



Dire Wolf Software TNC

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MHDC, March 24, 2018



Topics

- Brief review: terminology, concepts.
- Main Theme: Replace old hardware TNC with only software.
- Challenges of Building a better demodulator.
- APRStt
- AX.25 v2.2 link layer improvements, compatibility.





Radio + Teletype = RTTY



Simple Modem

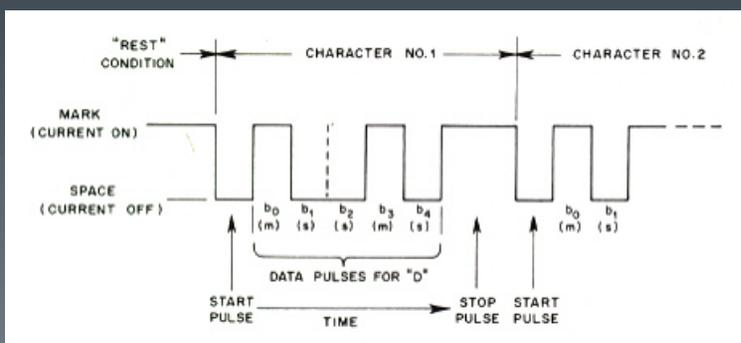
Audio & PTT



Modem was called a "terminal unit".

170 Hz AFSK

AFSK → SSB → FSK





Packet Radio

- Radical new concept.
- Vancouver Area Digital Communications Group, 1978.
- Each transmission was a short burst (“packet” or “frame”) containing:

Flag	Adresse	Kontrollinfo	Daten	CRC	Flag
01111110	112/224 Bits	8/16 Bits	$n * 8$ Bits	16 Bits	01111110

U(nprotocol) oder S(upervisory) Datenpaket

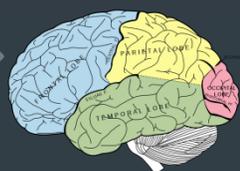


Packet Radio

Modem &
packet protocol



RS-232



Audio &
PTT



Terminal Node Controller (TNC).

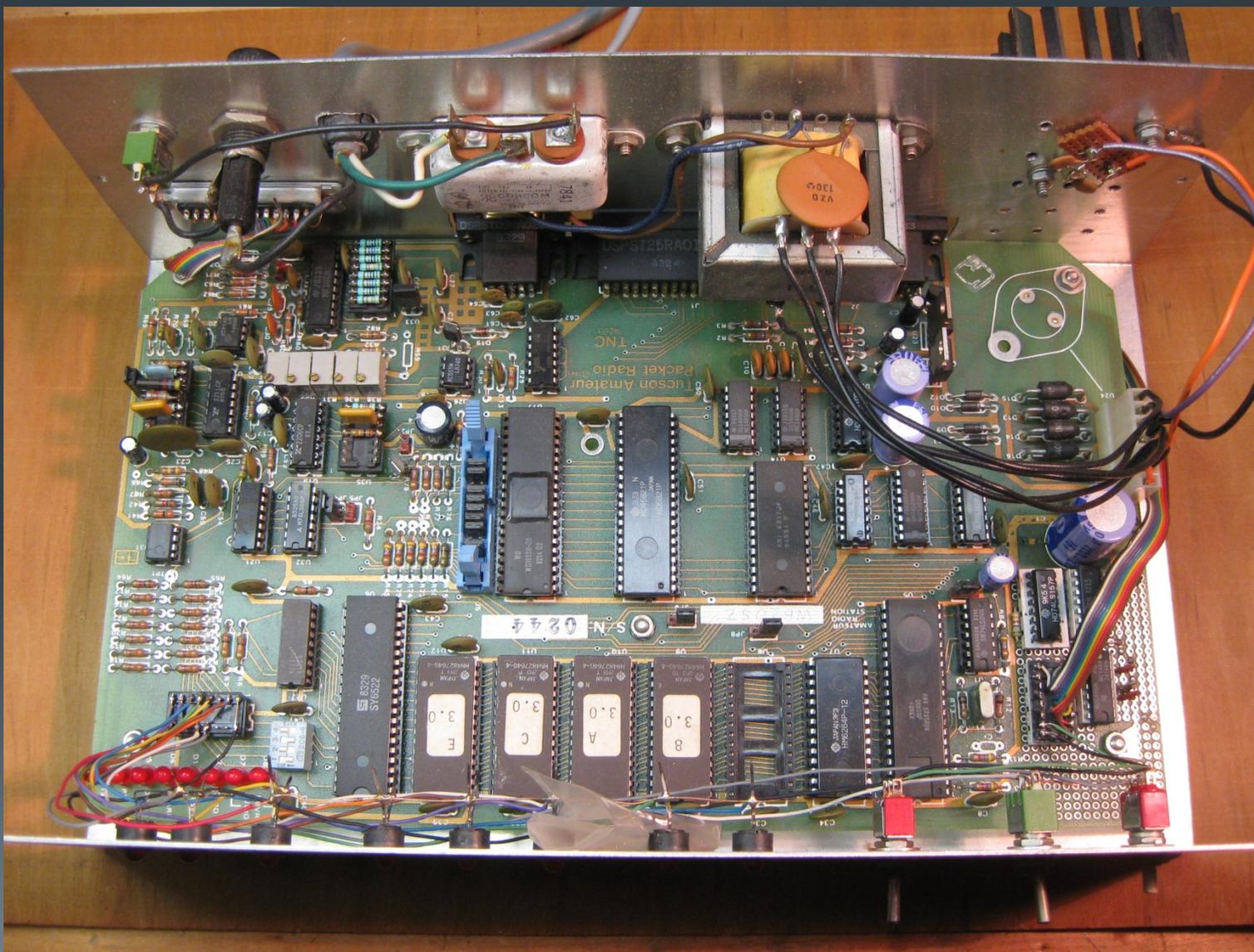
Modem + brains.



Advantages of Packet Radio

- Short bursts.
- Addresses.
- Shared channel.
- Error detection.
- ACK & retry – for “connected” mode.
- Repeaters.
- “Transparent” for “binary” data.

TAPR TNC-1 kit





Dumb Terminal to Human Interface

```
K1OJH>ALL,WORLI*:NEPRA meeting tonight at 7:00
```

```
cmd> c k7ve
```

```
*** CONNECTED to K7VE
```

```
I will bring the cable that you need tonight.
```

```
Great! See you there.
```

```
(ctrl-C)
```

```
cmd> d
```

```
*** DISCONNECTED from K7VE
```

Not good for computer to computer.



K.I.S.S. Interface



RS-232



Very simple
(KISS) TNC



Adresse	Kontrollinfo	Daten
112/224 Bits	8/16 Bits	n * 8 Bits

Flag	Adresse	Kontrollinfo	Daten	CRC	Flag
01111110	112/224 Bits	8/16 Bits	n * 8 Bits	16 Bits	01111110

Smaller brain needed for TNC.

- Transmit: TNC adds CRC and HDLC flags.
- Receive: TNC checks for correct CRC and removes it.



APRS – Data Types

“APRS is not a vehicle tracking system. ...”

- Positions (usually transmitting station.)
- Objects (usually on behalf of other entity.)
- Weather Reports.
- Telemetry.
- “Messages” to an individual or bulletins to groups.
- Queries and Responses.



Packet / APRS – late 20th Century



Hardware
from 1980's

RS-232





TNC replaced by software



Audio &
PTT



Cheaper.

Better Results.



What is Dire Wolf ?

Software replacement for the traditional TNC.

- Windows.
- Linux - x86, x86_64 PC, Raspberry Pi.
- Mac OSX.

- GPS Tracker.
- Digipeater.
- Internet Gateway (IGate).
- APRStt gateway.

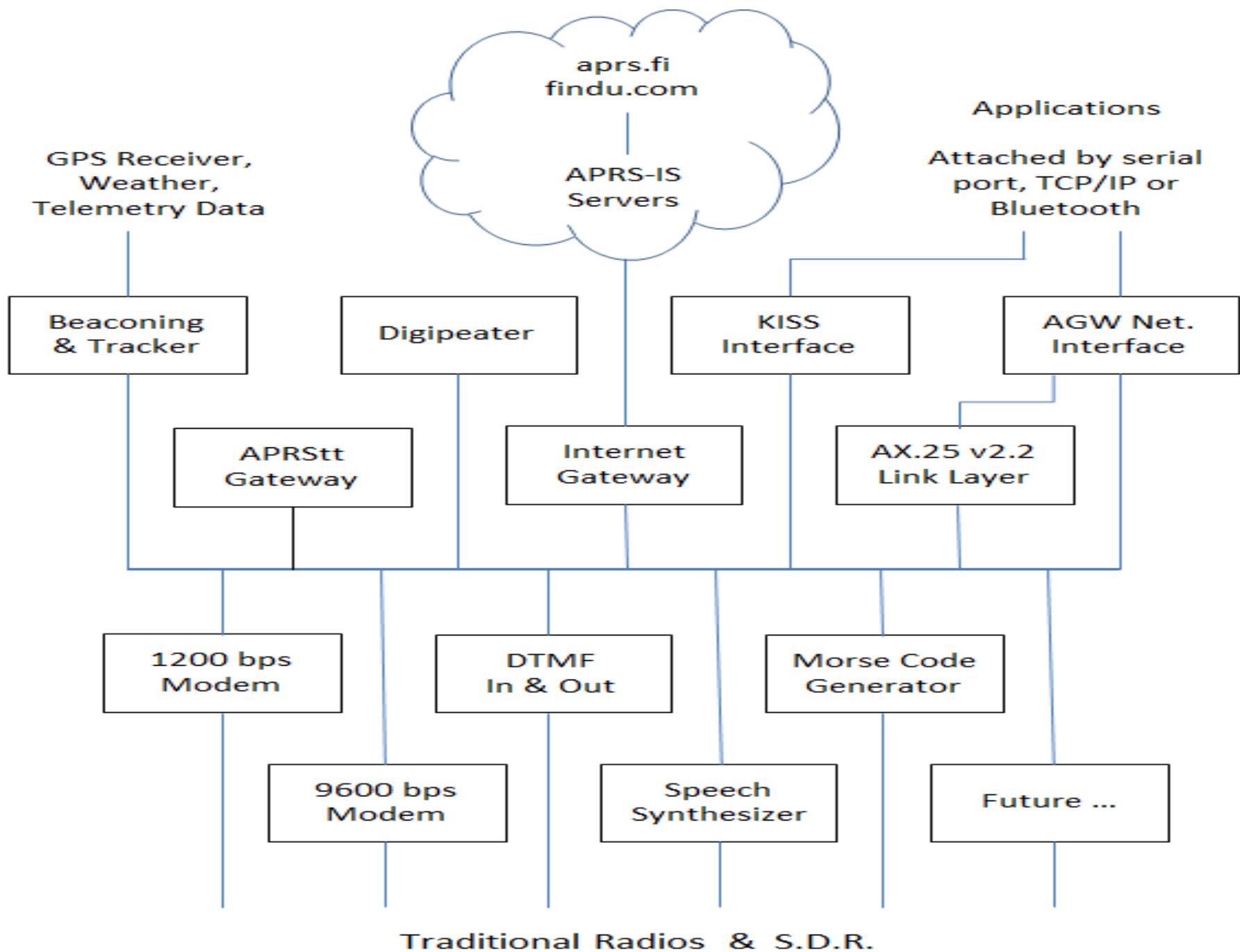
- Virtual TNC for applications such as [APRSIS32](#), [UI-View32](#), [Xastir](#), [APRS-TW](#), [YAAC](#), [UISS](#), [Linux AX25](#), [SARTrack](#), [RMS Express](#), [Outpost PM](#), Linpac, and many others.



Where did the name come from?

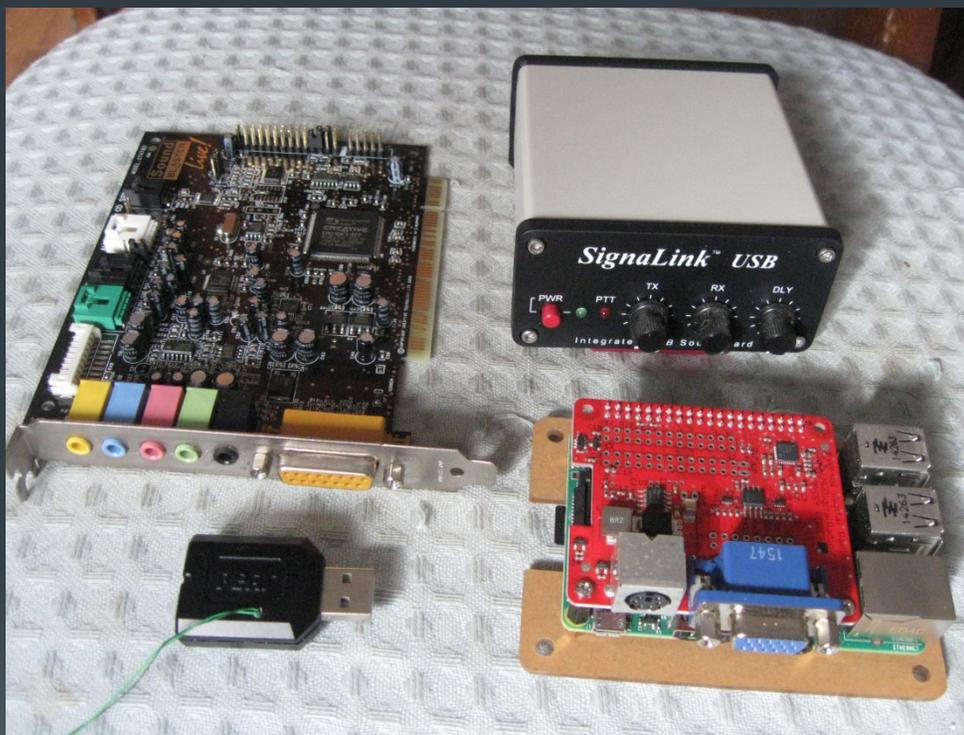
Decoded
Information from
Radio
Emissions for

Windows
Or
Linux
Fans

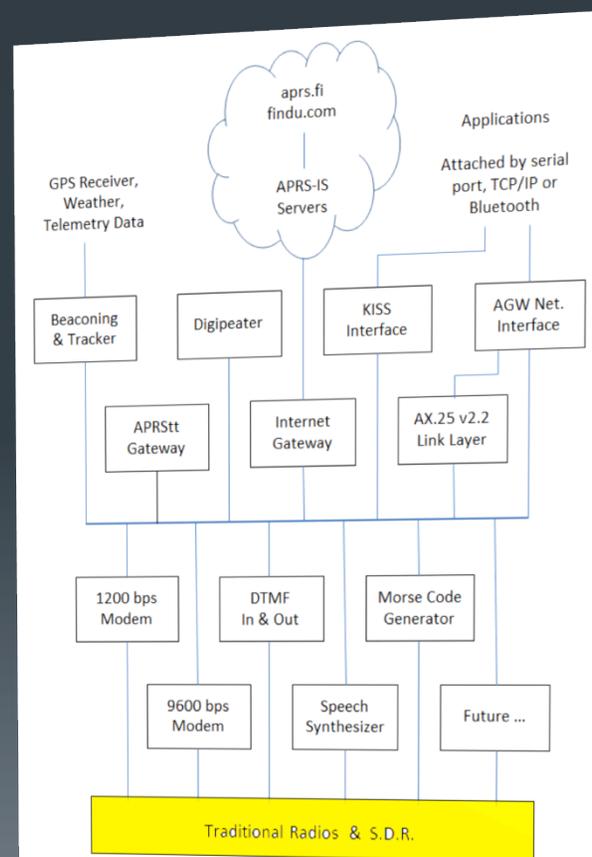




Traditional Radio Interface



Receiver audio → computer.
Computer audio → transmitter.





Software Defined Radio (SDR) Interface

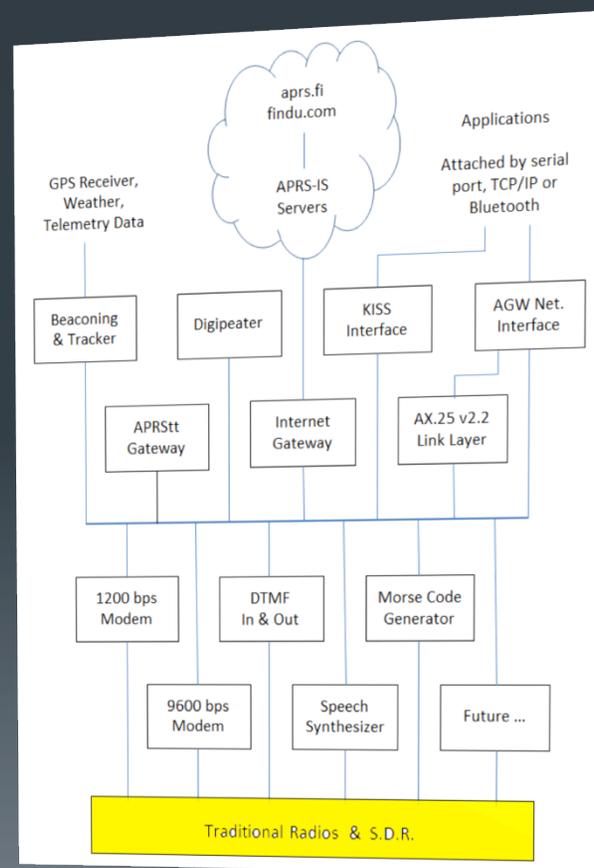
- Pipe into stdin

```
rtl_fm -f 144.39M | direwolf -
```

- Listen for audio on a UDP port.

(e.g. `gqrx v2.3` and later)

- Virtual audio cable. SDR#.





1200 bps modem



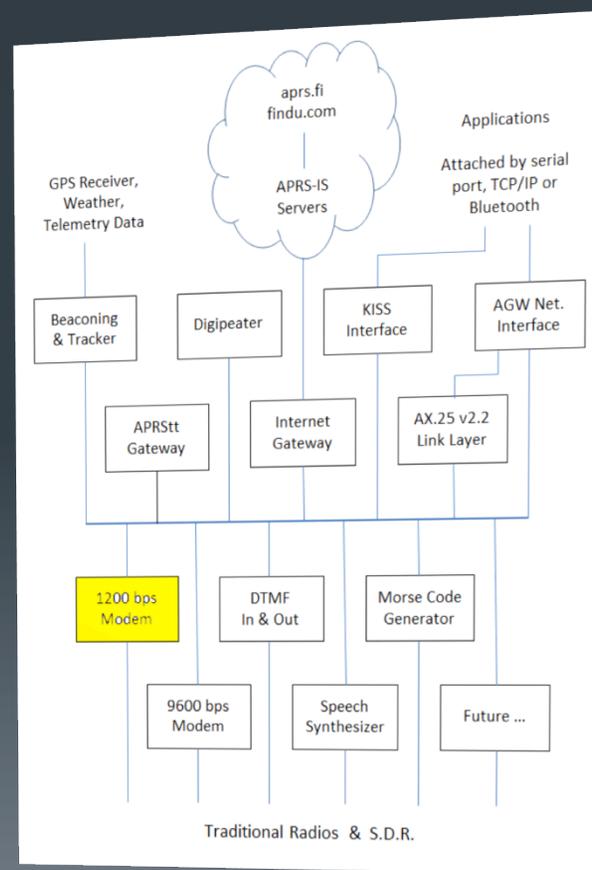
AX.25 Protocol Specification says nothing at all about modems.

AFSK 1200 / 2200 Hz.

Easy to implement.

Works with any radio.

But... we will see later....





9600 bps

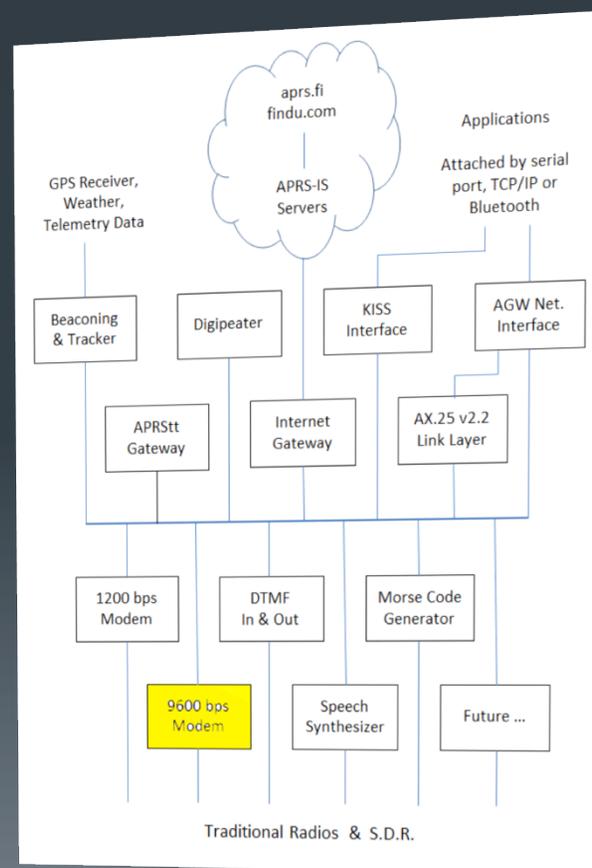


Original implementations around 1988 based on hardware by

K9NG G3RUH

Needs about 5 kHz of audio bandwidth.

Will not work with microphone and speaker connections.



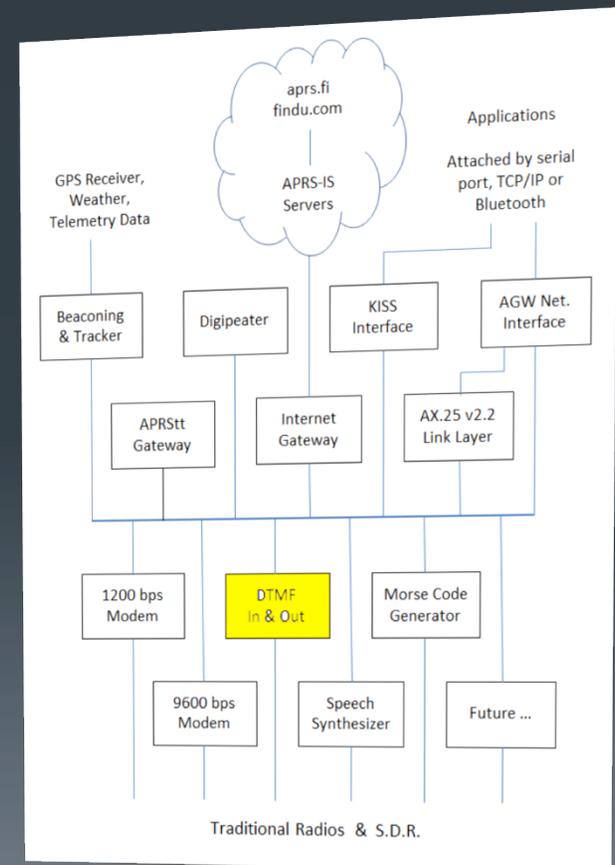
DTMF decode / encode

Received tone sequences are converted to packet like:

```
DTMF>APDW15:t12345#
```

Transmit tones by putting DTMF in the destination address.

```
WB2OSZ>DTMF:123 456
```





Speech Synthesizer

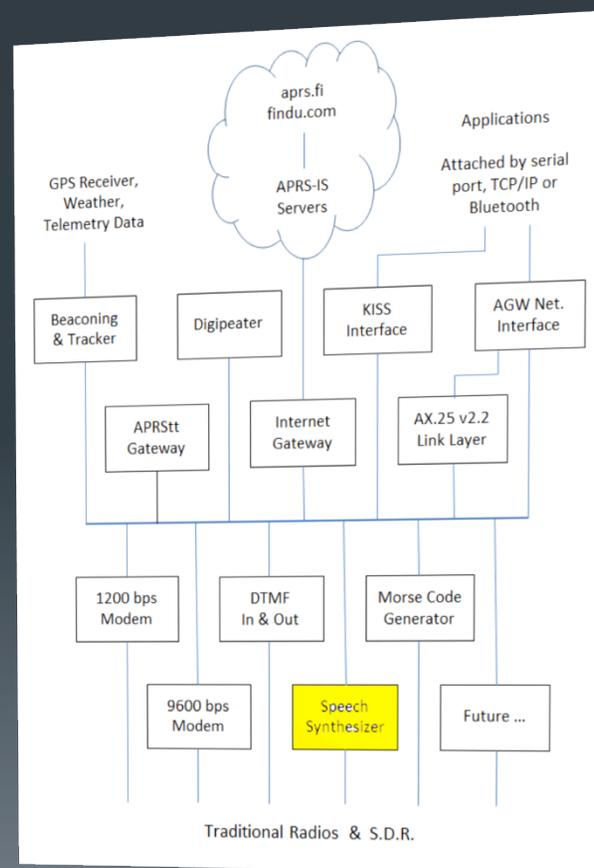
Any packet with SPEECH is sent to a user-supplied script which can invoke a text-to-speech synthesizer.



```
WB2OSZ>SPEECH:Hello, World!
```

Configuration file example:

```
CBEACON dest=SPEECH  
info="Club meeting tonight  
at 7 pm."
```



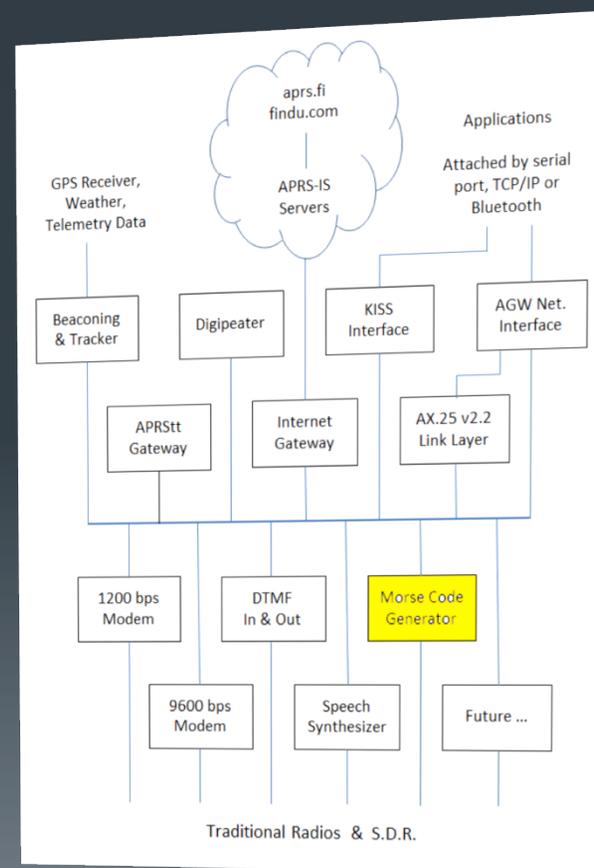


Send Morse Code



Any packet with MORSE as the destination is sent as Morse Code.

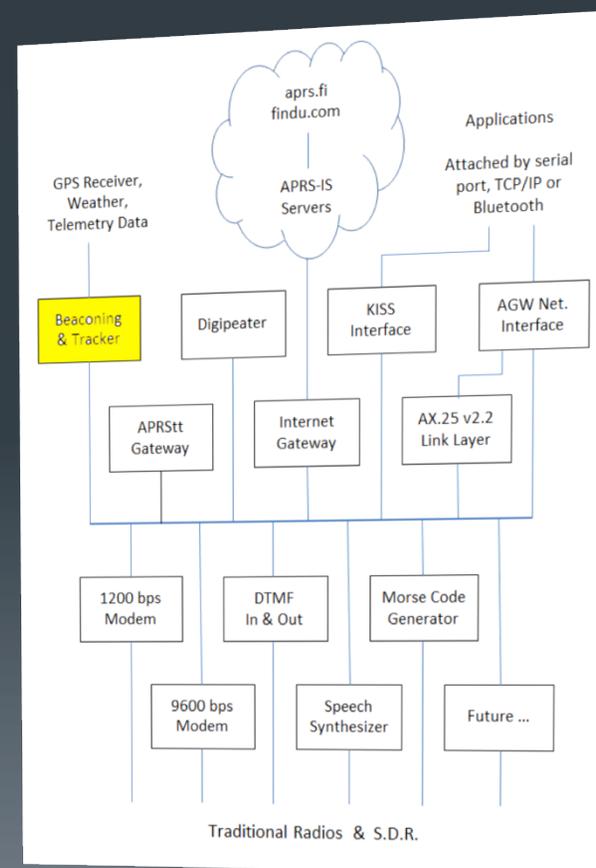
```
WB2OSZ>MORSE:CQ CQ
```





Beacons

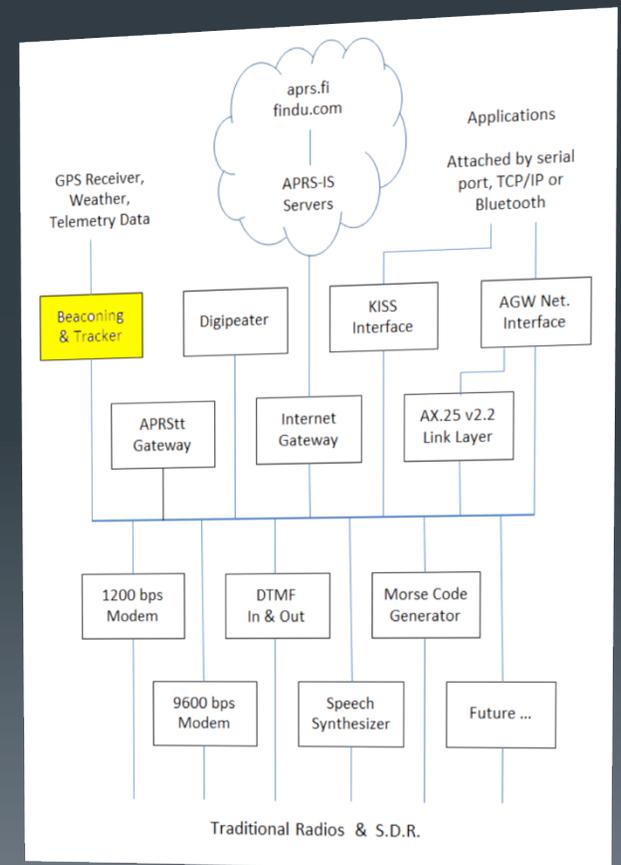
- Periodic position or object packets.
- When location comes from GPS we have a tracker.
- “Custom” beacons invoke user script.
- Weather. wxnow.txt
- Telemetry Toolkit.



Telemetry Tool Kit



- Building blocks for your own customized solutions.
- User-defined script to generate content.
- Raspberry Pi A/D converter example.

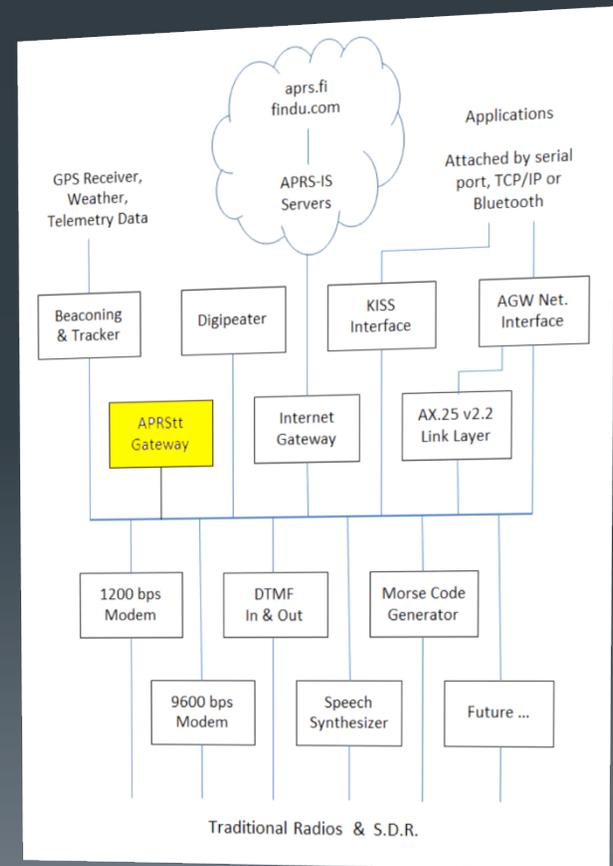


APRStt Gateway



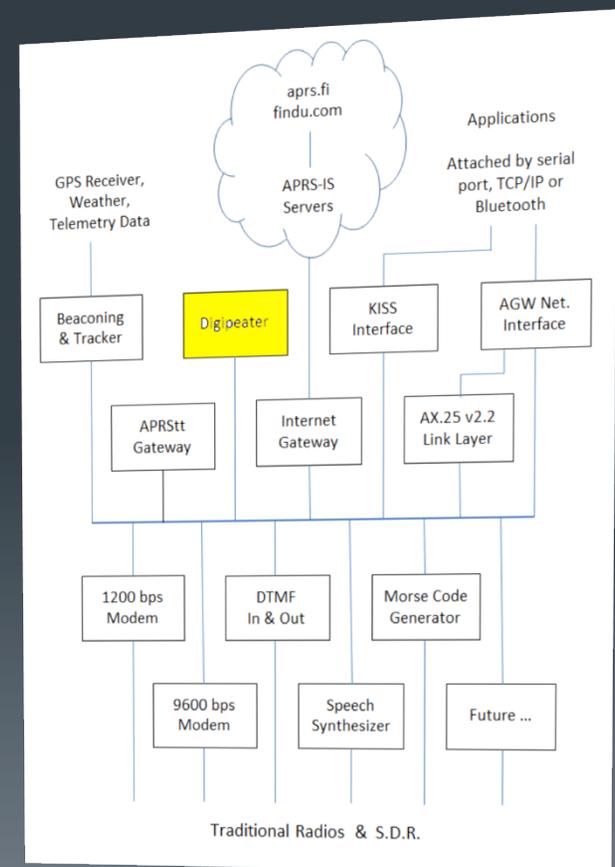
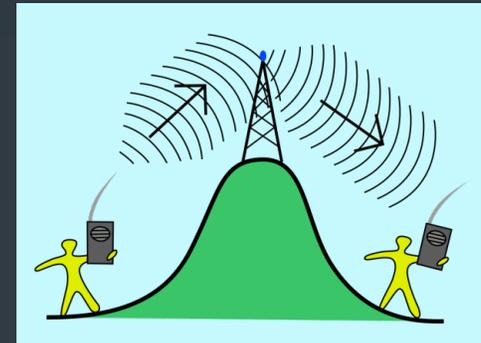
Converts Touch Tone sequences into APRS objects.

More details later...



Digital Repeater “digipeater”

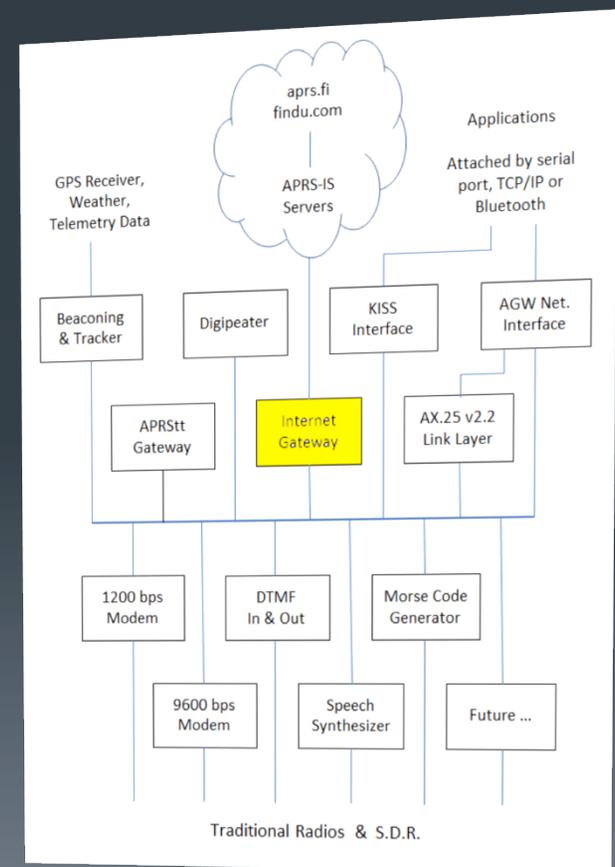
- Extends range.
- Store and Forward.
- Multiple channels.
- Filtering for special situations.
(addresses, distance, data type, symbol)

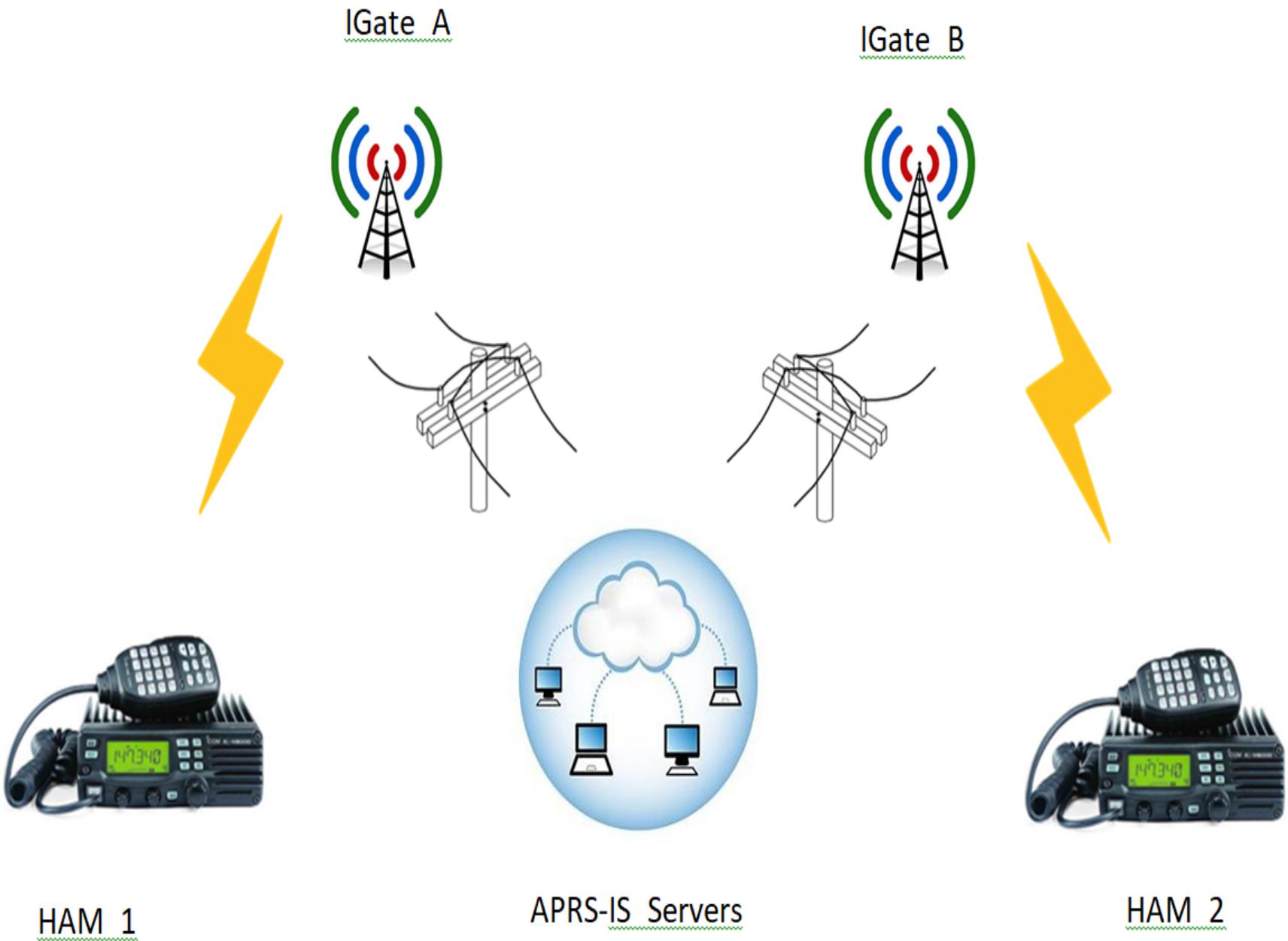


Internet Gateway "IGate"

Connect disjoint radio networks.

View APRS activity at <http://aprs.fi> or <http://findu.com> or with other applications.





IGate A

IGate B

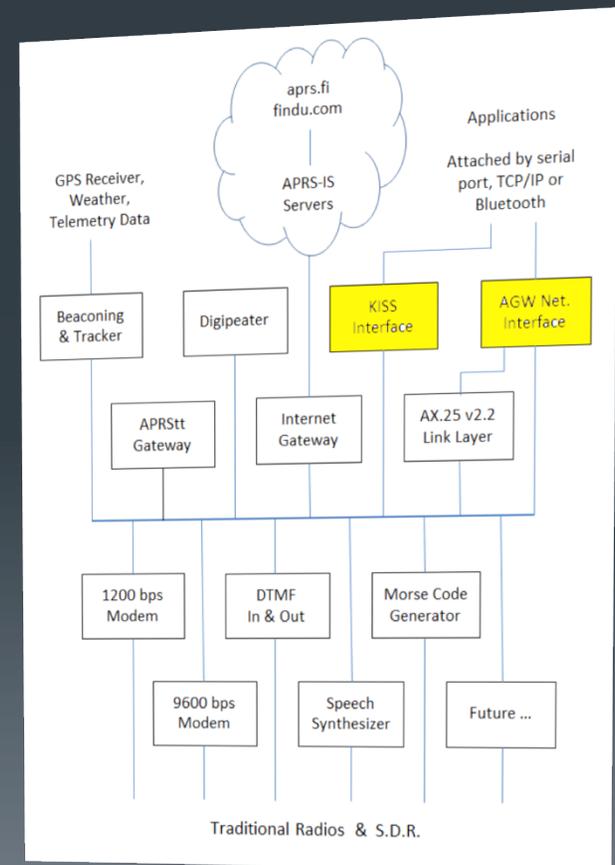
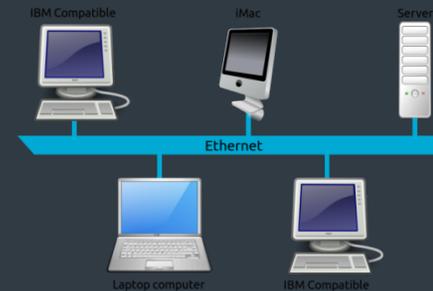
HAM 1

APRS-IS Servers

HAM 2

Application Interfaces

- KISS and AGW network interfaces.
 - AGW interface allows access to more brains in the TNC such as connected mode.
- Applications attached by:
 - RS-232 Serial Port.
 - TCP/IP (Ethernet, WIFI)
 - Bluetooth.
- Many simultaneous applications.





Building a Better Demodulator

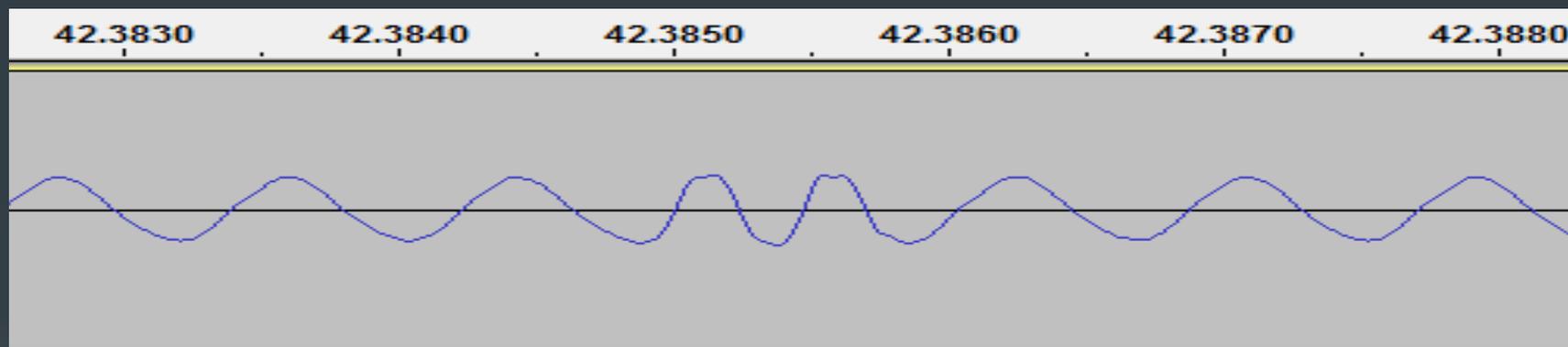
Decoding ideal signals is easy.

Decoding less-than-perfect signals is more of a challenge.



Audio Frequency Shift Keying

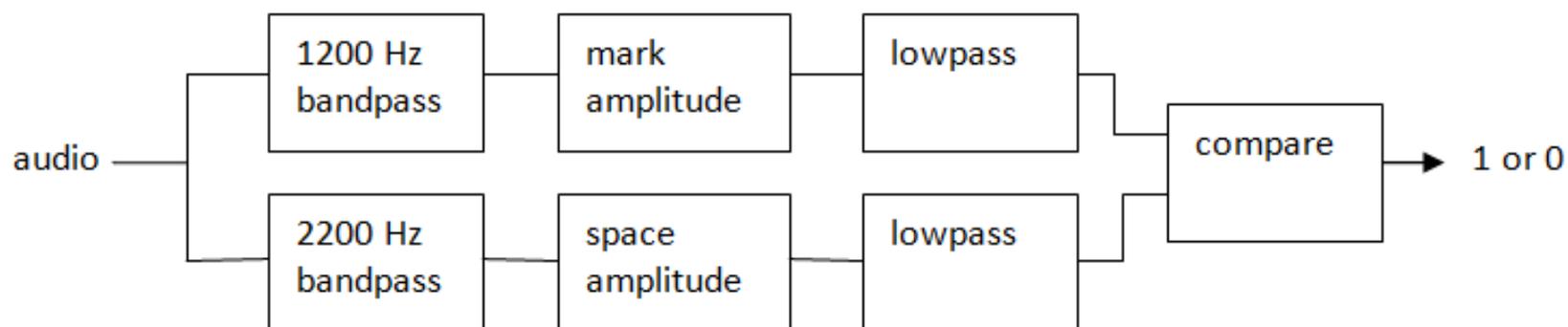
- Two logic levels represented by 1200 & 2200 Hz.



- Which of the two tones is present?



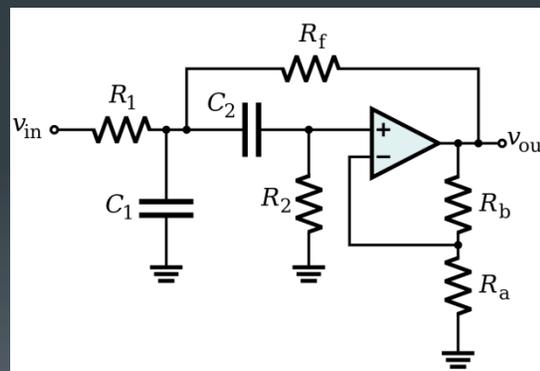
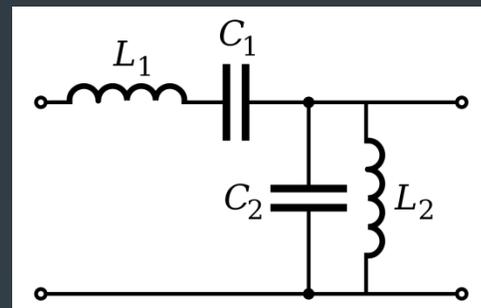
How to Demodulate AFSK





How to make audio filter?

- Inductors & capacitors.
- Active filters with op amps.
- How with software?
- No academic or professional background in Digital Signal Processing (DSP)





After much reading & experimenting

- OK with perfect signals.
- Not so good with real-world signals.



WA8LMF TNC Test CD

- Los Angeles, afternoon rush hour, frequency completely saturated.
- Downloadable file can be used to burn your own CD.
- Track 1: 25 minutes of flat audio from the discriminator.
- Track 2: De-emphasis to mimic typical receiver. (explained later)
- The de facto standard for measuring demodulator performance.



TNC Test CD Results

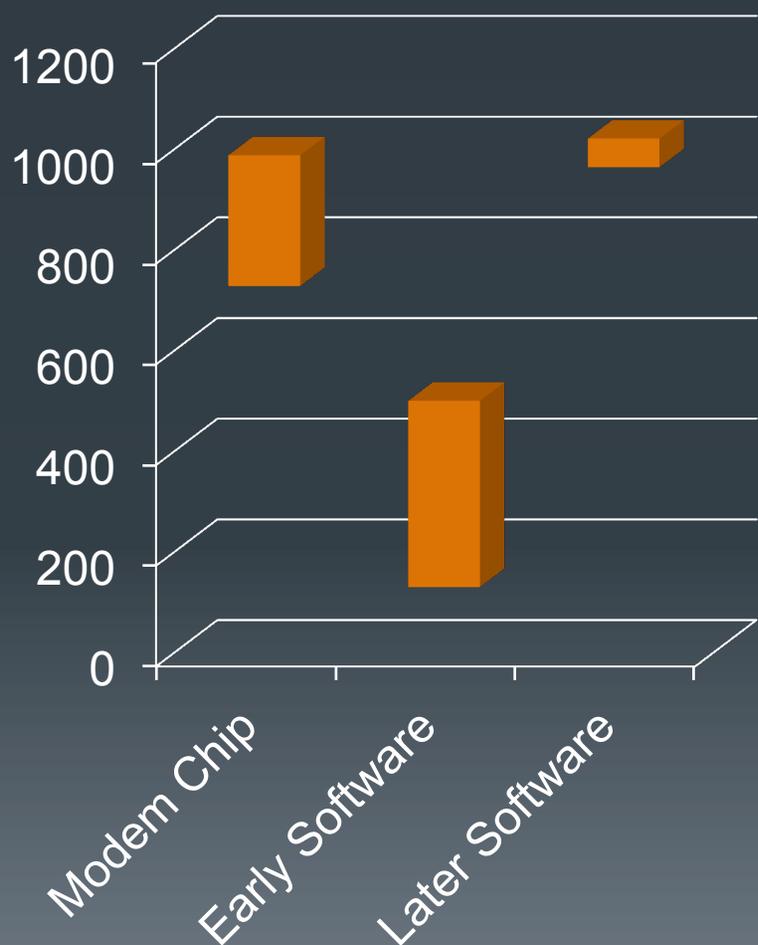
Do not take too seriously. Collected by different people, at different times, under different conditions. Most don't specify Track 1 / Track 2.

■ Linux PC multimon	*	130	
■ Linux PC soundmodem	*	412	
■ AGWPE	*	500	
■ AEA PK90		728	
■ TNC-X		818	
■ MFJ-1274		883	
■ AX25 Java Soundcard Modem	*	964	
■ KPC-3 (non-plus)		967, 986	
■ SCS Tracker DSP TNC 1.5s		988 / 943	(track 1/2)
■ Dire Wolf (fair test)	*	1011 / 1004	(track 1/2)
■ UZ7HO Soundmodem 0.83b	*	1021	
■ Dire Wolf (with cheating)	*	1028 / 1023	(track 1/2)

* = software on PC



TNC Decoding Comparison



- Poor results from early software modems.
- Bad reputation.
- More recent software better than hardware modems.
- The tarnished reputation endures.



Observations.

- TNC Test CD Track 2 had worse results than Track 1.
- For live local signals (same receiver), ratio of tone amplitudes varies. Similar or 2:1 ratio. Why?

```
K1NRO audio level = 39 (16/16)
```

```
[0]
```

```
K1NRO>APDW14,WIDE1-1:<IGATE,MSG_CNT=0,PKT_CNT=0,DIR_CNT=28,LOC_CNT=28,RF_CNT=118,UPL_CNT=134113,DNL_CNT=45179
```

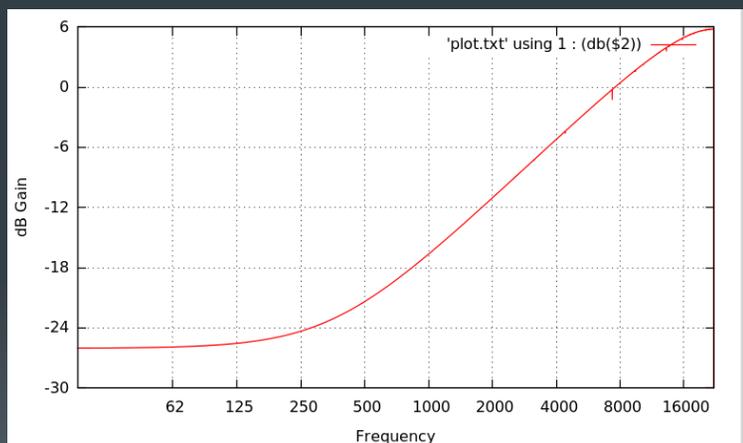
```
W1XM audio level = 57 (26/13)
```

```
[0] W1XM>APRX29:!4221.62NT07105.36W#PHG7570 MIT APRS  
iGate & Local Fill-in Cambridge, MA
```

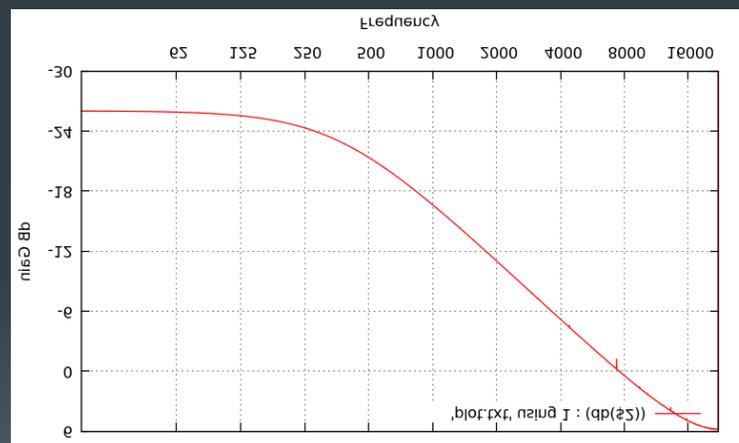


VHF FM voice transceivers.

**Transmitter pre-emphasis
boosts high frequencies
about 6 dB per octave.**



**Receiver de-emphasis
attenuates high
frequencies**

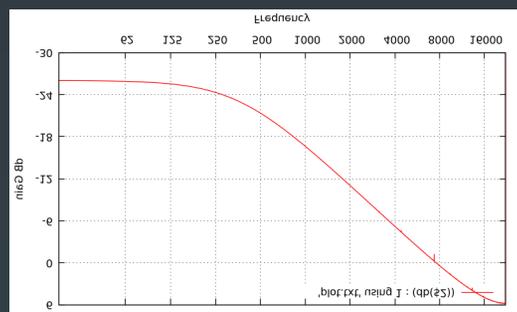


In theory, they should cancel out end to end.
IF (big if) everyone implemented the same response curves.

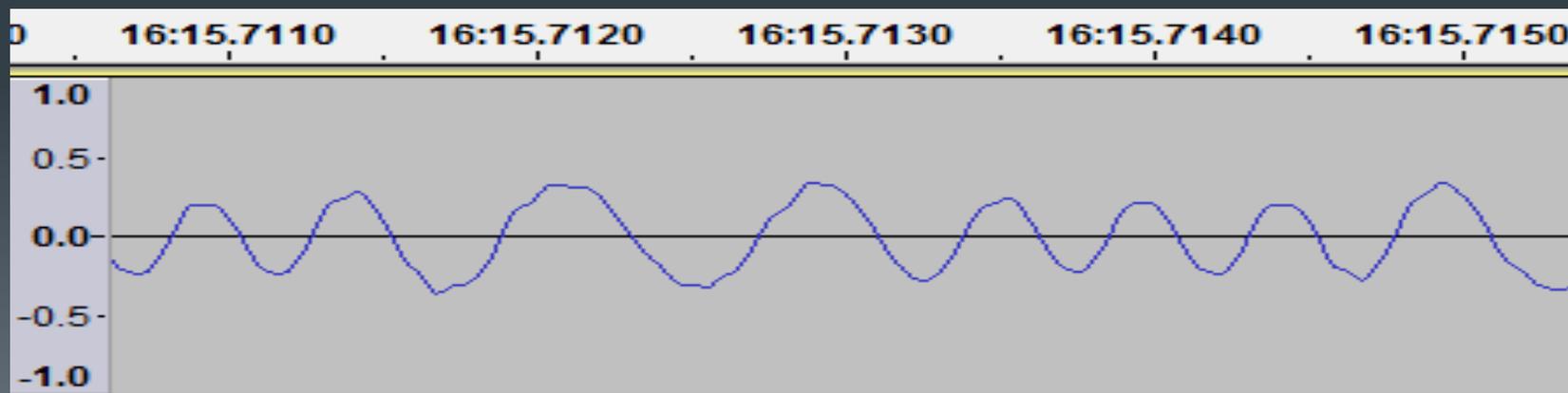


Transmit / Receive mismatch

Flat audio on transmit.

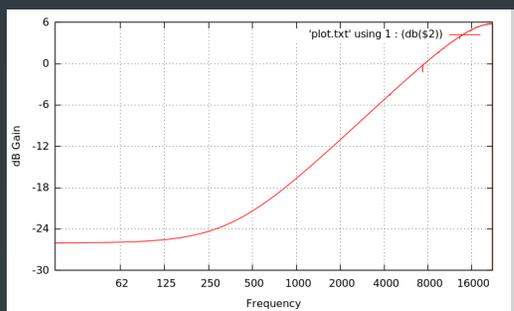


Higher frequency is much weaker than lower frequency.



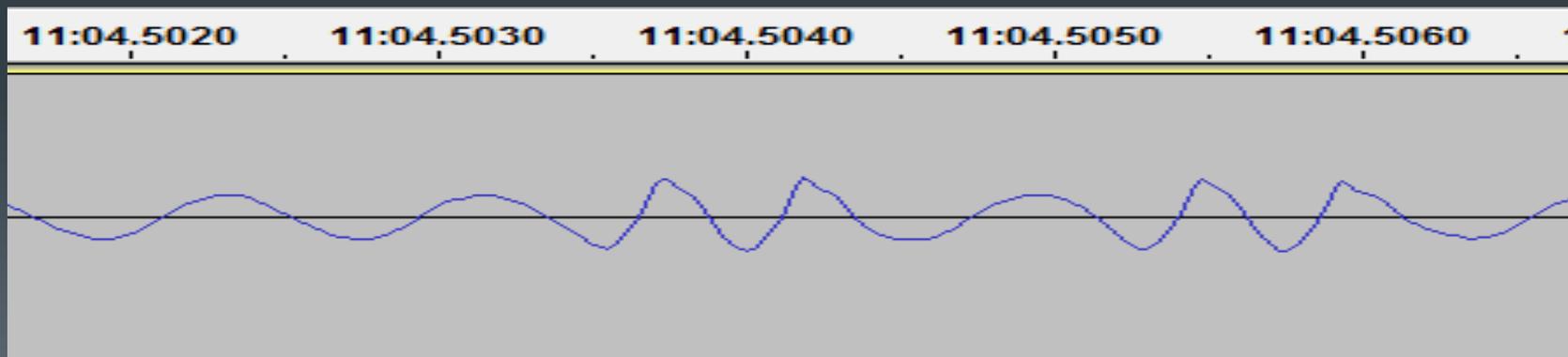


Transmit / Receive mismatch



Flat audio response for receiver.

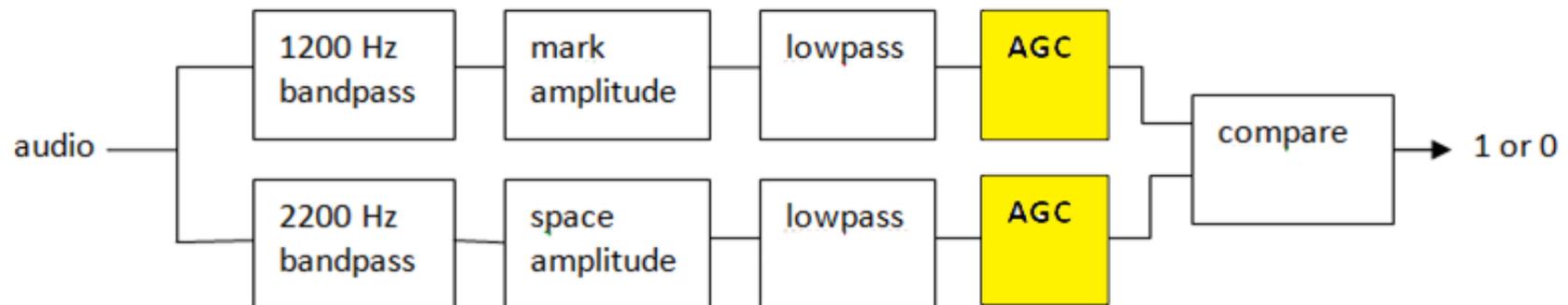
Higher frequency is stronger than lower frequency.





Transmit / Receive mismatch

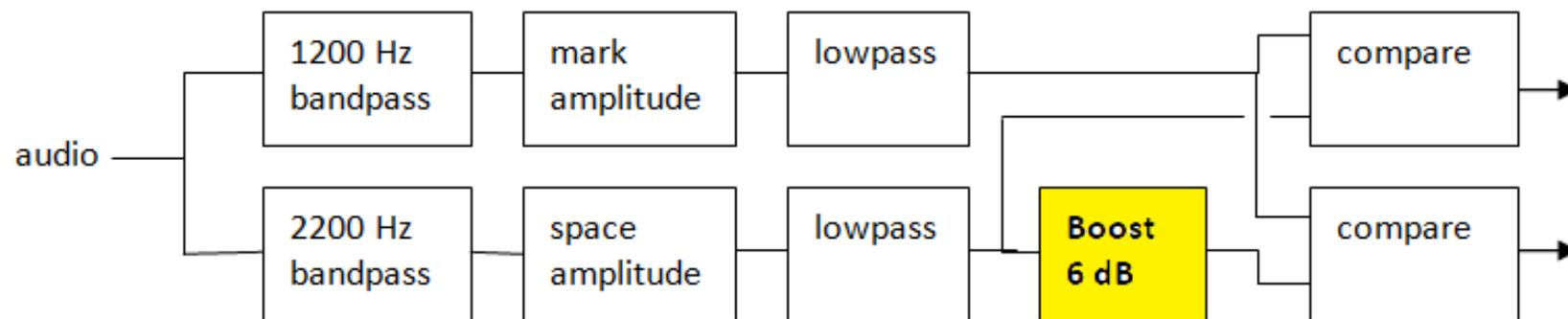
- Mismatched amplitudes – less reliable.
- Automatic gain control to normalize both amplitudes.
- Better results but...
- AGC takes time to adjust and can get thrown off by bursts of noise.





Boost Gain for Higher Tone.

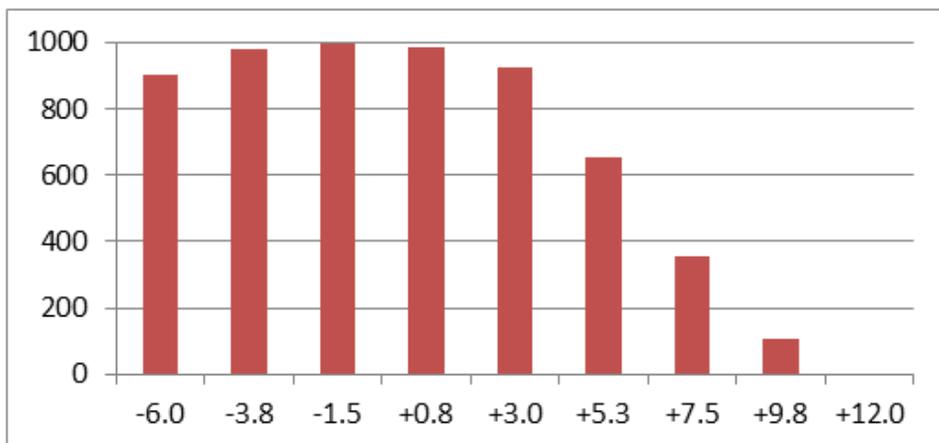
- Rather than AGC, try different fixed gains before the compare.



- The first works better with Track 1 (flat audio).
- The second works better with Track 2 (de-emphasis).

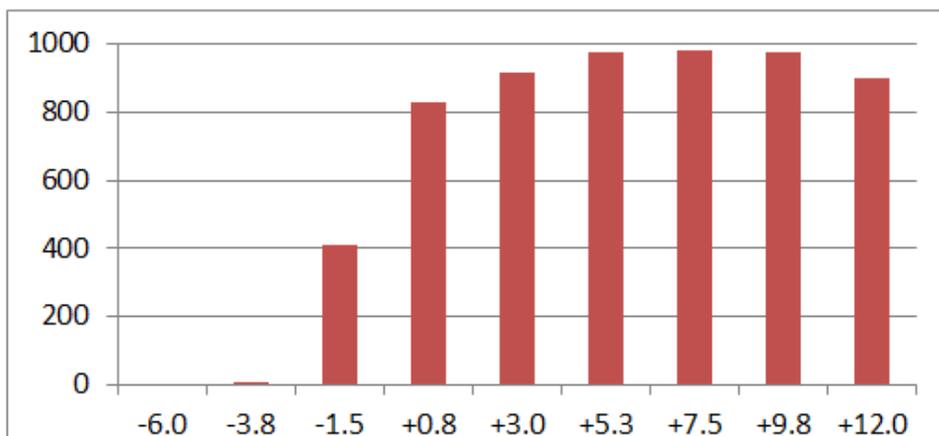


What is best gain?



Track 1 – flat audio.

Gain < 1 compensates for transmitters with pre-emphasis.



Track 2 – de-emphasis.

Gain around 2 (+6 dB) compensates for de-emphasis.



What is best gain?

- No one best value so we run 9 decoders in parallel & remove dupes.
- The | or _ character indicates success/failure for each of the 9.
- Track 1 does better with lower gains. e.g.

```
... Digipeater W6SCE-10 audio level = 50 (15/21)      |||||_
[0] K6SYV-10>ANP391,W6SCE-10*:!3444.00NS12000.40W#PHG7730/
Wn,SCAN/FIGUEROA Mt./A=003248<0x0d>
```

- Track 2 does better with higher gains. e.g.

```
... Digipeater W6SCE-10 audio level = 19 (2/1)      _|||||||
[0] K6SYV-10>ANP391,W6SCE-10*:!3444.00NS12000.40W#PHG7730/
Wn,SCAN/FIGUEROA Mt./A=003248<0x0d>
```



One Bad Apple Don't Spoil the Whole Bunch

- There is an old proverb, “*One bad apple spoils the barrel,*” which applies to AX.25 frames used for APRS and traditional packet radio.
- One bad bit → FCS wrong → discard frame.

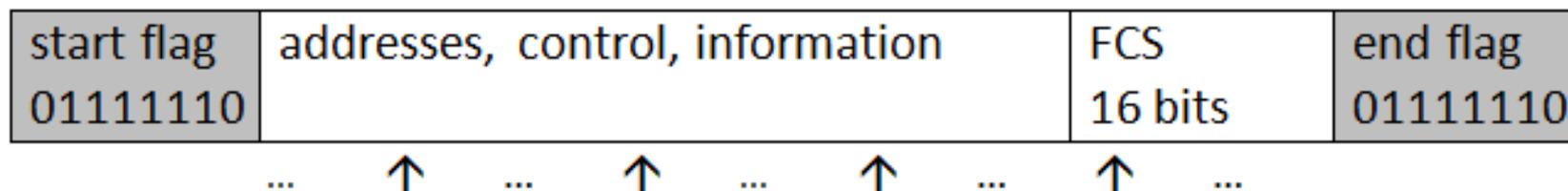
start flag	addresses, control, information	FCS	end flag
01111110		16 bits	01111110

↑ One corrupted bit causes FCS not to match



One Bad Apple Don't Spoil the Whole Bunch

- The Osmond Brothers offered the advice,
“Give it one more try before you give up...”
- That can also apply to AX.25 frames.



- Invert each of the bits – one at a time! – and recalculate the FCS.



Oops!

- False positives on the FCS check
& end up with bogus data.



Sanity check heuristic

A good AX.25 frame will have:

- An address part that is a multiple of 7 bytes.
- Between 2 and 10 addresses.
- Only upper case letters, digits, and space in the addresses.
- For APRS, certain values in the frame control and protocol octets.
- For APRS, the information part has only printable ASCII characters or:
 - 0x0a line feed
 - 0x0d carriage return
 - 0x1c used by MIC-E
 - etc. other non-printable characters used with APRS.



A new high score with cheating.

Not error “correction.” Not using redundant information, from the sender, to reconstruct the clobbered bit.

Try flipping each bit, one at a time, until we have a valid FCS (CRC) and the sanity check passes.

New high score:

Track 1: 1028

Track 2: 1023

Cheating - Would be deceptive to use it in a side by side comparison with other TNCs without making note of this feature.



The forgotten part of APRS.

APRStt



Few hams have

Almost everyone has



Portable radio with built in TNC.

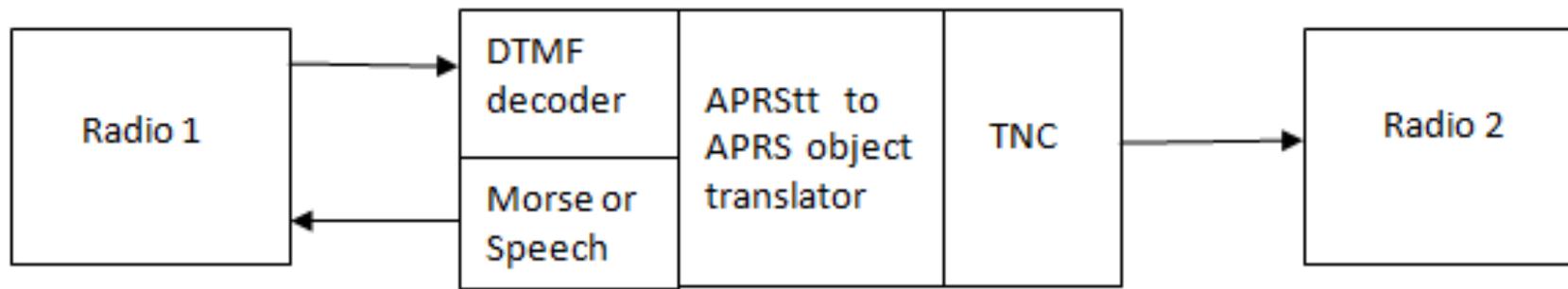


Portable radio with DTMF ("Touch Tone") pad.



APRStt

APRStt allows a user, equipped with only DTMF (commonly known as Touch Tone) generation capability, to enter information into the global APRS data network.





Touch Tone Sequences

```
field1 #  
field1 * field2 #  
field1 * field2 * field3 #
```

* field separator.

terminator.



Touch Tone Sequences

First tone of each field:

- **A** = callsign or object characteristics
- **B** = location data
- **C** = comment text or status
- **D** = message text – not defined anywhere, not implemented

Dire Wolf extension:

- **0 - 9** = compact all numeric form



Tedious & error prone!

Example from bicycle race.

```
C8 * B978 * AB166 * AA2B4C5B3B0A123 #
```

C8 = predefined “emergency” comment

B978 = standard form for one of 100 defined locations.

AB166 = primary symbol table, bicycle.

AA... = object name “BIKE 123”

This is why APRStt never became popular.



How could we shorten this?

Define compact, event specific, all numeric formats.

b nn #

5 digit numeric sequence:

b is 1 of 10 locations.

nn is the 2 digit object number.

e.g. 5 12 # Checkpoint 5, canoe 12 arrived.



Example for SAR event

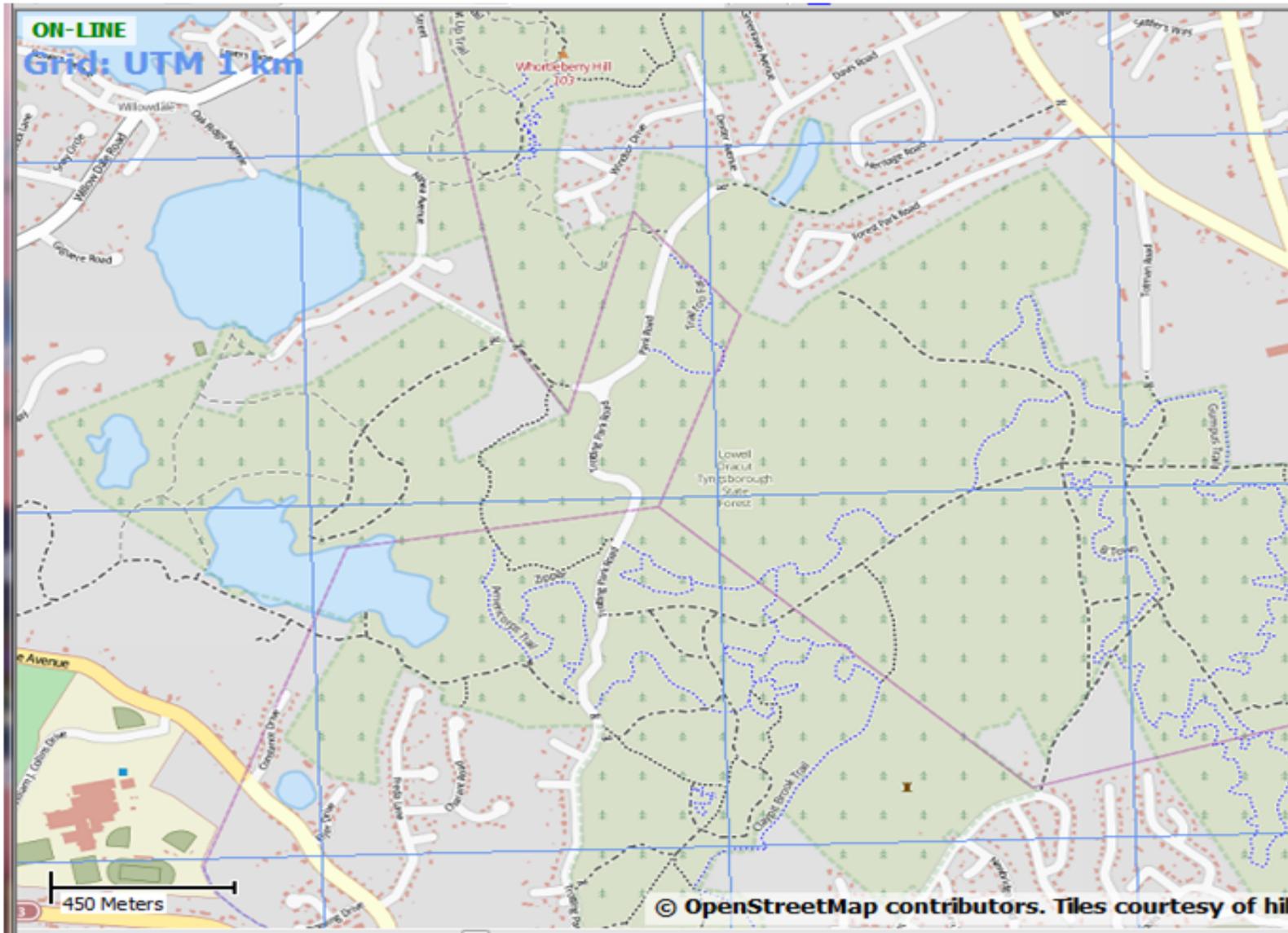
- Incident command wants to see search party locations on map.
- APRS trackers not available.

Solution:

Custom tone sequences for this event.

- 1 digit for team number.
- 6 digits for x, y coordinates.

Location Coordinates



4727000

4726000

4725000

East →

305000

306000

307000

↑
North



Location Coordinates

The area of interest covered by UTM coordinates of this form:

19T 30xxx0 472yyy0

Send only the xxx and yyy digits to keep messages shorter.



Object and message formats

Single digits were assigned to the search teams:

1 = Team A

2 = Team B

3 = Team C

Send position with 7 digits:

team-number location-easting location-northing

3

571

531



Search Team Position Report

Team C (represented by 3) at location 19T 305710 4725310

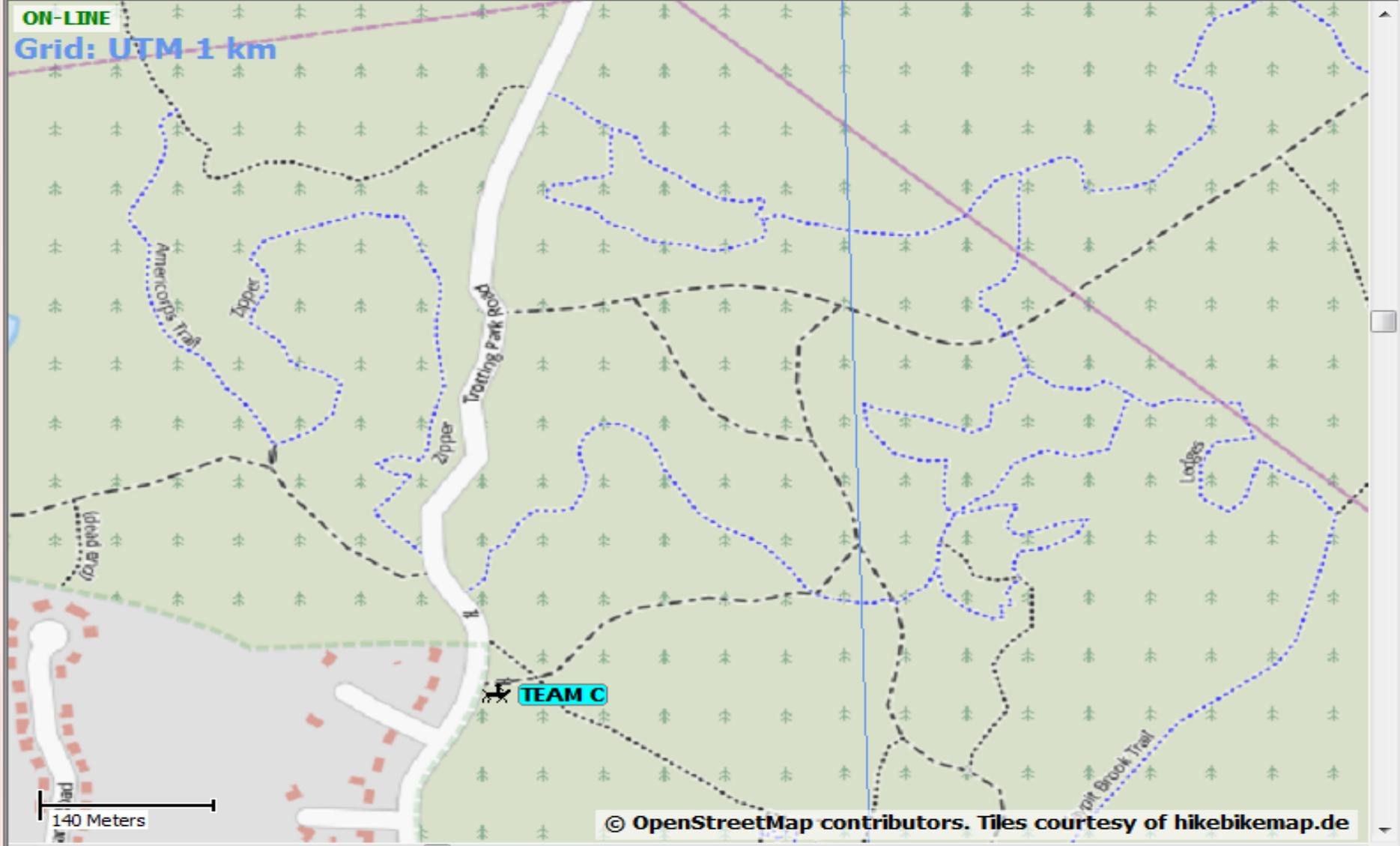
3 571 531 #

APRStt gateway responds, by voice:

“Team Charlie 5 7 1 east 5 3 1 north.”

APRStt gateway constructs an APRS “Object Report.”

Team C appears on the map.





Subject Found!

Team “A” wants to use different voice frequency:

1 digit for status

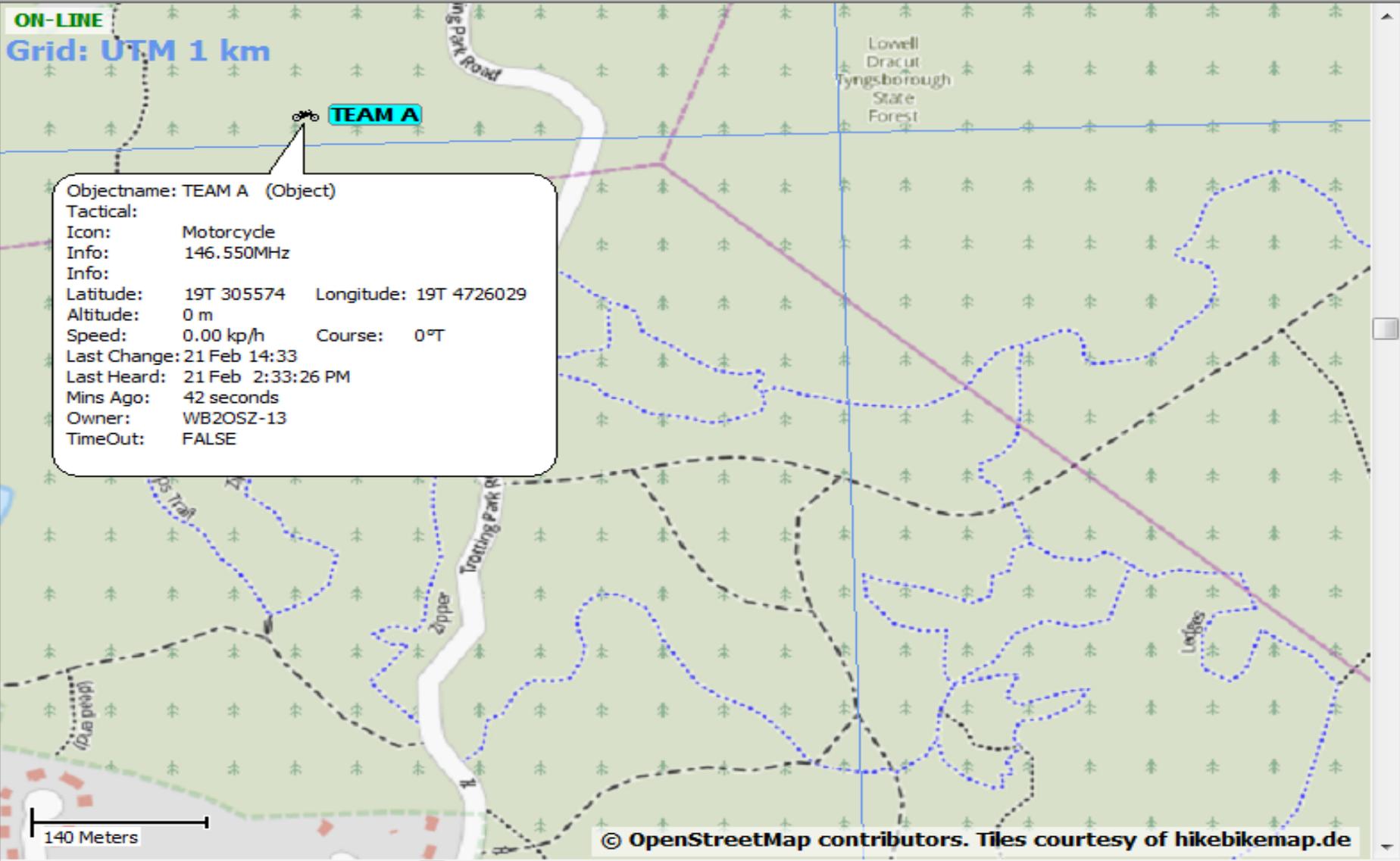
7 digits for team, location

C999999 for frequency

6 * 1 558 603 * C146550 #

Voice response:

“Team Alpha 5 5 8 east 6 0 3 north. Subject found.”





Object information in table format.

Object Information

No Sort Filter

Broadcast Interval: 15 **Broadcasting 0 Objects** BroadCast Now 2 Objects

Name	Tactical Name	Status	Easting	Northing	Last Change	Owner	Information
TEAM A		Active	19T 305574	19T 4726029	21 Feb 14:33	WB2OSZ-13	146.550MHz
TEAM C		Active	19T 305446	19T 4725828	21 Feb 11:50	WB2OSZ-13	

Edit
 Hide
 Delete
 Delete All
 Import GPX



APRStt - Try it. You'll like it.

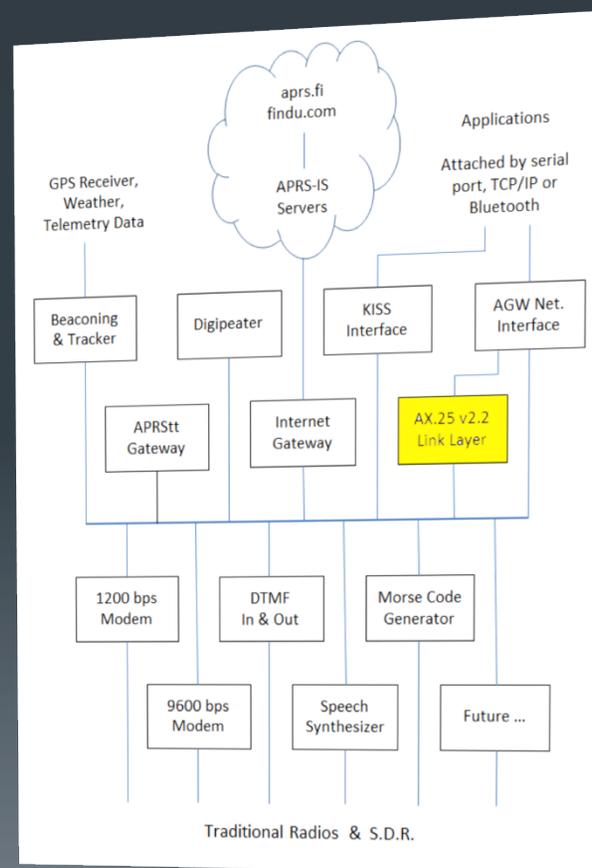
- Useful concept has a lot of untapped potential.
- Original form too difficult to use.
- Short, all numeric, event-specific forms make it easy.
- Used successfully at a couple events -- Needs more publicity.
- Try it.



AX.25 Link Layer v2.2



- Connected mode processing for applications such as Outpost PM.
- Based on AX.25 v2.2 standard (1998).
- New features not in v2.0 from 1984.
 - Negotiate Information size > 256 bytes.
 - Larger window size.
 - “Selective reject.”





Window Size: Number of info frames sent before waiting for an acknowledgement = 1

Ham A types:	TNC A sends:	TNC B sends:	Ham B sees:
The	0: The →		
Quick		← Ready for 1	The
Brown	1: Quick →		
Fox		← Ready for 2	Quick
Jumps	2: Brown →		
		← Ready for 3	Brown
	3: Fox →		
		← Ready for 4	Fox
	4: Jumps →		
		← Ready for 5	Jumps



Window Size = 3

More efficient

Ham A types:

TNC A sends:

TNC B sends:

Ham B sees:

The

0: The →

Quick

1: Quick →

Brown

2: Brown →

Fox

← Ready for 3

Jumps

3: Fox →

Over

4: Jumps →

5: Over →

← Ready for 6

The

Quick

Brown

Fox

Jumps

Over



Window Size Maximums

	AX.25 v2.0	AX.25 v2.2
Bits for Sequence Number	3	7
Default Window Size	4	32
Maximum Window Size	7	63

Larger Window Size is more efficient for large transfers.

More Information frames can be sent before waiting for a reply.

Less overhead of switching back and forth between transmit and receive. (Especially true for high speed where T/R switching time can be many times longer than the data.)



Resending Lost Frames - v2.0

Ham A types:

The
Quick
Brown
Fox
Jumps

TNC A sends:

0: The →
~~1: Quick →~~
2: Brown →
3: Fox →
4: Jumps →

TNC B sends:

← Ready for 1

1: Quick →
2: Brown →
3: Fox →
4: Jumps →

← Ready for 5

Ham B sees:

The

Quick
Brown
Fox
Jumps



v2.2 “Selective Reject” - Resend only what is necessary.

Ham A types:	TNC A sends:	TNC B sends:	Ham B sees:
The	0: The →		
Quick	1: Quick →		The
Brown	2: Brown →		
Fox	3: Fox →		
Jumps	4: Jumps →		
Over		← Resend 1 & 3	
	1: Quick →		Quick
	3: Fox →		Brown
	5: Over →		Fox
		← Ready for 6	Jumps
			Over



Interoperability

v2.2 TNC
(1998)

v2.0 TNC
(1984)

Connect request v2.2
(SABME) →

← I don't understand the
command.
(FRMR)

Connect request v2.0
(SABM) →

← Connection accepted.
(UA)



Questions?

For more information:

<https://github.com/wb2osz/direwolf>

https://groups.yahoo.com/neo/groups/direwolf_packet/info

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