Behind the Scenes of the DEFCON Badge

DEFCON 14
Friday, August 4

Joe Grand (Kingpin)
joe@grandideastudio.com
Thanks for Waking Up Early!

- We had to keep actual session title a secret until the badge was released
- We’ll look at the entire development process of the badge from conception to production units
- Read the short story in the DEFCON program
- Sorry if you were looking for a different kind of hardware hacking!
- Interrupt me and ask questions!
Development Process in a Nutshell

- Define the Specifications
- Preliminary Schematic
- Initial Breadboarding
- Code Development
- Final Schematic
- Create Bill-of-Materials
- Printed Circuit Board (PCB) Design
- Prototype Testing
- Parts Sourcing/Acquisition
- Place the Quantity Order
Specifications: Initial Proposal

- The Dark Tangent and Ping had a good idea of what they wanted before they called me
  - Quantity of 6,055 (that’s a lot!)
  - Total cost of under $5
  - Badge in the shape of DEFCON logo
  - Blinky LEDs
  - Battery needs to last at least the length of DEFCON
  - Must look wicked pissah (east coast) and/or totally rad (west coast)
Specifications: Concept Sketch

- Diameter: 4
- LED or Cutout
- Front Side Only
- Will Not Glow Point
- PCB - Solder Mask:
  - Green > Gold
  - Blue > White (inset of Yellow)
  - Black Pink (?)
  - Red > Purple
  - Yellow Vector Layer: Less Good
- Cutouts
- Silkscreen:
  - White PED - Not Good Black
- PIC 10F200?
  - Single Button!
  - (Wake on INT.)
  - No Need for Power Switch
- Modes: Steady On
  - Blink
  - Alternate Blink
  - Pwm Dimming?

DEFCON 14
BADGE
CONCEPT
3/31/06
4-5 pm

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Specifications: Defined Feature Set

- After some back-and-forth discussions, we settled on the functionality and artistic elements:
  - DEFCON logo and icons on top copper layer
  - Crossbones and smile to be cutout
  - Different soldermask colors for different DEFCON clientele
  - Single button for user control (no power switch)
  - Multiple LED states:
    - Both Steady On
    - Both Blink
    - Alternating
    - Random (Pseudo-random, actually)
Preliminary Schematic

DEFCON 14 CIRCUIT BOARD BADGE 2/28/06
PRELIMINARY SCHEMATIC

VCC

LEDs

PIC10F

6F8

SOT23-6

3V

CR2032 (DK# P189-ND)
W/ KEMISTONE 3002 BATTERY HOLDER (DK# 3002T-ND)

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Breadboarding/Code Development

1. Turn preliminary sketch into something physical
2. Evaluate different types of LEDs
3. Write the embedded code for the Microchip PIC10F202 processor
4. Fine-tune and tweak hardware and code until it functions as specified
Breadboarding

- Breadboarding: A method to build circuits without soldering or creating custom PCBs
  - The ideal method of prototyping
  - Utilizes a plug board and 24AWG solid wire
  - Not recommended for high frequency/RF circuits
Breadboarding: LED Evaluation
Breadboarding: Prototype Circuitry
Code Development

- Used CCS PCM compiler for Microchip PIC10F202 with MPLAB IDE v7.30
  - Ex.: www.ccsinfo.com
  - Free development tools are available, too (www.microchip.com)

- Simple state machine

  ```c
  typedef enum
  {
    SLEEP,
    STEADY,
    BLINK,
    ALT,
    RANDOM
  } state_type;
  ```
Code Development 2
Final Schematic
Drawing Schematics

- Many professional tools available, mostly in the $5k-$10k range
  - Ex.: Cadence/OrCAD Capture, [www.orcad.com](http://www.orcad.com)
  - Ex.: Altium/Protel DXP, [www.altium.com](http://www.altium.com)
- Demo licenses for some professional tools
  - Usually expire after 30 days
- Some fully-free software available
  - Ex.: gEDA, [http://geda.seul.org](http://geda.seul.org), complete open-source PCB, schematic capture, and simulation for Unix platforms
Drawing Schematics 2

- Microsoft Visio can perform rudimentary schematic capture using common symbols
  - Cannot easily create custom parts
  - Cannot export a Netlist for use with PCB design
Bill-of-Materials

- Cost issues (had to keep around $5/unit total)
- Had to make sure that all selected components were available in large quantities
- Used trusty Digi-Key and Mouser catalogs to create first draft BOM
- Enlisted Future Electronics to help with cost reduction and large quantity ordering
  - Typically 30% of the cost of Digi-Key, Mouser, etc.
  - More on this later…
Bill-of-Materials 2

DEFCON 14 Circuit Board Badge
Bill-of-Materials
Document Version 1.3, April 17, 2006

Note: BOM is for budgetary purposes only and does not include shipping costs or taxes

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Reference</th>
<th>Manufacturer</th>
<th>Manuf. Part #</th>
<th>Distributor</th>
<th>Distrib. Part #</th>
<th>Description</th>
<th>Unit Price</th>
<th>Per Build</th>
<th>MIN/MULT</th>
<th>Extended Price</th>
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<td>1</td>
<td>1</td>
<td>BT1</td>
<td>Keystone</td>
<td>3022TR</td>
<td>Fai</td>
<td>3022TR</td>
<td>Battery holder, 20mm coin cell, SMD</td>
<td>$0.1050</td>
<td>$0.1000</td>
<td>500/500</td>
<td>$50.00</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>C1</td>
<td>AVX</td>
<td>0603YC104JAT2A</td>
<td>Fai</td>
<td>0603YC104JAT2A</td>
<td>0.1uF bypass capacitor, 16V, X7R, 0603</td>
<td>$0.0096</td>
<td>$0.0096</td>
<td>100/100</td>
<td>$9.60</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>01_02</td>
<td>Lumax</td>
<td>SSL_LX10013USBC</td>
<td>Fai</td>
<td>SSL_LX10013USBC</td>
<td>10mm LED, Blue water clear, 800mcd, 3.6V</td>
<td>$0.7000</td>
<td>$0.7000</td>
<td>100/100</td>
<td>$14.00</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>R1_R2</td>
<td>Any</td>
<td>CRCW0603-102JRT1</td>
<td>Fai</td>
<td>CRCW0603-102JRT1</td>
<td>1 Oh, 5%, 1/10W, 0603</td>
<td>$0.0016</td>
<td>$0.0016</td>
<td>1000/1000</td>
<td>$3.20</td>
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<td>5</td>
<td>1</td>
<td>SW1</td>
<td>Panasonic</td>
<td>EVO-PPD-A25</td>
<td>Digi-Key</td>
<td>P808/STR-ND</td>
<td>SPST momentary pushbutton switch, 240gf, 50mA, SMD</td>
<td>$0.3250</td>
<td>$0.3250</td>
<td>100/100</td>
<td>$32.50</td>
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<td>6</td>
<td>1</td>
<td>U1</td>
<td>Microchip</td>
<td>PIC10F202T-40T</td>
<td>Digi-Key</td>
<td>PIC10F202T-40T-ND</td>
<td>PIC Microcontroller, SOT23-6 (includes programming)</td>
<td>$0.0416</td>
<td>$0.0416</td>
<td>100/100</td>
<td>$4.16</td>
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<td>7</td>
<td>1</td>
<td>PCB</td>
<td>e-Tecknet</td>
<td>DEFCON 1.0</td>
<td>e-Tecknet</td>
<td>PCB (includes assembly and testing)</td>
<td>$2.3100</td>
<td>$2.3100</td>
<td>100/100</td>
<td>$23.10</td>
<td></td>
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Build Quantity 6055

Total | $32,483.29
Approximate Per Unit Cost | $5.36
PCB Design

- Three general methods to create custom PCBs:
  1. Homebrew w/ PCB etching kit
  2. PCB prototyping systems
  3. Professional fabrication

- Printed Circuit Board (PCB) etching kit
  - Low-cost method for quick homebrew hacks (practically instant gratification)
  - Uses hazardous chemicals (ferric chloride) which etch away any copper on the circuit board that isn't protected by resistant ink or toner
  - Ex.: MAKE Magazine issue 2
PCB Design 2

November 1993

April 2000
PCB Design 3

- PCB prototyping systems
  - Highly specialized, accurate CNC machine
  - Allows quick in-house creation of prototype PCBs
  - > $10k for a decent system
  - Not practical for most hardware hacking purposes
  - Ex.: LPKF Laser & Electronics (www.lpkf.com) and T-Tech (www.t-tech.com)
PCB Design 4

- Professional fabrication
  - More convenient and better quality than homebrew, why bother with dangerous chemicals anymore?
  - Can handle very fine pitch, tight tolerances, etc.
  - Prototype and production quantities
  - Competition between firms leads to good deals for us
    - Prototype specials
    - On-time guarantees
    - Price matching
  - 2-layer board costs ~$20-30 each (~$1-$5 in quantity)
  - 4-layer board costs ~$50 each (~$3-$10 in quantity)
PCB Design 5

- Many production houses available online
  - Advanced Circuits, www.4pcb.com
  - Sierra Proto Express, www.sierraprotoexpress.com
  - AP Circuits, www.apcircuits.com
  - Express PCB, www.expresspcb.com

- e-Teknet fabricated and assembled the prototype and production DEFCON badges
  - Check them out in the exhibitor area…
  - (No, I didn’t get paid to put this in here!)
PCB Design 6

Design tools…

- Many professional tools available, some upwards of $5k-$10k
  - Ex.: Altium/Protel DXP, www.altium.com
  - Ex.: McCAD EDS, www.mccad.com, 200 pin limit for free

- Some fully-free software available
  - Ex.: gEDA, http://geda.seul.org, complete open-source PCB, schematic capture, and simulation for Unix platforms
  - Ex.: Express PCB offers a free captive design tool for use with their own manufacturing
PCB Design 7

- High-level process:
  1. Create schematic
  2. Output Netlist
  3. Import Netlist into PCB design software
  4. Create PCB
  5. Output Gerber plots
  6. Submit Gerber plots to PCB fab house
Badge PCB Design: Process

1. Verify desired size of badge & artistic elements
2. Create mechanical outline of board
3. Add logos to top side copper
4. Place components in desired locations
5. Import Netlist (based on final schematic)
6. Route board (keep all traces on bottom side)
7. Add logos to bottom side silkscreen
8. Run verification tests
9. Output Gerber plots
Badge PCB Design: Verifying Sizes

Y = BADGE ACTUAL SIZE

3550 mil

600 mil

600 mil

11756 mil
Badge PCB Design: Mechanical Layer

- Material: 0.062 in. FR4
- Copper: 1 oz.
- Drill Tolerance ±0.003 in.
- Fab Tolerance ±0.010 in.
- Max Component Height: N/A

Notes for PCB:
1. Use smallest routing bit as possible
2. Defined internal areas MUST be cut-out
Badge PCB Design: Top Layer
Badge PCB Design: Bottom Layer
Badge PCB Design: Mock-up
Prototype Testing

- Before placing large order of PCBs, need to verify that the design functions as expected
- Ordered a few bare prototype PCBs from e-Teknet
  - Had careful discussions with them to ensure that our complicated cutout areas and features were conveyed properly to their Chinese factory
  - I’m sure they’re sick of me by now! 😊
- Hand-assembled some boards
- Sent to The Dark Tangent and Ping for final sign-off
Prototype Testing: Current Measurements

DEFCON 14 BA06E - PROTOTYPE CURRENT MEASUREMENTS

3/19/06

1 RED, 1 BLUE

SLEEP ≈ 0.1 mA < NEGIGIBLE

STRESS = 0.88 mA

BLUE: 2.04 mA

BLINKS 3.4 mA min. to 0.72 mA max = 0.56 mA AVERAGE

ALTERNATE = 0.52 mA to 0.62 mA max = 0.56 mA AVERAGE

RANDOM = 0.24 mA to 1.57 mA max = 0.91 mA AVERAGE

1.144 mA AVG.
Prototype Testing:
Current Measurements 2

\[ CP_{2032} = 3.0 \text{ e 2.75mA} \text{ to } 3V \]

**Based on ideal conditions; continuous use:**

- **Sleep:** 756.8 hours \( \rightarrow \) Battery would self-discharge before then.
- **Steady:** 255.7 hours \( = 10.6 \text{ days} \)
- **Blink/Alternate:** 401.78 hours \( = 16.7 \text{ days} \)
- **Random:** 247.25 hours \( = 10.3 \text{ days} \)
Joe says “A-OK!”
Parts Sourcing

- Ended up being the most difficult/time consuming part of the process
- On strict deadline to obtain parts for 6,055 units and ship to e-Teknet to begin assembly
  - No parts == No badges for DEFCON! 😞
- Placed all quantity orders with Future Electronics
- Since Future (and most large distributors) has minimums and multiple requirements, ordered remaining pieces from Digi-Key & Mouser
- Used Digi-Key to purchase and program code into PIC10F202s
Issues w/ Future:

- Misquoted leadtimes
  - “They’ll be here in 3 weeks” – parts arrive after 6
- “Lost” parts
  - Only 500 LEDs were shipped – sales couldn’t find the other 11,700!? 
- Slow shipping
  - What part of “I need these parts tomorrow” do you not understand?

After much pressure, I was “upgraded” to a more competent sales contact

All problems were finally resolved!
Parts Sourcing 3

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**DEFCON 14 Circuit Board Badge**

*Bill of Materials*

*Document Version 1.3, April 17, 2006*

Note: BOM is for budgetary purposes only and does not include shipping costs or taxes.

<table>
<thead>
<tr>
<th>Part</th>
<th>Reference</th>
<th>Manufacturer</th>
<th>Manual Part #</th>
<th>Distributor</th>
<th>Distrib. Part #</th>
<th>Descriptions</th>
<th>Unit Price</th>
<th>QTY</th>
<th>MINU MLT</th>
<th>Extended Price</th>
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<tr>
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<td>BT1</td>
<td>Honeywell</td>
<td>70076R</td>
<td>FAI</td>
<td>300277R</td>
<td>Battery Tender, 20mm X 32mm, SWD</td>
<td>$0.1935</td>
<td>5000</td>
<td>MIX 4000</td>
<td>$9.6775</td>
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<tr>
<td>2</td>
<td>NCA</td>
<td>Honeywell</td>
<td>70076R</td>
<td>FAI</td>
<td>300277R</td>
<td>Battery Tender, 20mm X 32mm, SWD</td>
<td>$0.1935</td>
<td>5000</td>
<td>MIX 4000</td>
<td>$9.6775</td>
</tr>
<tr>
<td>3</td>
<td>CI</td>
<td>ACE</td>
<td>3801017/164172A</td>
<td>FAI</td>
<td>300277R</td>
<td>0.5 lbs Sintered, 16x24x12, SMD</td>
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<td>FAI</td>
<td>300277R</td>
<td>LED, 5 mm, 5mA, 3.0 V, SMD</td>
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<td>5000</td>
<td>9000</td>
<td>$57.50</td>
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<tr>
<td>1</td>
<td>KBR2</td>
<td>Ayr</td>
<td>70076R</td>
<td>FAI</td>
<td>300277R</td>
<td>14.5% BOA, 1000, SWD</td>
<td>$22.00</td>
<td>5000</td>
<td>9000</td>
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<td>Quanta</td>
<td>70076R</td>
<td>FAI</td>
<td>300277R</td>
<td>16x24x12, SMD</td>
<td>$2.0735</td>
<td>5000</td>
<td>9000</td>
<td>$10.3675</td>
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<td>300277R</td>
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<td>$2.0735</td>
<td>5000</td>
<td>9000</td>
<td>$10.3675</td>
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**Total**

$12,483.29

**Approximate Per Unit Cost**

$6.35

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- Mailed to eTelenet
- C1, SW1, C1 received & accepted

6/7/06

- 500 x D1/D2
- 15K = 10K

660 x R11

- 1/2 box
- 1/2 box

- 680 backorder
- Cancelled future

- Online components.com
- 11/0/06 receipt
- eTelenet

6/15/06

- 300 x 2,400 x 8400
Quantity Order

- Placed 6,055 unit order with e-Teknet
- While components were being acquired, they helped us decide on the seven soldermask colors and began PCB fabrication
- Sent them BOM, Parts Placement, and Test Procedure to aid in assembly
- Tested and approved First Articles
- Pulled the trigger on the full quantity build!
Quantity Order: Color Samples
Quantity Order: Final Colors

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Type</th>
<th>Color</th>
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<tr>
<td>5185</td>
<td>HUMAN</td>
<td>White</td>
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<tr>
<td>250</td>
<td>GOON</td>
<td>Pea #13</td>
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<tr>
<td>200</td>
<td>PRESS</td>
<td>Green (Standard)</td>
</tr>
<tr>
<td>200</td>
<td>SPEAKER</td>
<td>Blue #60</td>
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<tr>
<td>100</td>
<td>VENDOR</td>
<td>Purple #73</td>
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<tr>
<td>100</td>
<td>VIP</td>
<td>Black</td>
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<tr>
<td>30</td>
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Total: 6055
Parts Placement

DC14 Rev. 1.0 Parts Placement Top
Parts Placement 2

DC14 Rev. 1.0 Parts Placement Bottom
Test Procedure

DEFCON 14 Badge Revision 1.0
System Level Test Procedure

J. Grand, April 9, 2006

Front
Back
Test Procedure 2

Test Procedure:

1. Insert CR2032 lithium coin cell battery or apply power (+3V DC) to the following points:
Test Procedure 3

2. Press and release momentary switch on back of PCB
3. Both LEDs on front should illuminate:
Test Procedure 4

4. Press and release momentary switch on back of PCB
5. Both LEDs on front should blink on and off together
6. Press and release momentary switch on back of PCB
7. LEDs on front should alternate on and off (left on, right on, left on, etc.)
8. Press and release momentary switch on back of PCB
9. LEDs on front should illuminate in some random order
10. Press and release momentary switch on back of PCB
11. Both LEDs on front should be off
12. Remove power
13. Test complete
Test Procedure 5
First Article Approval: Front
First Article Approval: Back
DEFCON Badge Hacking Contest

- What can you do with two LEDs, a switch, some discrete, and a Microchip PIC10F202?
- The most obscure, obscene, or mischievous badge hack will be recognized and awarded at the DEFCON Award Ceremonies on Sunday
- Microchip development tools are available at the show for your use
- Find me later if you want to check out what I’ve done to mine 😊
Thanks for Coming!

Joe Grand (Kingpin)

joe@grandideastudio.com