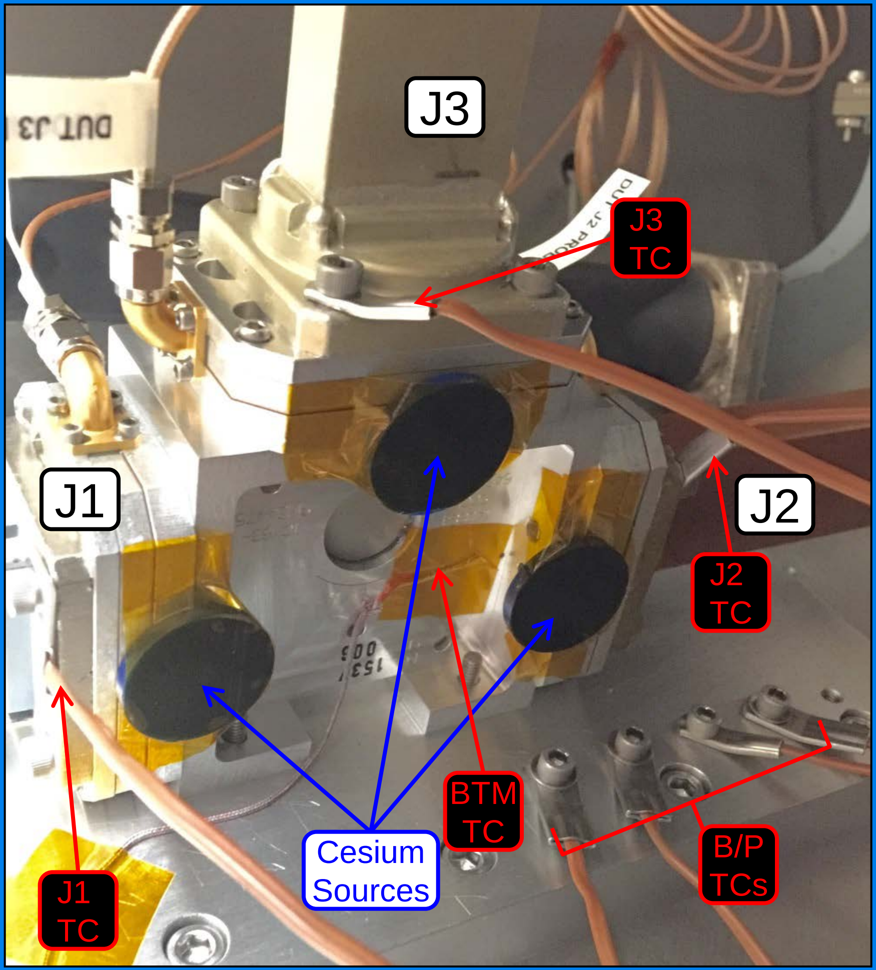
CIRCULATOR MULTIPACTION TESTING

Multipaction Test Set-up



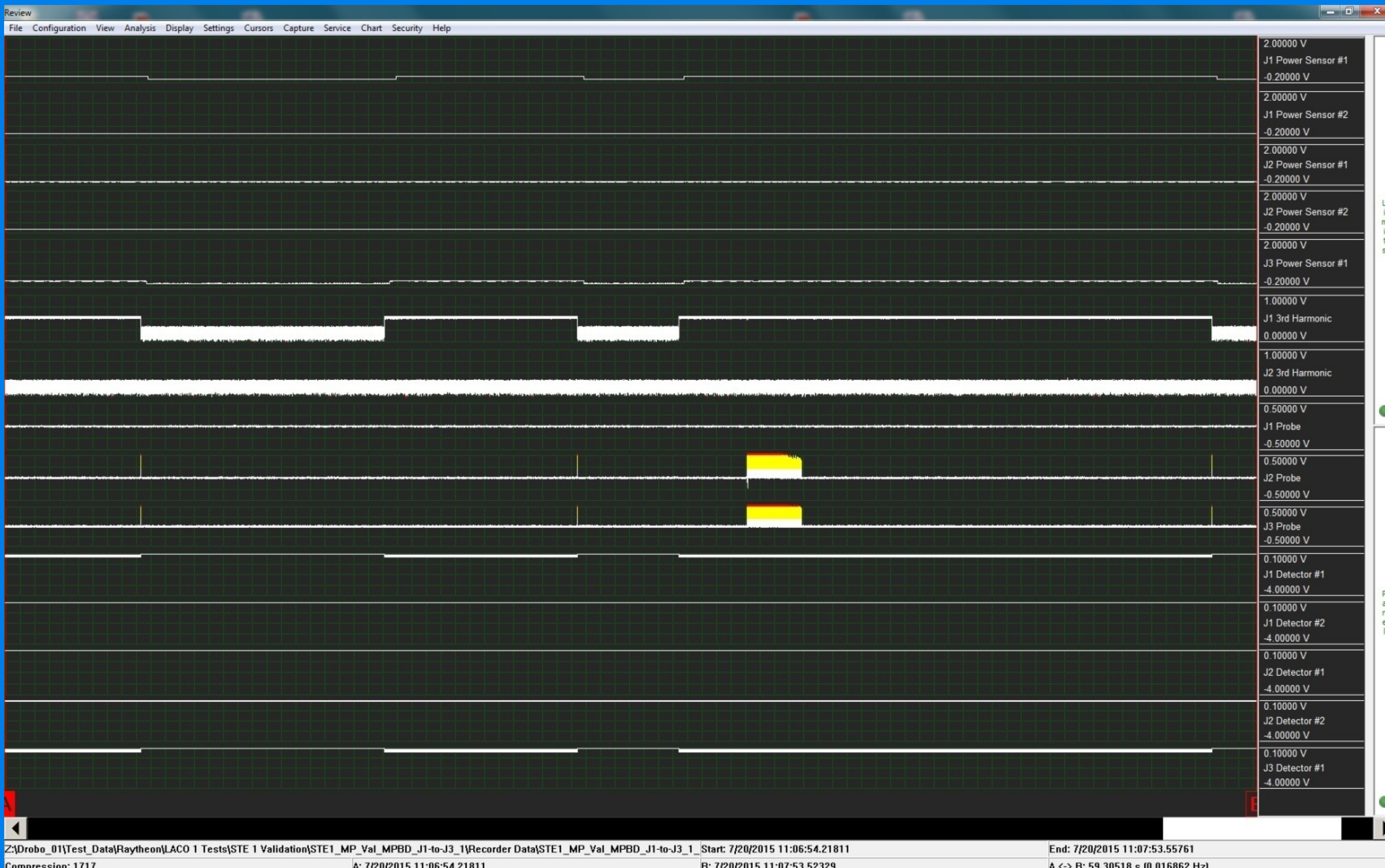
CIRCULATOR MULTIPACTION TESTING





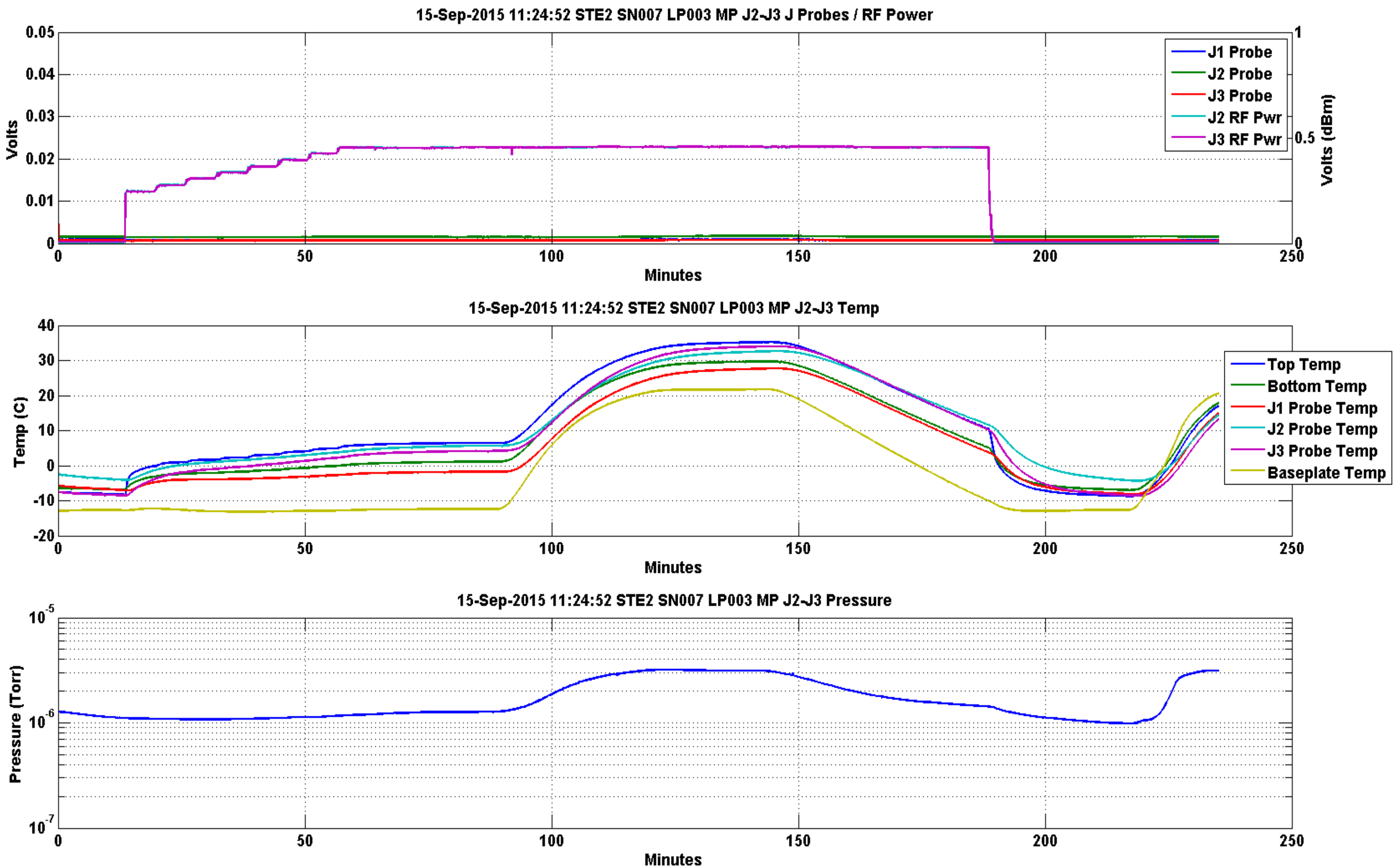
Images of the Unit in Thermal Vacuum Chamber, Including Current Probes, Temperature Sensors and Electron Sources

MULTIPACTION TEST RESULTS

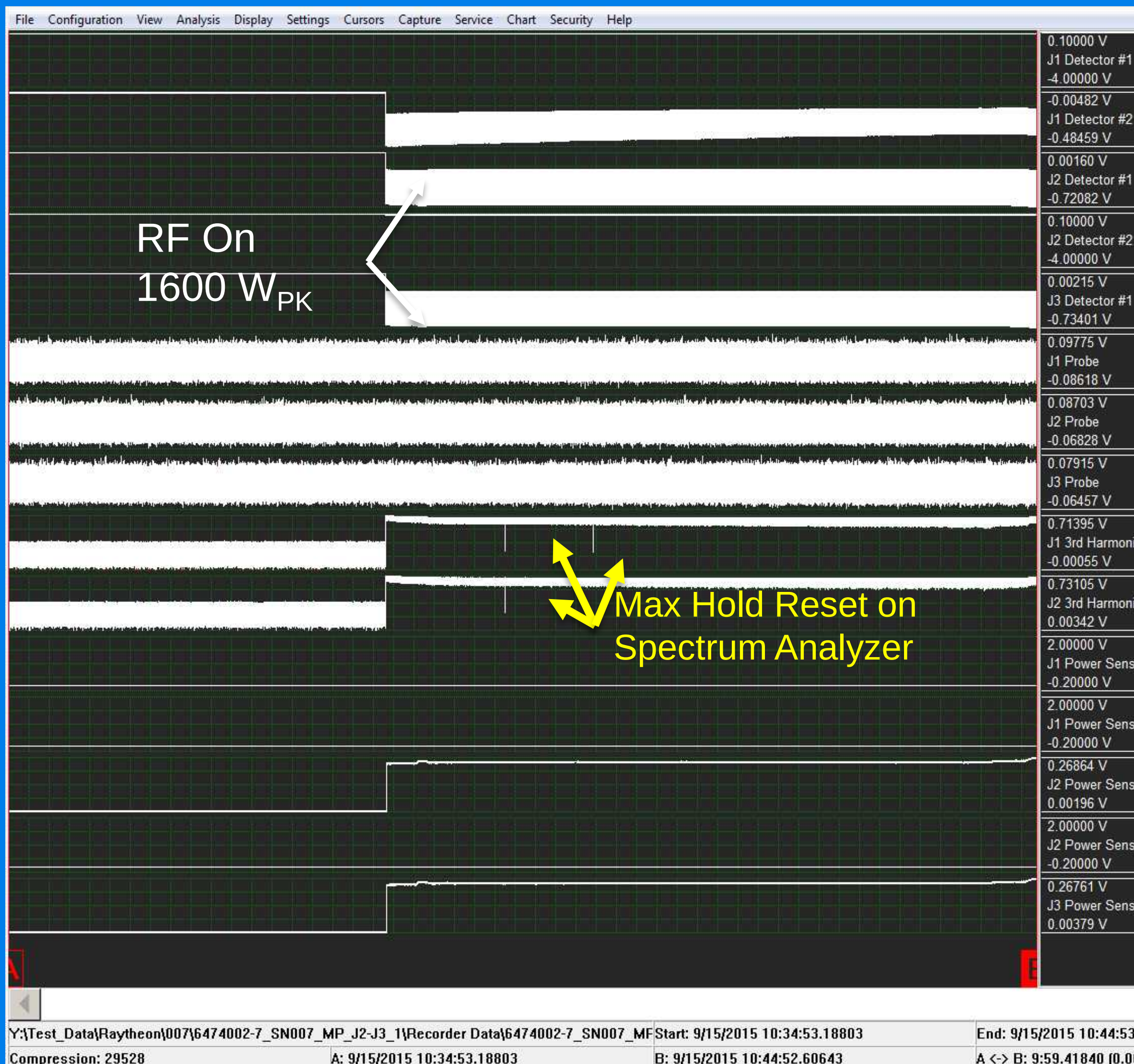


Multipaction Test on Standard Showing Event at 600 Watts peak

Circulator Multipaction Test
Input/Output Power, Temperature & Pressure Profile



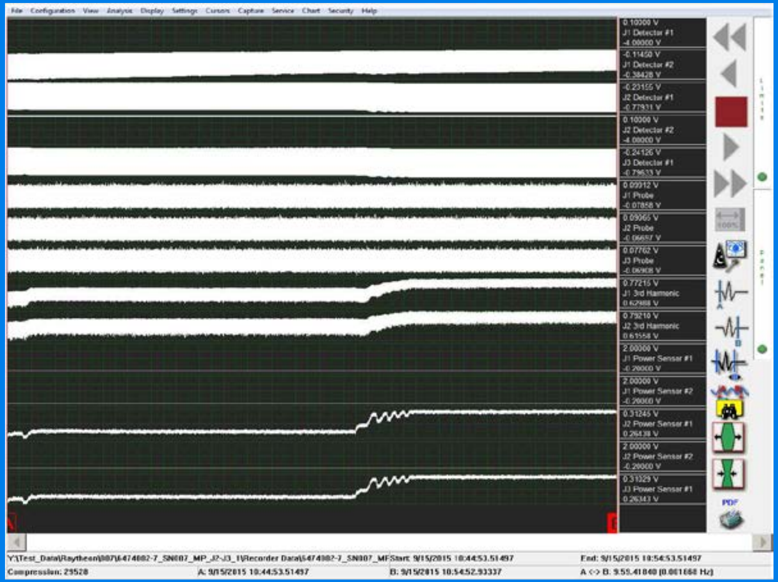
Circulator Multipaction Test Data-No Event



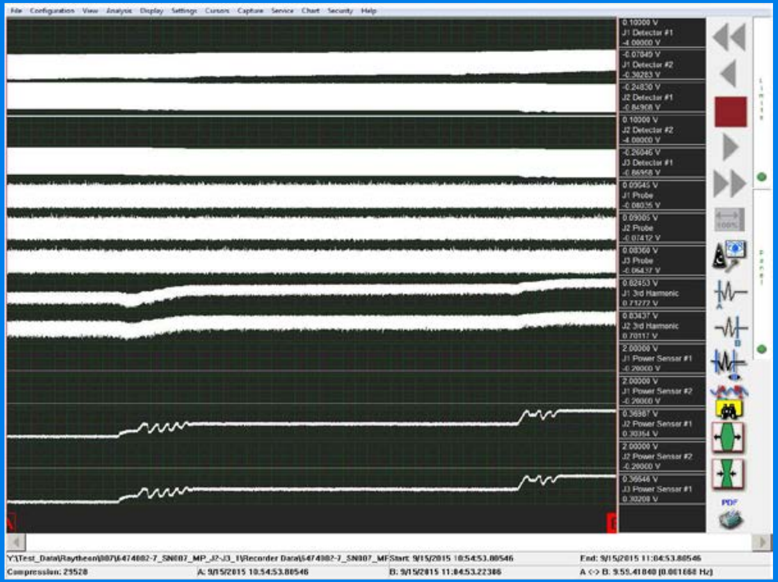
J1 detector #1
J1 detector #2
J2 detector #1
J2 detector #2
J3 detector #1
J1 Probe
J2 Probe
J3 Probe
J1 3rd Harmonic
J2 3rd Harmonic
J1 Power Sensor 1
J1 Power Sensor 2
J2 Power Sensor 1
J2 Power Sensor 2
J3 Power Sensor 1

Multipaction Test at 7.0 GHz, -15°C , 1600 Watts peak

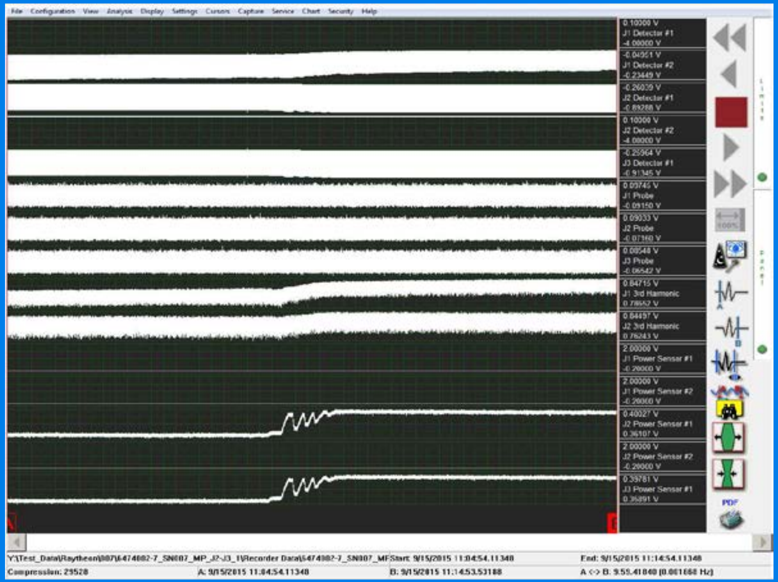
Circulator Multipaction Test Data-No Event



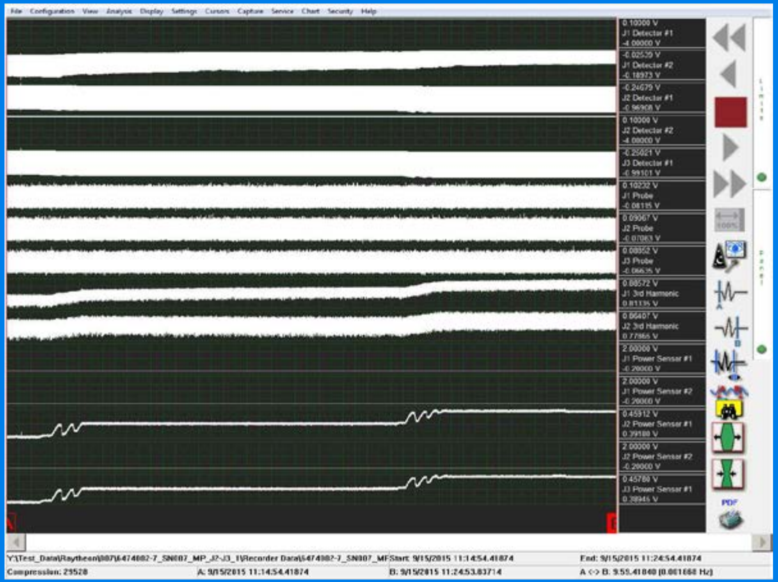
Test at -15°C , 1600-2000 Watts peak



Test at -15°C , 2000-2400 Watts peak

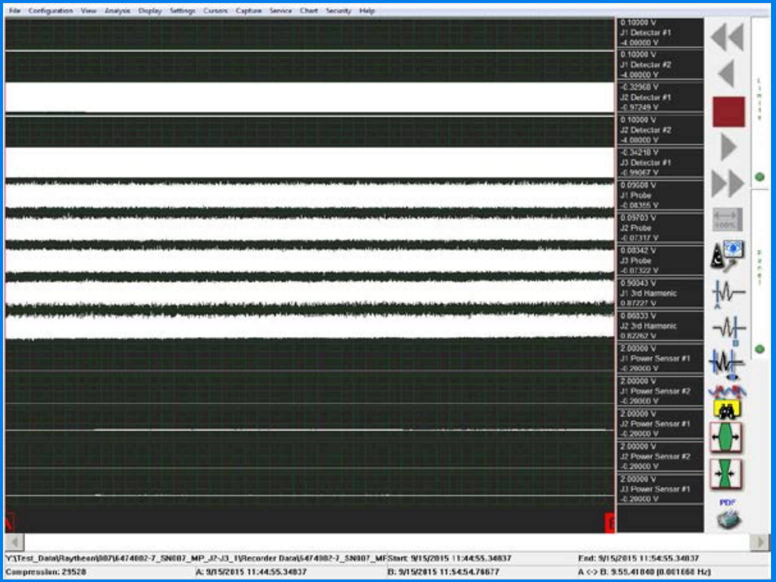


Test at -15°C , 2400-2600 Watts peak

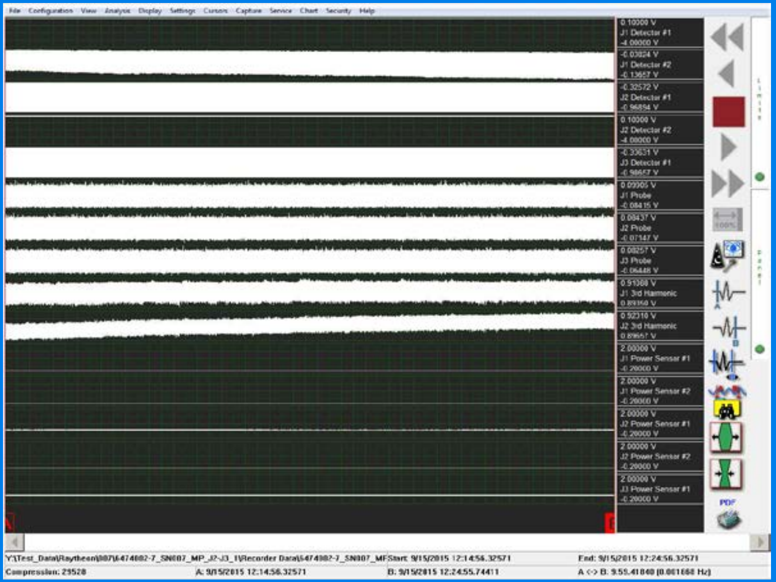


Test at -15°C , 2600-3000 Watts peak

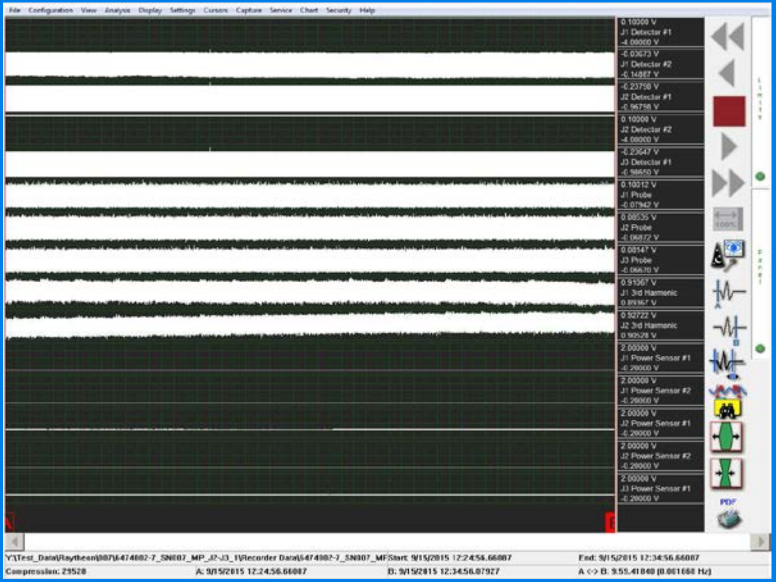
Circulator Multipaction Test Data-No Event



Test at -15°C , 3000 Watts peak Dwell

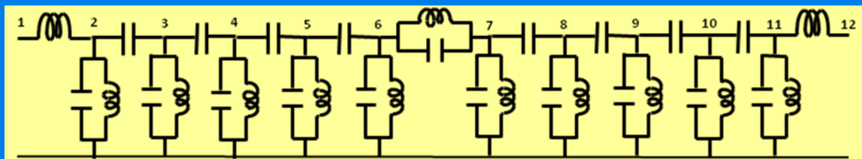


Test during temperature transition 3000 Watts peak

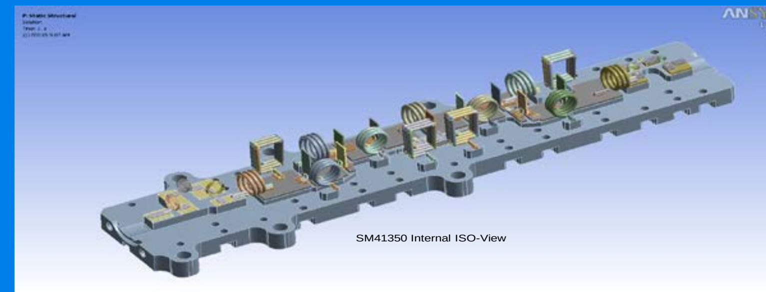


Test at +25°C , 3000 Watts peak Dwell

Band Pass Filter Design



Schematic of the Band Pass Filter



Filter assembly with housing, cover and connectors removed

Lumped element filter in the 150-250 MHz frequency band

Pseudo-elliptic response with 10 poles and one transmission zero

Uses air core inductors and ceramic single layer capacitors

Coils made of pure silver with minimum unloaded Q of 125 at 85 °C

Ceramic capacitors 0.010” or 0.025” thick with much higher Q, typically >2000

Mounting base made of a controlled expansion alloy to reduce thermal stress on shunt capacitors

Coils placed in individual cavities inside the housing to improve Q and avoid direct coupling between them

Inductors soldered on Copper-Tungsten carriers which are soldered to shunt capacitors to achieve high Q and robust attachment

High Power and Multipaction-Free Design

Table shows peak voltages at different nodes with 37.5 Watts peak power

Voltages calculated at *Fc* = 200 MHz and at frequencies of maximum group delay, (141 MHz and 256 MHz). Maximum voltage build-up 128 Volts, occurring at node 4 at 141 MHz

This voltage value is well below the break down voltage of all the material in the filter , but it’s not known if it will not cause a multipactor breakdown

Peak Voltage (Volts)	Node Number, Refer to Schematic											
Frequency	1	2	3	**4**	5	6	7	8	9	10	11	12
@ 141 MHz	27	43	116	**128**	117	93	90	77	60	43	24	21
@ 200 MHz	41	48	61	**65**	59	63	60	62	57	53	47	39
@ 256 MHz	54	80	112	**124**	122	113	76	68	57	44	32	23

High Power and Multipaction-Free Design

To protect the filter against Multipaction, it will be filled with low loss syntactic foam with high breakdown voltage (2.5KV/mm)

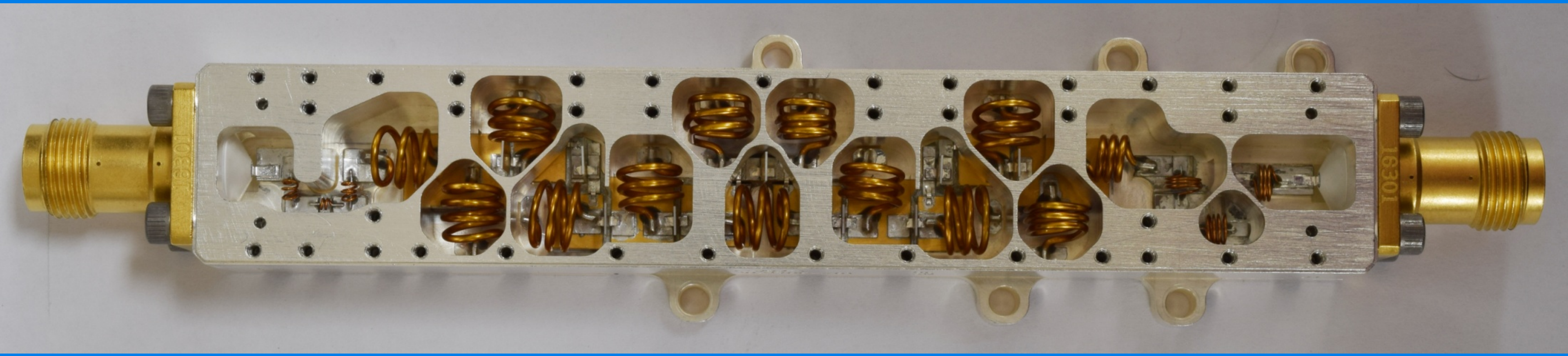
Multipaction not possible with dielectrically impregnated RF cavities due to the free mean path of the electron being much smaller than the physical gap

Theoretically, over the pass band frequency (150-250 MHz), gaps smaller that 0.037" will not multipact; however, all gaps will be filled with synthetic foam or with thin layers of Silicone RTV

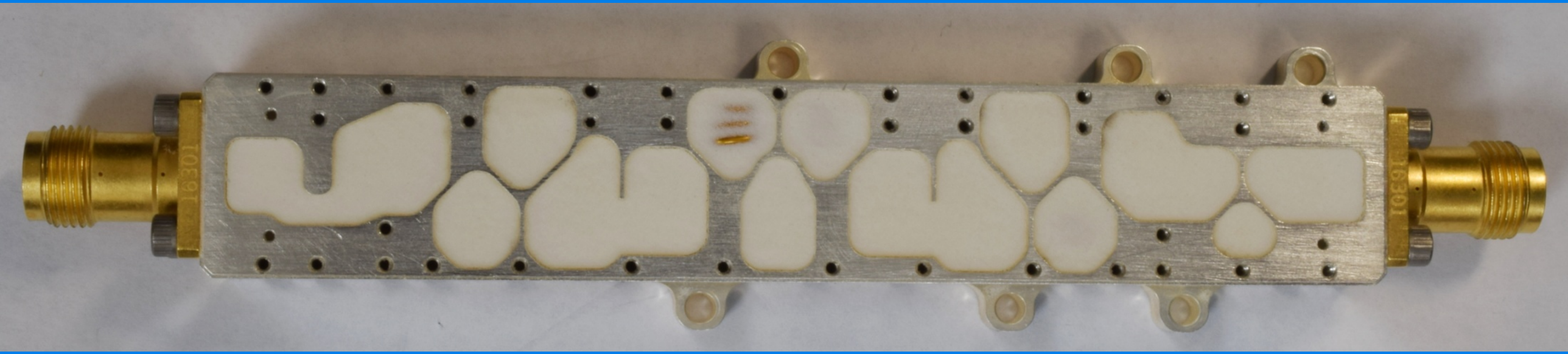
RTV filling in small confined regions will also minimize iso-thermal stresses. RTV is not ideal for bulk filling if cold processing temperatures are used due to the RTV mechanical properties as the temperature approaches Tg

Due to the large organic load in the filter, substantial venting must be used to allow for outgassing and prevent a Corona discharge. The foam and RTV is considered an infinite source of gas

High Power and Multipaction-Free Design



Filter with cover removed – before adding foam



Filter with cover removed – foam filled

BPF Multipaction Testing

Test Parameters

Parameter	Setting	Notes
Frequency	150 MHz and 250 MHz	
Power	80 W peak	4 W average
Pulse Width	2ms, 5% duty factor	
Pressure	<1.0e-5 Torr.	
Temperature	-45 and +85 Deg. C	
Electron Source	Cs—137 Source,	3 sources, 10 µc each
Sample Rate	10 KHz and 10 Hz	
Detection Methods	Return Loss Nulling Input/Output Third Harmonic	Instant Change in any two parameter and/or anomaly in Pico ammeters
	Current Probes	
# of Samples Tested	10	

BPF MULTIPACTION TESTING

Test Conditions

Test set-up calibrated prior to testing

Multipaction standard used to verify the set-up is capable to detect an event

Power level ramped from 10 Watts to 80 Watts with 5 minutes dwell at each level.
At the maximum level of 80 Watts peak, 4 Watts average, dwell time was 30 minutes

Forward, reflected and output powers continuously monitored and recorded

Return Loss Null and third harmonic continuously measured and recorded

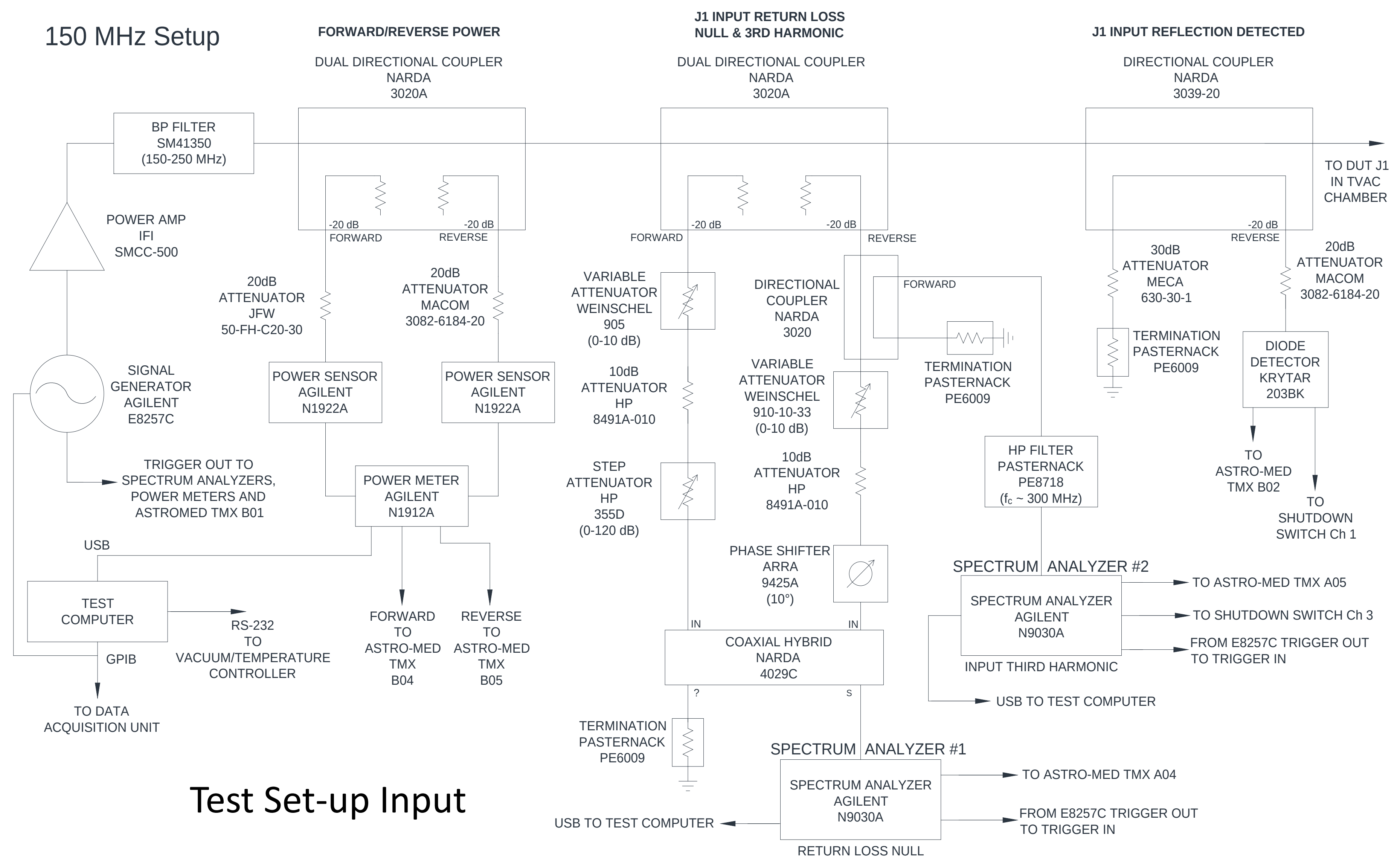
Pico ammeters placed at input and output through the vent holes to detect any possible anomaly

Thermocouples placed on DUT and base plate continuously monitor and record the temperatures.

Thermal vacuum chamber pressure continuously monitored

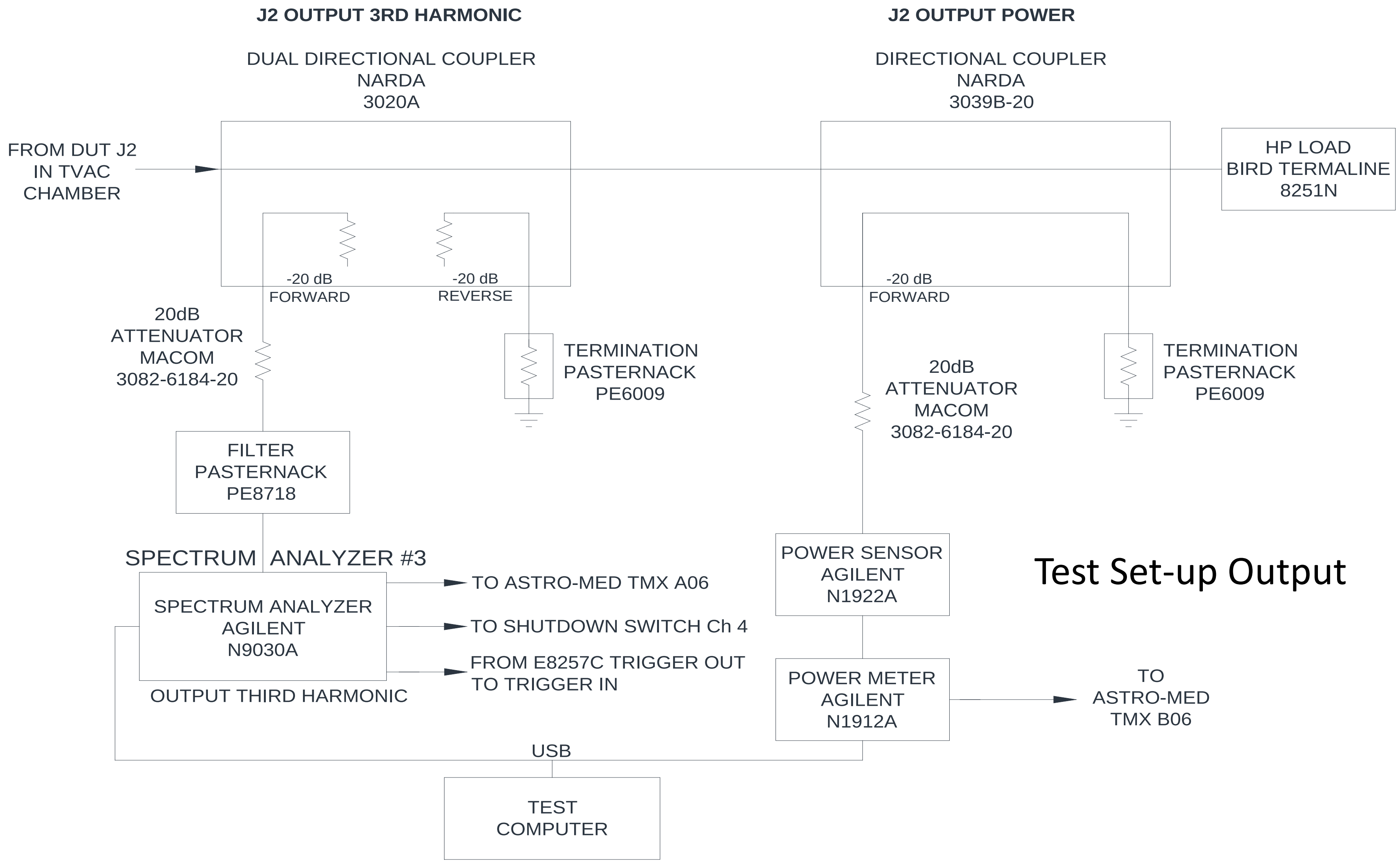
Visual Inspection after multipaction testing using a microscope at 10x magnification and RF test according to the test plan

BPF MULTIPACTION TESTING



Test Set-up Input

BPF MULTIPACTION TESTING



BPF MULTIPACTION TESTING

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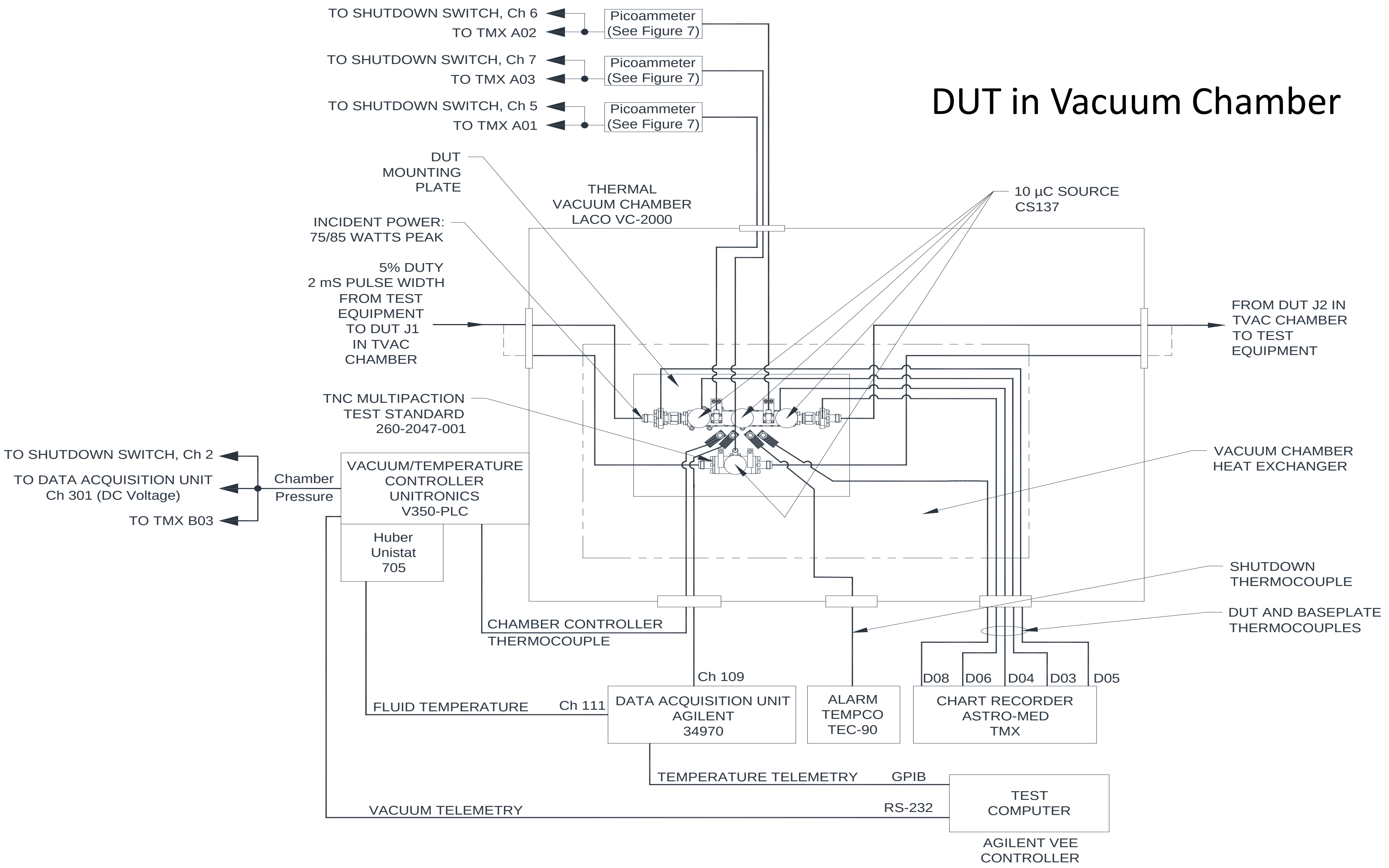
DUT in Vacuum Chamber



BPF MULTIPACTION TESTING

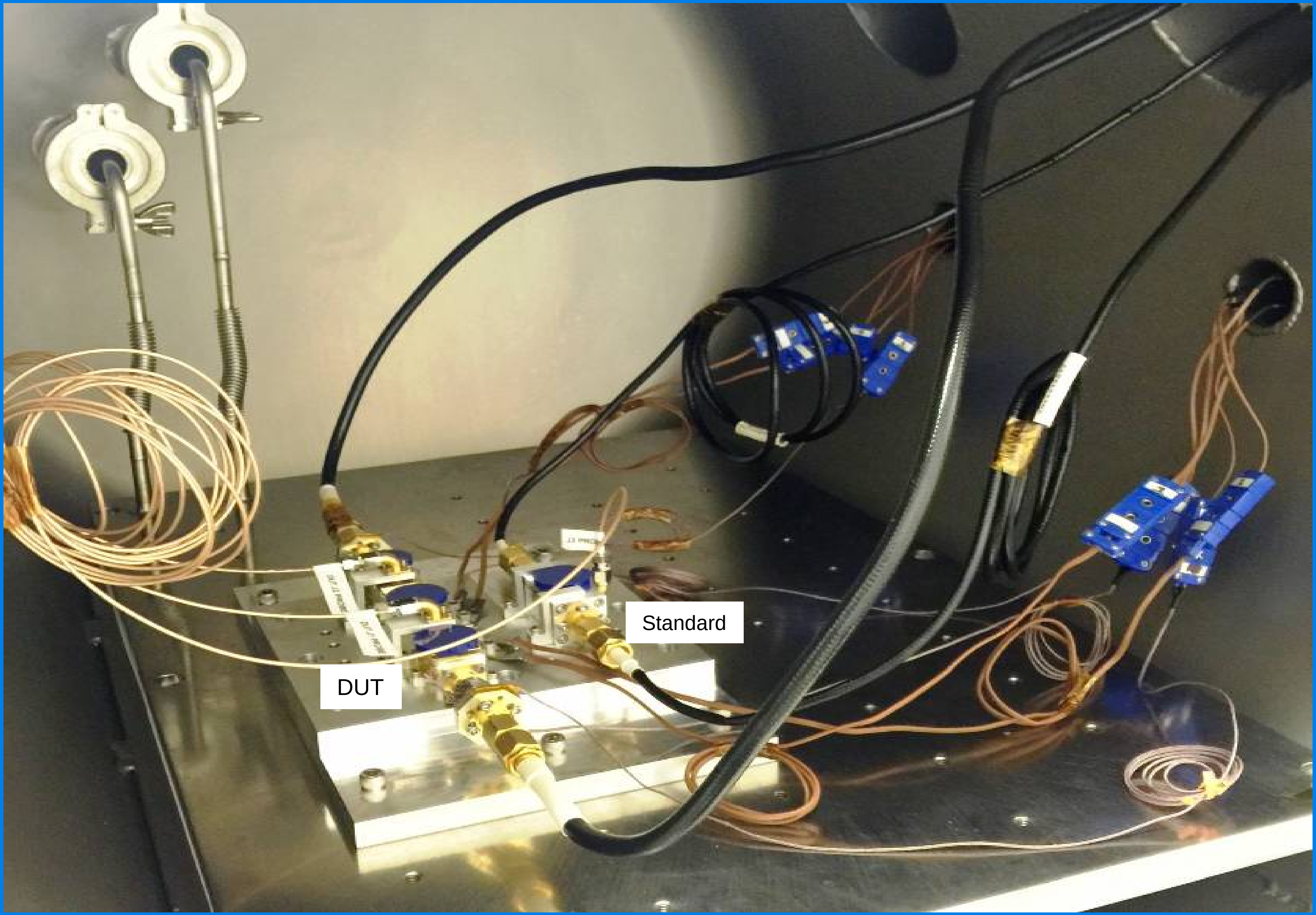
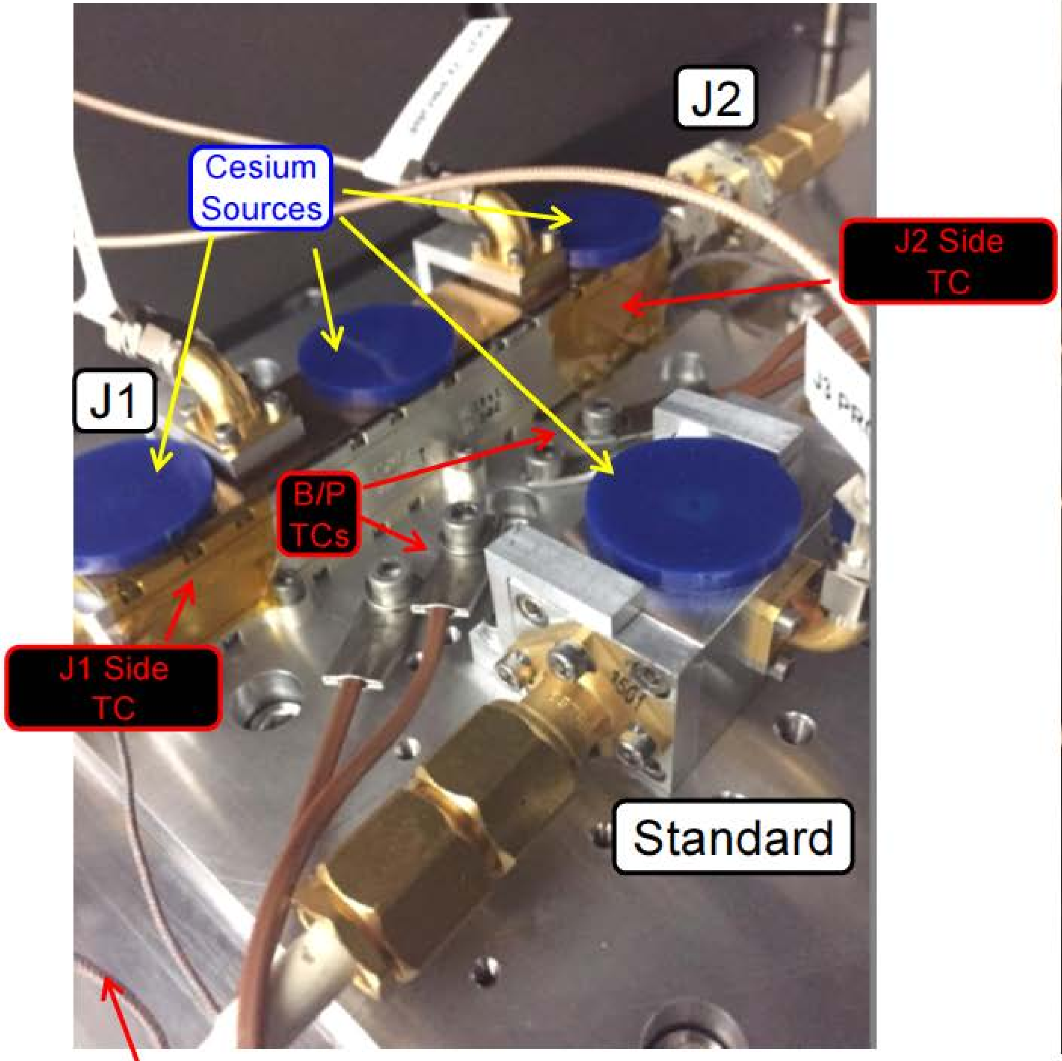
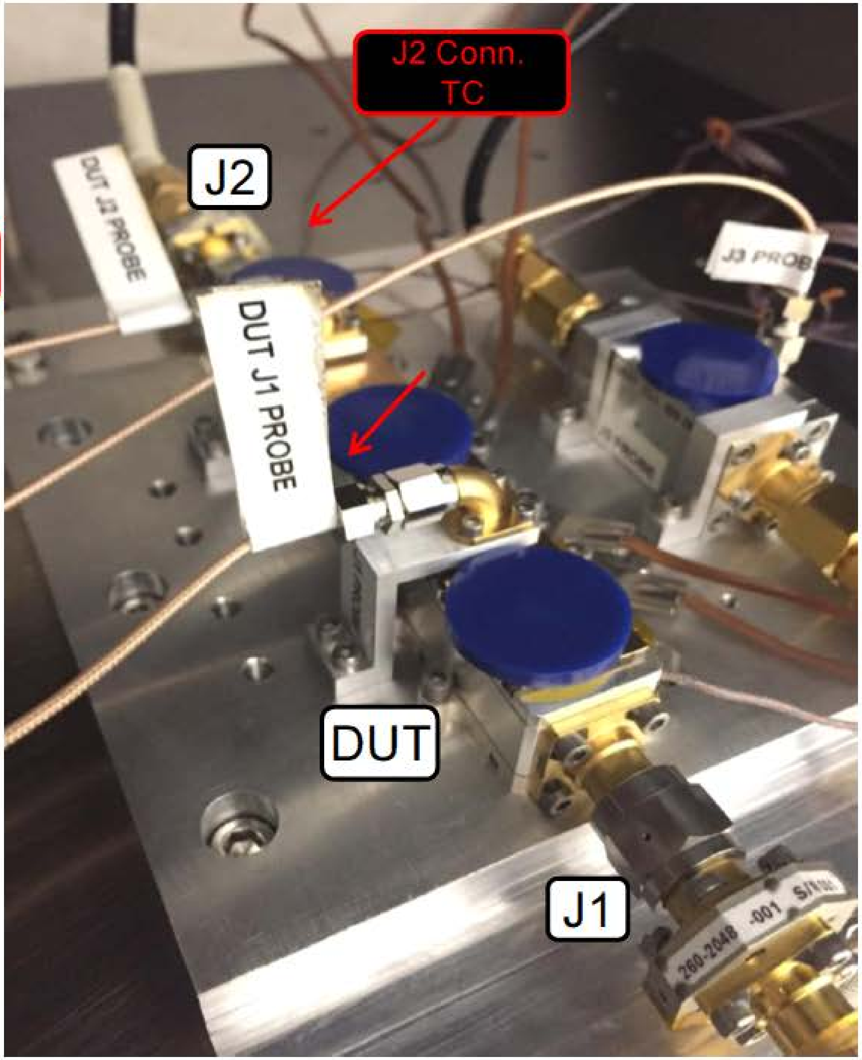


Image of the DUT and Multipaction Standard in Thermal Vacuum Chamber

BPF MULTIPACTION TESTING

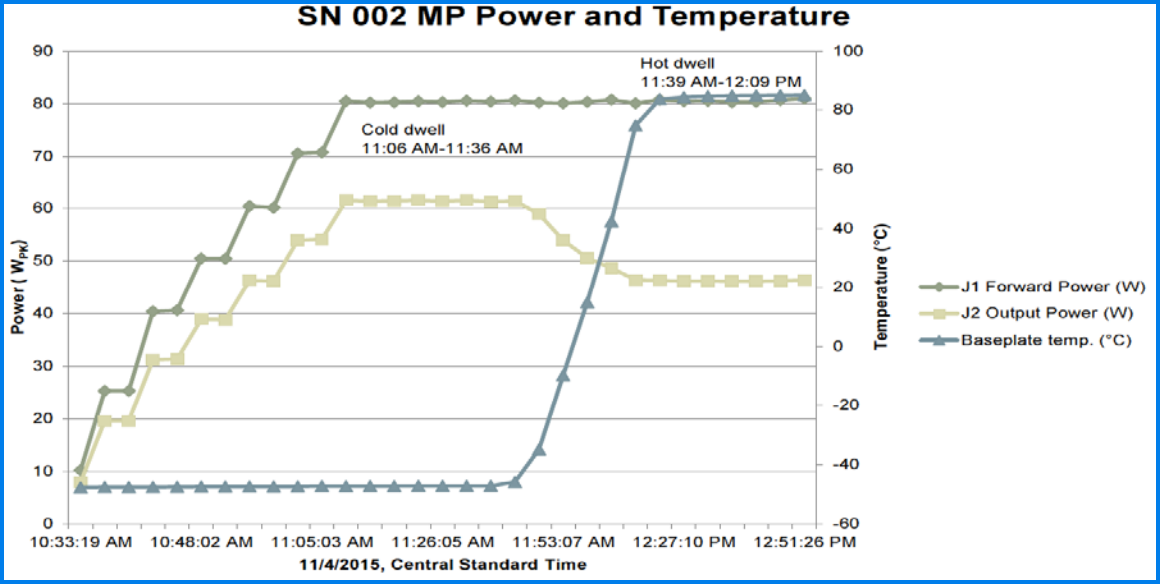


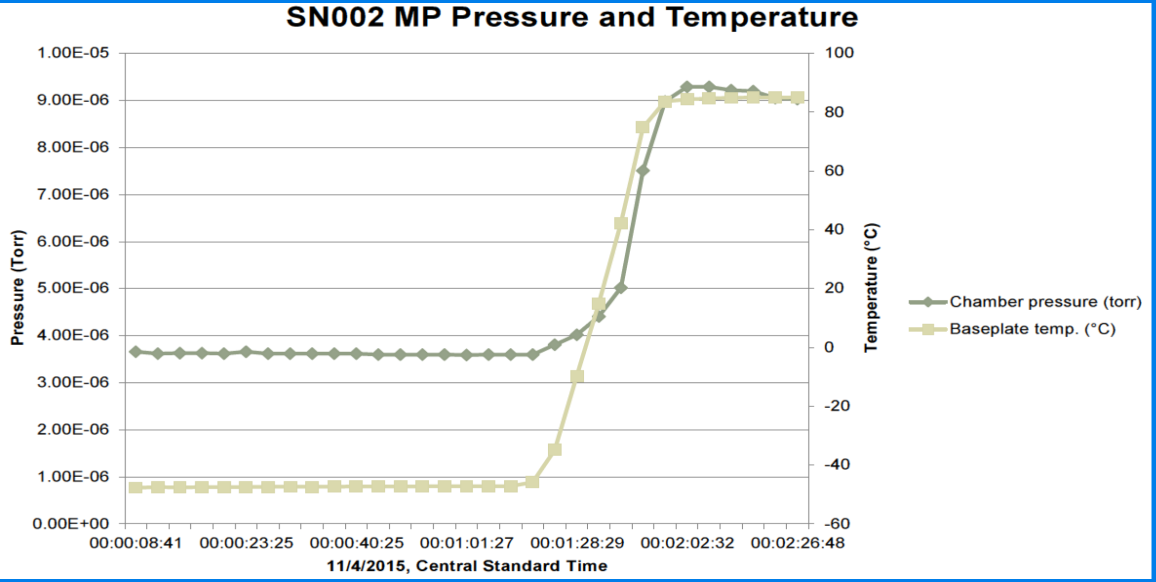


Images of the Unit in Thermal Vacuum Chamber, including Thermocouples, Current Probes and Electron Sources

BPF Multipaction Test Data

Power, Temperature and Pressure Profile

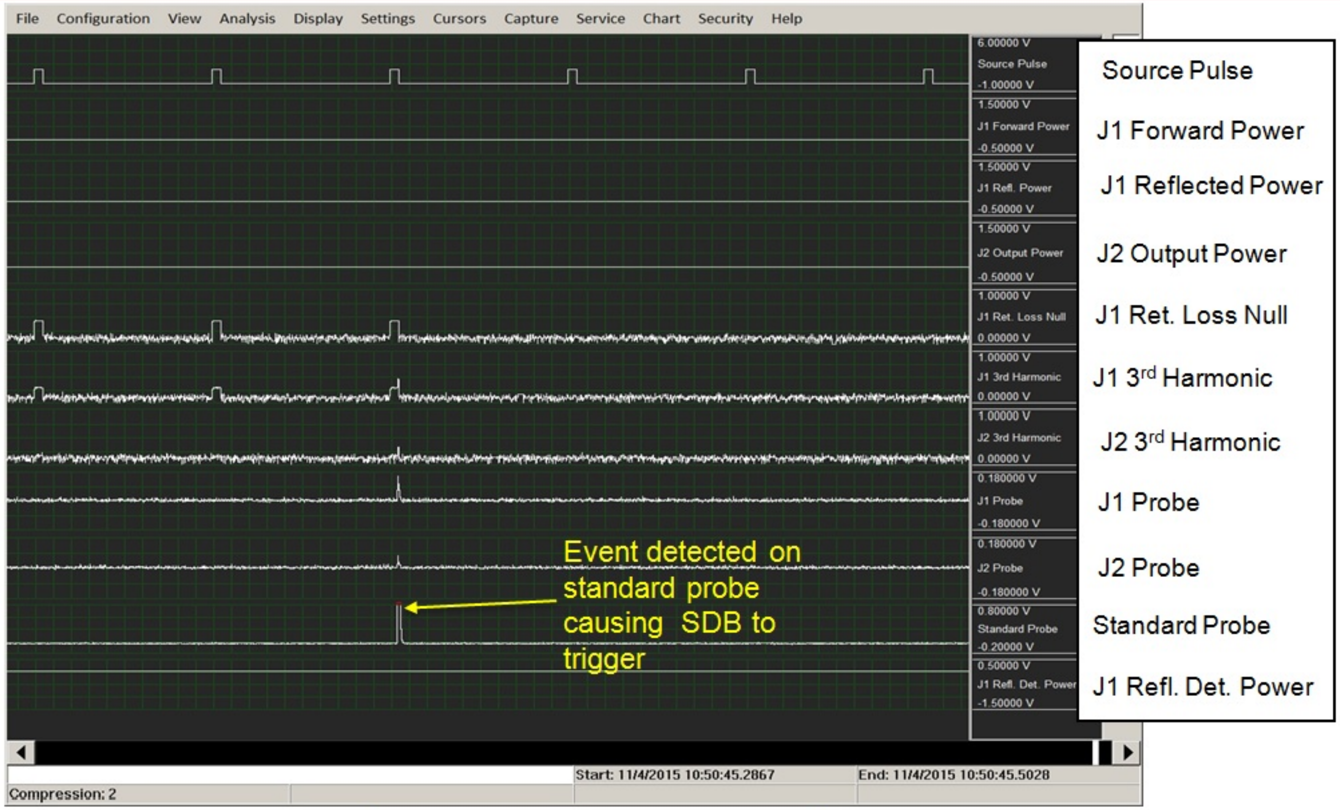




BPF Multipaction Test Data - Standard

UNCLASSIFIED

SN 002 MP (Pre-Test Standard, Event Zoom In)



Test Setup Verified

PN: 2021706-101
EXPORT CONTROLLED – SEE FIRST PAGE
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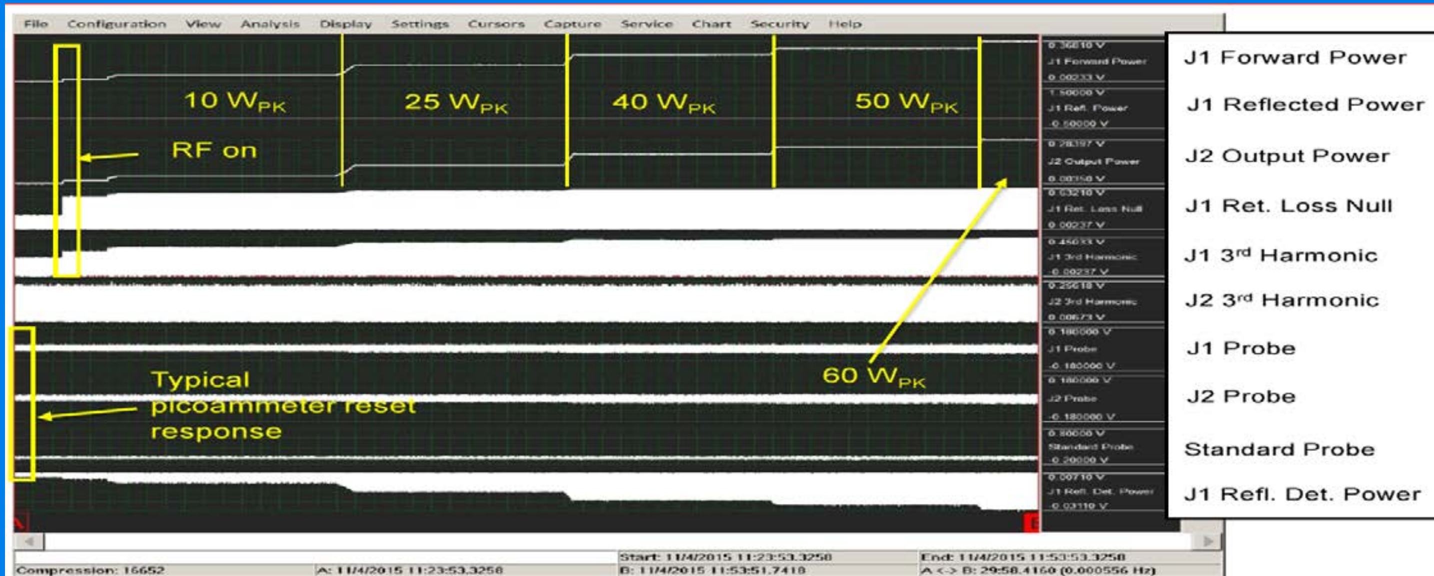
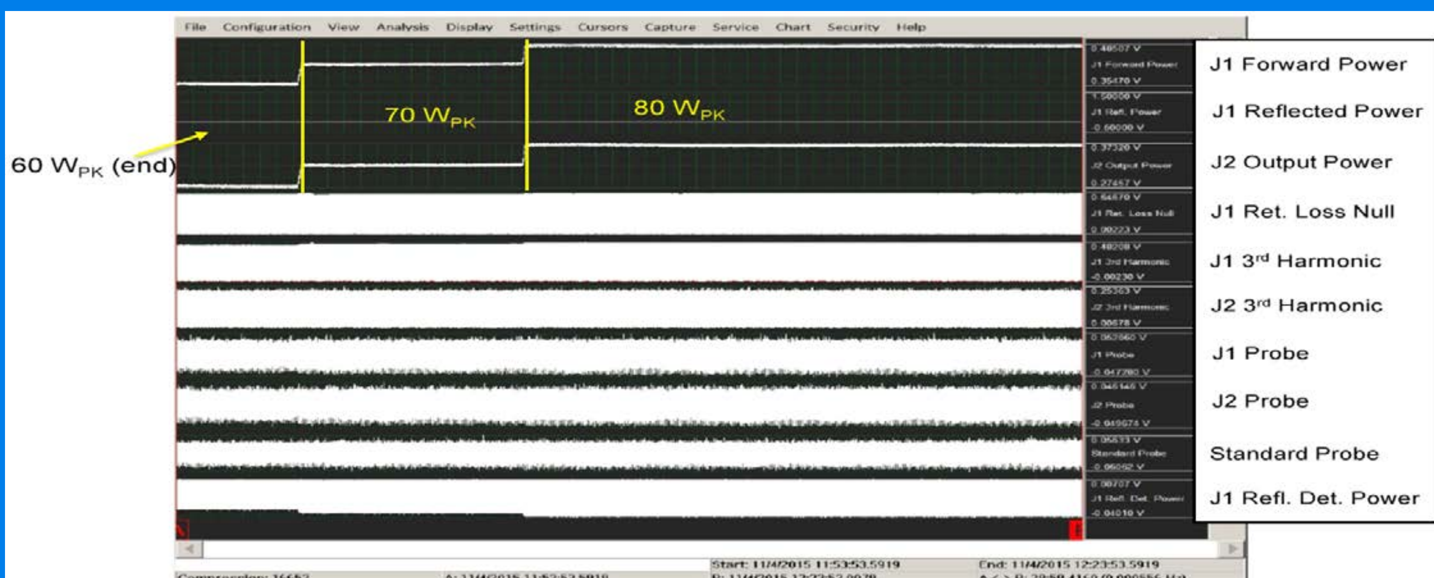
UNCLASSIFIED

Multipaction Standard Test Showing an Event at 6.93 Watts peak

BPF Multipaction Test Data – DUT, No Event

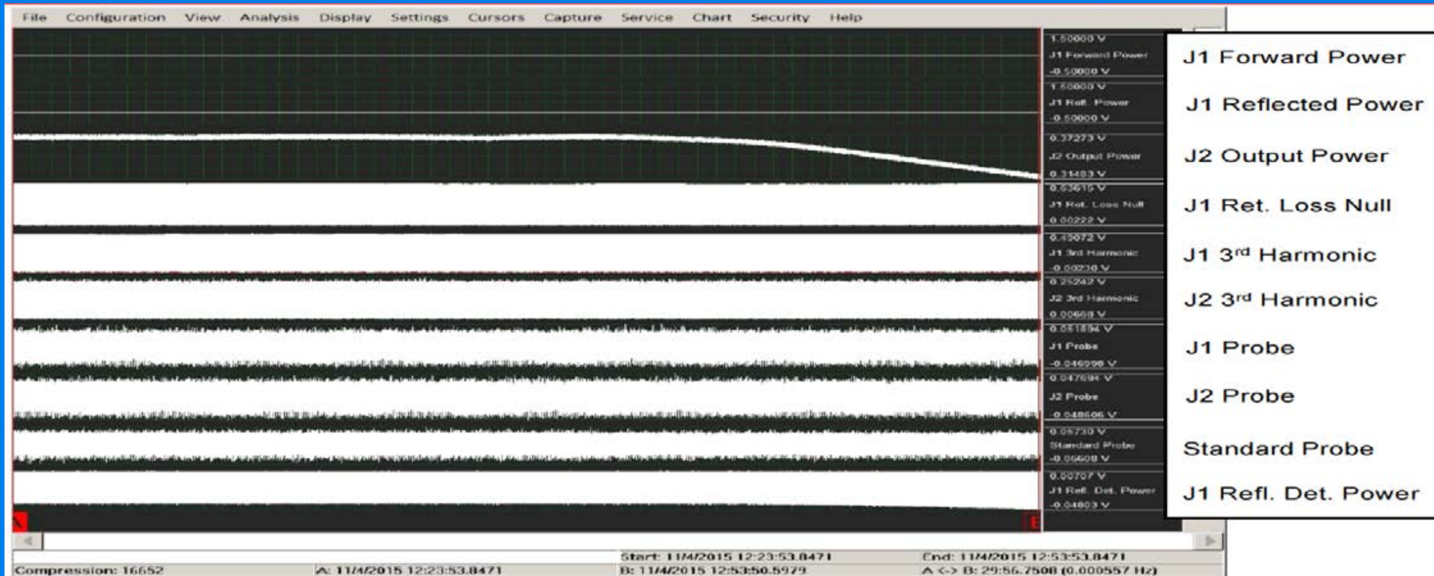


Test at 150 MHz, -45°C
10-60 Watts peak

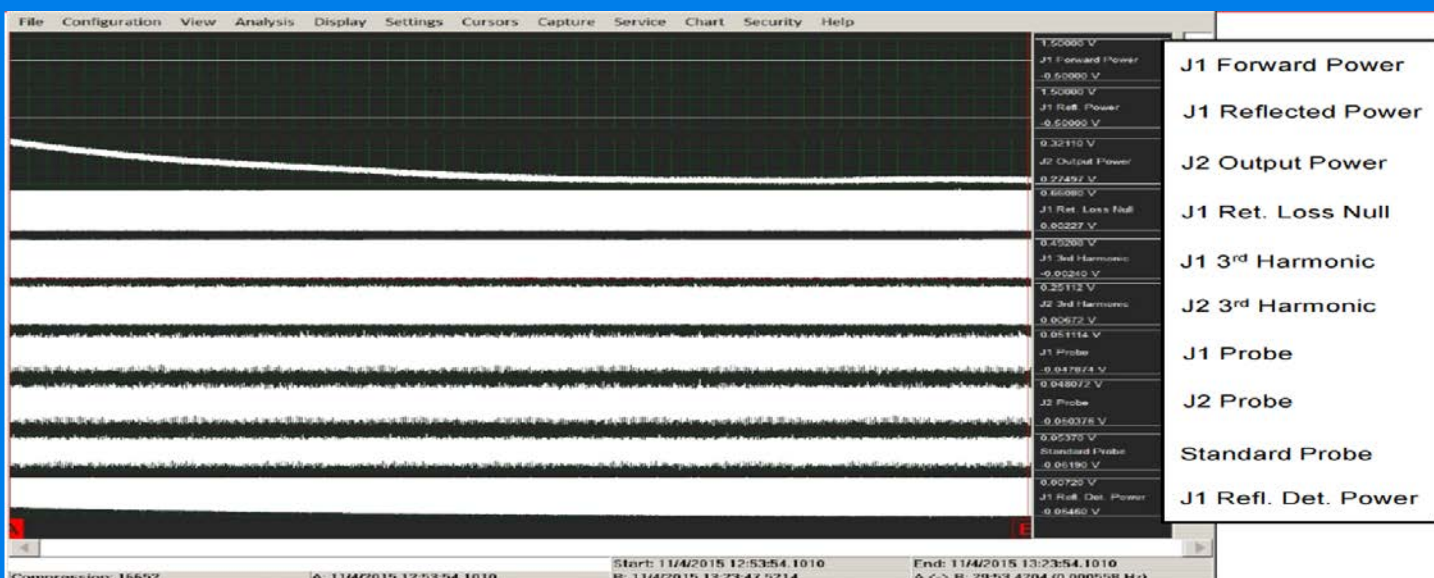


Test at 150 MHz, -45°C
70-80 Watts peak

BPF Multipaction Test Data – DUT, No Event



Test at 150 MHz, Cold to Hot Transition 80 Watts peak

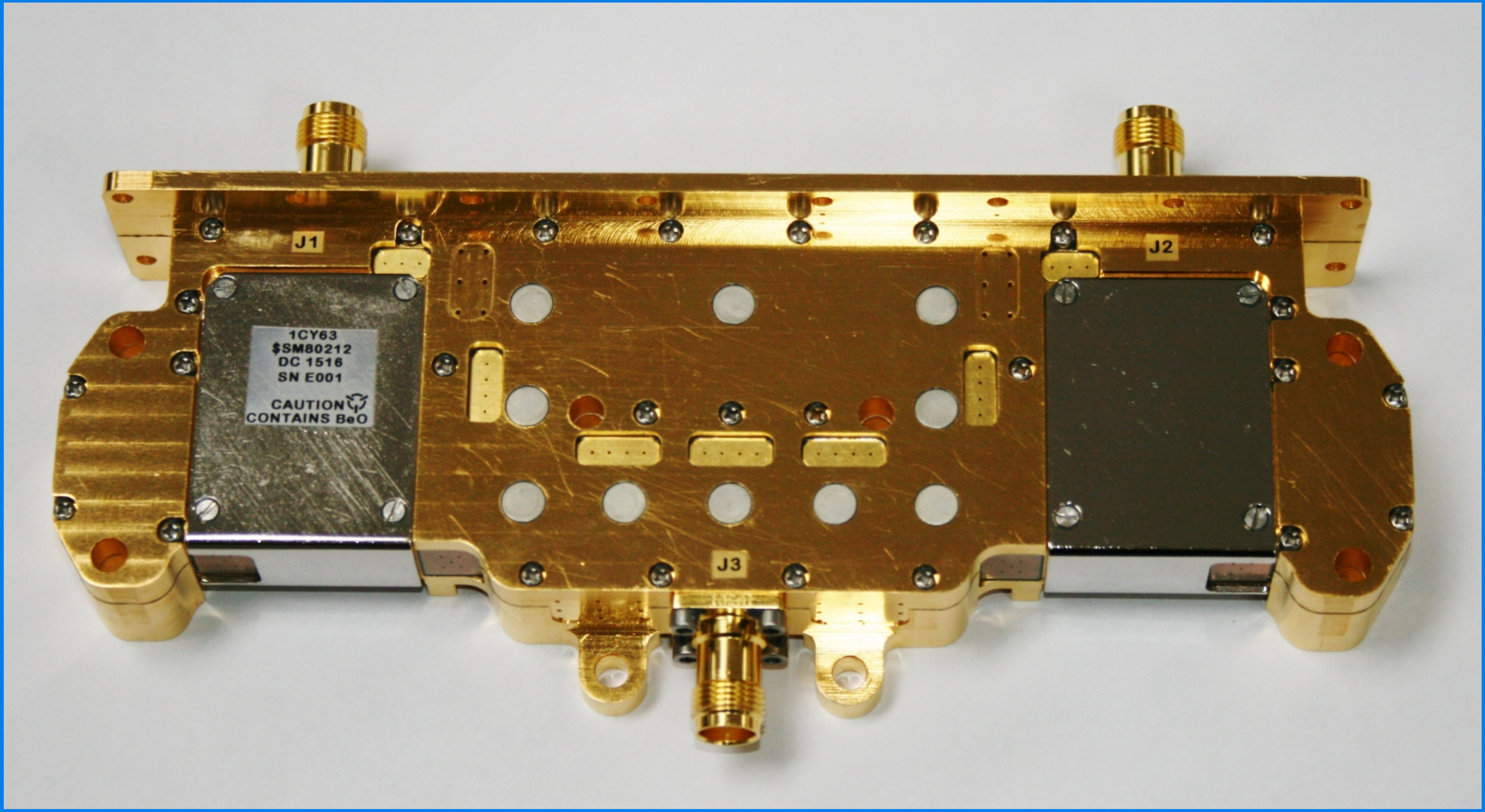


Test at 150 MHz, Hot, 80 Watts peak Dwell

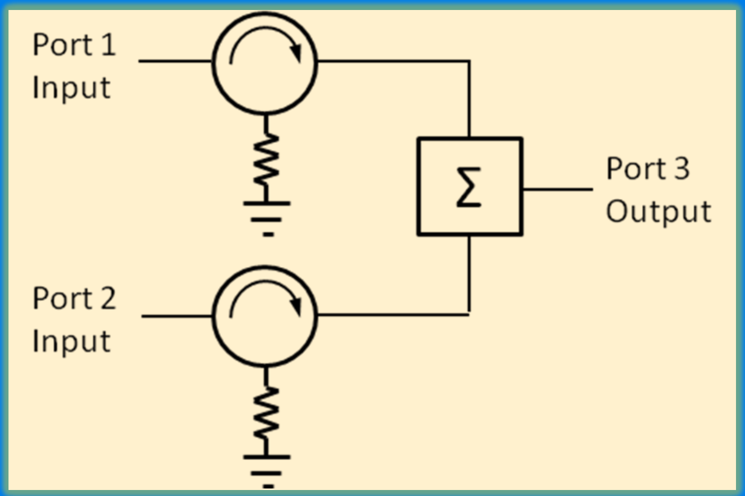
BPF Multipaction Test Data – DUT, No Event

Multipaction Test at 150 MHz, Hot, 80 Watts peak Dwell

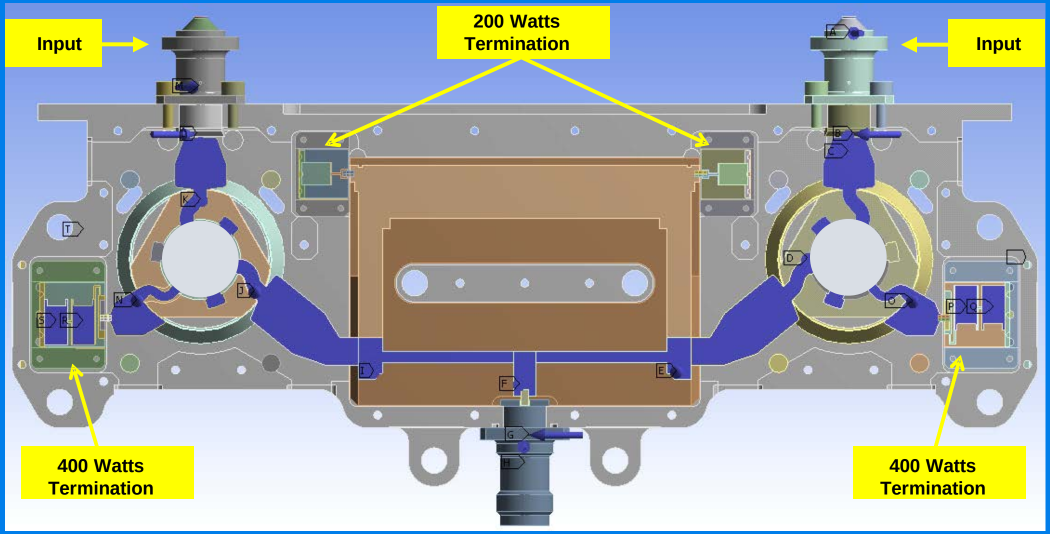
High Power L-Band Iso-Combiner



High Power L-Band Iso-Combiner



Iso-Combiner Schematic



Iso-Combiner Layout

A high power L-band iso-combiner designed and tested for multipaction

A 3-port device composed of a power combiner and two isolators, one at each input port

Iso-combiner required to handle 450 Watts combined average power

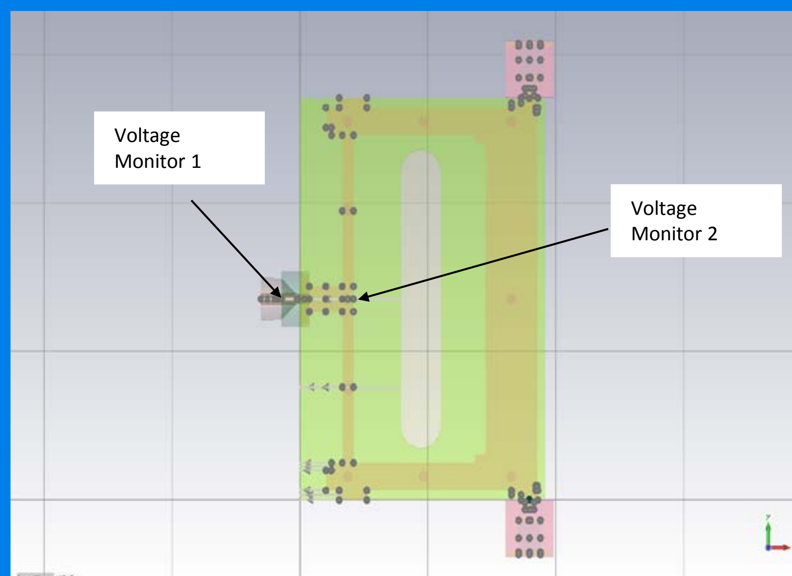
Iso-Combiner tested for Multipaction with combined input power up to 2028 Watts peak, 811.2 Watts average with no evidence of multipaction

ISO-COMBINER MULTIPACTION ANALYSIS

Combiner

EM simulation with CST Microwave Studio to calculate Electric Field distribution of the combiner and obtain the peak voltages over critical gaps with 3170 Watts CW (200 Watts+12 dB) power at each input port

Voltage monitor #1 in the connector area with 696.0 volts peak and a 2.48 mm gap
Voltage monitor #2 in the combiner area with 741.6 volts peak and a 3.24 mm gap.



Voltage Monitors on the Combiner for EM Simulation

ISO-COMBINER MULTIPACTION ANALYSIS

Gysel Combiner

Worst Case Peak Voltage and Multipaction Safety Margin

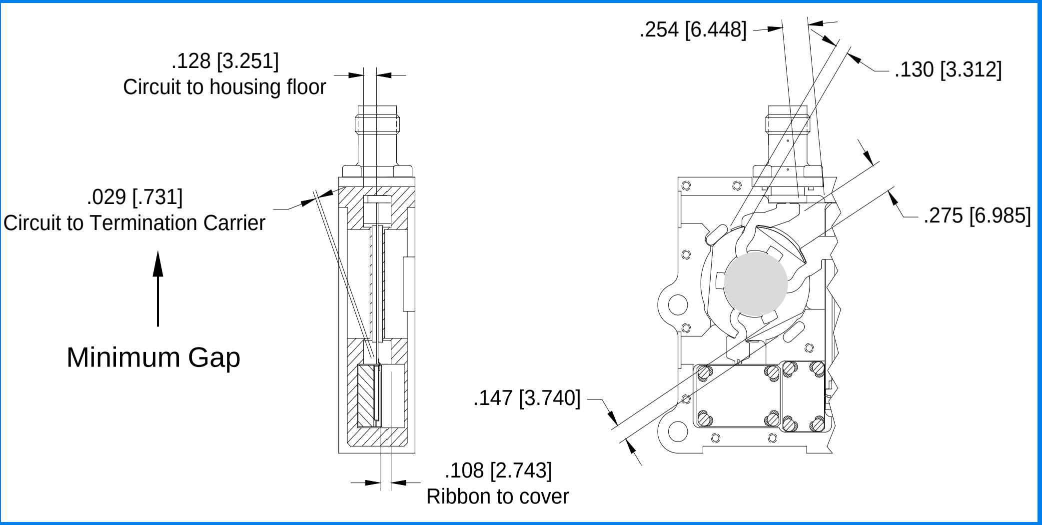
Voltage Monitor #	Gap (mm)	V_M	V_P	20Log (V_M/V_p)
1	2.48	241.9	696.0	**-9.2**
2	3.24	316.3	741.6	**-7.4**

V_P is the calculated voltage
V_M is Multipaction threshold (63 F gap for Silver)
Multipaction Safety Margin= 20 Log(V_M/V_P)

Safety margins are negative numbers, indicating that an unprotected device would multipact with the specified power levels.

ISO-COMBINER MULTIPACTION ANALYSIS

Isolator



The minimum gap in the isolator is the distance between circuit trace and termination carrier, 0.731 mm. At 1.55 GHz, *fd* = 1.133 GHz·mm and peak voltage threshold, V_P for aluminum will be 33.7 V, using ESA/ESTEC calculator

And maximum safe power is calculated from : $P = V_P^2 / Z = 22.71$

With Z = 50 ohms (the highest impedance in the isolator).

This represents -24.47dB margin over the 3170 Watts CW requirement

Without protection, the isolator would multipact with the specified power level

ISO-COMBINER MULTIPACTION ANALYSIS

To increase multipaction threshold, the iso-combiner is filled with a low loss Syntactic foam with high breakdown voltage (2.5KV/mm)

Foam will block any free path of secondary electron that may be released from the surface due to high RF power

In addition, thin layers of silicone RTV is used to fill any gap between different parts of the device

RF connectors are TNC Wedge type known for high breakdown threshold

ISO-COMBINER MULTIPACTION ANALYSIS

Thermal Analysis Summary

Different temperatures inside the device with 450 Watts combined average power and 0.35 dB Specified Insertion Loss (The actual Insertion Loss was <0.3 dB)

Ambient Temperature	Base plate Temperature	Connector Temperature (TNC pin)	Ferrite Temperature	Foam Temperature
81 °C	88.16°C	116.48 °C	97.64 °C	92.93 °C

These temperatures can affect the outgassing of the materials which may facilitate an eventual corona discharge with catastrophic results, and therefore needs to be verified by testing

ISO-COMBINER MULTIPACTION TESTING

Test Parameters

Parameter	Setting	Notes
Frequency	1575 MHz	
Combined Power Output Power (0.25dB component loss)	2028 W peak	811.2 W average
Pulse Width	2ms, 40% duty factor	
Pressure	<1.0e-5 Torr.	
Temperature	-5, +25 and +85 Deg. C	
Electron Source	Cs—137 Source,	3 sources, 10 μc each
Detection Methods	Dual Input Return Loss Nulling Input Third Harmonic Output Third Harmonic	Simultaneous increase in any two parameters
# of Samples Tested	2	

ISO-COMBINER MULTIPACTION TESTING

Test Conditions

Test-up calibrated before prior to Multipaction testing

A Multipaction standard used to verify the test set-up

Power level at each input port ramped from 50 Watts peak to 1014 Watts peak in 200 Watts intervals with 10 minutes dwell at each level. 60 minutes dwell at maximum power of 1014 Watts peak

Forward , reflected and output powers continuously monitored and recorded

Return loss nulls and third harmonic signals continuously monitored and recorded

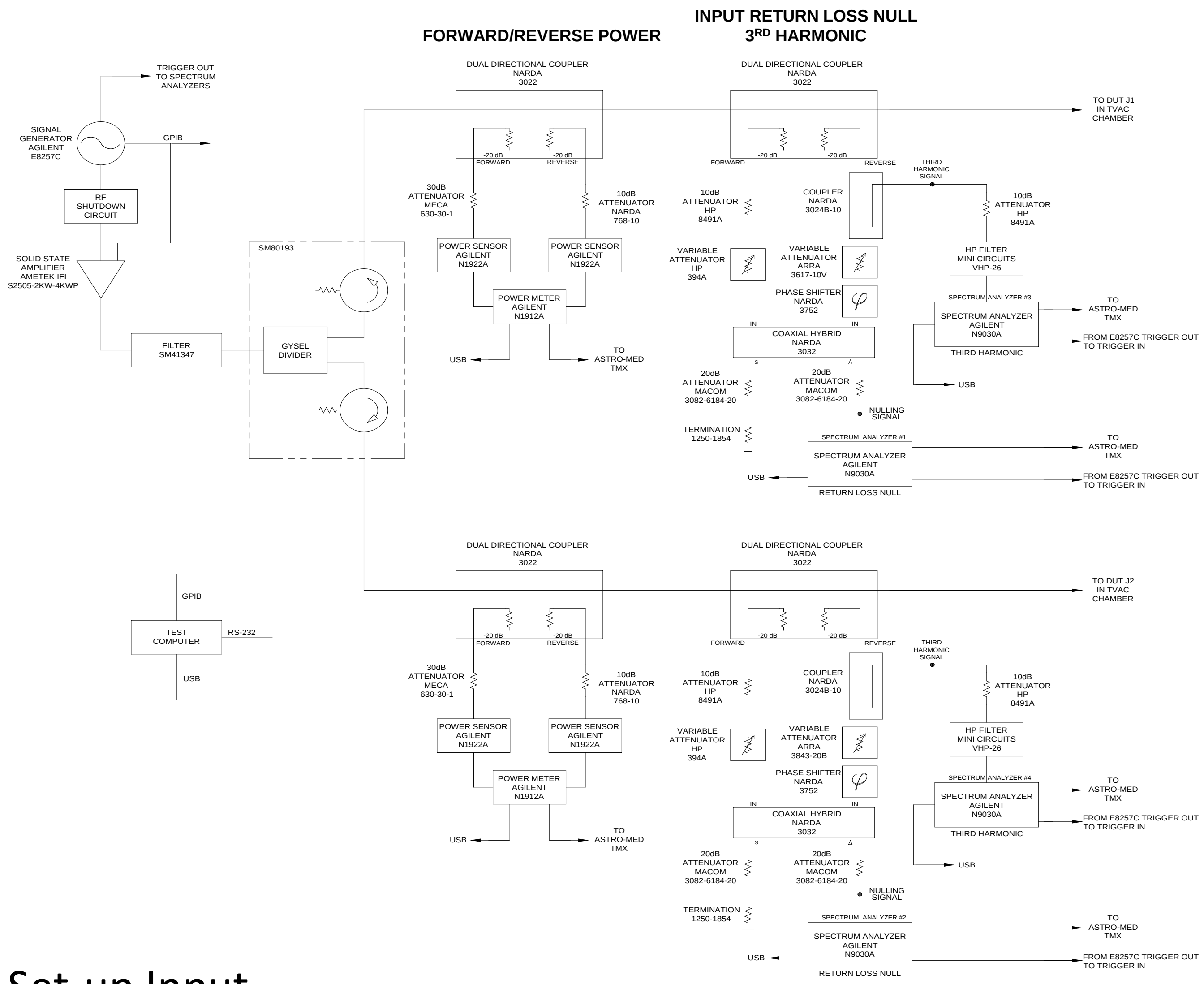
Several thermocouples placed on DUT and base plate to continuously monitor and record the temperature

Thermal vacuum chamber pressure continuously monitored

Visual Inspection after multipaction testing using a microscope at 10x magnification and RF test according to the test plan

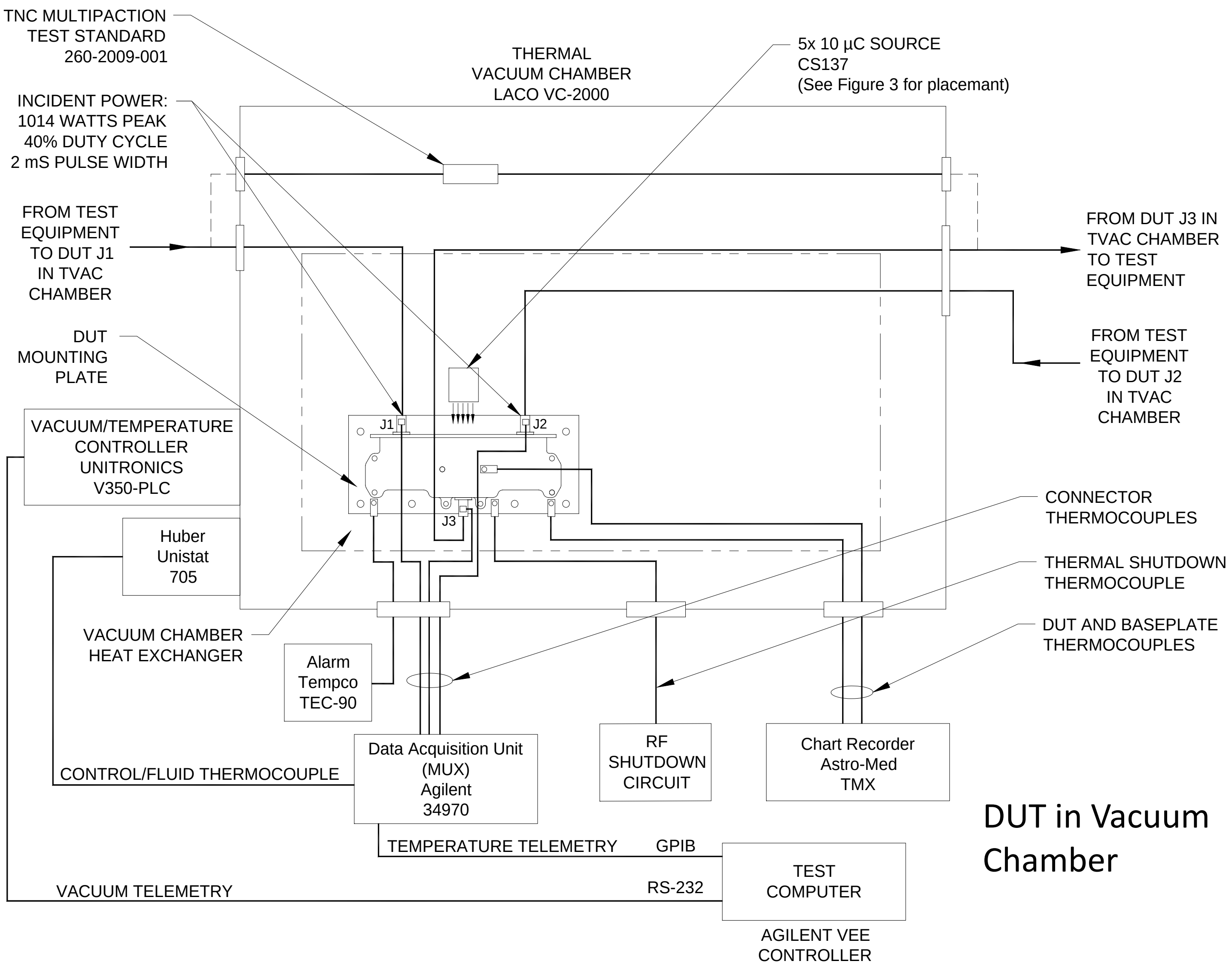
a HEICO company

MULTIPACTION TEST SET-UP



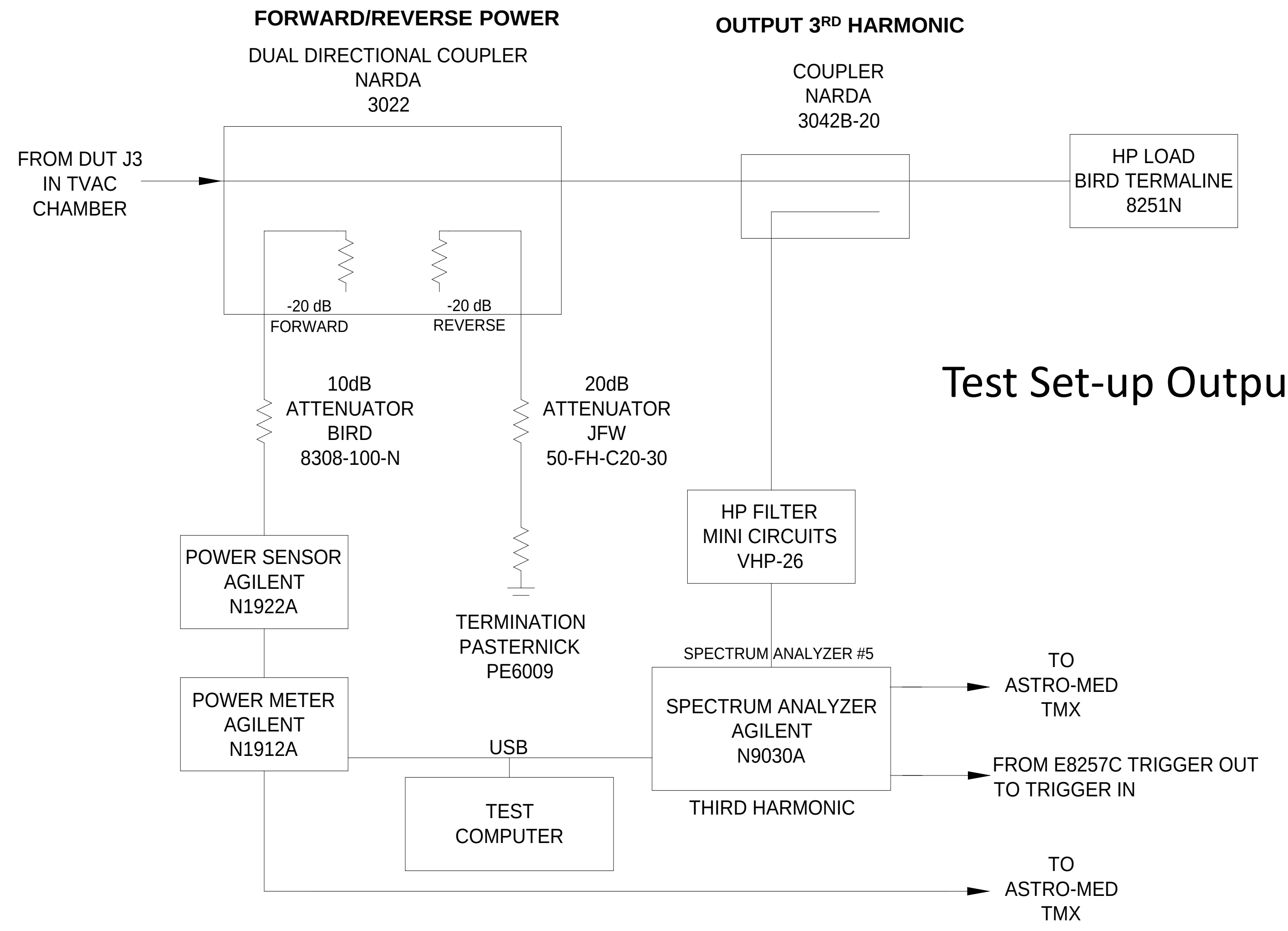
Test Set-up Input

MULTIPACTION TEST SET-UP



DUT in Vacuum Chamber

MULTIPACTION TEST SET-UP



Test Set-up Output

ISO-COMBINER MULTIPACTION TESTING

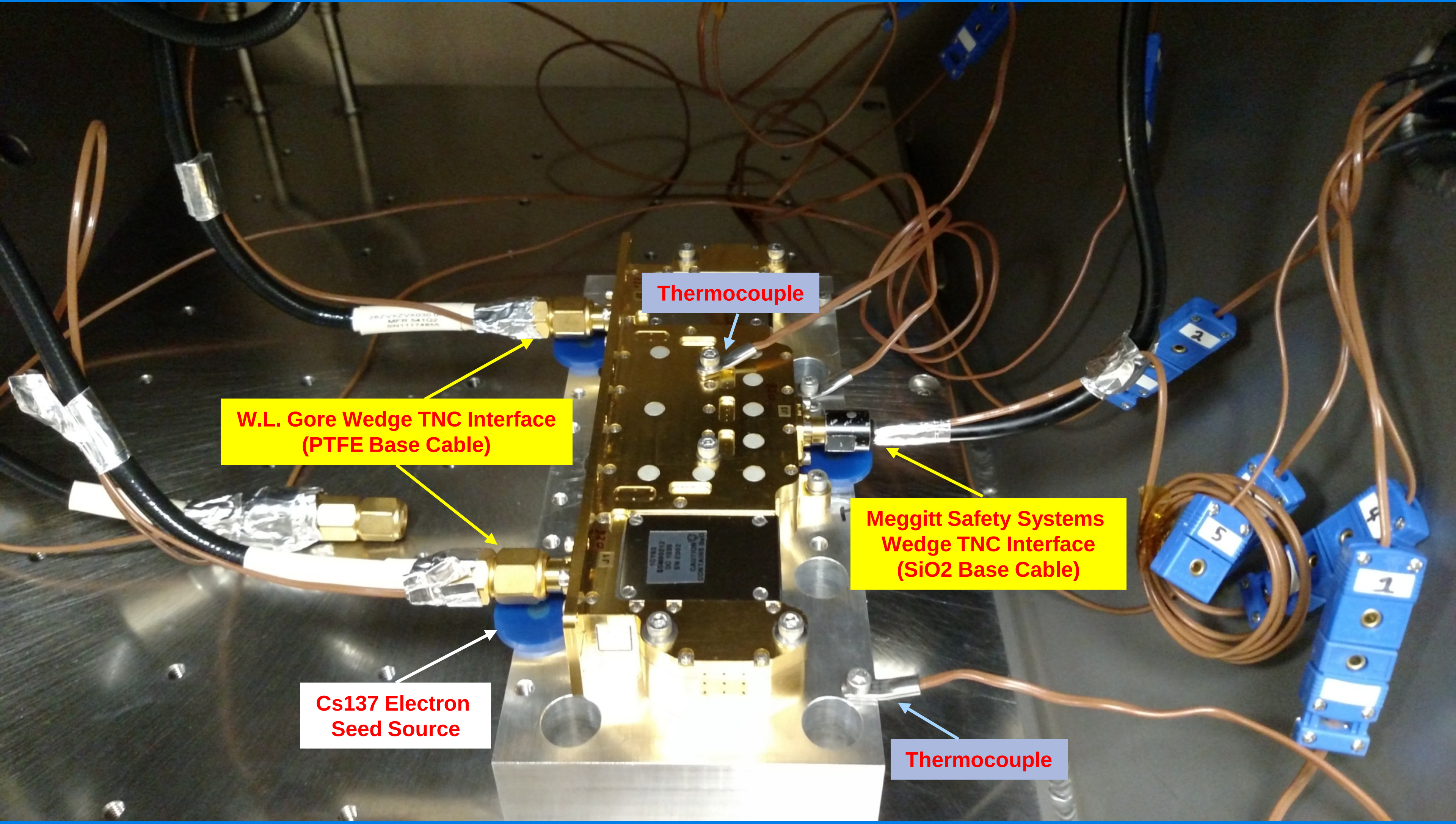


Image of the Unit in Thermal Vacuum Chamber, Including Temperature Sensors and Electron Sources

ISO-COMBINER MULTIPACTION TESTING

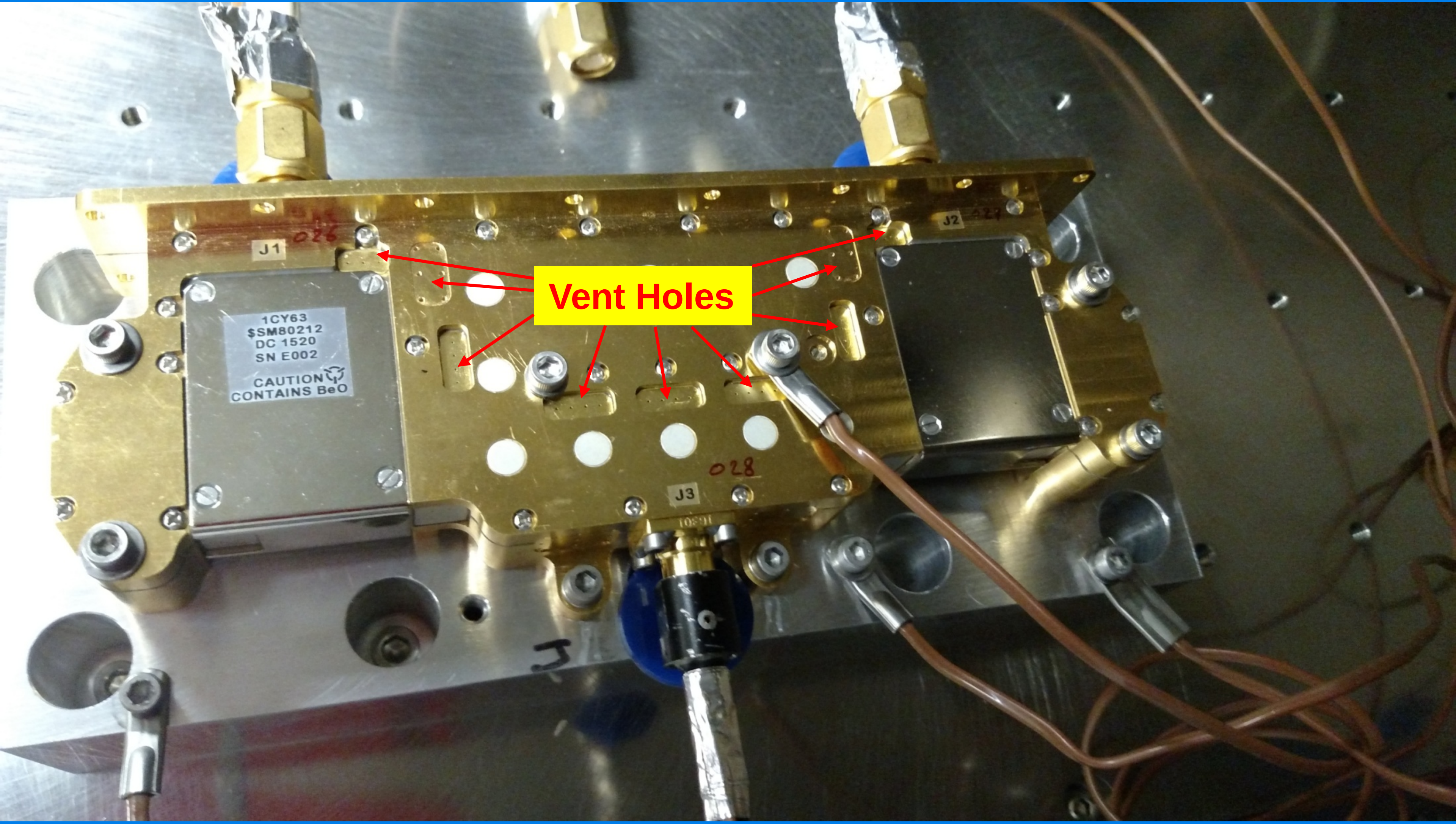
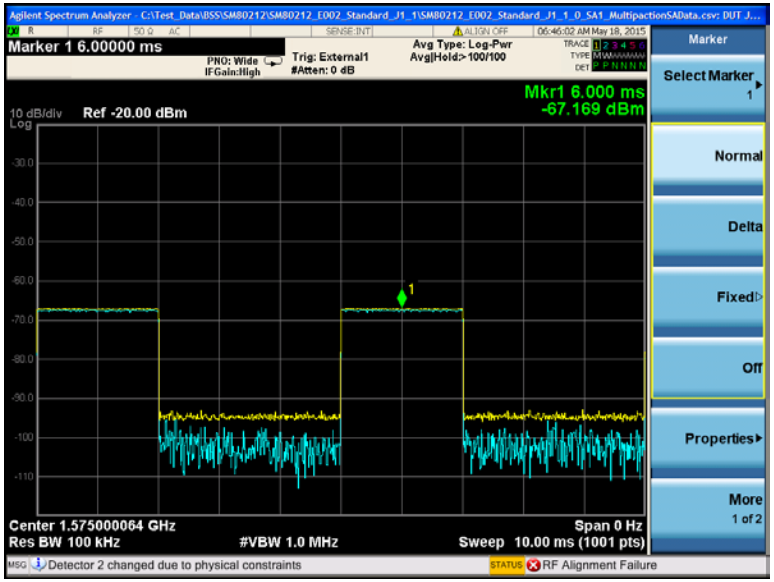


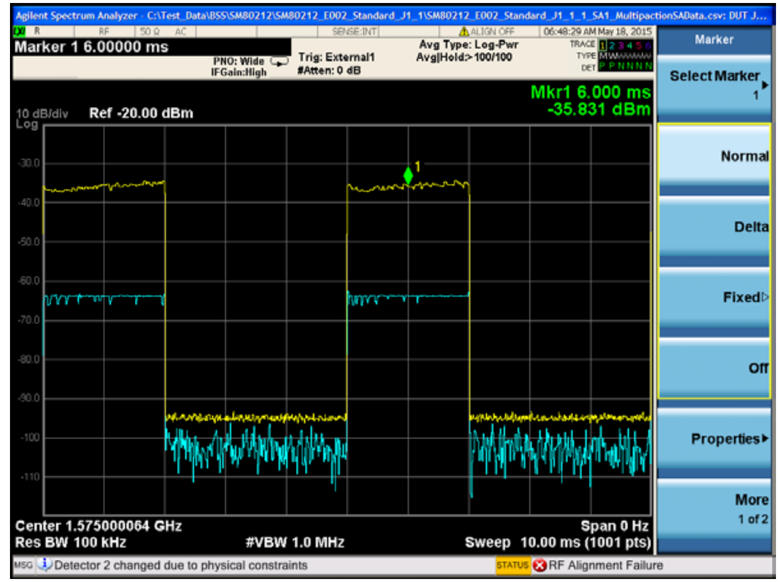
Image of the Unit in thermal Vacuum Chamber Showing Vent Holes

ISO-COMBINER MULTIPACTION TESTING

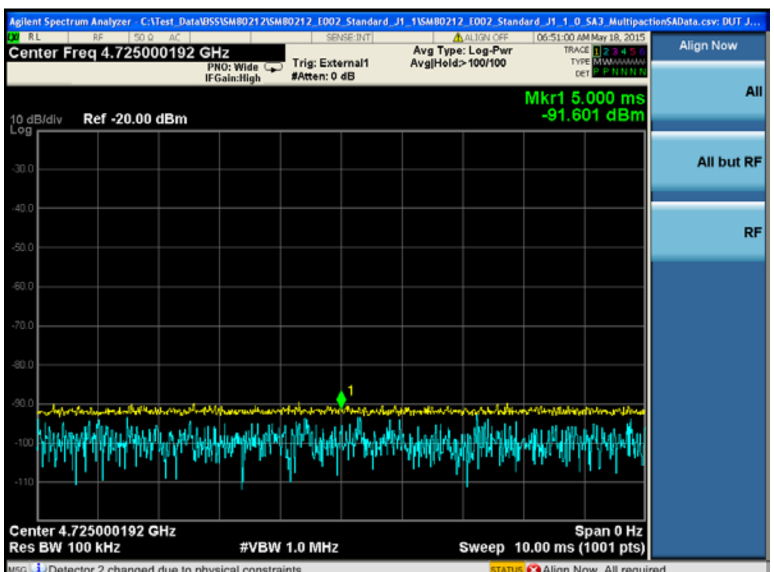
Multipaction Standard Showing Event



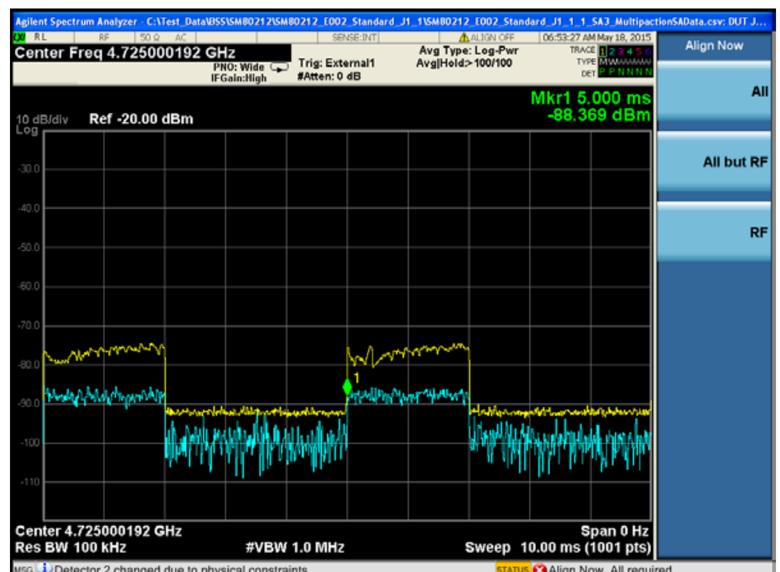
Return Loss Null Input, 5 Watts



Return Loss Null Input, 70 Watts Multipaction Event



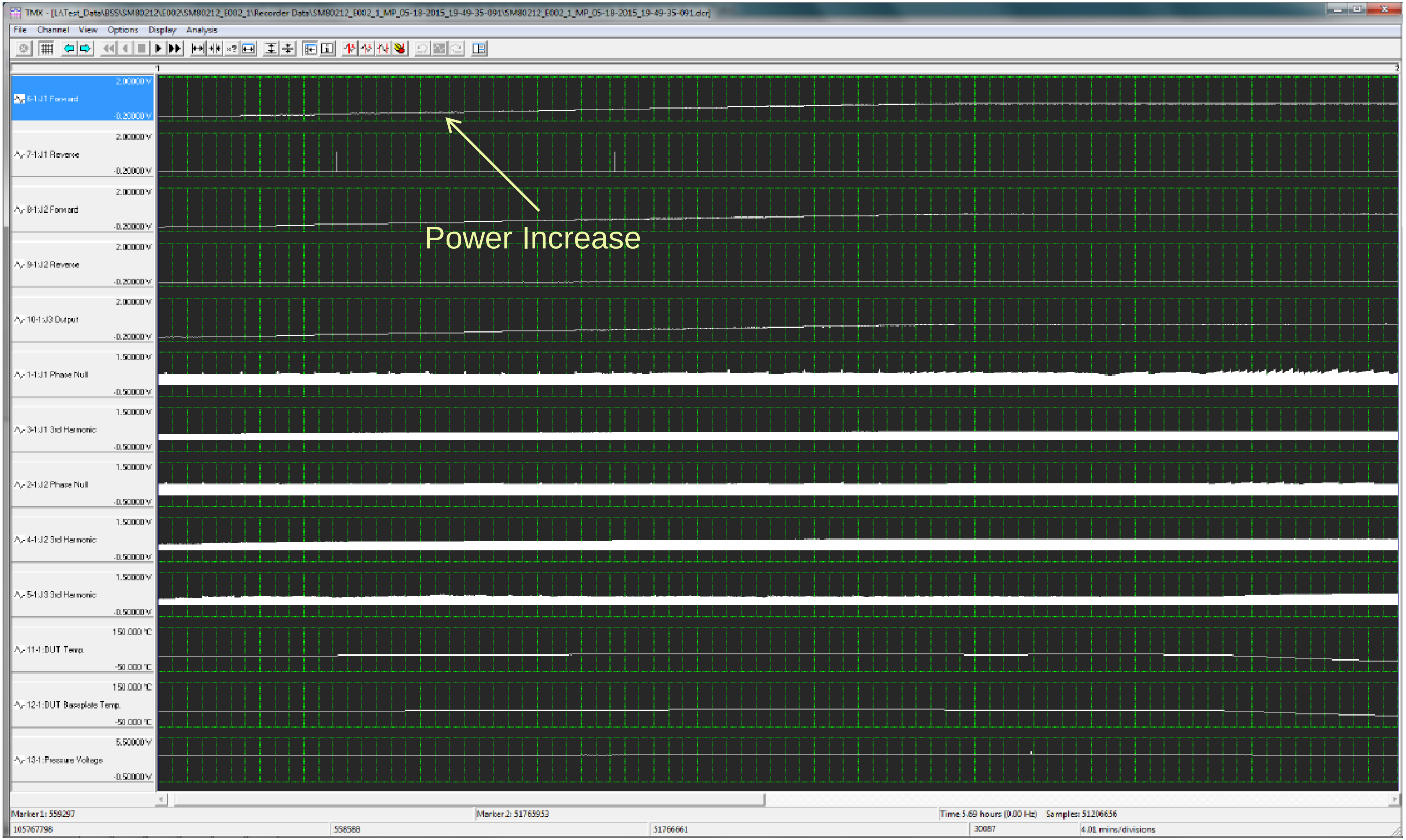
Third Harmonic Input, 5 Watts



Third Harmonic Input, 70 Watts Multipaction Event

ISO-COMBINER MULTIPACTION TESTING

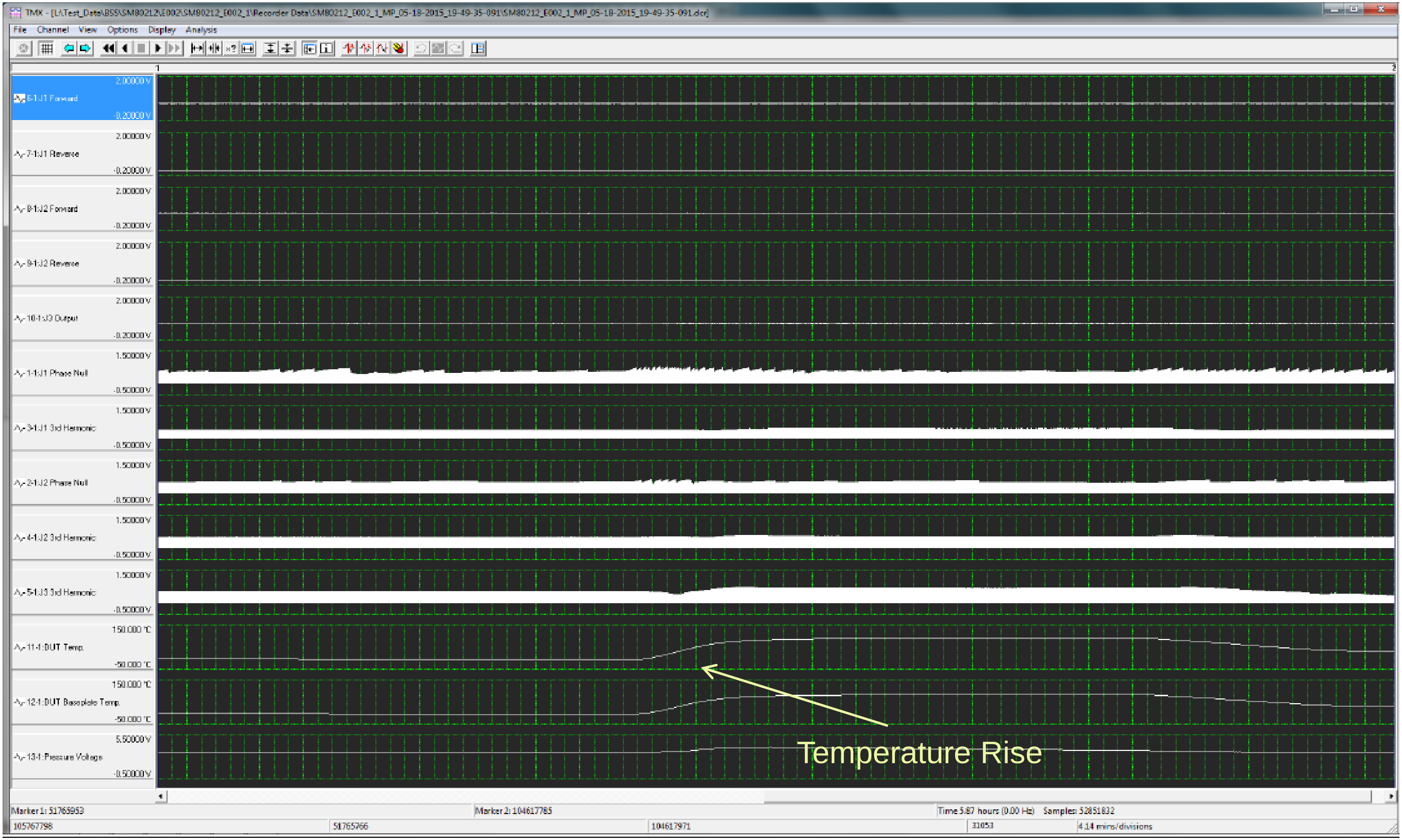
Multipaction Test on DUT Showing No Event



Combined Input Power Level Increased to 2028 W peak

ISO-COMBINER MULTIPACTION TESTING

Multipaction Test on DUT Showing No Event



At Max. Power, Temperature Raised to 85 °C

THANK YOU

Sierra Microwave Technology