MARC NEWLIN // MATT KNIGHT // BASTILLE NETWORKS

SO YOU WANT TO HACK RADIOS

A PRIMER ON WIRELESS REVERSE ENGINEERING

WHO ARE THESE GUYS

- Marc “mou$e whisperer” Newlin
  - Security Researcher @ **Bastille**
  - Discovered Mousejack vulnerability in 2016
  - Finished 2rd in DARPA Spectrum Challenge in 2013
  - Finished 3nd in DARPA Shredder Challenge in 2011

marc@**Bastille**.net
@marcnewlin

- Matt Knight
  - Software Engineer and Security Researcher @ **Bastille**
  - Reverse engineered the LoRa wireless protocol in 2016
  - BE & BA from Dartmouth

matt@**Bastille**.net
@embeddedsec

WHO IS THIS FOR?

WHY SHOULD YOU CARE?

WIRELESS SYSTEMS ARE EVERYWHERE

MOBILE

WIRELESS SYSTEMS
ARE EVERYWHERE

MOBILE

WIRELESS SYSTEMS
ARE EVERYWHERE

IOT

MOBILE

WIRELESS SYSTEMS
ARE EVERYWHERE

IOT

Fewer wires every year!

ABOUT THE INTERNET OF THINGS…

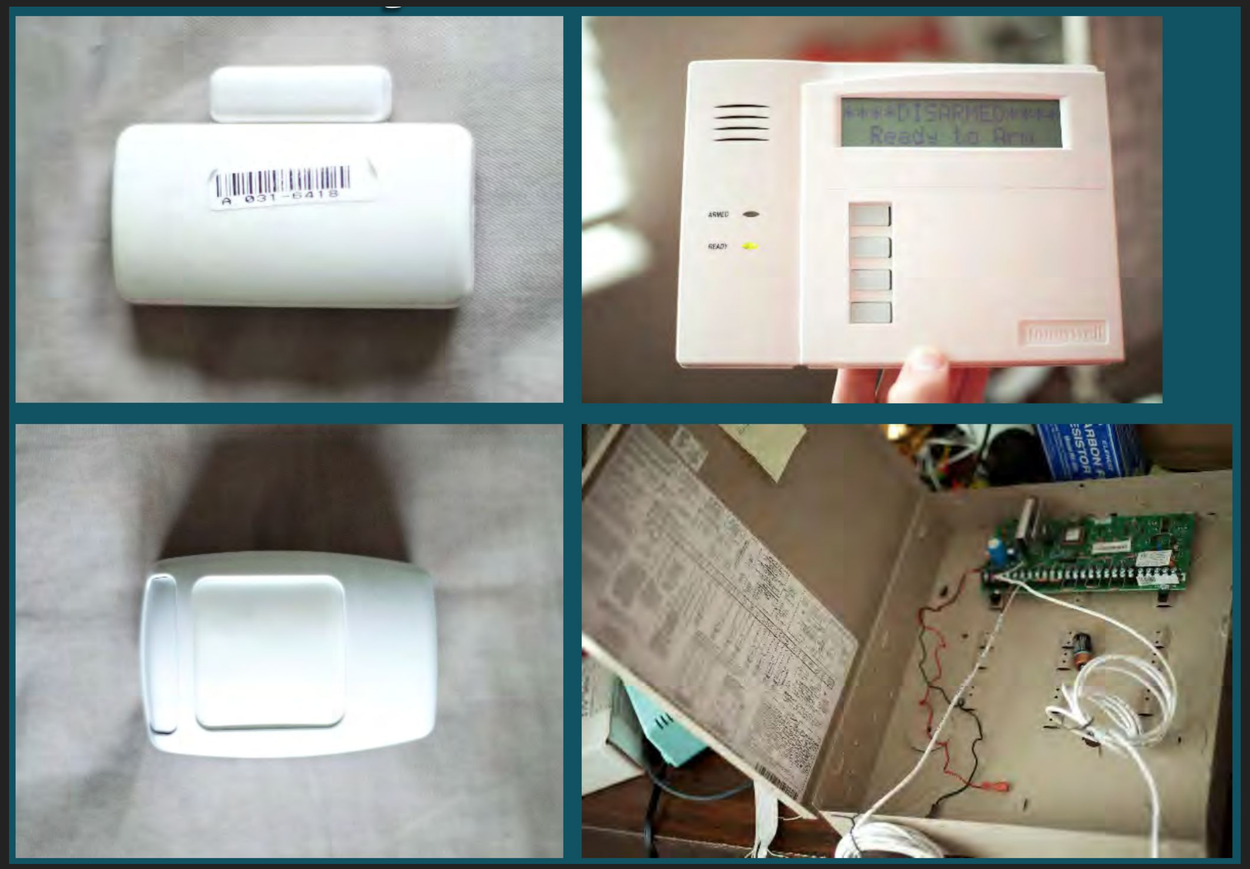
- Everyone's Favorite Buzzword™
- What is it, actually?
  - Sales and marketing speak for "connected embedded devices"
  - "Smart" devices are usually pretty stupid

EMBEDDED REALITIES

- Embedded systems are built on compromise
  - Size and cost constraints
  - Battery powered
  - Challenging deployment scenarios
  - Difficult to patch

Vulnerable by Virtue of Being Constrained

ALARM SYSTEM VULNERABILITIES



- Discovered by **Bastille**'s Logan Lamb in 2014
- Legacy RF link between home alarm system sensors and control panel is vulnerable to:
  - Jamming (denying alarm reporting)
  - Command injection (trigger false alarms)
  - Eavesdropping (detect occupancy, monitor movement)

Image credit: Logan Lamb

MOUSEJACK

- Discovered by **Bastille**'s Marc Newlin in 2015
- RF link between non-Bluetooth wireless keyboards and mice (100MMs of devices) vulnerable to:
  - Command injection (running arbitrary commands at current permissions level)
  - Eavesdropping (sniffing passwords, credit card #s, etc.)

@krystalmead

IOT VILLAGE FEEDBACK

- Interest in Software Defined Radio and RF systems is high
- RF is intimidating!
  - Too much EE for software people
  - Too academic!

NO PHD?

NO PROBLEM!

AGENDA

1. So you want to hack RF…
2. Introduce essential RF concepts
3. Introduce RF reverse engineering workflow that applies to all systems
4. Do it live!
    1. Wireless camera flash
    2. Wireless LED strip controller
    3. HP wireless keyboard

This is what it’s all about

WHAT WE WON'T COVER

Digital Signal Processing

SO YOU WANT TO

HACK WIRELESS

BARRIERS TO ENTRY

- Lower than ever before
- Commodity hardware is:
  - Really powerful
  - Increasingly cheap
- Free (beer && liberty) software is abundant!

HARDWARE TOOLS

- Dedicated Radio Chipset (Hardware Defined Radio)
  - Does 1 protocol really well
  - Pros: single-protocol performance, cost, simplicity, low power
  - Cons: lack of flexibility
- Examples:
  - Ubertooth ($200)
  - RFCat / Yardstick One ($100)
  - nRF24 dongles ($35)
  - ApiMote ($90)

HARDWARE TOOLS

- Software Defined Radio (SDR)
  - Swiss army knife for most-things RF
  - Pros: flexibility (can implement any protocol)
  - Cons: cost, complexity, power, performance (software and RF)
- Examples:
  - Ettus USRP ($686—>$$$$$)
  - HackRF ($300)
  - BladeRF ($420-$650)

FREE SOFTWARE

- SDR:
  - GNU Radio: open source digital signal processing suite
  - GNU Radio OOT Modules: third party plugins
    - gr-lora, gr-nordic
  - Baudline, Inspectrum, Fosphor: powerful analysis tools
- HDR:
  - Bluez, libubertooth, Killerbee
  - Marc’s nRF24 library

TOOLS ARE RIDICULOUS

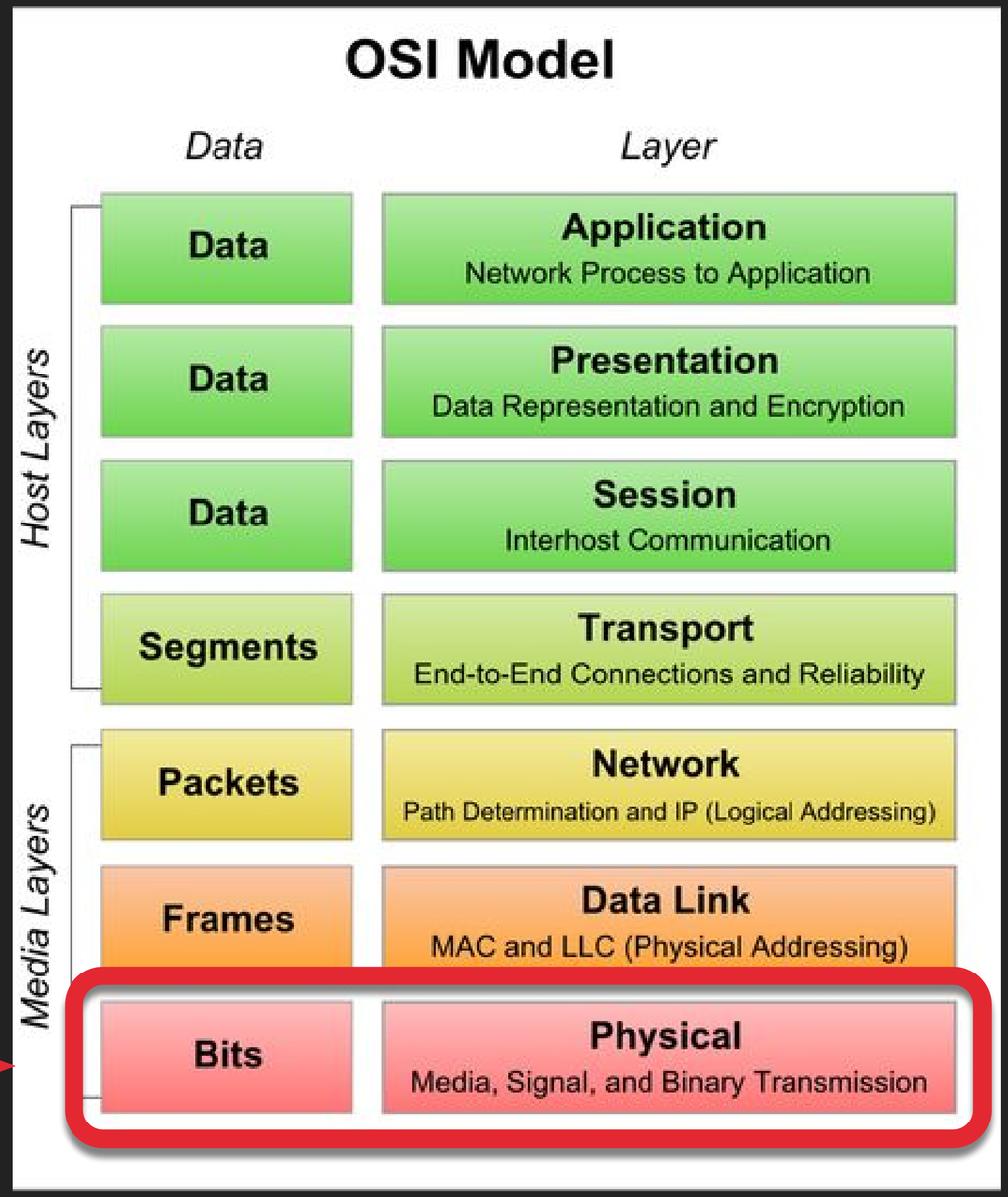
OFFENSIVELY

~~OBSCENELY~~ SHORT

RADIO CRASH COURSE

PHY LAYER

- Lowest layer in communication stack
- In wired protocols: voltage, timing, and wiring defining 1s and 0s
- In wireless: patterns of energy being sent over RF medium

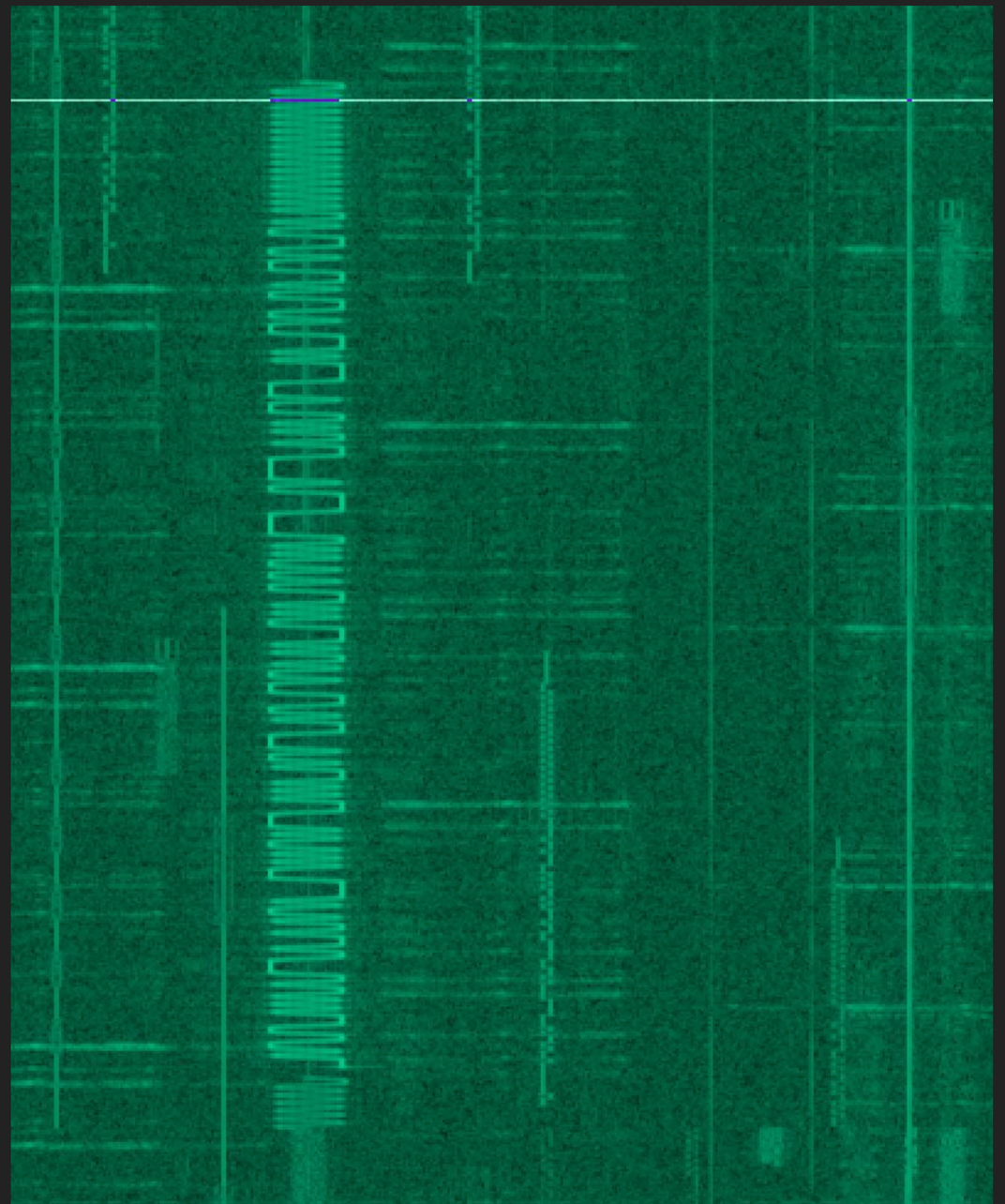


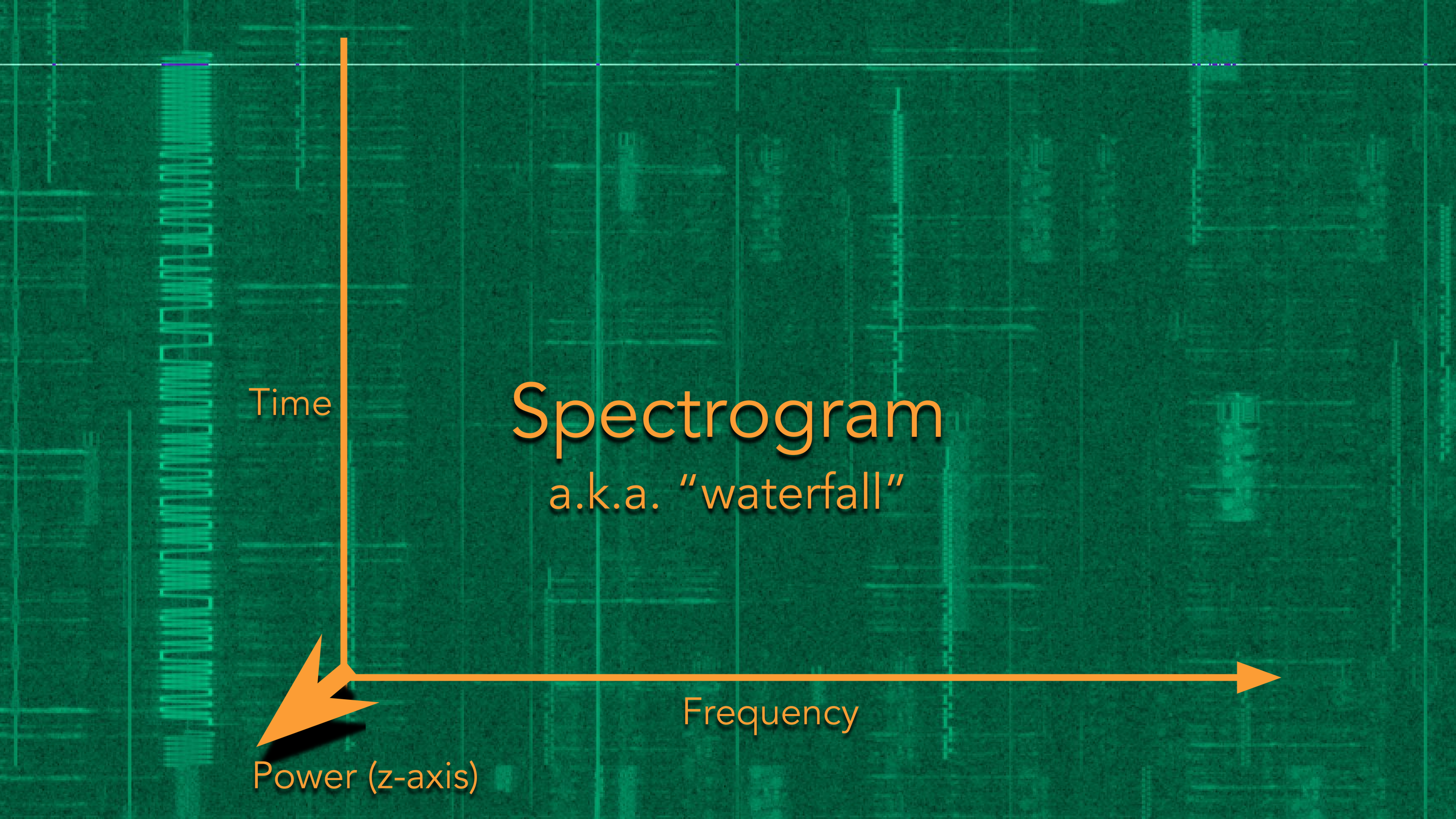
http://www.tech-faq.com/wp-content/uploads/2009/01/osimodel.png

WHAT IS RF?

- “One of the four fundamental forces of the universe” — Tom Rondeau, DARPA Program Manager, former GNU Radio lead

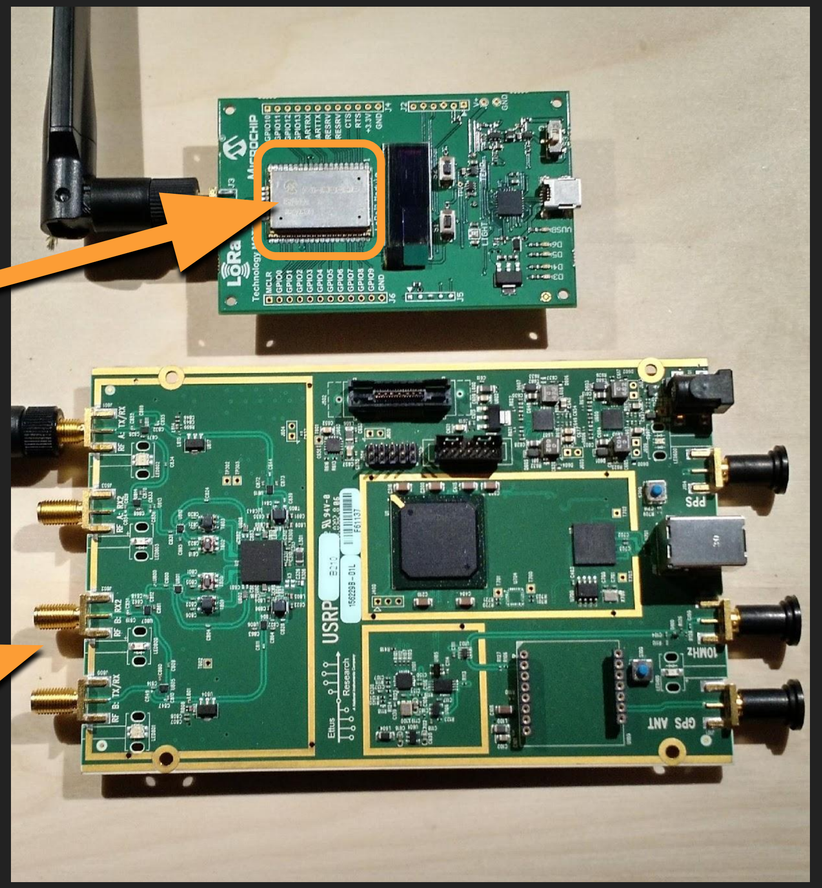
- “Radio Frequency”
- Electromagnetic waves
- Energy




Time
Spectrogram
a.k.a. “waterfall”
Frequency
Power (z-axis)

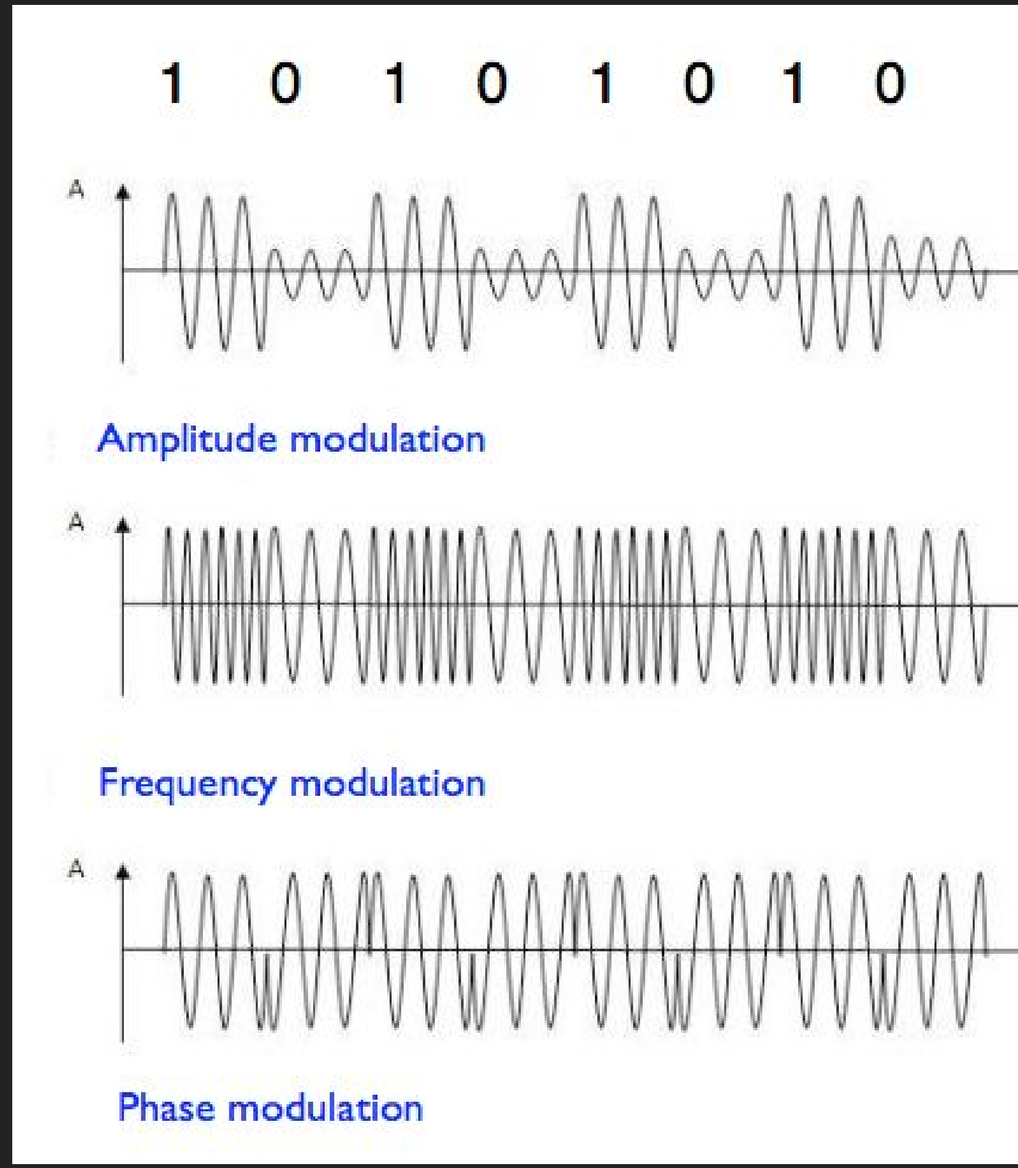
MANIPULATING RF

- Done with a radio
- Hardware defined
  - RF and protocol in silicon
- Software defined radio (SDR)
  - Flexible silicon handles RF
  - Protocol-specific components implemented in software (CPU or FPGA)



PHY COMPONENTS

- Modulation
  - How digital values are mapped to RF energy
- RF parameters that can be modulated:
  - Amplitude
  - Frequency
  - Phase
  - some combination of the above



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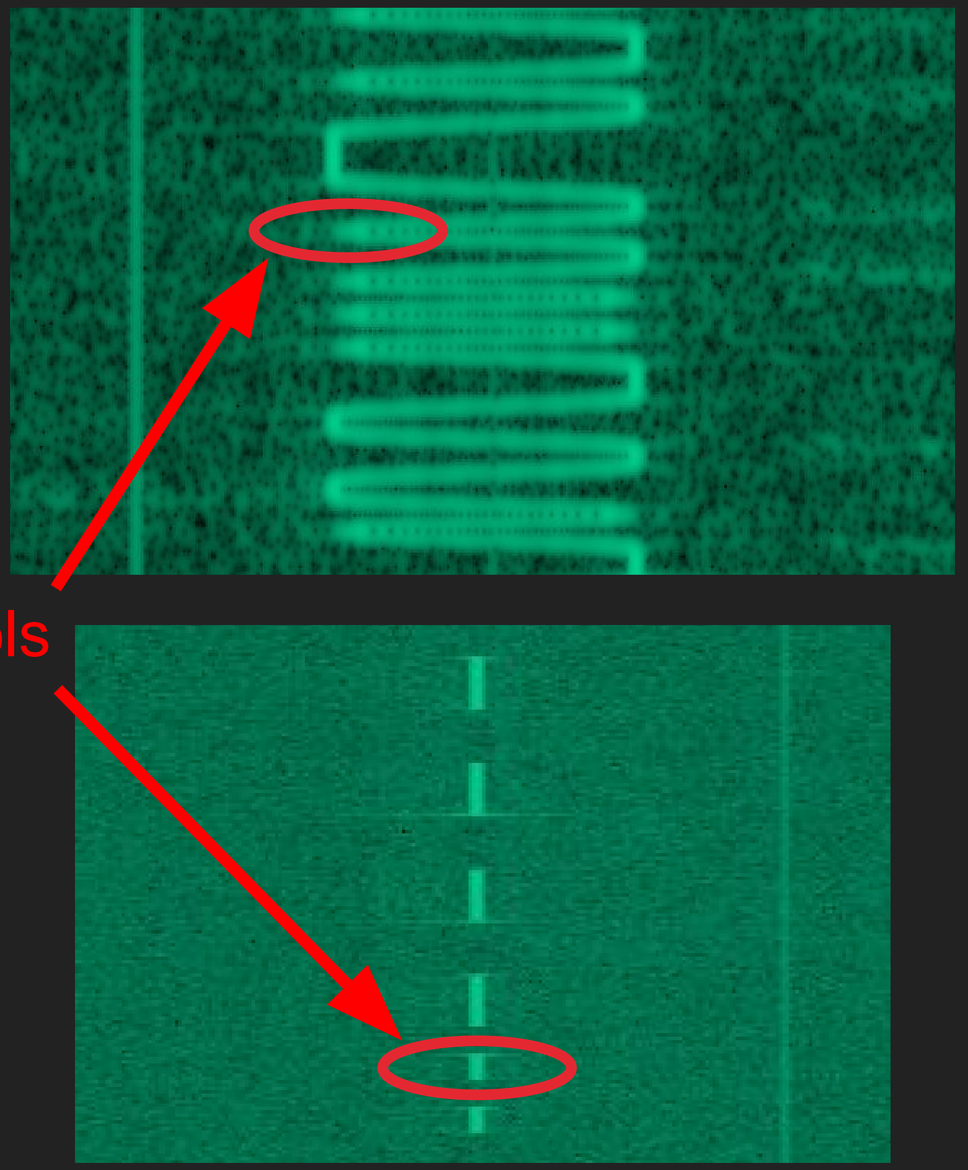
MODULATION

- Modulators can modulate analog or digital information

- Digital modulation
  - Symbols: discrete RF energy state representing some quantity of information

COMMON IOT PHYS

- Frequency Shift Keying: FSK, GFSK
  - RF energy alternates between two frequencies to signify digital values
- Amplitude Shift Keying: ASK, OOK
  - Changes in RF power on a certain frequency signify digital values



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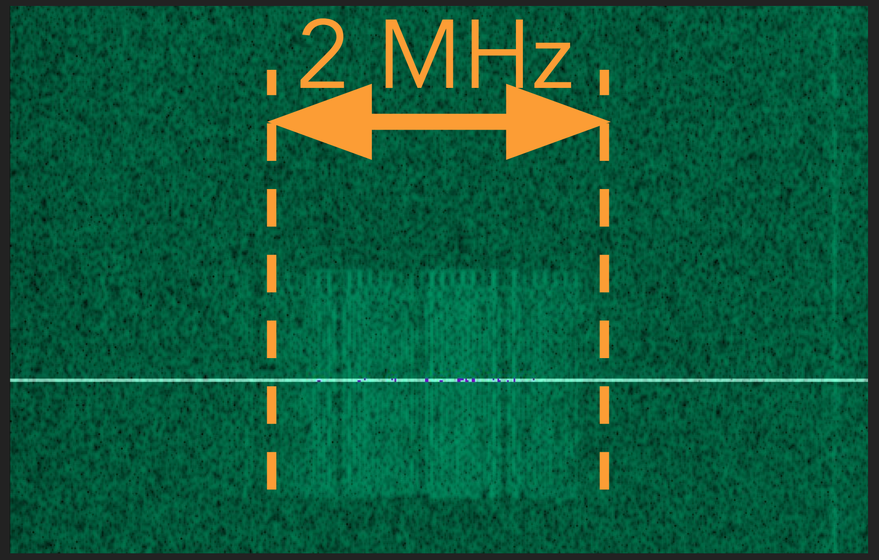
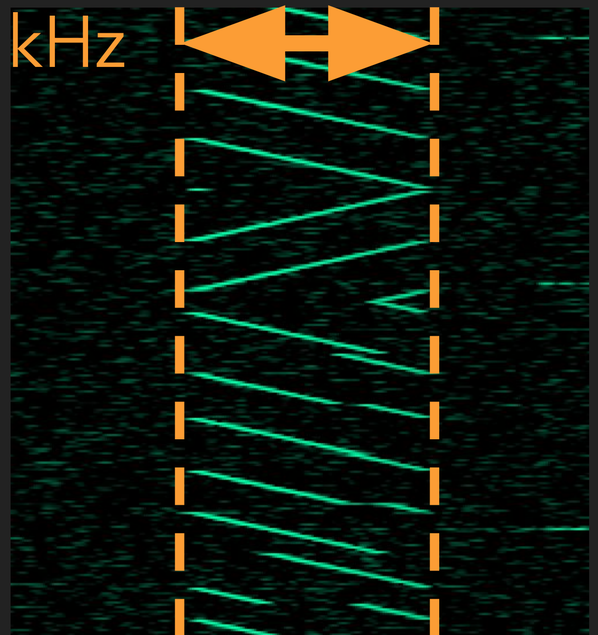
MORE COMPLICATED IOT PHYS

- Spread spectrum
  - Data bits are encoded at a higher rate and occupy more spectrum
  - Resilient to RF noise
- Examples:
  - 802.15.4 (top)
  - LoRa (bottom)



125, 250, or 500 kHz



RADIOS CONTINUED

- Radios can have two functions:
  - Transmitting
  - Receiving

- If a radio can do both it is dubbed a transceiver

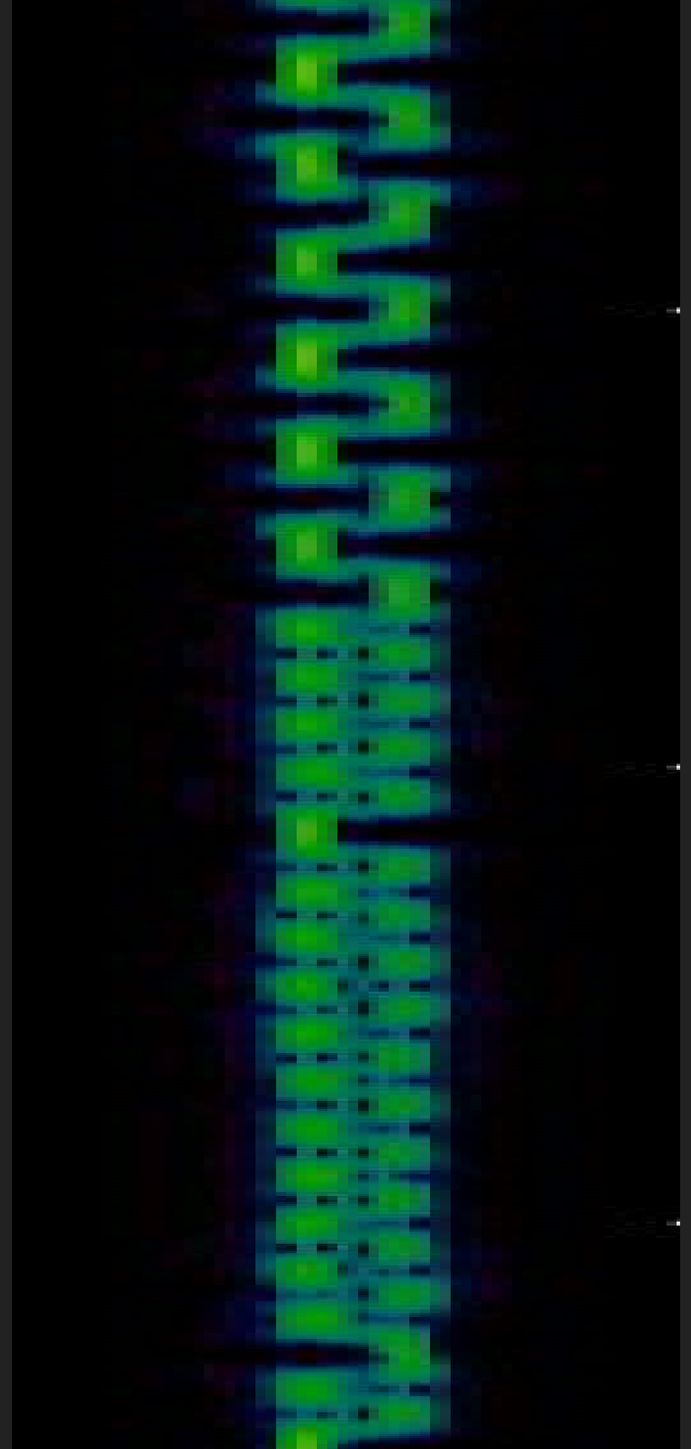
ON REVERSE ENGINEERING

- How does one reverse engineer an arbitrary wireless system?
- Main objective: figure out how data is mapped to symbols
- Reverse engineering boils down to building receivers

WIRELESS REVERSE ENGINEERING

METHODOLOGY

[INTERACTIVE]



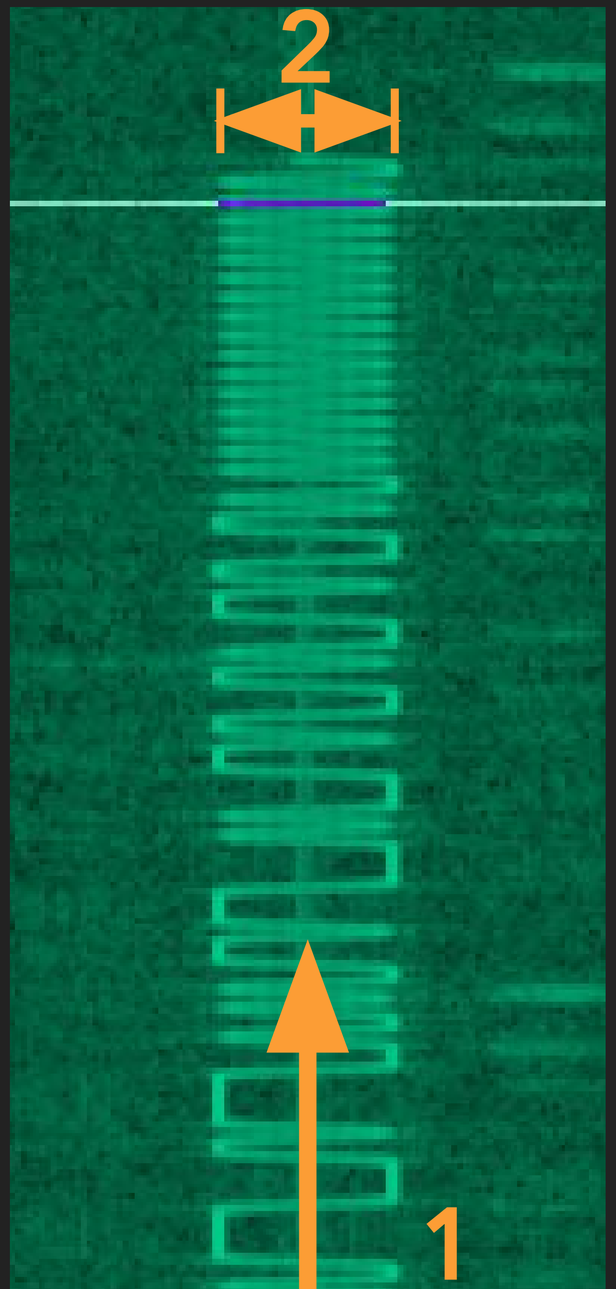
LET’S FORMALIZE THIS

RF REVERSE ENGINEERING METHODOLOGY

1. Characterize the channel

1. CHANNEL CHARACTERIZATION

- Things to identify:
  1. Where on the spectrum is it? i.e. what is its Center Frequency?
  2. How wide is the channel? (kHz or MHz)
  3. Is the channel static or does it hop? If latter, what pattern/timing?



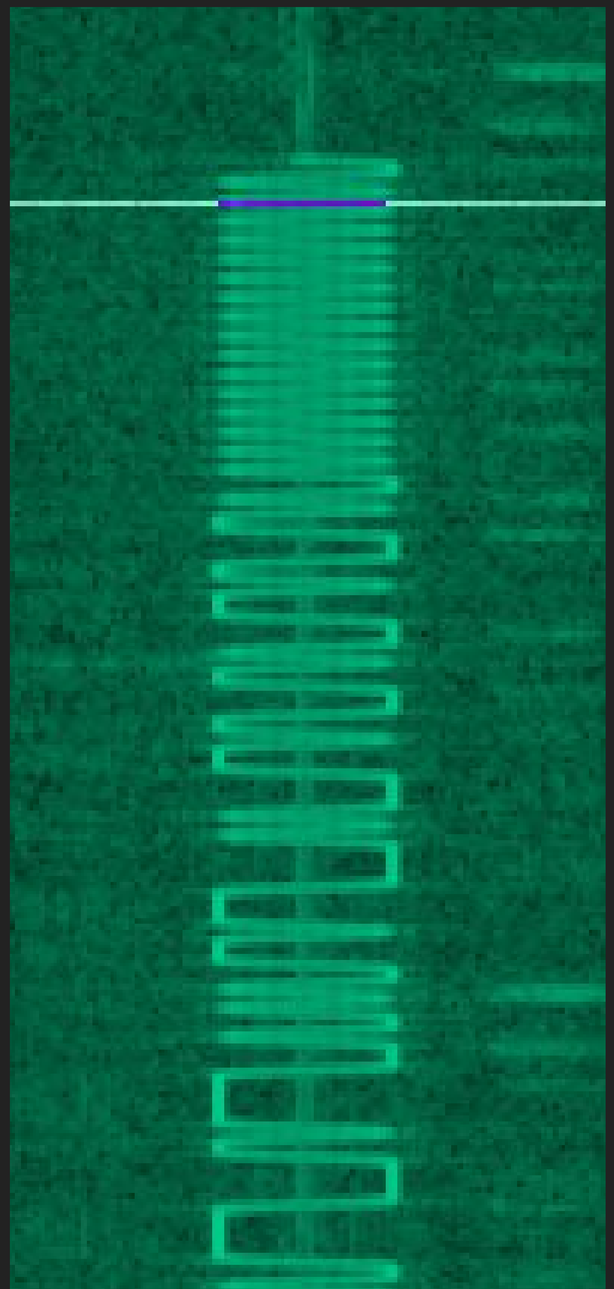
RF REVERSE ENGINEERING METHODOLOGY

1. Characterize the channel
2. Identify the modulation

2. IDENTIFY THE MODULATION

- Defines how data is mapped to RF energy
- This is the scariest part!
- …until you realize that most modulations are variations on a theme

- How to identify:
  1. OSINT/Documentation
  2. Intuition!

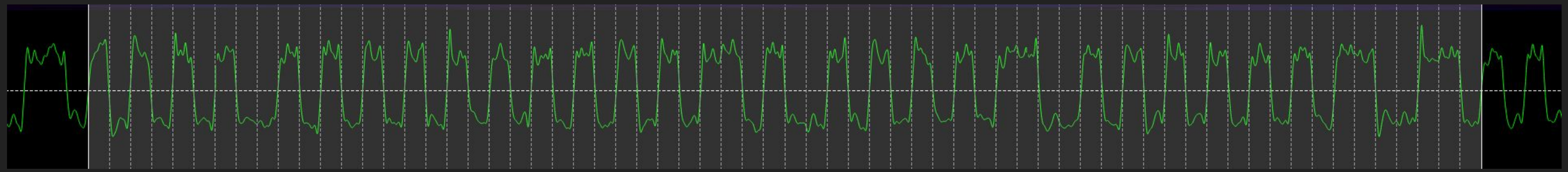


RF REVERSE ENGINEERING METHODOLOGY

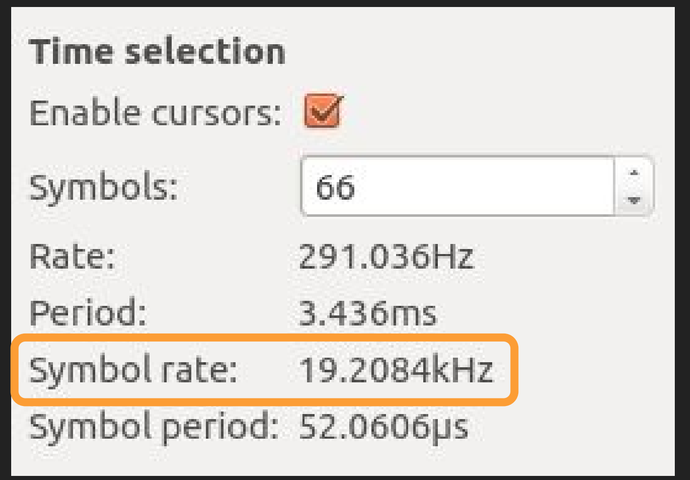
1. Characterize the channel
2. Identify the modulation
3. Determine the symbol rate

3. DETERMINE SYMBOL RATE

- How often does the symbol state change?



- How to identify:
  - OSINT/Documentation
  - Measurement (Baudline, Inspectrum)



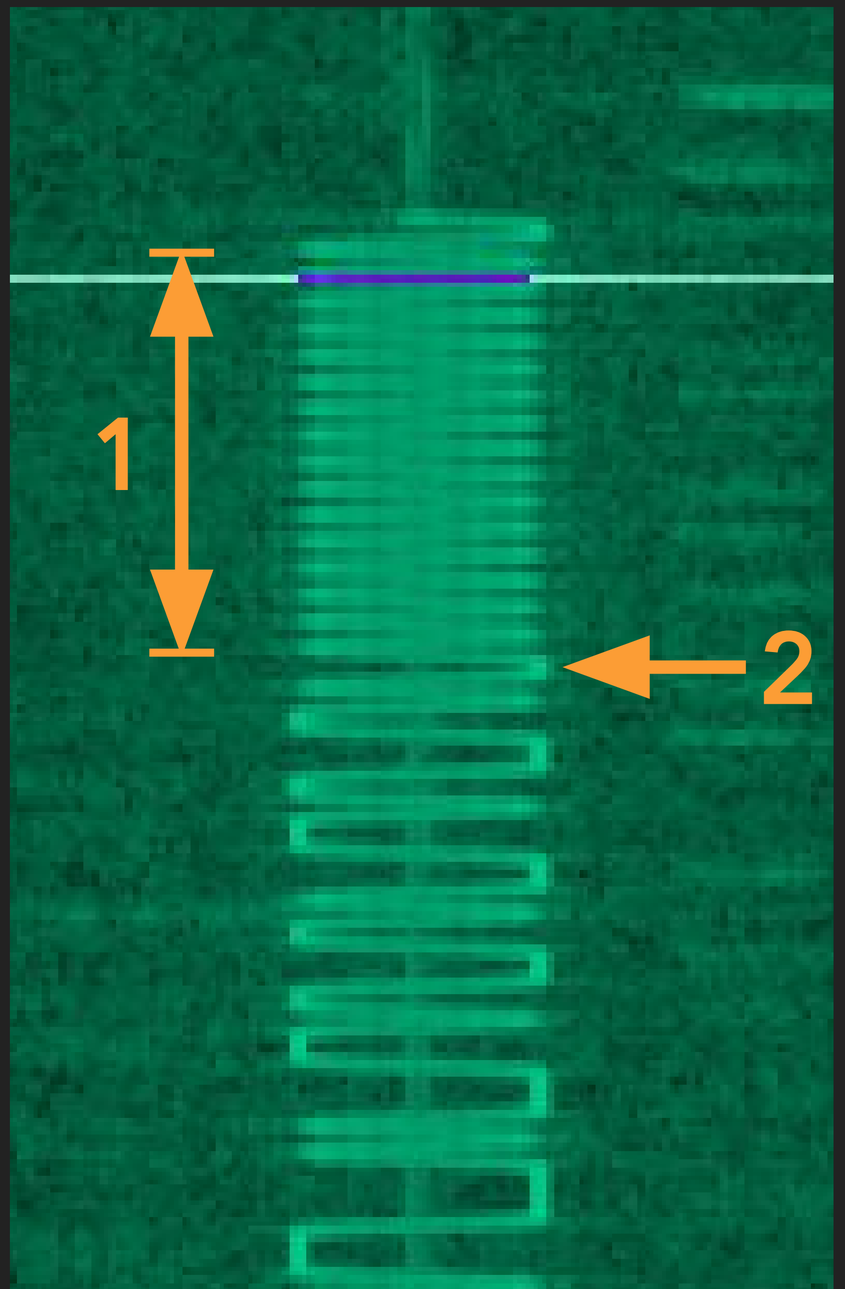
RF REVERSE ENGINEERING METHODOLOGY

1. Characterize the channel
2. Identify the modulation
3. Determine the symbol rate
4. Synchronize

4. SYNCHRONIZE

- Things to identify:
  1. Preamble: pattern that tells receivers “data to follow”, clock recovery
  2. Start of Frame Delimiter (SFD): tells receiver “preamble is over, data follows from here on out”

- These are present in essentially ALL digital communication schemes!



RF REVERSE ENGINEERING METHODOLOGY

1. Characterize the channel
2. Identify the modulation
3. Determine the symbol rate
4. Synchronize
5. Extract symbols

5. EXTRACT SYMBOLS

- De-map symbols into data based on the expected modulation topology
- Profit! (more on this later)

RF REVERSE ENGINEERING METHODOLOGY

1. Characterize the channel
2. Identify the modulation
3. Determine the symbol rate
4. Synchronize
5. Extract symbols

LET’S SEE IT IN ACTION

BUT FIRST

A word on

OPEN SOURCE INTELLIGENCE

OPEN SOURCE INTELLIGENCE (OSINT)

- Information gleaned from public sources:
  - FCC/regulatory filing documents
  - Technical documentation (datasheets, application notes)
  - Patents
  - etc.

- See Marc's prior talks on OSINT from FCC filings

RF REVERSE ENGINEERING METHODOLOGY

0. Open-source intelligence research

1. Characterize the channel
2. Identify the modulation
3. Determine the symbol rate
4. Synchronize
5. Extract symbols

Frequency Shift Keying

CAMERA FLASH TRIGGER

Yongnuo YN560-TX Flash Controller

- Remotely triggers camera flashes
- Wireless configuration of flash settings
- Flashes can be grouped for granular control

- Let’s reverse it and see how it works!

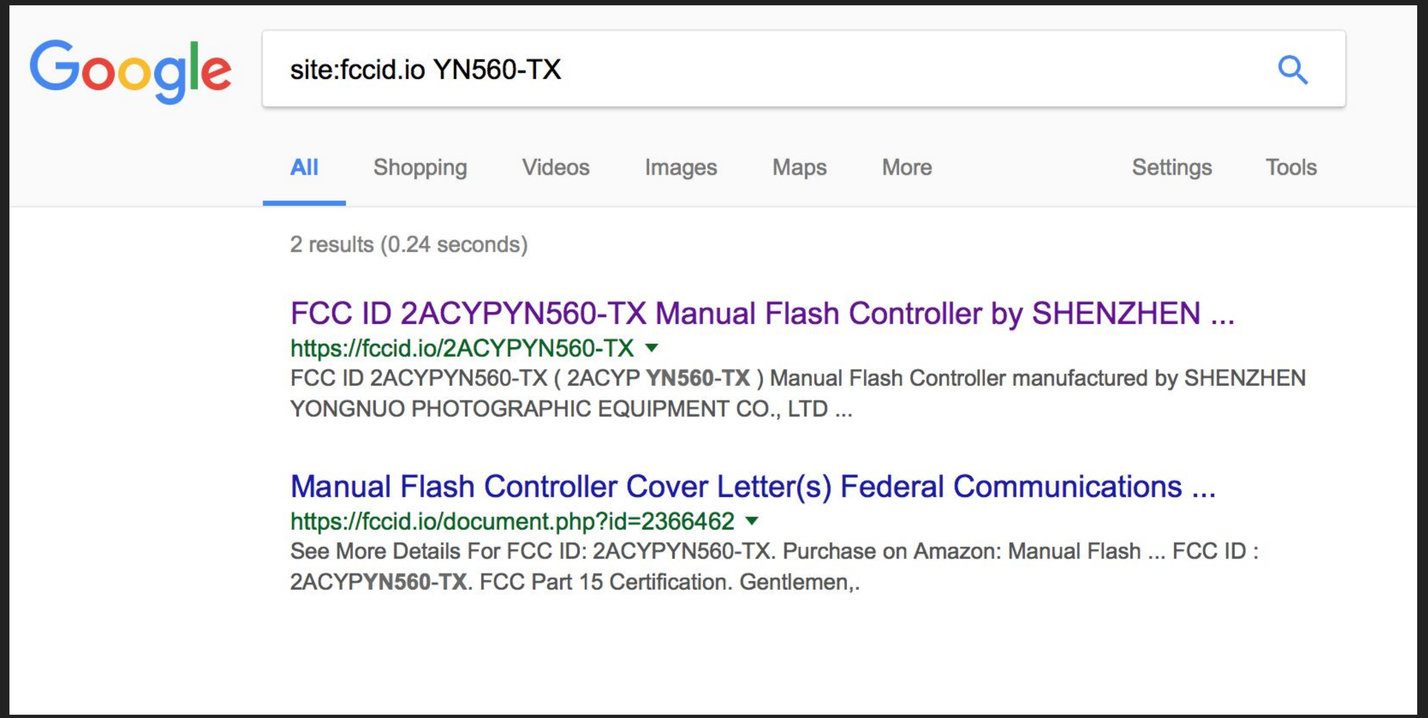
RF REVERSE ENGINEERING METHODOLOGY

0. Open-source intelligence research

1. Characterize the channel
2. Identify the modulation
3. Determine the symbol rate
4. Synchronize
5. Extract symbols

0. OSINT

- No FCC ID silkscreen!
- Google:
  - “site:fccid.io YN560-TX”



FCC Test Report EUT Description

Channel and modulation clues

Report No.: CST-TCB140624031

1 General Information

1.1 Description of Device (EUT)

Trade Name	:	**YONGNUO**
EUT	:	Manual Flash Controller
Model No.	:	YN560-TX
DIFF.	:	N/A
Type of Antenna	:	PCB Antenna, Max. Gain: 1.5dBi
Operation Frequency	:	2402.5-2456.5MHz
Channel number	:	16
Modulation type	:	FSK

Good start… Let's see what else we can find

FCC Test Report EUT Description

Channel list			
CH1	2402.5 MHz	CH9	2429.5 MHz
CH2	2405.5 MHz	CH10	2432.5 MHz
CH3	2408.5 MHz	CH11	2438.5 MHz
CH4	2411.5 MHz	CH12	2441.5 MHz
CH5	2414.5 MHz	CH13	2444.5 MHz
CH6	2417.5 MHz	CH14	2450.5 MHz
CH7	2420.5 MHz	CH15	2453.5 MHz
CH8	2426.5 MHz	CH16	2456.5 MHz

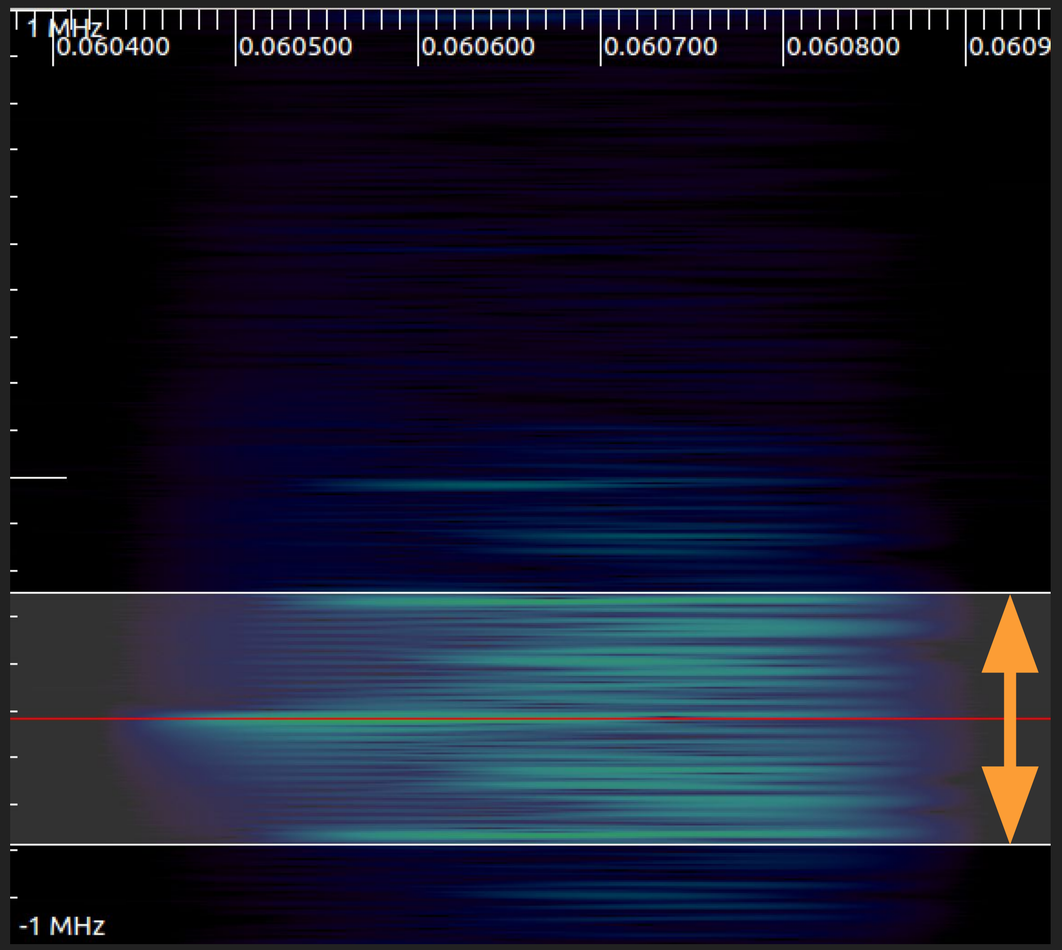
Detailed channel mapping

RF REVERSE ENGINEERING METHODOLOGY

0. ✓ Open-source intelligence research
1. Characterize the channel → 16 channels, center frequencies, MISSING: bandwidth
2. Identify the modulation → FSK
3. Determine the symbol rate
4. Synchronize
5. Extract symbols

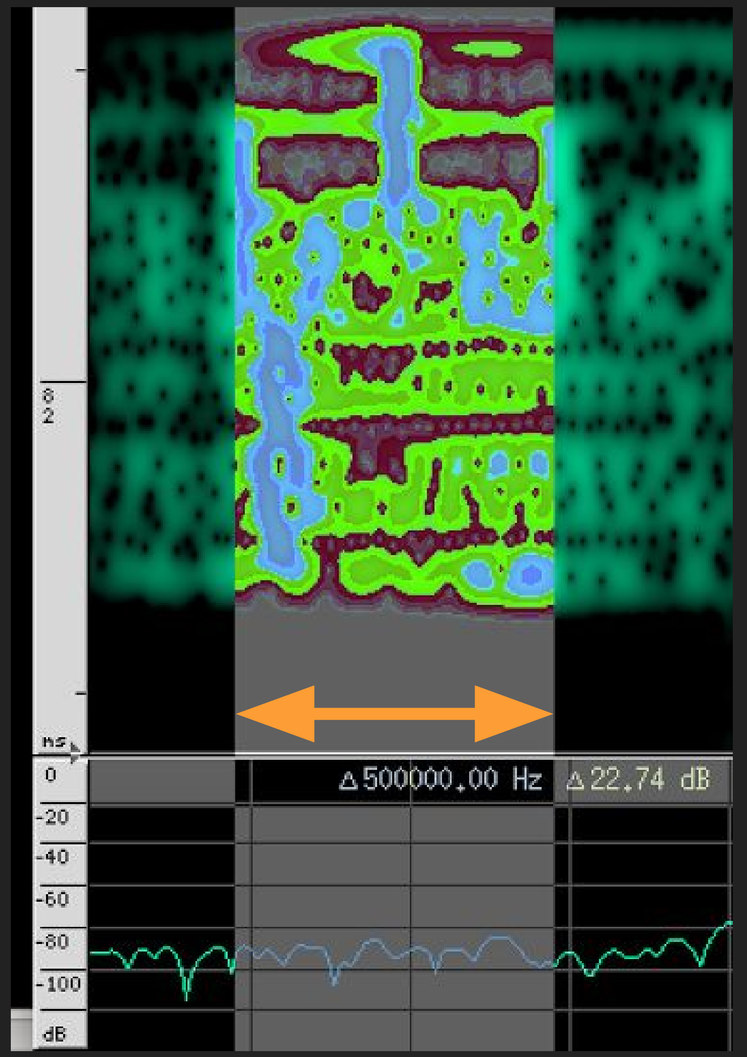
OSINT gets us on our way!

Bandwidth Measurement



Inspectrum

500 kHz



Baudline

RF REVERSE ENGINEERING METHODOLOGY

0. ✓ Open-source intelligence research
1. ✓ Characterize the channel → 16 channels, center frequencies, 500 kHz bandwidth
2. ✓ Identify the modulation → FSK
3. Determine the symbol rate
4. Synchronize
5. Extract symbols

Symbol Rate Measurement

Time selection

Enable cursors: ☑

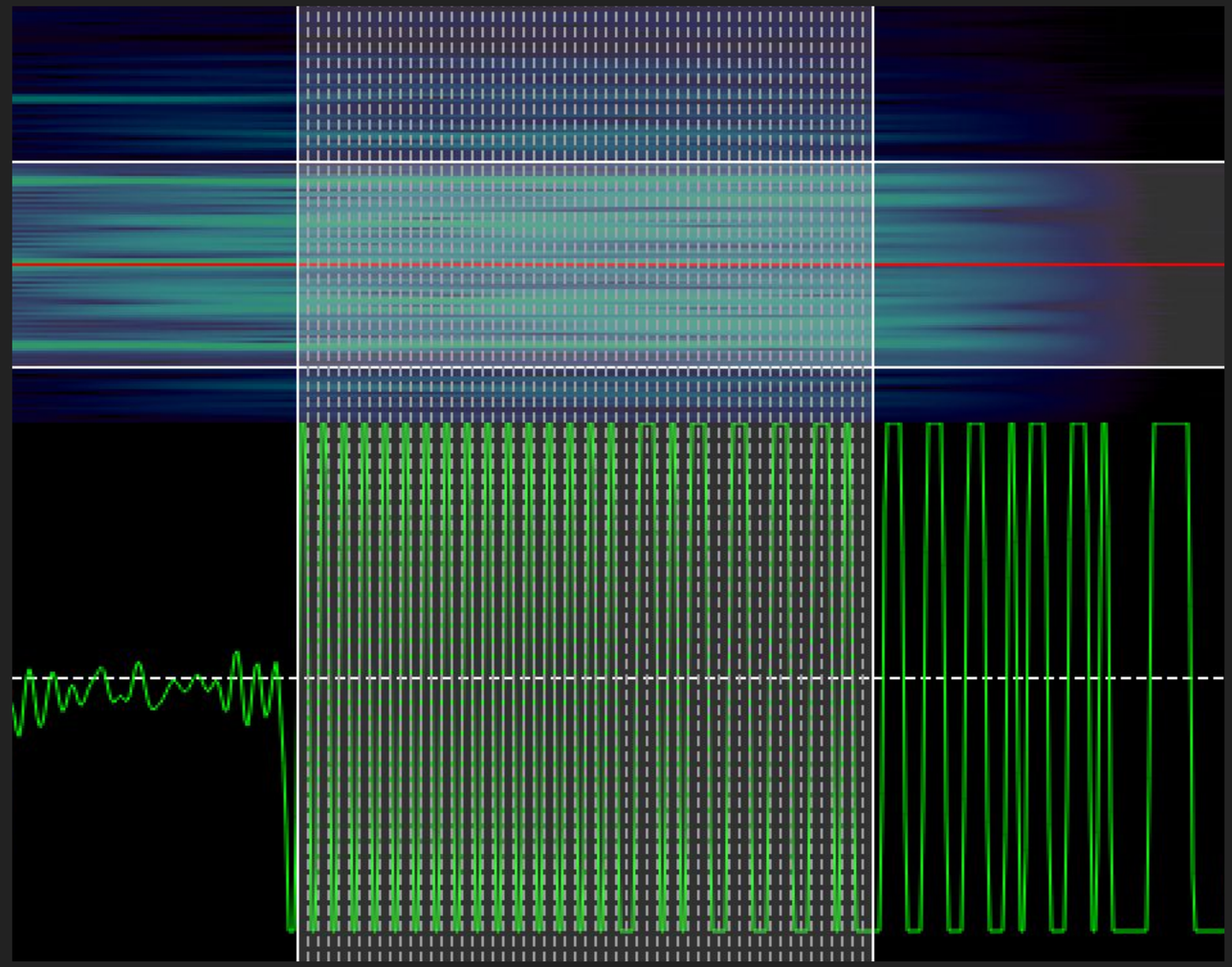
Symbols: 56

Rate: 8.92857kHz

Period: 112µs

Symbol rate: 500kHz

Symbol period: 2µs



Inspectrum Cursors

RF REVERSE ENGINEERING METHODOLOGY

0. ✓ Open-source intelligence research
1. ✓ Characterize the channel → 16 channels, center frequencies, 500 kHz bandwidth
2. ✓ Identify the modulation → FSK
3. ✓ Determine the symbol rate → 500 kHz
4. Synchronize
5. Extract symbols

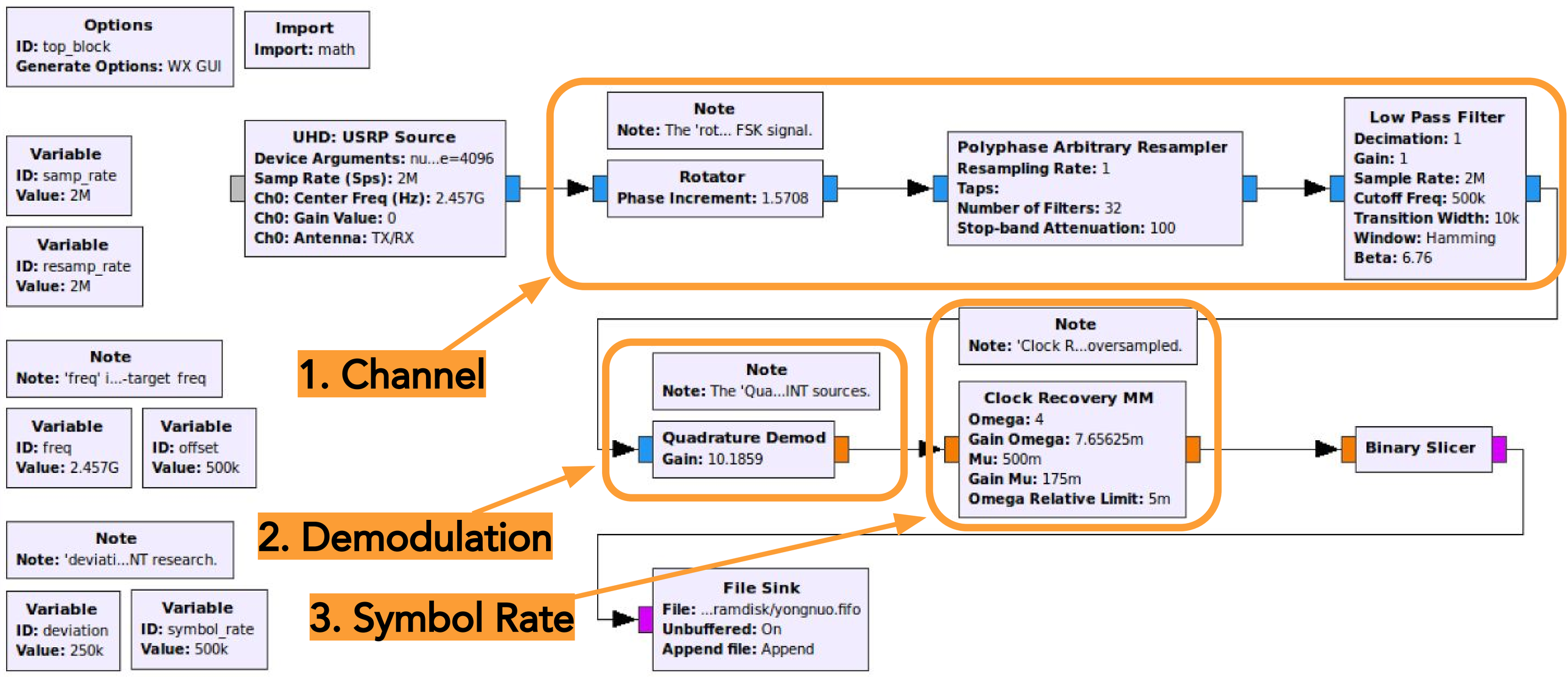
RF REVERSE ENGINEERING METHODOLOGY

0. ✓ Open-source intelligence research
1. ✓ Characterize the channel
2. ✓ Identify the modulation
3. ✓ Determine the symbol rate
4. Synchronize
5. Extract symbols

GNU Radio Flowgraph to produce a stream of symbols

Python scripting to parse symbols into data

Translate Params into GNU Radio Flowgraph



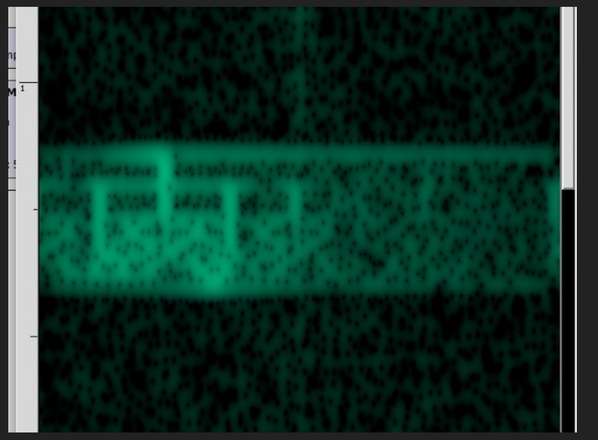
4. Synchronization and 5. Symbol Extraction

1. Look for preamble
   a. 0b010101...
2. Look for SFD to synchronize
   a. Empirically observed to be 0b00
3. Read out frame using approximate MTU size
   a. Dump N bits
4. Parse frame

Application Layer

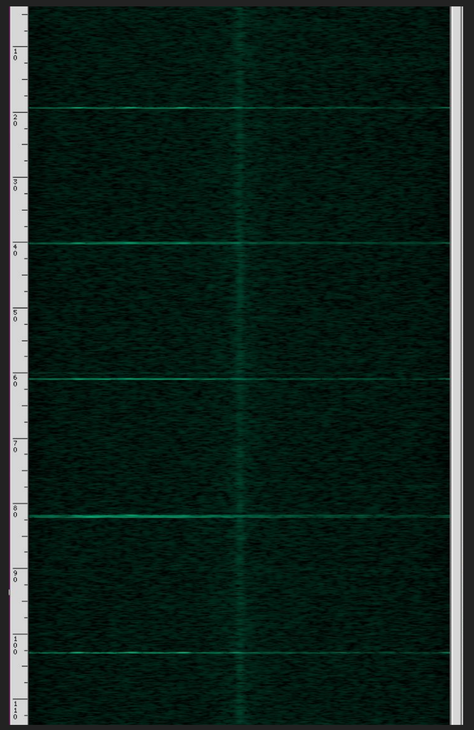
Trigger Flash

- 1 broadcast command fires all camera flashes



Configuration

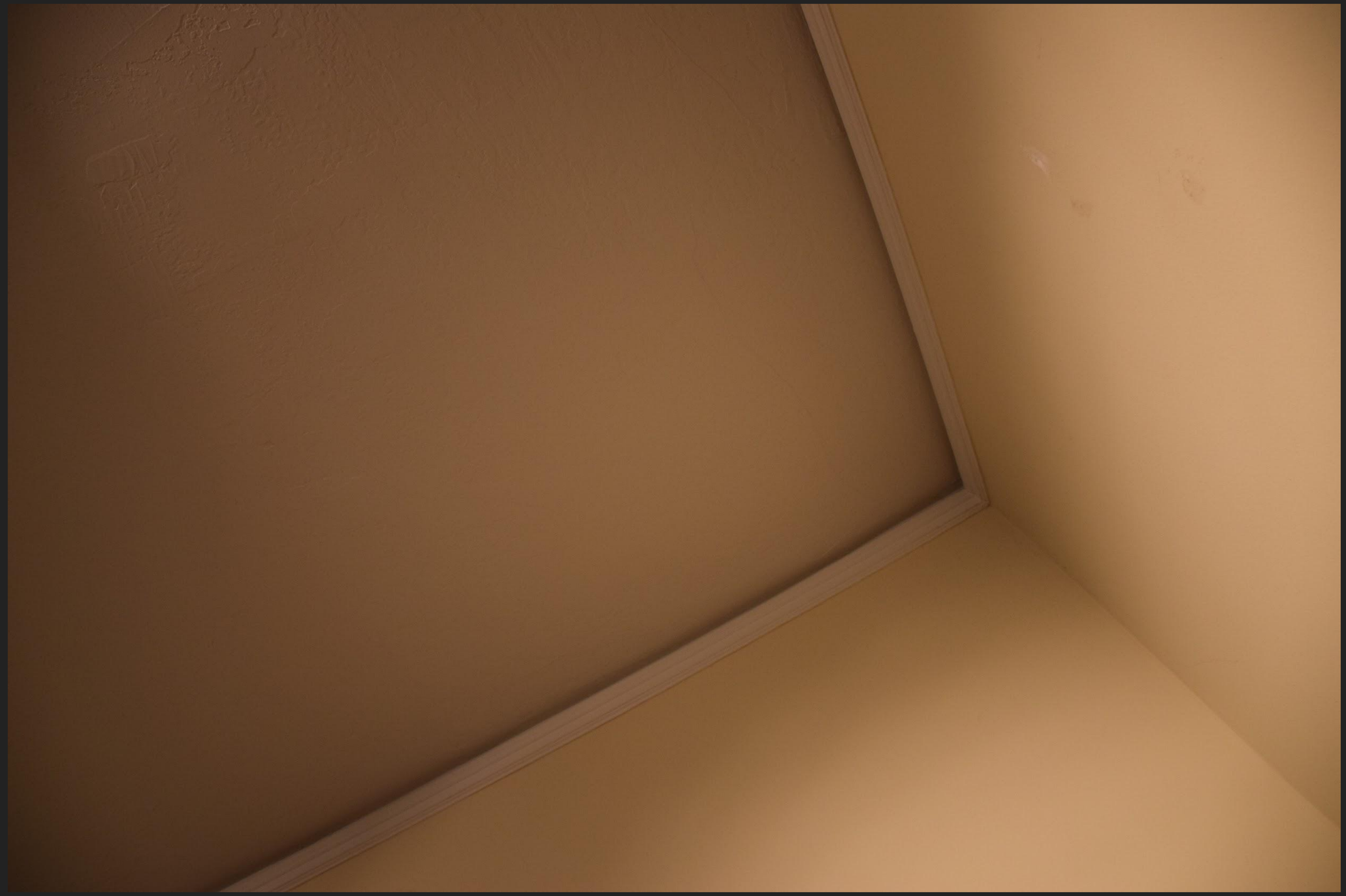
- Updates a single flash group’s settings
  - Target group, mode (On/Manual/Multi), flash power
- 5 commands, only the 4th carries state information

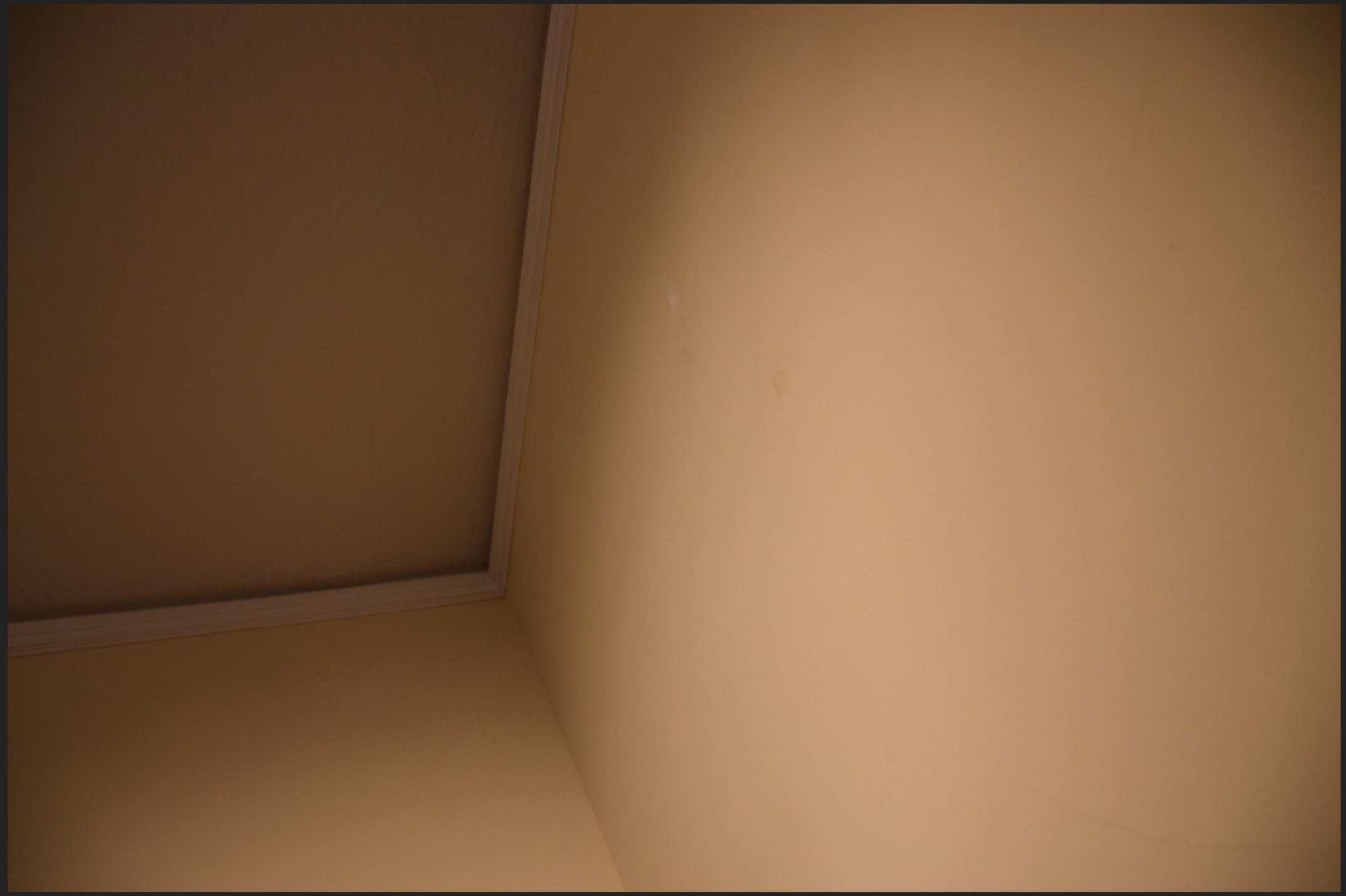


Demo Time!

Bonus Content:

Blooper Reel!





On-Off Keying / Pulse-Width Modulation

RF LED CONTROLLER

[404 Model Not Found]

- USB LED Strip
  - RF Remote Control
  - Unknown Vendor
  - Unknown Model Number
  - No FCC ID

RF LED Controller Reverse Engineering Workflow

0. Open-source intelligence research

1. Characterize the channel
2. Identify the modulation
3. Determine the symbol rate
4. Synchronize
5. Extract symbols

RF Wireless Remote

RGB LED Controller

Instructions

- 19 Dynamic Modes
- 20 Static Colors
- 256-Grade PWM
- Speed Adjustable
- Brightness Adjustable
- Card Type Remote
- Ultra Slim Design
- Demo Mode
- 1 to 1 Remote Paired
- Auto Save Function

1. Turn On/Standby

Press this key to turn on unit or switch to standby mode. Unit will turn on and restore to previous status at powering on moment.

2/9. Dynamic Modes Adjust

Switch to dynamic mode from static color mode, or switch between dynamic modes.

3/8. Dynamic Speed Adjust

Adjust dynamic playing speed. Press Speed+ to increase speed and press Speed- to decrease speed Unit will switch to dynamic mode If press this key at static color mode.

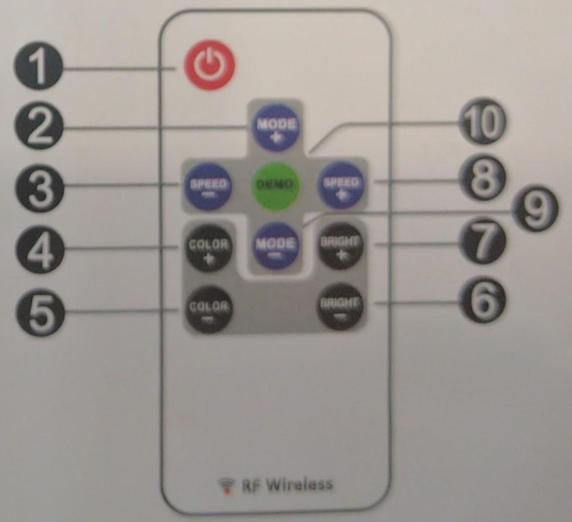
4/5. Static Color Adjust

Switch to static color mode from dynamic mode, or switch between different static colors.

6/7. Brightness Adjust

Adjust static color brightness. Press Bright+ to increase brightness and press Bright- to decrease. Unit will switch to static color mode If press this key at dynamic mode.

Functions



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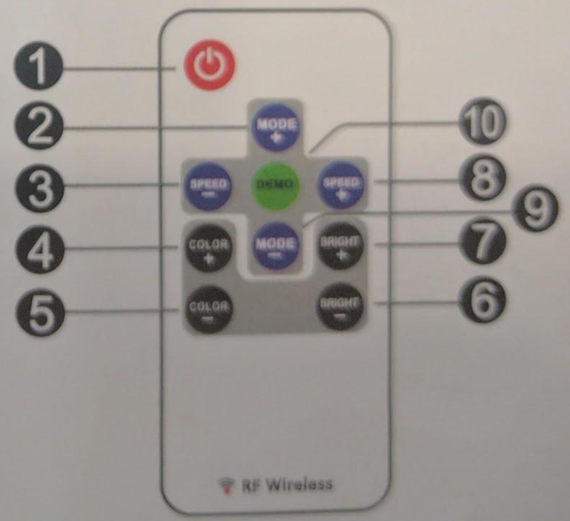
Adjust static color brightness. Press Bright+ to increase brightness and press Bright- to decrease. Unit will switch to static color mode If press this key at dynamic mode.

Functions



Nothing Useful

10. Demo Mode

Press this key will switch to Demo mode. In Demo mode, it will loop play 9 dynamic modes, each mode repeat 3 times.

Installing

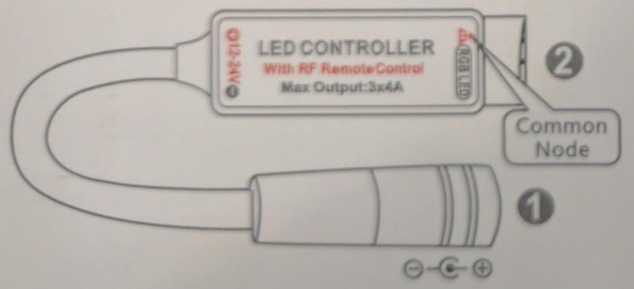
1. Power Supply

This unit accepts DC 12V to 24V power supply. The inner pole polarity is positive and sleeve is negative. Please select proper power supply according to the LED application.

2. LED Output

This unit support common anode connection LED products. The mark '⚠' indicates the common connection node. The peak output current is 4A per channel, please reduce load if main unit is overheating.

CAUTION! Do not short circuit the LED output, this may lead to permanent damage!



3. Remote Controll

Please pull out the insulate part before using. The RF wireless remote signal can pass through barrier, so it's not necessary to aim at the main unit when operate. For proper receiving remote signal, do not install the main unit in closed metal parts. The remote battery is 3V CR2025 type, please only replace with same type battery.

Specification

Dynamic mode	19 modes
Static Color	20 colors
PWM Grade	256 levels
Brightness Grade	5 levels
Speed Grade	10 levels
Demo mode	Yes
Working Voltage	DC 12~24V
Output Current	3-way, peak 4A per channel
Remote frequency	433.92MHz
Remote distance	>30m at open area

10. Demo Mode

Press this key will switch to Demo mode. In Demo mode, it will loop play 9 dynamic modes, each mode repeat 3 times.

Installing

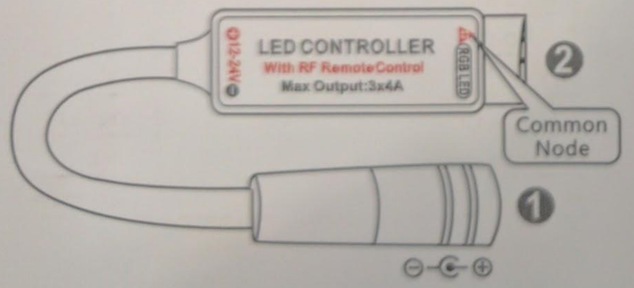
1. Power Supply

This unit accepts DC 12V to 24V power supply. The inner pole polarity is positive and sleeve is negative. Please select proper power supply according to the LED application.

2. LED Output

This unit support common anode connection LED products. The mark '⏚' indicates the common connection node. The peak output current is 4A per channel, please reduce load if main unit is overheating.

CAUTION! Do not short circuit the LED output, this may lead to permanent damage!



3. Remote Controll

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Specification

Dynamic mode	19 modes
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PWM Grade	256 levels
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Speed Grade	10 levels
Demo mode	Yes
Working Voltage	DC 12~24V
Output Current	3-way, peak 4A per channel
Remote frequency	433.92MHz
Remote distance	>30m at open area

433.92 MHz Center Frequency

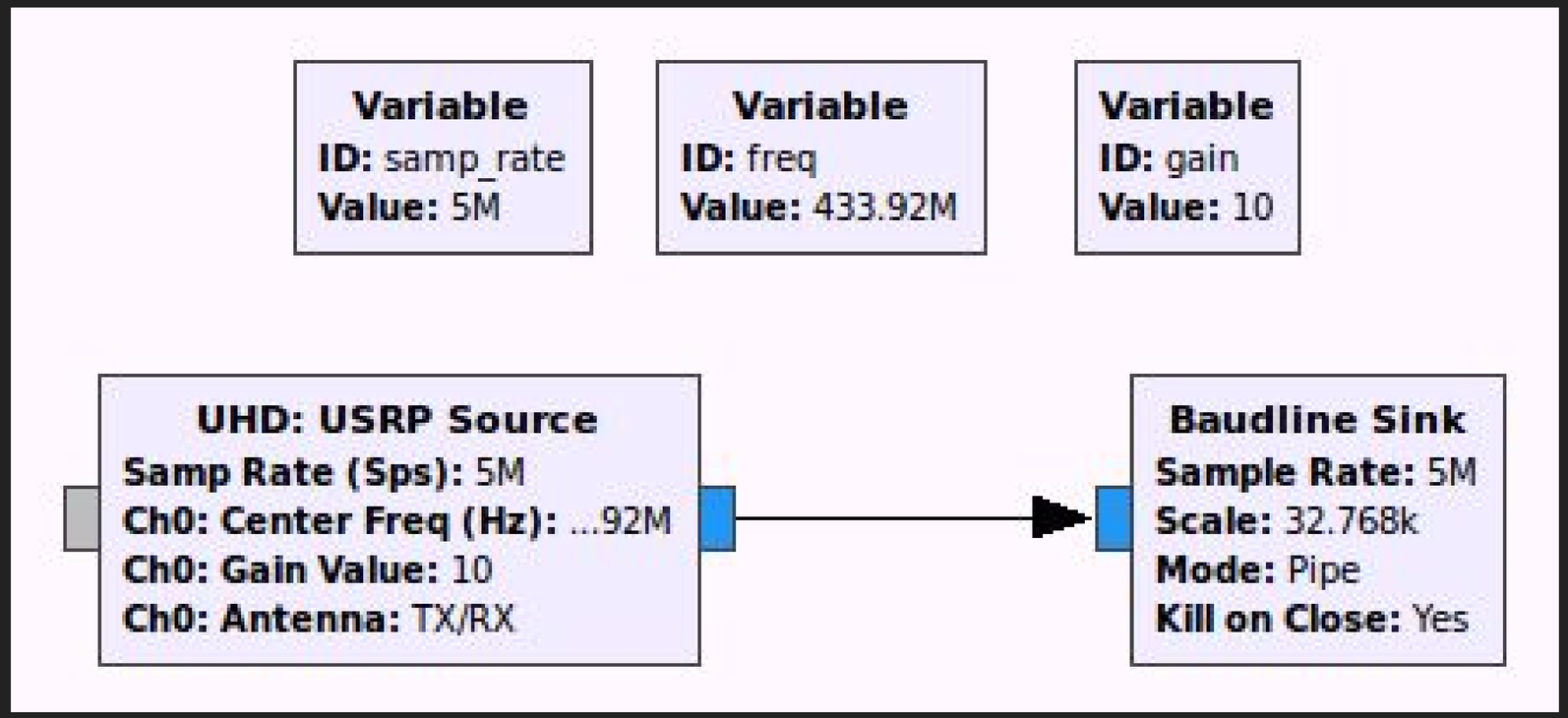
RF LED Controller Reverse Engineering Workflow

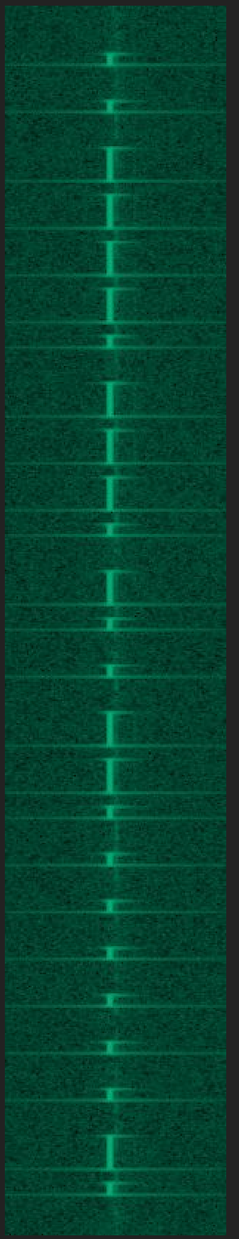
0. Open-source intelligence research
1. Characterize the channel → 433.92 MHz Center Frequency
2. Identify the modulation
3. Determine the symbol rate
4. Synchronize
5. Extract symbols

RF LED Controller Reverse Engineering Workflow

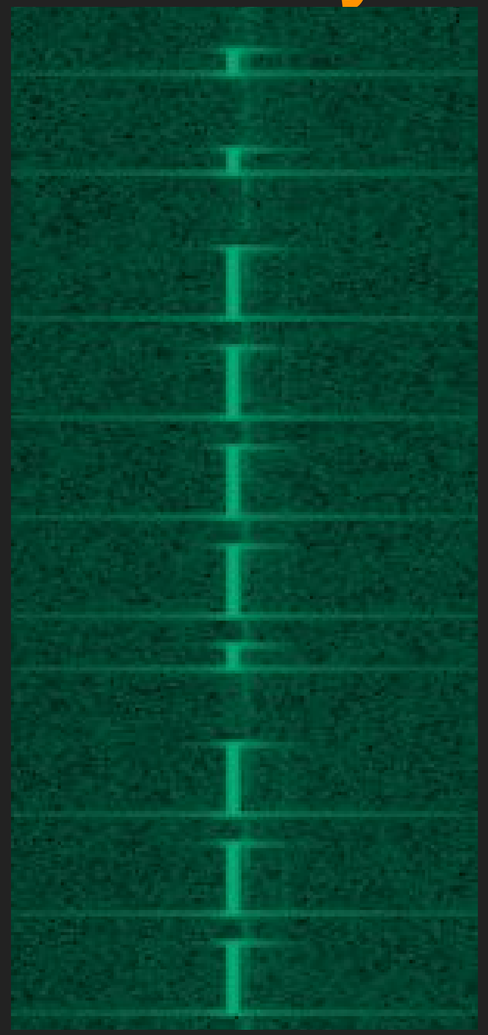
0. Open-source intelligence research
1. Characterize the channel
2. Identify the modulation
3. Determine the symbol rate
4. Synchronize
5. Extract symbols

Visually Determine the Modulation

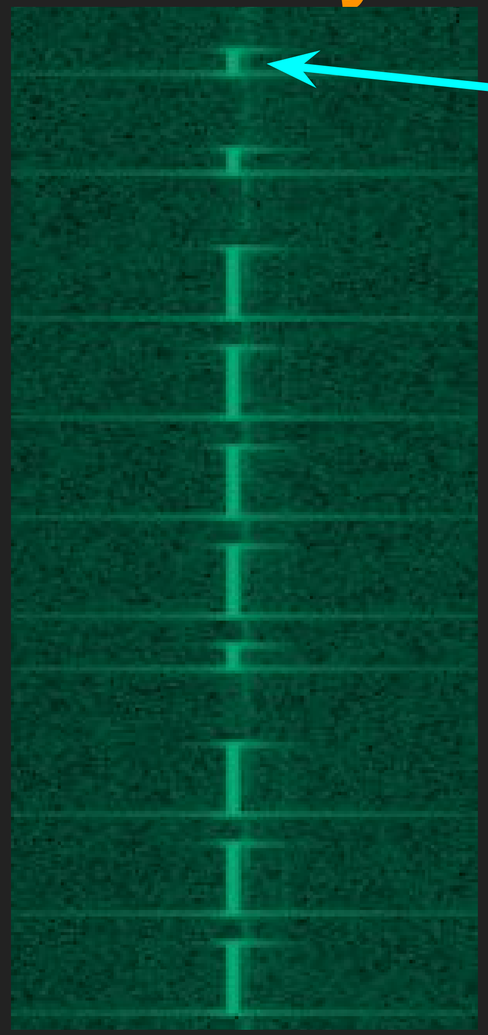




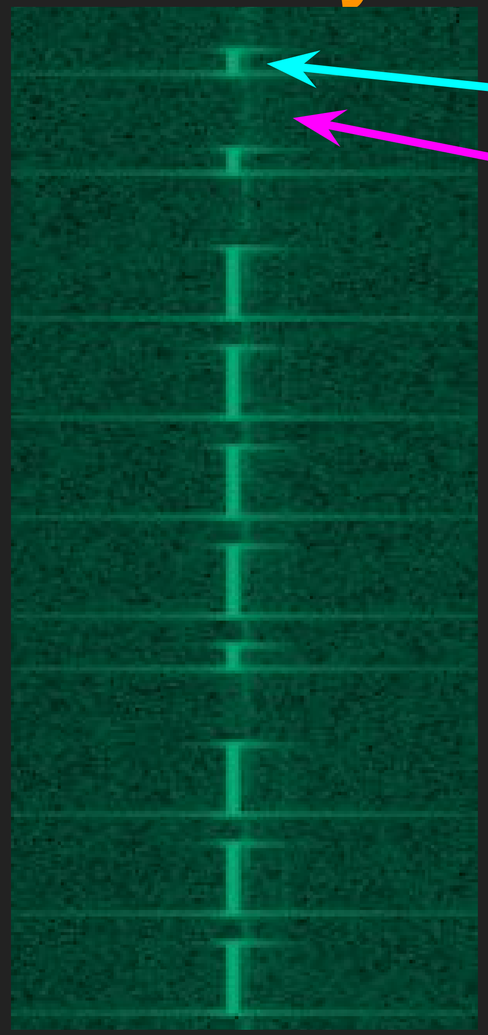
Visually Determine the Modulation



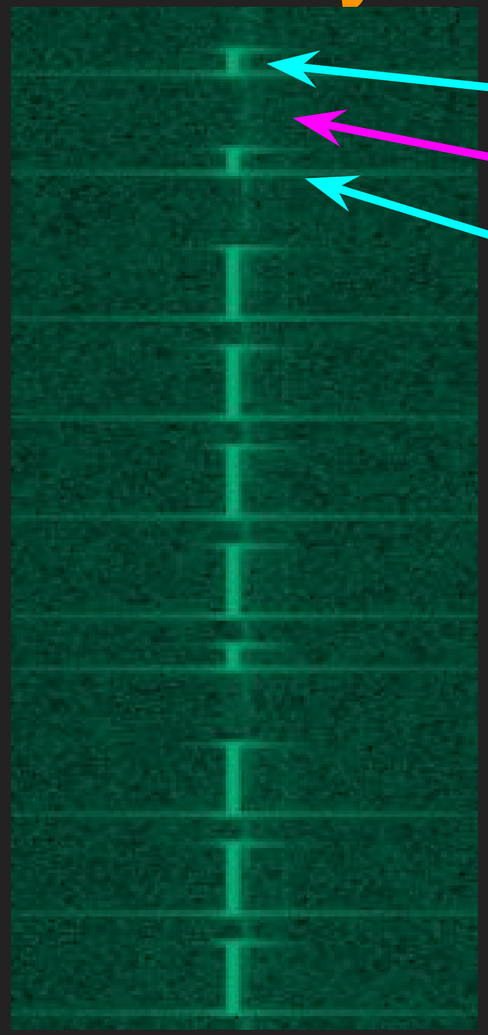
Visually Determine the Modulation



Visually Determine the Modulation



Visually Determine the Modulation

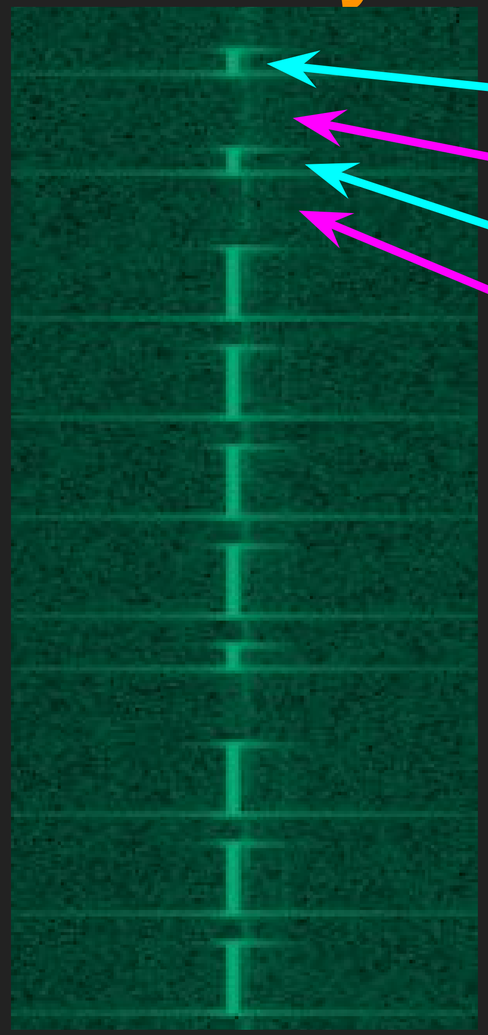


Transmitter On

Transmitter Off

Transmitter On

Visually Determine the Modulation



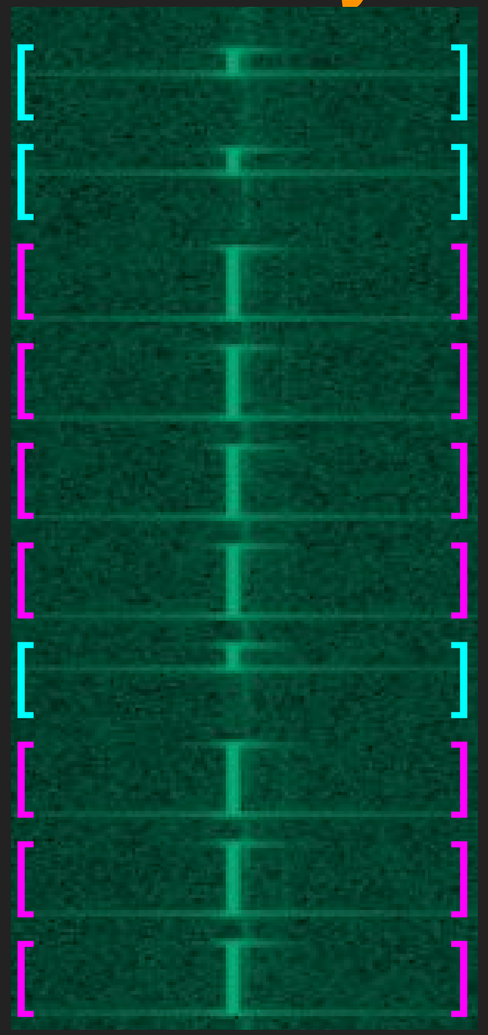
Transmitter On

Transmitter Off

Transmitter On

Transmitter Off

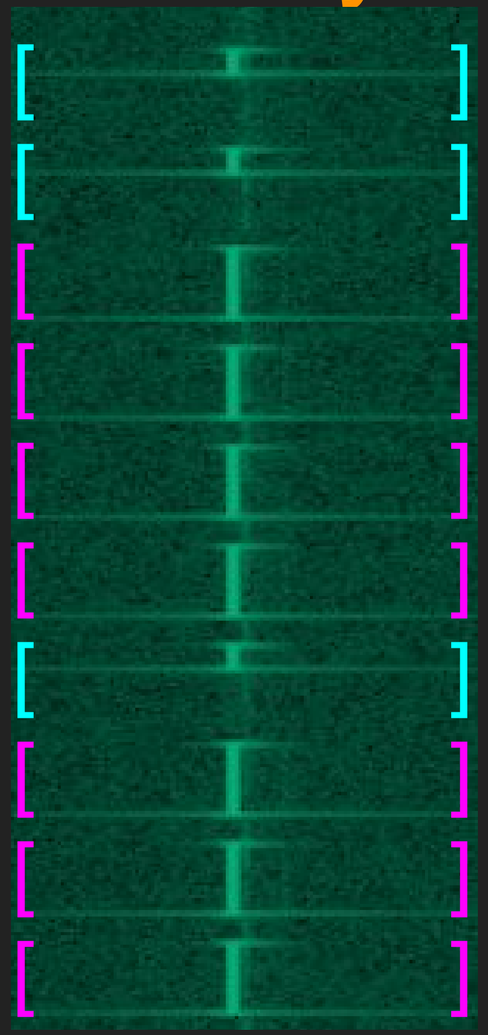
Visually Determine the Modulation



On for ~450us
Off for ~1200us

On for ~1200us
Off for ~450us

Visually Determine the Modulation



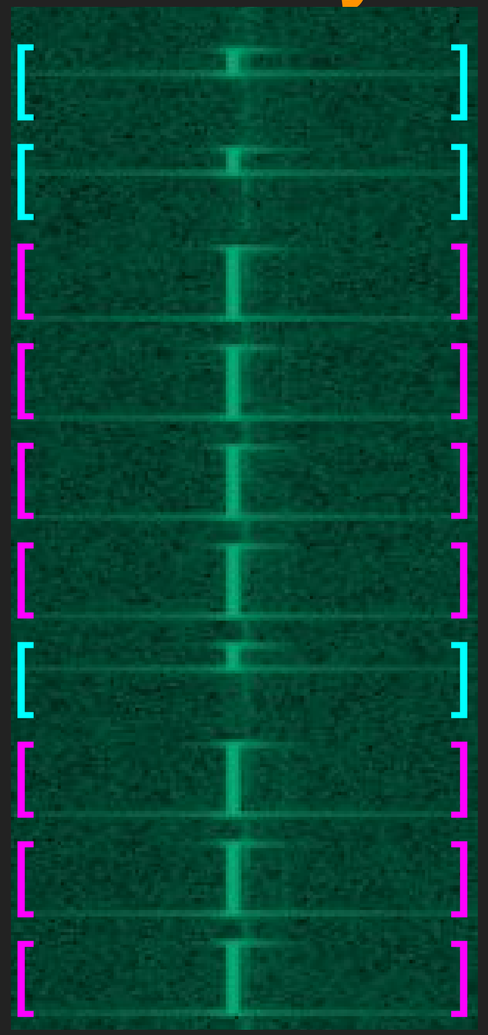
On for ~450us
Off for ~1200us

0

On for ~1200us
Off for ~450us

1

Visually Determine the Modulation



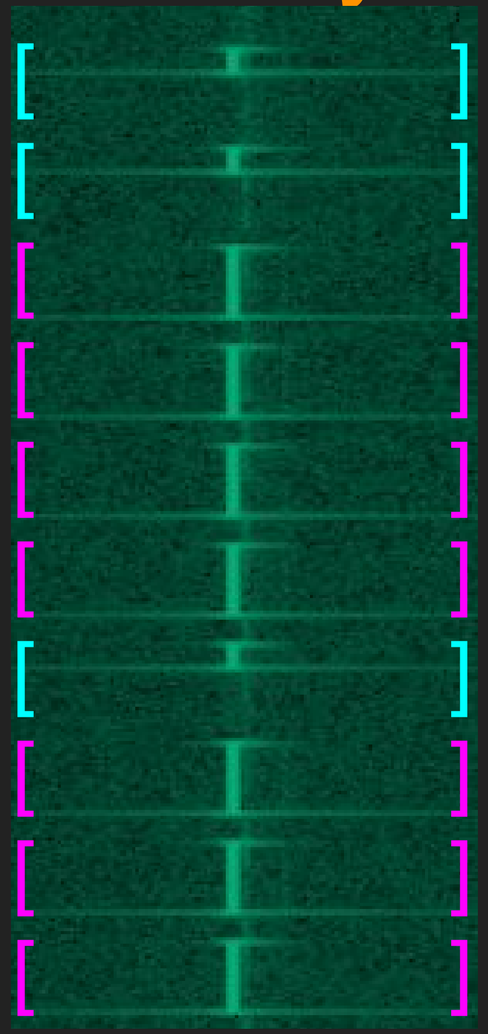
On for ~450us
Off for ~1200us

0

On for ~1200us
Off for ~450us

1

Visually Determine the Modulation



On for ~450us
Off for ~1200us
0

On for ~1200us
Off for ~450us
1

Pulse Width Modulation (On-Off Keying)

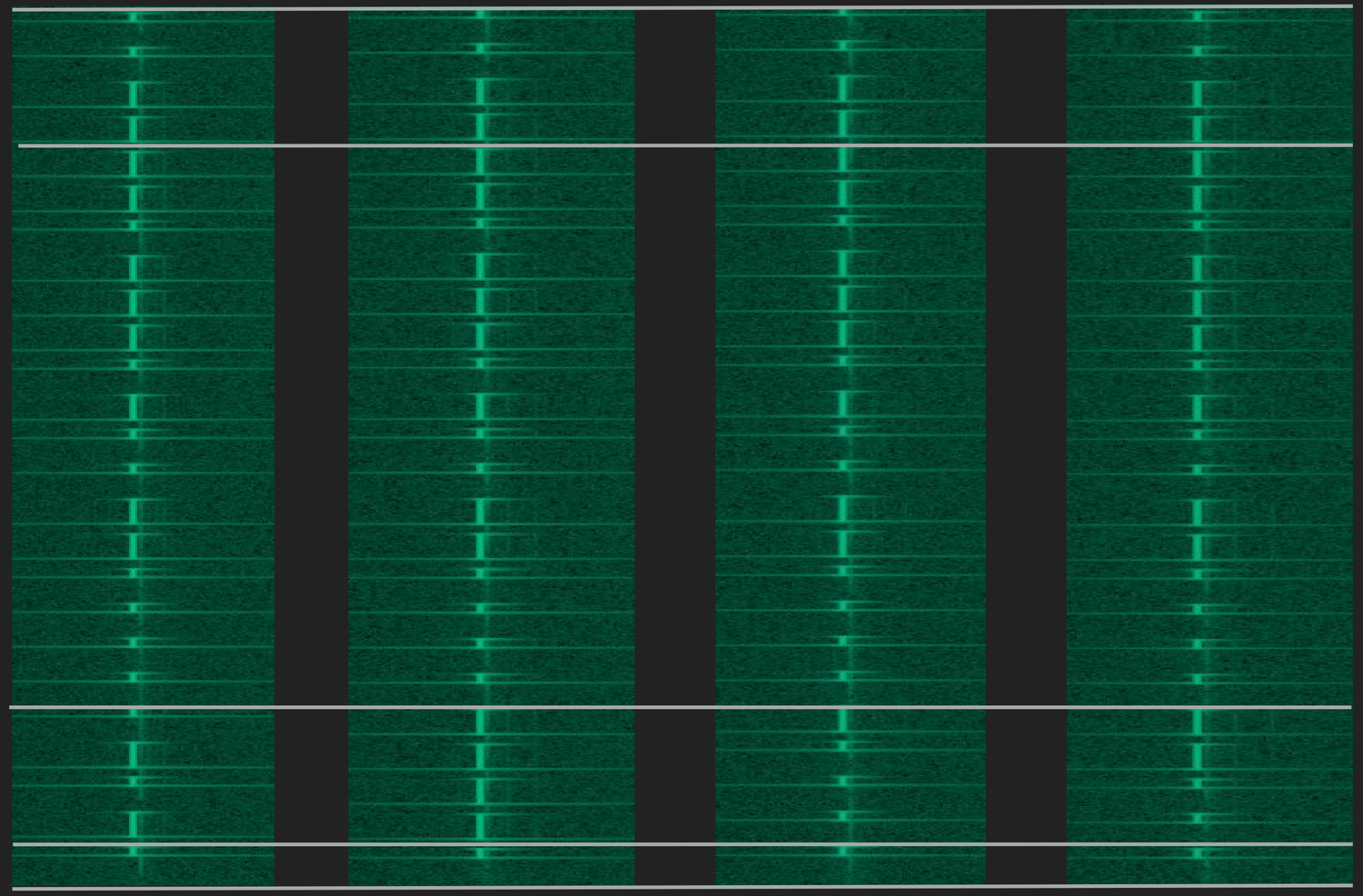
RF LED Controller Reverse Engineering Workflow

0. Open-source intelligence research
1. Characterize the channel
2. Identify the modulation → Pulse Width Modulation / On-Off Keying
3. Determine the symbol rate → ~600b/s (1650us symbol duration)
4. Synchronize
5. Extract symbols

RF LED Controller Reverse Engineering Workflow

0. Open-source intelligence research
1. Characterize the channel
2. Identify the modulation
3. Determine the symbol rate
4. Synchronize
5. Extract symbols

Button Waveforms in Baudline



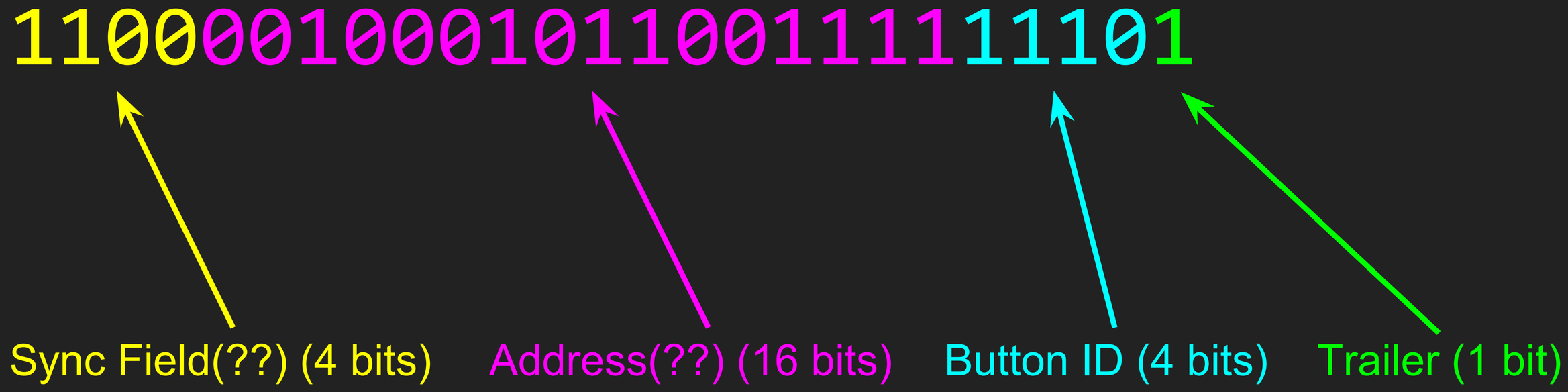
Sync Field(??) (4 bits)

Address(??) (16 bits)

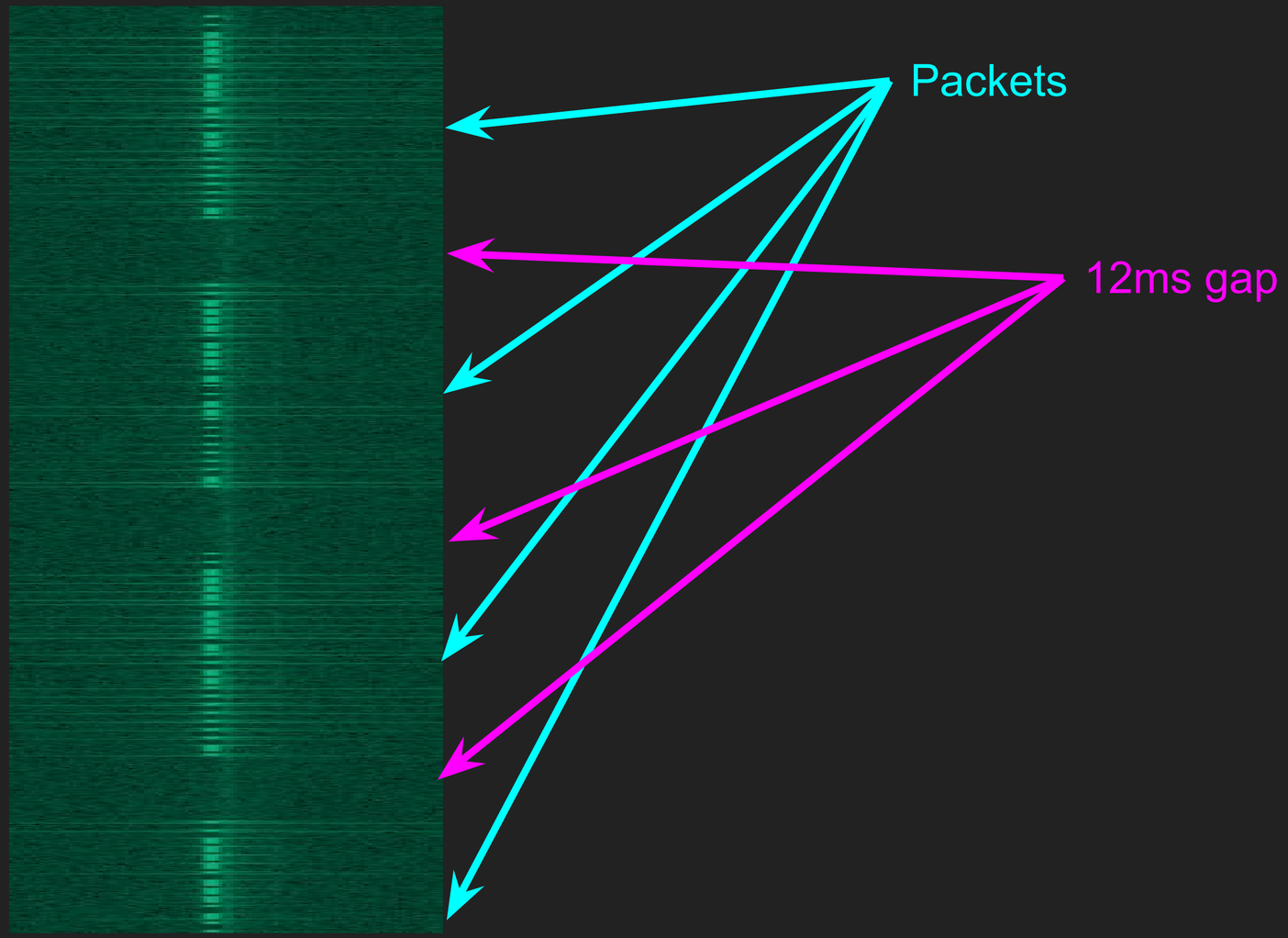
Button ID (4 bits)

Trailer (1 bit)

RF LED Controller Packet Format



Packet Spacing



What do we know?

- 433.92 MHz center frequency [channel]
- Pulse width modulation [modulation]
  - 600b/s data rate [symbol timing]
  - Bit 1 is ~1200us on and ~450us off
  - Bit 0 us ~450us on and ~1200us off
- Packets are 25 bits long [synchronize]
  - 4 sync bits (??)
  - 16 address bits (??)
  - 4 button id
  - 1 trailer
  - 12ms spacing between packets

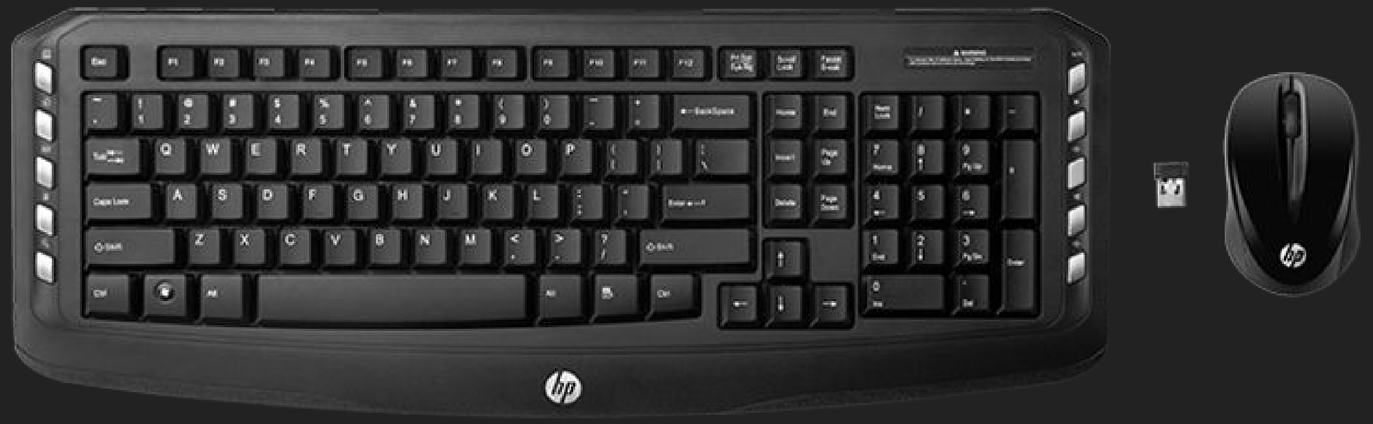
RF LED CONTROLLER DEMOS

TDMA Frequency Shift Keying

HP KEYBOARD

HP CLASSIC WIRELESS DESKTOP

- 2.4GHz Wireless Keyboard/Mouse
- OEM = ACROX
- Keyboard
  - FCC ID PRDKB14
- Mouse
  - FCC ID PRDMU26
- Dongle
  - FCC ID PRDRX02



HP DONGLE TEST REPORT

EUT	2.4GHz Receiver
MODEL NO.	MRN
FCC ID	PRDRX02
POWER SUPPLY	5Vdc (host equipment)
MODULATION TYPE	GFSK
DATA RATE	1M bit/sec.
OPERATING FREQUENCY	2403MH~2480MHz
NUMBER OF CHANNEL	78
ANTENNA TYPE	Printed antenna
DATA CABLE	NA
I/O PORT	USB
ACCESSORY DEVICES	NA

HP KEYBOARD TEST REPORT

1.1.1 Product Details

The following brands are provided to this EUT.

Brand Name	Model Name	Product Name	Description
ACROX	KBIM, K2BM	HP Wireless Keyboard K2500	Marketing purpose
HP			

1.1.2 Specification of the Equipment under Test (EUT)

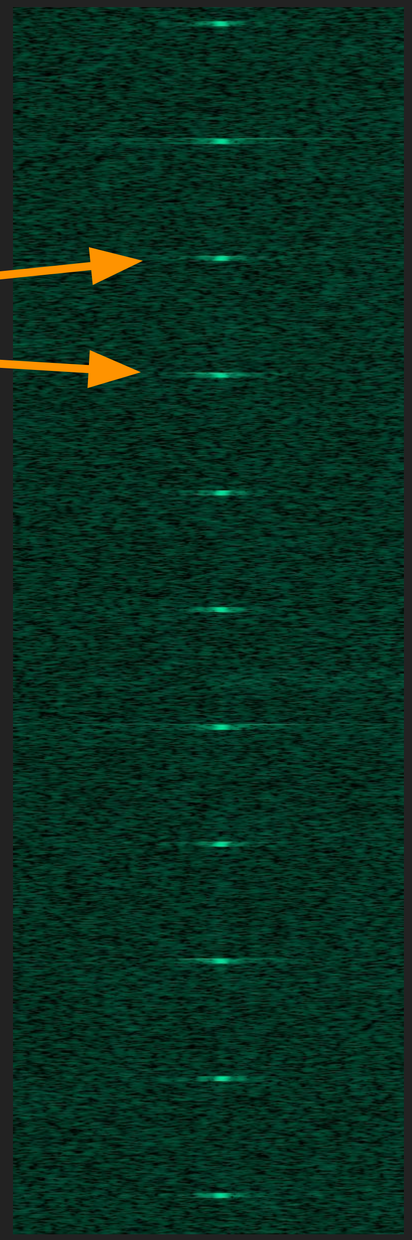
RF General Information				
Frequency Range (MHz)	**Modulation**	**Ch. Freq. (MHz)**	**Channel Number**	**Channel Bandwidth (MHz)**
2400-2483.5	FSK	2408-2474	1-34 [34]	2

HP DONGLE DMESG OUTPUT

```
[  +0.276333] usb 1-3.1: new full-speed USB device number 21 using xhci_hcd
[  +0.091959] usb 1-3.1: New USB device found, idVendor=3938, idProduct=1032
[  +0.000012] usb 1-3.1: New USB device strings: Mfr=1, Product=2, SerialNumber=0
[  +0.000008] usb 1-3.1: Product: 2.4G RF Keyboard & Mouse
[  +0.000007] usb 1-3.1: Manufacturer: MOSART Semi.
[  +0.000470] usb 1-3.1: ep 0x81 - rounding interval to 64 microframes, ep desc says 80 microframes
[  +0.002402] input: MOSART Semi. 2.4G RF Keyboard & Mouse as /devices/pci0000:00/0000:00:14.0/usb1/1
[  +0.054089] hid-generic 0003:3938:1032.0009: input,hidraw2: USB HID v1.10 Keyboard [MOSART Semi. 2
[  +0.004330] input: MOSART Semi. 2.4G RF Keyboard & Mouse as /devices/pci0000:00/0000:00:14.0/usb1/1
[  +0.055401] hid-generic 0003:3938:1032.000A: input,hiddev0,hidraw3: USB HID v1.10 Mouse [MOSART Ser
```

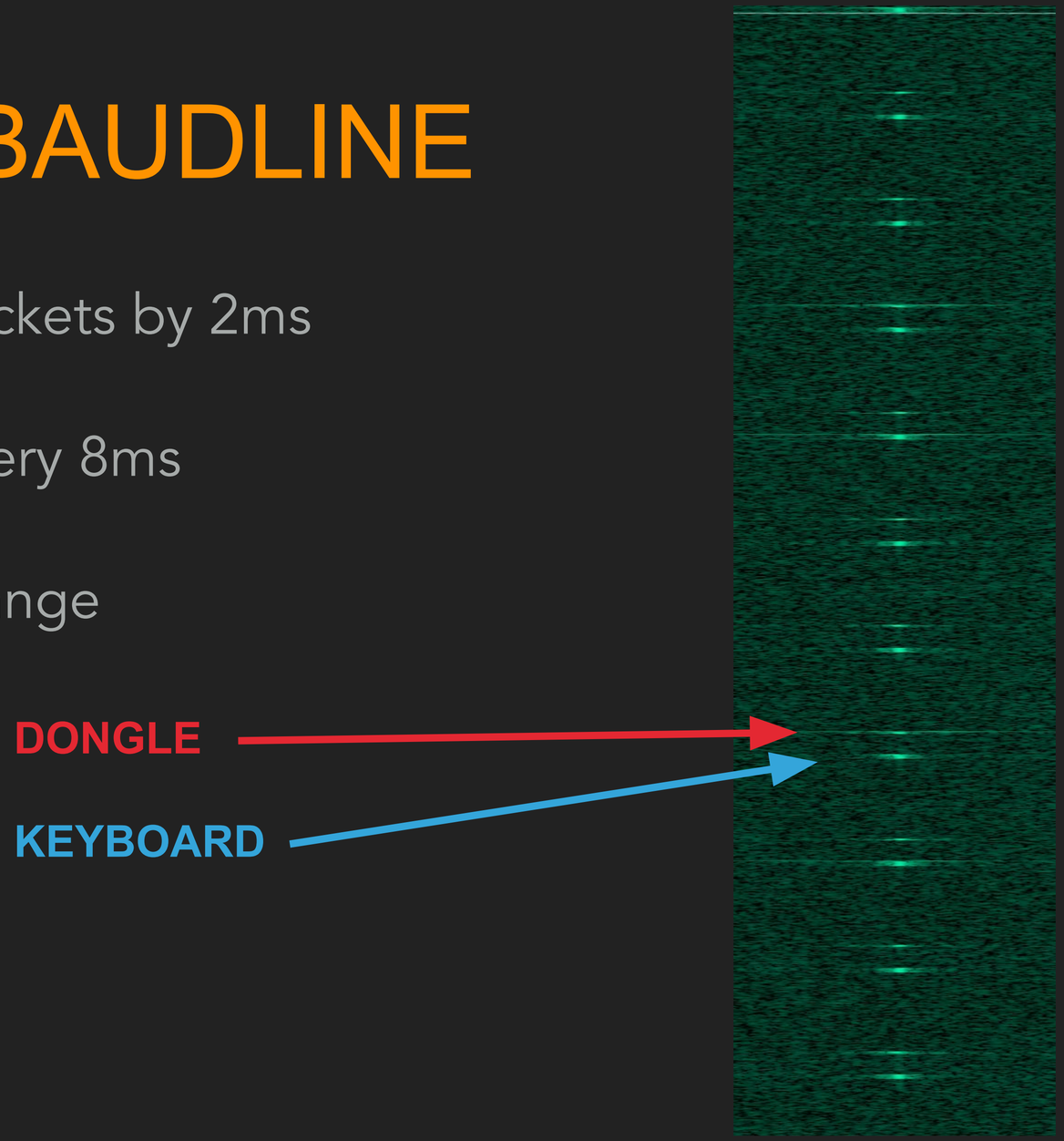
DONGLE IN BAUDLINE

- Always transmitting at 8ms intervals
- No channel hopping
- TDMA? (Time Division Multiple Access)

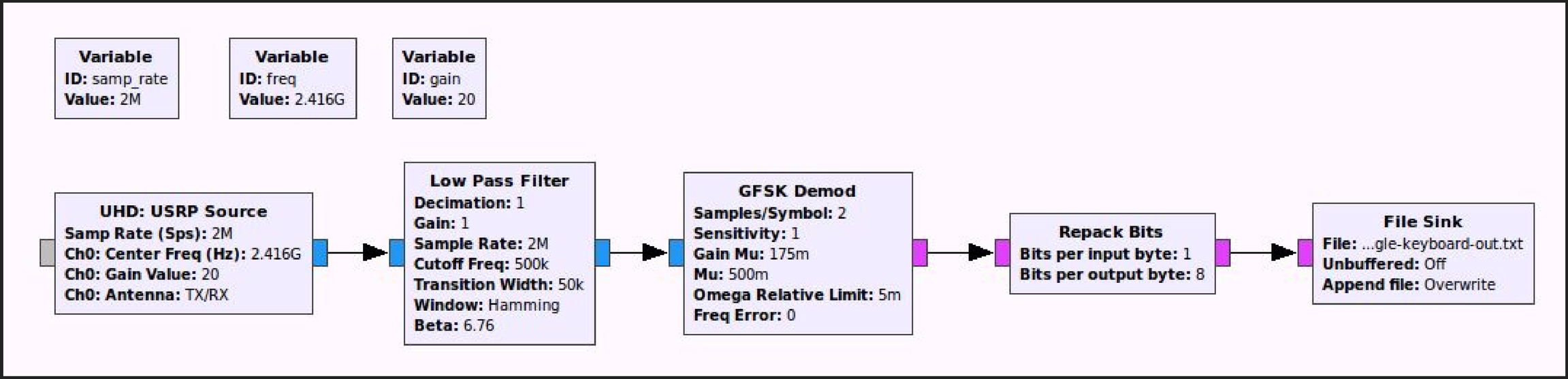


KEYBOARD IN BAUDLINE

- Keystrokes follow dongle packets by 2ms
- Keyboard transmits up to every 8ms
- Dongle behavior doesn’t change



KEYBOARD DEMOD FLOWGRAPH



GREP FOR PACKETS

```
xxd -p demod.out |
tr -d "\n" |
grep -Po "(00|ff|aa|55)+.{8}" |
sort |
uniq -c |
sort -nr |
Head -n 10
```

GREP FOR PACKETS

```
xxd -p demod.out |
tr -d "\n" |
grep -Po "(00|ff|aa|55)+.{8}" |
sort |
uniq -c |
sort -nr |
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Head -n 10
```

Bytes to Hex

Grep for Packets

GREP FOR PACKETS

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xxd -p demod.out |
tr -d "\n" |
grep -Po "(00|ff|aa|55)+.{8}" |
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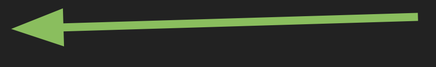
```

Bytes to Hex



Grep for Packets

Sort by Count

DONGLE PACKET BYTES

```
ffffaaaaaaaaaaaaaaaaeddd4e8
```

```
sed s/[dongle packets]//g
```

KEYBOARD PACKET BYTES

```
aaaaaaaddd4e8
```

GREP, GREP, AND GREP SOME MORE!

```
aaaaaa ddd4e8 2e db 3f 384a
aaaaaa ddd4e8 2d db 37 6092
aaaaaa ddd4e8 28 db 3f 98f8
aaaaaa ddd4e8 25 db 3f c9ba
aaaaaa ddd4e8 25 db 21 3649
aaaaaa ddd4e8 21 db 27 30f5
aaaaaa ddd4e8 20 db 3f 3951
```

GREP, GREP, AND GREP SOME MORE!

```
aaaaaa ddd4e8 2e db 3f 384a
aaaaaa ddd4e8 2d db 37 6092
aaaaaa ddd4e8 28 db 3f 98f8
aaaaaa ddd4e8 25 db 3f c9ba
aaaaaa ddd4e8 25 db 21 3649
aaaaaa ddd4e8 21 db 27 30f5
aaaaaa ddd4e8 20 db 3f 3951
```

preamble

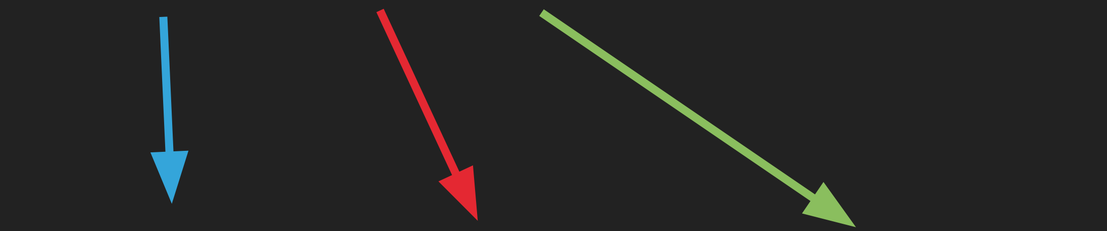
GREP, GREP, AND GREP SOME MORE!

```
aaaaaa ddd4e8 2e db 3f 384a
aaaaaa ddd4e8 2d db 37 6092
aaaaaa ddd4e8 28 db 3f 98f8
aaaaaa ddd4e8 25 db 3f c9ba
aaaaaa ddd4e8 25 db 21 3649
aaaaaa ddd4e8 21 db 27 30f5
aaaaaa ddd4e8 20 db 3f 3951
```

preamble address

GREP, GREP, AND GREP SOME MORE!

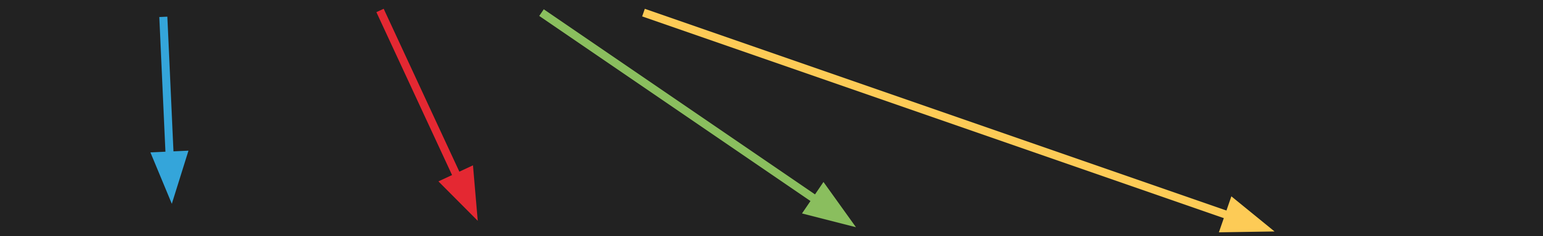
```
aaaaaa ddd4e8 2e db 3f 384a
aaaaaa ddd4e8 2d db 37 6092
aaaaaa ddd4e8 28 db 3f 98f8
aaaaaa ddd4e8 25 db 3f c9ba
aaaaaa ddd4e8 25 db 21 3649
aaaaaa ddd4e8 21 db 27 30f5
aaaaaa ddd4e8 20 db 3f 3951
```



preamble address sequence

GREP, GREP, AND GREP SOME MORE!

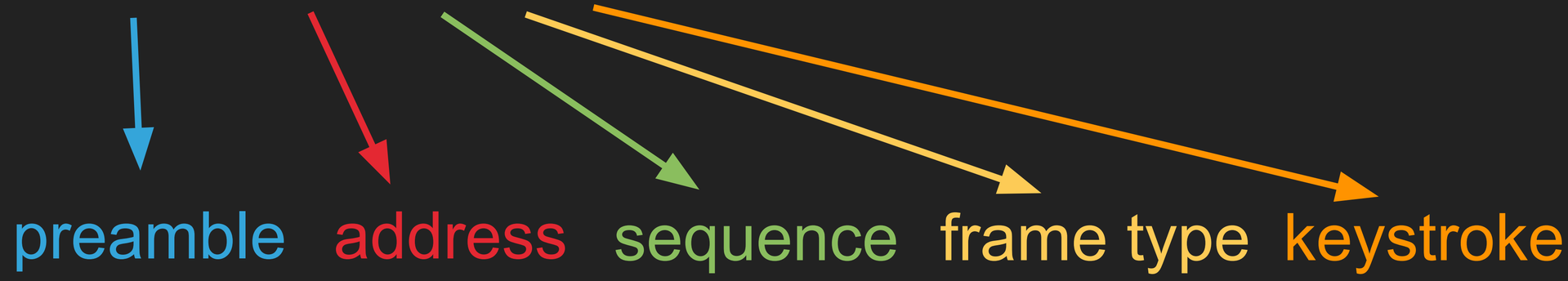
```
aaaaaa ddd4e8 2e db 3f 384a
aaaaaa ddd4e8 2d db 37 6092
aaaaaa ddd4e8 28 db 3f 98f8
aaaaaa ddd4e8 25 db 3f c9ba
aaaaaa ddd4e8 25 db 21 3649
aaaaaa ddd4e8 21 db 27 30f5
aaaaaa ddd4e8 20 db 3f 3951
```



preamble address sequence frame type

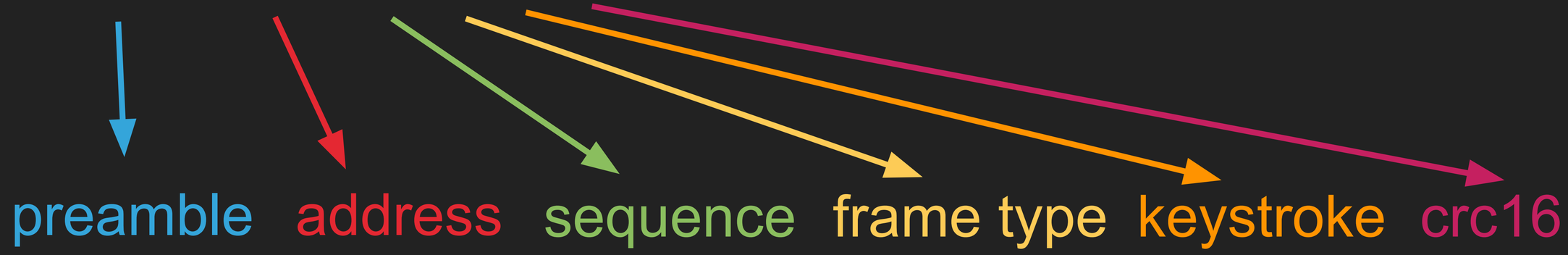
GREP, GREP, AND GREP SOME MORE!

```
aaaaaa ddd4e8 2e db 3f 384a
aaaaaa ddd4e8 2d db 37 6092
aaaaaa ddd4e8 28 db 3f 98f8
aaaaaa ddd4e8 25 db 3f c9ba
aaaaaa ddd4e8 25 db 21 3649
aaaaaa ddd4e8 21 db 27 30f5
aaaaaa ddd4e8 20 db 3f 3951
```



GREP, GREP, AND GREP SOME MORE!

```
aaaaaa ddd4e8 2e db 3f 384a
aaaaaa ddd4e8 2d db 37 6092
aaaaaa ddd4e8 28 db 3f 98f8
aaaaaa ddd4e8 25 db 3f c9ba
aaaaaa ddd4e8 25 db 21 3649
aaaaaa ddd4e8 21 db 27 30f5
aaaaaa ddd4e8 20 db 3f 3951
```



tl;dr

smarter people than me made that easy

Common Threads

Methodology Revisited

Reverse Engineering Methodology

0. Open-source intelligence research
1. Characterize the channel
2. Identify the modulation
3. Determine the symbol rate
4. Synchronize
5. Extract symbols

1. Channel Characterization

All 3 PHYs share a common notion of a channel

Camera Flash Controller	RF LED Strip	Keyboard
+/- 250 kHz in 2.4 GHz	433.92 MHz	2416 MHz

2. Identify Modulation

Modulation is the biggest variable

(but OSINT makes identifying it easy)

Camera Flash Controller	**RF LED Strip**	**Keyboard**
Frequency Shift Keying	Pulse-Width Modulation / On-Off Keying	TDMA Frequency Shift Keying

3. Symbol Rate Recovery

All 3 PHYs share a common notion of discrete symbol timing

Camera Flash Controller	RF LED Strip	Keyboard
500,000 symbols/s	600 symbols/s	1,000,000 symbols/s

4. Synchronization

All 3 PHYs contain synchronization features
(preamble and/or Start of Frame delimiter)

Camera Flash Controller	RF LED Strip	Keyboard
(0b01010101...00)	Sync Field (assumed)	Preamble (0xaa..aa) SFD (3 byte address)

5. Symbol Extraction

Once you get here it’s just bits on a disk

Reverse Engineering Methodology

0. Open-source intelligence research
1. Characterize the channel
2. Identify the modulation
3. Determine the symbol rate
4. Synchronize
5. Extract symbols

Same process for
3 different PHYs!

Conclusions

Disparate wireless systems can be rationalized via process

OSINT will help you skip the complex/domain-specific radio parts

Once you demodulate, you have bits on a disk which you can handle any way you please

One last thought to leave you with...

The IoT is full of holes...

marc@Bastille.net
@marcnewlin

matt@Bastille.net
@embeddedsec

It’s up to you to find them!

marc@Bastille.net
@marcnewlin

matt@Bastille.net
@embeddedsec

Thanks!

marc@Bastille.net
@marcnewlin

matt@Bastille.net
@embeddedsec

Questions?

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@marcnewlin

matt@Bastille.net
@embeddedsec