Evaluation Of High-Temperature Performance of Semi-Additive Rectifier Circuits up to 175°C

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Background

◊ The development of reliable electronic devices for harsh environments(temperature, humidity, vibration, etc.) is growing.

◊ We are currently facing the challenge of developing high-temperature electronics with stable, reliable, and long application life in these conditions.

◊ Among them, rectifiers are used in power conversion circuits and tools to convert AC to DC.

◊ High-temperature operation and performance analysis of the Rectifier have been mainly focused on up to 125°C.

Motivation

◊ A study on rectifiers is needed to meet the demand for high-reliability electronics that can withstand extreme thermal conditions.

◊ Analyzing these circuits' voltage drop, leakage currents, and high-temperature efficiency will help with performance comparisons and identify the advantages and disadvantages of these methods.

◊ This research investigates the semi-additive(ablation) method for designing rectifiers as an alternative to additive manufacturing.

◊ The findings from this research will contribute to the development of optimized, high-performance circuits suitable for extreme operation conditions in EVs, drilling, aerospace, power, and high-temperature manufacturing applications.

Research Objectives

◊ Rectifiers Analysis of Electrical Performance at High-Temperature.

◊ Design optimization for High-Temperature operation.

◊ Identifying the effects of used components, layouts, and thermal characteristics of circuits.

◊ To create a reference for higher temperature testing at 175°C and beyond.

◊ Using the JEDEC JESD22 standard as a reference for testing.

Standards	Standards Name	Temperature range
Automotive	AEC-Q100	-40°C to +150°C
	AEC-Q200	-40°C to +125°C
Aerospace	MIL-STD-810G/H	-55°C to +125°C
	RTCA DO-160	-55°C to +85°C
Power Electronics	**JEDEC JESD22**	**Up to +175°C**
	IEC 60747-15	Up to +200°C
	IEC 60068-2-14	Up to +150°C

Components Specification

	Component	Description	Specification
1	Capacitor	CAP CER 1µF 25V X7R1206	T_{range}= -55° C to +175° C, V_{DC} =16-25V , C ≤ 0.910 µ
2	Diode	D2PAK SiC Schottky	$V_{R.Peak}$ = 650V, V_F = 25V, I_F=4A, T_J = -40ºC to 175ºC
3	Ceramic Substrate	Copper Clad Alumina	Size: 5in*5in, t :1mm (ceramic), t_{Cu}: 1 oz. (35µ)
4	Interconnect	SAC Paste	SAC305(Tin/Sn-Ag-Cu) [217-219ºC=Melting T]

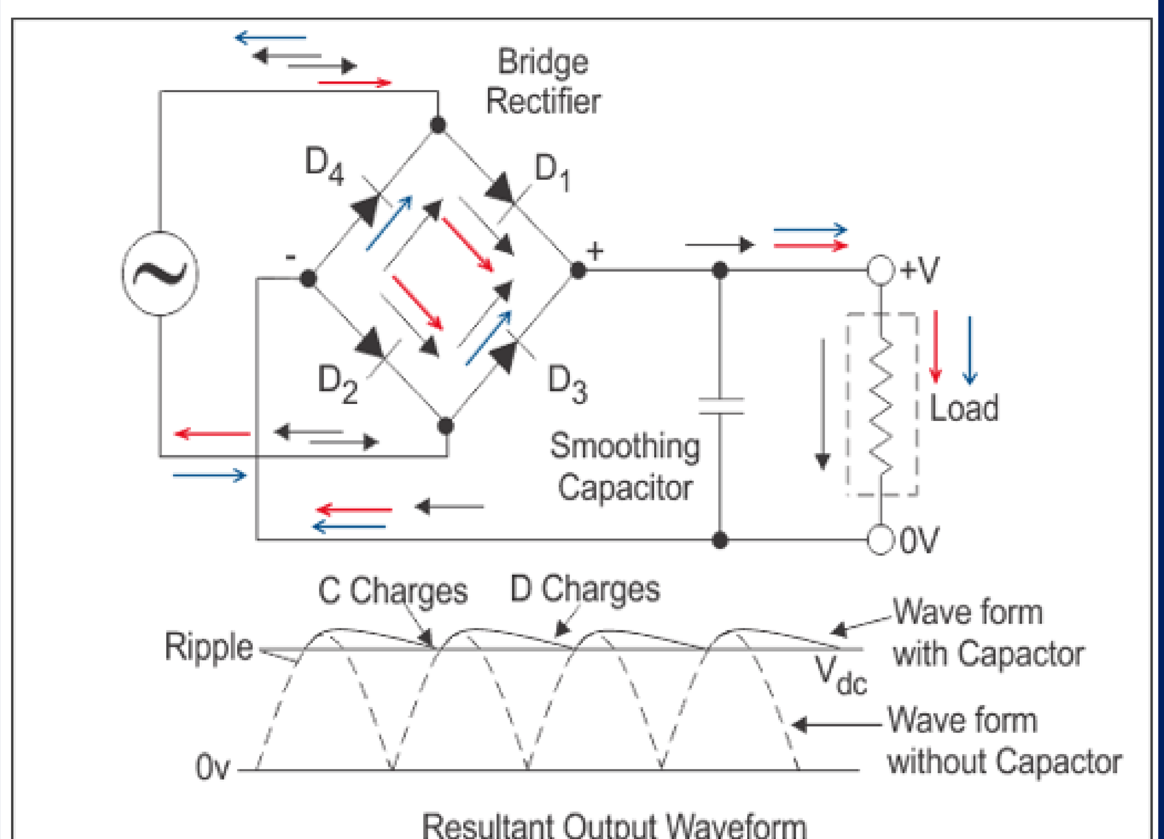
Print Platform / LPKF U4 Protolaser Machine

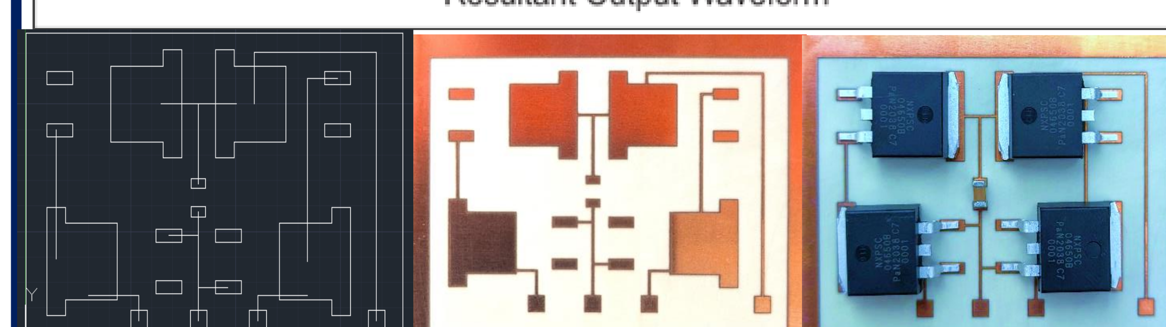
- The LPKF U4 Protolaser machine will be used for selective laser ablation of Cu-clad ceramic substrate to get our desired circuit of FWR and HWR.
- Isolate creates the outline border between clad copper & circuit.
- Hatch parameter removes the excess copper around the circuit.

Cu-clad Ceramic Substrate

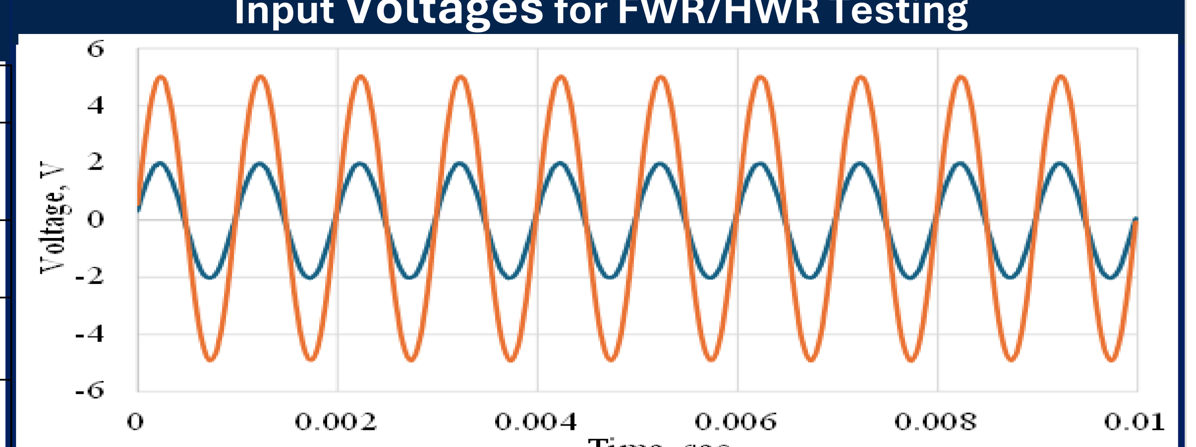
	Isolate	Hatch
Frequency	60 kHz	35 kHz
Power	5.2 W	5.4 W
Mark Speed	225 mm/s	250 mm/s
Repetition	5	5
Pulse Energy	87µJ	154µJ

Working Principle and Design of FWR

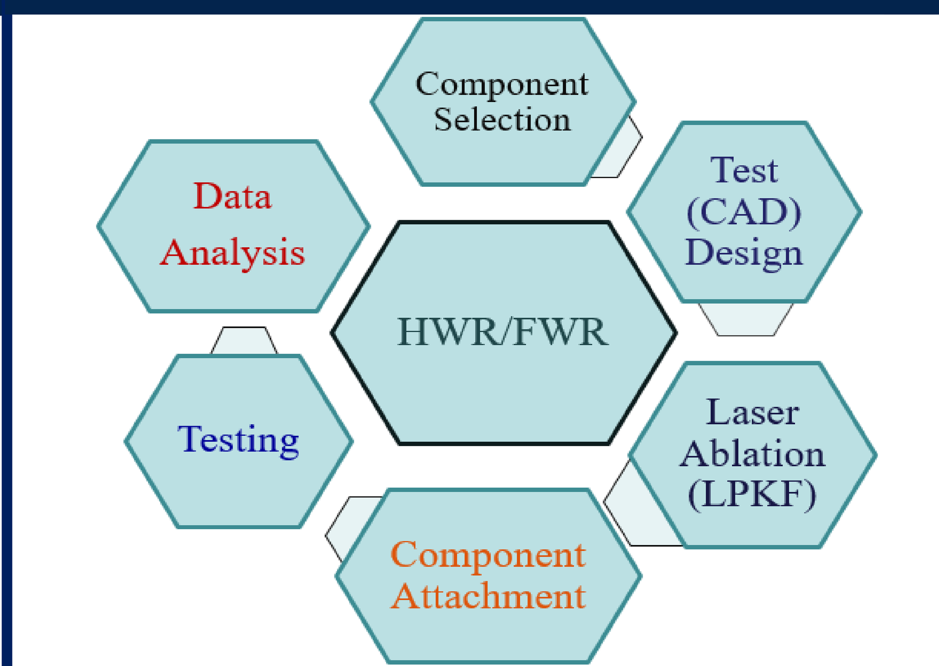




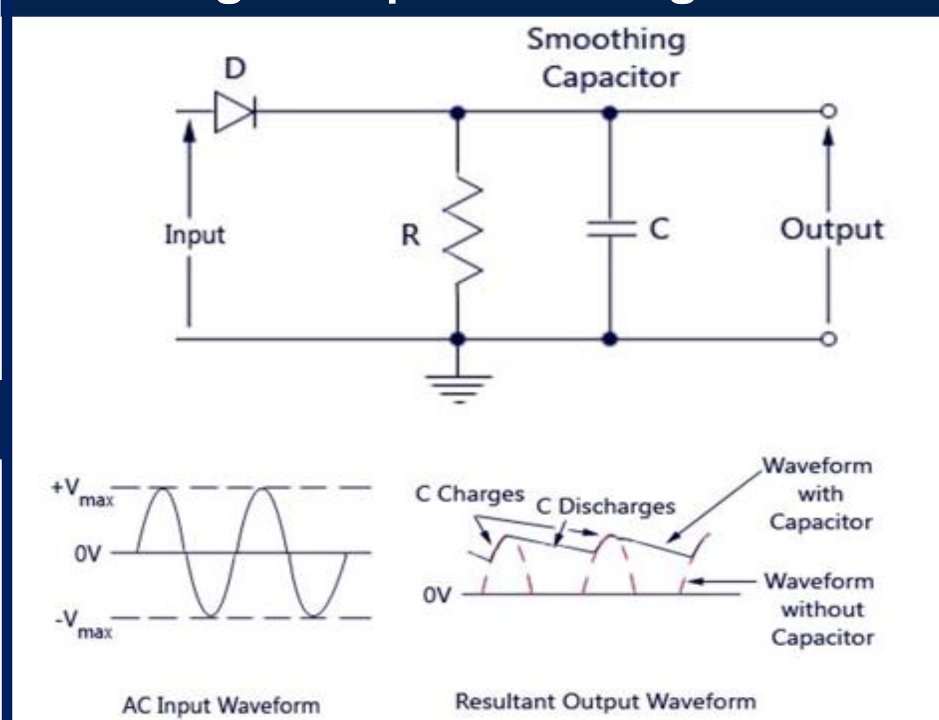
Input Voltages for FWR/HWR Testing

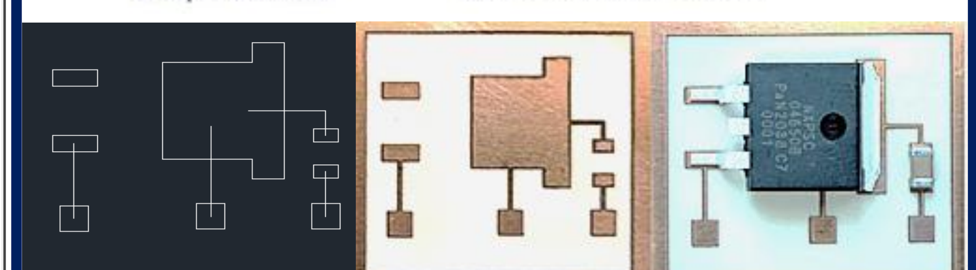


Process Flowchart

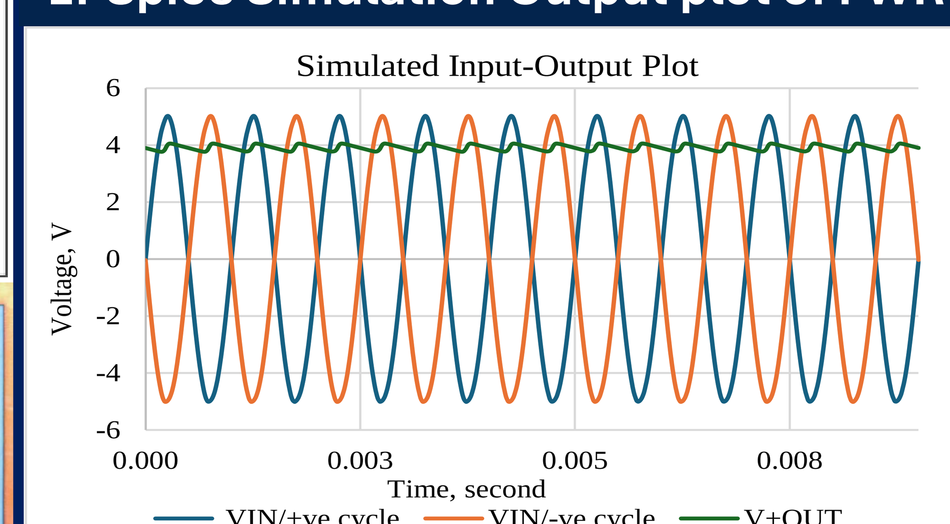


Working Principle and Design of HWR

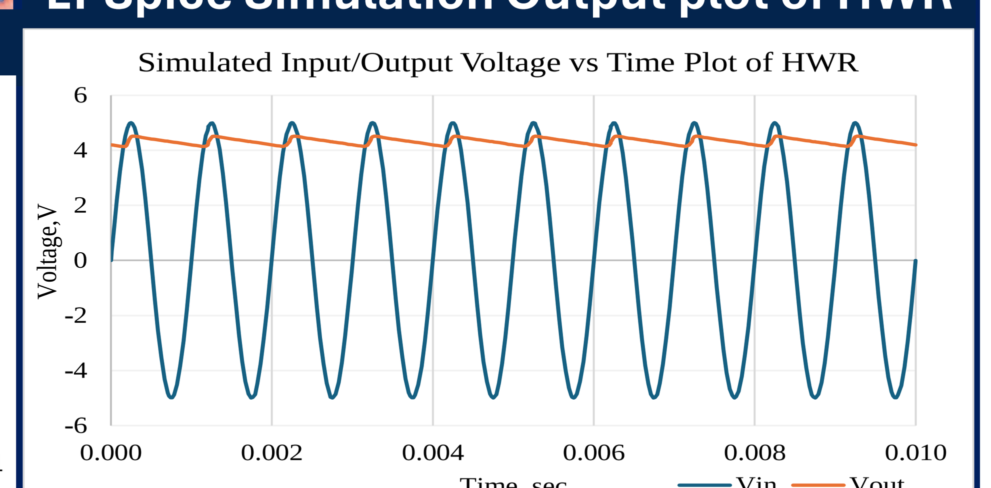




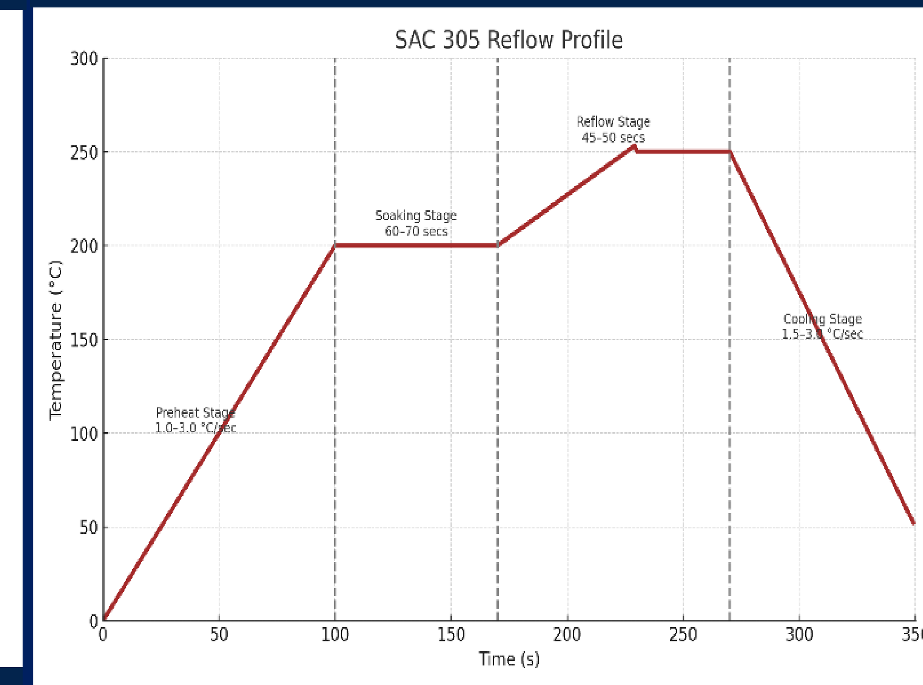
LT Spice Simulation Output plot of FWR



LT Spice Simulation Output plot of HWR

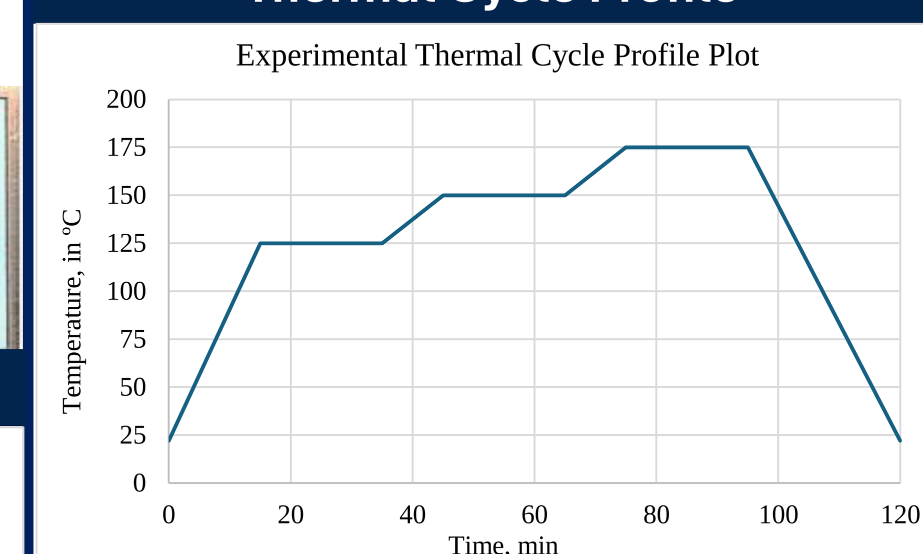


Reflow profile of Interconnect material



Test Setup of Rectifiers

Thermal Cycle Profile



Diode Characteristics

Table 6. Characteristics

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
Static characteristics							
V_F	forward voltage	I_F = 4 A; T_j = 25 °C; Fig. 6		-	1.5	1.7	V
		I_F = 4 A; T_j = 150 °C; Fig. 6		-	1.8	2.1	V

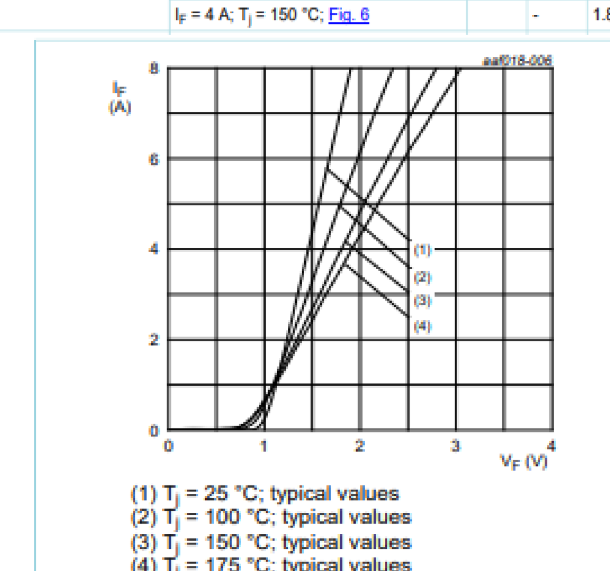
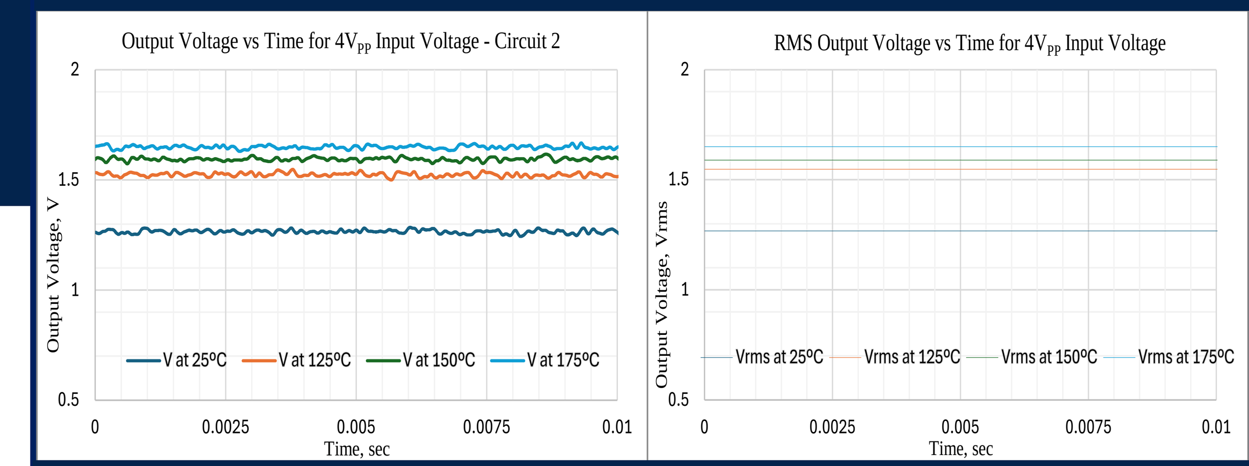


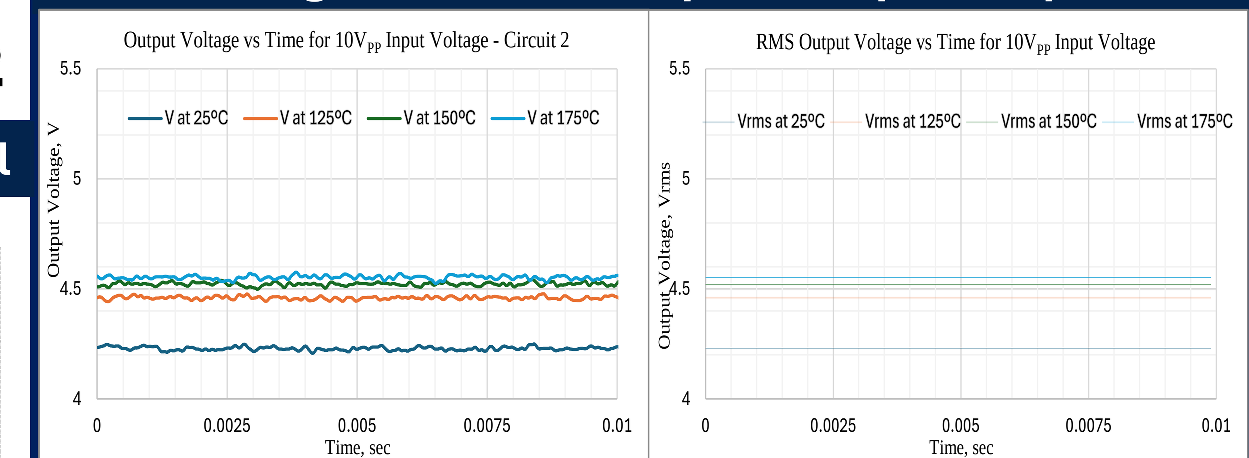
Fig. 6. Forward current as a function of forward voltage; typical values

Diode Characteristics from Manufacturer's Datasheet

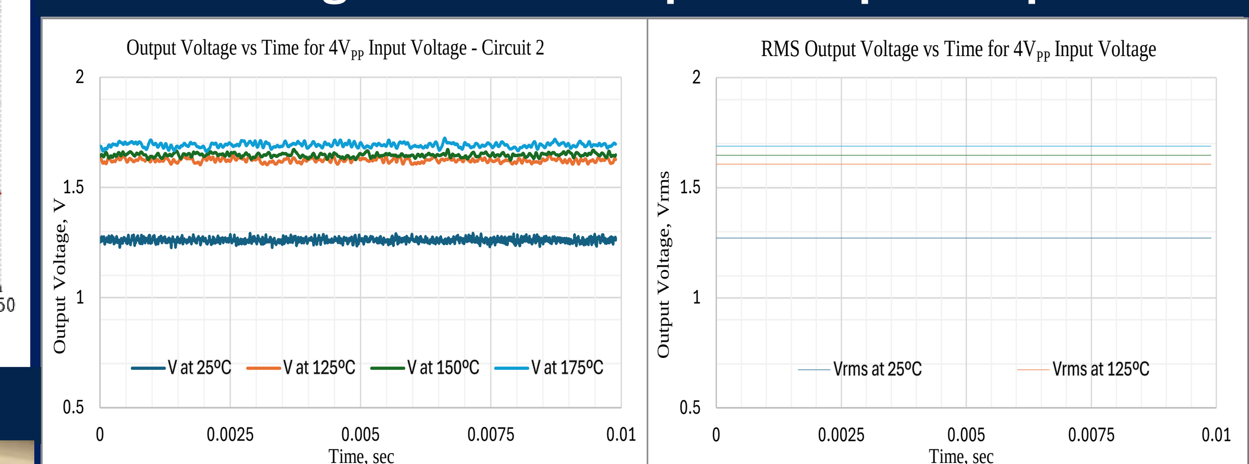
Testing of HWR for 4Vpeak-to-peak input



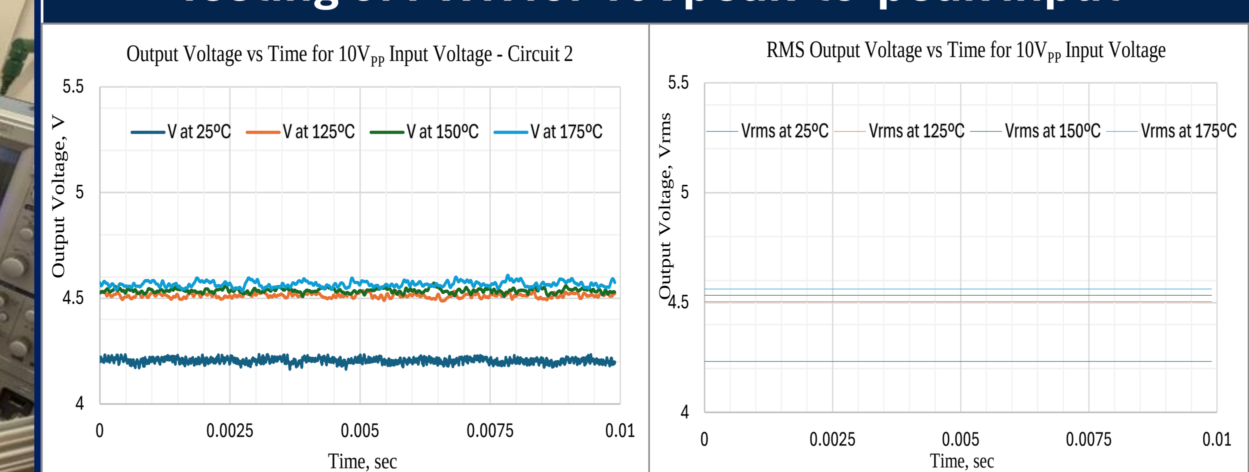
Testing of HWR for 10Vpeak-to-peak input



Testing of FWR for 4Vpeak-to-peak input



Testing of FWR for 10Vpeak-to-peak input



Data Analysis

◊ As stated in "Diode Characteristics" provided by SiC Schottky Diode Manufacturer, for the same Current(4A) and different Temperatures of 25°C & 150°C, there is a voltage increment of +0.3V(max 0.4V).

◊ From experimental measurements and plots, we can also see a similar voltage increment.

Test I/P	Output(25°C)	Output(150°C)	Difference
4Vpp	1.28V	1.65V	+0.37V
10Vpp	4.23V	4.55V	+0.32V

Conclusions

◊ At room temperature, nearly identical results were obtained from LT Spice Simulation and Measured Output from printed rectifiers using Oscilloscope.

◊ Both FWR & HWR performed well up to 175°C without malfunctioning, strengthening the selection of components and operational stability.

◊ It was observed that as the temperature of the thermal chamber increased during testing, the output voltage increased, which is justified by the Diode datasheet.

Acknowledgements

The project was sponsored by the NextFlex Manufacturing Institute under PC8.2 Project titled – Additive Die Packaging for Cryogenic and High-Temperature Operations. This material is based, in part, on research sponsored by the Air Force Research Laboratory under agreement number FA8650-20-2-5506, as conducted through the flexible hybrid electronics manufacturing innovation institute, NextFlex. The US Government is authorized to reproduce and distribute reprints for Governmental purposes, notwithstanding any copyright notation thereon. The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of the Air Force Research Laboratory or the US Government.