Hardware Hacking, Tweaking, and Bending:
Making Technology Do Things It Was Never Intended To Do

University of Advancing Technology

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Introduction to Hardware Hacking

- Hacker v. Attacker
- What is Hardware Hacking and Reverse Engineering?
- Legal Issues
- A Brief History of Hardware Hacking
- Challenges and Trends
- Examples of Interesting Hacks

Hacker v. Attacker

- Hacker: Somebody involved in the exploration of technology
- Attacker: Malicious goals of theft or illegitimately breaking into a system
- Terms often confused and hyped (intentionally?) by media
- Contrary to popular belief, hacking does not have to be illegal

What is Hardware Hacking?

- Doing something with a piece of hardware that has never been done before
  - Personalization and customization (e.g., "hot rodding for geeks")
  - Adding functionality
  - Capacity or performance increase
  - Defeating protection and security mechanisms (**not** for profit)
- Creating something extraordinary
- Harming nobody in the process

What is Hardware Hacking? 2

- Some attempts at defining "hack":
  - The Jargon File v4.4.7, The Meaning of Hack, **`www.catb.org/~esr/jargon/html/meaning-of-hack.html`**
  - Dictionary.com, **`http://dictionary.reference.com/search?q=hack`**
  - The MIT Gallery of Hacks (Building Hacking), **`http://hacks.mit.edu/Hacks/Gallery.html`**
- It's a noun and a verb!
  - Noun: "That Furby hack was really cool."
  - Verb: "Let's hack the Atari Flashback 2 to play actual game cartridges."

What is Reverse Engineering?

- The art of learning from practical examples
- Examining products or technologies to see how they work
  - Ex.: Opening a product and creating a schematic based on the circuit board layout
- Often a subset of hardware hacking

Why Hardware Hacking?

- Curiosity and fun
  - To see how things work
- Improvement and innovation
  - Make products better/cooler (build a better mousetrap)
  - Some products are sold to you intentionally limited or "crippled"
- Education
  - Learn by doing
- Grass-roots technology development
  - Sow a thousand seeds and see what blooms

Why Hardware Hacking? 2

- Consumer protection
  - I don't trust glossy marketing brochures...do you?
- Security competency
  - Test hardware security schemes and look for failures/weaknesses
  - People generally trust hardware devices as "secure"
- Good for the environment?
  - Old/obsolete hardware gets reused instead of brought to the landfill

Legal Issues

- I am not a lawyer!
- Thin line between good and evil
  - Recent laws (DMCA) have worked to prevent reverse engineering by enabling large corporations to flex their muscle against potential threats
  - However, there is legal precedent that explicitly protects certain types of reverse engineering
- "Shrink wrap" or explicit agreements used to waive your rights
  - Ex.: You don't actually **own** what you're reverse engineering

Legal Issues 2

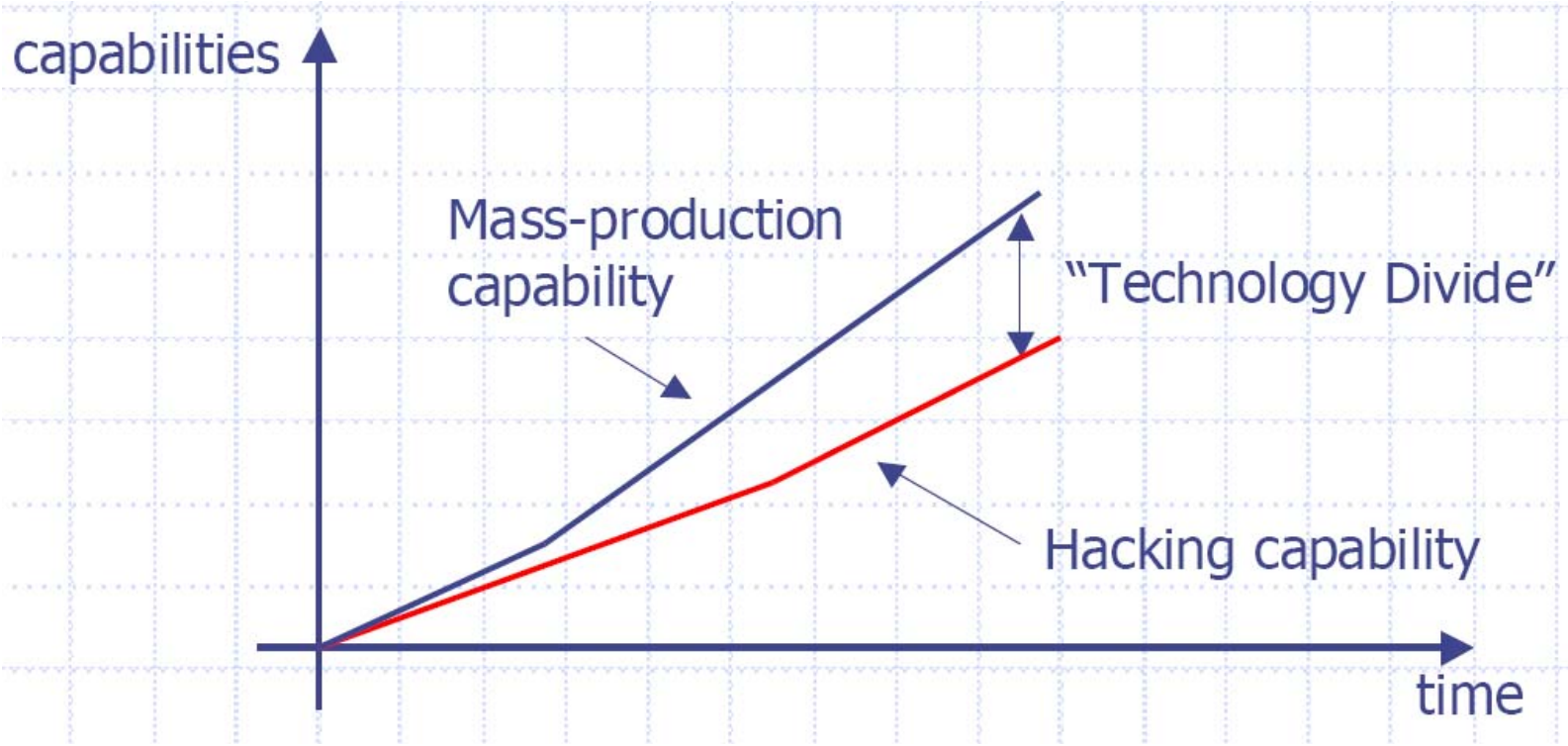
- Reverse engineering a patented product does not grant you a license to use it
  - Patents contain a full disclosure of the technology, anyway
- Cannot copy or use a copyrighted work
- Trade secrets (confidential, but not legally protected) are fair game
- Check with a lawyer if you have any questions!

A Brief History of Hardware Hacking

- Hacking is not just about breaking and tweaking - it's also about creating!
- Arguably dates back 200 years
  - Charles Babbage's Difference Engine (early 1800s)
  - William Crooke's discovery of the electron (mid 1800s)
- Hardware hackers you might have heard of:
  - Benjamin Franklin, Thomas Edison, Alexander Graham Bell, Bill Hewlett and Dave Packard, Steve(s) Jobs and Wozniak
- Early hardware hacking included:
  - Wireless telegraphy, vacuum tubes, radio, television, transistors, computers

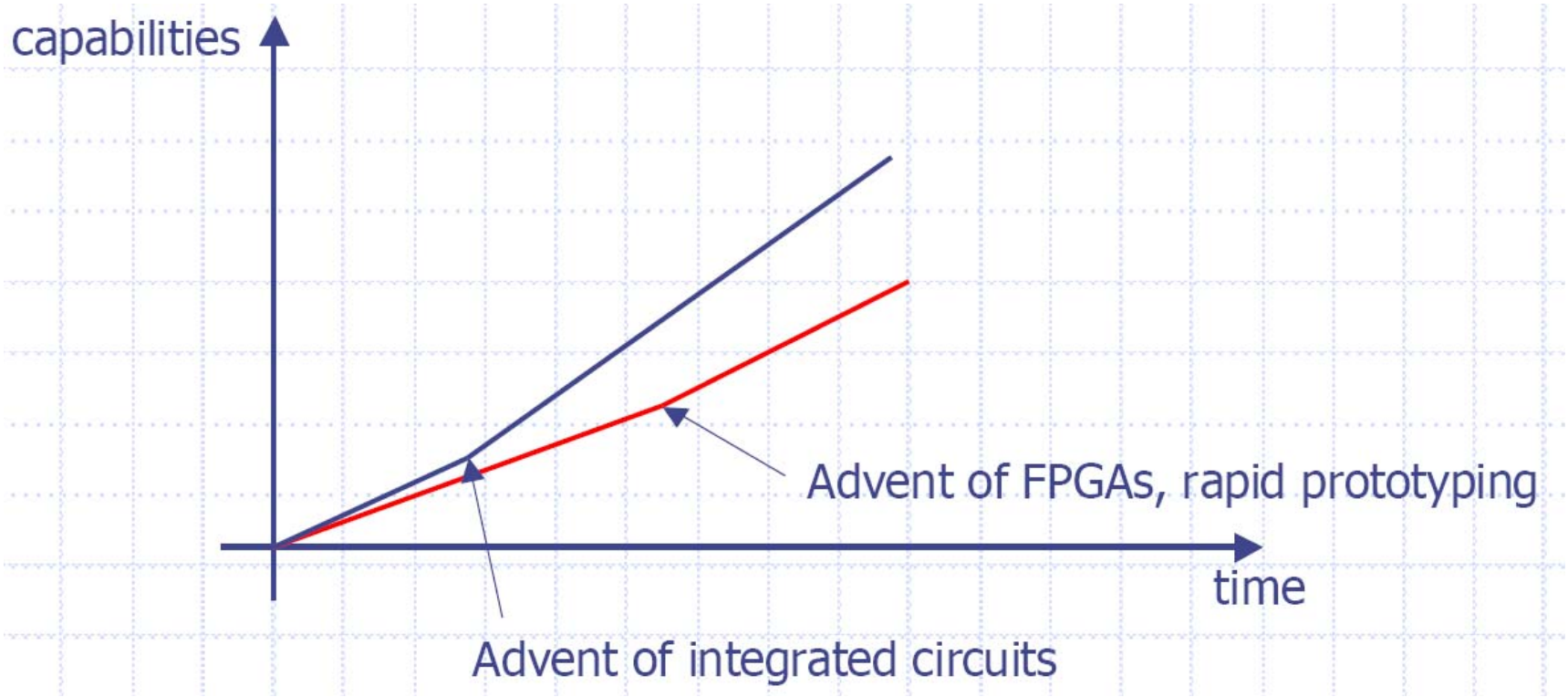
The Technology Divide

- Differential between mass production and hobbyist capabilities



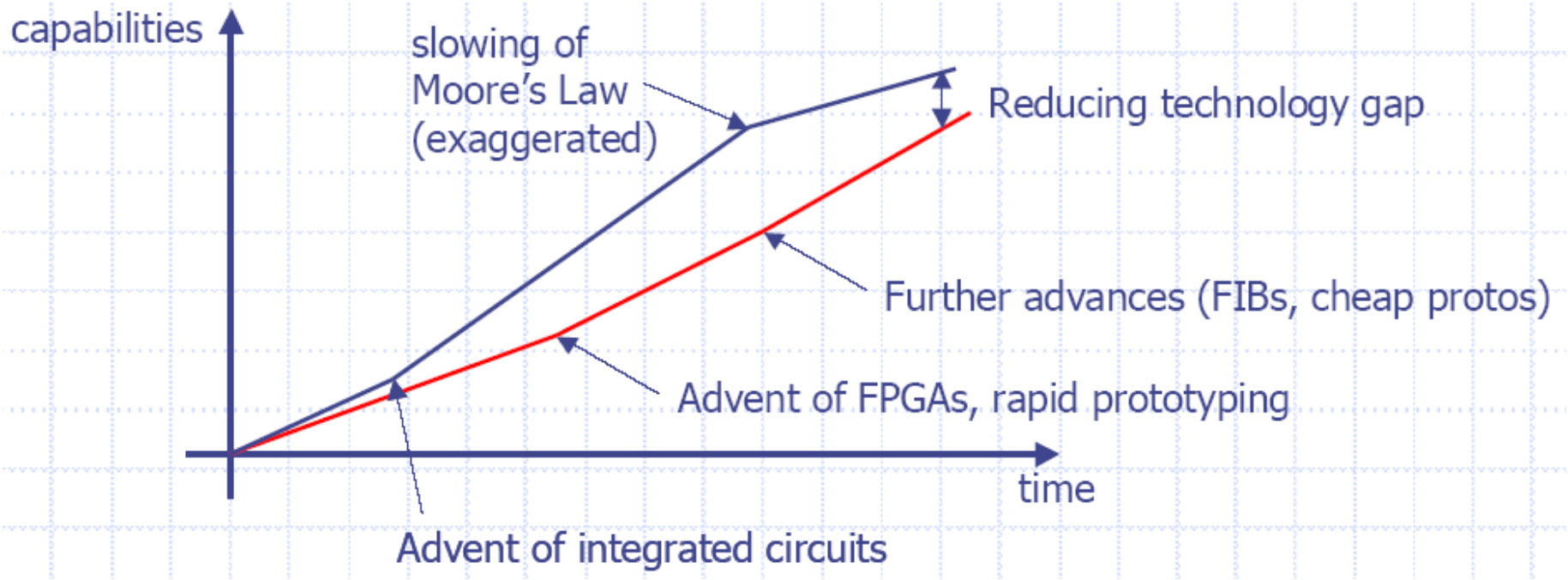
The Technology Divide 2

- Differential between mass production and hobbyist capabilities



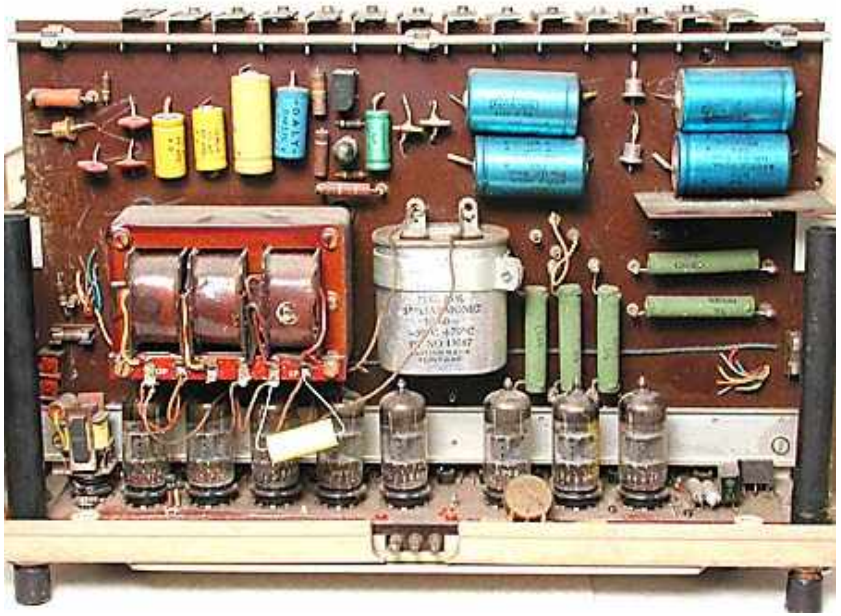
The Technology Divide 3

- Differential between mass production and hobbyist capabilities



Evolution of the Technology Divide

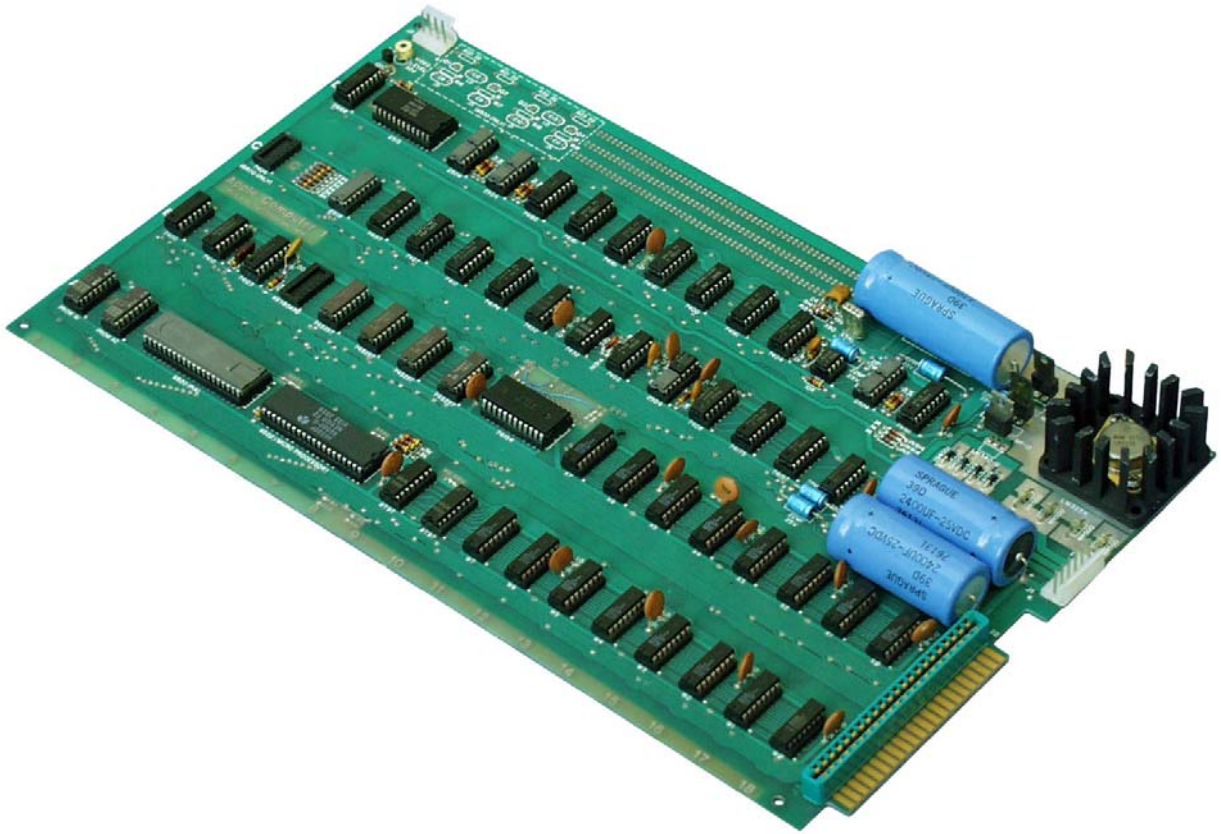
- In the beginning (1940s-1960s)
  - Production and hobbyist technology the same
  - Your own two eyes, a soldering iron, and some discrete components



Picture: **www.vintagecalculators.com/html/anita_mk_8.html**

Evolution of the Technology Divide 2

- ICs lead the way to greater integration (1970s-1980s)



Picture: **www.applefritter.com/pictures/images/apple1platine.jpg**

Evolution of the Technology Divide 3

- In the 1970s-1980s, most boards used SSI/MSI chips
  - SSI (Small Scale Integration) = <10 gates
  - MSI (Medium Scale Integration) = 10-100 gates
  - LSI (Large Scale Integration) = 100-1000 gates
  - VLSI (Very Large Scale Integration) = >10000 gates
- At SSI and MSI level, most logic functions visible to the "naked eye"

Evolution of the Technology Divide 4

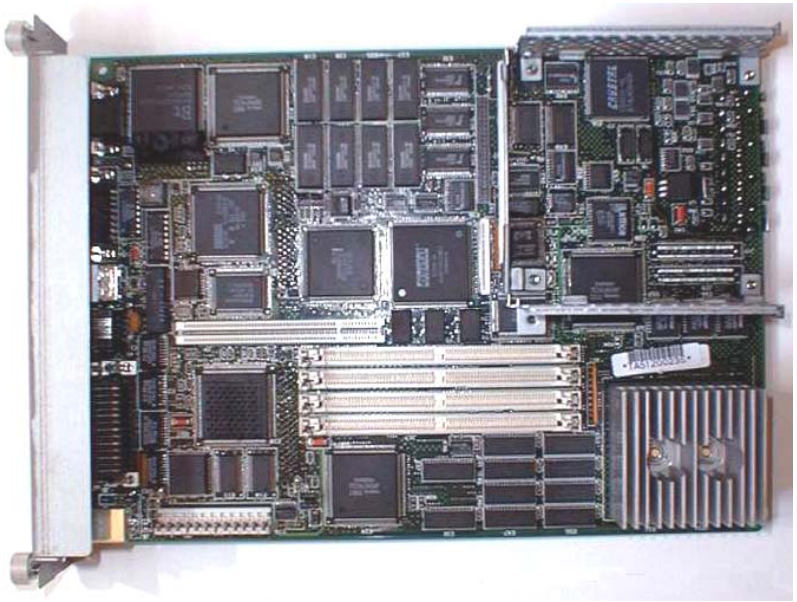
- Early 1990s
  - Mass-market adoption of technology drives integration
  - Fine-pitch surface mount technology, increasing integration, and escalating clock speeds
  - Hardware hacking stagnates as interest in software/network hacking increases
  - Hardware hacking now requires high-end test equipment, microscopes, soldering irons

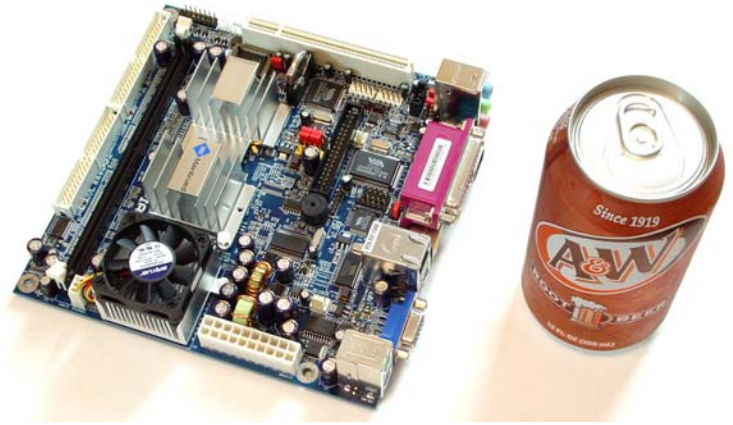
Evolution of the Technology Divide 5

- Late 1990s
  - BGA technology widely deployed
    - Die connections ("pins") located underneath device package
    - Working with BGAs inaccessible to hobbyists
    - Requires sophisticated soldering and rework equipment
    - Inspection and repairing of ball/solder joints expensive
  - High board clock speeds obsolete cheap test equipment
    - Low-cost oscilloscopes have ~100 MHz bandwidth
    - Motherboards hit 133 MHz signaling in late 1990s (now over 400 MHz!)

Evolution of the Technology Divide 6

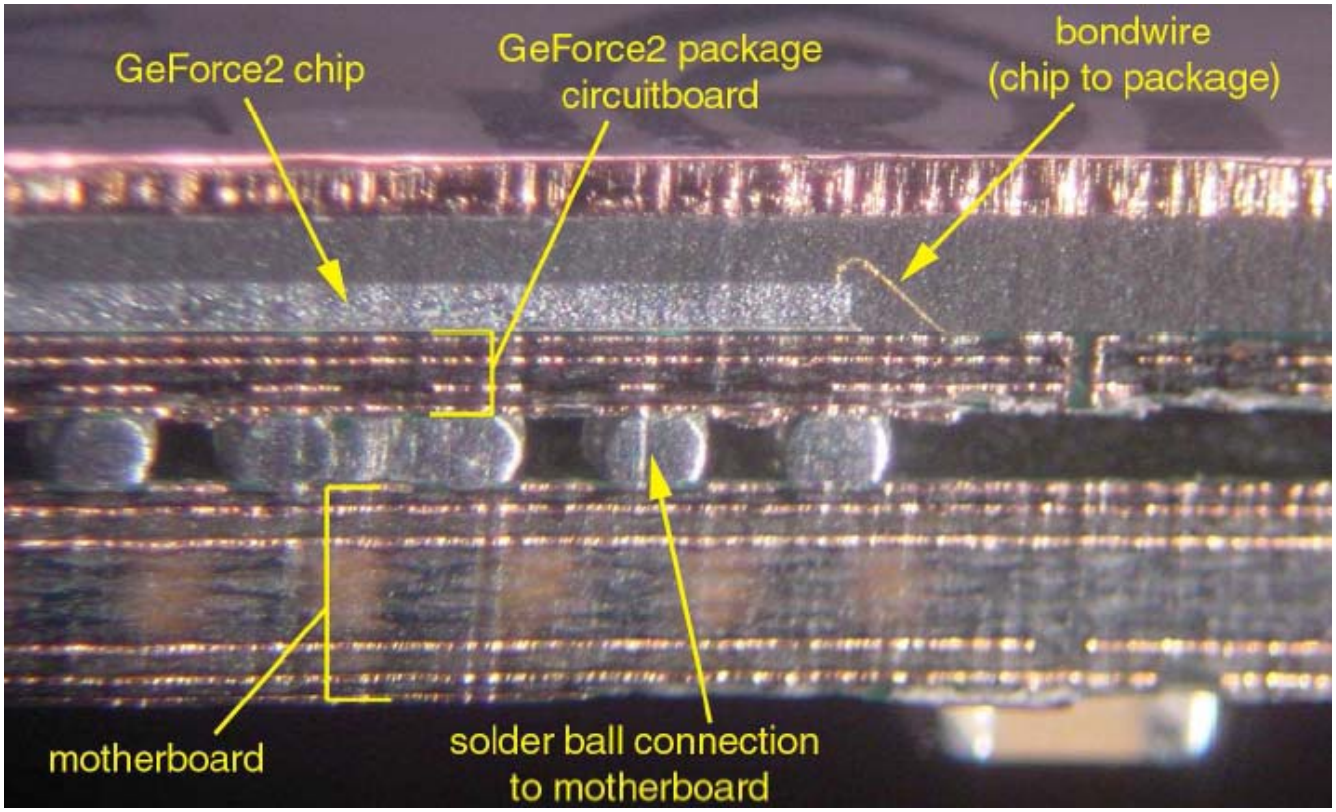
- Early 1990s v. Late 1990s: Do more with less!





Evolution of the Technology Divide 7

- Cross section of modern circuit board showing hidden BGA connections and buried traces



Picture: Hacking the Xbox

Hardware Hacking Challenges

- Advances in chip packaging
  - Ultra-fine pitch and chip-scale packaging (e.g., BGA, COB, CIB)
  - Not as easy to access pins/connections to probe
  - Discrete components can now easily be inhaled
- Highly-integrated chips (sub-micron)
  - Difficult, but not impossible, to probe and modify
  - Building a full-custom chip as a hobby project is still too expensive (> $100K)

Hardware Hacking Challenges 2

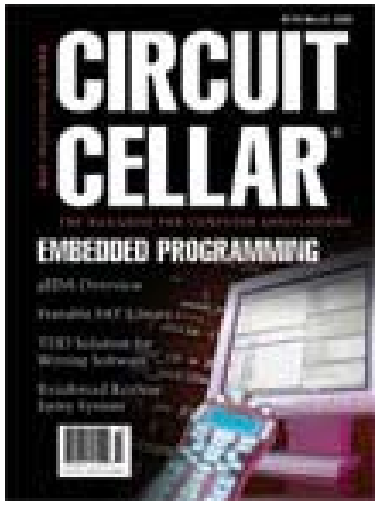
- Cost of equipment
  - Advanced tools still beyond the reach of average hobbyist (probing, decapping, SEMs, etc.)
  - "State of the art" defined by what hackers can find in the trash and at flea markets
- Societal pressures
  - Hardware hacking is practically becoming mainstream, but "hacker" is still a naughty word

Emerging Trends

- Economic downturn of early 2000 is a blessing to hardware hackers
  - Growth of technology slows down
  - Price competition bring rapid PCB prototyping prices into the < $100 range
  - Excess inventory drives down component costs
  - IC analysis services become affordable for the mere mortal

Emerging Trends 2

- Hardware hacking is making a comeback!
  - Was overshadowed for many years by network/software programming and hacking
  - Many resources, web sites, forums, magazines, people available to learn from



Make Magazine

- Full-color, quarterly hybrid magazine/book (also known as a *mook*) published by O'Reilly
- Launched January 2005, already 80,000 paid subscribers
- Focused on all aspects of the do-it-yourself ethos
  - Electronics, Mechanical, Metal, Wood Working, Food, Anything!
- Community-based sharing of hacks, projects, pictures
  - **`http://www.makezine.com`**
  - **`http://flickr.com/groups/make/pool`**

Make Magazine 2

- Even the media likes it!
  - "It's the kind of magazine that would impress MacGyver" -- Marcus Chan, San Francisco Chronicle
  - "This is Popular Mechanics for the modern age with a 1968 James Brown attitude." -- Wayne Bedsoe, Knoxville News Sentinel
  - "If you're the type who views the warnings not to pry open your computer as more a challenge than admonition, MAKE is for you." -- Rolling Stone

Hacks!

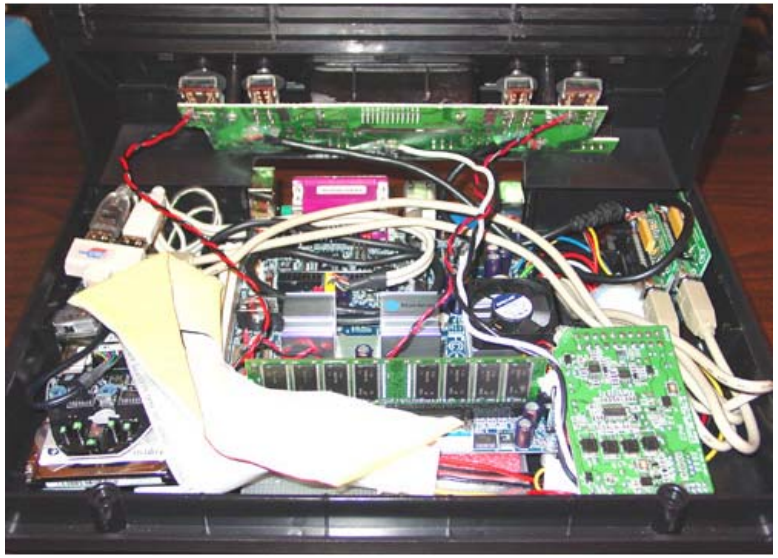
- Case Modifications
- Game Consoles
- Consumer Products
- Other Technologies
- ...Only a tiny sampling of the thousands of amazing hacks out there (and the ones I think are particularly cool)!

Case Mods: Atari 2600PC

- Fully-featured PC designed into the case of an Atari 2600 (remember those?)
- Wanted a DVD/CD media station and all-purpose video game/computer emulator
- 1GHz VIA EPIA M10000 motherboard, 512MB DRAM, 60GB hard drive, CD-RW/DVD combo drive, wireless keyboard and mouse, 802.11b wireless USB adapter, 2 Stelladaptor Atari controller-to-USB interfaces

Case Mods: Atari 2600PC 2

- *Game Console Hacking* and Make issue 2



Case Mods: Millennium Falcon Xbox

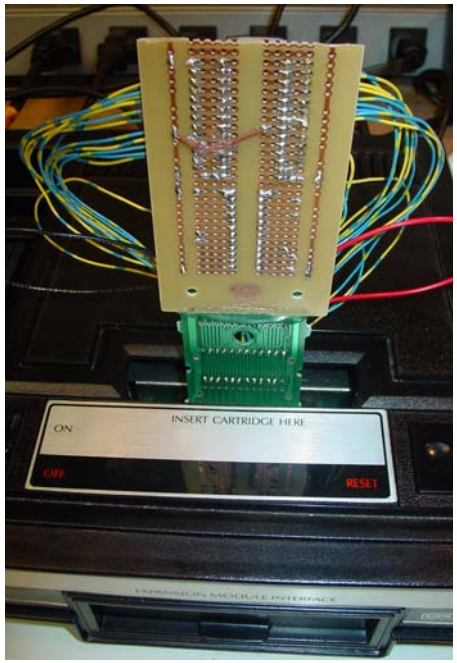
- Stripped down Xbox retrofitted into an original 1979 Star Wars Millennium Falcon
  - **www.darkops.co.uk**
- Xbox w/ 4 gamepad ports, 6 fan "hyper drive" cooling system, concealed DVD drive

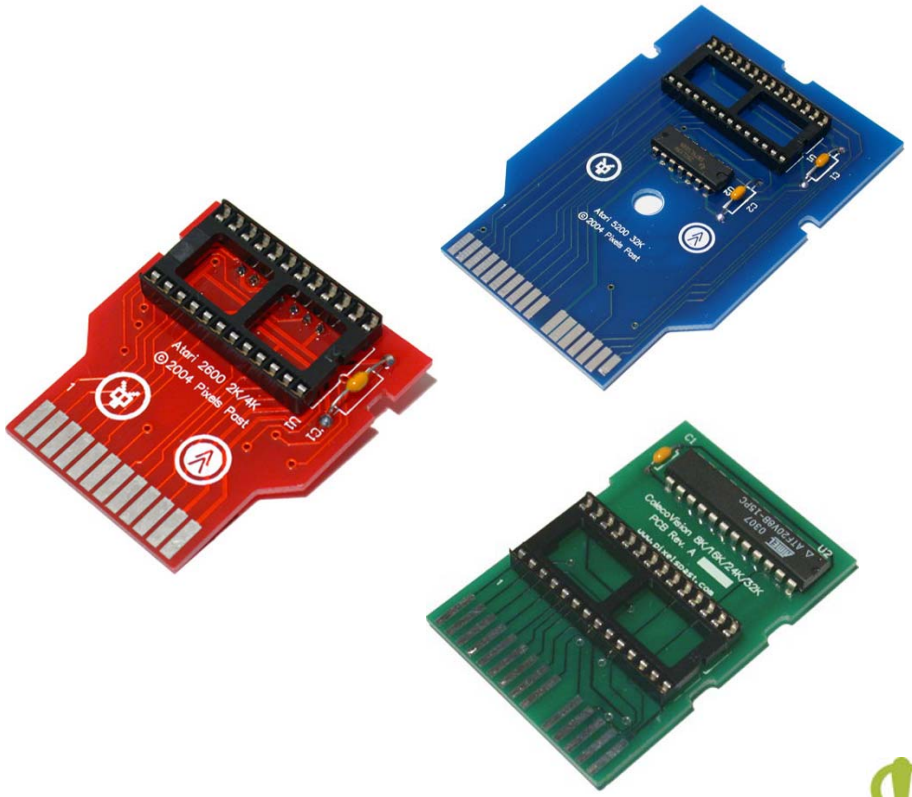
Game Consoles: Retro/Classic

- Thriving homebrew game development community
  - Ex.: **`www.atariage.com`**
- Primarily driven by nostalgia and the desire to use old technology to create new things
- Excellent way to learn about electronics and programming
  - The challenge is in overcoming constraints of these early systems (ex.: limited ROM, RAM, and processor power, necessary low-level hardware interaction, etc.)

Game Consoles: Retro/Classic 2

- Custom circuit boards to build actual cartridges for retro systems (Atari 2600, Atari 5200, Atari 8-bit, Colecovision)
  - **`www.pixelspast.com`**

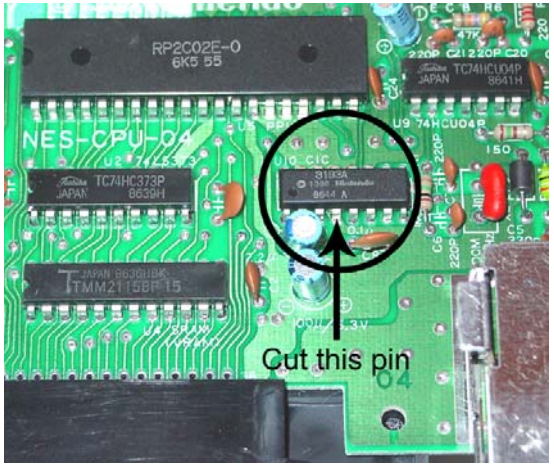


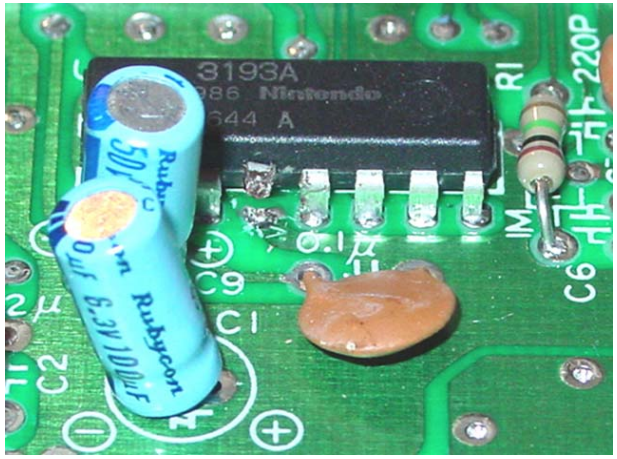


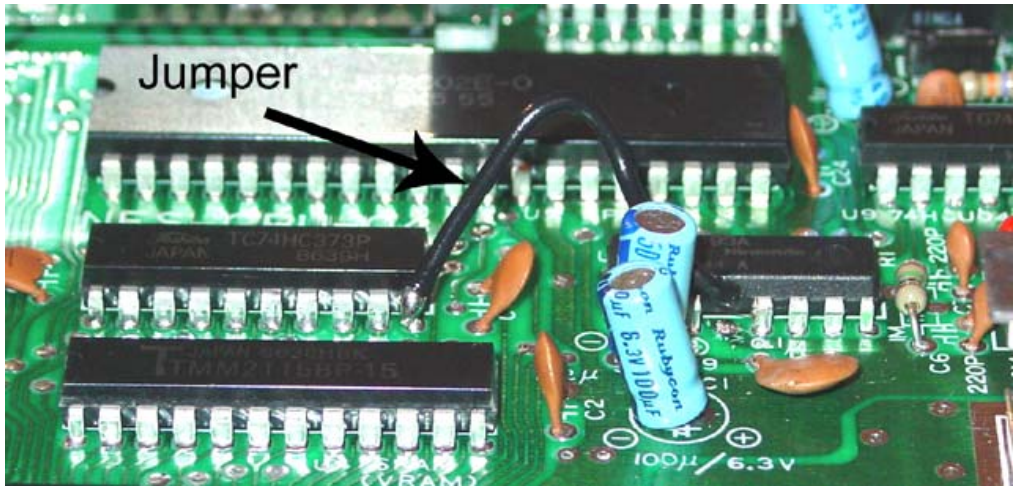
Game Consoles: Retro/Classic 3

- Disabling the Nintendo NES "Lockout Chip"
  - Security mechanisms used by Nintendo to maintain exclusivity on cartridge manufacturing and to control game distribution
  - Lockout chip inside the NES communicates with an identical chip inside the cartridge (e.g., as a "lock" and "key")
  - Can be disabled with a simple trace cut and additional wire
  - Hack allows foreign games and unlicensed third-party games to be played on the console
  - *Game Console Hacking*, chapter 7

Game Consoles: Retro/Classic 4





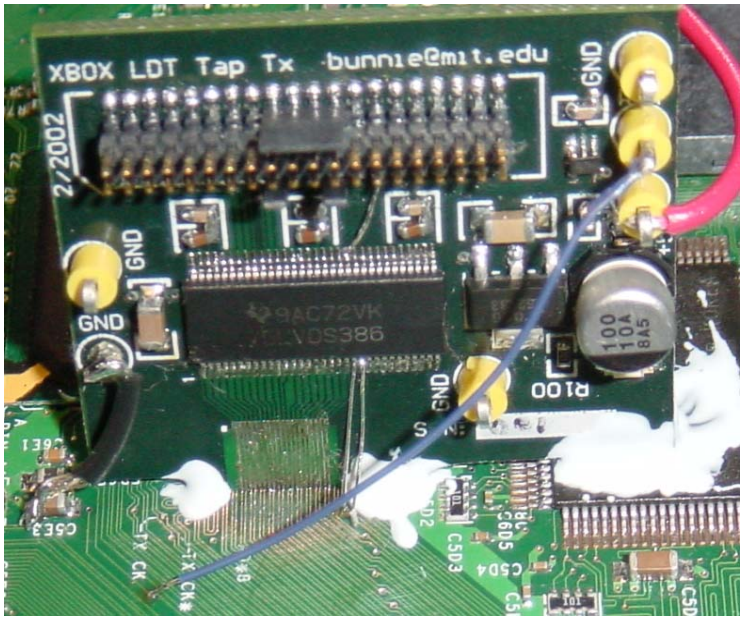


Game Consoles: Xbox

- Andrew "bunnie" Huang's Xbox hacking
  - *Hacking the Xbox: An Introduction to Reverse Engineering* and **`www.xenatera.com/bunnie/proj/anatak/xboxmod.html`**
  - Custom-built tap circuit used to intercept data transfer over Xbox's HyperTransport bus
  - Able to retrieve symmetric encryption key used for protection of a secret boot loader
  - Allowed him to execute untrusted/unauthorized code on the system

Game Consoles: Xbox 2

- Tap board uses single LVDS-to-CMOS logic converter (TI SN75LVDS386) interfaced to a Xilinx Virtex-E FPGA



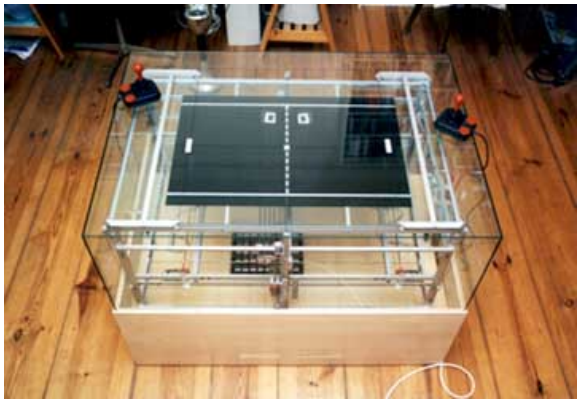
Picture: Hacking the Xbox

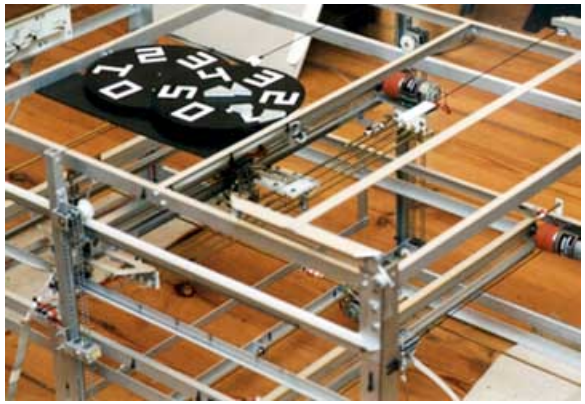
Game Consoles: Gran Turismo 4 Steering Wheel Mount

- Woodworking skills > Paying $ for expensive gaming chair
  - $18 in parts + time + fun v. $199
  - **`http://berserk.org/gt4`**

Game Consoles: Pong Mechanik

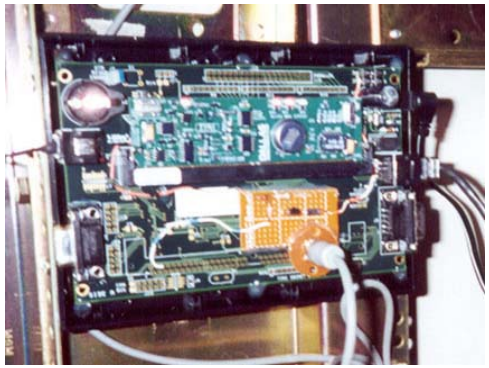
- Art project created by Niklas Roy
  - Interviewed in Make issue 1
- Completely mechanical version of Pong: Motors, relays, solenoids, strings, & pulleys!
  - **`www.cyberniklas.de/pongmechanik/indexen.html`**
- No microprocessors, semiconductors, or other electronic components





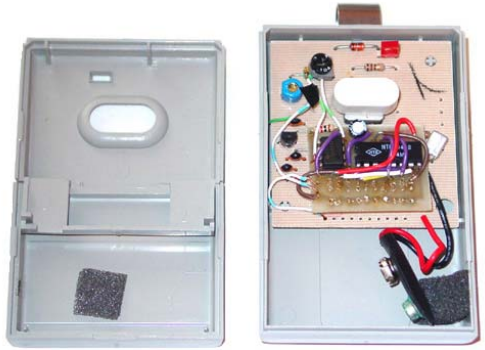
Consumer: VaxBar

- Built in January 2001
- Simple access control system to prevent un-authorized employees from eating our snacks!
- Original DEC VAX 11/785 housing w/ custom-designed Java-based web server and iButton authentication



Consumer: Universal Garage Door Opener

- Replaced DIP switches with timer and counter to automatically cycle through all 2^{10} (1024) possible combinations
- Built in July 1994 as a hobbyist project
  - **Still** works on many garage door types that use a selectable "security code"
  - Who changes their garage door systems that often?



Consumer: Dakota Single-Use Digital Camera

- One of the few low-cost, single-use digital cameras (~$10.99 at Ritz or Wolf Camera)
- Intended to be used like a disposable camera
  - Sticker on unit says "Camera does not connect to home computers."
- Quickly hacked to convert to regular, multi-use camera via USB
  - **`http://cexx.org/dakota`**
- Underground community has created custom firmware, image dumping software, webcam, etc.

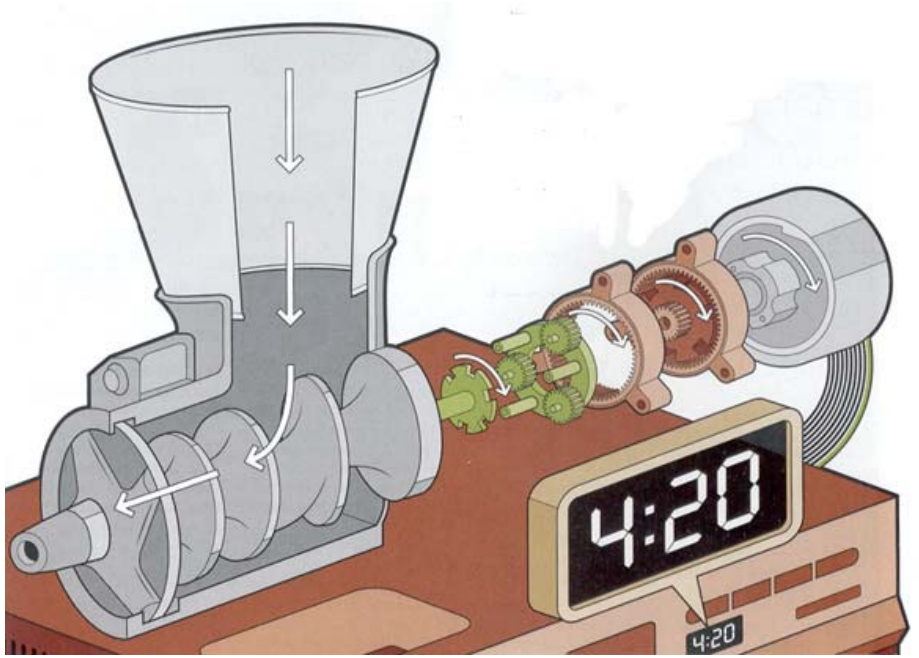
Consumer: Dakota Single-Use Digital Camera 2

Pictures: Make, issue 3

Consumer: VCR Cat Feeder

- "Liberate a motor from an old VHS deck, attach it to a food chopper, and program the deck's recording timer to fill Fluffy's bowl on schedule."
  - **`http://makezine.com/03/catfeeder`**
- Any old VCR has a programmable timer that connects to a motor for recording TV shows
- Hack the VCR so the motor operates a food delivery mechanism instead of the video head
- One of many curiously insane hacks created by James Larsson (he's also created a clock by measuring decay rates of a prawn sandwich)

Consumer: VCR Cat Feeder 2



Pictures: Make, issue 3

Wireless:
Dell TrueMobile 1184

- One of many broadband access point/routers
- Port scan reveals open ports 80, 333, 1863, 1864, 4443, 5190, 5566
- Device based on vLinux distribution
  - **`www.onsoftwarei.com/product_vlinux.htm`**
  - *Hardware Hacking: Have Fun While Voiding Your Warranty*, chapter 10

Wireless: Dell TrueMobile 1184 2

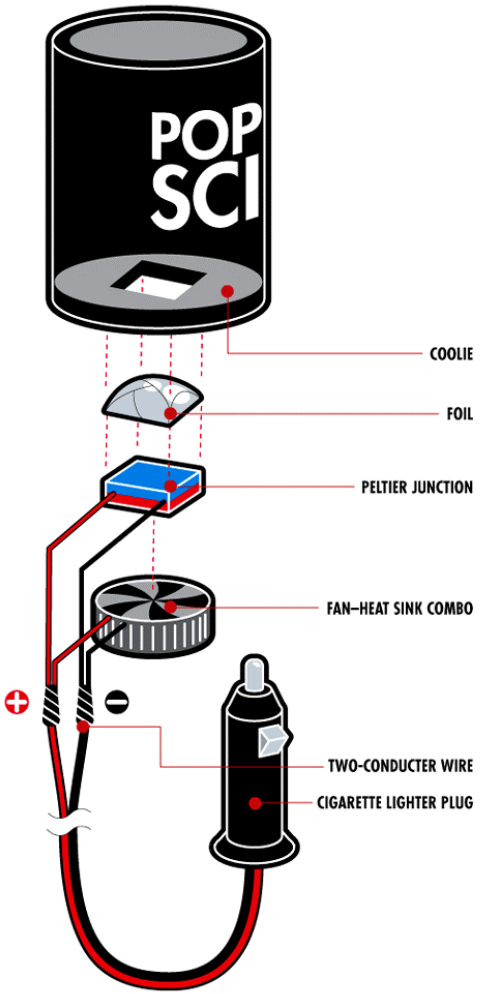
- Can *telnet* into port 333 with default password to gain complete control of the device
  - username: root, password: admin
- No special hardware tools or reprogramming is necessary
- Many devices running Linux which can make hacking/experimentation easier
  - **`www.linuxdevices.com`**
  - **`www.ucdot.org`**
- Linksys WRT54G is another good one for hacking: Open source firmware, etc.

Wireless: Can Antenna (Cantenna)

- What better way than to use your empty Pringles can or coffee can as a WiFi antenna?
  - **`www.turnpoint.net/wireless/has.html`**
- Perfect for increasing network range or for "wardriving"
- Many variations exist...

Other: Self-Chilling Beer Mug

- Keep drink cold wherever you go!
- Uses Peltier junction (moves heat to one side, leaving the other cold)
  - **www.popsci.com/popsci/automotivetech/59ca1196aeb84010vgnvcm1000004eecbccdrcrd.html**

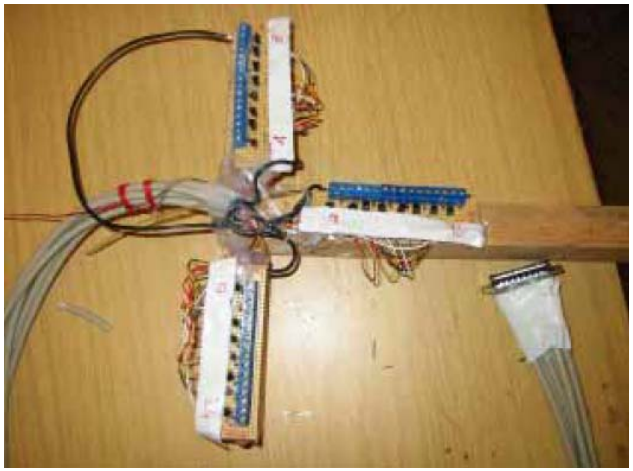


Pictures: Scott Fullam, DefCon 12

Other: Blinkenlights

- Eight floors of a building turned into a huge interactive display
  - 144 lamps behind front windows
  - Each lamp computer-controlled to form 18x8 pixel monochrome matrix
  - Linux PC w/ 192-channel Parallel I/O card
  - **`www.blinkenlights.de`**
- Created by the Chaos Computer Club to celebrate its 20th anniversary (Sept. 2001)
- Followed up by the "Arcade" project in Paris 2002
  - 20x26 pixel greyscale matrix
  - Play Tetris, Pong, Breakout, Pac Man, etc.

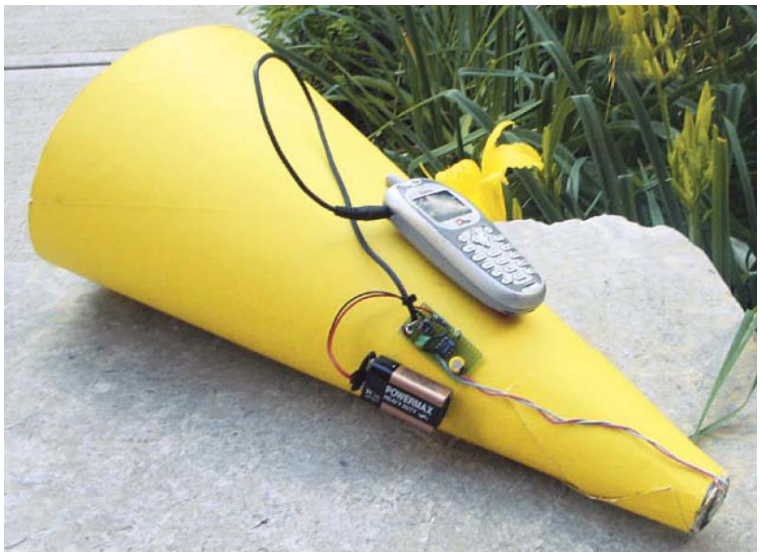
Other: Blinkenlights 2



Pictures: Chaos Computer Club

Other: Anonymous Megaphone

- "Bring anonymous voices into public spaces, stage an anonymous protest, or speak to the masses without revealing your identity."
  - **`http://makezine.com/04/diy_megaphone/`**
- Cellphone (auto answer) -> Audio amplifier -> Paper cone



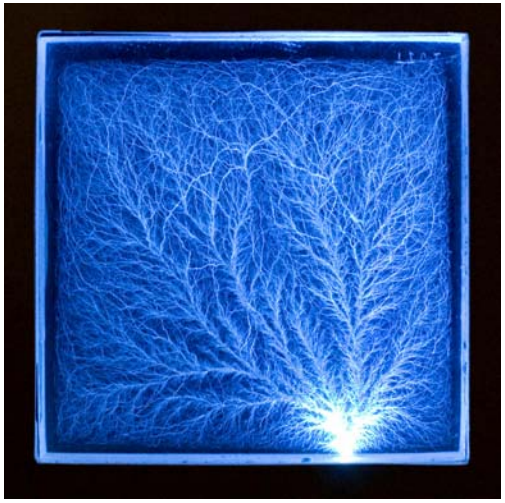
Picture: Make, issue 4

Other: Joe's Random Hacks

- Laser Listener: Window Vibration Audio Reconstruction Project (left)
- Joystick-Controlled Pneumatic Cannon (right)

Other: Technology as Artwork

- Lichtenberg Lightning Frame (left)
- Tank Searchlight Lamp (right)



Other: Technology as Artwork 2

- Solder Stencil End Table (left)
- Macintosh Aquarium (right)

Other: Technology as Artwork 3

- Hard Drive Coffee Table

Thanks & Have Fun!

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Books and Magazines: Hardware Hacking

- Make Magazine (w/ blog updated daily), **`www.makezine.com`**
- J. Grand, et al, "Hardware Hacking: Have Fun While Voiding Your Warranty," Syngress Publishing, 2004, ISBN 1-93-226683-6.
- J. Grand, et al, "Game Console Hacking," Syngress Publishing, 2004, ISBN 1-93-183631-0.
- S. Fullam, "Hardware Hacking Projects for Geeks," O'Reilly Media, 2003, ISBN 0-59-600314-5.

Books and Magazines: Hobbyist and Robotics

- Nuts & Volts Magazine, **`www.nutsvolts.com`**
- Servo Magazine, **`www.servomagazine.com`**

Books and Magazines: General Electrical Engineering

- Circuit Cellar Magazine, **`www.circuitcellar.com`**
- EDN Magazine, **`www.edn.com`**
- Horowitz and Hill, “The Art of Electronics,” Cambridge University Press, 1989, ISBN 0-52-137095-7.
- K. Amdahl, "There Are No Electrons," Clearwater Publishing, 1991, ISBN 0-96-278159-2.
- M. M. Mano, “Digital Logic and Computer Design,” Prentice-Hall, 1979, ISBN 0-13-214510-3.
- K. R. Fowler, "Electronic Instrument Design," Oxford University Press, 1996, ISBN 0-19-508371-7.

Web Sites: Hardware Hacking

- hack a day, **`www.hackaday.com`**
- I-Hacked.com: Taking Advantage of Technology, **`www.i-hacked.com`**
- Bill Miller's CircuitBending.com, **`http://billtmiller.com/circuitbending`**
- TiVo Techies, **`www.tivotechies.com`**

Web Sites: Electrical Engineering

- Parallax, Inc., **`www.parallax.com`**
- ePanorama.net, **`www.epanorama.net`**
- The EE Compendium: The Home of Electronic Engineering and Embedded Systems Programming, **`http://ee.cleversoul.com`**
- Discover Circuits, **`www.discovercircuits.com`**
- WebEE: The Electrical Engineering Homepage, **`www.web-ee.com`**
- University of Washington EE Circuits Archive, **`www.ee.washington.edu/circuit_archive`**

Web Sites: Other

- Cambridge University Security Group - TAMPER Laboratory, **`www.cl.cam.ac.uk/Research/Security/tamper`**
- Molecular Expressions: Chip Shots Gallery, **`http://microscopy.fsu.edu/chipshots/index.html`**

Distributors: Electrical Engineering

- Digi-Key, **www.digikey.com**
- Mouser, **www.mouser.com**
- Jameco, **www.jameco.com**
- Newark In One, **www.newarkinone.com**
- Future Electronics, **www.futureelectronics.com**
- Radio Shack, **www.radioshack.com**
- American Science & Surplus, **www.sciplus.com**

Distributors: Tools and General Hardware

- Contact East/Jensen Tools, **www.contacteast.com**
- Test Equity, **www.testequity.com**
- The Home Depot, **www.homedepot.com**
- Lowe's, **www.lowes.com**
- Hobby Lobby, **www.hobbylobby.com**
- McMaster-Carr, **www.mcmaster.com**