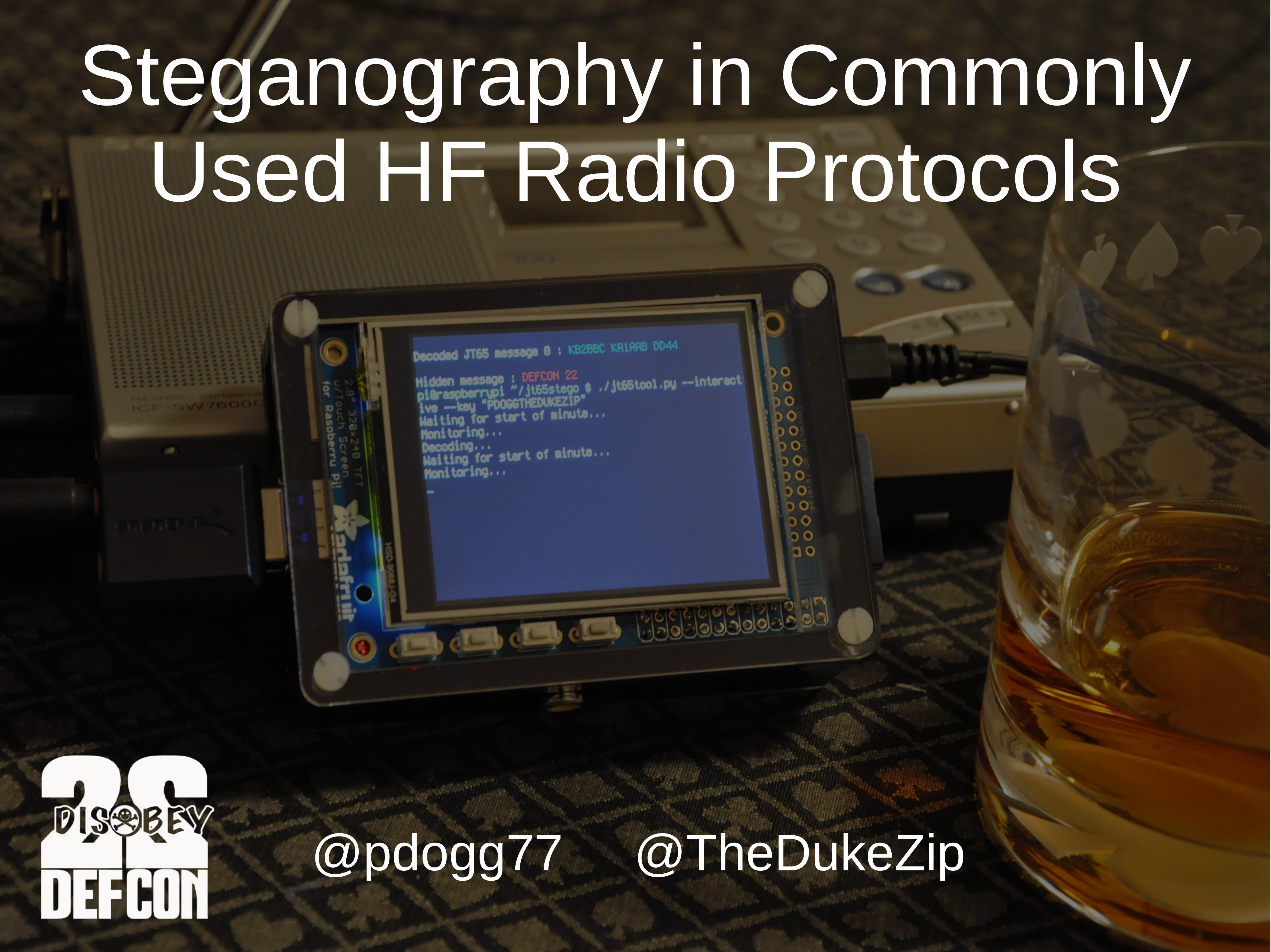
Steganography in Commonly Used HF Radio Protocols



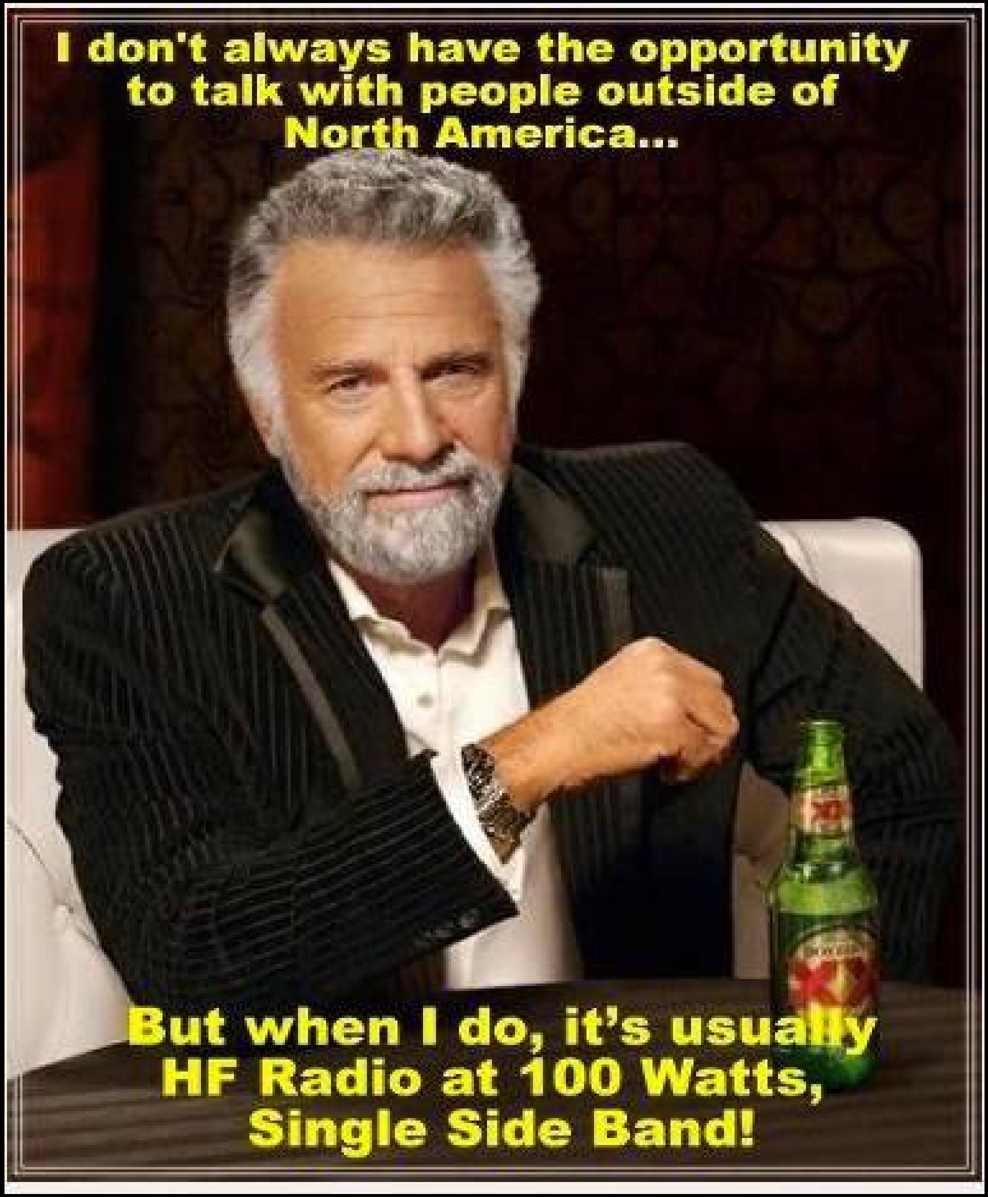
```
Decoded JT65 message 0 : KB2BBC KA1AAB DD44

Hidden message : DEFCON 22
pi@raspberrypi ~/jt65stego $ ./jt65tool.py --interact
ive --key "PDOGGTHEDUKEZIP"
Waiting for start of minute...
Monitoring...
Decoding...
Waiting for start of minute...
Monitoring...
_
```

@pdogg77 @TheDukeZip

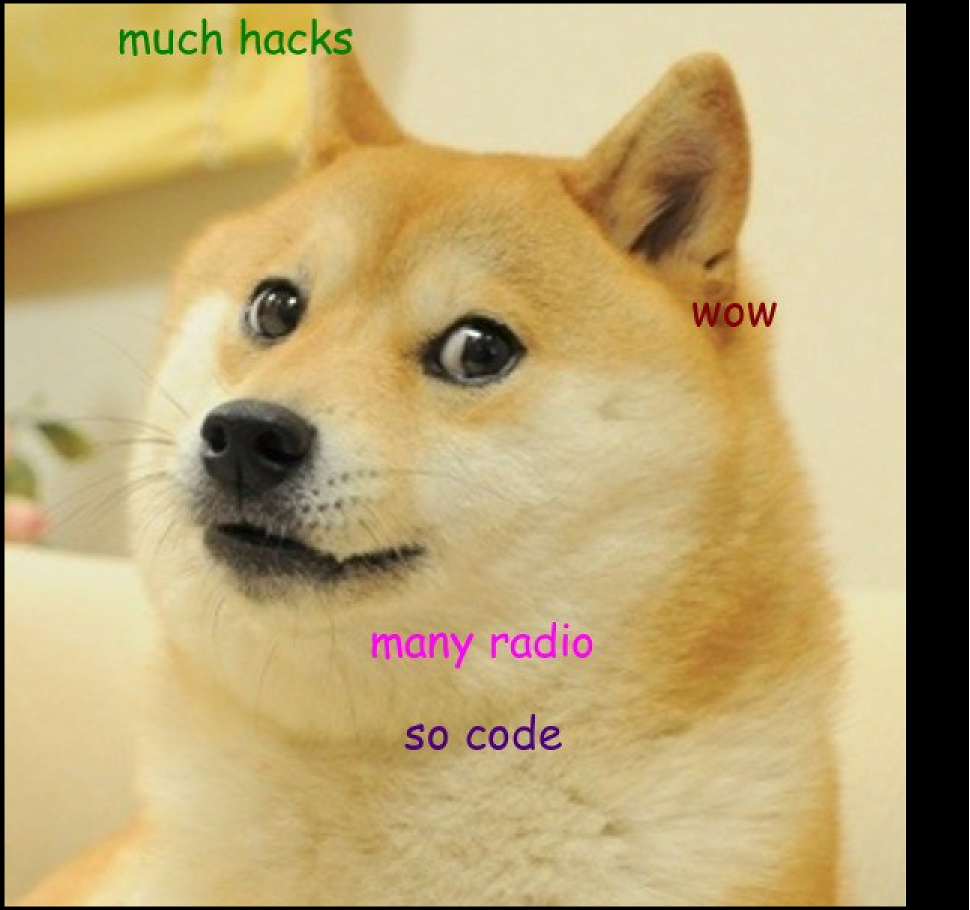
pdogg

- Paul / pdogg / @pdogg77
- Day Job: Security Researcher at Confer Technologies Inc.
- Hobby: Licensed as an amateur radio operator in 1986, ARRL VE
- This is my second trip to DEF CON


I don't always have the opportunity to talk with people outside of North America...
But when I do, it's usually HF Radio at 100 Watts, Single Side Band!

thedukezip

- Brent / thedukezip / @thedukezip
- Software & Systems Engineer (RF)
- Licensed ham radio op since 2006, ARRL VE



Why You Shouldn't Do This And Why We Didn't Do It On The Air

FCC Regulations (Title 47 – Part 97)

§ 97.113 Prohibited transmissions.

(a) No amateur station shall transmit:

…

(4) Music using a phone emission except as specifically provided elsewhere in this section; communications intended to facilitate a criminal act; messages encoded for the purpose of obscuring their meaning, except as otherwise provided herein; obscene or indecent words or language; or false or deceptive messages, signals or identification.

How This Project Started... Final Warning Slide...

- Hackers + Drinks = ***Project***
- WANC - We are not cryptographers
- We are not giving cryptographic advice
- You should talk to a cryptographer
- If you are a cryptographer, we welcome your input

What?

We set out to demonstrate it was possible (or impossible) to create a:

- Low Infrastructure
- Long Range
- Covert
- Point to Point, Broadcast or Mesh
- Short Message Protocol

Using existing consumer radio and computer equipment, leveraging a commonly used digital mode

Why?

- Avoid censorship
- Avoid spying

- We believe you have the right to communicate without this interference
- You COULD use our method to communicate, OR use similar techniques to create your own method

… Or “The Terrorists”

No Internet?

Amateur radio operators have expertise in this!

[photo: John Amodeo, NN6JA]

Amateur Radio

- Many frequency bands reserved for amateur radio operators to communicate
- Voice chat, digital modes...
- Take a multiple choice test to get licensed

- Reminder: The rules say you can't do what we're showing you...

AirChat

- Anonymous Lulzlabs
- Encrypted communication in plain sight
- Cool project with a different purpose
- Also breaks the rules

Good Steganography / Good OPSEC

- … means hiding well in plain sight.
- Invisible to normal users
- “Plausible deniability”
- Not this →

More Like This

Ways to Hide...

- Protocol features (headers, checksums etc)
- Timing or substitution
- Errors
- No “spurious emissions” etc... (against the rules, obvious, very “visible”)
- Candidate Protocol must:

    … be in widespread common use

    … have places to hide

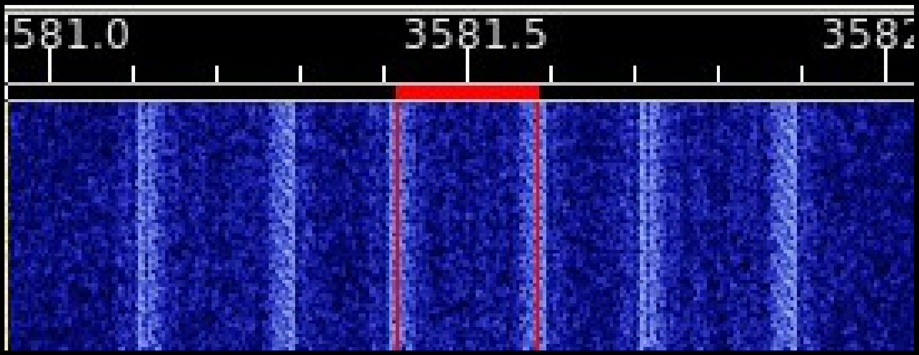
    … be relatively power efficient

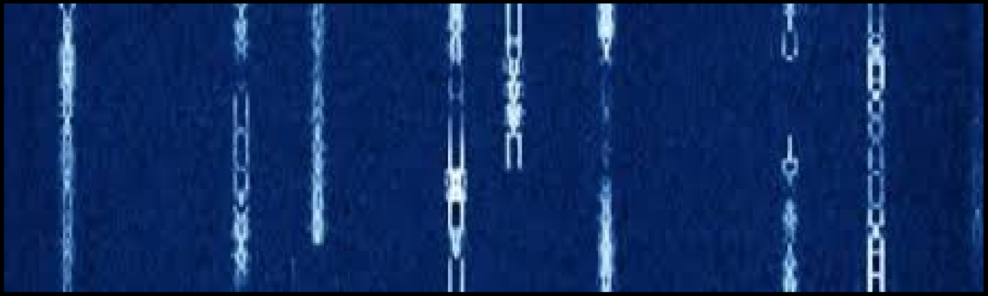
    Need no special hardware or closed software

Popular Sound Card Digital Modes

- RTTY
  - In use on radio since at least the 1920s
  - Baudot code – 5 bit symbols with a stop and a shift – “mark and space”
  - Amateurs almost always use a 45 baud version with 170hz carrier shift
  - Limited character set

- PSK31 etc.
  - Phase shift keying 31 baud...
  - Developed by Peter Martinez G3PLX in 1998
  - VERY tight protocol - “Varicode”





JT65

- Developed by Joe Taylor – K1JT – 2005
- Original paper: “The JT65 Communications Protocol”
- Designed for Earth-Moon-Earth communications. Also now widely used for skywave contacts
- Very power efficient
- Structured communication, very low data rate
- Open source implementation

JT65 Conversations

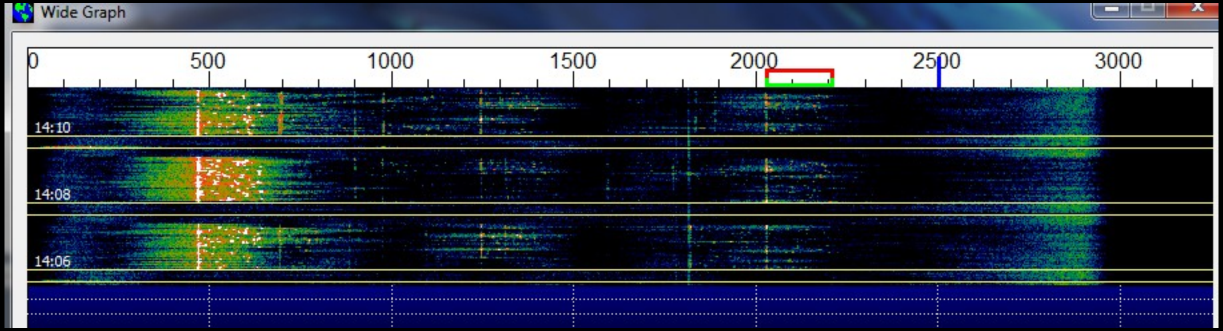
Some Common HF Ham Freqs:

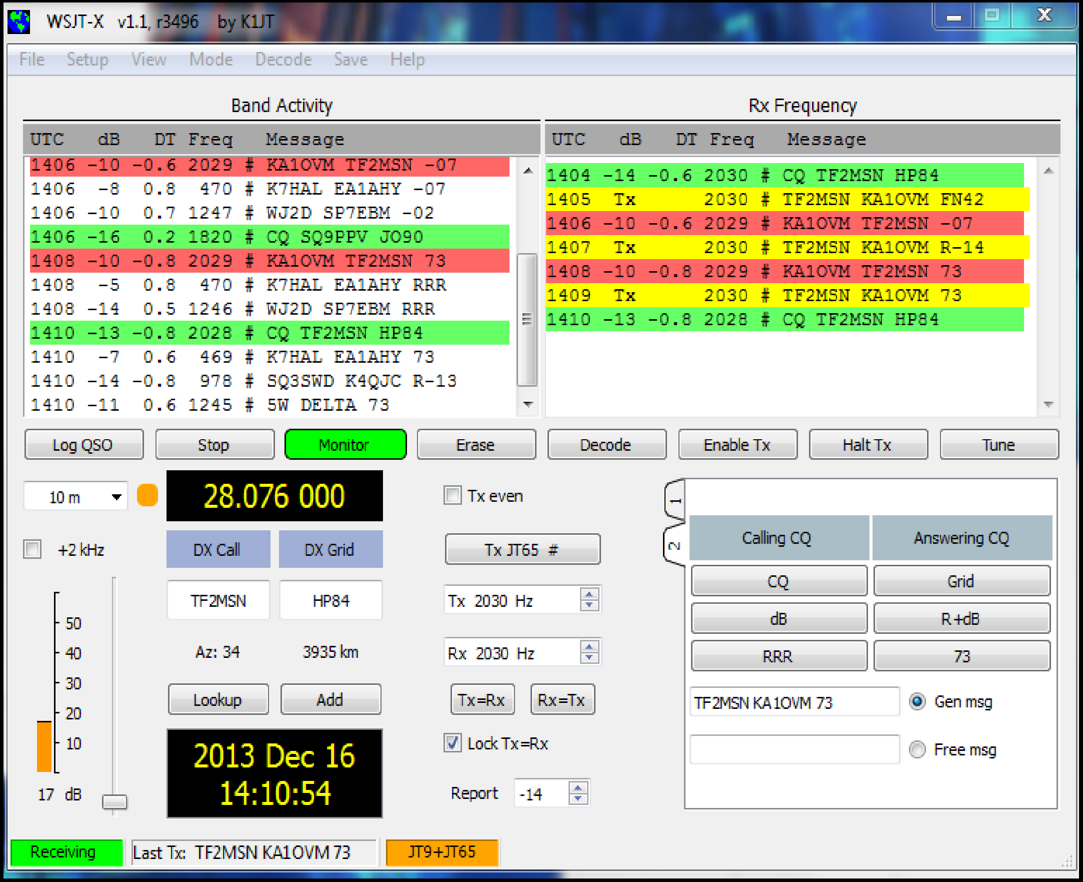
20m 14.076MHz

15m 21.076MHz

10m 28.076MHz

Upper Side Band





Band Activity

```
UTC   dB   DT Freq   Message
1406 -10 -0.6 2029 # KA1OVM TF2MSN -07
1406  -8  0.8  470 # K7HAL EA1AHY -07
1406 -10  0.7 1247 # WJ2D SP7EBM -02
1406 -16  0.2 1820 # CQ SQ9PPV JO90
1408 -10 -0.8 2029 # KA1OVM TF2MSN 73
1408  -5  0.8  470 # K7HAL EA1AHY RRR
1408 -14  0.5 1246 # WJ2D SP7EBM RRR
1410 -13 -0.8 2028 # CQ TF2MSN HP84
1410  -7  0.6  469 # K7HAL EA1AHY 73
1410 -14 -0.8  978 # SQ3SWD K4QJC R-13
1410 -11  0.6 1245 # 5W DELTA 73
```

Rx Frequency

```
UTC   dB   DT Freq   Message
1404 -14 -0.6 2030 # CQ TF2MSN HP84
1405  Tx      2030 # TF2MSN KA1OVM FN42
1406 -10 -0.6 2029 # KA1OVM TF2MSN -07
1407  Tx      2030 # TF2MSN KA1OVM R-14
1408 -10 -0.8 2029 # KA1OVM TF2MSN 73
1409  Tx      2030 # TF2MSN KA1OVM 73
1410 -13 -0.8 2028 # CQ TF2MSN HP84
```

10 m

28.076 000

□ +2 kHz

TF2MSN HP84

Az: 34 3935 km

2013 Dec 16 14:10:54

50 40 30 20 10

17 dB

□ Tx even

Tx JT65 #

Tx 2030 Hz

Rx 2030 Hz

☑ Lock Tx=Rx

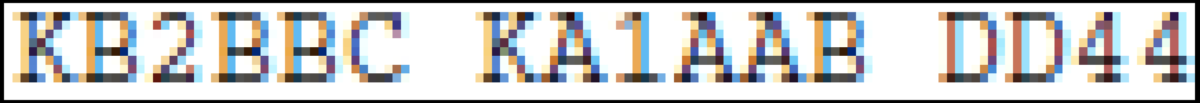
Report -14

TF2MSN KA1OVM 73 ● Gen msg

○ Free msg

Receiving | Last Tx: TF2MSN KA1OVM 73 | JT9+JT65

Some JT65 Technical Details



KB2BBC KA1AAB DD44

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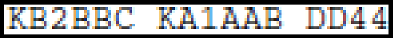

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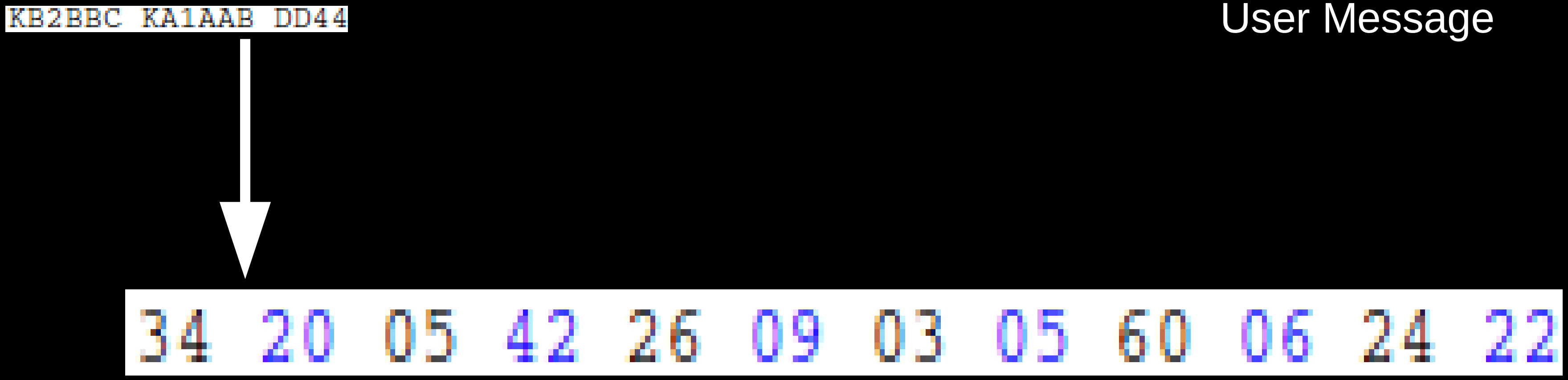
User Message

Some JT65 Technical Details

User Message



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34 20 05 42 26 09 03 05 60 06 24 22

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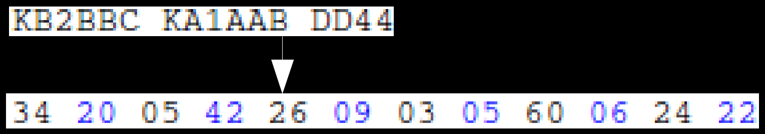

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User Message

Source Encoding

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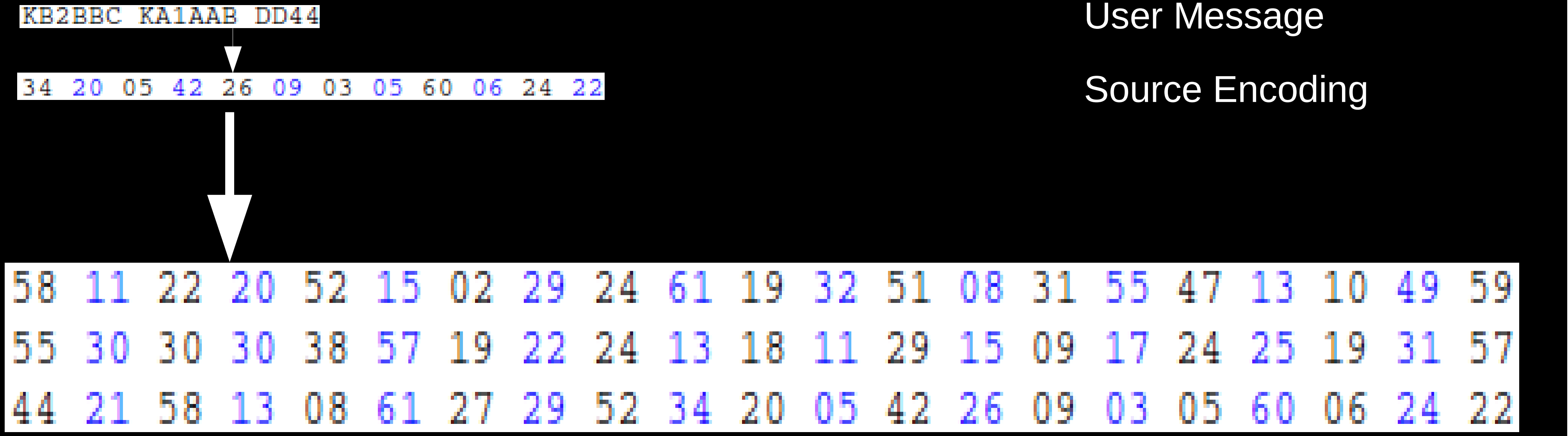

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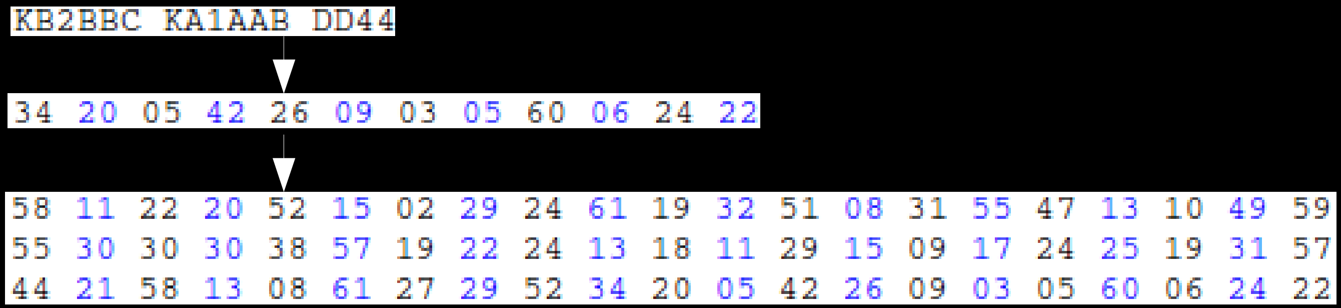

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FEC

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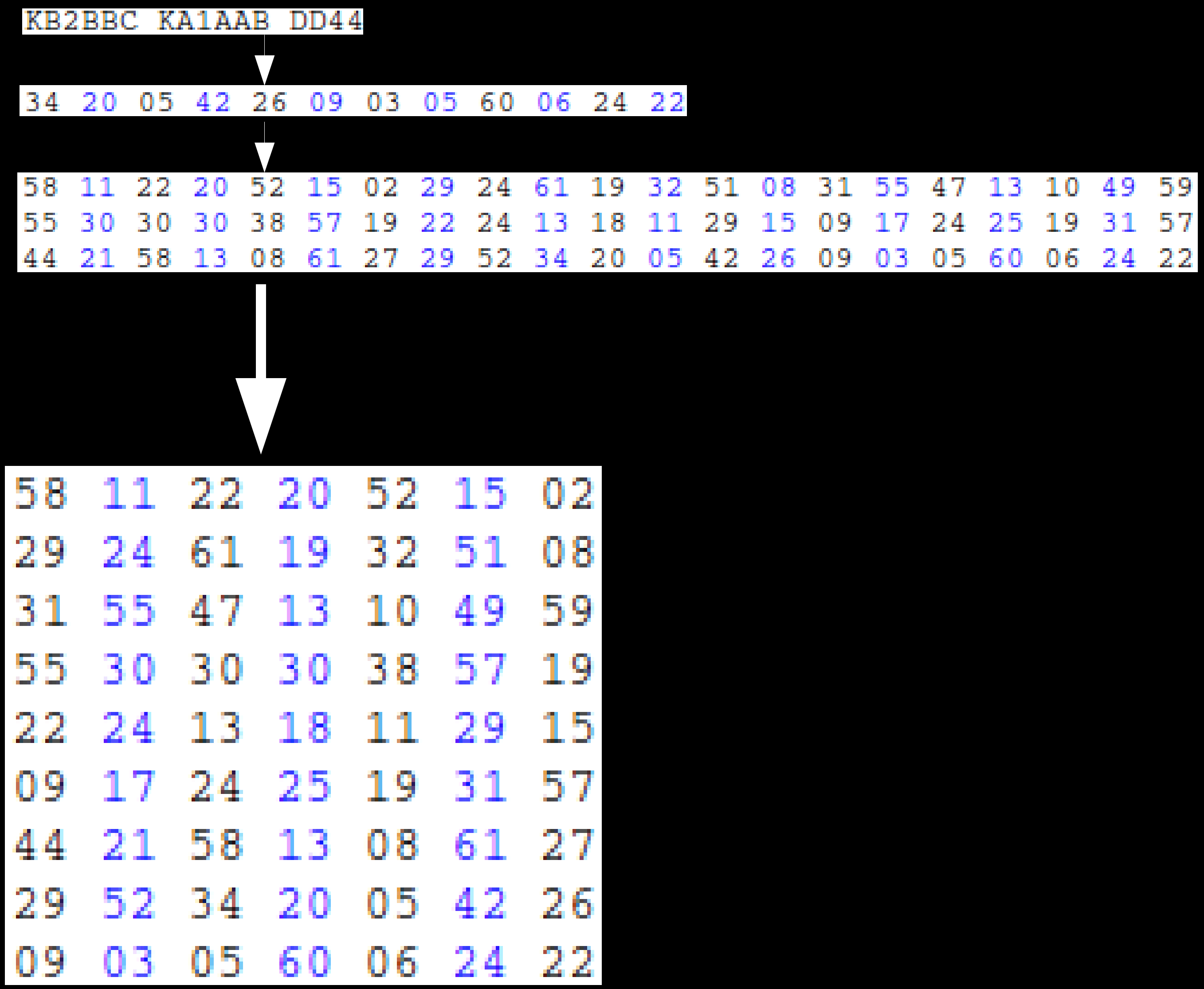

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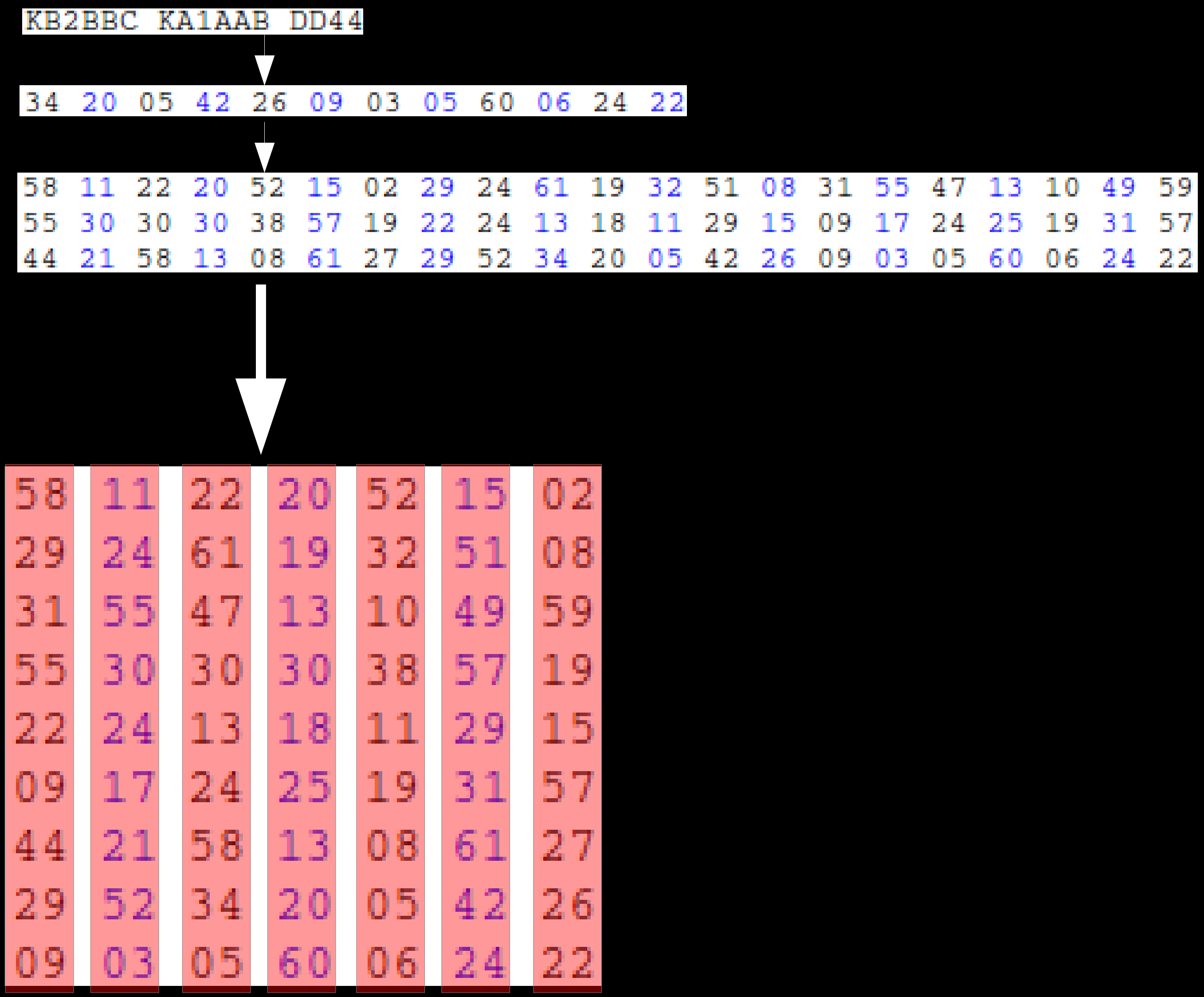

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FEC

58	11	22	20	52	15	02
29	24	61	19	32	51	08
31	55	47	13	10	49	59
55	30	30	30	38	57	19
22	24	13	18	11	29	15
09	17	24	25	19	31	57
44	21	58	13	08	61	27
29	52	34	20	05	42	26
09	03	05	60	06	24	22

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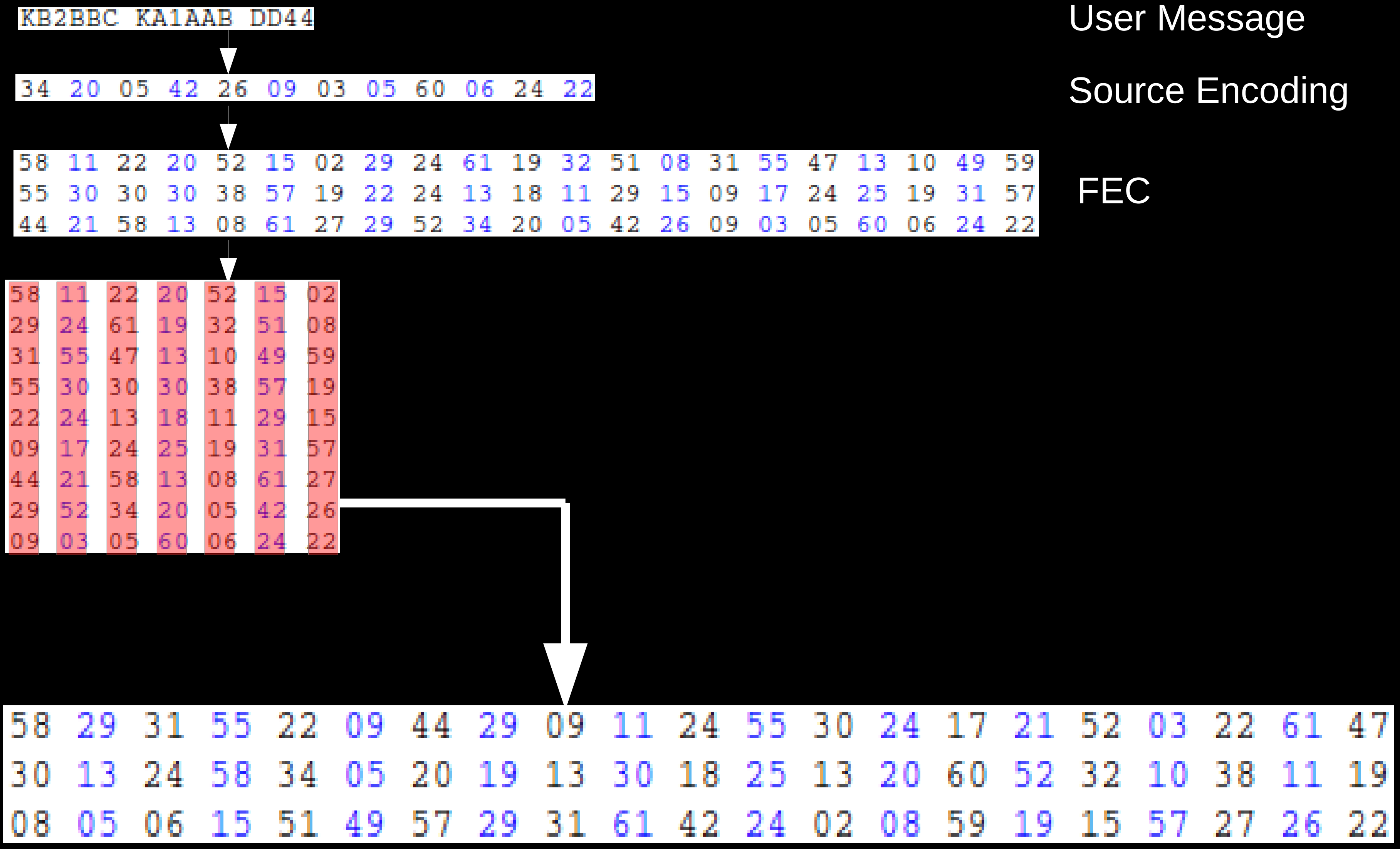

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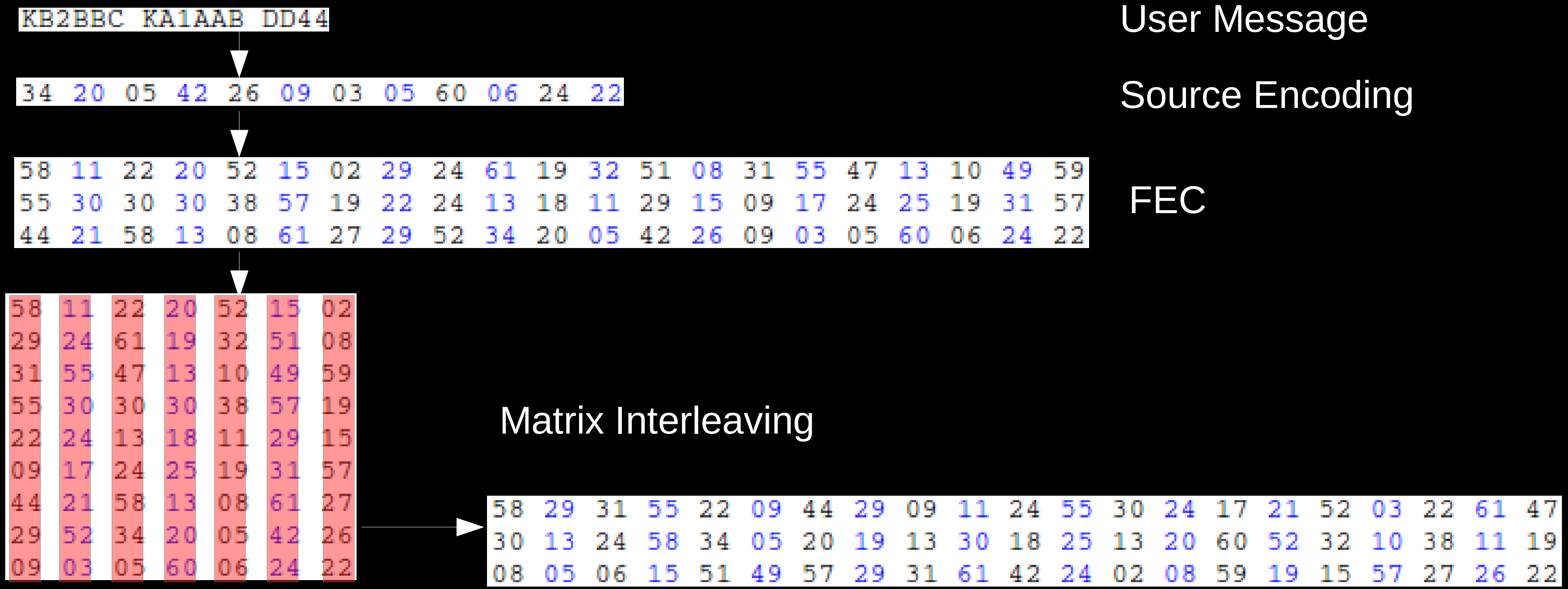

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Matrix Interleaving

```
58 29 31 55 22 09 44 29 09 11 24 55 30 24 17 21 52 03 22 61 47
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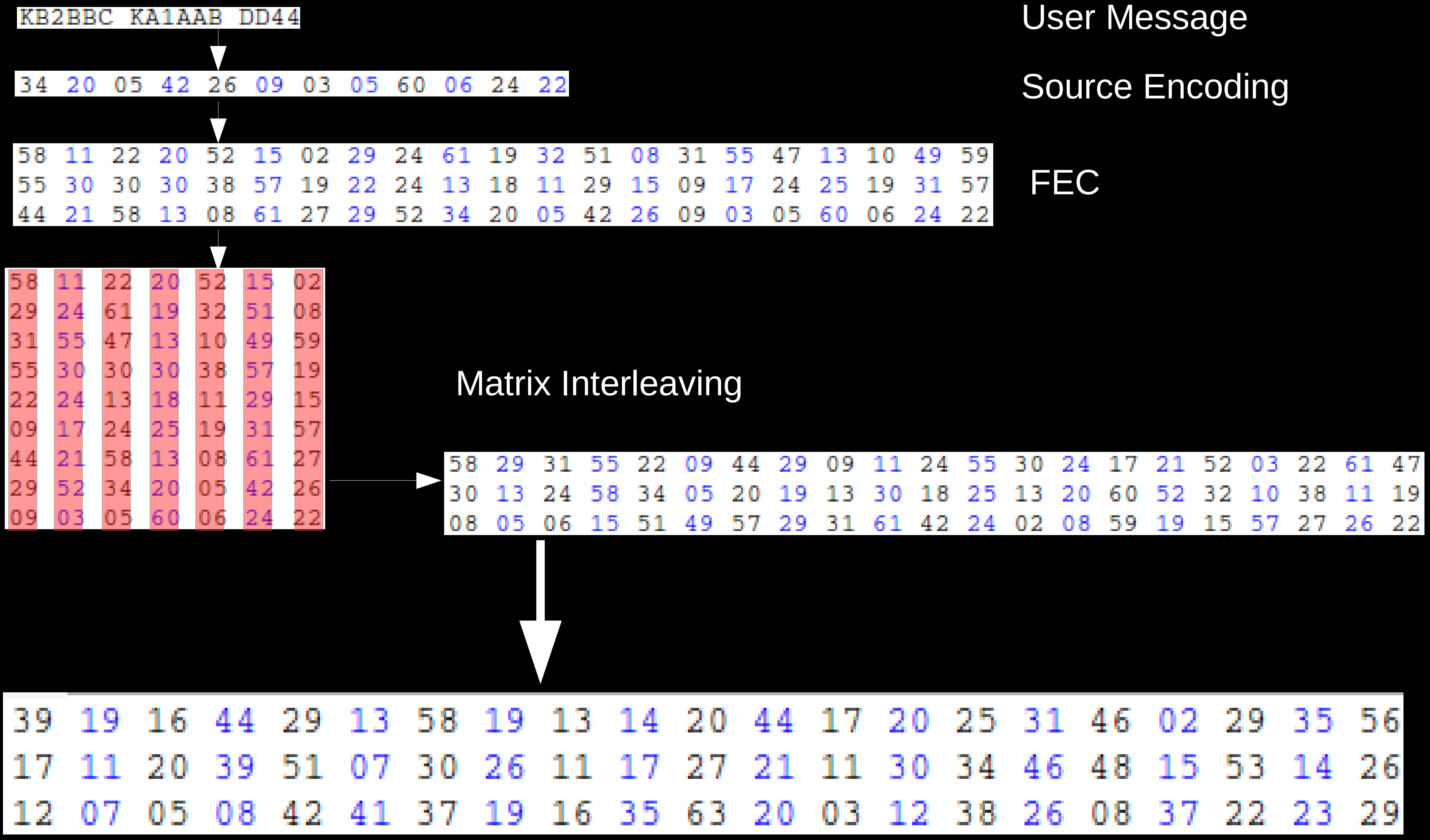

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```
39 19 16 44 29 13 58 19 13 14 20 44 17 20 25 31 46 02 29 35 56
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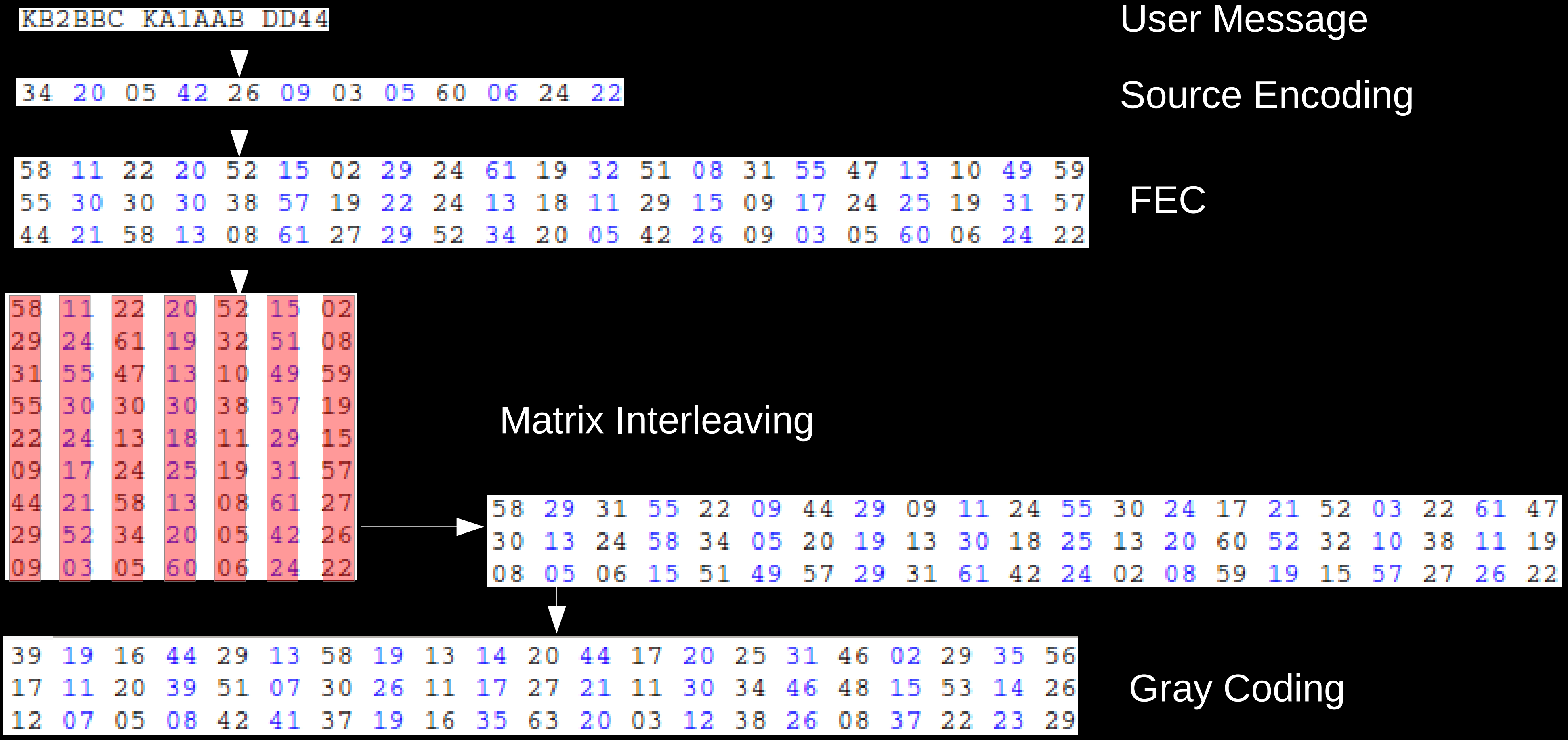

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Gray Coding

```
39 19 16 44 29 13 58 19 13 14 20 44 17 20 25 31 46 02 29 35 56
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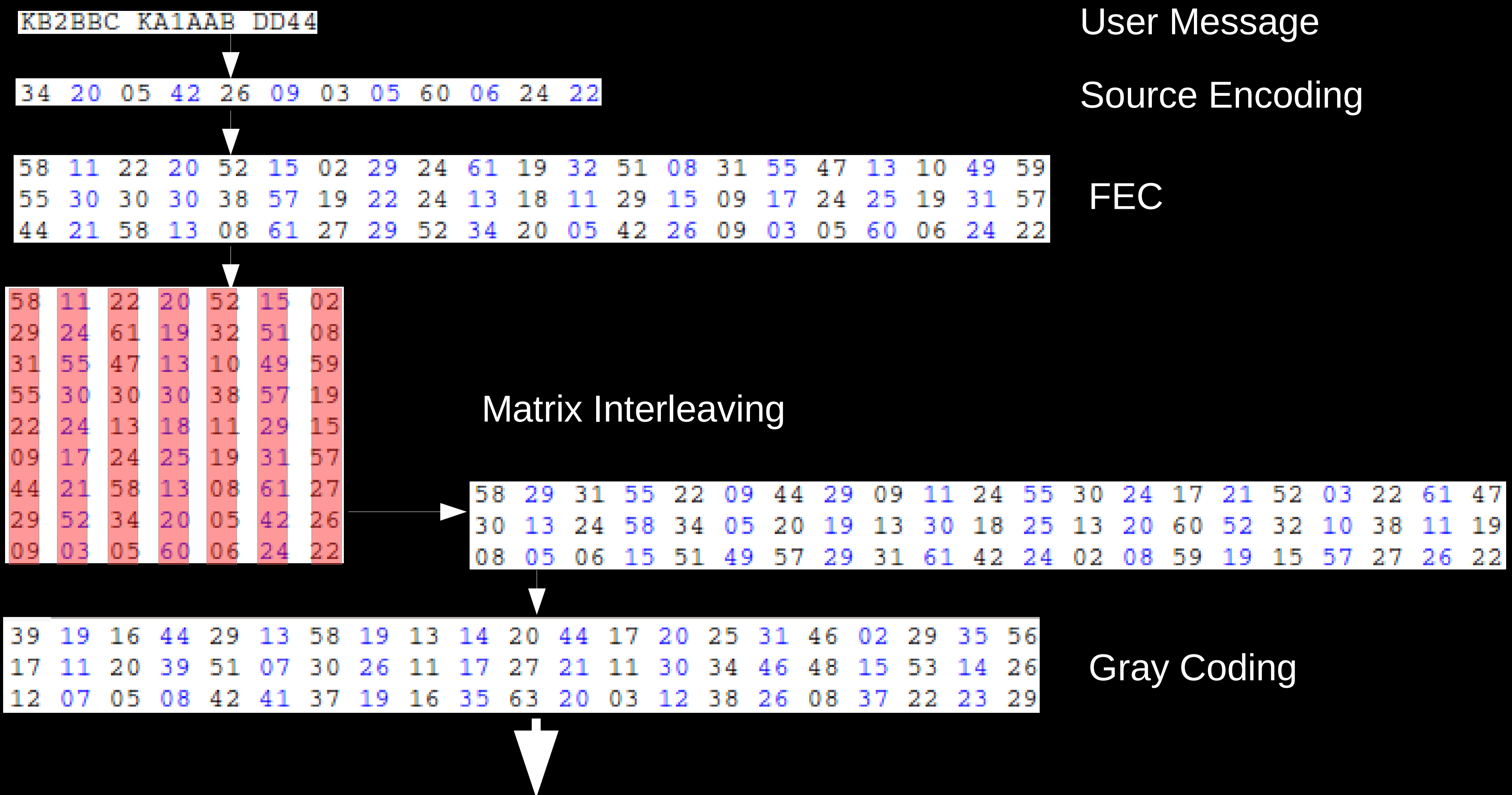

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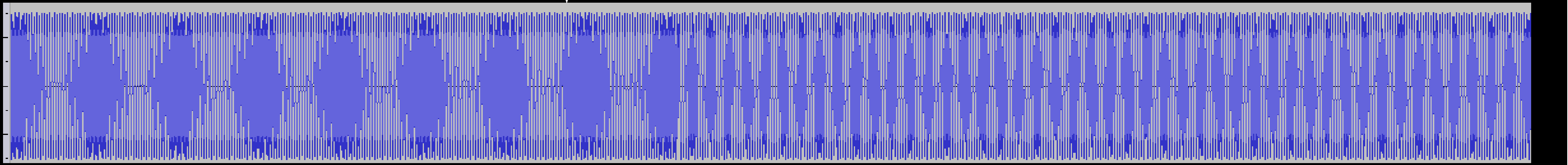
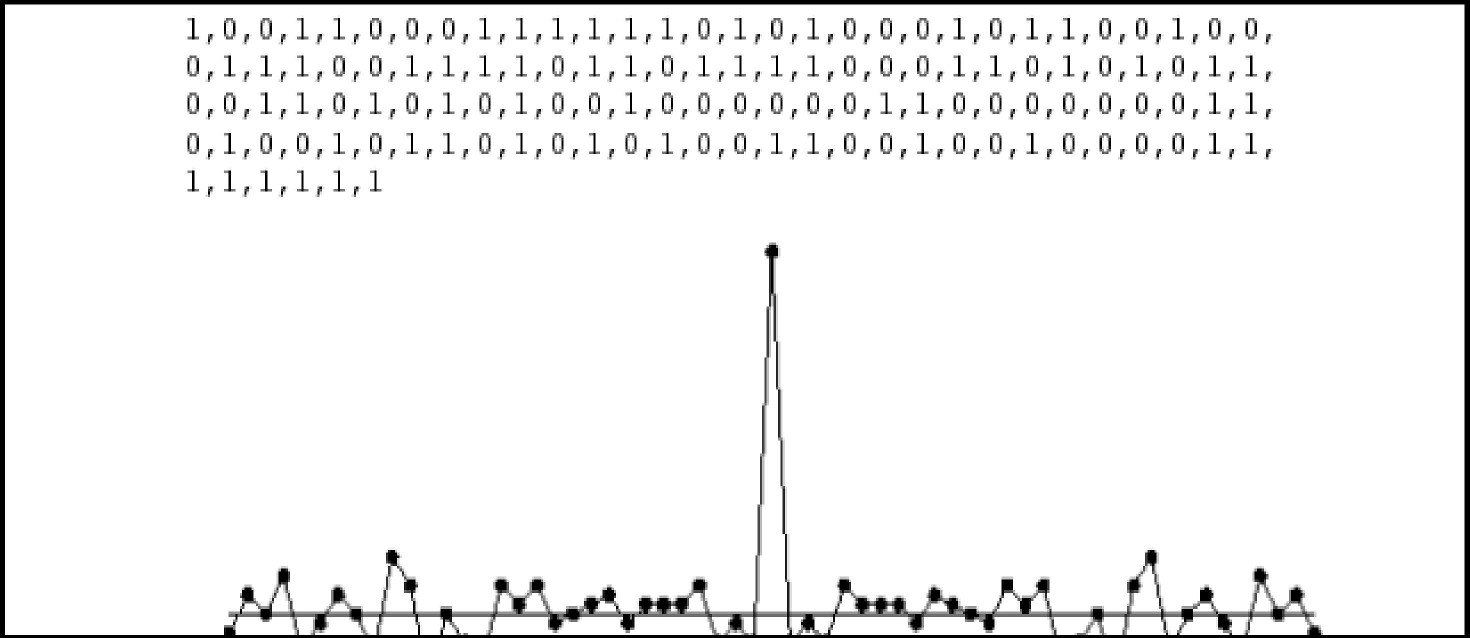


Audio

- JT65 “packet” sliced into 126 .372s intervals – 47.8s
- 1270.5 Hz sync tone - “pseudo-random synchronization vector”
- Symbols - 1270.5 + 2.6917(N+2)m Hz
  - N is the integral symbol value, 0 ≤ N ≤ 63
  - m assumes the values 1, 2, and 4 for JT65 sub-modes A, B, and C



```
1,0,0,1,1,0,0,0,1,1,1,1,1,1,0,1,0,1,0,0,0,1,0,1,1,0,0,1,0,0,
0,1,1,1,0,0,1,1,1,1,0,1,1,0,1,1,1,1,0,0,0,1,1,0,1,0,1,0,1,1,
0,0,1,1,0,1,0,1,0,1,0,0,1,0,0,0,0,0,0,1,1,0,0,0,0,0,0,0,1,1,
0,1,0,0,1,0,1,1,0,1,0,1,0,1,0,0,1,1,0,0,1,0,0,1,0,0,0,0,1,1,
1,1,1,1,1,1
```

Hiding in Reed Solomon Codes

- Exploit error correction!
- Easy/PoC Mode: Shove in some errors... :) (static “key”)
- Medium mode: Shove in errors, add some random cover
- Hard Mode: Encrypt and pack message, add FEC
- Prior Work: Hanzlik, Peter “Steganography in Reed-Solomon Codes”, 2011

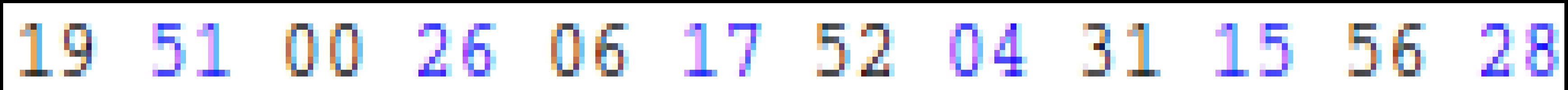
Encoding Steganography (Basic)

Steg: DEF CON 22

Encoding Steganography (Basic)

Steg: DEF CON 22

Source Encoding:

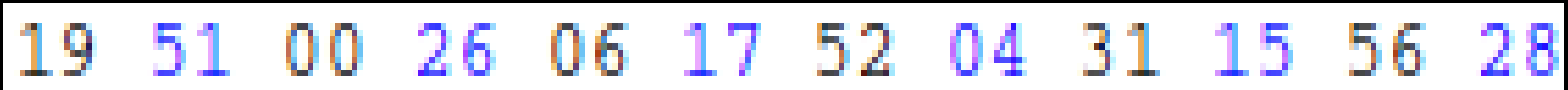


```
19 51 00 26 06 17 52 04 31 15 56 28
```

Encoding Steganography (Basic)

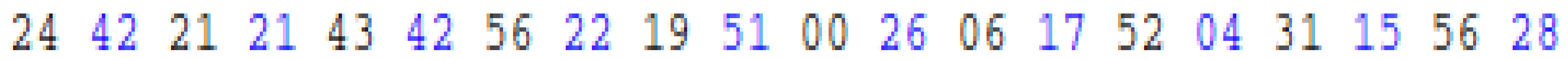
Steg: DEF CON 22

Source Encoding:



```
19 51 00 26 06 17 52 04 31 15 56 28
```

FEC:



```
24 42 21 21 43 42 56 22 19 51 00 26 06 17 52 04 31 15 56 28
```

Can tolerate 4 errors

Hiding Steganography

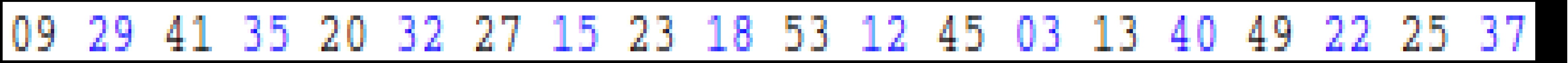
Key: pdogg thedukezip

Generate 20 'locations' based on SHA512

Hiding Steganography

Key: pdogg thedukezip

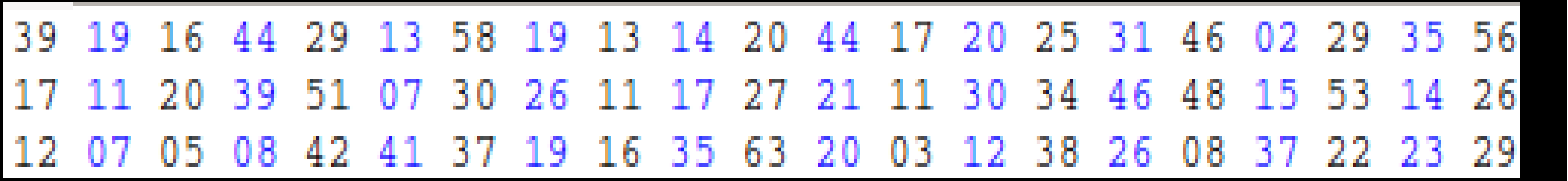
Generate 20 'locations' based on SHA512



```
09 29 41 35 20 32 27 15 23 18 53 12 45 03 13 40 49 22 25 37
```

Injecting Errors

JT65: KB2BBC KA1AAB DD44



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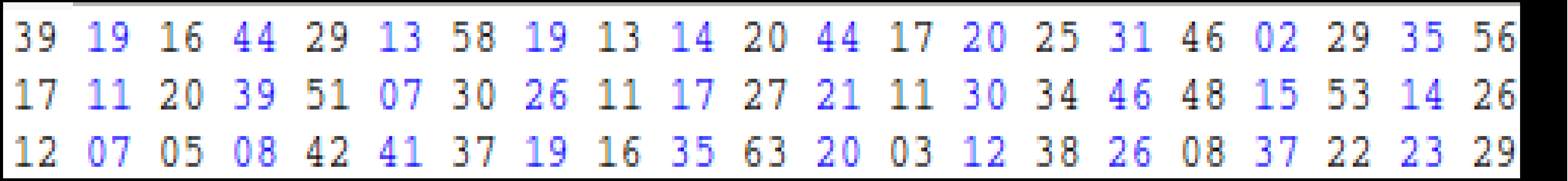

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```
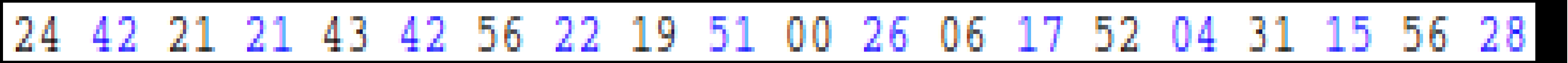
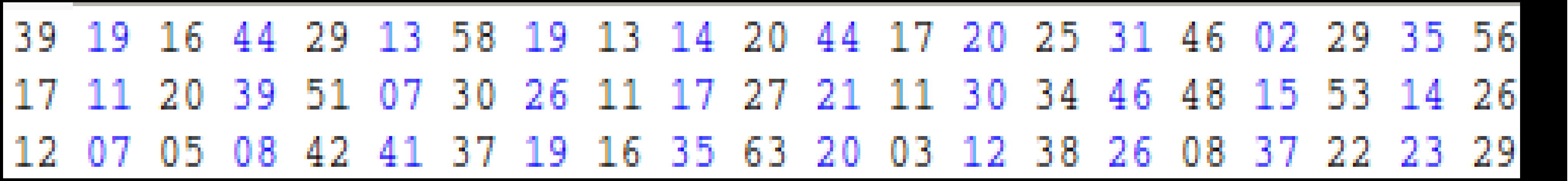

Steg: DEF CON 22



```
24 42 21 21 43 42 56 22 19 51 00 26 06 17 52 04 31 15 56 28
```

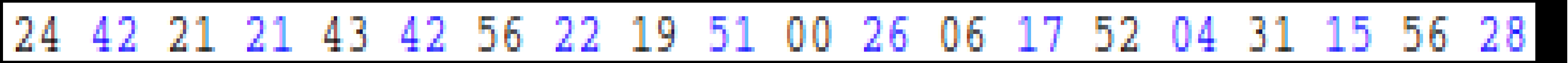
Injecting Errors

JT65: KB2BBC KA1AAB DD44



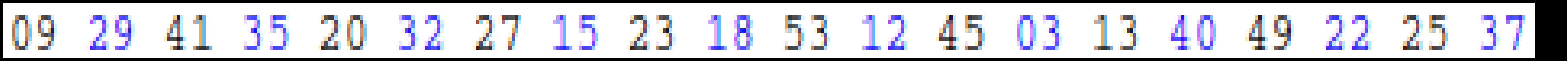
```
39 19 16 44 29 13 58 19 13 14 20 44 17 20 25 31 46 02 29 35 56
17 11 20 39 51 07 30 26 11 17 27 21 11 30 34 46 48 15 53 14 26
12 07 05 08 42 41 37 19 16 35 63 20 03 12 38 26 08 37 22 23 29
```

Steg: DEF CON 22



```
24 42 21 21 43 42 56 22 19 51 00 26 06 17 52 04 31 15 56 28
```

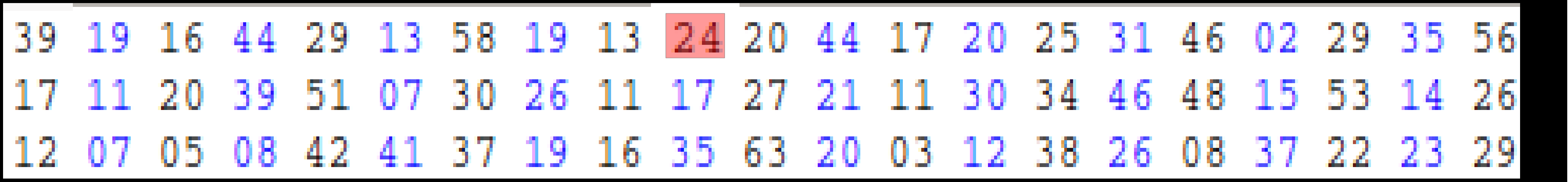
Key: pdogg thedukezip



```
09 29 41 35 20 32 27 15 23 18 53 12 45 03 13 40 49 22 25 37
```

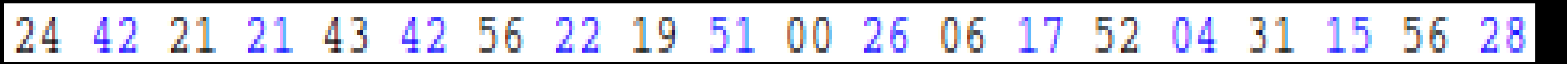
Injecting Errors

JT65: KB2BBC KA1AAB DD44



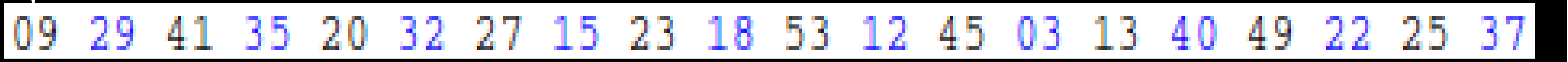
```
39 19 16 44 29 13 58 19 13 24 20 44 17 20 25 31 46 02 29 35 56
17 11 20 39 51 07 30 26 11 17 27 21 11 30 34 46 48 15 53 14 26
12 07 05 08 42 41 37 19 16 35 63 20 03 12 38 26 08 37 22 23 29
```

Steg: DEF CON 22



```
24 42 21 21 43 42 56 22 19 51 00 26 06 17 52 04 31 15 56 28
```

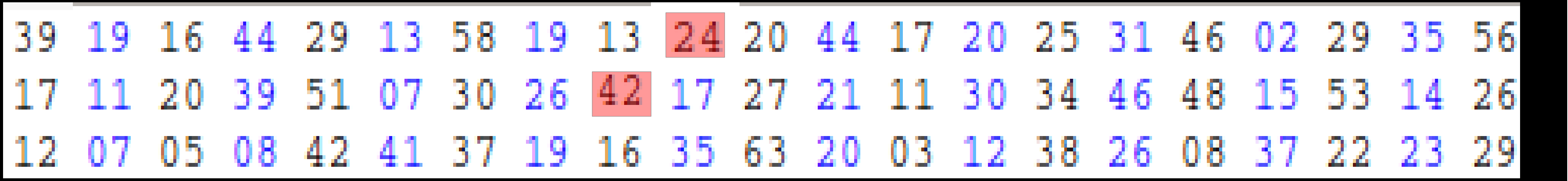
Key: pdogg thedukezip



```
09 29 41 35 20 32 27 15 23 18 53 12 45 03 13 40 49 22 25 37
```

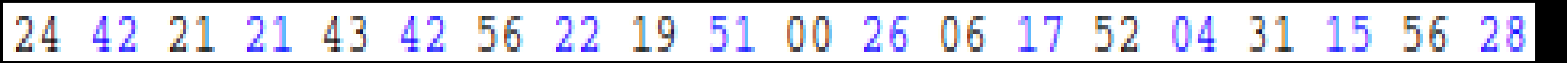
Injecting Errors

JT65: KB2BBC KA1AAB DD44



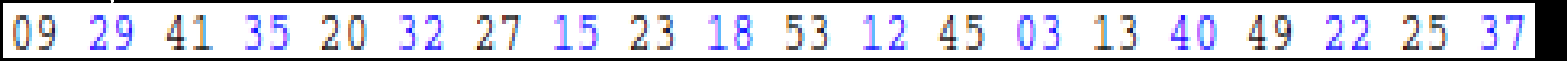
```
39 19 16 44 29 13 58 19 13 24 20 44 17 20 25 31 46 02 29 35 56
17 11 20 39 51 07 30 26 42 17 27 21 11 30 34 46 48 15 53 14 26
12 07 05 08 42 41 37 19 16 35 63 20 03 12 38 26 08 37 22 23 29
```

Steg: DEF CON 22



```
24 42 21 21 43 42 56 22 19 51 00 26 06 17 52 04 31 15 56 28
```

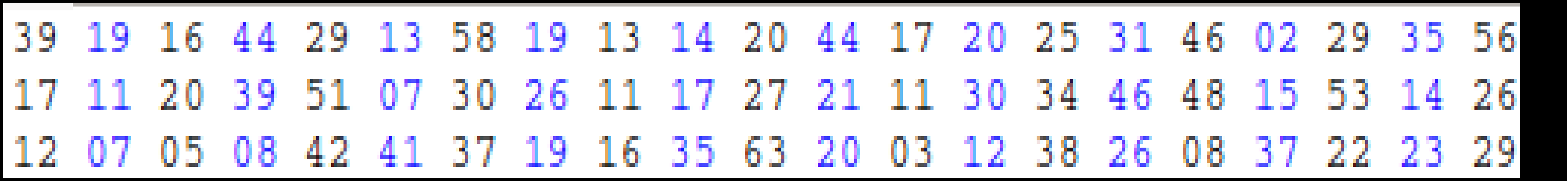
Key: pdogg thedukezip



```
09 29 41 35 20 32 27 15 23 18 53 12 45 03 13 40 49 22 25 37
```

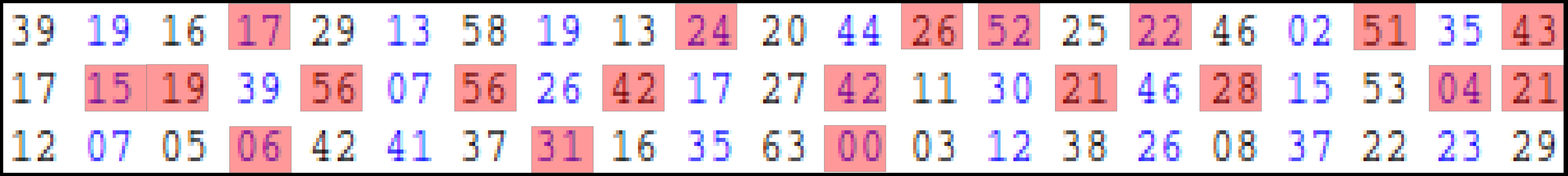
Injecting Errors

JT65: KB2BBC KA1AAB DD44



```
39 19 16 44 29 13 58 19 13 14 20 44 17 20 25 31 46 02 29 35 56
17 11 20 39 51 07 30 26 11 17 27 21 11 30 34 46 48 15 53 14 26
12 07 05 08 42 41 37 19 16 35 63 20 03 12 38 26 08 37 22 23 29
```

JT65: KB2BBC KA1AAB DD44
Steg: DEF CON 22
Key: pdogg thedukezip



```
39 19 16 17 29 13 58 19 13 24 20 44 26 52 25 22 46 02 51 35 43
17 15 19 39 56 07 56 26 42 17 27 42 11 30 21 46 28 15 53 04 21
12 07 05 06 42 41 37 31 16 35 63 00 03 12 38 26 08 37 22 23 29
```

What About Encryption?

What About Encryption?

- We have 12 * 6 = 72 bits to play with
- We need 8 bit bytes...
- Well that gives us exactly 9 bytes

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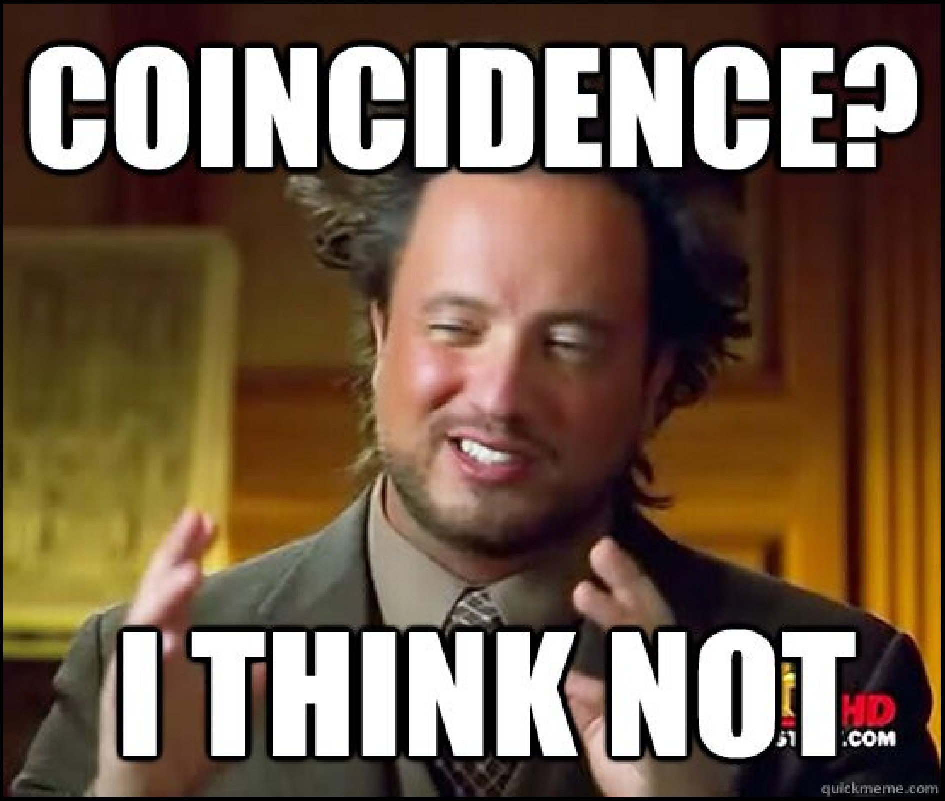
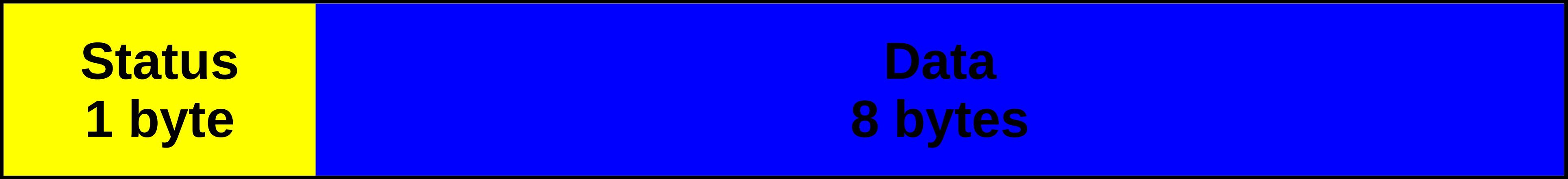


“Packing” Function



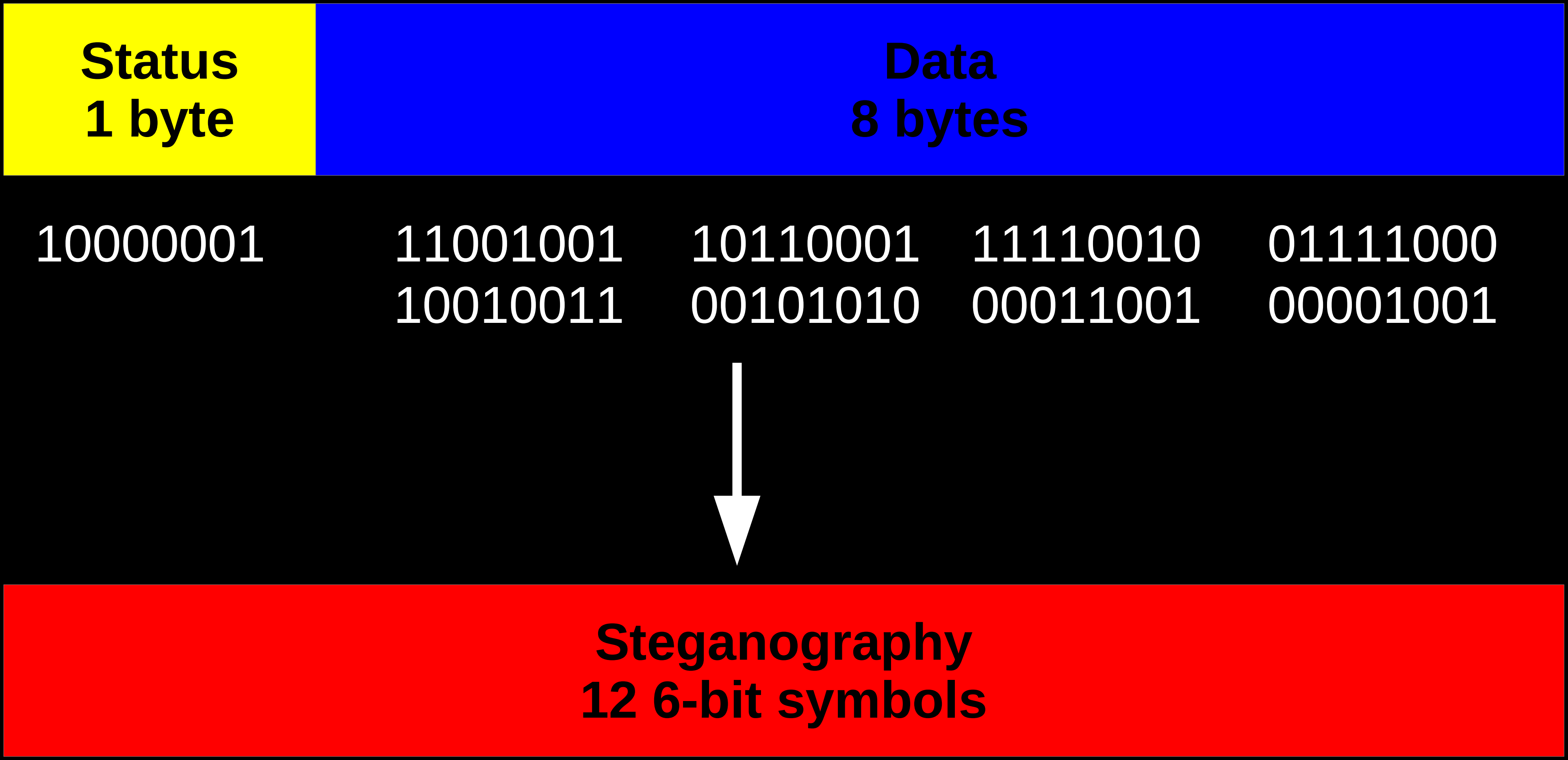
Status
1 byte

Data
8 bytes

10000001

11001001 10110001 11110010 01111000
10010011 00101010 00011001 00001001

“Packing” Function



Status
1 byte

Data
8 bytes

10000001

11001001 10110001 11110010 01111000
10010011 00101010 00011001 00001001

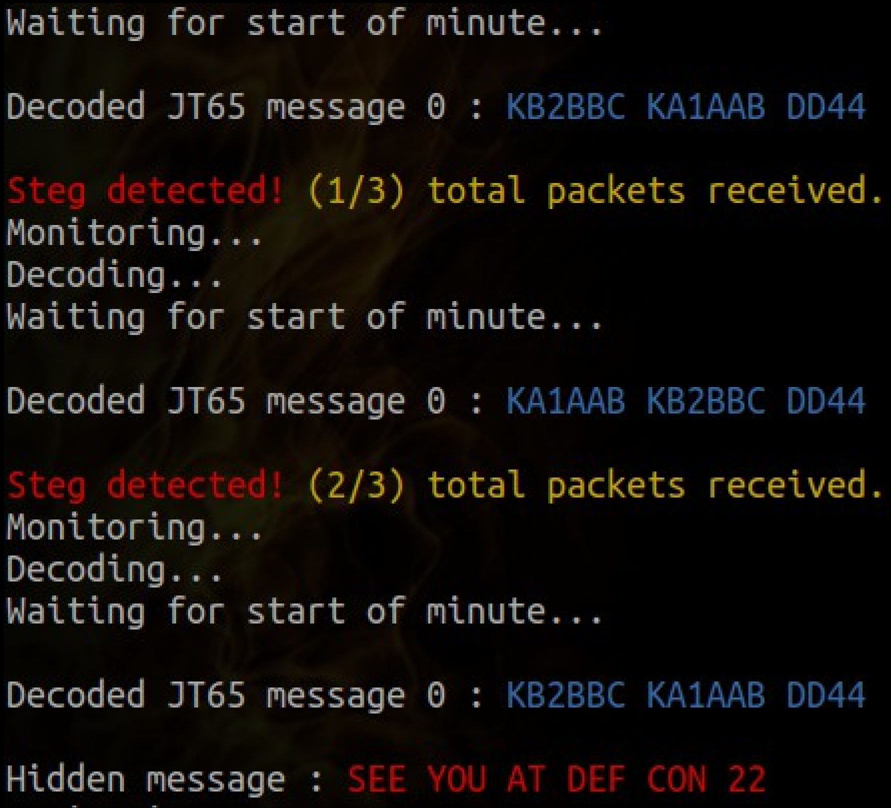
Steganography
12 6-bit symbols

100000 011100 100110 110001 111100 100111
100010 010011 001010 100001 100100 001001

“Status” Byte

Status
1 byte

- Track how many total packets in message
- Flags for first / last packet
- Track size for stream ciphers



```
Waiting for start of minute...

Decoded JT65 message 0 : KB2BBC KA1AAB DD44

Steg detected! (1/3) total packets received.
Monitoring...
Decoding...
Waiting for start of minute...

Decoded JT65 message 0 : KA1AAB KB2BBC DD44

Steg detected! (2/3) total packets received.
Monitoring...
Decoding...
Waiting for start of minute...

Decoded JT65 message 0 : KB2BBC KA1AAB DD44

Hidden message : SEE YOU AT DEF CON 22
```

“Status” Byte – Stream Cipher

First packet: `(0x80) | (# of total packets)`

Middle packets: `Packet Number`

Last packet: `(0x40) | (# of bytes in packet)`

Max size: 64 packets (512 bytes)

1 bit	1 bit	6 bits
First Packet?	**Last Packet?**	**First? : # of total packets** **Last? : # of bytes in packet** **Else : Packet Number**

“Status” Byte – Block Cipher

First packet:

```
(0x80) | (# of total packets)
```

Other packets:

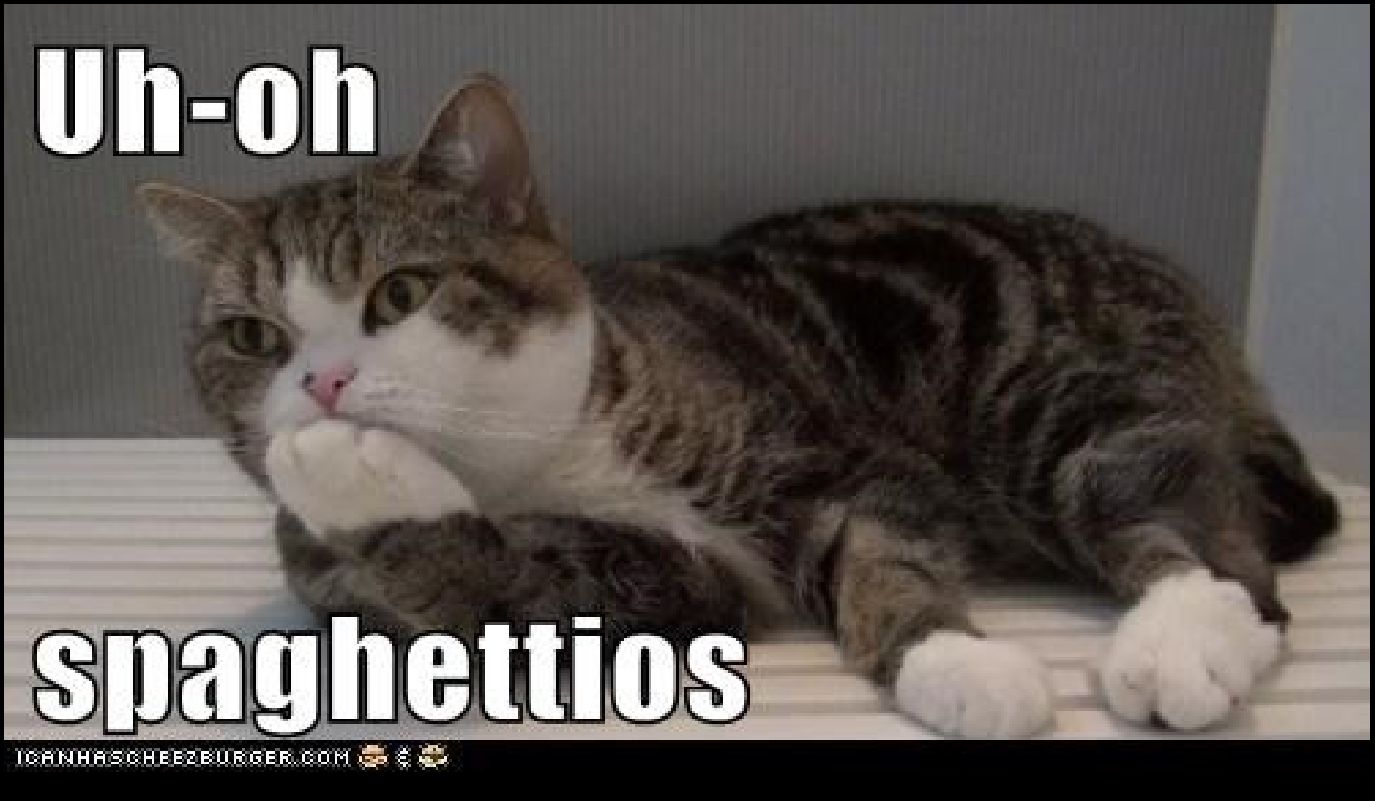
```
Packet Number
```

Max size: 128 packets (1024 bytes)

1 bit	7 bits
First Packet?	**First? : # of total packets** **Else : Packet Number**

Hiding the Status Byte

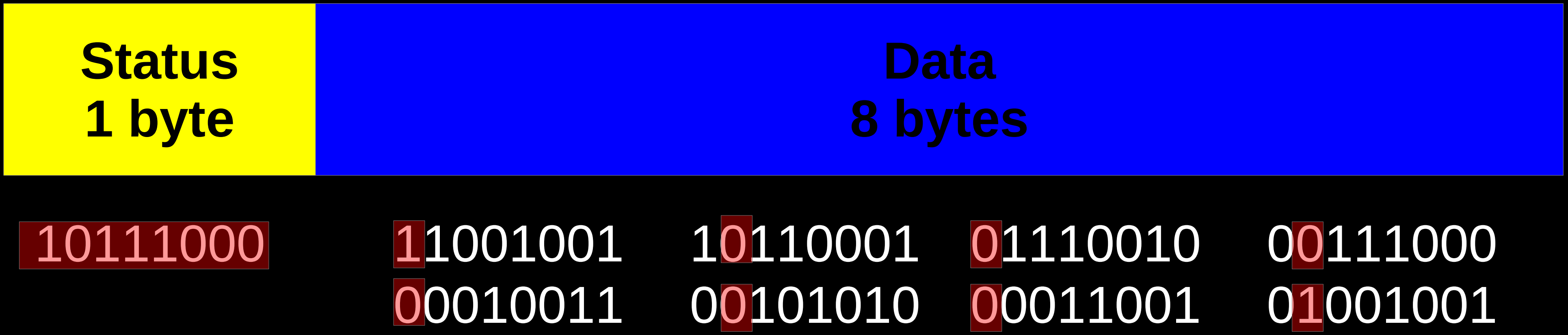
- We'll talk about analysis in a bit...
- Steganography traffic was trivial to pick out of normal traffic because of this byte :(



Perform Bit Swap

Status 1 byte	Data 8 bytes
10000001	11001001 10110001 11110010 01111000 10010011 00101010 00011001 00001001

Perform Bit Swap



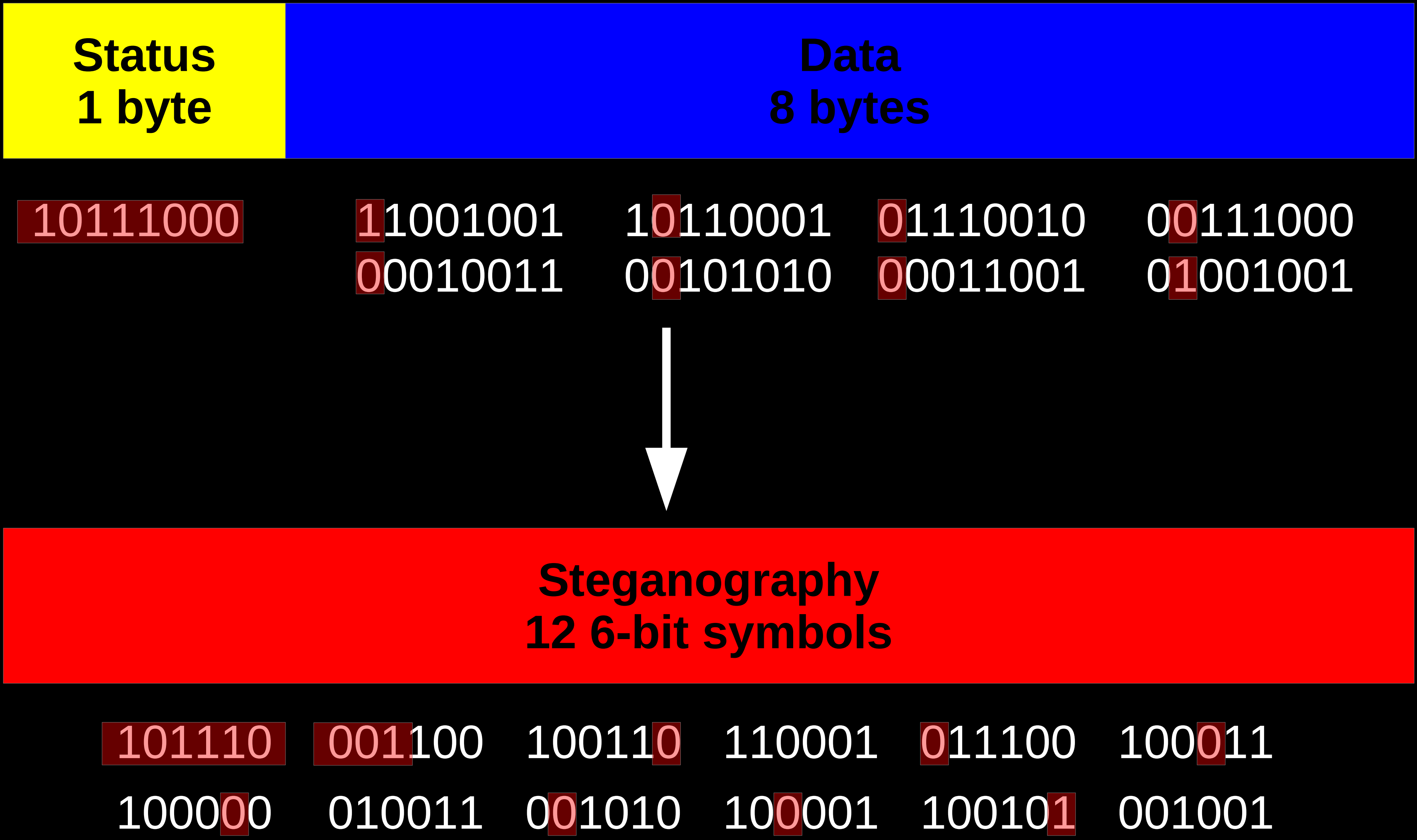
Status
1 byte

Data
8 bytes

10111000

11001001 10110001 01110010 00111000
00010011 00101010 00011001 01001001

Perform Bit Swap



Status
1 byte

Data
8 bytes

10111000

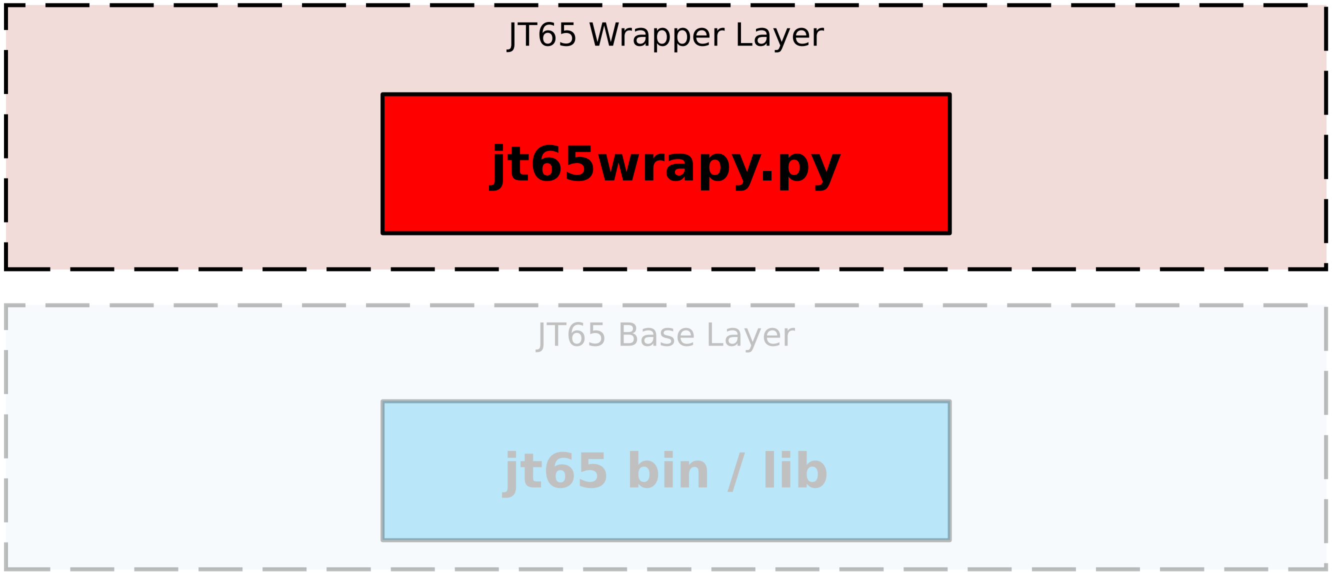
11001001 10110001 01110010 00111000
00010011 00101010 00011001 01001001

Steganography
12 6-bit symbols

101110 001100 100110 110001 011100 100011
100000 010011 001010 100001 100101 001001

JT65 Base Layer

jt65 bin / lib

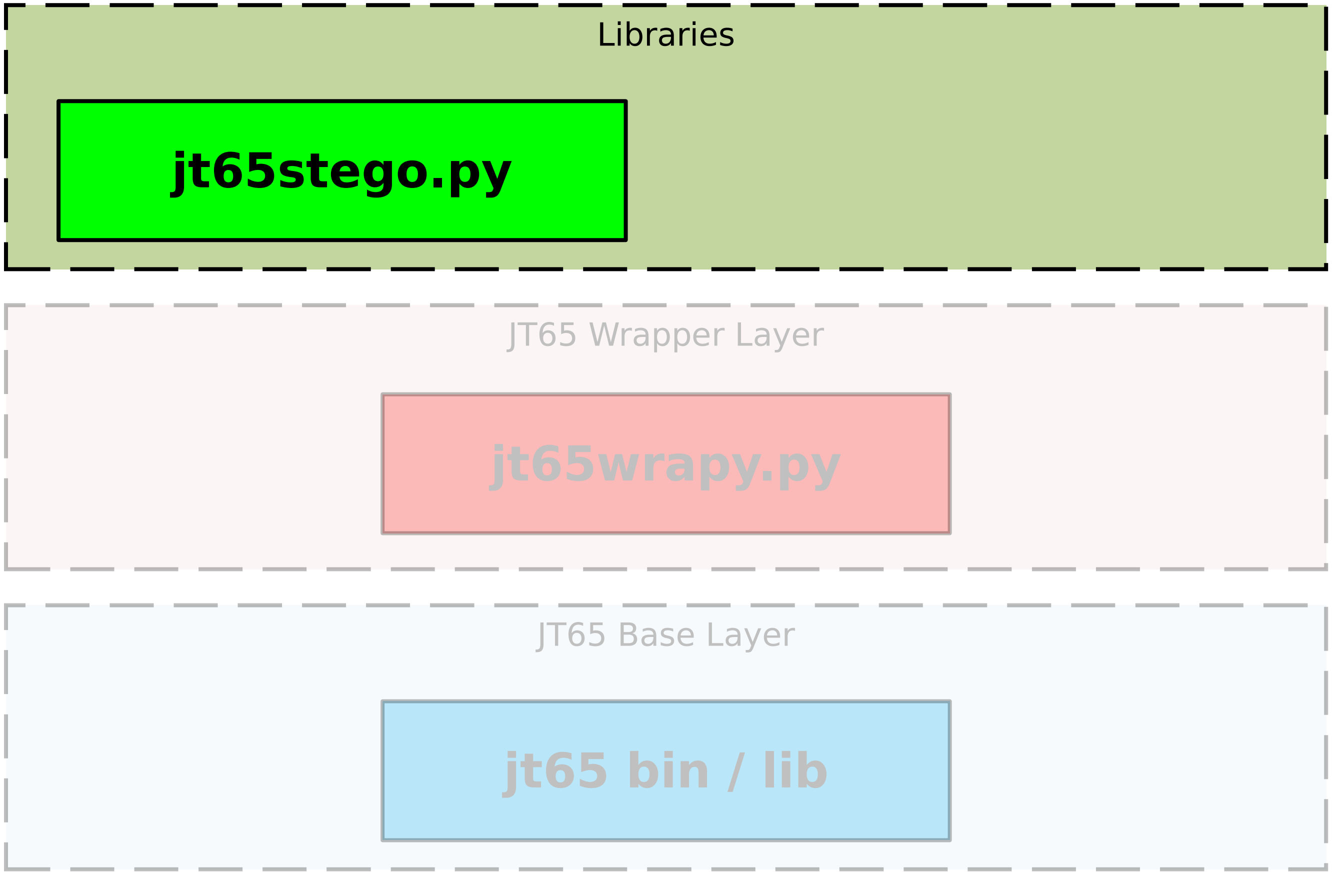


JT65 Wrapper Layer

jt65wrapy.py

JT65 Base Layer

jt65 bin / lib



Libraries

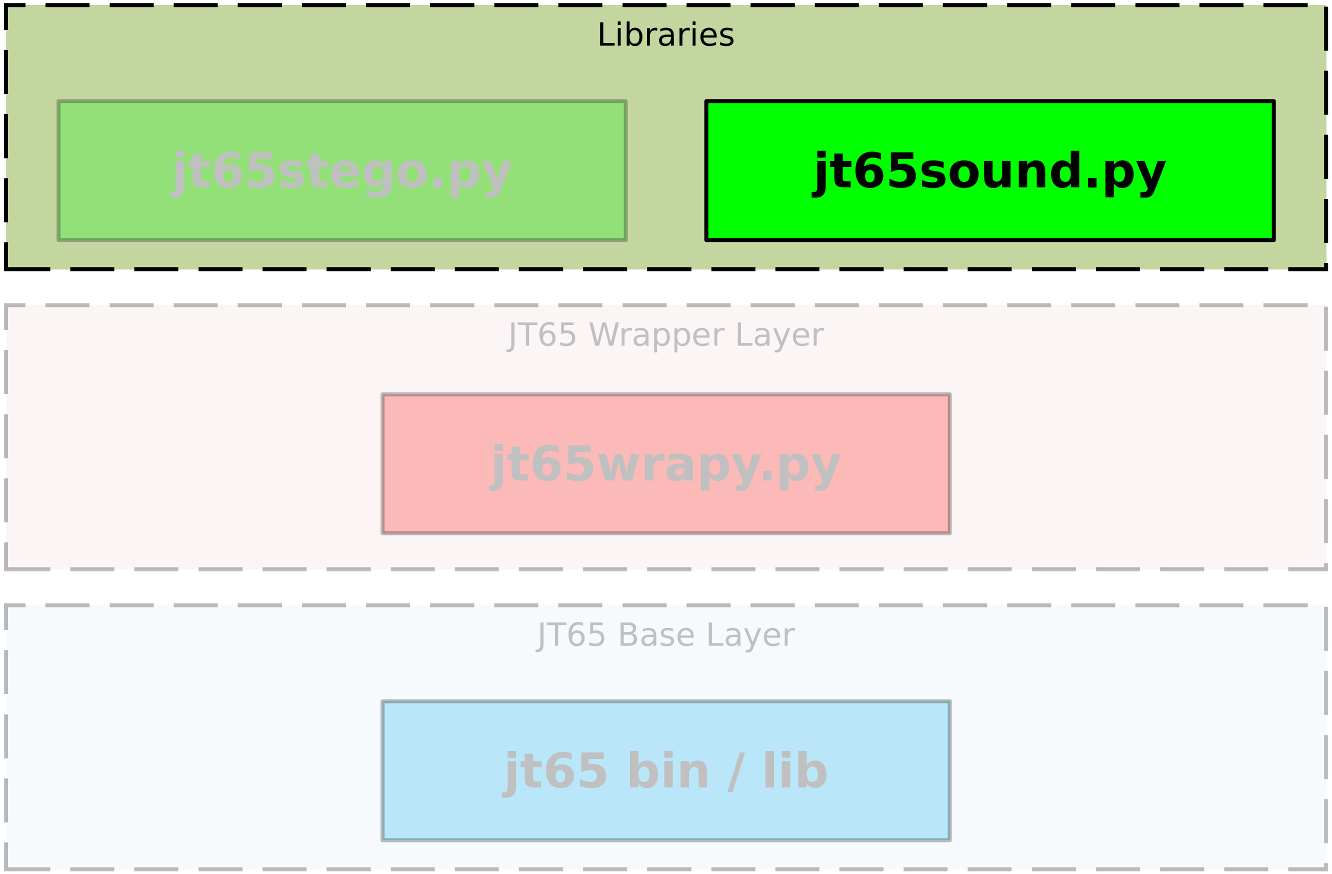
jt65stego.py

JT65 Wrapper Layer

jt65wrapy.py

JT65 Base Layer

jt65 bin / lib



Libraries

jt65stego.py

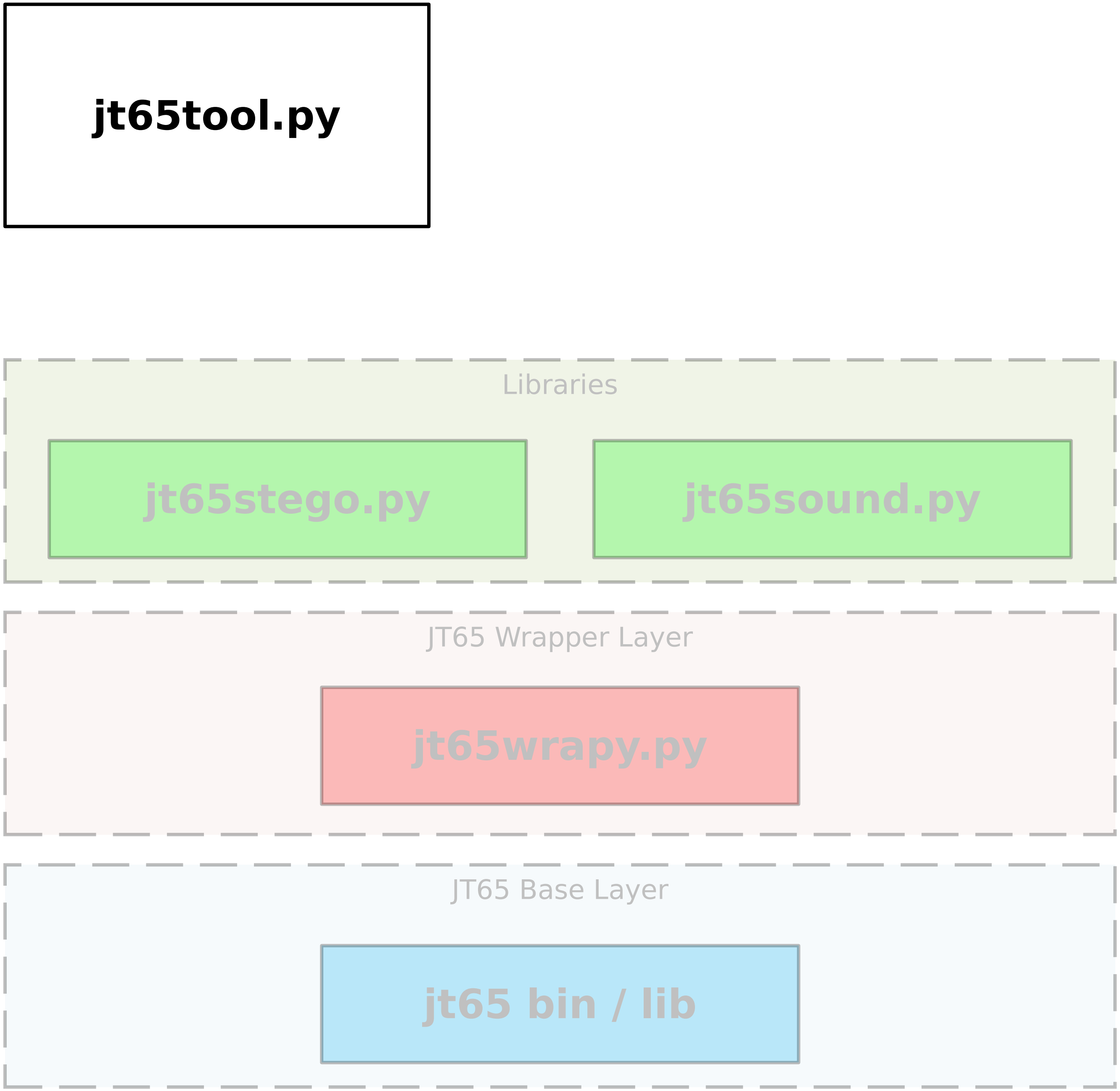
jt65sound.py

JT65 Wrapper Layer

jt65wrapy.py

JT65 Base Layer

jt65 bin / lib



jt65tool.py

Libraries

jt65stego.py

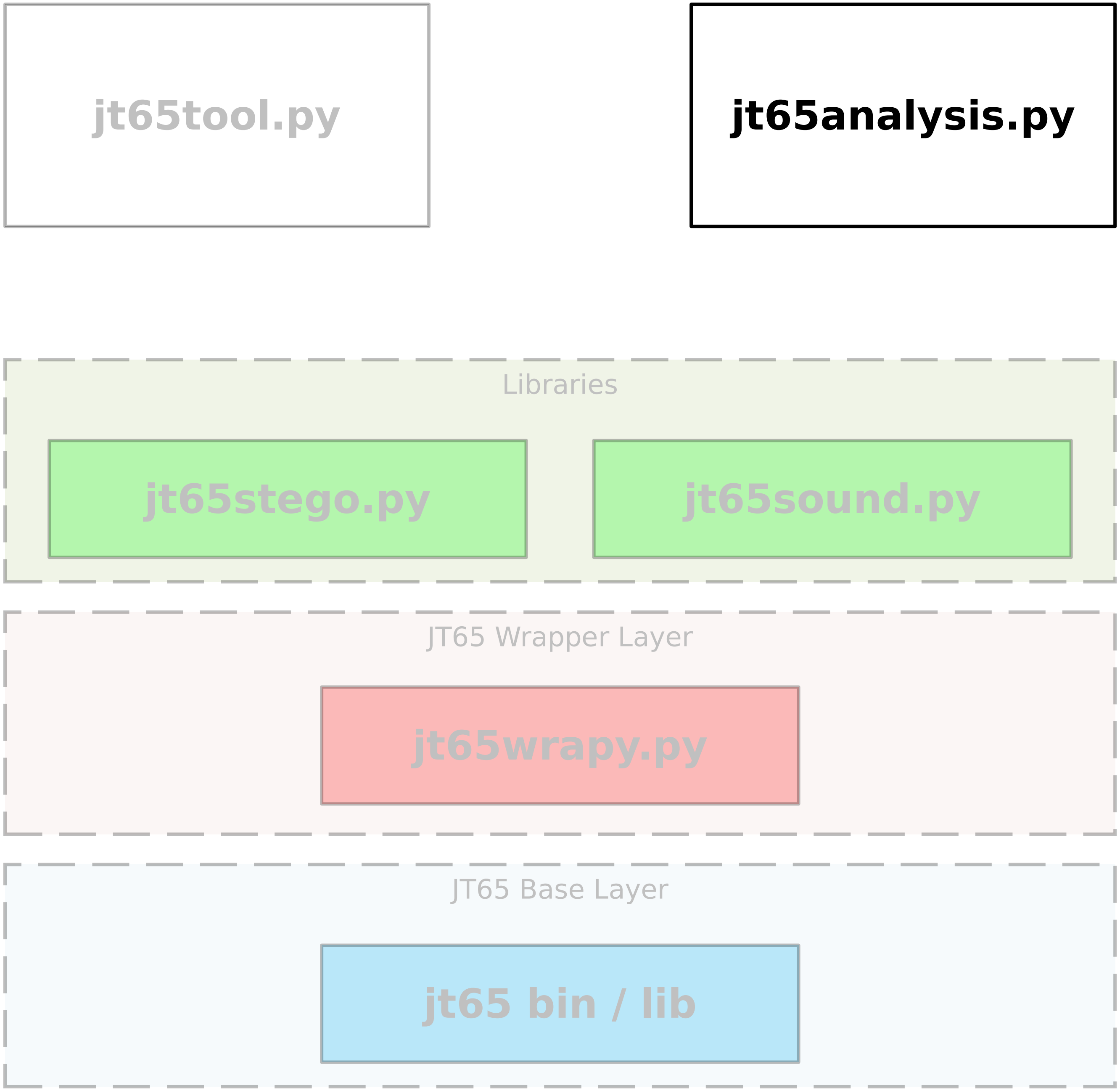
jt65sound.py

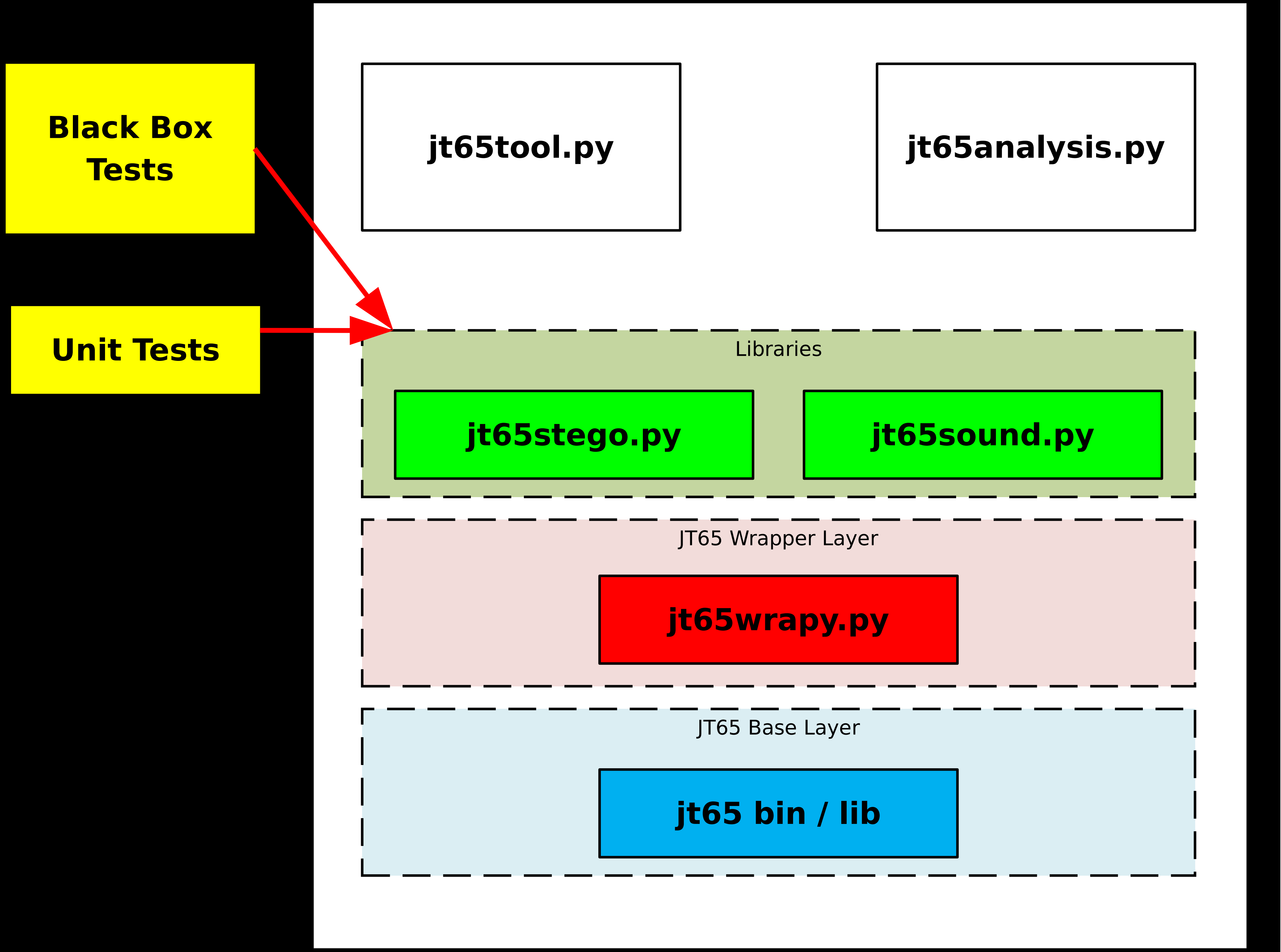
JT65 Wrapper Layer

jt65wrapy.py

JT65 Base Layer

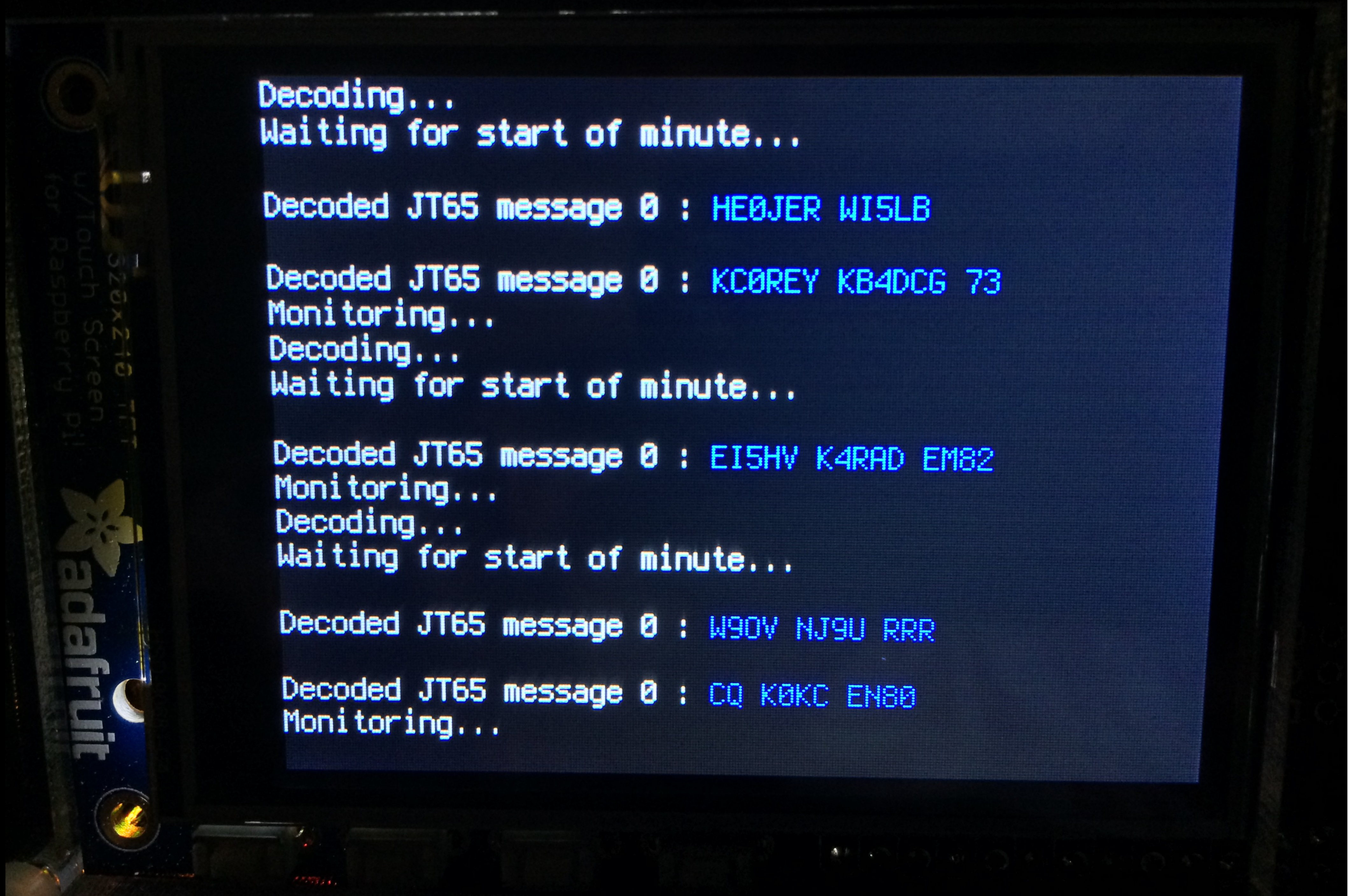
jt65 bin / lib


jt65tool.py
jt65analysis.py
Libraries
jt65stego.py
jt65sound.py
JT65 Wrapper Layer
jt65wrapy.py
JT65 Base Layer
jt65 bin / lib


Black Box Tests
Unit Tests
jt65tool.py
jt65analysis.py
Libraries
jt65stego.py
jt65sound.py
JT65 Wrapper Layer
jt65wrapy.py
JT65 Base Layer
jt65 bin / lib

Tool Demo...

“Feed Reader” RasPi Demo...

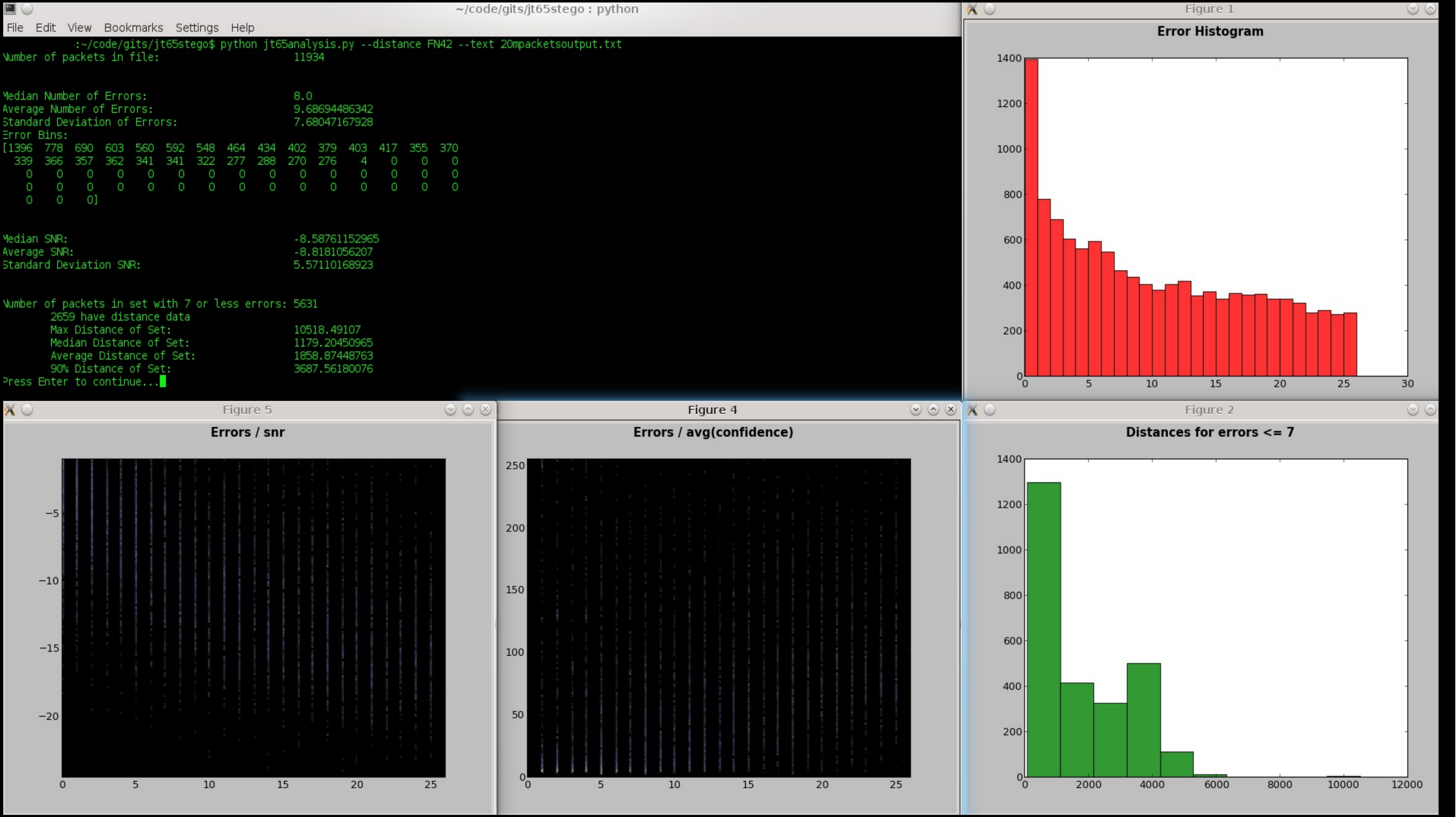


```
Decoding...
Waiting for start of minute...

Decoded JT65 message 0 : HE0JER WI5LB

Decoded JT65 message 0 : KC0REY KB4DCG 73
Monitoring...
Decoding...
Waiting for start of minute...

Decoded JT65 message 0 : EI5HV K4RAD EM82
Monitoring...
Decoding...
Waiting for start of minute...

Decoded JT65 message 0 : W9OV NJ9U RRR

Decoded JT65 message 0 : CQ K0KC EN80
Monitoring...
```

Analysis/Steganalysis

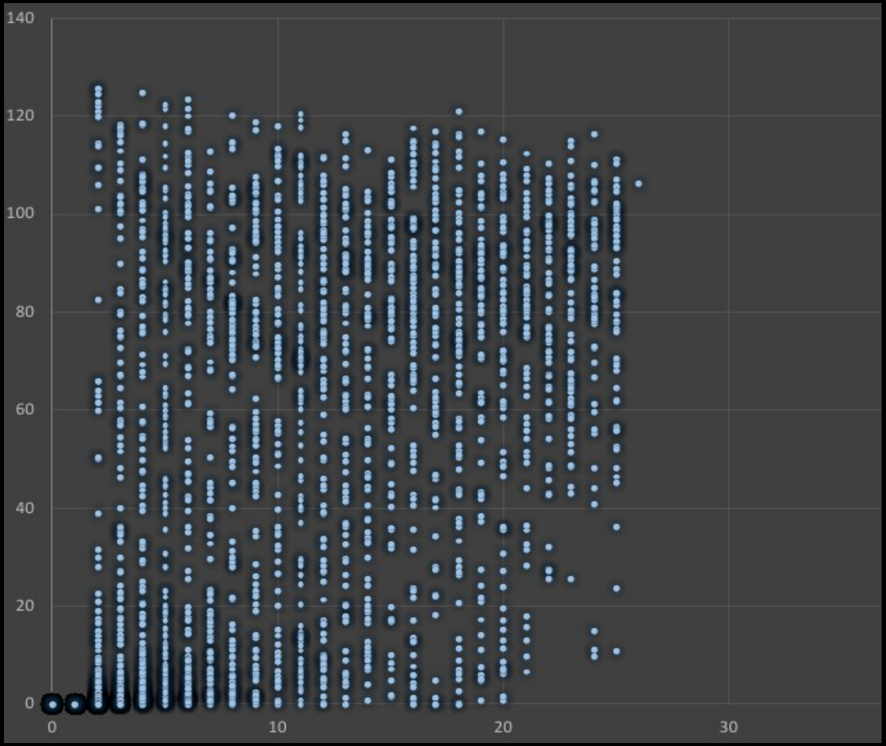
- Defined set of legitimate JT65 packets
- “Known Cover Attack”
- Receive packet → Decode → Encode
- Demodulator provides “probability” or confidence
- Theory:
  - Packets suspected to contain steganography can be easily distinguished by some quantitative measure

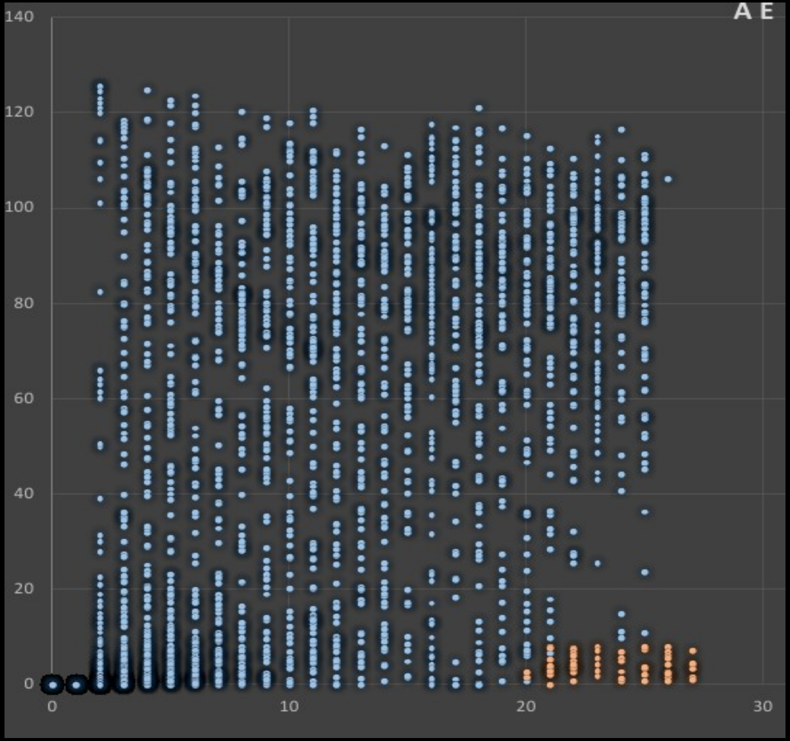
Analysis Module



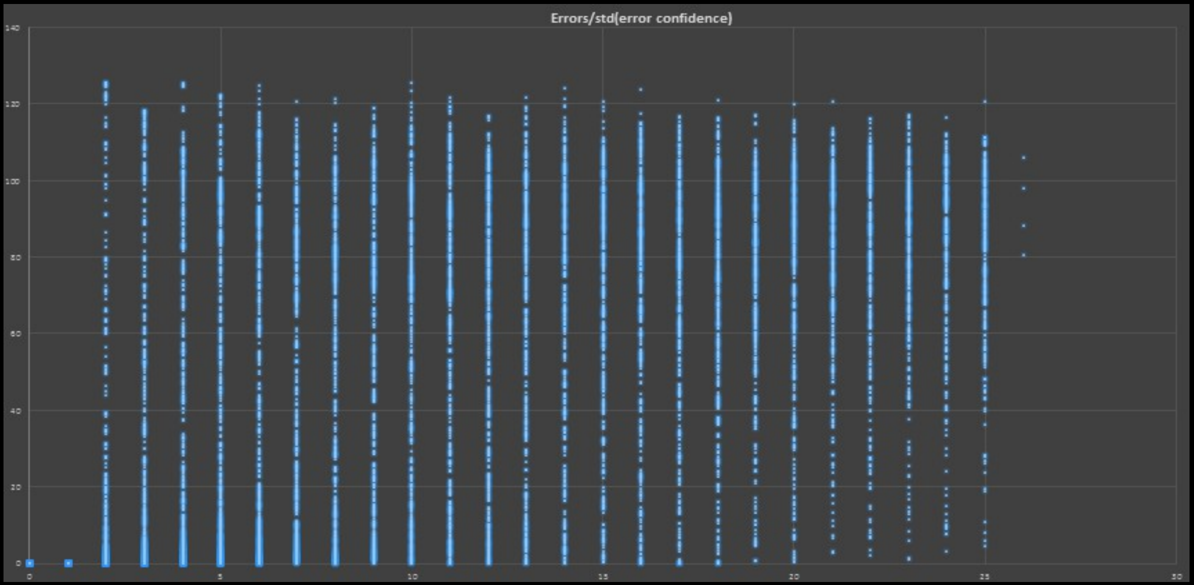
```
        :~/code/gits/jt65stego$ python jt65analysis.py --distance FN42 --text 20mpacketsoutput.txt
Number of packets in file:                        11934


Median Number of Errors:                          8.0
Average Number of Errors:                         9.68694486342
Standard Deviation of Errors:                     7.68047167928
Error Bins:
[1396  778  690  603  560  592  548  464  434  402  379  403  417  355  370
  339  366  357  362  341  341  322  277  288  270  276    4    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0]


Median SNR:                                       -8.58761152965
Average SNR:                                      -8.8181056207
Standard Deviation SNR:                           5.57110168923


Number of packets in set with 7 or less errors: 5631
        2659 have distance data
        Max Distance of Set:                      10518.49107
        Median Distance of Set:                   1179.20450965
        Average Distance of Set:                  1858.87448763
        90% Distance of Set:                      3687.56180076
Press Enter to continue...
```

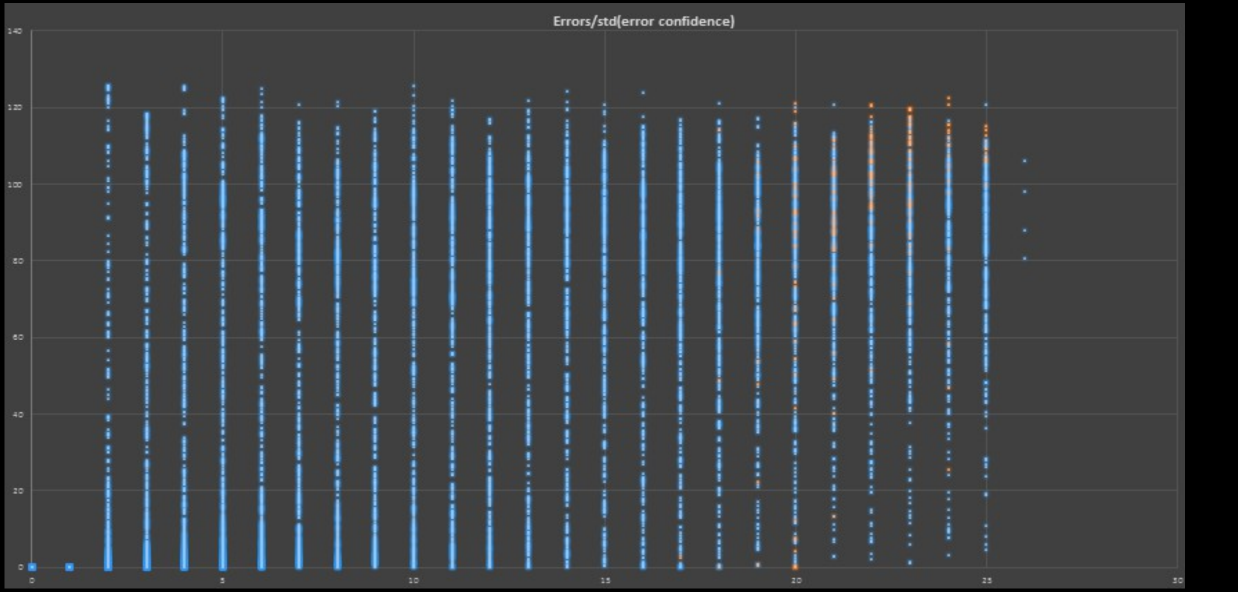
Finding Steganography is Easy



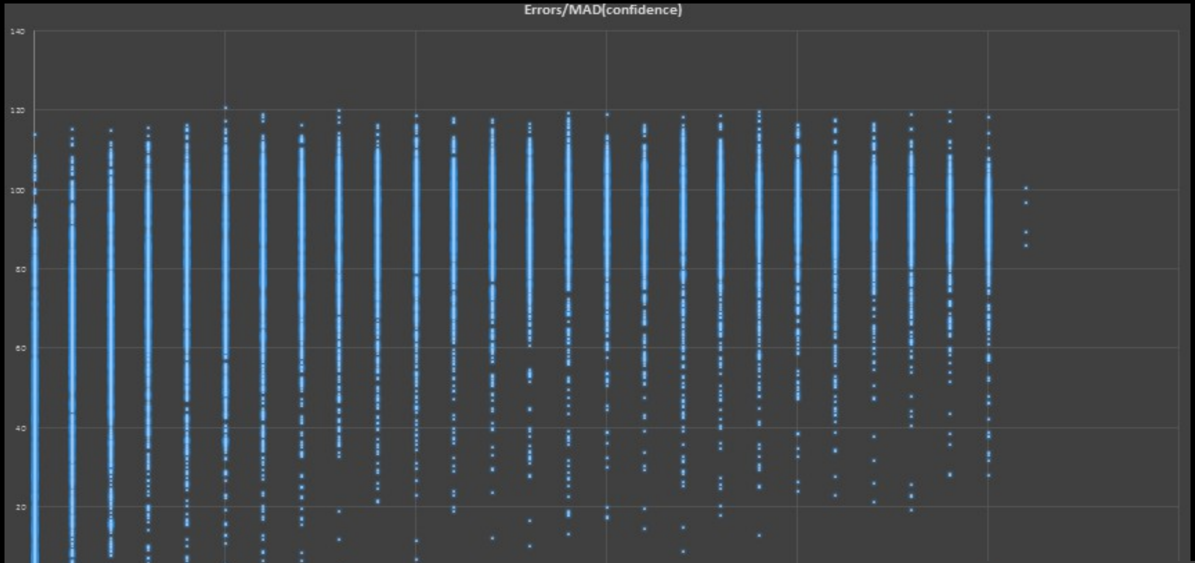


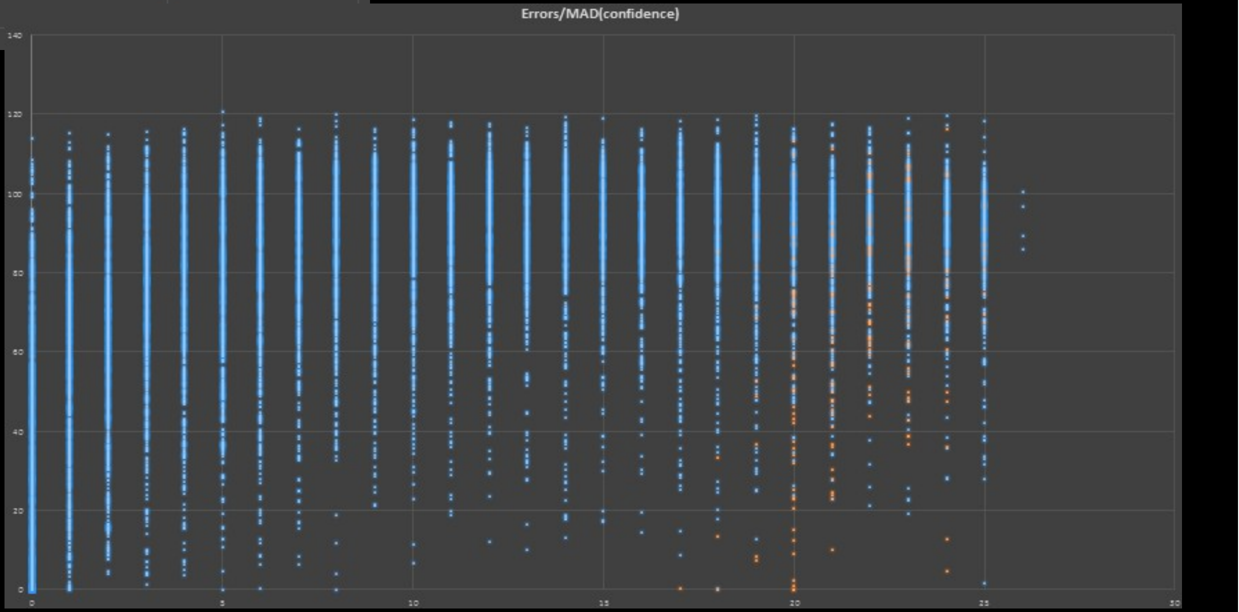
Finding Steganography is Hard



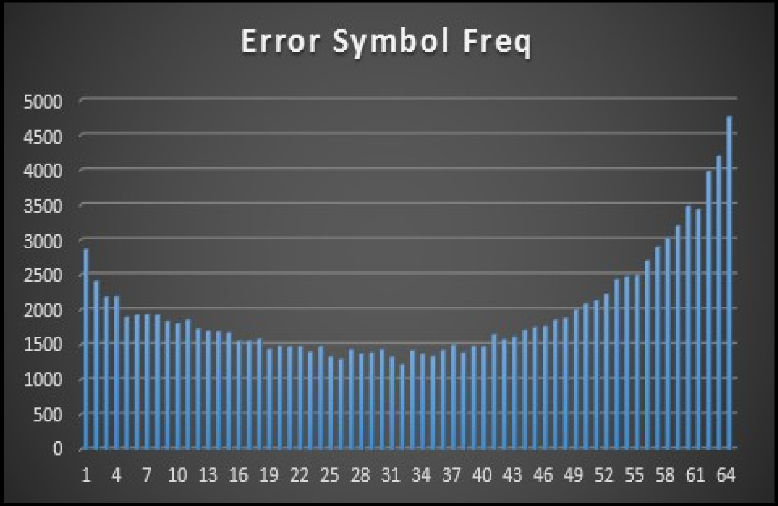


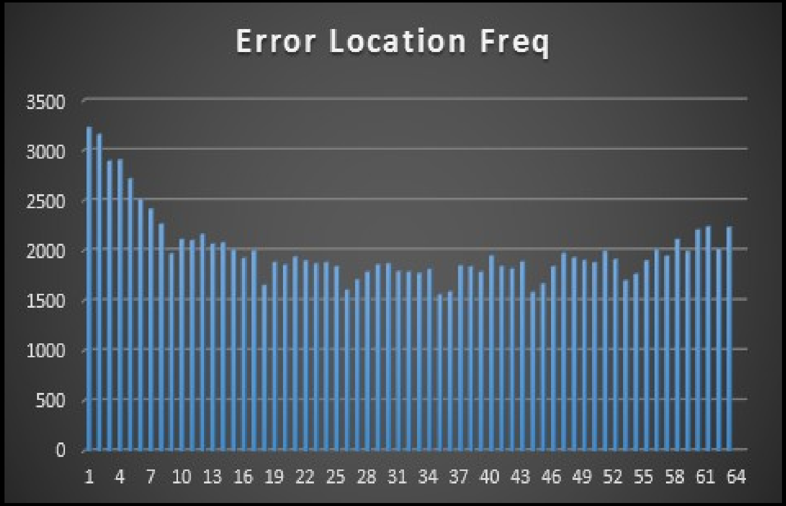
Finding Steganography is Hard

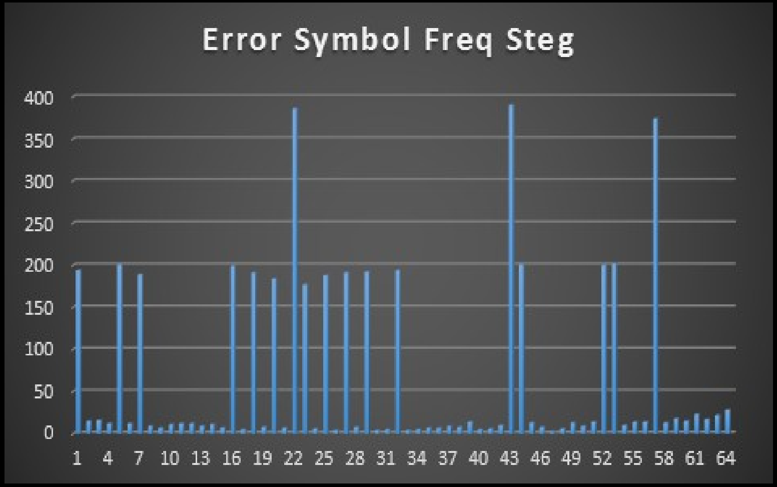


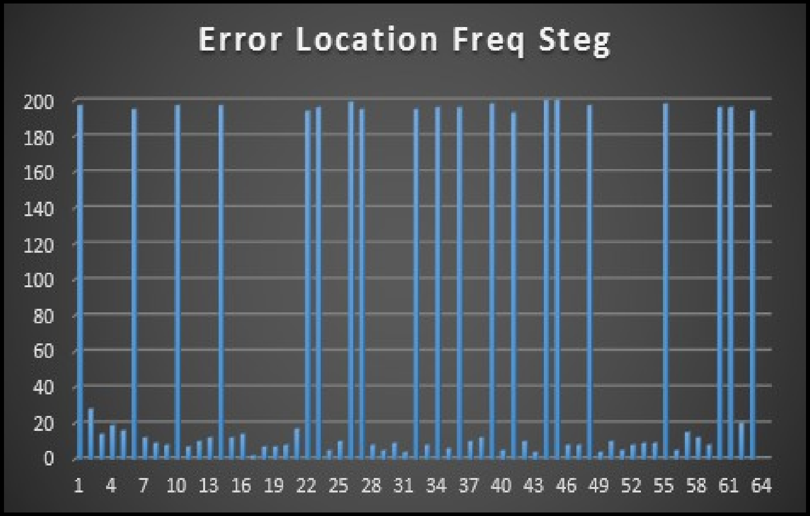


Interesting Patterns (and a warning)



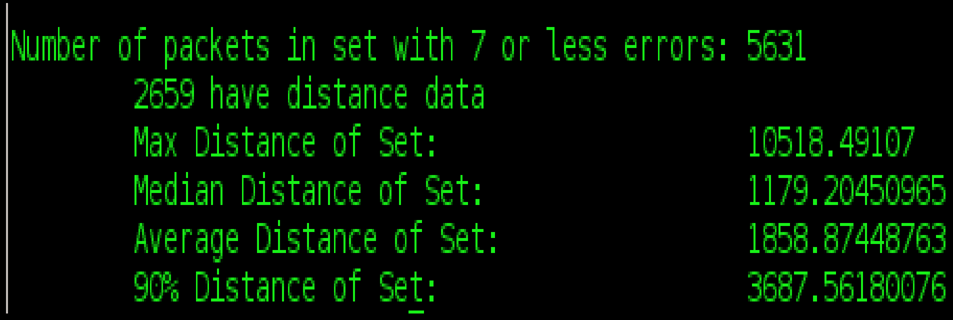




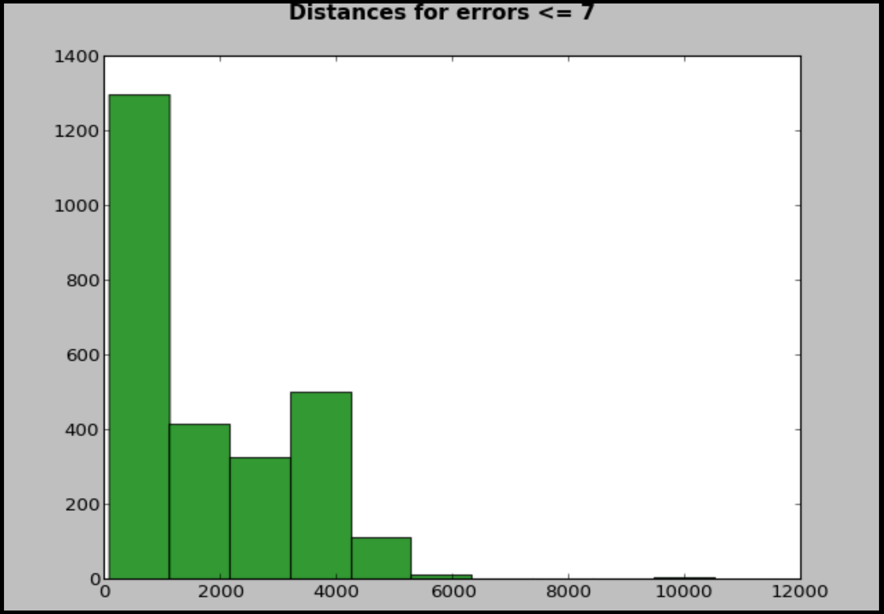


Distance

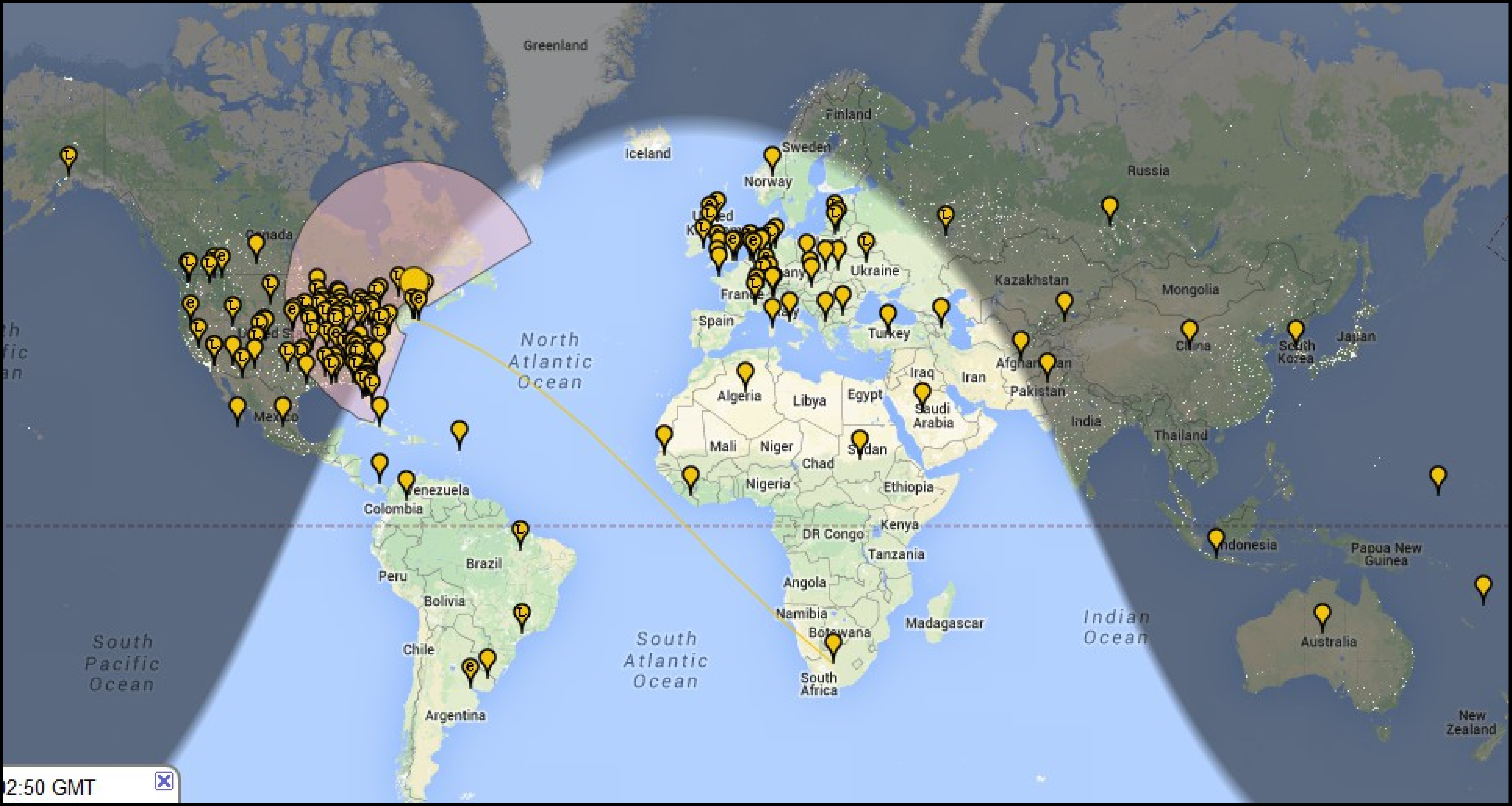
- Considering we cannot SEND these packets
- Let's pretend we received them (<= 7 errors)
- How far away were the senders?



```
Number of packets in set with 7 or less errors: 5631
        2659 have distance data
        Max Distance of Set:                    10518.49107
        Median Distance of Set:                 1179.20450965
        Average Distance of Set:                1858.87448763
        90% Distance of Set:                    3687.56180076
```



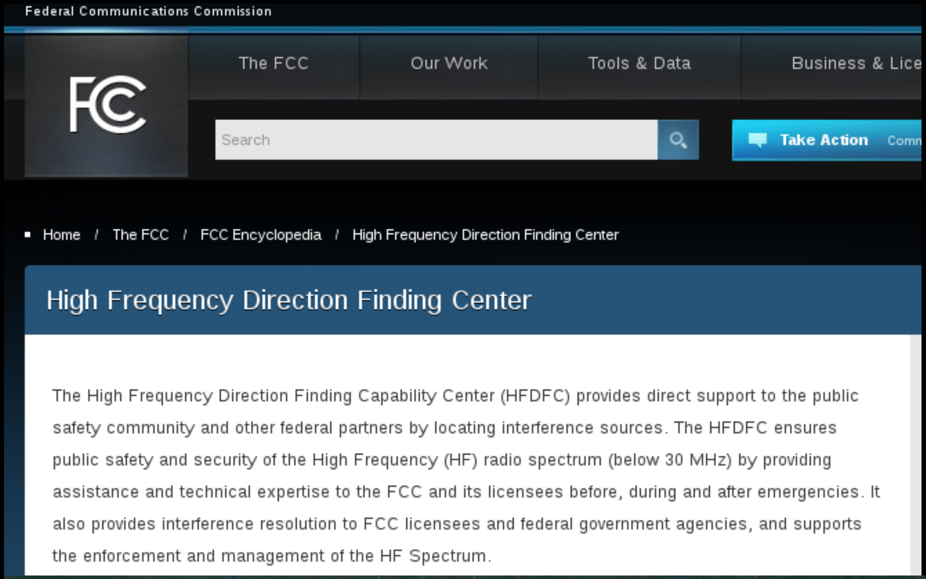
Effectiveness as a World Wide Short Message Protocol



“Vulnerabilities” / Known Limitations

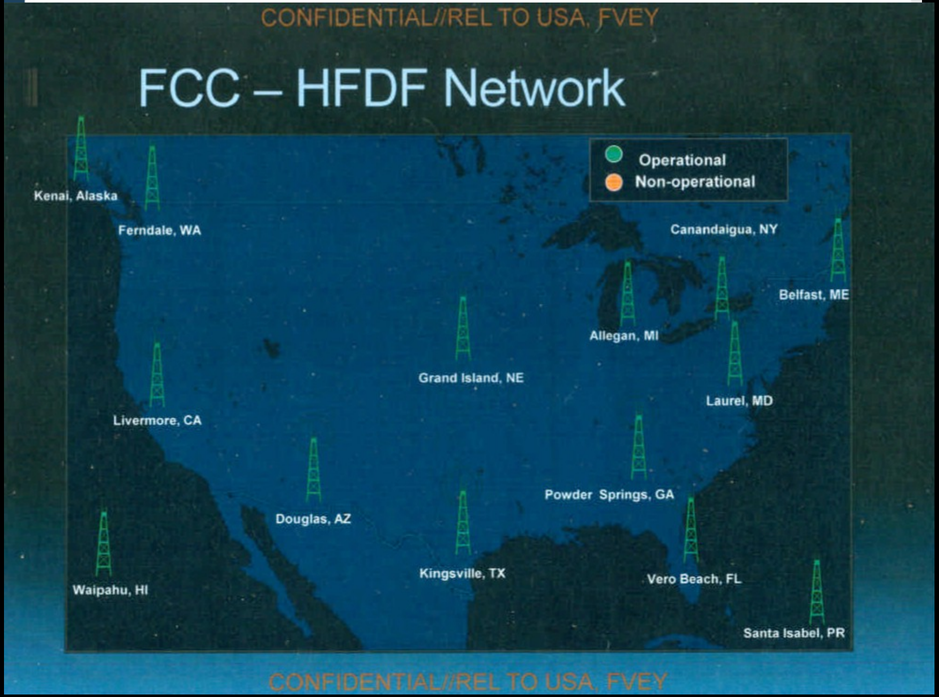
- Analysis and Detection
  - As discussed / other methods
- Transmitter location (foxhunting)
  - Well studied problem/game by amateurs and TLAs
  - FCC/DEA/NSA - SANDKEY(1)
- Message Forgery
- Storage / long term cryptographic analysis

(1) http://cryptomeorg.siteprotect.net/dea-nsa-sandkey.pdf

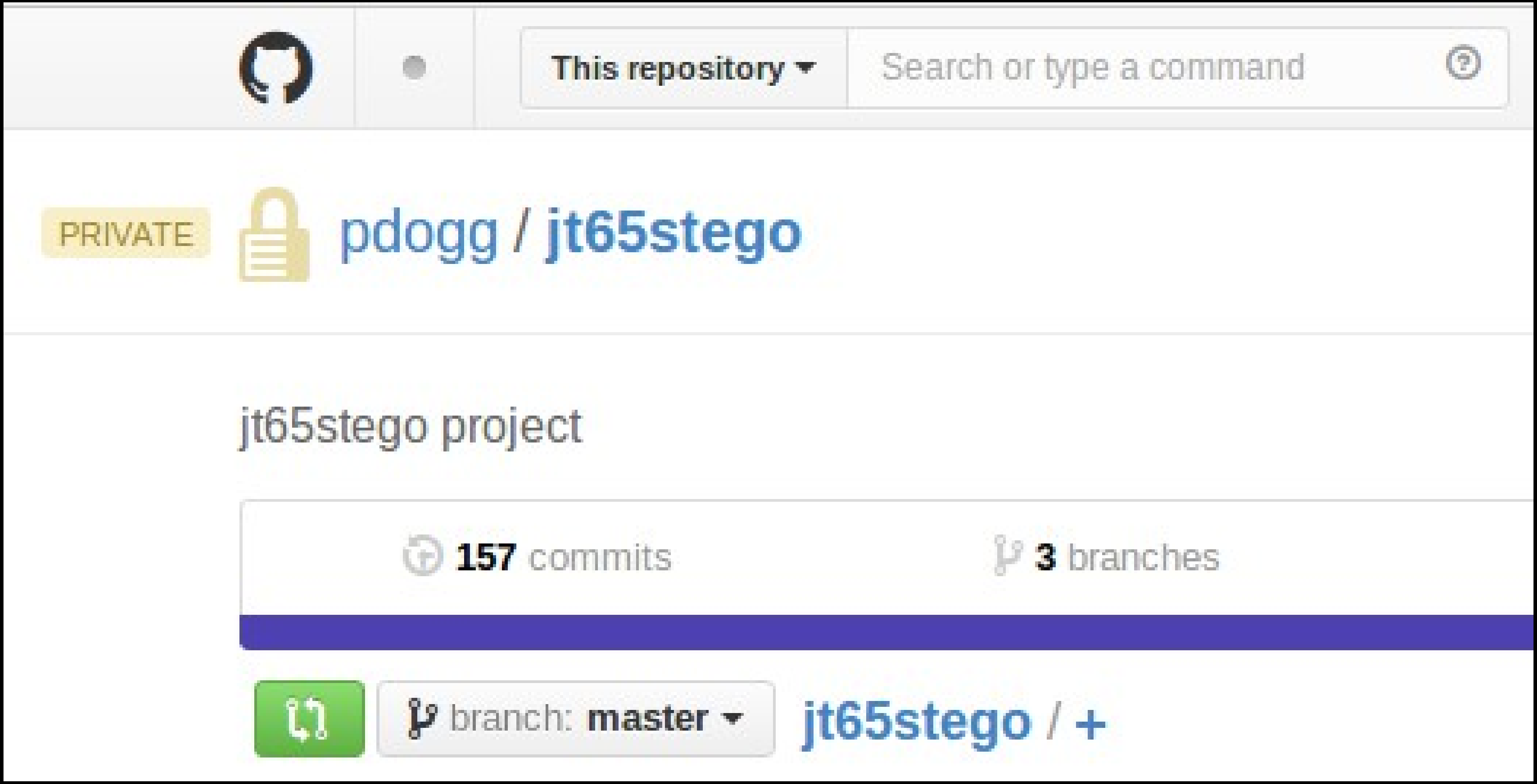

Federal Communications Commission
FCC
The FCC
Our Work
Tools & Data
Business & Lice
Search
Take Action
Comm
Home / The FCC / FCC Encyclopedia / High Frequency Direction Finding Center

High Frequency Direction Finding Center

The High Frequency Direction Finding Capability Center (HFDFC) provides direct support to the public safety community and other federal partners by locating interference sources. The HFDFC ensures public safety and security of the High Frequency (HF) radio spectrum (below 30 MHz) by providing assistance and technical expertise to the FCC and its licensees before, during and after emergencies. It also provides interference resolution to FCC licensees and federal government agencies, and supports the enforcement and management of the HF Spectrum.



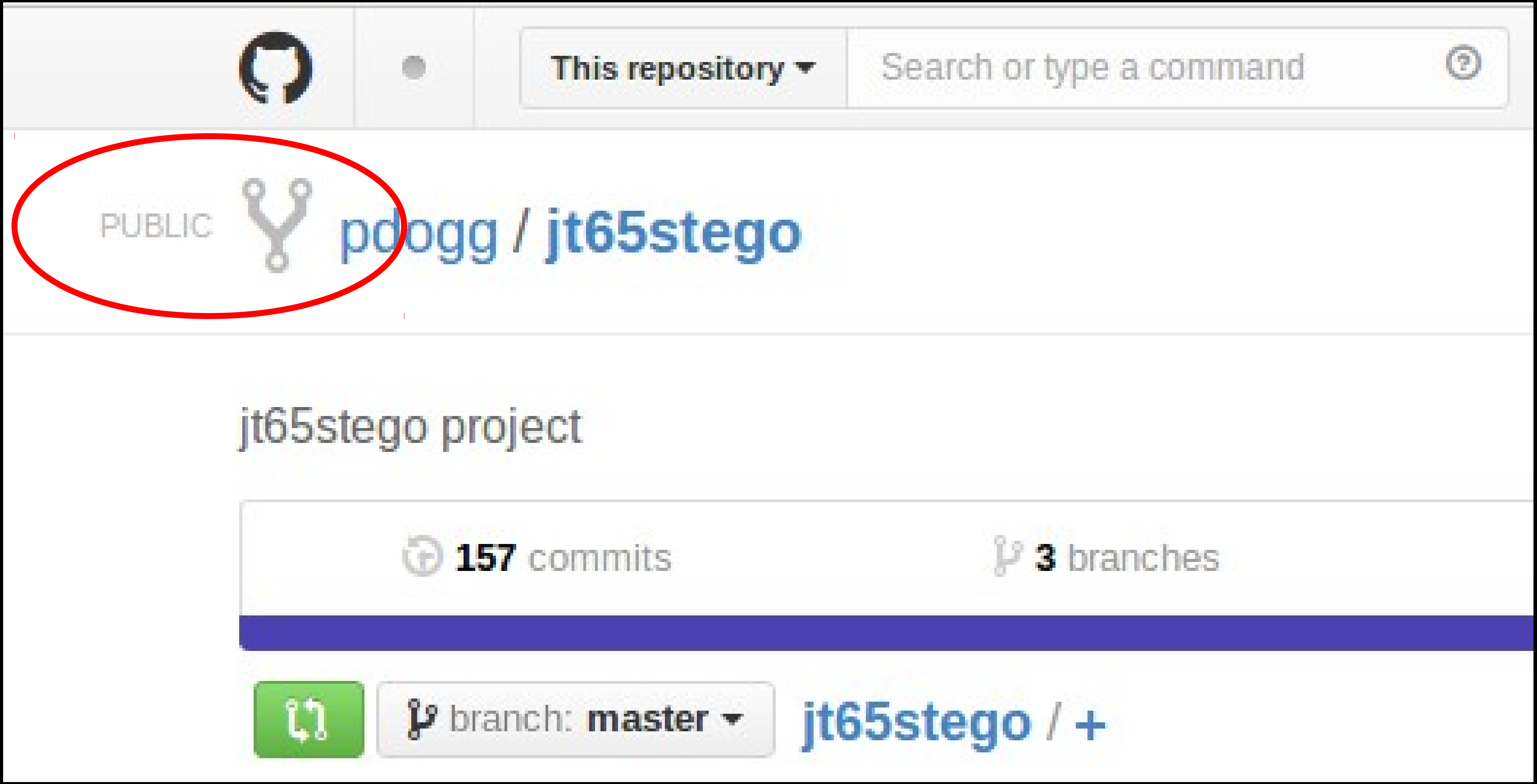
How to get it?



pdogg / jt65stego

jt65stego project

Available today!



This repository ▾ Search or type a command

PUBLIC pdogg / jt65stego

jt65stego project

157 commits

3 branches

branch: master ▾ jt65stego / +

Oh yeah, it's on your conference DVD too...

Conclusions

- Protocols and methods such as those presented can, in theory, provide a platform for short message communications with desirable properties:
  - Low infrastructure
  - Long distance
  - Covert
  - Plausibly deniable
- Potential for analysis and detection
  - Especially for well equipped adversaries

Next Steps / Further Areas of Study

- Continued Detection / Counter Detection Work
- Cryptographic Improvements
- Enhanced amateur applications
- Useful protocols and networks

Ham Exam

Crypto & Privacy Village

Sunday 12 PM – 3 PM

Cram Session

Wireless Village

Sunday 9 AM – 12 PM

THANKS!

@pdogg77
@TheDukeZip

https://www.github.com/pdogg/jt65stego/

Special Thanks @masshackers