Development of High-Temperature Capable Semi-Additive Logic Gate Circuits on Copper-Clad Ceramic Substrates for Automotive Applications

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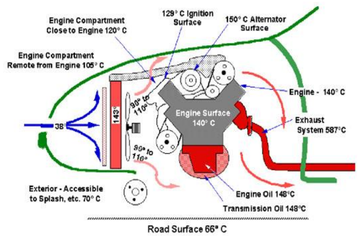
INTRODUCTION

The automotive industry increasingly relies on advanced electronic systems that must withstand harsh operating environments, particularly extreme temperatures exceeding 150°C. Conventional electronic packaging and silicon-based circuits suffer significant performance degradation and reliability issues at elevated temperatures, posing critical safety risks. To overcome these limitations, this research introduces copper-clad ceramic substrates combined with advanced semi-additive manufacturing techniques to develop robust, high-temperature capable digital logic gate circuits



ECU Location	Detail Position	Required Temperature
Passenger Room	Under dashboard	-30 to +85°C
Engine Room	ECU Box	-30 to +105°C
	Underhood	-30 to +125(150)°C
	Connected to Engine	-30 to >+175°C

OBJECTIVES

- Investigate copper-clad ceramic substrates for high thermal conductivity, electrical insulation, and mechanical robustness.
- Develop logic gates (NAND, NOR, NOT) capable of stable operation at automotive temperature ranges (up to 250°C).
- Validate circuit designs through extensive simulation and experimental testing across various temperature conditions.

MATERIALS AND METHODS

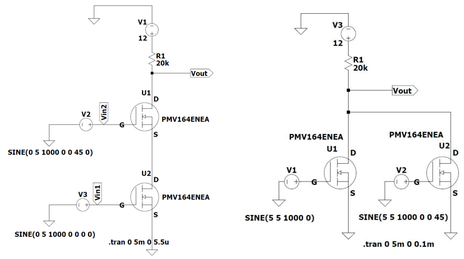
- Substrate – Copper Clad Ceramic (Al_2O_3 96%)
  - Excellent thermal conductivity (24.7 W/mK)
  - Copper layer thickness: ~35 µm
- MOSFETS – N Channel Surface Mount (SiC)
- Interconnect Material - SAC 305 (96.5% Sn, 3% Ag, 0.5% Cu)
  - Thermal conductivity: 50 W/mK

LPKF Process Recipe Parameter

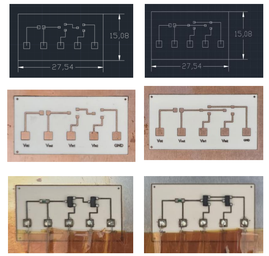
S.N.	Parameters	Isolate	Hatch	Units
1.	Frequency	60	35	kHz
2.	Power	5.2	5.4	W
3.	Pulse Energy	87	154	µJ

CIRCUIT DESIGN AND PROTOTYPING

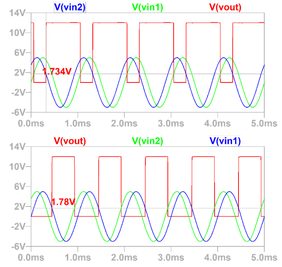
- NAND, NOR, and NOT gates designed and optimized using LTSpice



NAND and NOR Gate Schematic

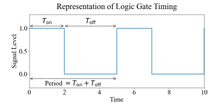


Prototyping of NAND & NOR



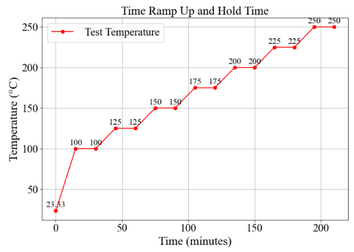
Simulation Results

Gate	T_{OFF} (ms)	T_{ON} (ms)	Period(ms)
NAND	0.2620	0.7380	1.000
NOR	0.5146	0.4875	1.002
NOT	0.3837	0.6127	0.996

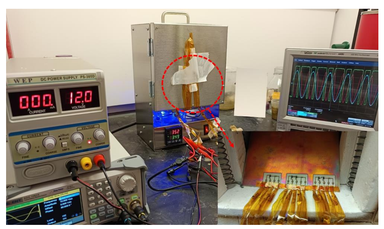


EXPERIMENTATION

- Temperature Ramps from 23 °C and from 100 °C to 250 °C
- Parameters monitored: output voltage, logic threshold, timing metrics

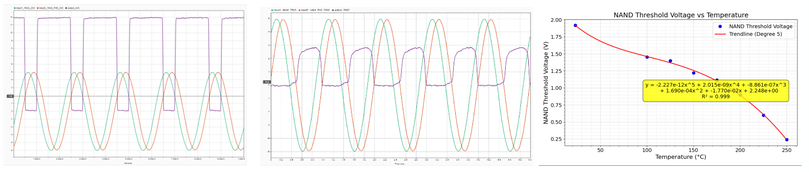


Test Temperature Ramp and Hold

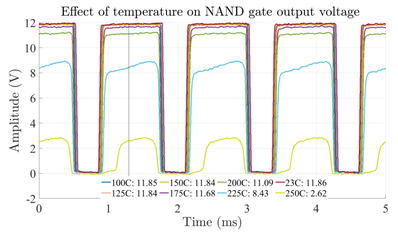


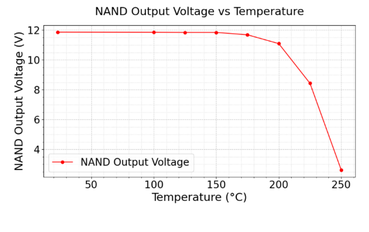
Experimental Setup of High-Temperature Testing

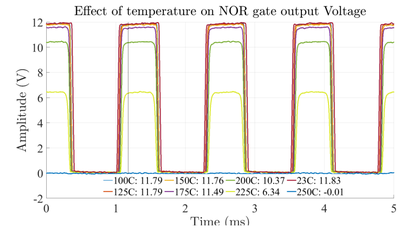
EFFECT ON LOGIC THRESHOLD

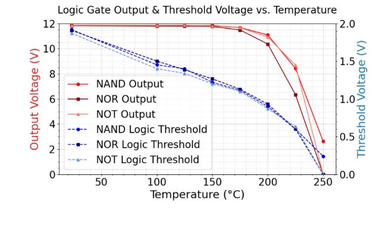


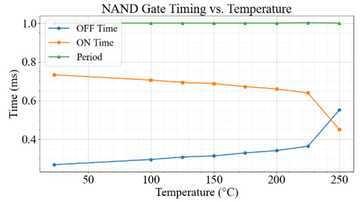
EXPERIMENTAL OBSERVATIONS

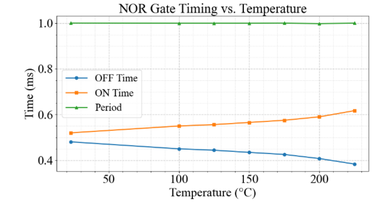












- Output Voltage maintained ~11–12 V (close to nominal) from 23 °C to ~200 °C.
- Minor shifts in conduction intervals as temperature increased.

CONCLUSIONS

- Circuits functioned reliably up to ~200 °C without significant loss in switching behavior
- Copper-clad ceramic substrates with SiC MOSFETs enable reliable operation at temperatures up to 200°C
- Results establish a pathway for robust electronic designs suitable for harsh automotive environments

ACKNOWLEDGMENTS

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