TKey, an open source/open hardware security token

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MC

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Tillitis history

Tillitis history

TCR projects split in September 2022:

- Glasklar Teknik AB: System Transparency and the Sigsum transparency log. https://system-transparency.org/ https://sigsum.org/
- Tillitis: The hardware department! https://tillitis.se/

Tillitis Tkey - an open source hardware security token

Tillitis TKey

- A RISC-V computer for sensitive computations.
- Open source software and hardware (BSD2, CERN-OHL, some parts still GPLv2)
- https://github.com/tillitis
- https://dev.tillitis.se/

You can use it for

- Authentication.
- Digital signatures.
- Hardware root of trust.
- (Signed) random number generator.
- (Slow) encryption.
- A protected environment for sensitive computations.
- Other things... It's a general computer!

Advantages

- The client (computer/mobile) decides the function of the TKey.
- No need for new hardware for new functionality.
- Can write custom software.
- No risk for persistent threats.
- Secrets and private keys are not stored persistently on the device.

Advantages 2

- You can verify that the TKey comes from the vendor.
- You can make your own TKey, or just choose your own base hardware secret.

Basic TKey use with killer app: our SSH Agent

I want to login to something, typically a server (or Github, Gitlab or sign my Git commits):

- My client started the tkey-ssh-agent automatically.
- I insert the TKey into my client.
- `$ ssh some-server`
- The agent automatically loads the device app `signer`, Ed25519 signatures.
- TKey starts to blink the status LED.
- I touch the touch sensor.
- "I'm in!"
- Just like any security token.

But... It's a general computer!?

- How can we trust general applications sent from the client?
- What if we don't share anything between the apps?
- ...and guarantee software integrity?
- ...by measuring the apps,
- and creating new secrets for this combination of app and device.
- These secrets never leave the TKey.

Measured boot

- Use immutable code to measure the application, mix in a hardware secret: get a new identity!
- Inspired by TCG DICE (nee RIoT from Microsoft Research): Trusted boot for constrained environments.

Advantages of measured boot

- Software integrity is guaranteed.
- The measured identity can be used to create key material.
- Private keys are not stored on the TKey.
- Unlimited number of private keys.
- Secrets don't leak between device applications.

Different than verified boot

- **Forced** verified boot would lock TKey device apps to a specific vendor.
- Unacceptable in an open platform.

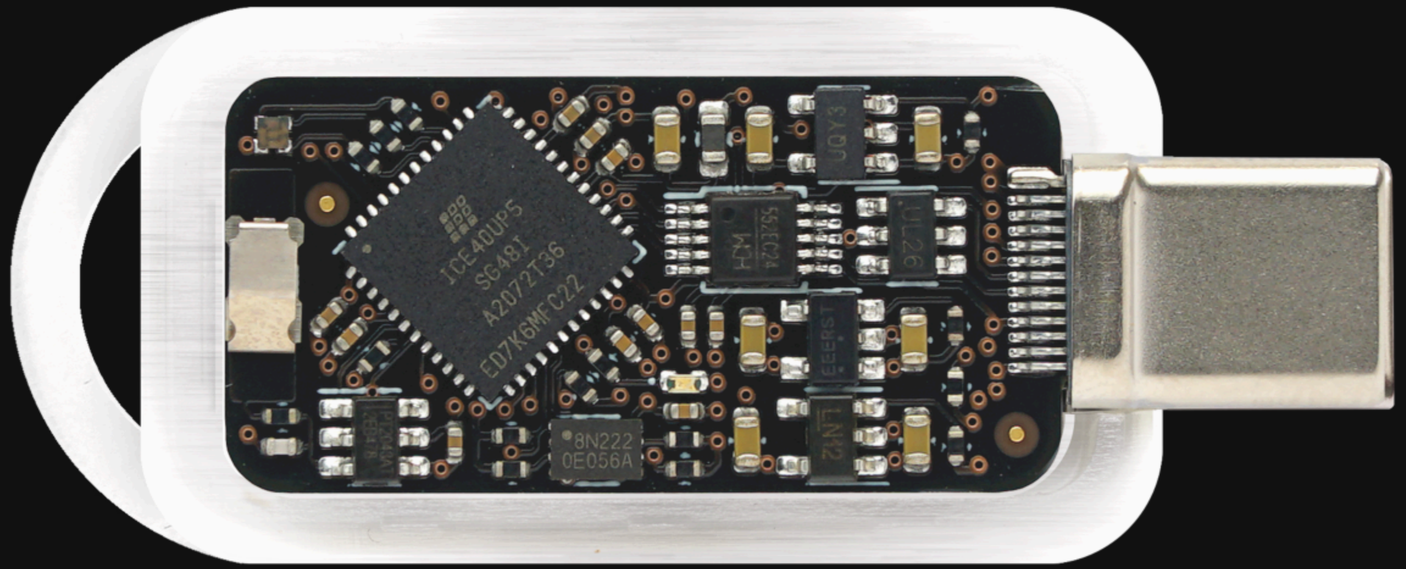
Measured boot & Compound Device Identity

```
CDI = blake2s(UDS, blake2s(application), USS)
```

CDI is a cryptograpic mix of:

- Unique Device Secret (UDS) in hardware, something the user **has**.
- Optional User Supplied Secret (USS), something the user **knows**.
- Measurement (hash digest) of TKey device application, **integrity** of the application.

Hardware



TKey Specs

- 32 bit RISC-V PicoRV32 (Claire Wolf) softcore @ 18 MHz.
- 128 kiB RAM.
- Memory mapped hardware cores.
- Firmware mode/app mode.
- No interrupts.
- No persistent storage. (1 MiB flash usable during hardware dev)
- No OS.

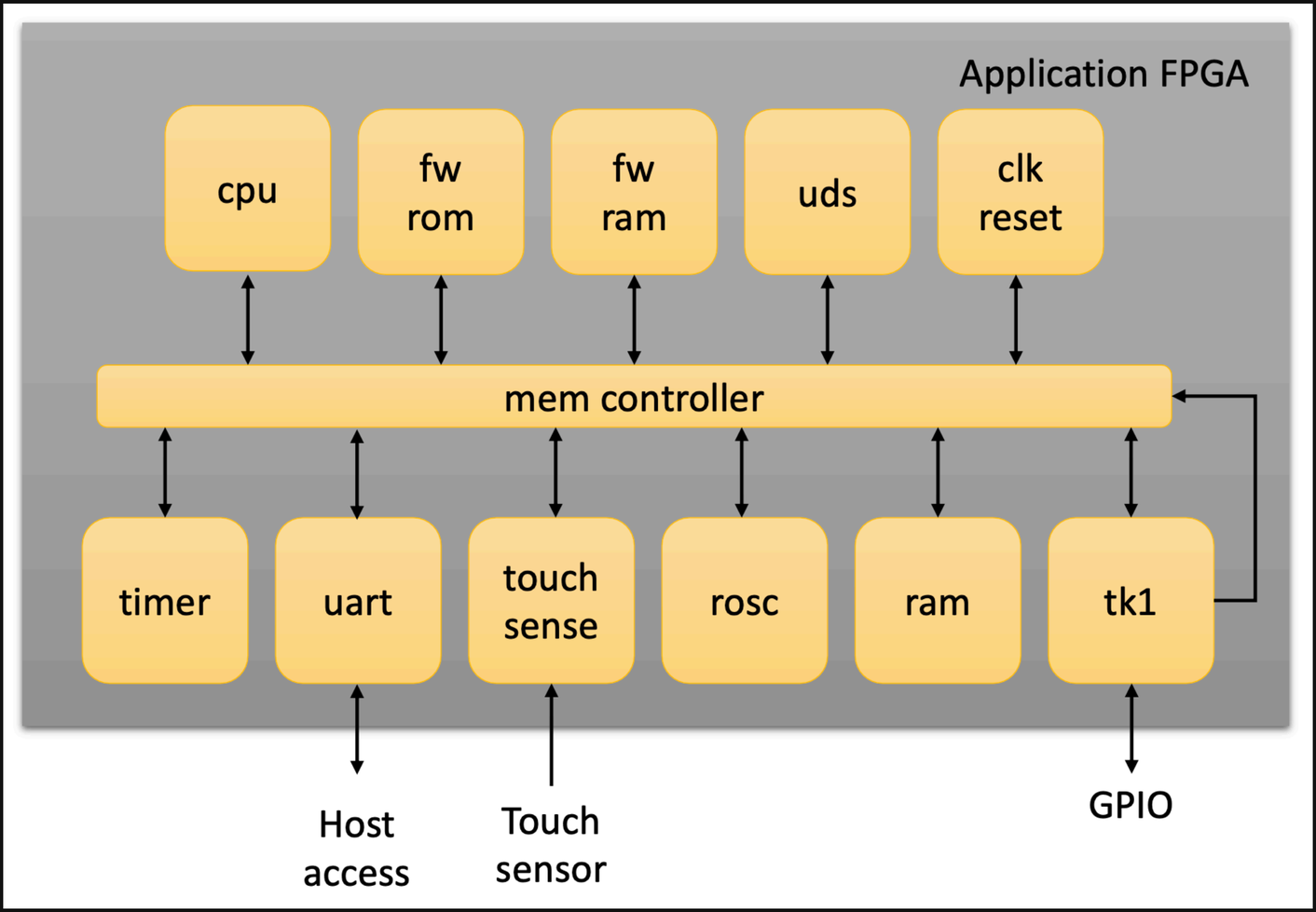
Hardware design and testing tools

- Only open source tools!
- Chip design in Verilog.
- Limits choice of FPGA chip.
- Limits choice of PCB manufacturers.
- Yosys & NextPNR for synthesis, place & route, mapping and timing.
- Icestorm tools for bitstream generation.
- Developed NVCM programming tools.
- Icarus and Verilator for module and systems simulation.
- PCB design with KiCAD.
- Everything published!

FPGA chip

- Lattice iCE40 UltraPlus UP5K FPGA.
- Good support in open source tools.
- Lockable internal configuration memory (NVCM).
- Limited resources (~5 k LUTs, 120 kbit block RAM, 1024 kbit SPRAM).
- Paying for reversing other FPGA chips.

In the FPGA


Application FPGA
cpu
fw rom
fw ram
uds
clk reset
mem controller
timer
uart
touch sense
rosc
ram
tk1
Host access
Touch sensor
GPIO

Security Monitor

- Write xor Execute (W^X) and memory access control.
- Registers to set protected memory area.
- FW_RAM always protected.
- Can be set by software, but not disabled.
- Watches program counter (PC).
- If PC enters forbidden area, feed it illegal instruction.
- Halts CPU - no exit condition.
- Outside core watches CPU and blinks LED red if halted.
- Very simple implementation compared to changing the CPU.

First ever TKey device app

```
        li a0, 0xff000024 # LED MMIO
        li a1, 0x1
loop:
        sw a1, 0(a0)
        addi a1, a1, 1

        li a2, 0
        li a3, 100000
delay:
        addi a2, a2, 1
        blt a2, a3, delay
        j loop
```

Our software

- Emulator: friendly qemu fork, also as OCI image.
- Simple firmware/boot loader. (~4 kiB)
- Some client applications: tkey-ssh-agent, tkey-verification, tkey-sign, tkey-random-generator, and their device applications.
- Client libraries: Go, Python supported. Also started Java (Imad Alihodzic).
- Device libraries: C supported, from LLVM-15.
- tkey-builder OCI image for podman/docker.

Some external software

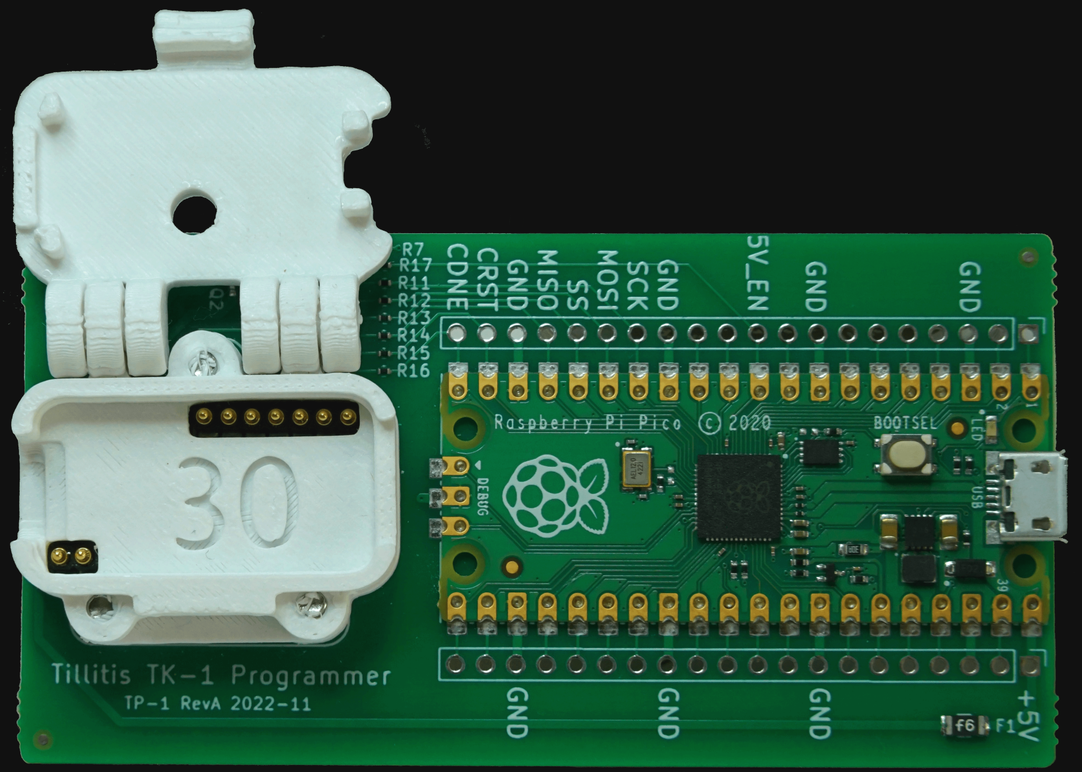
- Device libraries: rusTkey (Danny van Heumen).
- Client libraries: Typescript using WebSerial (Mihir Patil et al), part of Cryptum.
- Experimental bringup of Zig (Morten Linderud and Mikael Ågren independently).
- Tinygo (Ron Evans).
- `tkey-age-plugin`: A plugin to the age encryption tool. (Daniel Lublin)
- All known projects: https://dev.tillitis.se/projects/

Supply chain

- PCB assembled Sweden.
- FPGA provisioned in airgapped environment at Tillitis HQ, Gothenburg.
- User verifiable firmware and identity.

TKey Unlocked & Programmer Board

- Unprovisioned TKey - empty, unlocked NVCM.
- Programming board for NVCM and SPI flash.



Status

- First official hardware release in March 2023: https://shop.tillitis.se/
- Several client apps available for Linux, macOS, and Windows.
- Reproducible builds:
  - For FPGA bitstream, firmware.
  - For all TKey device apps.
  - For client apps, but not on macOS (shared libs).
- Device verification service up and running.
- Everything released on Github: https://github.com/tillitis/

Future

- Writing more apps, supporting more use cases.
- Native USB HID.
- System reset from device app.
- Secure persistent storage.
- Extended memory access control.
- Faster UART (500 kBaud) & hardware flow control.
- 18 -> 24 MHz.

Later/other people

- Smaller version.
- Biometrics?
- FIDO2 app.
- Looking at other FPGA chips.
- HSM using TKey design with a Lattice ECP5 FPGA (Joachim Strömbergson)
- Trust anchor in a bigger computer?

Summary

- A new RISC-V computer with interesting hardware features
- in a USB stick form factor
- with no persistent state
- that uses measured boot to create unique identities based on what the user **has**, **knows**, and **the software integrity**.
- Client & device SDKs available.
- Custom SSH Agent in Go and other useful apps.
- Devices are user verifiable from production to end users.
- Open licences (BSD2, CERN-OHL, some parts still GPLv2)
- All known projects: https://dev.tillitis.se/projects/

The End

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- General inquiries, **hello@tillitis.se**
- #tillitis @ irc.oftc.org, #tillitis:matrix.org
- https://tillitis.se/
- https://shop.tillitis.se/
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Verifying the TKey

- Load a signer app, get public key and firmware digest.
- Do a challenge/response to prove possession of private key.
- Vendor signature over a message containing serial number, device public key, and firmware digest.
- Publish the vendor signature over the message, indexed by serial number.
- User verifies by querying for serial number.
- Looks up the published data, the vendor signature, for this serial number.
- Runs same device app to recreate the vendor signed messsage.
- Challenge/response - prove that the TKey app has same private key.
- Signed by vendor?
- Genuine!