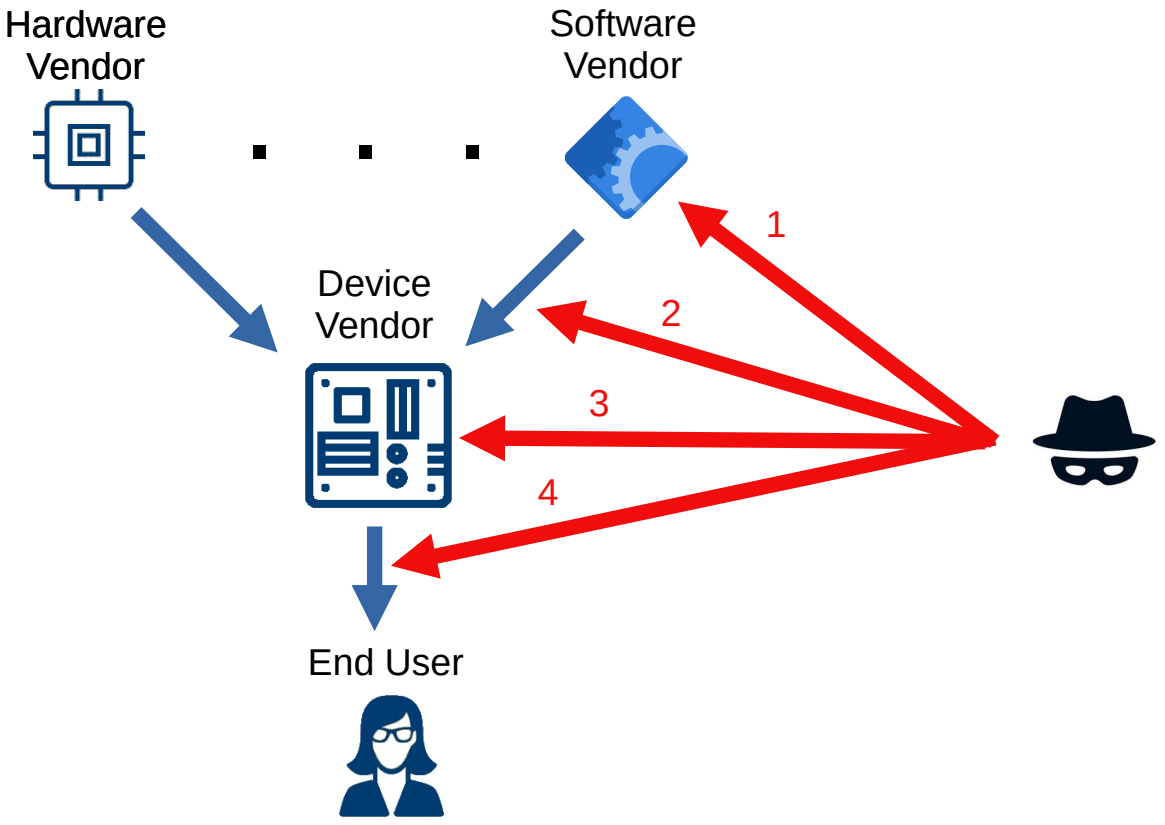
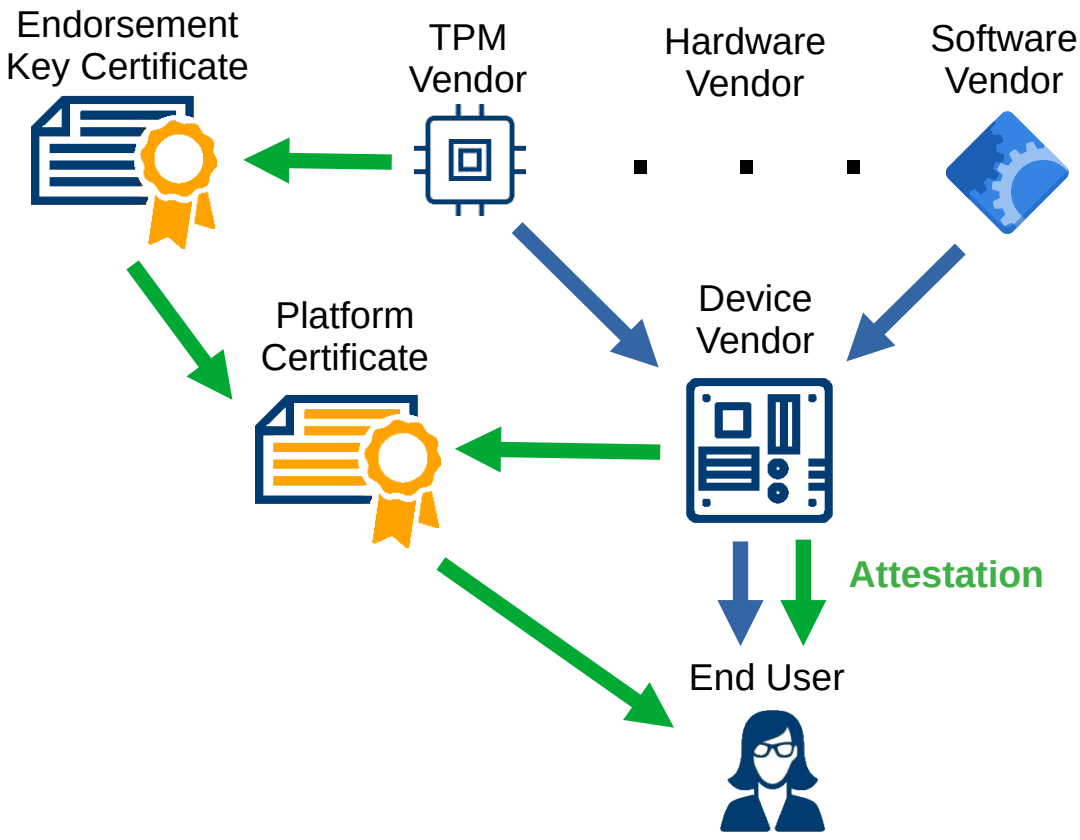
A Trusted Business Card: Demonstrating Supply Chain Defenses

How do you know that your new device is authentic and untampered?

Supply Chain Attacks



Supply Chain Defense with TPM



The end user can verify:

- Authenticity of TPM
- Authenticity of device
- Authenticity of firmware

Demonstration

```
Verification Report for Trusted Business Card at /run/media/dave/0021-1F61/ESP/
Verifying Endorsement Key Certificate from Infineon
    EK.CRT verification: /run/media/dave/0021-1F61/ESP/EK.CRT: OK
Verifying that the Card's EK.DER matches the EK certificate
    EK created on card matches EK from Infineon Certificate
Verifying platform cert against EK and CA certs
    Attribute certificate is valid.
Verifying Attestation Key Certificate from Dave
    AK.CRT verification: /run/media/dave/0021-1F61/ESP/AK.CRT: OK
Verifying that the Card's AK.DER matches the AK certificate
    AK created on card matches AK from AK Certificate
Verifying vendor signature binding AK and EK:
    Verified OK
Verifying TPM_QUOTE
    Decrypting quote with AK
    Quoted data matches pcr10 data
    Hash of quoted data matches decrypted signature
Verifying RIM Signatures
    Verifying rim for CARD.JPG - Signature Verified Successfully
    Verifying rim for SAFFORD.PDF - Signature Verified Successfully
Verifying event log:
    PCR 10 SHA256: 3F8D95BFE924C9A5033C1B3D840A2B32365DB0481ACC8E8C4A7ECF5B3590450B  MATCHES
Verifying that current challenge file was used.
    Correct challenge file was used.
Writing a new random challenge. Reset the card for it to be measured.
Verifying flash image - press boot-reset on the card
    press enter when ready
    Reading flash. This should take about one minute...
    Files fw/flash.img and out.bin are identical
```

Detail Slides

Why a Trusted Business Card?

- To celebrate TCG's 25th
- To demonstrate full supply chain protection on an inexpensive IoT device
  - Supply chain of embedded electronics is now critical
  - It's the cheapest, smallest, simplest, easiest supply chain demonstration for TCG.
- It's an Arduino development board
  - Learn how to write arduino sketches
- It's an esp32 development board
  - Learn esp-idf command line build and flash tools
- It's a TPM development board
  - Prototype new and interesting TPM applications

Supply Chain Attacks

- **1**: Attacking the upstream hardware and software supply vendors
  - Solarwinds
  - Xzutils
  - Supermicro
- **2**: Attacking the transportation/shipping from suppliers to device vendor
- **3**: Attacking the device vendor
  - Hamas pagers (counterfeit vendor)
  - Counterfeit devices
- **4**: Attacking the transportation/shipping from device vendor to user
  - Targeted firmware insertion during shipping

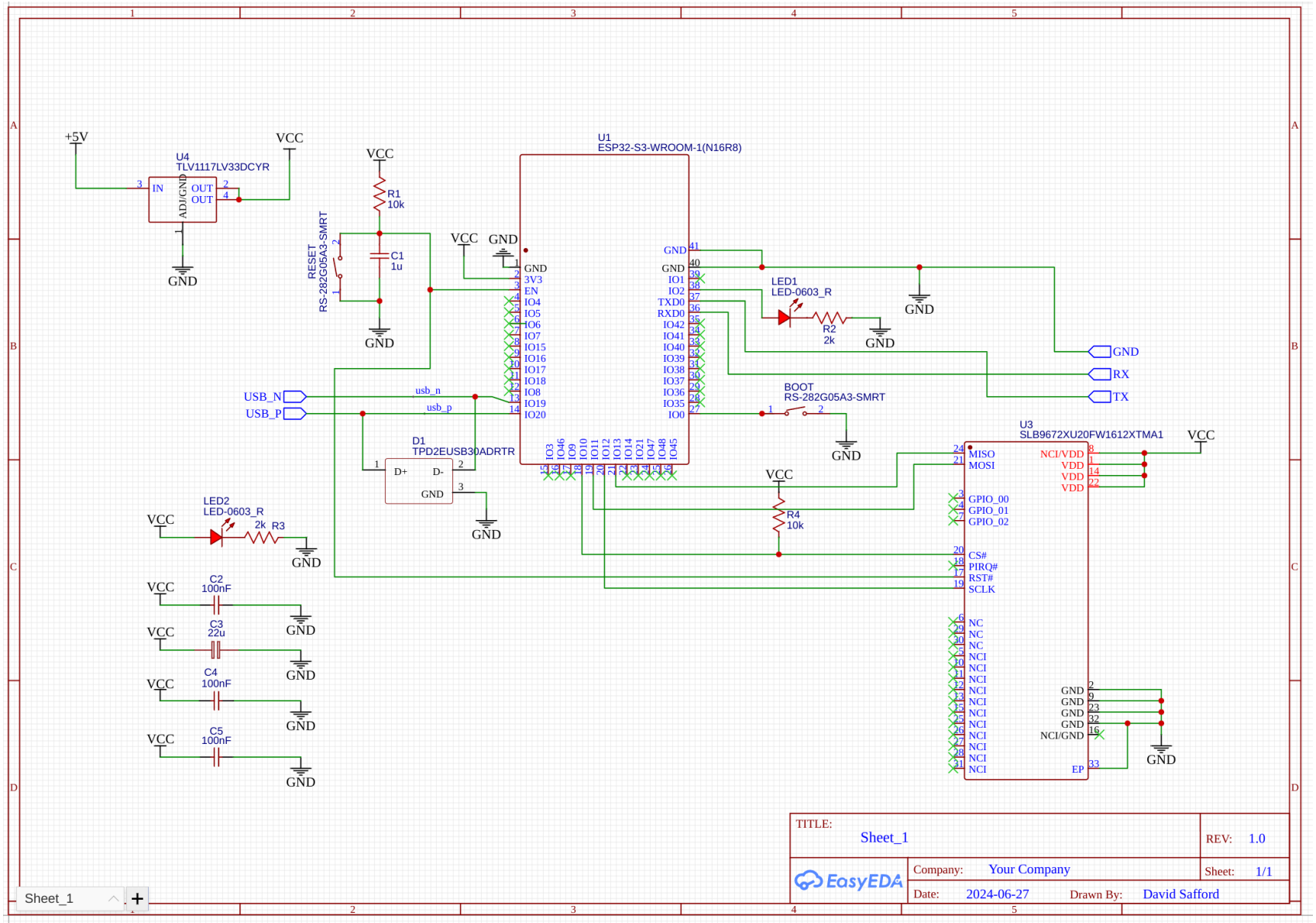
TBC – A simple example

- Hardware
  - ESP32-S3
    - 32bit dual core
    - 16mb flash
    - 8mb PSRAM
    - efuse based secure boot*
  - Infineon TPM
- Firmware
  - Application
  - WolfTPM/WolfSSL
  - WolfTPM HAL
  - tinyusb
  - FreeRTOS
  - esp-idf bsp
- Software
  - certify/verify scripts
  - Openssl
  - Paccor
  - certgen/cel_verify C

100% Open Hardware and Open Source
*not activated on demo cards, so you can play

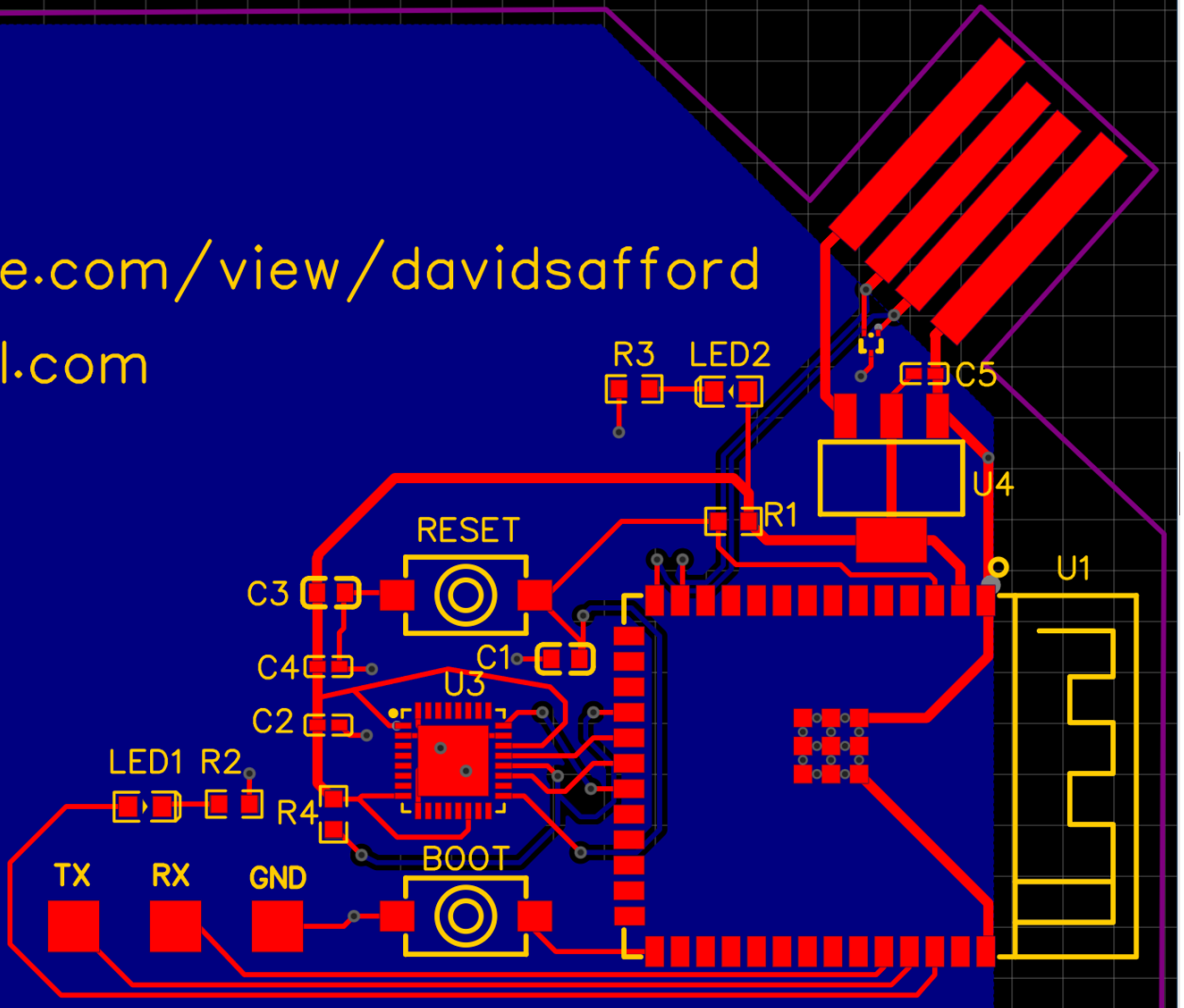
Application Functionality

- USB-MSC: VFAT thumb drive to serve resume, certs and log
- USB-ACM: Firmware loading and debug over serial
- Full Supply chain attestation
  - Endorsement Key Cert
  - Platform Cert
  - Attestation Key Cert
- WolfTPM provides full TPM stack on the card,
- Measured boot and runtime
- CEL-IMA-TLV attestation with signatures in RIM


+5V
VCC
U4
TLV1117LV33DCYR
IN
OUT
OUT
ADJ/GND
GND
R1
10k
C1
1u
RESET
RS-282G05A3-SMRT
U1
ESP32-S3-WROOM-1(N16R8)
GND
3V3
EN
IO4
IO5
IO6
IO7
IO15
IO16
IO17
IO18
IO8
IO19
IO20
IO3
IO46
IO9
IO10
IO11
IO12
IO13
IO14
IO21
IO47
IO48
IO45
GND
IO1
IO2
TXD0
RXD0
IO42
IO41
IO40
IO39
IO38
IO37
IO36
IO35
IO0
LED1
LED-0603_R
R2
2k
BOOT
RS-282G05A3-SMRT
USB_N
USB_P
usb_n
usb_p
D1
TPD2EUSB30ADRTR
D+
D-
GND
LED2
LED-0603_R
2k
R3
C2
100nF
C3
22u
C4
100nF
C5
100nF
R4
10k
U3
SLB9672XU20FW1612XTMA1
MISO
MOSI
GPIO_00
GPIO_01
GPIO_02
CS#
PIRQ#
RST#
SCLK
NC
NCI
NCI/VDD
VDD
GND
NCI/GND
EP
RX
TX
TITLE:
Sheet_1
REV:
1.0
Company:
Your Company
Sheet:
1/1
Date:
2024-06-27
Drawn By:
David Safford
EasyEDA
Sheet_1

David Safford
https://sites.google.com/view/davidsafford
david.safford@gmail.com

TCG 25



BOM Cost (qty 1)

- PCB (jclpcb.com) $3
- Esp32 $4
- TPM $5
- Everything else $3

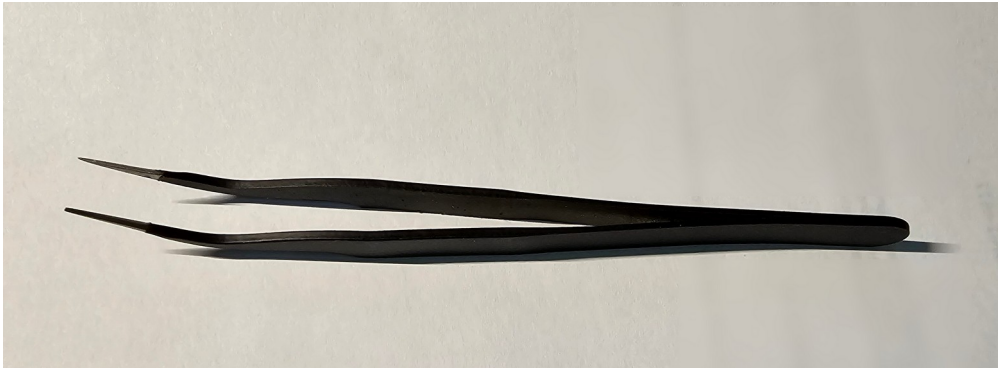
$15 Total

Detailed BOM (Digikey)

Schematic ID	Manufacturer ID	Digikey ID	Description
U1	ESP32-S3-WROOM-1-N16R8	1965-ESP32-S3-WROOM-1-N16R8CT-ND	ESP32S3
U2	SLB9672AU20FW1613XTMA1	448-SLB9672AU20FW1613XTMA1CT-ND	TPM
D1	TPD2EUSB30ADRTR	296-28153-1-ND	ESD Diode Pair
U4	TLV1117LV33DCYR	296-28778-1-ND	3.3V regulator
Led1, Led2	QTLP601CRTR	1080-1407-1-ND	Led, red
Boot, Reset	RS-282G05A3-SMRT	CKN10384CT-ND	Switch, tactile
R1, R4	RMCF0603JT10K0	RMCF0603JT10K0CT-ND	RES 10K
R2, R3	ERJ-3EKF2001V	P2.00KHCT-ND	RES 2K
C1	CL05A105KP5NNNC	1276-1076-1-ND	CAP CER 1UF 10V
C2, C4, C5	CL05B104KA5NNNC	1276-6720-1-ND	CAP CER 0.1UF 25V
C3	CL10A226MQ8NRNC	1276-1193-1-ND	CAP CER 22UF 6.3V

The High Cost of Assembly

- Precision Placement Device ($2)



- Reflow Station ($49)

Warning

- I used leaded solder paste for assembly.
- Try not to lick the front of the card.

Learn Arduino Programming

Espressif build tools

- `idf.py set-target esp32s3`
- `idf.py menuconfig`
- `idf.py build`
- `idf.py -p /dev/ttyACM0 flash monitor`

Espressif ROM mode tools

- `Esptool` `read/write flash`
- `Espefuse` `read/write efuse`
- `Espsecure` `sign/verify bootloader/app images`

- These are enabled with hardware (boot button) and are independent from any firmware in flash

ESP32 Secure boot

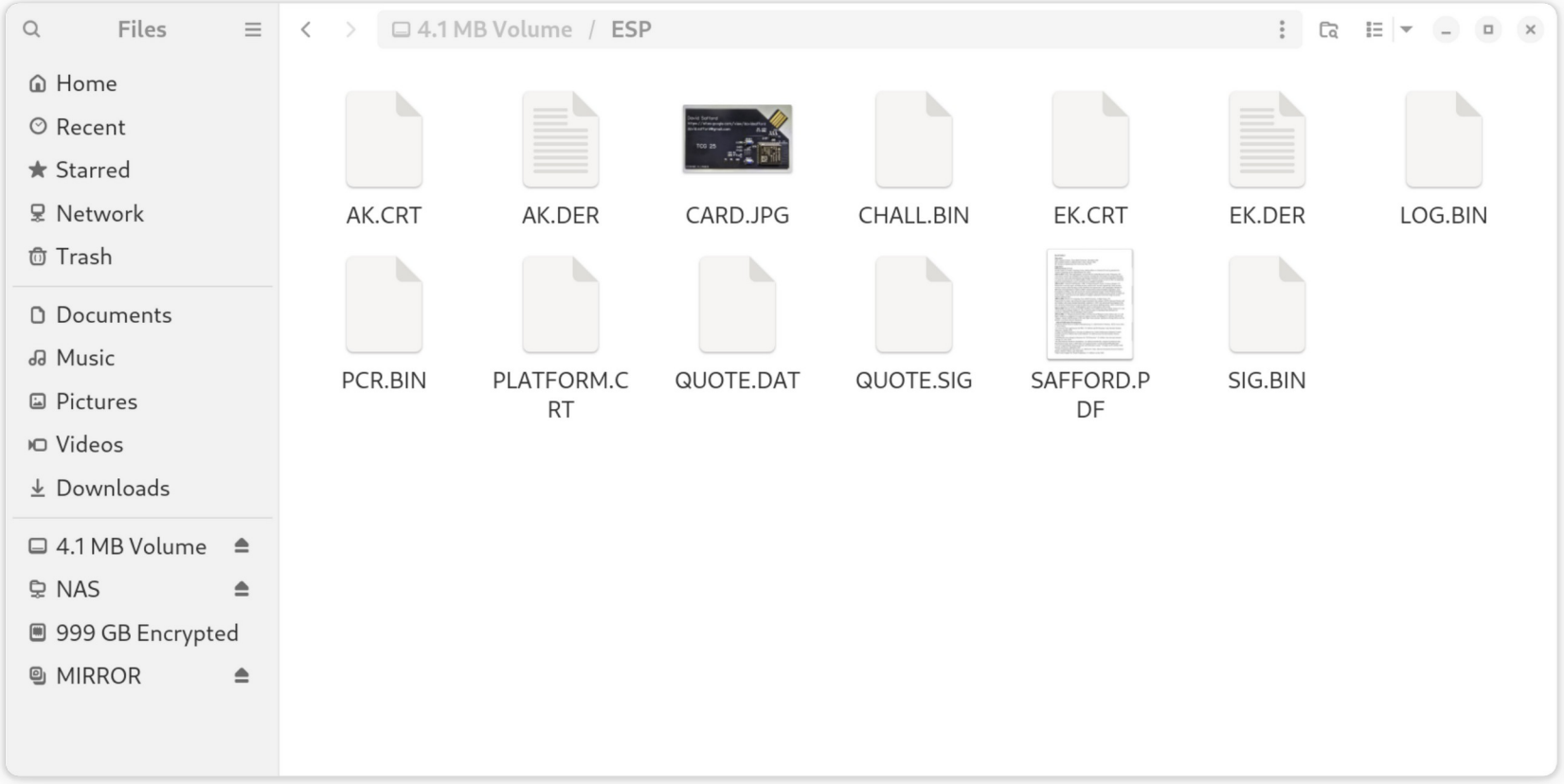
- The good news:
  - Fully supported and documented in esp-idf
  - Based on efuse in chip, so serves as hardware RoT
- The bad news:
  - Once SB is enabled, you can no longer read flash or efuse through ROM tools.
  - This makes supply chain verification difficult.
  - You can tell secure boot is enabled, but not who signed it.
- Workaround:
  - Ship with SB disabled, so end user can provably enable SB.

Keys and Certificates

- Infineon OPTIGA(TM) RSA Root CA 2 (Root for EK.CRT)
- Infineon OPTIGA(TM) TPM 2.0 RSA CA 065 (intermediate for EK.CRT)
- safford_ca.com.pem (Self-signed root for AK.CRT and PLATFORM.CRT)
- EK.DER, EK.CRT (signed by Infineon)
- AK.DER, AK.CRT – issued based on verification of EK, signed by Dave
- PLATFORM.CRT binds EK to Platform description, signed by Dave

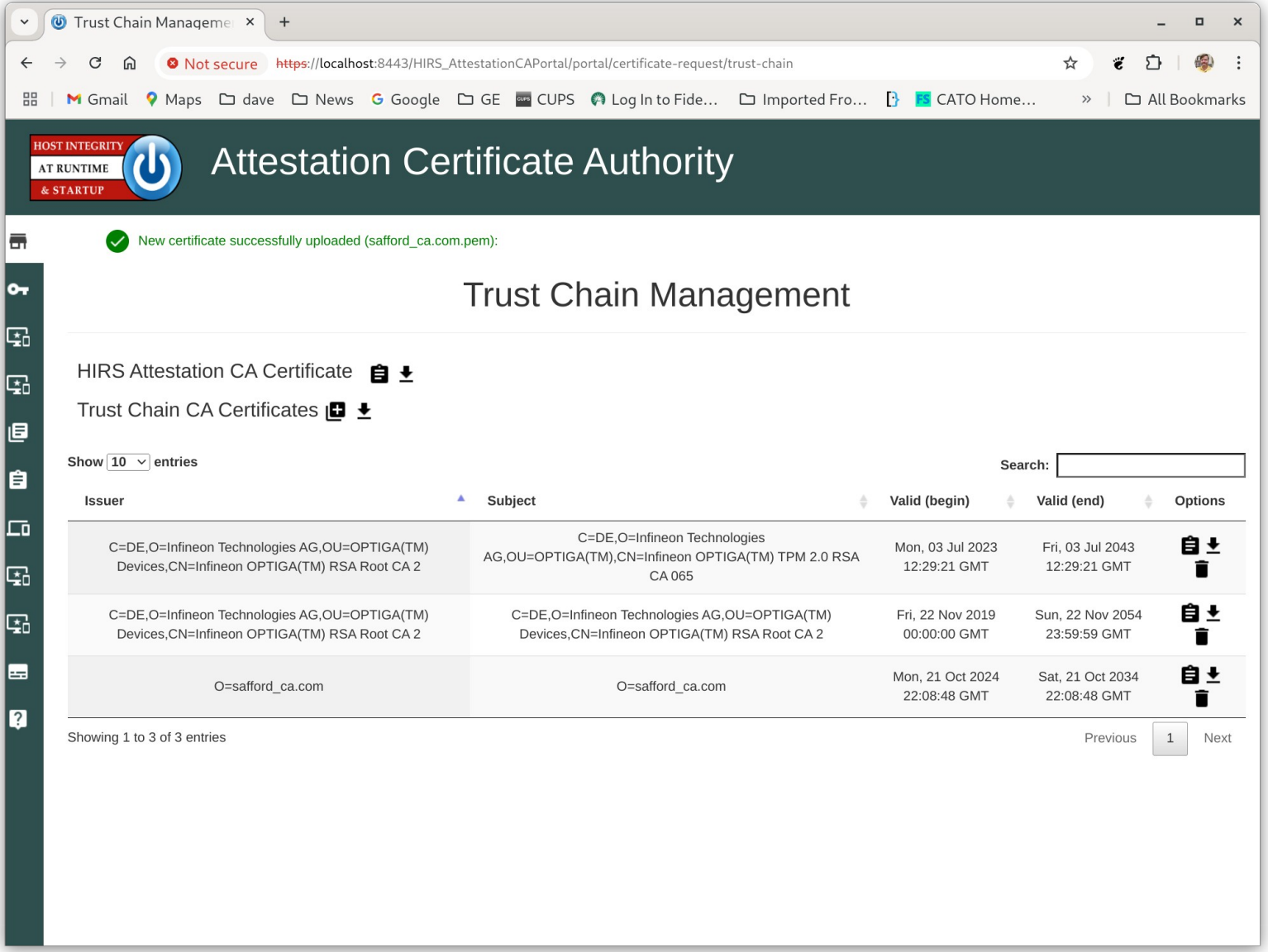
- Verifying a Quote with AK proves:
  - Talking to Infineon certified TPM
  - Platform characteristics, including EK and AK certified by Dave

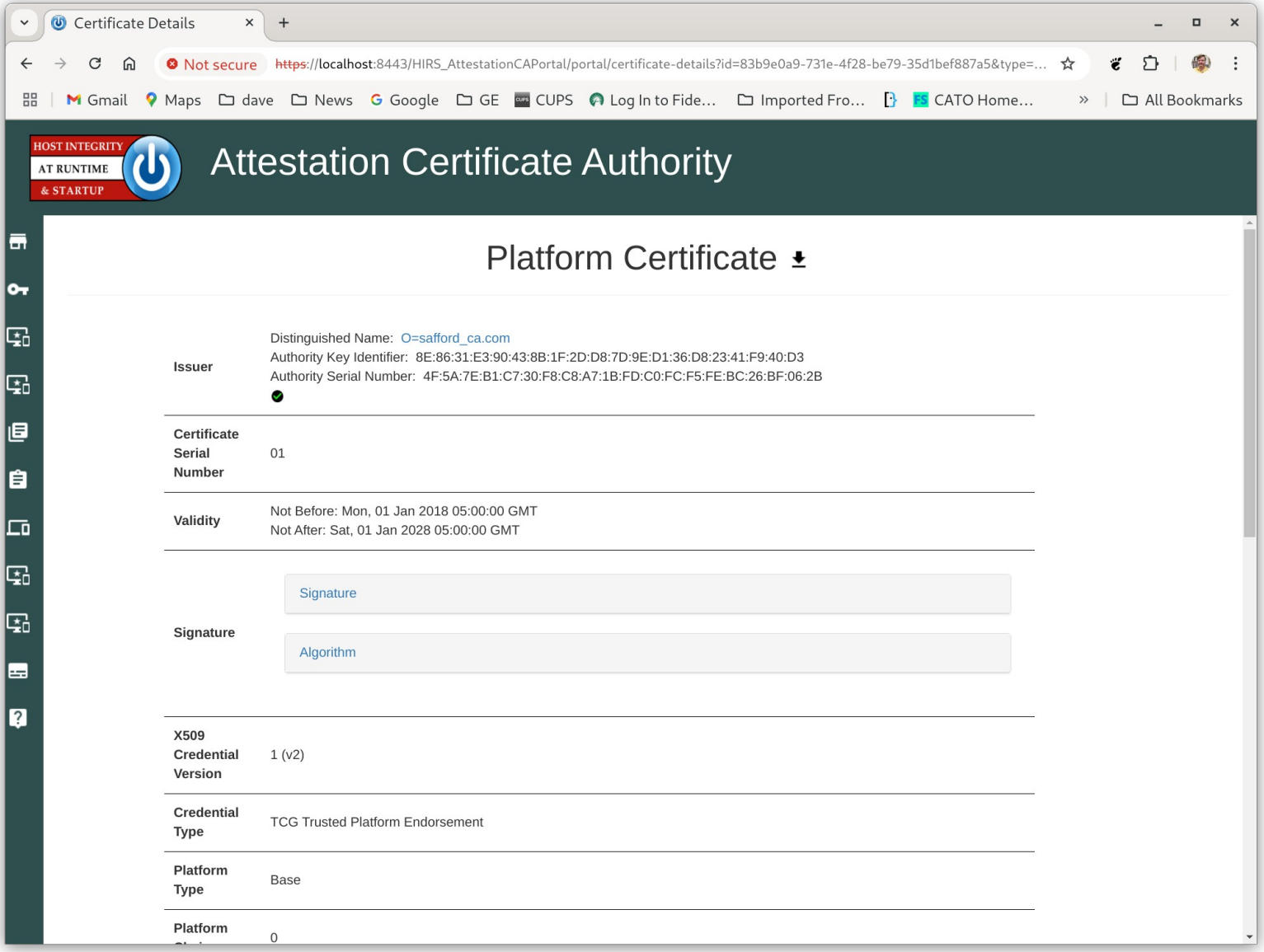
TBC appears as a flash drive



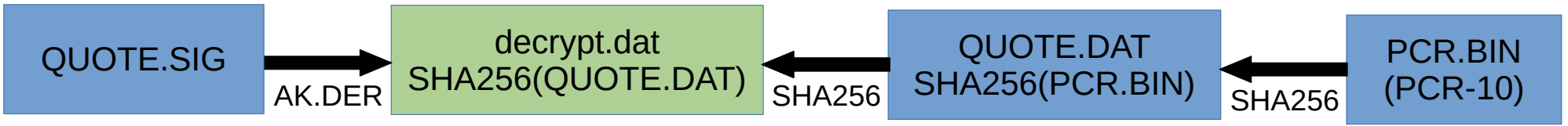
Files on the card

- EK.DER - Endorsement Key (public)
- EK.CRT - Endorsement Key Certificate, signed by Infineon
- PLATFORM.CRT - Platform Certificate, signed by Safford, binds EK.CRT to platform
- AK.DER - Attestation Key (public)
- AK.CRT - Attestation Key Certificate, signed by Safford
- SIG.BIN - Signature by Safford, binding AK.DER to EK.DER
- CHALL.BIN - Challenge from verifier that will be included in Quote
- PCR.BIN - PCR values, anchoring Event Log
- QUOTE.DAT - Data actually Quoted by TPM
- QUOTE.SIG - Output of TPM Quote
- LOG.BIN - Event Log
- CARD.JPG - Image of card
- SAFFORD.PDF - Resumé


Trust Chain Manageme
Not secure
https://localhost:8443/HIRS_AttestationCAPortal/portal/certificate-request/trust-chain
Gmail
Maps
dave
News
Google
GE
CUPS
Log In to Fide...
Imported Fro...
CATO Home...
All Bookmarks
HOST INTEGRITY
AT RUNTIME
& STARTUP
Attestation Certificate Authority
New certificate successfully uploaded (safford_ca.com.pem):
Trust Chain Management
HIRS Attestation CA Certificate
Trust Chain CA Certificates
Show 10 entries
Search:
Issuer
Subject
Valid (begin)
Valid (end)
Options
C=DE,O=Infineon Technologies AG,OU=OPTIGA(TM) Devices,CN=Infineon OPTIGA(TM) RSA Root CA 2
C=DE,O=Infineon Technologies AG,OU=OPTIGA(TM),CN=Infineon OPTIGA(TM) TPM 2.0 RSA CA 065
Mon, 03 Jul 2023 12:29:21 GMT
Fri, 03 Jul 2043 12:29:21 GMT
C=DE,O=Infineon Technologies AG,OU=OPTIGA(TM) Devices,CN=Infineon OPTIGA(TM) RSA Root CA 2
C=DE,O=Infineon Technologies AG,OU=OPTIGA(TM) Devices,CN=Infineon OPTIGA(TM) RSA Root CA 2
Fri, 22 Nov 2019 00:00:00 GMT
Sun, 22 Nov 2054 23:59:59 GMT
O=safford_ca.com
O=safford_ca.com
Mon, 21 Oct 2024 22:08:48 GMT
Sat, 21 Oct 2034 22:08:48 GMT
Showing 1 to 3 of 3 entries
Previous
1
Next


Certificate Details
Not secure
https://localhost:8443/HIRS_AttestationCAPortal/portal/certificate-details?id=83b9e0a9-731e-4f28-be79-35d1bef887a5&type=...
Gmail
Maps
dave
News
Google
GE
CUPS
Log In to Fide...
Imported Fro...
CATO Home...
All Bookmarks
HOST INTEGRITY
AT RUNTIME
& STARTUP
Attestation Certificate Authority
Platform Certificate
Issuer
Distinguished Name: O=safford_ca.com
Authority Key Identifier: 8E:86:31:E3:90:43:8B:1F:2D:D8:7D:9E:D1:36:D8:23:41:F9:40:D3
Authority Serial Number: 4F:5A:7E:B1:C7:30:F8:C8:A7:1B:FD:C0:FC:F5:FE:BC:26:BF:06:2B
Certificate Serial Number
01
Validity
Not Before: Mon, 01 Jan 2018 05:00:00 GMT
Not After: Sat, 01 Jan 2028 05:00:00 GMT
Signature
Signature
Algorithm
X509 Credential Version
1 (v2)
Credential Type
TCG Trusted Platform Endorsement
Platform Type
Base
Platform
0

Verifying the TPM_Quote



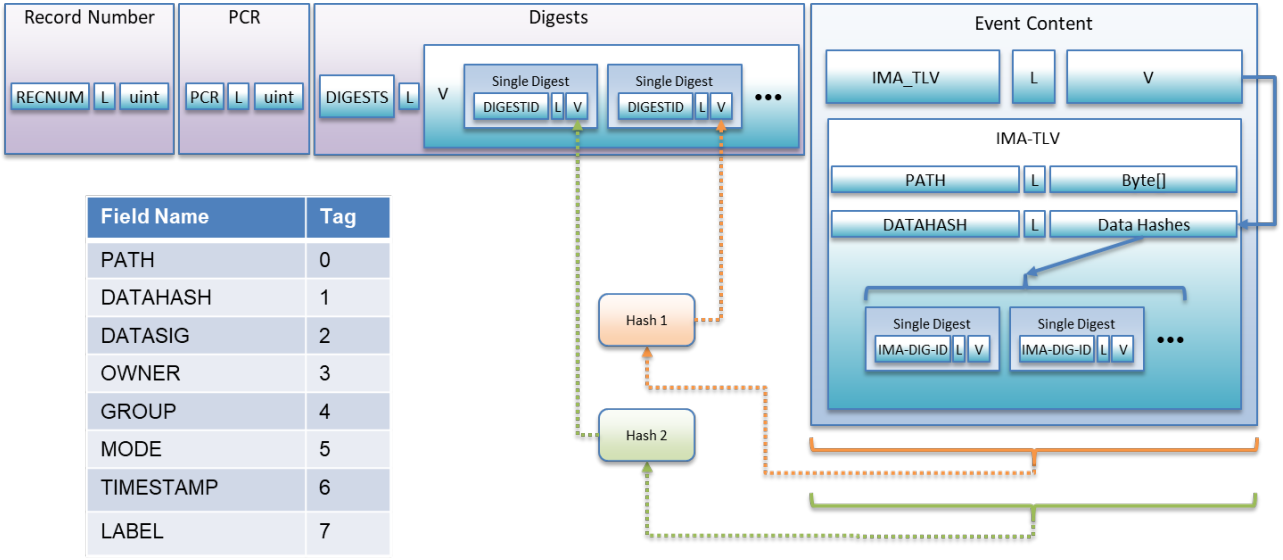
Normally we could do this entire check with tpm2_checkquote utility, but it cannot handle the raw data blobs from WolfTPM, so we have to do these checks manually with openssl.

Example Quote Verification

```
Decrypting QUOTE.SIG with AK

Decrypted data:
00000000  30 31 30 0d 06 09 60 86  48 01 65 03 04 02 01 05  |010...`.H.e.....|
00000010  00 04 20 ea ca a1 c3 4b  d9 9c b3 63 af 60 5f db  |.. ....K...c.`_.|
00000020  2b 0b 99 65 e0 93 2e 55  92 28 70 4f fd 16 e8 57  |+..e...U.(pO...W|
00000030  f1 a0 66                                          |..f|

sha256 of QUOTE.DAT
00000000  ea ca a1 c3 4b d9 9c b3  63 af 60 5f db 2b 0b 99  |....K...c.`_.+..|
00000010  65 e0 93 2e 55 92 28 70  4f fd 16 e8 57 f1 a0 66  |e...U.(pO...W..f|

QUOTE.DAT
00000000  ff 54 43 47 80 18 00 22  00 0b e1 27 0c 17 cb b3  |.TCG..."...'....|
00000010  2f 04 60 27 27 5e 1c 07  be 9b 44 6e 80 76 e4 7d  |/.`''^....Dn.v.}|
00000020  27 32 64 f7 02 a3 59 d9  28 0b 00 00 00 00 00 00  |'2d...Y.(.......|
00000030  17 67 73 9e 27 9f e7 c0  94 6e df a3 01 ad bb dd  |.gs.'....n......|
00000040  1c 87 f7 a5 06 00 00 00  01 00 0b 03 00 04 00 00  |................|
00000050  20 32 d4 a6 27 37 ff 00  e2 90 01 06 26 8f 90 40  | 2..'7......&..@|
00000060  df dc 45 6e 5e 01 85 d3  87 2f 3f 0b 4b 4b e6 bf  |..En^..../?.KK..|
00000070  89                                                |.|

hashed PCR.BIN
00000000  32 d4 a6 27 37 ff 00 e2  90 01 06 26 8f 90 40 df  |2..'7......&..@.|
00000010  dc 45 6e 5e 01 85 d3 87  2f 3f 0b 4b 4b e6 bf 89  |.En^..../?.KK...|

PCR.BIN
00000000  a4 84 07 20 57 9f a9 c1  71 ac b2 26 f8 39 82 db  |... W...q..&.9..|
00000010  9d 9f c1 0f 67 32 ad 08  f6 86 08 4b 33 81 c2 01  |....g2.....K3...|
```

CEL_IMA_TLV

- An example of how to do measurement safely
  - Entire content field, including types and lengths are measured



Field Name	Tag
PATH	0
DATAHASH	1
DATASIG	2
OWNER	3
GROUP	4
MODE	5
TIMESTAMP	6
LABEL	7

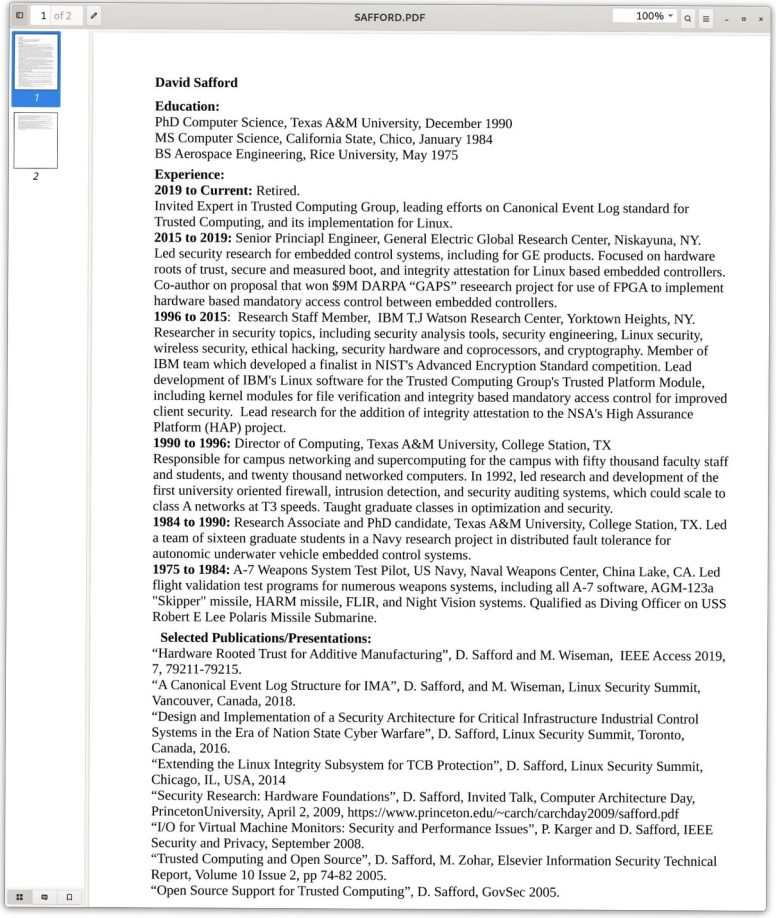
Example Card Verification

```
Verification Report for Trusted Business Card at /run/media/dave/0021-1F61/ESP/
Verifying Endorsement Key Certificate from Infineon
    EK.CRT verification: /run/media/dave/0021-1F61/ESP/EK.CRT: OK
Verifying that the Card's EK.DER matches the EK certificate
    EK created on card matches EK from Infineon Certificate
Verifying platform cert against EK and CA certs
    Attribute certificate is valid.
Verifying Attestation Key Certificate from Dave
    AK.CRT verification: /run/media/dave/0021-1F61/ESP/AK.CRT: OK
Verifying that the Card's AK.DER matches the AK certificate
    AK created on card matches AK from AK Certificate
Verifying vendor signature binding AK and EK:
    Verified OK
Verifying TPM_QUOTE
    Decrypting quote with AK
    Quoted data matches pcr10 data
    Hash of quoted data matches decrypted signature
Verifying RIM Signatures
    Verifying rim for CARD.JPG - Signature Verified Successfully
    Verifying rim for SAFFORD.PDF - Signature Verified Successfully
Verifying event log:
    PCR 10 SHA256: 3F8D95BFE924C9A5033C1B3D840A2B32365DB0481ACC8E8C4A7ECF5B3590450B  MATCHES
Verifying that current challenge file was used.
    Correct challenge file was used.
Writing a new random challenge. Reset the card for it to be measured.
Verifying flash image - press boot-reset on the card
    press enter when ready
    Reading flash. This should take about one minute...
    Files fw/flash.img and out.bin are identical
```

Example Attestation Verification

```
Verifying Measurement log from Quote

PCR 10 SHA256: A4840720579FA9C171ACB226F83982DB9D9FC10F6732AD08F686084B3381C201
MATCHES

SEQ 0 PCR 10 CEL_CONTENT_IMA_TLV
    Filename /data/esp/safford.pdf
    Filehash: D0471A5C5E9F00A0A2E761924C6AFF6EB966E8A468822E9016D0DED8751E18F2
    Entire Content TLV Verified by digest
    File Hash Verified by signed RIM

SEQ 1 PCR 10 CEL_CONTENT_IMA_TLV
    Filename /data/esp/card.jpg
    Filehash: 8D5C6DB2635740A84188CDE92D8A8CD56E5F16175F8992C59033B6FBB998AF66
    Entire Content TLV Verified by digest
    File Hash Verified by signed RIM

SEQ 2 PCR 10 CEL_CONTENT_IMA_TLV
    Filename /data/esp/chall.bin
    Filehash: 063F1995CA9EF8471D7F40992E27BD075A04E04F4F6EBA270E1CDBE2FC7CAAF6
    Entire Content TLV Verified by digest
```

The validated Files



1 of 2 SAFFORD.PDF 100%

David Safford

Education:
PhD Computer Science, Texas A&M University, December 1990
MS Computer Science, California State, Chico, January 1984
BS Aerospace Engineering, Rice University, May 1975

Experience:
2019 to Current: Retired.
Invited Expert in Trusted Computing Group, leading efforts on Canonical Event Log standard for Trusted Computing, and its implementation for Linux.
2015 to 2019: Senior Principapl Engineer, General Electric Global Research Center, Niskayuna, NY. Led security research for embedded control systems, including for GE products. Focused on hardware roots of trust, secure and measured boot, and integrity attestation for Linux based embedded controllers. Co-author on proposal that won $9M DARPA "GAPS" reseearch project for use of FPGA to implement hardware based mandatory access control between embedded controllers.
1996 to 2015: Research Staff Member, IBM T.J Watson Research Center, Yorktown Heights, NY. Researcher in security topics, including security analysis tools, security engineering, Linux security, wireless security, ethical hacking, security hardware and coprocessors, and cryptography. Member of IBM team which developed a finalist in NIST's Advanced Encryption Standard competition. Lead development of IBM's Linux software for the Trusted Computing Group's Trusted Platform Module, including kernel modules for file verification and integrity based mandatory access control for improved client security. Lead research for the addition of integrity attestation to the NSA's High Assurance Platform (HAP) project.
1990 to 1996: Director of Computing, Texas A&M University, College Station, TX
Responsible for campus networking and supercomputing for the campus with fifty thousand faculty staff and students, and twenty thousand networked computers. In 1992, led research and development of the first university oriented firewall, intrusion detection, and security auditing systems, which could scale to class A networks at T3 speeds. Taught graduate classes in optimization and security.
1984 to 1990: Research Associate and PhD candidate, Texas A&M University, College Station, TX. Led a team of sixteen graduate students in a Navy research project in distributed fault tolerance for autonomic underwater vehicle embedded control systems.
1975 to 1984: A-7 Weapons System Test Pilot, US Navy, Naval Weapons Center, China Lake, CA. Led flight validation test programs for numerous weapons systems, including all A-7 software, AGM-123a "Skipper" missile, HARM missile, FLIR, and Night Vision systems. Qualified as Diving Officer on USS Robert E Lee Polaris Missile Submarine.

Selected Publications/Presentations:
"Hardware Rooted Trust for Additive Manufacturing", D. Safford and M. Wiseman, IEEE Access 2019, 7, 79211-79215.
"A Canonical Event Log Structure for IMA", D. Safford, and M. Wiseman, Linux Security Summit, Vancouver, Canada, 2018.
"Design and Implementation of a Security Architecture for Critical Infrastructure Industrial Control Systems in the Era of Nation State Cyber Warfare", D. Safford, Linux Security Summit, Toronto, Canada, 2016.
"Extending the Linux Integrity Subsystem for TCB Protection", D. Safford, Linux Security Summit, Chicago, IL, USA, 2014
"Security Research: Hardware Foundations", D. Safford, Invited Talk, Computer Architecture Day, PrincetonUniversity, April 2, 2009, https://www.princeton.edu/~carch/carchday2009/safford.pdf
"I/O for Virtual Machine Monitors: Security and Performance Issues", P. Karger and D. Safford, IEEE Security and Privacy, September 2008.
"Trusted Computing and Open Source", D. Safford, M. Zohar, Elsevier Information Security Technical Report, Volume 10 Issue 2, pp 74-82 2005.
"Open Source Support for Trusted Computing", D. Safford, GovSec 2005.

Lessons Learned

- Interesting Use Case
  - Goal is to prove authenticity of card
  - No “users” on card
    - No privacy concern
  - Don’t want to set owner auth
  - CA/vendor/Privacy CA can all be one
  - Verify AK on card with Quote
  - With Esp32, you have to verify images before enabling secure boot