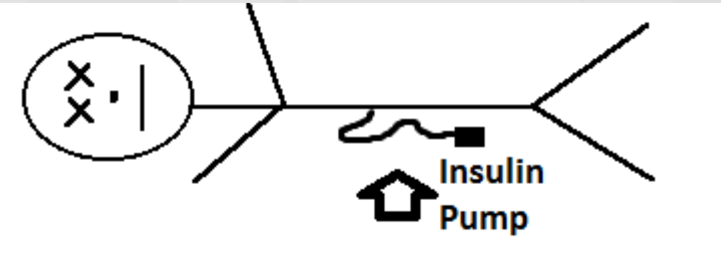
Hacking Medical Devices for Fun and Insulin: Breaking the Human SCADA System

Jay Radcliffe
jay.radcliffe@gmail.com
@jradcliffe02

Can “evil” people hack medical devices?



Me (AKA Dad)

Why Diabetic Devices?

- On my 22nd birthday I was diagnosed with diabetes
- Being a geek, I have a huge assortment of devices to "help" me with my condition
- Defcon 2009 – Parking Meter hacking

Type I Diabetes

- When a person loses the ability to produce insulin
- Rather then the pancreas producing insulin, a person has to administer a synthetic insulin as replacement
- Sounds simple, but there is no magic formula
- Infinite number of variables (Stress, Time of Day, Physical Activity, Illness, Fiber, Fat content)

How Diabetes Works

- Non-PWDs have a blood sugar between 90 – 120
- The liver and pancreas work together to control these levels
- Pancreas produces insulin, which is used to process the sugar into energy (for use or storage)
- Liver holds a sugar (glucose) reserve that can be used if levels get too low

Normal Sugar Relationship

- Normal person eats a Snickers bar (32g Carbs)
- As that sugar enters the blood stream, pancreas produces insulin to match that quantity of sugar to allow the conversion to energy
- Sugar levels might jump 20 “points” as insulin takes effect

Abnormal Sugar Relationship

- PWD eats a Snickers Bar (32g Carbs)
- Diabetics have an equation Amount of Insulin per Grams of Carbs (Mine is 1U Insulin / 10g Carbs)
- Ideally, Insulin is given at the perfect time and mimics human insulin, keeping sugar levels stable.

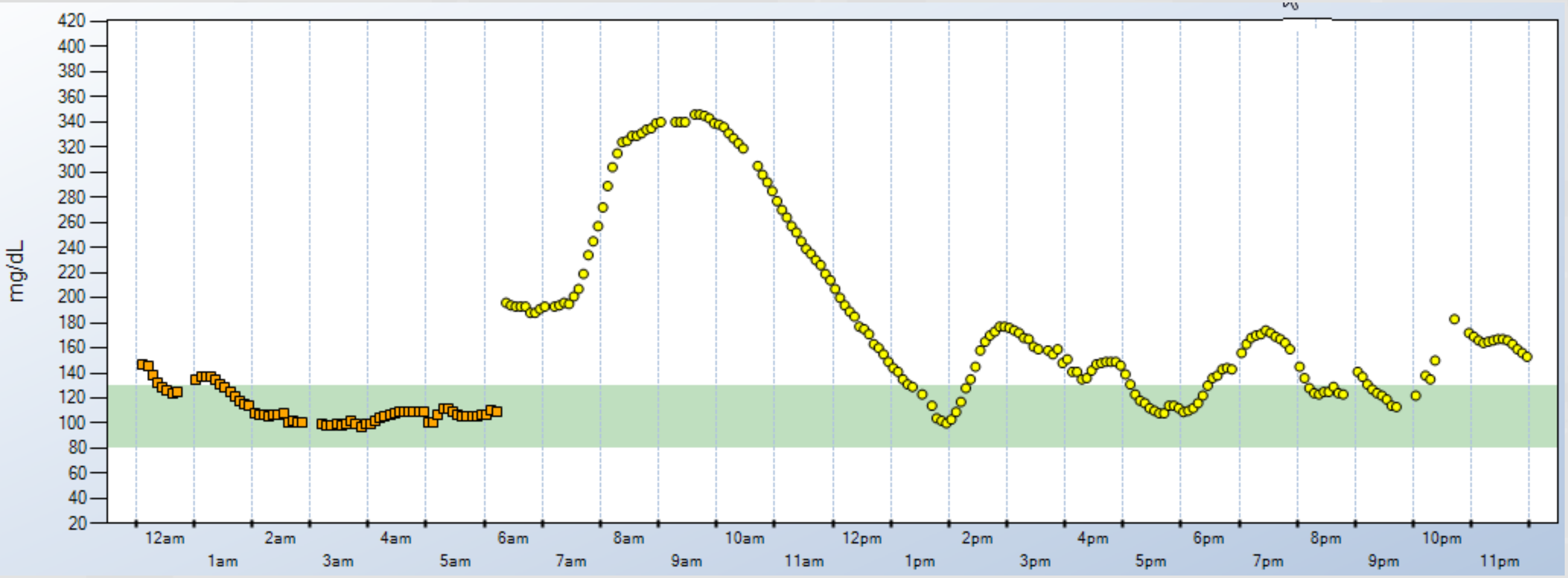
Abnormal Sugar Relationship – No Insulin

- If no Insulin is administered, blood sugar has a huge spike (In my case, 200+ points within 40 minutes)
- Sugar can not be processed into energy, body does two things
  - Filters sugar out through the kidneys. Very stressful to kidneys. Extreme Thirst.
  - Body switched to fat for energy. Also very stressful, causes ketosis potentially ketoacidosis.
- Headaches, blurry vision, long term kidney damage

Abnormal Sugar Relationship – Overdose of Insulin

- If too much Insulin is given, blood sugar can crash to under 60
  - Heart and Brain run on sugar exclusively
  - Body starts to shutdown, conserving available sugar to respiration and heart
  - Starts with: Sweating, loss of fine motor control, shaking hands, overly drunk feeling
  - Uncorrected leads to coma, respiratory failure and death
- Some diabetics lose the ability to feel these symptoms

A Good Day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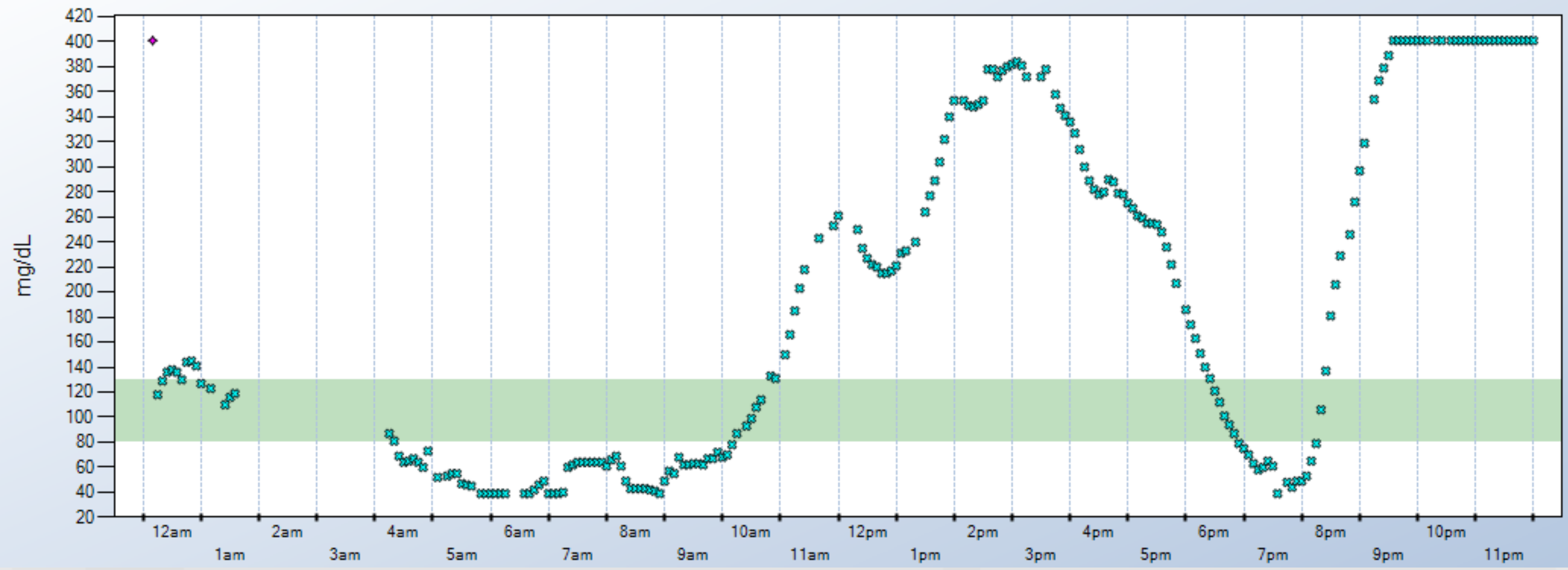
Bad Day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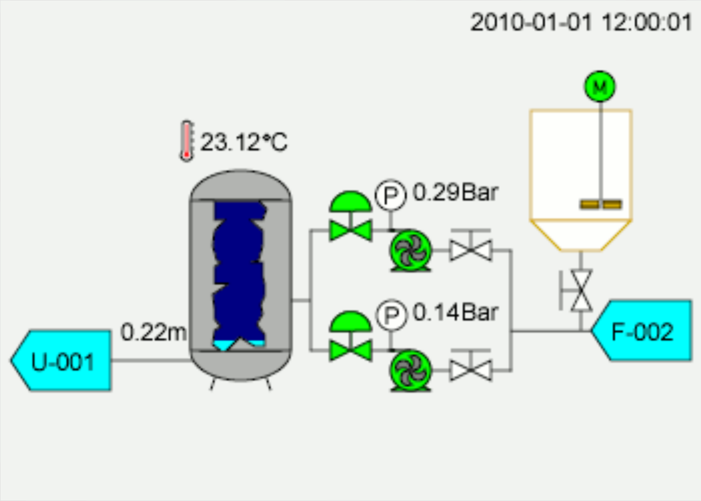
Human Chemical Plant

- Body is like a complex chemical plant
- Relationship between pressure and temperature of chemicals just like insulin and sugar
- The SCADA system monitors the pressure, and adds or removes heating to keep pressure constant.
- Pressure gets too high = BOOM
- Pressure gets too low = water delivery failure



Human SCADA System

- Similar to water, diabetics monitor sugar levels and adjust insulin and food intake to control levels
- Sugar too low? Drink fruit juice or other sugar foods
  - Hard to precisely measure amount of carbs/sugar consumed
  - Could take hours to process total amount of sugar
- Sugar too high? Adjust insulin or wait
  - Fast acting Insulin lasts 3-4 hours in human system, can not be removed. Not easily adjusted
- Frustrating never-ending manual process

Two Technologies – One Purpose

- Continuous Glucose Monitors (CGM)
  - New Technology
  - Small wire in tissue to measure electrical elements of fluid
  - Graphs sugar values over time
  - Huge leap forward

- Insulin Pump
  - Delivers insulin in 2 ways
    - Basel: Every 3 minutes
    - Meal: At Mealtime
  - Delivered through tubing attached to body
  - Tubing replaced every 3 days

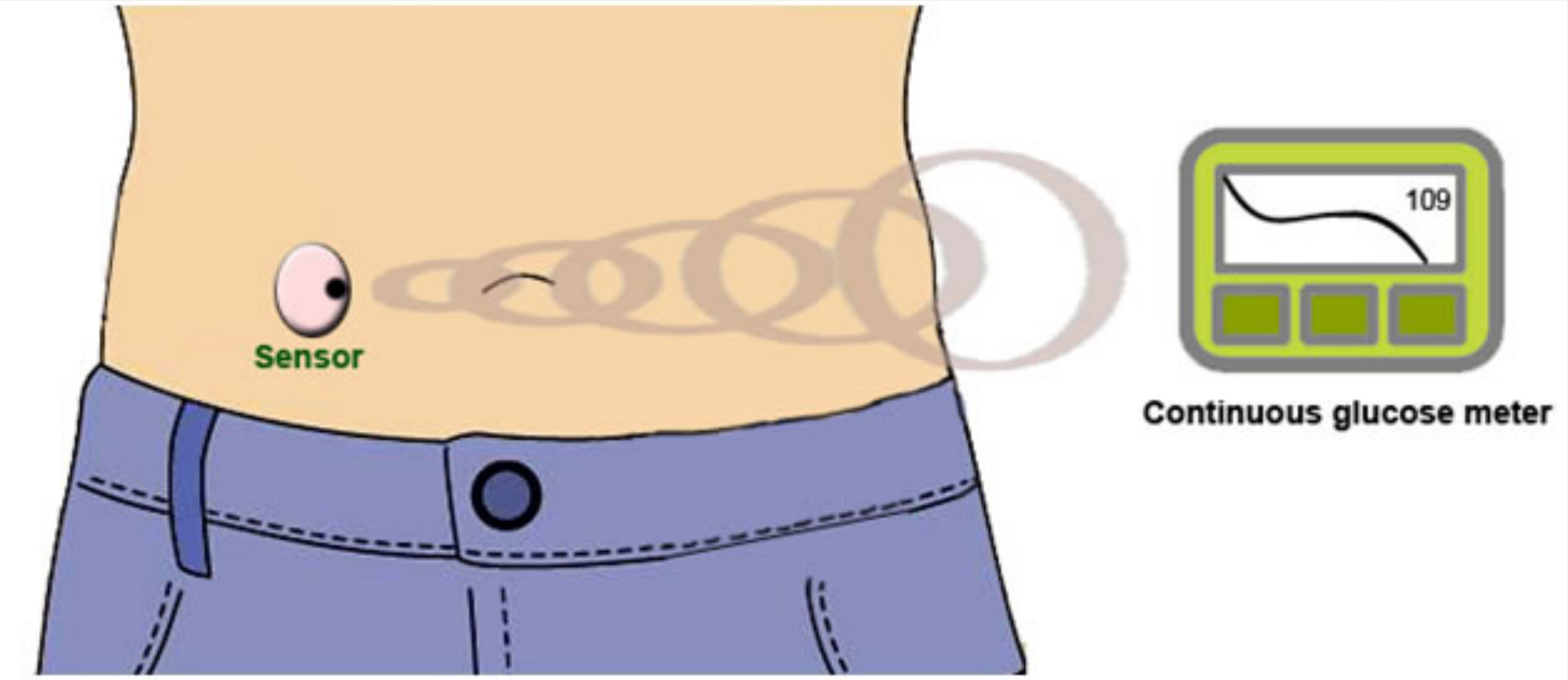
Diabetic Pressure Gauge

- Pre-Tech: Urine Tasting (Yes, for real)
  - Very imprecise, gross, no synthetic insulin
- Early 80's Home Test Kit
  - Blood test, poke finger, get value
  - Live Demonstration!
  - Accuracy varies (10-15%) Cost = $0.75 - $1.25 per test
  - No contextual information (direction/history)
- Still most common used method

Deeper into CGM systems

- Mid-2000's advent of Continuous Glucose Meters
- Measures resistive value of interstital fluid to measure sugar levels
- Wireless Sensor attached to special wire inserted into tissue
- Needs blood testing every 12 hours to calibrate, sensor lasts 7 days (Per FDA regulations) $40-70 per sensor

CGM



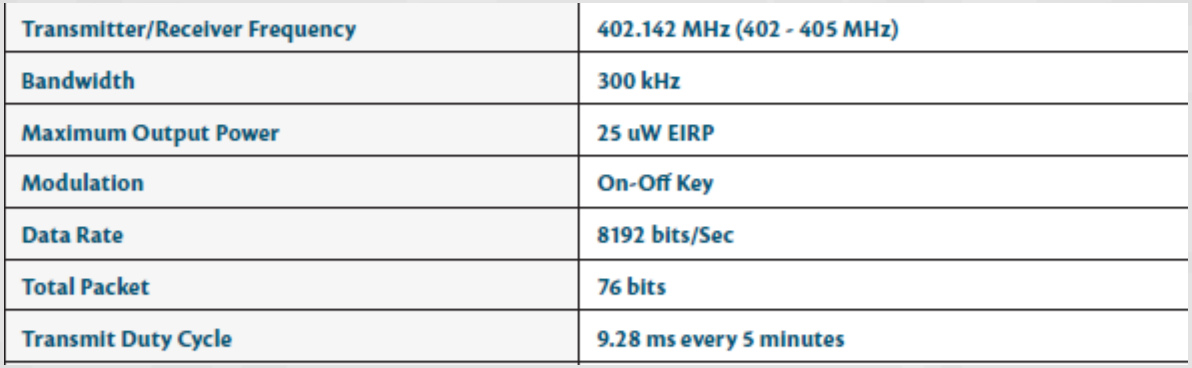
Picture from Armozyme.com

CGM Recon Work

- Hypothesis: CGM wireless results are transmitted with little to no security. These results can be vulnerable.
  - Sensor runs on 1.5v “watch” battery for 2 years. Crypto would require more horsepower (200k+ transmits)
  - Non-bidirectional communication. Sensor has no knowledge of what is receiving the data
  - Sensor is unaware of time or sequence numbers
- How do we verify this?

CGM Recon Research - Manual

- First, read the manual
  - RTFM: FCC Disclosure



Transmitter/Receiver Frequency	402.142 MHz (402 - 405 MHz)
Bandwidth	300 kHz
Maximum Output Power	25 uW EIRP
Modulation	On-Off Key
Data Rate	8192 bits/Sec
Total Packet	76 bits
Transmit Duty Cycle	9.28 ms every 5 minutes

  - Small Transmission (9ms, 76 bit packet)
  - Sounds like: 🔈
  - No ACK back, confirms beacon

CGM Recon Research - FCC

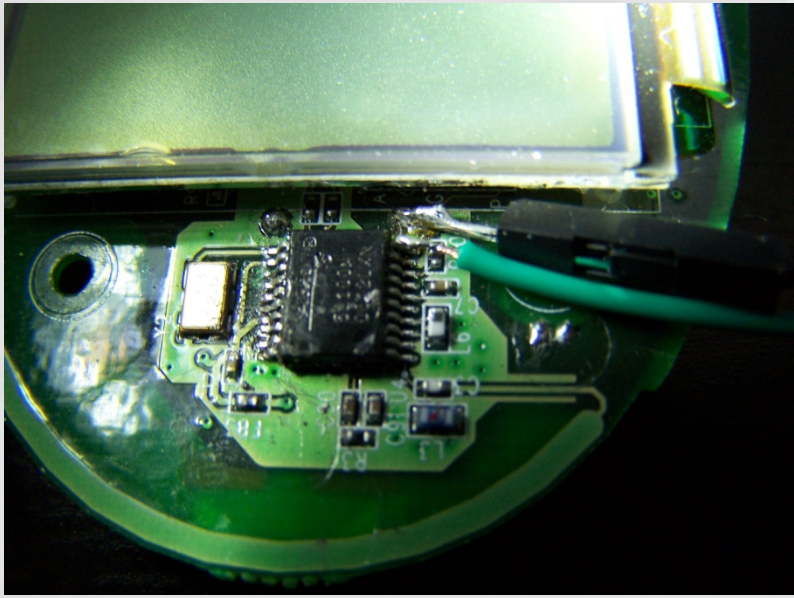
- All RF Transmitting devices go through FCC testing and verification
- FCC issues a TX ID for all devices
- Very Detailed Report. Screen Caps from Spectrum Analyzers, Oscilloscopes
- http://transition.fcc.gov/oet/ea/fccid/

CGM Recon Research - Patent

- When companies file a patent, documents are published that show how the device is made and it's function
- http://www.freepatentsonline.com
- Very detailed on operation of devices

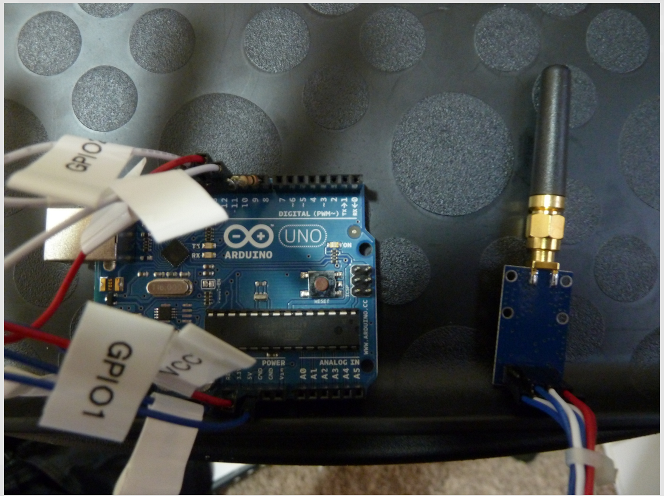
CGM Recon Research – Unboxing

- Taking a CGM Apart
- AMIS 52100M Chip
- Antenna Visible
- Out Of Production Chip
- Datasheet has good hints
- Same chip used in ICS environments (ICS/SCADA)



CGM – HandsOn How to Listen

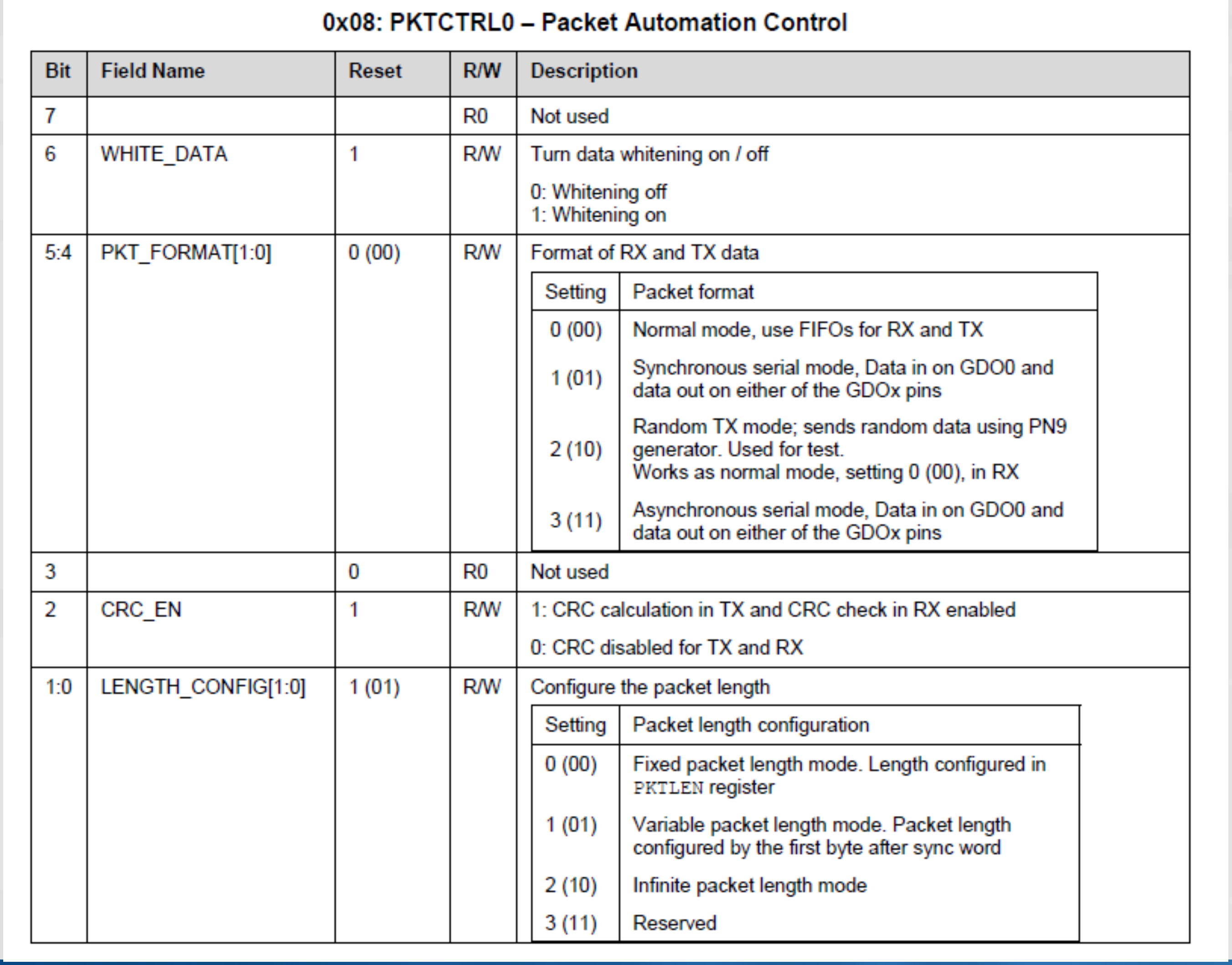
- Ardunio Based Solution
  - Ardunio is a hardware based platform that has RF modules that it can use
  - RFM22B by HopeRF /CC1101 by TI
  - Cover 300mhz – 900mhz (sub-1ghz)



CGM - HandsOn Ardunio Problems

- First, hard to program. Registers have to be set according to the manual, all in binary/hex notation.
- Example: Register 0x08 Packet Control
- 8 bits of data in the register

CC1101 Register Example



0x08: PKTCTRL0 – Packet Automation Control

<table>
<tr><th>Bit</th><th>Field Name</th><th>Reset</th><th>R/W</th><th>Description</th></tr>
<tr><td>7</td><td></td><td></td><td>R0</td><td>Not used</td></tr>
<tr><td>6</td><td>WHITE_DATA</td><td>1</td><td>R/W</td><td>Turn data whitening on / off
0: Whitening off
1: Whitening on</td></tr>
<tr><td>5:4</td><td>PKT_FORMAT[1:0]</td><td>0 (00)</td><td>R/W</td><td>Format of RX and TX data
<table>
<tr><th>Setting</th><th>Packet format</th></tr>
<tr><td>0 (00)</td><td>Normal mode, use FIFOs for RX and TX</td></tr>
<tr><td>1 (01)</td><td>Synchronous serial mode, Data in on GDO0 and data out on either of the GDOx pins</td></tr>
<tr><td>2 (10)</td><td>Random TX mode; sends random data using PN9 generator. Used for test.
Works as normal mode, setting 0 (00), in RX</td></tr>
<tr><td>3 (11)</td><td>Asynchronous serial mode, Data in on GDO0 and data out on either of the GDOx pins</td></tr>
</table></td></tr>
<tr><td>3</td><td></td><td>0</td><td>R0</td><td>Not used</td></tr>
<tr><td>2</td><td>CRC_EN</td><td>1</td><td>R/W</td><td>1: CRC calculation in TX and CRC check in RX enabled
0: CRC disabled for TX and RX</td></tr>
<tr><td>1:0</td><td>LENGTH_CONFIG[1:0]</td><td>1 (01)</td><td>R/W</td><td>Configure the packet length
<table>
<tr><th>Setting</th><th>Packet length configuration</th></tr>
<tr><td>0 (00)</td><td>Fixed packet length mode. Length configured in PKTLEN register</td></tr>
<tr><td>1 (01)</td><td>Variable packet length mode. Packet length configured by the first byte after sync word</td></tr>
<tr><td>2 (10)</td><td>Infinite packet length mode</td></tr>
<tr><td>3 (11)</td><td>Reserved</td></tr>
</table></td></tr>
</table>

CGM - HandsOn Ardunio Problems

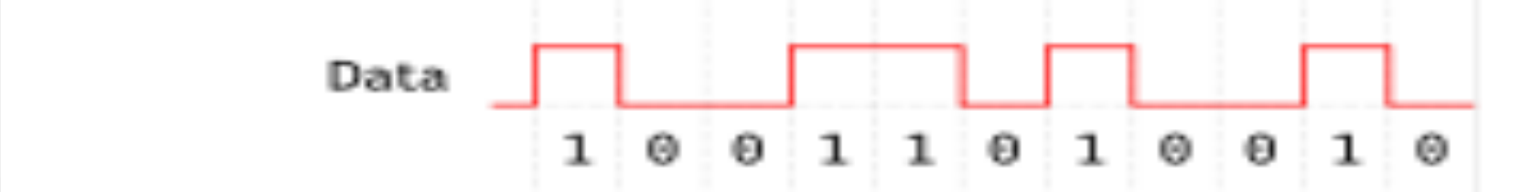
- Even after you determine the register settings, you have to set them
- Little to no verification that value has taken
- Lost 2 weeks to this
- Thought I was writing to register, turns out none of the register values were being changed
- Zero indication of that

CGM – HandsOn Hardware is Different

- First Real difference between Systems/Computer world and Hardware World
- Hardware is very concerned with cycles, so much of the hardware code I saw did little to no verification of it's actions. If I had this issue with a perl program or shell script I would have gotten an error.
- Note: We see a lot of exploits and vulnerabilities based on this concept in software. Buffer overflows due to not verifying boundaries (strcpy). Can this be the case in hardware land?

CGM – Signal Dissection

- What is On-Off Keying? (AKA OOK)
- Simplest form of RF Modulation



- Pure Binary, no signal = 0, signal = 1. Very fast
- 8192 bits / sec * 9ms = ~ 76 bits

CGM – Signal Dissection

- Next problem: The RF module wants to know certain parameters of the transmission
  - Preamble: This is a series of binary 1s and 0s used to indicate that data is going to be coming shortly
    - Used to “warm-up” the RF gain settings and to wake from a power saving mode
  - Sync Word: Think of this as the secret word. Set of characters that assure that the transmission format is correct.
  - CRC/CRC Location: This is usually 8 bits at the end that are used to make sure there is data integrity.

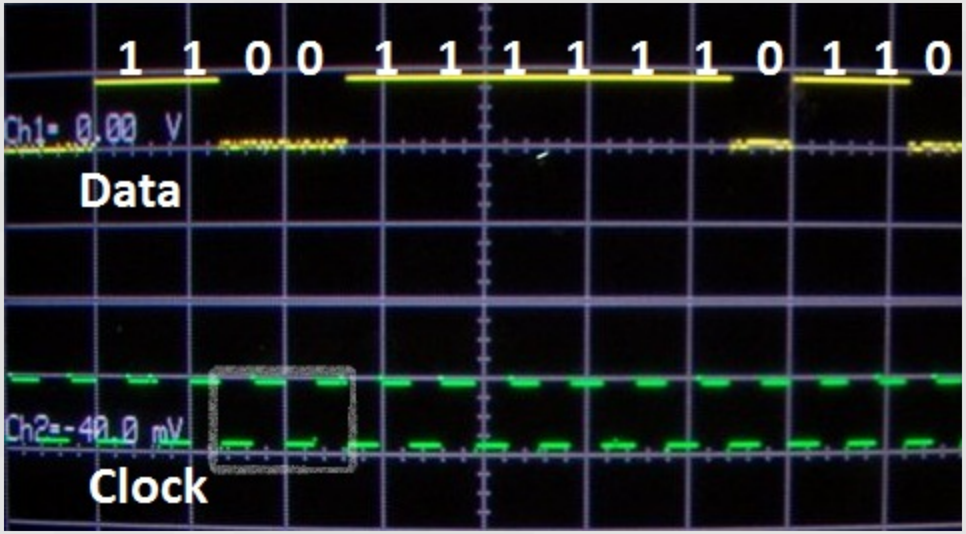
CGM – Signal Dissection Example

- TESTING TESTING 31337 12345 15
- |______Preamble_____||_SYNC__||__Data__||_CRC_|

- If 31337 is not received, RF Module ignores it
- If 15 is not the CRC (assume CRC is 1+2+3+4+5) RF module ignores it
- Guess what, I have no idea the format!
- AMIS Data Sheet indicated that it doesn’t use Preamble, only sync word, which is set in the by the manufacturer

CGM – Signal Dissection Example

- Direct mode is a configuration for the RF module that allows you to “see” all the signals on a given frequency
- Only way to view is with an oscilloscope or logic analyzer



CGM - Signal Dissection

- Here's what is known:
  - 76 bit transmission
  - CRC exists(Patent docs mention it)
  - There is a transmitter ID
    - 5 Characters
    - First char is 0 or 1, last 4 are [0-9,A-Z] (From Manual)
  - There is a Sync word of unknown length and value
  - There is some numerical data for the electrical resistance

CGM – Signal Catching

- Took a couple days to get some things figured out
  - Mid-80’s borrowed oscilloscopes – Manual not so friendly
  - RF module settings way too sensitive (AGC)
  - More register battles
- Eventually captured two 9.3ms transmission exactly 5 min apart!

CGM – Signal Transcription

- Collected 10 transmissions and decoded with paper and pen
- Looks like total jibberish – not what I was expecting
- I expected TCPdump like precision

CGM – Signal Transcription

- Was expecting a preamble per my research:
  - 10101010 = Research Preamble (8 bit)
- What I saw:
  - 1111 up to 11111111
- Re-read AMIS documents
- “RF Sense”
  - Chip expects a “wake-up” transmission
  - Series of 1s make sense!
  - Variance makes sense, RF module wakeup/setteling

CGM – Signal Transcription

- Think like a cryptographer
  - Known values in "plain-text" = last 4 of TX ID (CTA3)
  - Most of the transmission is identical every time (Sync, transmitter ID)
  - Data will change little in 5 min intervals
  - Patterns in "crypt-text"?

CGM – Signal Transcription

- Without changing any bits, only alignment I see something!
- Of 40 captured Transmissions 80% had this same series of 24 bits, all starting after Preamble/RF Wakeup
- Tried Inversion (AMIS chip option) - No luck
- Reached out to TI for help
  - Clueless. Obscure way to use this chip.
  - Got questioned on the ethics of my work

CGM – Signal Transcription

- Just too many combinations of settings, all impact how the direct mode behaves
- Zero real documentation, Zero users experienced
- Way beyond intended purpose (Definition of Hacking)

CGM – Security Risks

- Replay Attacks
  - Method: Capture and repeat packet
  - Impact: Incorrect Values or DoS
  - Limitations: Physical Range, Can’t manipulate values (yet)
- Denial of Service
  - Method: “Jamming” legitimate signal
  - Impact: User would get no values from CGM
  - Limitations: Physical Range, Non-Critical functions

CGM – Security Risks

- Injection
  - Method: If you can reverse the format, you can construct a sensor transmission. Listen and catch TX ID, then retransmit with fake data portion
  - Impact: User inputs incorrect values into insulin equation. Too much/too little insulin.
  - Limitations: Human Intelligence, Gut Feeling, Experience. Currently unknown data format.

Two Technologies – One Purpose

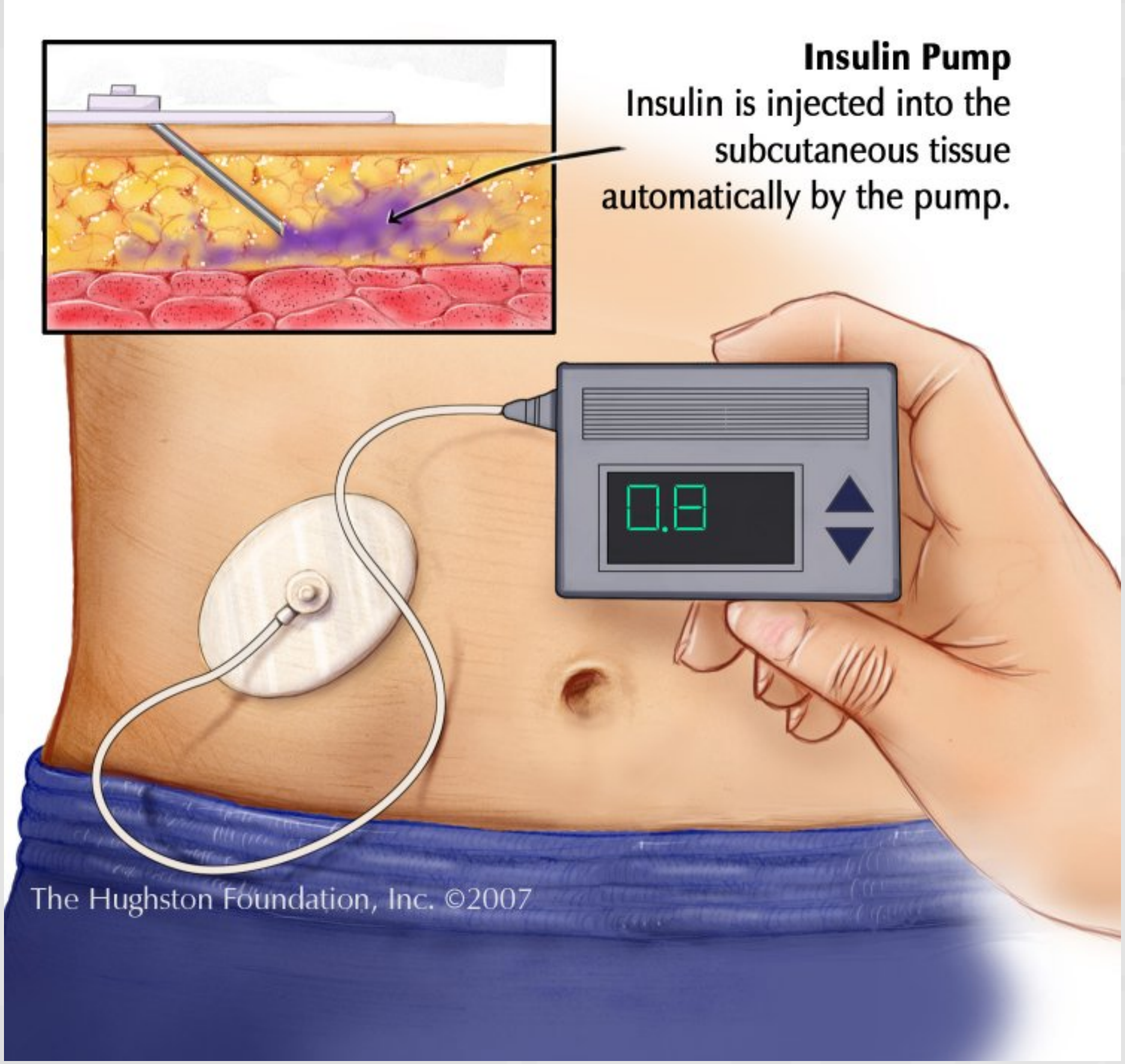
- Continuous Glucose Monitors (CGM)
  - New Technology
  - Small wire in tissue to measure electrical elements of fluid
  - Graphs sugar values over time
  - Huge leap forward

- Insulin Pump
  - Delivers insulin in 2 ways
    - Basel: Every 3 minutes
    - Meal: At Mealtime
  - Delivered through tubing attached to body
  - Tubing replaced every 3 days

Pump

- Insulin Pumps are used to delivery insulin to patients, hooked to a person via tubing 24/7
- Blood Meters can send measurements wirelessly to Insulin Pump for easier user experience
- Special USB dongles used to program Insulin Pumps and download history data
- Special wireless remotes used to deliver insulin

Pump



Insulin Pump
Insulin is injected into the subcutaneous tissue automatically by the pump.
0.8
The Hughston Foundation, Inc. ©2007

Pump – Recon

- Hypothesis: Wireless communication with insulin pumps are not secured and can be subject to attacks
  - Communication is more complex, probably bi-directional
  - Ancient windows programs used for config (will not install on anything above XP) indicate lack of knowledge
  - Devices not designed to be updated. No way of patching. 5+ year life span.

Pump – Recon

- Java Based Config program
  - Set logging from NONE to HIGH
  - BAM! Shows full packets, command structure, ACK responses, everything.

    -
      ```
      INFO: XXXXXX Command-sendCommand: SENDING CMD 0x5A (Set RF Power On-command packet)
      ```

    -
      ```
      INFO: XXXXXX Command-encode: about to encode bytes = <0xA7 0x31 0x33 0x70 0x5A 0x00 0xA8>
      ```

    -
      ```
      INFO: XXXXXX SerialPort-write(int buffer[])(20MS): writing <0x0A 0x0B 0xA8 0x6D 0x16 0x8E 0x39 0xB2 0x94 0xB5 0x55 0xA9 0xA5>
      ```

Pump – Signal Decoding

- Encoding?!
  - Encoding makes the message longer, but not double. Wonder how?
- Jar file
  - Not obfuscated, shows full encoding method
  - Not crypto complicated
  - Shows *all* commands and packet structure.

Pump – Signal Transmission

- Jar/Log Analysis
  - Talks directly to serial port (USB-to-Serial)
  - Only unique piece of information needed is Serial Number of pump
- Pump analysis
  - No ability to stop/block receiver
  - No verification step on pump
  - Does exactly what it’s told, no questions asked

Pump – Other Wireless Commands

- Remote Controls
  - All have optional remotes with unique IDs
  - Pump has to be configured to allow that ID
- Blood Meter
  - Blood Meter has Unique ID, sends beacon out with value + ID
  - Pump has to be configured to allow that ID
- Data Download
  - Has all historical data

Pump – Security Risks

- Hardware Needed
  - RF Serial/USB device are easy to get. $100 New, as low as $20 on eBay. No restrictions.
  - Remotes for pumps: Also trivial to acquire.
- Information Needed
  - Serial Number: Can be socially engineered.
  - Serial Number can be scanned for. Six digits number. Very feasible.

Pump – Security Risks

- Full Remote Control
  - Method: Send command to pump to allow Remote Control ID 12345.
  - Impact: Full meal insulin delivery control.
  - Limitations: Physical Range (100ft, more with mods), Pump Notification of Delivery
  - Very scary. Applies to any configurable setting. Including the variables on how much insulin to deliver.
  - “root” access to the device (and technically your body)

Future Potential

- JDRF Artificial Pancreas project
  - Links CGM and Insulin pump together
  - Eliminate User Intervention!
  - CGM data will be used to act without the user, *very* dangerous.
  - Makes security of CGM transmission much more important

Next Gen CGM

- New RF range (2.4ghz) bluetooth?
- Some already using bluetooth in pumps, partnering with CGM on new pump features
- Bluetooth better or worse? Maybe both
  - Tools for research
  - Tools for exploits (Metasploit module for Insulin pumps? AHHHHH!)

Suggestions

- New RF chips have crypto on board, use it
- Use IR rather then RF – Painful, but more secure
- Verify New Config
- Setting a Passcode
- Keep range limited
  - One pump uses 13mhz OOK. Near 20 meter ham band where 1 watt transmissions can be global.
- Blocking
  - Researchers are working on RF blocking necklaces for stopping RF OOK Pacemakers from malicious interference

Applying to Other Worlds

- Same Hardware RF Chips used in ICS/SCADA environments
- Older SCADA wireless uses OOK wireless in sub-1ghz bands
- Same techniques, different targets
- Harder to replace, more costly

Hardware Hacking Research

- Huge value, more should be done
  - Everything becoming wireless or connected
  - There is always a threat lurking, shouldn’t be ignored
  - Don’t hide behind obscurity, way too many smart people, it always fails
- It’s really hard
  - Think of trying to transcribe TCP packets on oscilloscope
  - More tools needed, more interest needed.

Feedback

- Please Remember to Complete Your Feedback Form!
- Questions? Comments?
- jay.radcliffe@gmail.com
- Twitter: @jradcliffe02