Tamper-Sensing Meshes in the Wild

Jan Sebastian Götte & Björn Scheuermann
TU Darmstadt
contact: research@jaseg.de

2026-06-04

What is a Tamper Sensing Mesh?

- Embedded looped conductor covering a surface
- Detects physical intrusion
  - Drills, saws, lasers etc.
- Triggers some tamper response
  - Deleting keys
  - Raising alarms
  - Explosions?
- Widely used in HSMs, payment terminals, ATMs, nuclear weapons

The History of Tamper-Sensing Meshes

- **1870**: First patents using literal wire meshes to protect bank vaults [1, 2]
- **1902**: Multi-layer, orthogonal meshes documented [3]
- **1971**: Printed circuit technology adopted [4]
- **1990s**: Widespread commercial adoption with cryptographic applications

Other, hard to date examples: NSA use for protecting ciphering machines [5, 6], US use in nuclear weapons [7]

Commercial Applications Today

- Datacenter HSMs (Key management, payment processing)
- Card Payment Terminals (PIN encryption)
- ATM Encrypting Pin Pads (PIN encryption)
- Key Safes for Emergency services access (Germany only?)
- Mail Franking Machines (credit counter)
- Slot Machines (likely for DRM)

Our Survey

Sample Size: 30 devices
Device Types:

- 23 Card payment terminals (Verifone, Ingenico, SumUp, etc.)
- 3 ATM Encrypting Pin Pads (NCR, Sagem)
- 2 HSM modules (SafeNet, Utimaco)
- 1 Franking machine
- 1 German slot machine CPU

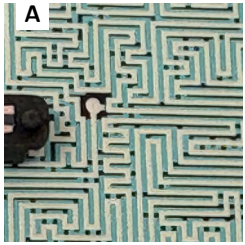
Mesh Materials and Structure Sizes Observed

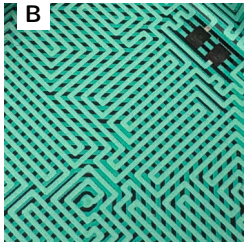
- **Rigid PCB (FR-4):** Photolithographic etching, 100 µm to 200 µm
- **Polyimide/Copper FPC:** Photolithographic etching, 100 µm to 200 µm
- **Silver ink FPC:** Screen printing, 500 µm to 3000 µm
- **Carbon ink FPC:** Screen printing, 500 µm to 3000 µm
- **Gold laser direct structuring:** Laser Direct Structuring, 50 µm to 200 µm
- **IBM/Gore mesh:** Printed, 200 µm to 1500 µm

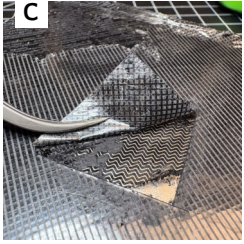
Survey Specimens - External Photos

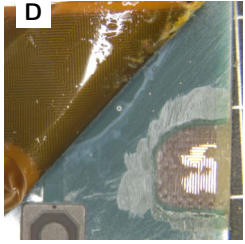
Survey Specimens - Internal Photos

Mesh Trace Layouts



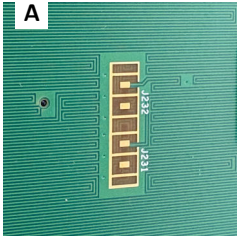


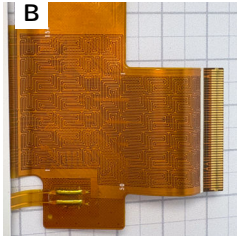


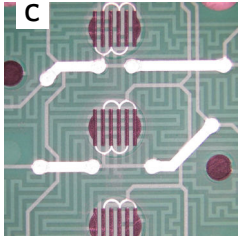


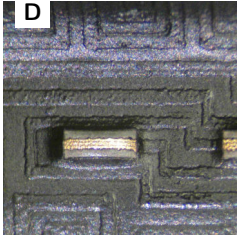
A: Offset layers (H12)
B: Orthogonal patterns (H14)
C: Orthogonal + area pattern (H30)
D: Spaced layers (H28)

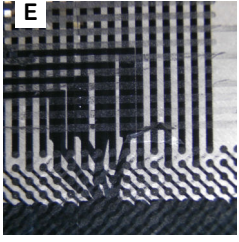
Mesh Materials and Manufacturing





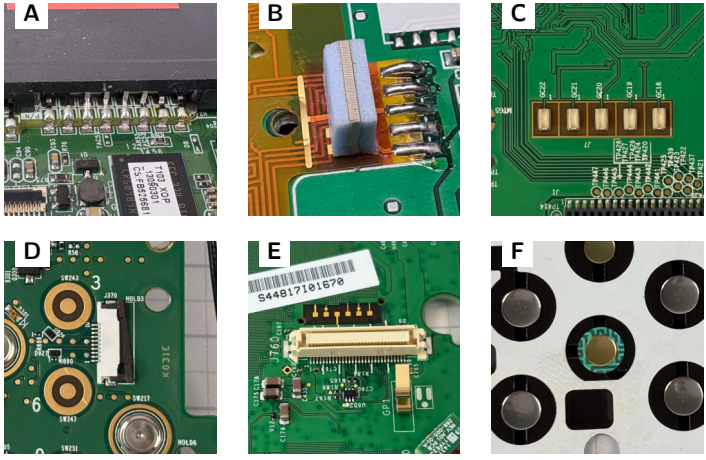






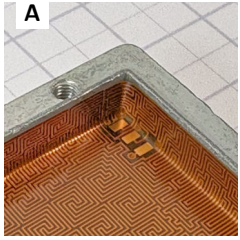
A: Rigid PCB (H10)
B: Flexible PCB (H15)
C: Silver ink (H14)
D: Laser Direct Structuring (H32)
E: Carbon ink (H30)

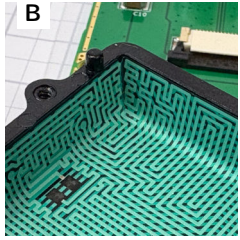
Mesh Connection Methods

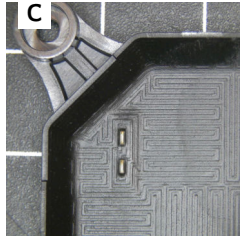


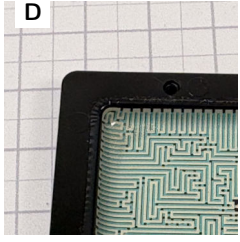
A: Direct soldering (H05) **B:** Elastomeric connector (H31) **C:** EMI gasket (H14)
D: FPC connector (H20) **E:** Stacking connector (H17) **F:** Tactile dome (H06)

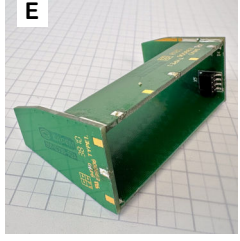
3D Mesh Construction Styles





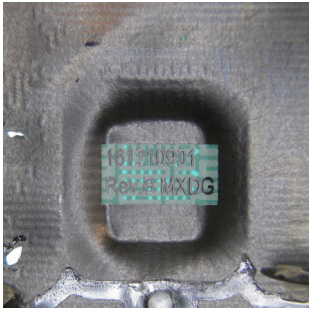




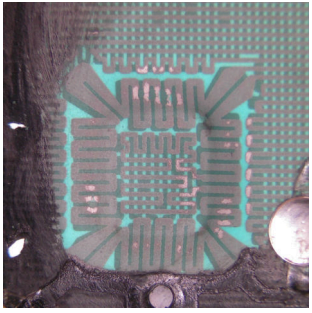


A: Folded with overlap (H03)
B: Folded without overlap (H14)
C: Laser Direct Structuring (H32)
D: Thermoformed (H12)
E: House-of-Cards (H08)

Thermoforming Example



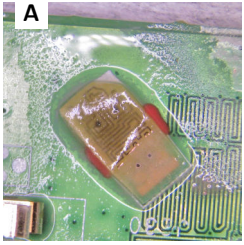
Before removing lacquer

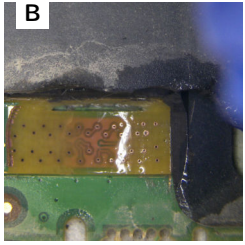


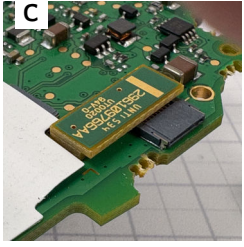
After removing lacquer

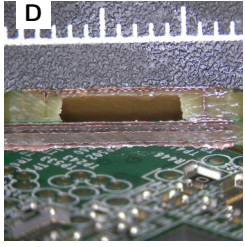
Formed cavities in printed foil mesh specimen H24

Sandwich-Style Construction









A: Obstacle mesh coupons (H17)
B: Via-fence meshes (H24)
C: Planar sandwich stack (H24)
D: PCB lid with cavity (H14)

Security Issues Observed

- Incomplete mesh coverage
- Meshes not overlapping at edges leaving gaps for probe insertion
- Gaps at mesh-PCB interfaces
- Thermoformed cavities with enlarged structure size at corners
- In one case, an opaque lacquer was easily removed with acetone (without damaging the mesh!)
- Trace patterns visible through cover layers due to surface unevenness

Design Recommendations (1/2)

- Commodity PCB manufacturing process design rules in the 100 µm to 200 µm range are better than the state of the art in mesh structure size
- Avoid ink printing processes or thermoforming because of their large structure size
- Carefully think about your literal corner cases (and edges)!
  - Overlap meshes where possible.
- Use potting and cover layers, but verify that they work
  - Check that you *actually* can't see what's below
  - Test their chemical resistance (and that of your mesh)

Design Recommendations (2/2)

- Mixing tough potting or enclosure materials and fragile mesh materials makes life harder for an attacker
  - Consider using steel instead of plastic (also helps against X-ray inspection!)
  - Use thin substrates and thin conductive layers for the mesh
  - Balance adhesion so removing potting / cover layers tears away traces below
- Overlap mesh layers at a 50% structure size offset
- Space (some) mesh layers apart in Z direction to constrain attack tools
- Use a pressure-sensitive connection method like tactile domes or elastomeric conncetors

Thank you!

Questions?

research@jaseg.de

Specimen List (1/2)

ID	Device	Manufacturer	Type	Year
H01	PED	Verifone	VX 570	ca. 2010
H02	Slot machine	Merkur / ADP	Sam 12 EC2	ca. 2012
H03	EPP	Sagem	USA1315-4240	2014
H04	EPP	Sagem	USA1316-5120	2007
H05	PED	Xac	xAPT-103	2014
H06	PED	Ingenico	iCT250-11T1860A	2016-17
H08	PED	Sagem	NOR4100-4220	2012
H09	PED	Hypercom	M4230	2010
H10	PED	Worldline	YOMANI XR	2016
H11	PED	Banksys	C-ZAM Smash	2004
H12	PED	Hypercom	Optimum P2100	2010
H13	PED	Ingenico	iCT 220-11T2938A	2016
H14	PED	Verifone	H5000	2016
H15	PED	Verifone	MX 925	2018
H16	PED	Verifone	V200c CTLS	2021
H17	PED	Verifone	VX 680	2014

Specimen List (2/2)

ID	Device	Manufacturer	Type	Year
H18	PED	Ingenico	i7910	2010
H19	PED	Banksys	XENTA	2004-2011
H20	PED	Verifone	VX 520 3G	2017
H21	PED	Verifone	V400m Plus 4G	2018
H22	PED	Ingenico	Move 3500	2020
H23	PED	Ingenico	iPP 350-11T1718A	2015
H24	PED	Ingenico	iWL255-01T2117A	2016
H25	Franking Mach.	Neopost	IJ-25	ca. 2001
H27	PED	Sumup	AIR1E205	2021
H28	EPP	NCR	5814 UEPP	2019
H29	HSM	SafeNet	VBD-05	2018
H30	HSM	Irdeto	Mayflower	2011
H31	PED	SumUp	SumUp 3G	2019
H32	PED	SumUp	SumUp Air	2022

PED: Pin Entry Device; EPP: Encrypting Pin Pad; HSM: Hardware Security Module

References I

[1] "Improvement in Protecting Safes and Vaults from Burglars". U.S. pat. 106324A. Aug. 16, 1870. URL: https://patents.google.com/patent/US106324A/en?q=(G08B13%2f126)&oq=(G08B13%2f126)&sort=old (visited on 09/10/2025).

[2] "Improvement in Electro-Magnetic Envelopes for Safes, Vaults". U.S. pat. 110362A. Dec. 20, 1870. URL: https://patents.google.com/patent/US110362A/en?q=(G08B13%2f126)&oq=(G08B13%2f126)&sort=old (visited on 09/10/2025).

[3] Henry M. Sutton, Walter L. Steele, and Michael Coerver. "Electrically-Protected Structure". U.S. pat. 708093A. Individual. Sept. 2, 1902. URL: https://patents.google.com/patent/US708093A/en?oq=US708093 (visited on 09/10/2025).

References II

[4] Conrad S. Ham and Elwood R. Horwinski. "Printed-Circuit Type Security Apparatus for Protecting Areas". U.S. pat. 3594770A. Lewis Engineering Co. July 20, 1971. URL: https://patents.google.com/patent/US3594770A/en?q=(H01L23%2f576)&oq=(H01L23%2f576)&sort=old&page=2 (visited on 09/10/2025).

[5] David G. Boak. *A History of U.S. Communications Security (The David G. Boak Lectures), Volume I*. (US) National Security Agency, 1973. URL: http://archive.org/details/history_comsec-nsa (visited on 02/18/2025).

[6] David G. Boak. *A History of U.S. Communications Security (The David G. Boak Lectures), Volume II*. (US) National Security Agency, 1981. URL: http://archive.org/details/history_comsec_ii-nsa (visited on 02/18/2025).

[7] Ashton Carter et al., eds. *Managing Nuclear Operations*. Washington, D.C: Brookings Institution, 1987. 751 pp. ISBN: 978-0-8157-1313-5 978-0-8157-1314-2.