Screen-Printed In-Mold Electronics Reliability on Polycarbonate Substrates under Sustained High Temperature Conditions

Shriram Kulkarni[1], Pradeep Lall[1], Scott Miller[2]

(1). Auburn University Electronics Packaging Research Institute, Auburn University, Auburn, AL 36849

(2). NextFlex National Manufacturing Institute, San Jose, CA

Tele: (334) 8443424, Email: lall@auburn.edu

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Problem Statement

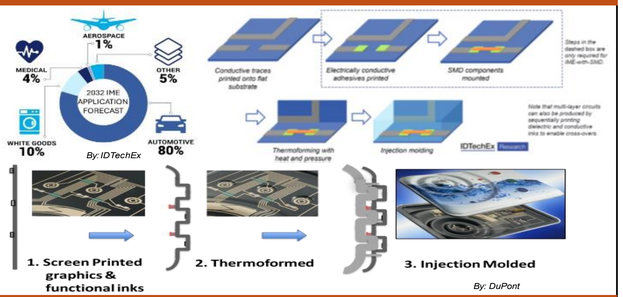
- **Increased use of wire harnesses** in the automotive sector adds weight, leading to higher CO_2 emissions.
- **IME (In-Mold Electronics) offers a solution** by integrating printed electronics, reducing wire harness reliance, and enhancing design flexibility.
- **Thermoforming is crucial** in IME but can impact the performance of conductive traces.
- **Limited research exists** on how thermoforming affects screen-printed samples.
- This study investigates the **effects of thermoforming on the electrical performance and reliability** of screen-printed samples on polycarbonate substrates.

King, G., Bentley Bentayga wiring harness is weirdly beautiful, July 2016

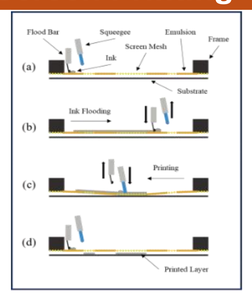
Objectives

- Evaluate the **impact of thermoforming** on the electrical performance of screen-printed circuits on polycarbonate substrates.
- Determine the **optimal thermoforming parameters** to maintain the integrity of conductive traces.
- Investigate the **changes in electrical performance**, before and after thermoforming .
- Assess the **long-term reliability** of screen-printed electronics under sustained high-temperature conditions by subjecting thermoformed samples to 85°C, following the AEC-Q100 Grade 3 Standard, and monitor their HTOL performance overtime.

In-Mold Electronics



Screen Printing–Process & Equipment



Screen Printing Process

ATMA AT-70PD Screen Printer

ATMA AT-70PD	
Working Table Size	700 mm X 800 mm
Substrate Thickness	0-120 mm
Table Adjustments (X, Y)	± 10mm, ± 10mm

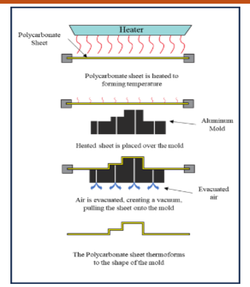
Printing Parameters	
Squeeze Speed	230 mm/s
Flood Bar Speed	260 mm/s
Screen Mesh and Material	300 Stainless Steel Mesh

Ink & Interconnect Materials

Ink Properties (Silver Nanoparticle Conductive Ink)	
Viscosity	10000-18000cp
Sheet Resistance	<40mΩ/sq./mil
Sintering Temperature	120°C for 20 mins.

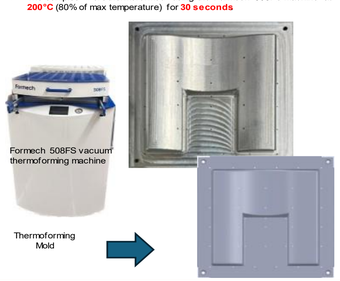
Electrically Conductive Adhesive (ECA) Properties	
Material	Silver Conductive Epoxy
Viscosity	40000cP to 90000cP
Sintering Temperature	120°C for 20 mins.
Sheet Resistance	100-150 mΩ/sq./mil

Thermoforming–Process & Equipment



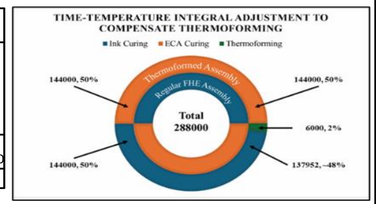
Thermoforming Process

- The samples were thermoformed using the Formech 508FS machine at **200°C** (80% of max temperature) for **30 seconds**



Time-Temperature Profile

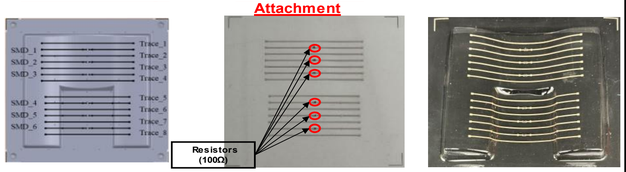
Regular FHE Assembly	Thermoformed Assembly
Ink Curing(120°C for 20 mins) +**ECA Curing**(120°C for 20 mins)	**Ink Curing**(120°C for 19 mins) +**ECA Curing**(120°C for 20 mins) + **Thermoforming** (200°C for 30 sec)
120x1200 + 120x1200	120x1150 + 120x1200 + 200x30
288000	288000

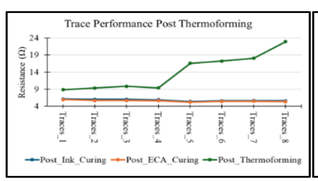


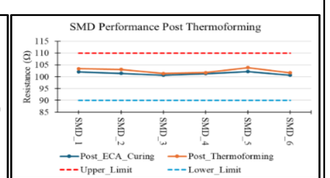
- Using the calculation the ink curing was done for **19 mins at 120°C**.

Traces and Component Attachment

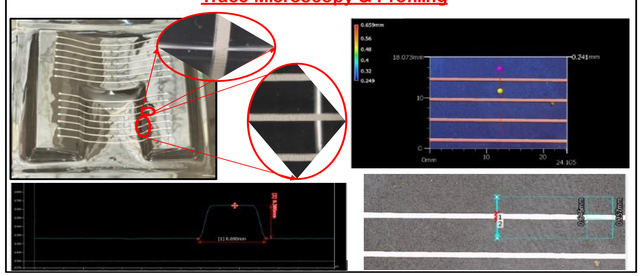
Test Vehicle Design | **After Component Attachment** | **After Thermoforming**





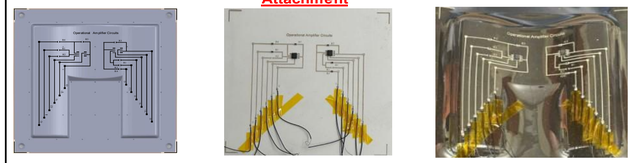


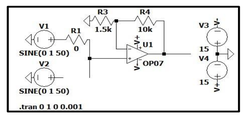
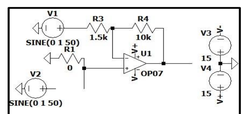
Trace Microscopy & Profiling

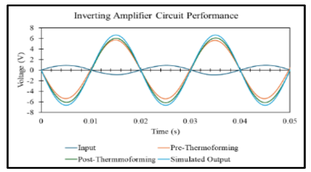


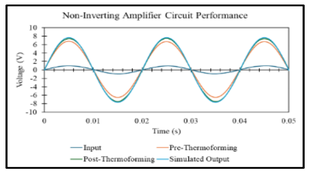
Demonstrator Circuits: Inverting and Non-Inverting Amplifier Circuits

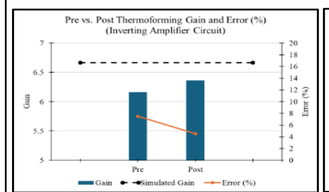
Test Vehicle Design | **After Component Attachment** | **After Thermoforming**

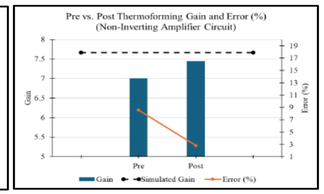


Non-Inverting Amplifier Circuit		$Gain = \frac{V_{out}}{V_{in}} = \frac{R_2 + R_1}{R_2}$ $Gain = 7.6$
Inverting Amplifier Circuit		$Gain = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$ $Gain = 6.6$







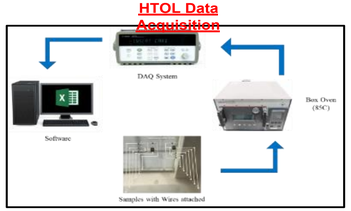


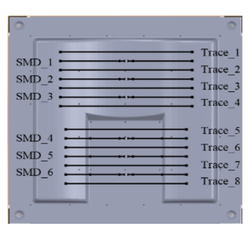
High Temperature Operation Life (HTOL)

Standard

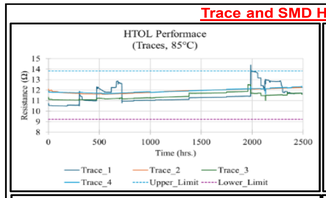
(AEC-Q100 Grade III) 85°C for 1000 hrs.

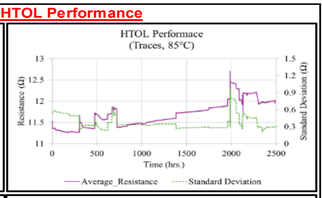
HTOL Data Acquisition

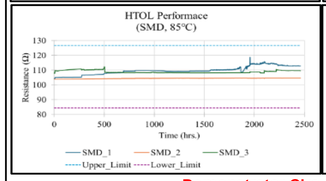


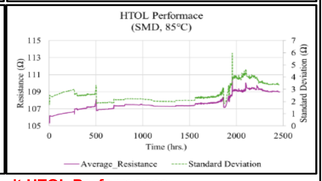


Trace and SMD HTOL Performance

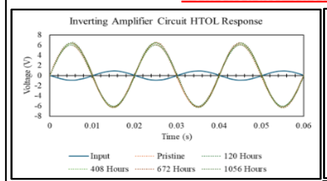


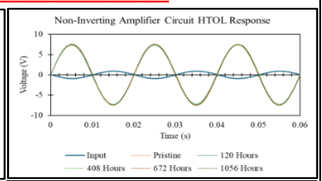


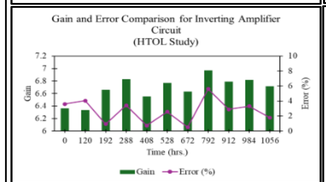


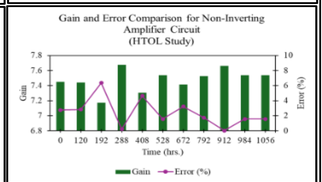


Demonstrator Circuit HTOL Performance



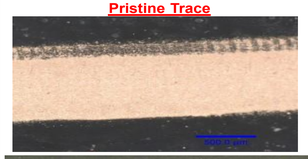


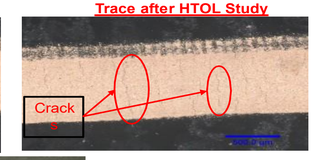




- HTOL results confirm that traces, SMDs, and circuits maintained stable electrical performance under prolonged thermal exposure, demonstrating their reliability for high-temperature applications

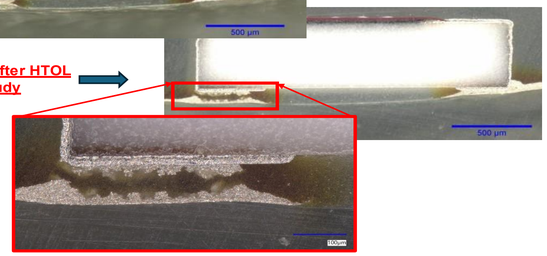
Pristine Trace | **Trace after HTOL Study**





Pristine Sample

Failure after HTOL Study



Conclusions

- Traces: Showed stable performance post-curing but increased resistance in high-stretch areas after thermoforming. Maintained reliability after 2500 hours of HTOL testing at 85°C.
- SMDs: Consistently reliable before and after thermoforming, with no significant degradation beyond the AEC-Q100 Grade III 1000-hour requirement.
- Circuits: Inverting and non-inverting amplifiers remained stable, with post-thermoforming results closely matching simulations (error <10%). HTOL tests (1,056 hours) showed maximum errors of 6% and 7%, meeting AEC-Q100 Grade III standards.
- Conclusion: Screen-printed thermoformed conductive structures demonstrate high reliability, confirming their suitability for automotive electronics in high-temperature environments.

Acknowledgment

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