Lecture #21

Other I/O, Humans & Security

18-348 Embedded System Engineering

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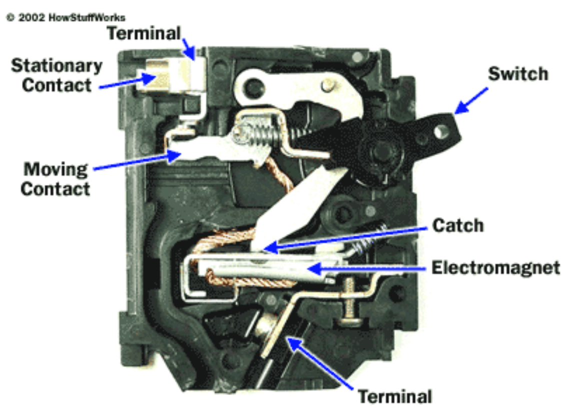
Monday, 4-April-2016

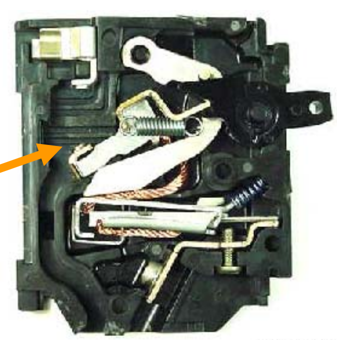
Electrical & Computer ENGINEERING

Carnegie Mellon

Traditional Circuit Breaker



Limit to operation is high-current arcing when contacts are opened



http://electronics.howstuffworks.com/circuit-breaker2.htm

PROGRAMMABLE CIRCUIT BREAKER

on Mon-January-2005

The ESS60-T is a programmable electronic circuit breaker that enables users to program the current rating, program the low-voltage threshold, control circuits remotely, and prioritize loads during battery backup. The solid state circuit breaker is designed for switching DC loads common in telecommunications equipment functioning in wireless infrastructure, switching stations, and routing stations. It is particularly suited to 48V battery backup applications, because its programmable design gives users control over loads.

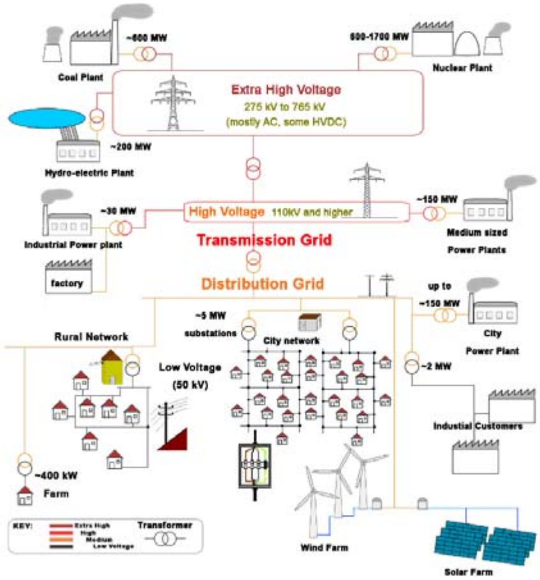
E-T-A Circuit Breakers

Tag it:

http://www.electronicsincanada.com/index.php/PROGRAMMABLE-CIRCUIT-BREAKER.html

Just One Piece of the Power Grid

- **The whole grid is moving toward Internet-based real time control**



Is There a Security Problem Here?

[Wikipedia]

Where Are We Now?

- **Where we've been:**
  - Analog Output
  - Analog Input
- **Where we're going today:**
  - Human I/O – LEDs and switches
  - Other typical embedded I/O
- **Where we're going next:**
  - Gentle introduction to control
  - RTOS
  - Bluetooth & CAN
  - Booting & robust systems

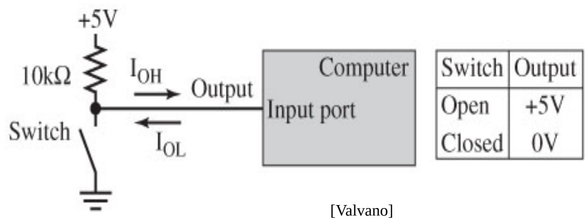
Preview

- **Switches**
  - Debouncing
  - Switch Matrices
- **LEDs**
  - LED Matrices
  - Seven Segment Displays
  - LCD overview
- **Linear electromagnetic devices**
  - Relays
  - Solonoids
- **Rotational Devices**
  - Shaft encoders
- **Other I/O-related concerns**
  - Security
  - Human factors

Input Switches Revisited

- **Pull-up input switch**
  - Draws current from +5V when open

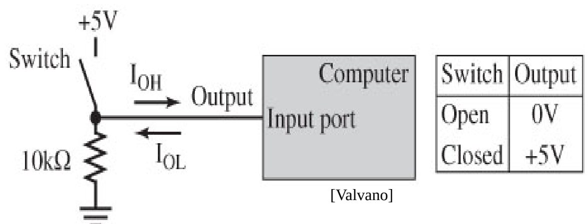
Figure 8.1
A simple switch interface.



[Valvano]

- **Pull-down input switch**
  - More prone to noise fluctuations (less noise margin at 0V on most ICs)

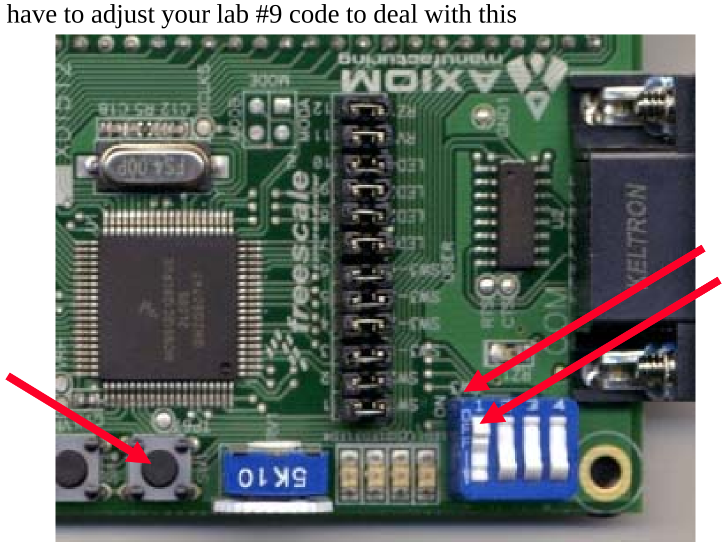
Figure 8.2
Another simple switch interface.



[Valvano]

CPU Module Switches Are Pull-Down/Active Low

- **Horrible human interface marking – "OFF" side is really "ON"**
  - Arrow points to OFF position in the DIP switches – but PCB says "ON"
  - May have to adjust your lab #9 code to deal with this

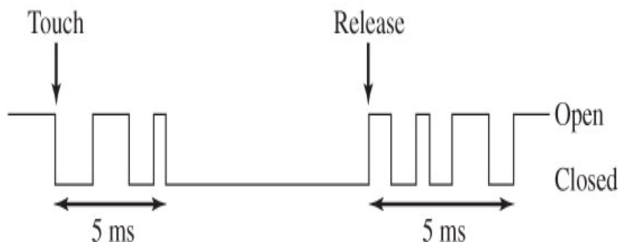


Switch Bounce

- **Switches have mechanical contacts**
  - They take time to move positions
  - They take time to mechanically stabilize when opening and closing
  - They create sparks, especially when opening at high current

Figure 8.4
Switch timing showing bounce on touch and release.

[Valvano]



- Caution: 5 ms is representative for small switches, but not a universal number!

Hardware Switch Debounce

- **Problem with bad circuit – causes arcing when closing the switch**
  - Almost-infinite current when switch is first closed to discharge the capacitor
    - Switch bounces when being closed, so you get an arc from that high current

Figure 8.6
Switch bounce removed with a capacitor (this is a bad circuit).

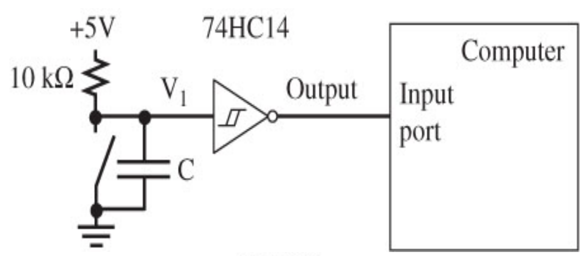
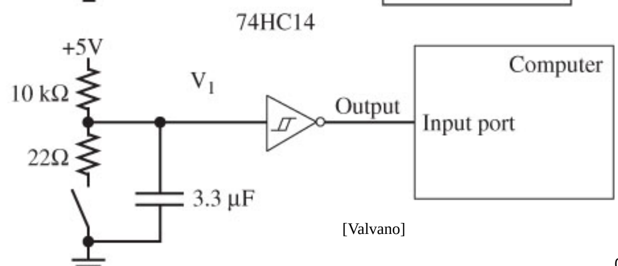
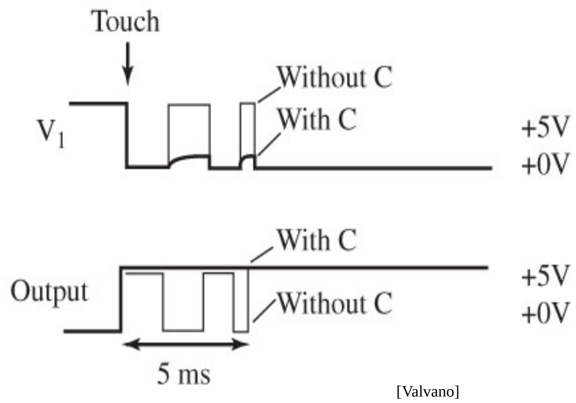


Figure 8.11
A hardware interface that removes the bounce (good circuit compared to Figure 8.6).



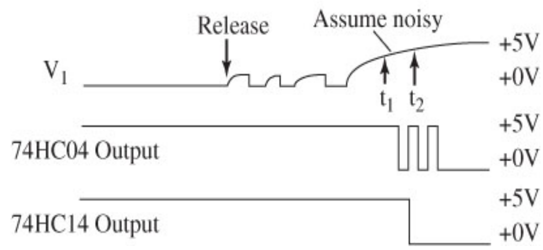
[Valvano]

Figure 8.7
Switch touch bounce is removed by the capacitor.

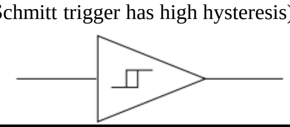


[Valvano]

Figure 8.13
Timing showing why a 74HC14 is used instead of a regular digital gate.



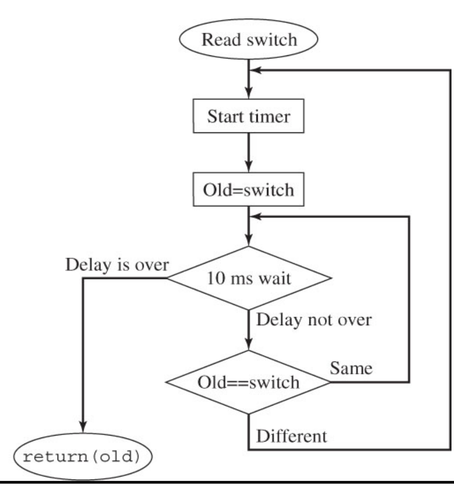
(Schmitt trigger has high hysteresis)



Software Debouncing

- **Saves external hardware components**
  - Idea: wait until switch value is steady for 10 ms
  - BUT, counts on input hardware on IC to clean up indeterminate voltages
    - "Metastable" inputs – hang at middle of switching threshold for a long time

Figure 8.16
Another software flowchart for debouncing the switch.



[Valvano]

How Do You Read Multiple Switches?

- **Simple way – one I/O pin per switch**
  - This scales very poorly for large number of switches!

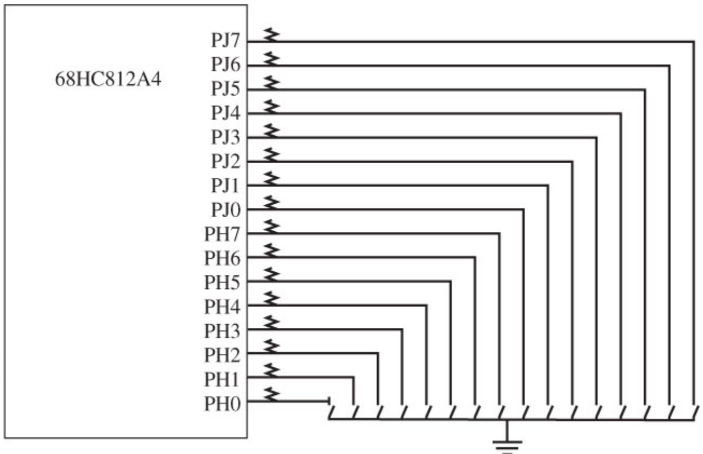


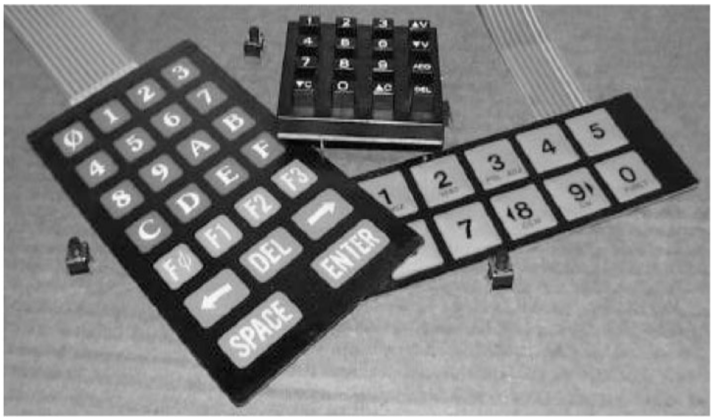
Figure 8.24
Hardware interface for the 6812.

[Valvano]

Interfacing To Many Switches

- **How can you reduce number of contacts for multiple switches?**
  - For desktop keyboards – use an 8-bit microcontroller and serial interface
  - For other applications, need a clever switch arrangement

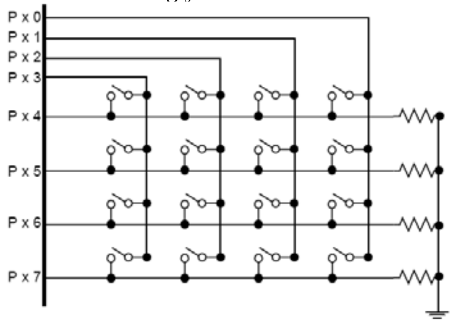
Figure 8.20
Multiple keys are implemented by placing the switches in a matrix. (Notice there are fewer wires in the cable than there are keys.)



[Valvano]

Switch Matrix

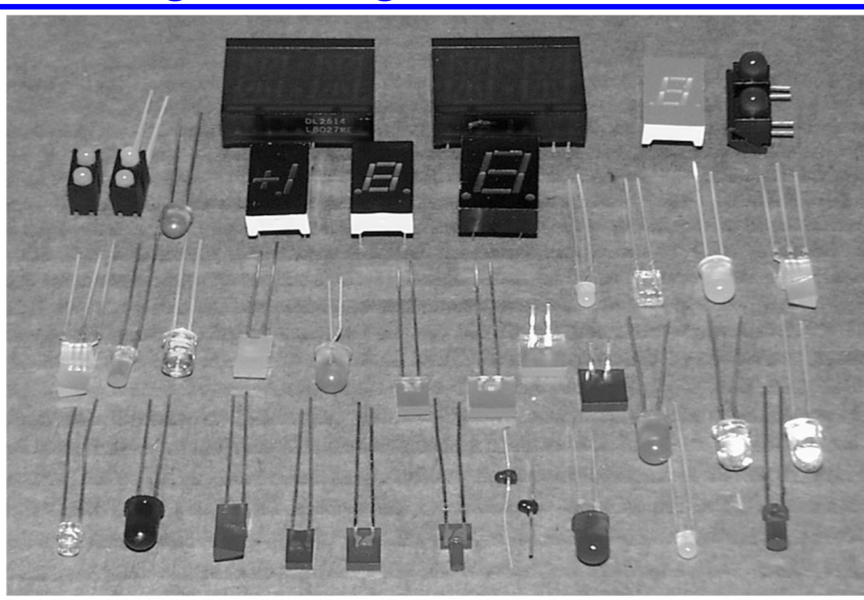
- **Uses 2*sqrt(N) pins for N switches**
  - Control input to switch as well as reading output
  - Activate only one Column (Px0, Px1, Px2, Px3) to high
    - Configure rest as ignored inputs or set to high impedance
  - Read Row values to find a depressed key (Px4, Px5, Px6, Px7)
  - What happens when two keys are pressed?
    - Short between two rows if they are in the same column, but that's OK
    - Size resistors accordingly to ensure reasonable current with multiple closures



[Freescale]

Figure 1. Resistor Matrix Keypad Using Parallel Port Pins

LEDs – Light Emitting Diodes

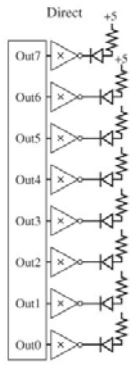


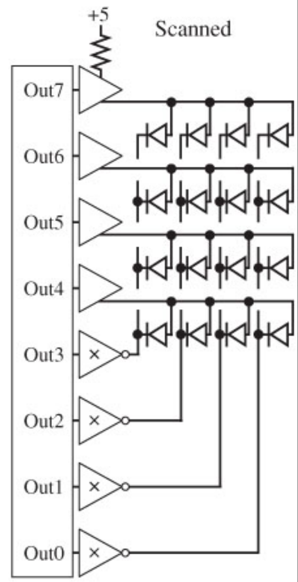
[Valvano]

Figure 8.28
LEDs come in a wide variety of shapes, sizes, colors and configurations.

Driving LEDs

- **The matrix trick works on driving LEDs too**
  - Direct LEDs – one LED per output pin
  - Scanned LEDs:
    - Set one of Out4..Out7 high to activate a row of LEDs
    - Set one of Out0..Out3 high to activate a column of LEDs (output of inverter is low)
    - Only LED at intersection of selected row/column will see voltage difference

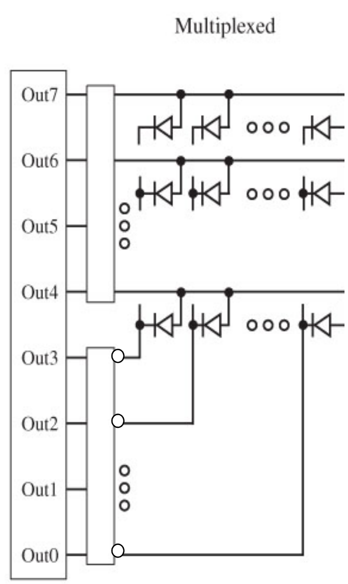




[Valvano]

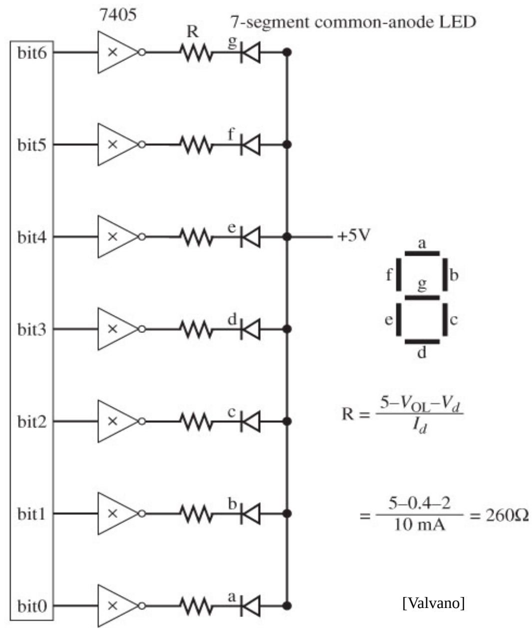
Multiplexed LEDs Scale Even Better

- **To turn on one multiplexed LED:**
  - Set Out4..Out7 to be the <u>number</u> of the row of the LED
    - For 4 output bits, there are 16 rows
  - Set one of Out0..Out3 to be the <u>number</u> of the column of the LED (output of inverter is low)
    - For 4 output bits, there are 16 columns
  - LED at specified row number/column turns on
- **Practicalities:**
  - One LED is always on
    - So perhaps 15x15 instead of 16x16
  - Need to turn each LED on long enough to be reasonable brightness
    - Perhaps make extra-bright
  - Diagram doesn't show resistors to control LED current!

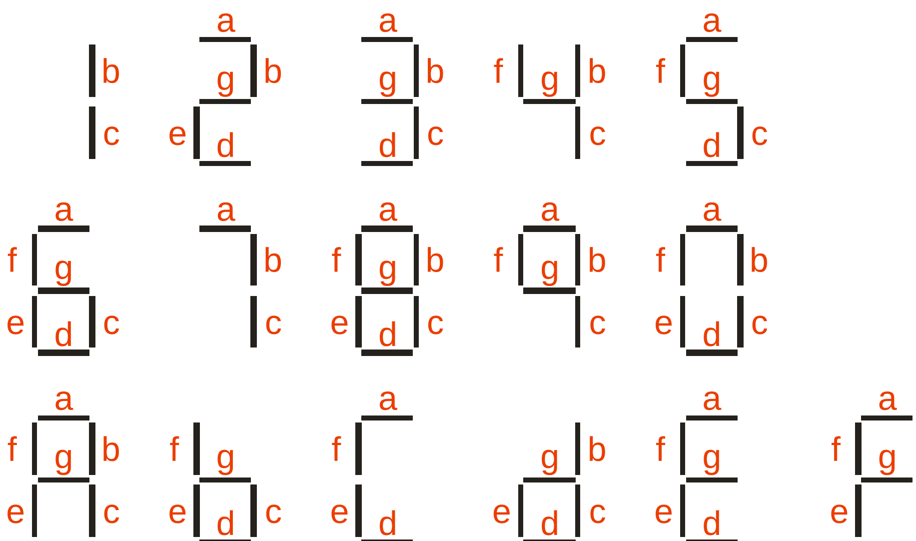


Seven-Segment Displays

Figure 8.35
Seven-segment common-anode LED interface.

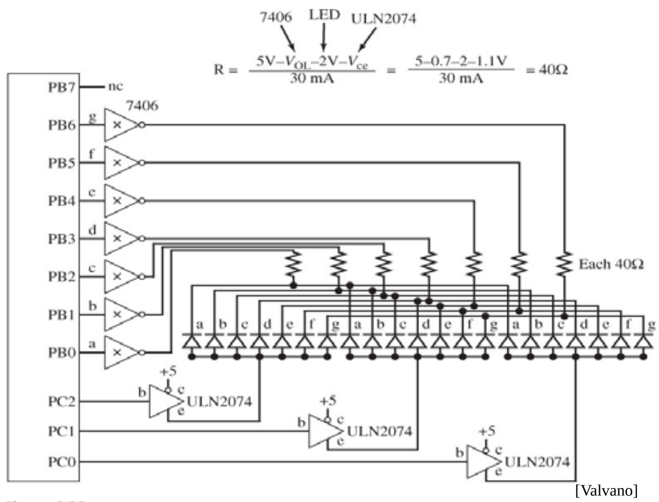


LED Hex Digits



Scanned Seven-Segment Display (3 digits)

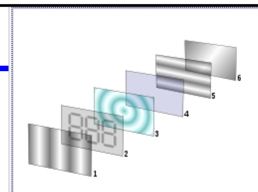
- **Turn on by: PBx high (one per segment) and PCx high (one per digit)**
  - Resistor on PBx side so only one diode at a time goes through each resistor
  - PB side of diode goes low; PC side goes high, turning diode ON = light



[Valvano]

Figure 8.38
Circuit used to scan a LED interface. (For the MC9S1232 replace PB with PT and replace PC with PM.)

LCD – Liquid Crystal Display



Reflective twisted nematic liquid crystal display.

1. Polarizing filter film with a vertical axis to polarize light as it enters.
2. Glass substrate with ITO electrodes. The shapes of these electrodes will determine the shapes that will appear when the LCD is turned ON. Vertical ridges etched on the surface are smooth.
3. Twisted nematic liquid crystal.
4. Glass substrate with common electrode film (ITO) with horizontal ridges to line up with the horizontal filter.
5. Polarizing filter film with a horizontal axis to block/pass light.
6. Reflective surface to send light back to viewer. (In a backlit LCD, this layer is replaced with a light source.)

http://en.wikipedia.org/wiki/Liquid_crystal_display

- **Low power, high contrast display technology**
  - Pre-configured electrodes for display shapes
  - Display has two fixed polarization layers
  - Liquid crystals twist the polarization of light passing through
    - If crystals don't twist, all light is blocked
      (horizontal | no twist | vertical ➔ no light)
    - If crystals twist, light gets through
      (horizontal | 90° twist | vertical ➔ all light)
  - Color & gray scale:
    - Gray scale: intermediate levels of twist by varying voltage
    - Color: use color filters on sub-pixels (3 colors per pixel)
- **Interfacing methods vary**
  - ASCII LCD has on-board microcontroller
    - Just send it bytes
  - Raw interface is usually done via scan lines
    - Similar to writing to DRAM
    - Uses a per-pixel capacitor to save row state
    - Must be refreshed periodically
  - Much lower power than LED
    - Passes through light source instead of emitting light

A Word About Human Computer Interaction

- **Not everyone is a 21 year old male engineering student**
  - (Nor a female engineering student!)
  - So don't design as if that is who your user population is
  - There are experts in the area of HCI – use them!

How full is this battery?

- **Consider how well your system will work with these populations:**
  - Non-English speakers
  - Left-handed (7-10% of population)
  - Color blind (esp. red/green – 7-10% of population)
  - Presbyopia (most people over 45 or so)
  - Polarized sunglasses (LCDs are also polarized; sometimes the wrong way)
  - Hearing impaired; wearing hearing protection
  - Gloves, coats, hats
  - Children (size, weight, child-proofing)
  - Arthritis (can't manipulate small knobs, e.g., childproofing mechanisms)
  - Pets (e.g., cat on keyboard)

I have always wished that my computer would be as easy to use as my telephone.

My wish has come true.

I no longer know how to use my telephone.

– Bjarne Stroustrup, inventor of C++

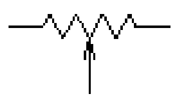
http://www2.research.att.com/~bs/bs_faq.html#really-say-that

Example Usability Problem

- **How do you flush this toilet without getting sprayed in the face?**

Rotational Position Measurement

- **Potentiometer**
  - Variable resistance
  - Problem – requires A/D conversion
  - Problem – wears out
  - Problem – single turn – can't put on a wheel
  - Problem – noise, calibration, …



[Wikipedia]

[Wikipedia]

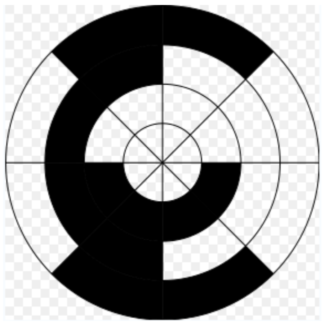
- **Alternate approach – how can we do this cheap & digital?**

Optical Shaft Encoder

- **Idea – use an optical pickup (e.g., photo transistor) looking at a disk on a shaft**
  - Sense “white” or “black” as a “zero” or “one”
  - Can spin as many times as desired without mechanical limitation
  - No wear surfaces, no friction
- **Simplest encoder**
  - One digital “tick” per revolution
  - E.g., a piece of white tape on a black tire
- **Relative positional encoder**
  - Multiple “ticks” per revolution – like gear teeth
  - Need to keep track of how many ticks you’ve seen
  - Can put a really large number of ticks on a disk
    - Limit is tick size and diameter of shaft encoder disk

Absolute Position Shaft Encoder

- **Use multiple concentric shaft encoder values**
  - Any angle reads bars as a set of bits
  - Gives unique binary number for any rotational angle
- **Diagram is conceptual**
  - Real encoders don’t have the lines
  - Real encoders pattern on outer edge only
  - Resolution limited by inner-most band sized
- **Don’t use regular binary counting!**
  - Bit edges & read head won’t be perfectly aligned
  - Use **gray code** to eliminate glitches
    - Each adjacent # differs by only one bit
    - E.g.,: 000, 001, 011, 010, 110, 111, 101, 100, 000

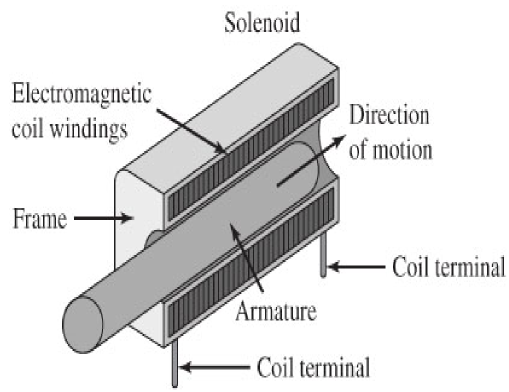


[Wikipedia]
Note: real disk doesn’t have the lines – just the large black bars

Solonoids (Reminder Slide)

- **Used to generate a short-stroke linear motion**
  - Release driven by spring, gravity, or second solonoid on same armature

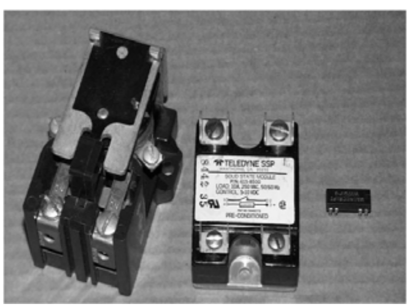
Figure 8.64
Mechanical drawing of a solenoid showing that the EM coil causes the armature to move.



Relays

- **Used when switching high currents**
  - Uses a solonoid + spring (or similar arrangement) to open and close a switch
  - Provides physical isolation when open ("air gap")
  - Can be "open" or "closed"
  - For high current applications, need special care to deal with arcing
    - Software used to open switch at the zero crossing on AC circuits, reducing contactor wear

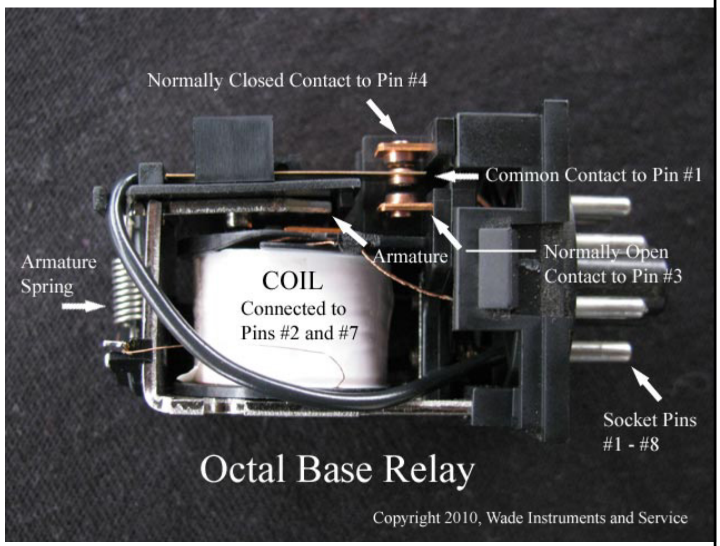
Figure 8.60
Photo of an EM, solid-state, and reed relay.



[Valvano]

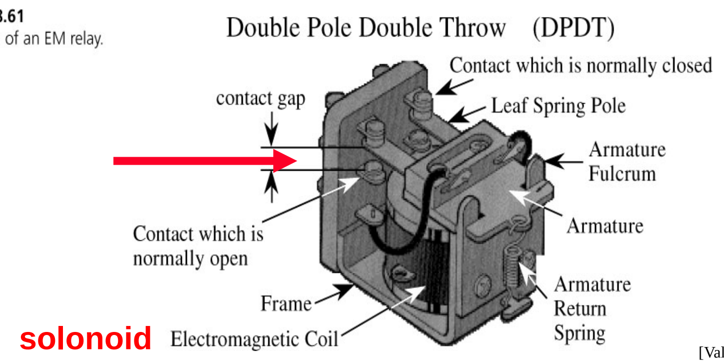
"Ice Cube" Control Relay (e.g., for Elevators)

- Metal "Common Contact" swings up and down with armature



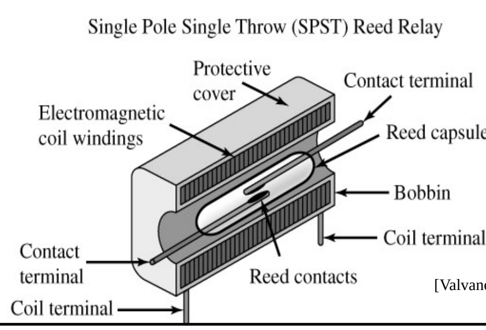
http://www.wadeinstruments.com/relays/control_relay_tutorial.htm

Figure 8.61
Drawing of an EM relay.



[Valvano]

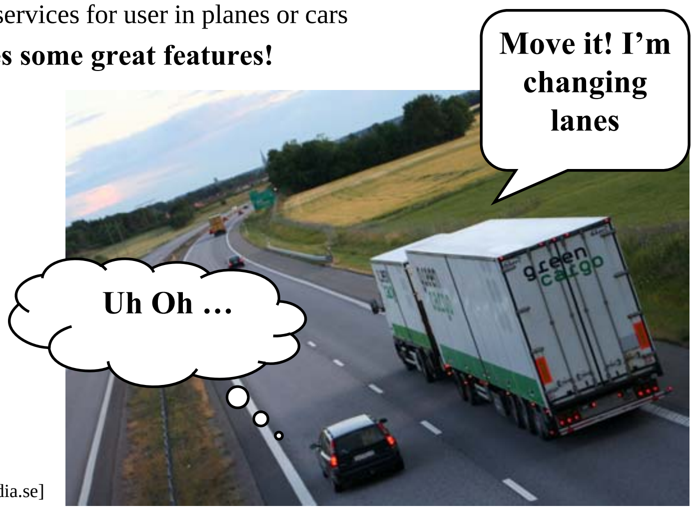
Figure 8.63
Drawing of a reed relay.



[Valvano]

Embedded Systems and the Internet

- **General trend to add connectivity from embedded to external world**
  - Add Internet connectivity to household appliances
  - Wireless vehicle-to-vehicle networks
  - Additional services for user in planes or cars
- **Why? Enables some great features!**



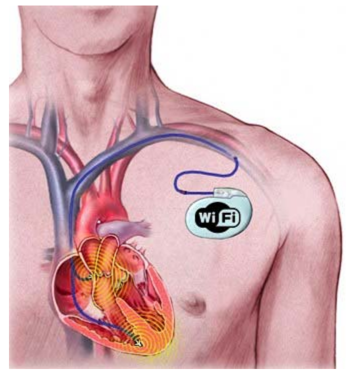
[fredrikmedia.se]

Security Basics In One Informal Slide

- **Properties you may care about:**
  - Secrecy – nobody else can see your data
    - Huge in Internet systems; not necessarily important for embedded
    - Usually provided via encryption
  - Integrity – you are sure the data has not been altered
    - Usually the #1 concern for safety-critical systems
    - Best provided via digital signatures or secure hash functions
  - Authentication – only authorized sources can read/write/manipulate system
    - Important for all systems
  - Privacy – nobody can infer personal information about you
    - Not quite the same as secrecy – you might want to have privacy from trusted parties
  - Availability – system will operate when you need it to
    - "Denial of service attacks" are a financial problem for web sites, but potentially deadly for embedded systems
- **Key insights for embedded systems**
  - Encryption is often the wrong tool for integrity+authentication
  - It's a really good idea to take a security course while you're at CMU

Misconception #1: Security Through Obscurity

- **It's so complicated that we don't need security!**
  - It took a couple grad students a semester to reverse engineer the unpublished communications protocol for a wireless pacemaker
  - You can even access the debug mode
  - PS: the debug mode is a defibrillator.



[engadget.com]

- **Reality: Reverse engineering is not as hard as you would imagine**
  - Its only a matter of time and money
  - Anti-tamper techniques are pretty tricky to get right

Misconception #2: We Can Trust the User

[brother-usa.com]


- **Misconception 2.1: Assume user will maintain the system**
  - This is semi-reasonable for PCs
  - But what about my mom's sewing machine?
  - Is your mom a qualified sysadmin?
  - Will a bot-herder send spam from sewing machines?
    - (or a portable Windows-based oscilloscope?)

- **Misconception 2.2: Assume outside attackers only, trust the user**
  - In embedded systems, the user is often the most hostile attacker
    - Anyone jail-break their iPhone?
    - Did you secure it after the jail-break?
  - Even in critical systems – modifying car engine software
    - Re-tune engine for high performance/bad emissions
    - Over-ride max engine and vehicle speed
      - » Put in place because OEM tires max out at 90 mph

http://gizmodo.com/5395645/dutch-hacker-holds-jailbroken-iphones-hostage-for-5-ransom-while-exposing-security-vulnerability

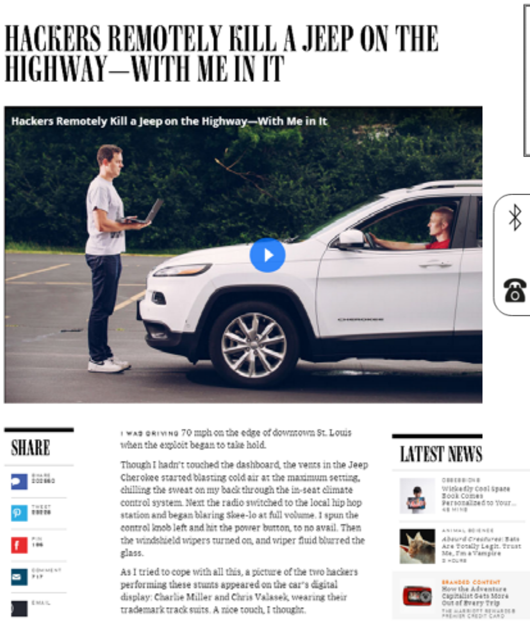
Misconception #3: Discipline Will Solve Security

- **Hackers can't hurt your car if the infotainment system doesn't talk to the braking system**
  - Solution: don't put a connection between the radio and the brakes…
    BUT – this is unrealistic; it will happen because customers demand it!
- **Product idea: Radio volume to achieve constant SNR**
  - Noise based on wheel speed, tire pressure, road surface
  - Which sensors have good information about this?
  - *The electronic stability control system!*
    - *Which is an evolution of anti-lock braking*
  - Reality: the connectivity will happen, denial is counter productive
  - Prototype vehicle of a Big-3 manufacturer suffered failure when the radio speaker caused an engine controller malfunction

[miniusa.com]

Misconception #4: Just Slap a Firewall in There

- **Obviously, we share some vulnerabilities that Internet and PCs have**
  - Especially if we run standard Internet communication protocol stacks
  - And, we often have fewer run-time resources to fight off attacks, no sysadmin, etc.
- **Standard approach:**
  - Firewalls
  - Intrusion detection systems
  - Strong cryptographic mechanisms
- **Reality: Embedded network ≠ Internet**
  - Standard security solutions don't necessarily fit
- **Quickly becomes a research area:**
  - What goes into an embedded gateway?
    - How do you transfer real time control data between CAN and Internet?
  - Strong cryptography?
    - How do you crowbar a 20 byte multicast authenticator into an 8 byte packet?



HACKERS REMOTELY KILL A JEEP ON THE HIGHWAY—WITH ME IN IT

Hackers Remotely Kill a Jeep on the Highway—With Me in It

SHARE

I WAS DRIVING 70 mph on the edge of downtown St. Louis when the exploit began to take hold.

Though I hadn't touched the dashboard, the vents in the Jeep Cherokee started blasting cold air at the maximum setting, chilling the sweat on my back through the in-seat climate control system. Next the radio switched to the local hip hop station and began blaring Skee-lo at full volume. I spun the control knob left and hit the power button, to no avail. Then the windshield wipers turned on, and wiper fluid blurred the glass.

As I tried to cope with all this, a picture of the two hackers performing these stunts appeared on the car's digital display: Charlie Miller and Chris Valasek, wearing their trademark track suits. A nice touch, I thought.

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http://www.wired.com/2015/07/hackers-remotely-kill-jeep-highway/

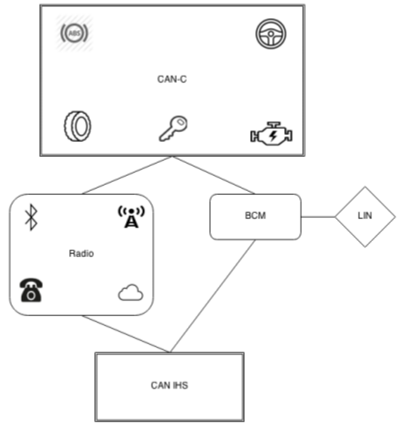
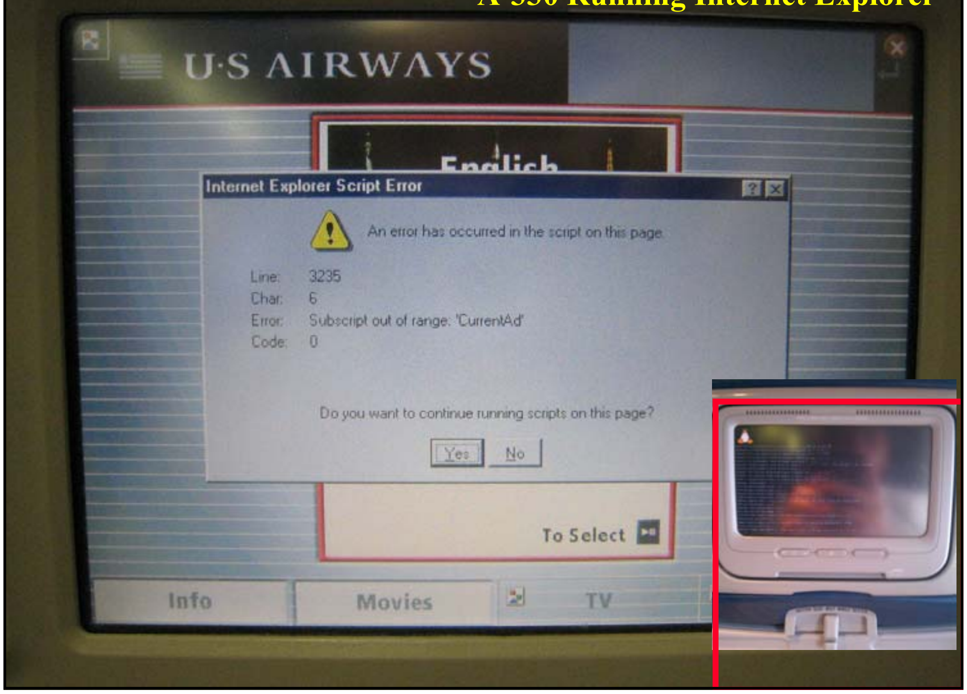


Figure: 2014 Jeep Cherokee architecture diagram

http://illmatics.com/Remote%20Car%20Hacking.pdf

A-330 Running Internet Explorer



Privacy

- **Embedded systems can collect all sorts of info**
  - Location, health, driving habits, activity, …
  - Consumption (food, electricity, gasoline, …)
  - Who should have access to that information? Who actually does have access?
  - Do you believe that anonymization really works? (mostly it doesn't)
- **Privacy is really hard to get right**
  - Even if you have perfect crypto, there is more to it than that
  - People willingly give away info
  - Governments and companies actively try to get info without permission
  - Will privacy sell as a feature? How much would you pay?
- **Do we actually have privacy?**
  - "You have zero privacy anyway," Sun Microsystems chief executive Scott McNealy famously said in 1999. "Get over it."
  - December 2010, Google Chief Executive Eric Schmidt in a CNBC interview: "If you have something that you don't want anyone to know, maybe you shouldn't be doing it in the first place."
  - 2014: NSA tracks who is on Tor; scans e-mail/chat/phone; etc.

Review

- **Switches**
  - Know how to do debouncing in software
- **Matrix interface**
  - Know how to read switches with a matrix
  - Know how to light LEDs with a matrix
- **Electromagnetic devices**
  - Know general principle of operation for a relay
  - Know general principle of operation for a solonoid
  - Know general principle of operation for a stepper motor
- **Rotational Devices**
  - Know how a shaft encoder works
  - Be able to recognize/create a gray code
  - Know how steps per revolution works on stepper motors
- **Security**
  - Key security properties
  - Four myths
- **Human Interaction Considerations**
  - Examples of things to consider