Integrity Enhancements for Embedded Linux Devices

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Embedded Linux Integrity

• Server	$10K+	PB	4768 Crypto card Trusted and Secure Boot
• PC	$1K	TB	TPM Trusted and Secure Boot (Win8)
• mobile	$500	GB	Restricted Boot
• embedded	$50	MB	Nothing
• Sensor	$10	KB	Nothing

Example Embedded Linux Devices

- Pogoplug
- TP-Link MR3020
- D-Link DIR-505
- Linksys WRT54G

MR-3020 Main Components

Three main chips

- SoC (32 bit MIPS)
- RAM (32MB)
- SPI Flash (4MB)

Partition	Name	Size	Contents
mtd0	“boot”	64KB	u-boot
mtd1	“kernel”	1024KB	Linux Kernel
mtd2	“rootfs”	2816KB	Linux root filesystem
mtd3	“config”	64KB	config data
mtd4	“ART”	64KB	radio config data

Recent Embedded Linux Vulnerabilities

- **2012: 4.5 Million home routers compromised in Brazil**
  - https://www.securelist.com/en/blog/208193852/The_tale_of_one_thousand_and_one_DSL_modems
  - Many different Broadcom based devices, across 4 ISPs
  - Redirected all clients to malicious DNS servers
  - Router Exploit: “**get.pl http://192.168.1.1/password.cgi**”
  - Only on internal interface, so **CSRF** required
- **2013: D-Link DIR-645 home router gives away password**
  - http://archives.neohapsis.com/archives/bugtraq/2013-02/0151.html
  - Unauthenticated request from **WAN**/WLAN
  - Exploit: “**curl -d SERVICES=DEVICE.ACCOUNT http://<device ip>/getcfg.php**”

Recent Embedded Linux Vulnerabilities

- **2013: Five new vulnerabilities in Linksys routers**
- https://superevr.com/blog/2013/dont-use-linksys-routers/
  - WRT54GL Firmware Upload CSRF Vulnerability
  - EA2700 XSS Vulnerability
  - EA2700 File Path Traversal Vulnerability (CSRF required)

    POST /apply.cgi
    submit_button=Wireless_Basic&change_action=gozila_cgi&next_page=/etc/passwd
  - EA2700 Password Change Insufficient Authentication and CSRF Vulnerability
  - EA2700 Source Code Disclosure Vulnerability (CSRF)
    - Adding trailing / returns source code of any page
    - **http://192.168.1.1/Management.asp/**

Recent Embedded Linux Vulnerabilities

- **2013: Researchers Hack over a Dozen Home Routers**
- http://securityevaluators.com//content/case-studies/routers/soho_router_hacks.jsp
- 2 remote (CSRF) root (Belkin N300, Belkin N900)
- N300/N900:
  - **<form name="belkinN300" action="http://192.168.2.1/apply.cgi" method="post"/>**
  - **<form name="belkinN900" action="http://192.168.2.1/util_system.html"**
- 4 local (WLAN) root (same, plus Netgear WNDR4700)

Embedded Integrity Issues

- No way to “measure” firmware
  - Supply chain can load malicious firmware
- No way to “lock” firmware
  - Remote malware can root-kit the firmware
- No way to sign-authenticate updates
  - Easy to push malicious firmware updates
- No secure or trusted boot
  - Malware is neither blocked or attested

Current Embedded BIOS Integrity

Device	Measure BIOS?	Lock BIOS?	Signed/local updates?	Secure Boot?
Pogoplug	Yes - SATA	No	No	No
D-Link DIR-505	No	No	No	No
TP-Link MR3020	No	No	No	No
Linksys WRT54G	Yes - JTAG	No	No	No

Traditional Hardware Root of Trust Approaches for Integrity

- “Trusted Boot”
  - **Measurement/Attestation chain** rooted in hardware TPM (trusted platform module)
  - List of SHA-1 hashes of everything read or executed on system
  - If Malicious code or data is accessed, its measurement will be in list, and the measurement cannot be removed from the TPM.
  - Assumes trusted remote management system to verify
- “Secure Boot”
  - **Appraisal chain** rooted in UEFI 3.2.1 BIOS
  - No code is executed unless it is signed
  - Assumes secure boot code AND PUBLIC KEY are immutable
  - Assumes all sensitive files signed

NIST - Integrity Protection Guidelines

- BIOS Integrity Measurement (Is my BIOS correct?)
  - Draft NIST-SP800-155-December-2011
    - BIOS Integrity Measurement (BIOS/UEFI “Trusted Boot”)
- BIOS Integrity Protection (Can I keep it that way?)
  - NIST-SP800-147-April-2011
    - Non-bypassable
    - Authenticated update
    - Secure local update
- Does Not Cover:
  - Signature checking of OS being booted (“Secure Boot”)

Constraints

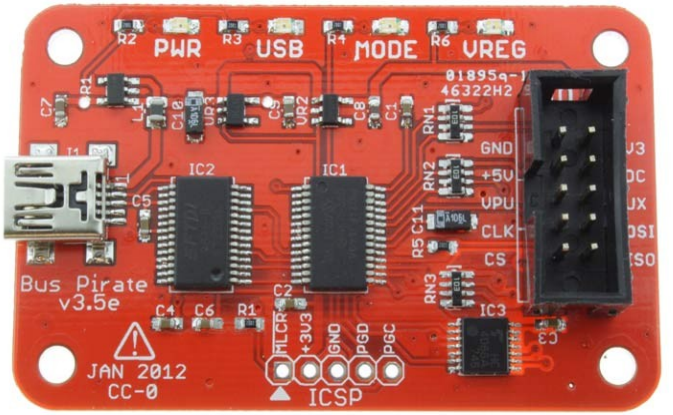
- Vendors unwilling to spend any money on security
  - Retail price of $35 means hardware cost ~ $10
- **What can be done for NO additional cost?**

How can we “Measure” firmware?

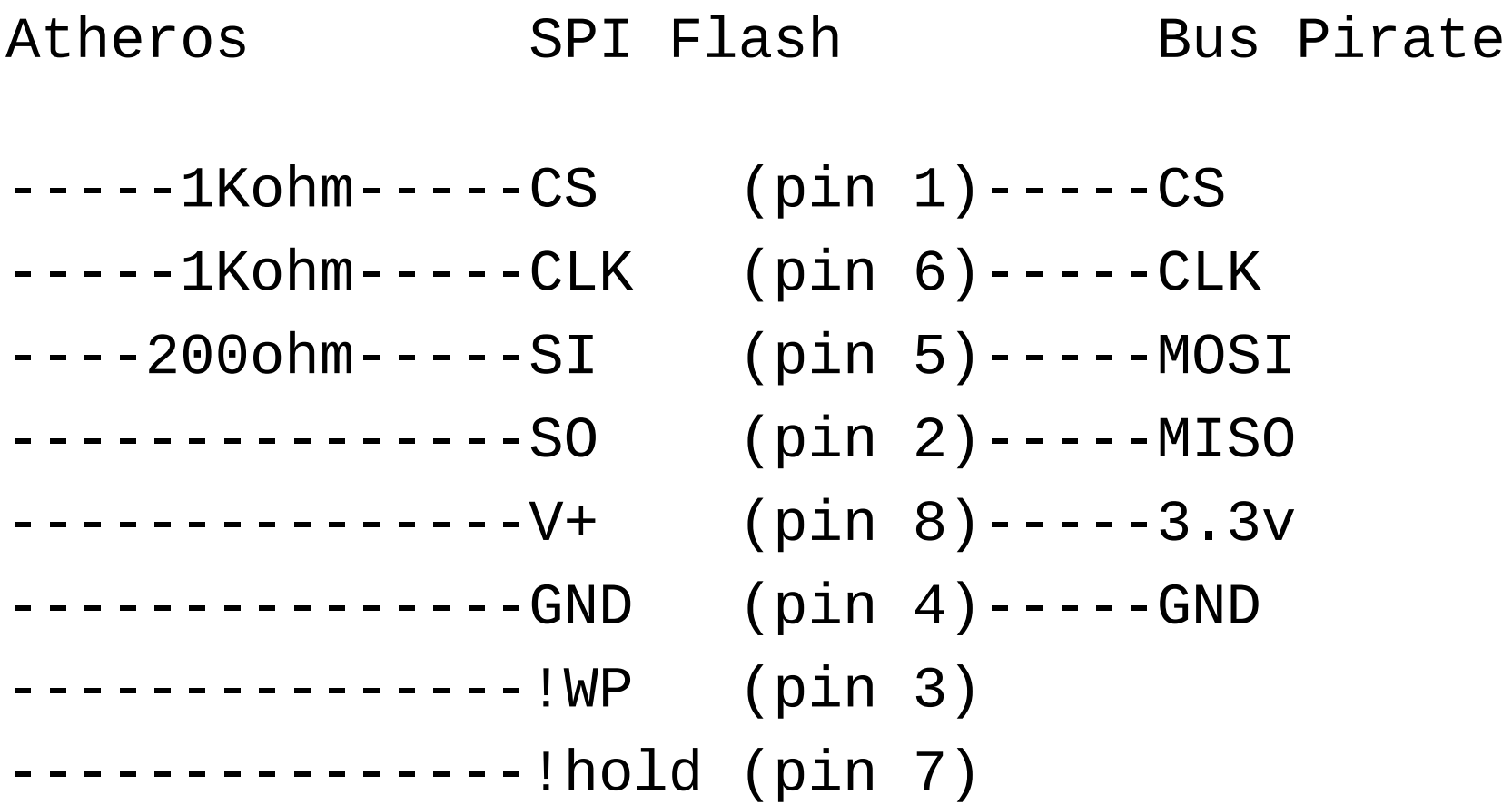
- “Trusted boot” normally requires TPM chip
  - Expensive ($.75)
- Without a measurement root of trust, how do we verify BIOS? We can't just ask it, because it may lie.
- Other methods:
  - SPI Header (many PC BIOS's have this)
  - JTAG header (Linksys WRT54 had this)
  - Immutable (ROM) bootstrap in CPU chip (Broadcom)
  - Unsolder flash chip, and read it in flash programmer (UGH!)

Reading SPI Flash on MR-3020/DIR-505

- DIR-505 and MR3020 are both Atheros SOC.
- Can add SPI in-circuit read support with just 3 additional isolation resistors
  - $30 buspirate (USB – SPI) interface
    - http://dangerousprototypes.com/docs/Bus_Pirate
  - Free flashrom software
    - http://flashrom.org



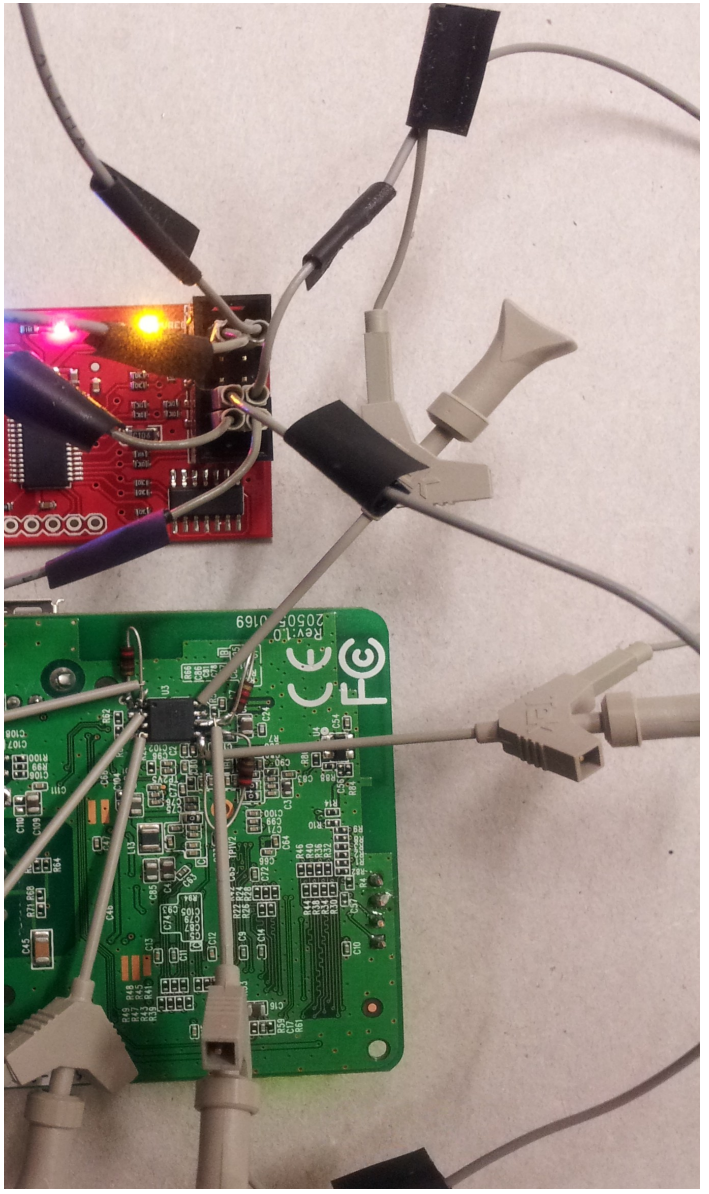
In-Circuit-Programming Mod
(works for both MR3020 and DIR-505)



In-Circuit SPI Flash Reading

Bus Pirate

MR-3020 with SPI isolation resistors



How can we “lock” firmware?

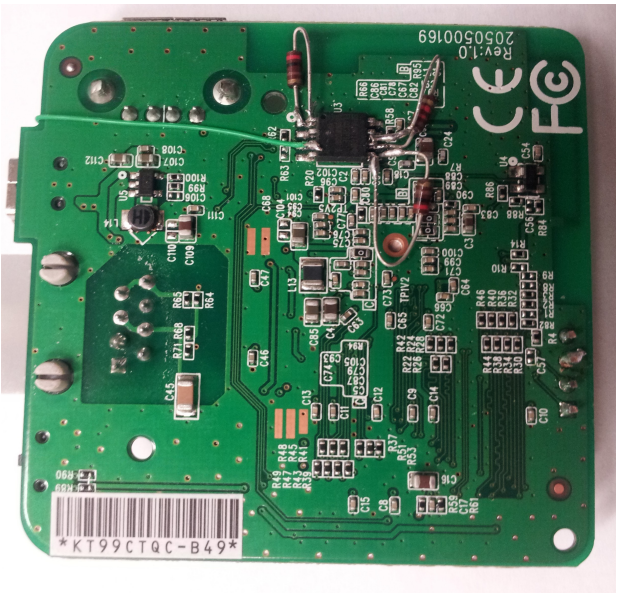
- SPI flash chips have hardware and software write protection
  - Status Register non-volatile protection bits:
    - Write disable bit – when 1 enables write protection
    - BP0 – BP4 – selects which addresses protected
  - !WP pin – when low, enables Hardware Protection Mode which locks status register from software changes.
- How do you allow local updates?
  - Physical presence proven by holding button at boot
  - !WP latch reset by power cycle
  - Immutable boot can update stage2, but verifies signature
  - Disassemble and remove shorting washer (chromebook)

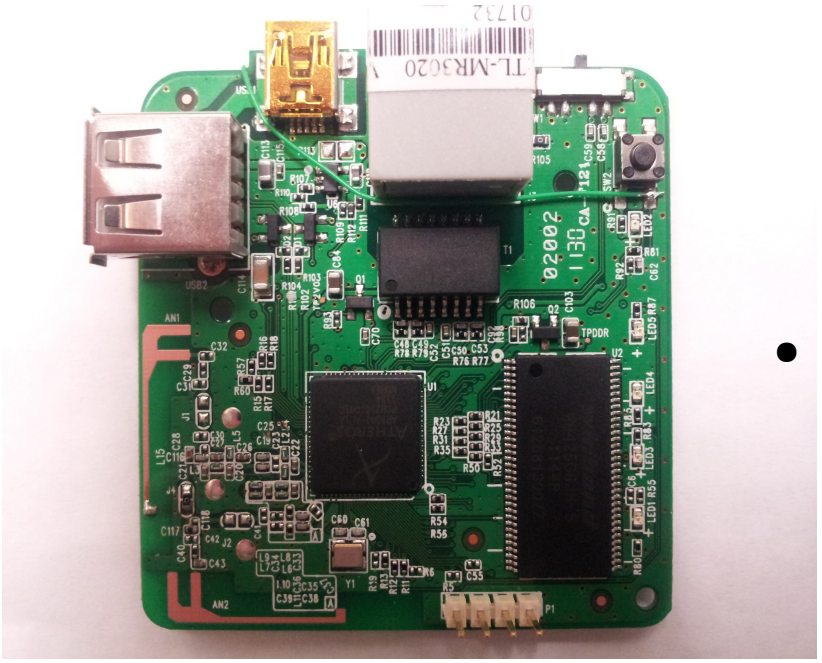
Integrity Protection on MR3020/DIR-505

- MR3020
  - WPS button pressed at boot to unlock flash
  - Reverts to HPM on reset after upgrade
- DIR-505
  - Control !WP directly from unused fourth position of existing mode switch
- U-boot modified
  - Locks flash on every boot
  - If !WP held high at boot, will unlock flash

MR3020 Integrity Protection Mods

- Bottom side - SPI flash with isolation resistors and !WP line from WPS button

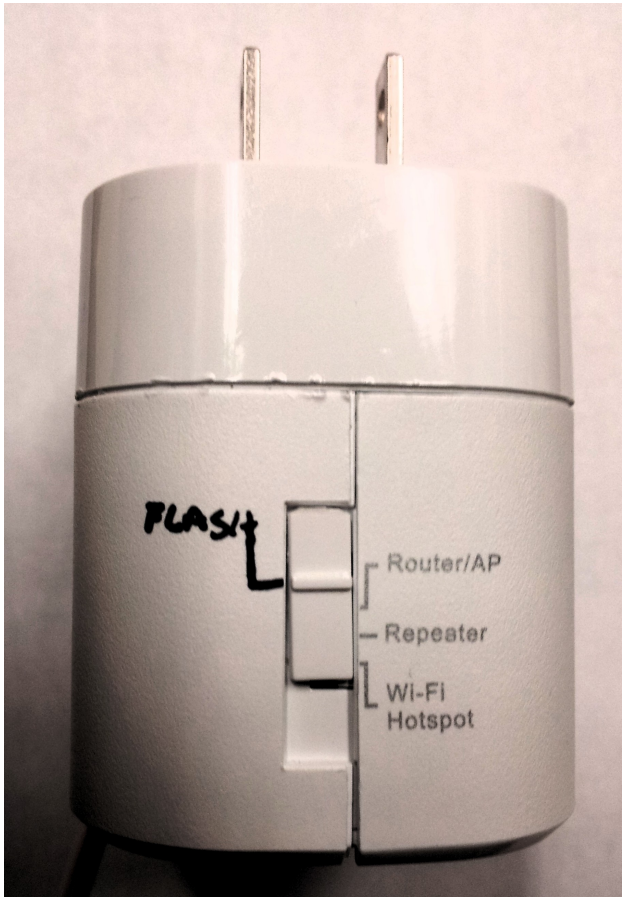




- Top side – WPS button and serial console header

DIR-505 Integrity Protection Mods

- Using the mode switch's extra fourth position for !WP control
- Or can use the WPS button as done with MR3020



Secure Boot on MR3020/DIR-505

- Modify u-boot to verify signature on kernel before boot
  - Public key stored at end of u-boot partition
    - Public key protected with !WP mods
  - Kernel signature stored at end of kernel partition
  - Code derived from PolarSSL code (GPL)
    - Raw binary public key and PKCS1.5 signature
    - Adds 8kb to compressed u-boot (total 62K)

Modified u-boot

- Write protection

```
Write_protect: starting SR = 2
Write_protect: ending SR = 9c
Write_unprotect: starting SR = 9e
Write_unprotect: ending SR = 9e
Write_unprotect failed.

…

Write_protect: starting SR = 2
Write_protect: ending SR = 9c
Write_unprotect: starting SR = 9e
Write_unprotect: ending SR = 2
Write_unprotect succeeded.
```

U-boot modifications

- Secure boot

```
## Booting image at 9f020000 ...
kernel sha1 E9321D87C091F971C8D955C399EBA53807429A61
modulus:
929275845306 3D803DD603D5E777D7888ED1D5BF35786190FA2F23EBC0848AEA
DDA92CA6C3D80B32C4D109BE0F36D6AE7130B9CED7ACDF54CFC7555AC14EEBAB
93A89813FBF3C4F8066D2D800F7C38A81AE31942917403FF4946B0A83D3D3E05
EE57C6F5F5606FB5D4BC6CD34EE0801A5E94BB77B07507233A0BC7BAC8F90F79
signature:
2CB0F653FF3BBCFF2E31ACC0840F02A84975B7167291BB36EEE3F74D02EB3B6A
ACADE02CBCF6E2326230C296E4D8A8D70F309479B388A99591AD5C41938280E3
F51EA9865ED8A0360A0F5BD6A6C676C363B43E5461D9CCF00D46E1B5449CB262
BDE36CAD4AFBEE51ED731BBF48340F290DF8DD844791D81259CEDF99CD1CA2E6
rsa verify kernel succeeded
   Uncompressing Kernel Image ... OK
```

BIOS Integrity with Zero Cost Mods

Device	Measure BIOS?	Lock BIOS?	Signed/local updates?	Secure Boot?
Pogoplug	Yes - SATA	Yes	Yes	Yes
D-Link DIR-505	Yes - buspirate	Yes	Yes	Yes
TP-Link MR3020	Yes - busoirate	Yes	Yes	Yes
Linksys WRT54G	Yes - JTAG	Yes	Yes	Yes

Summary

- At zero cost, we can:
  - Measure firmware
    - Bus pirate
  - Lock firmware
    - HPM mode of flash chips, physical presence for write
  - Authenticate firmware updates
    - RSA signature on updates
  - Add secure boot
    - U-boot verifies signature on linux kernel