Virginia Tech Ground Station TNC Interfacing Tutorial

Zach Leffke, MSEE (zleffke@vt.edu)

Research Associate

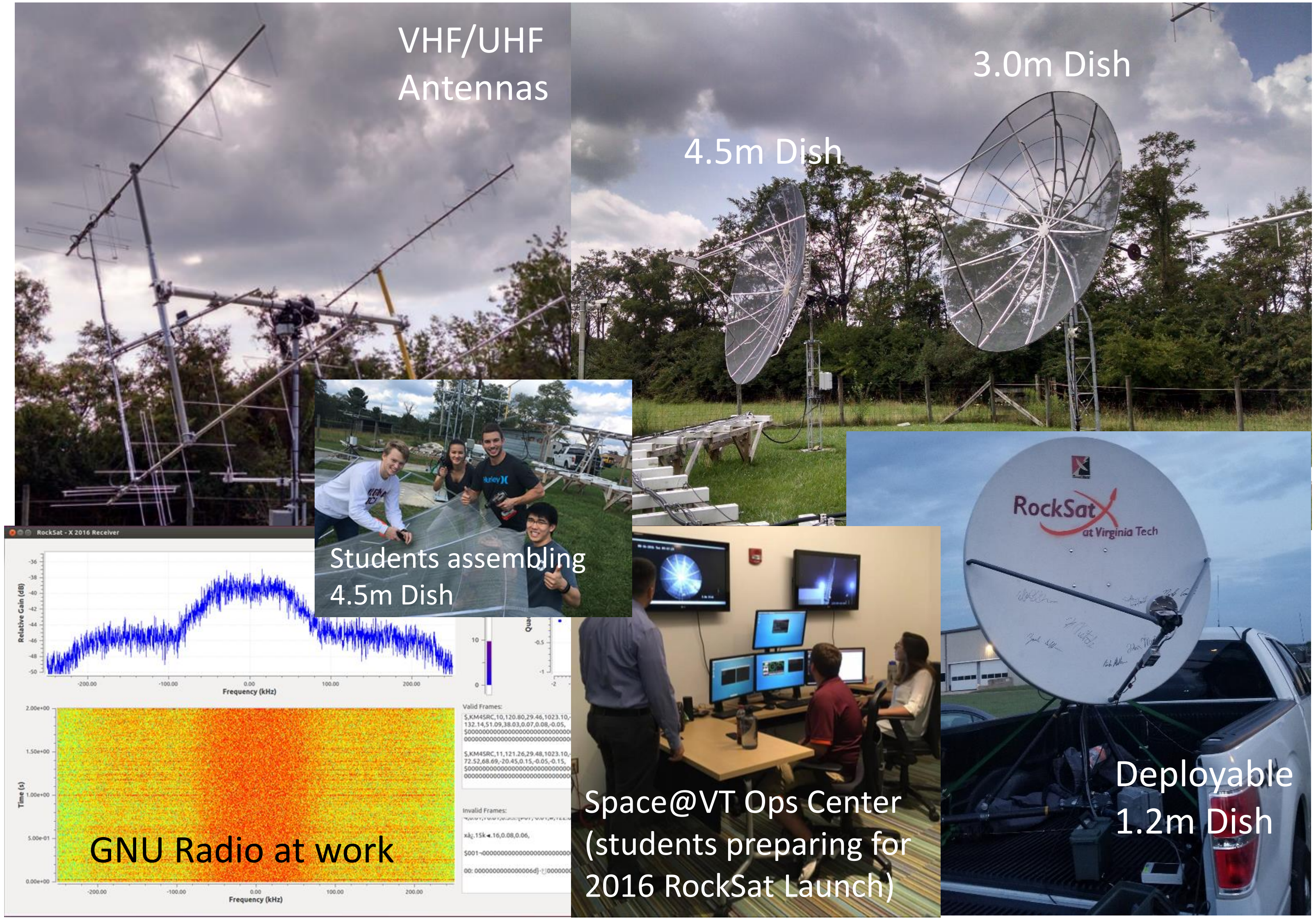
Aerospace Systems Lab

Ted & Karyn Hume Center for National Security and Technology

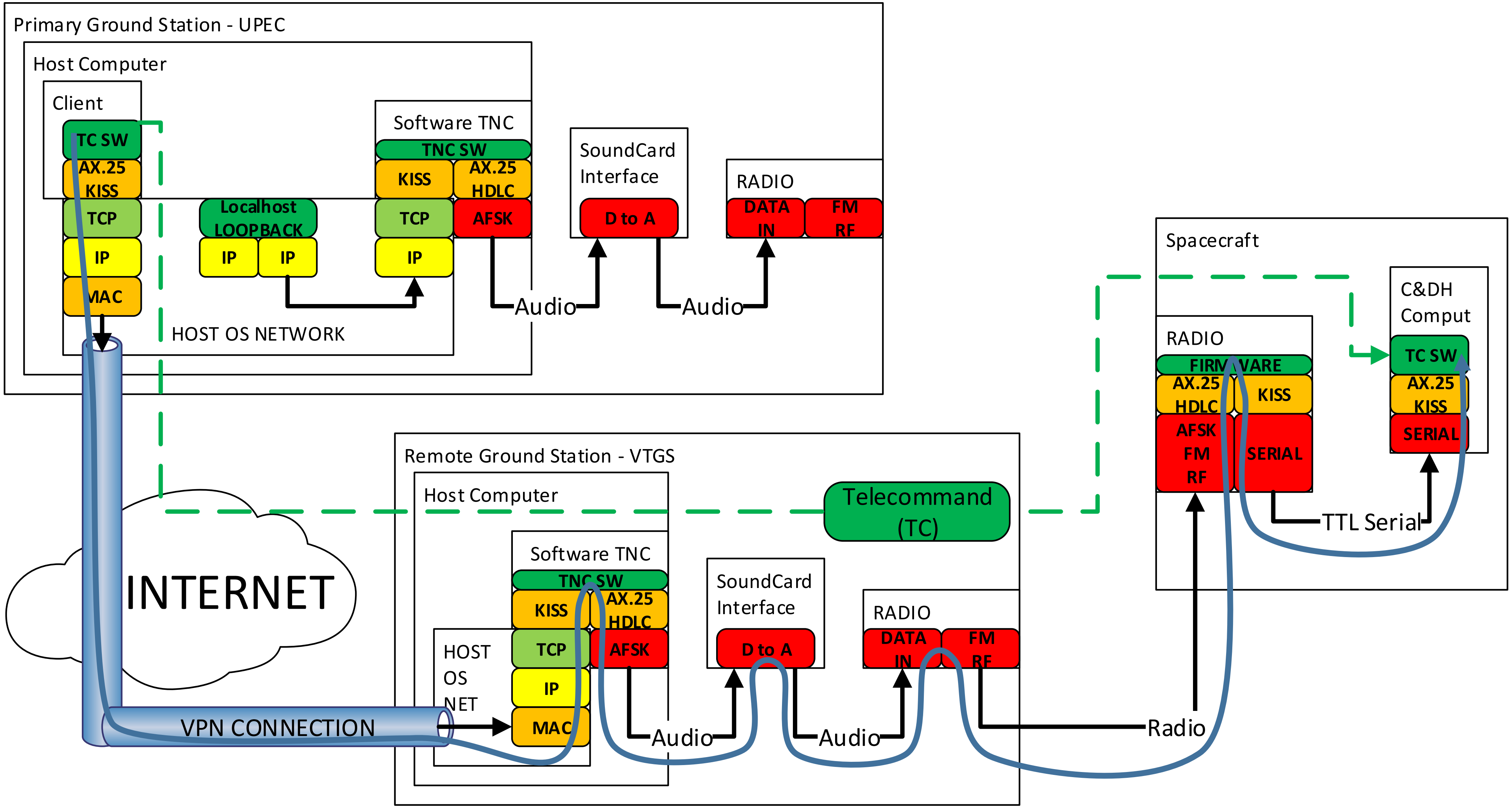
3/23/2018

Agenda

- TNC Connection Overview
- KISS Protocol
- AX.25/HDLC Protocol
- AFSK/FSK/GMSK Modulation
- ….System Review….
- OSI Stack
- Remote Connection
- VTGS Remote Interface
- Summary



Preview of the Finale…………..



TNC Connection Overview

TNC Implementation Types

Hardware Radio DATA Jack

Specific Interface Examples

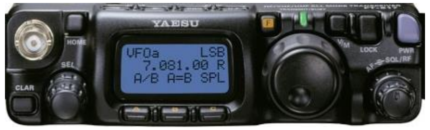
TNC Implementation Summary

- Multiple implementation options exist
  - Hardware TNC Ground Station
  - Software TNC + Sound Card
  - Software Defined Radio Receiver
  - Software Defined Radio Transceiver
- Hybrid SDR RX / HW Radio TX implementations

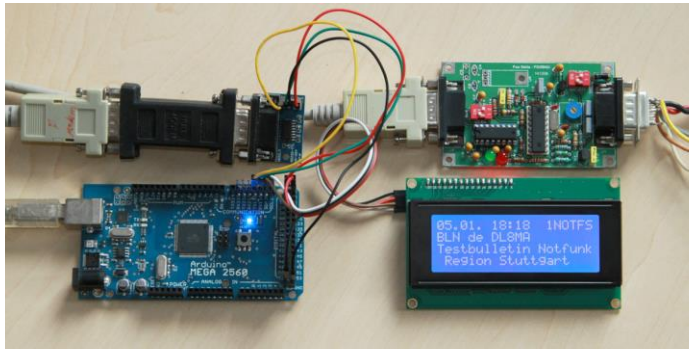


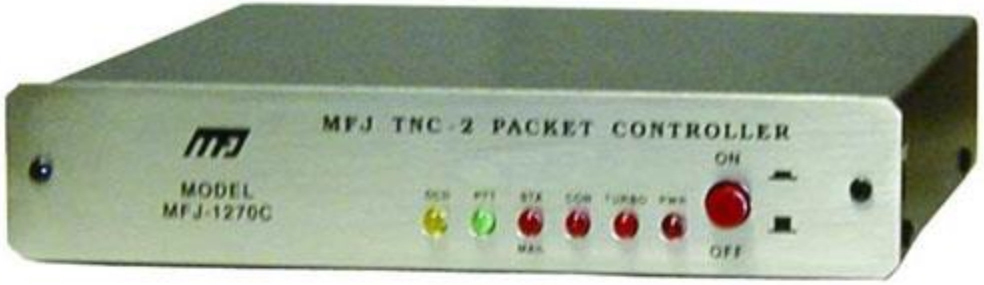


Hardware Radios – Common for Satellite



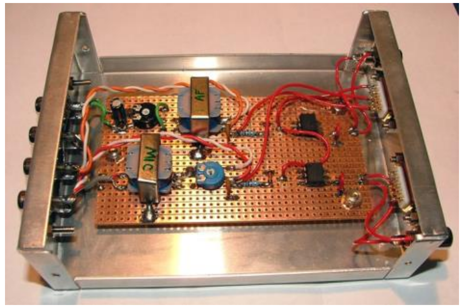
Hardware TNCs





Radio Sound Card Interfaces

- Good ones offer optical isolation (optocouplers).
- Appear as a soundcard to host computer OS.
- HW control of TX/RX volume.
- Also used for ***non-packet modes***. Make sure one with the proper capabilities is selected.
- Different ***non-sound related*** options available (such as PTT control, and CW keying). Again, make sure one with the proper features is selected.



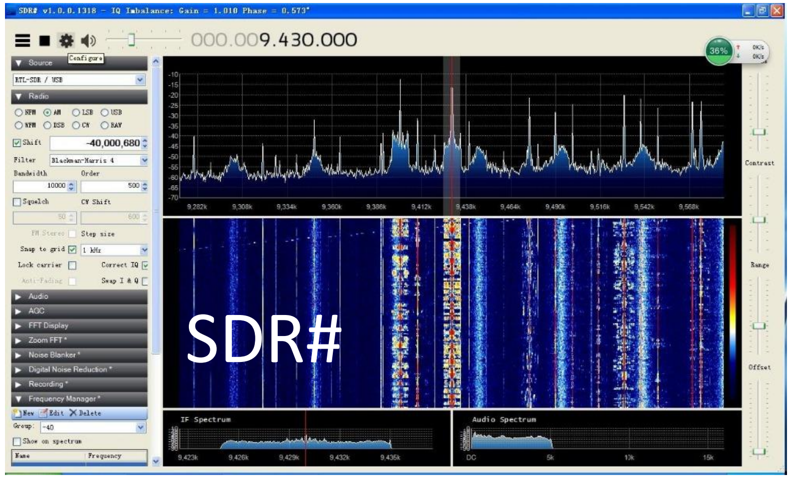
Software Defined Radios

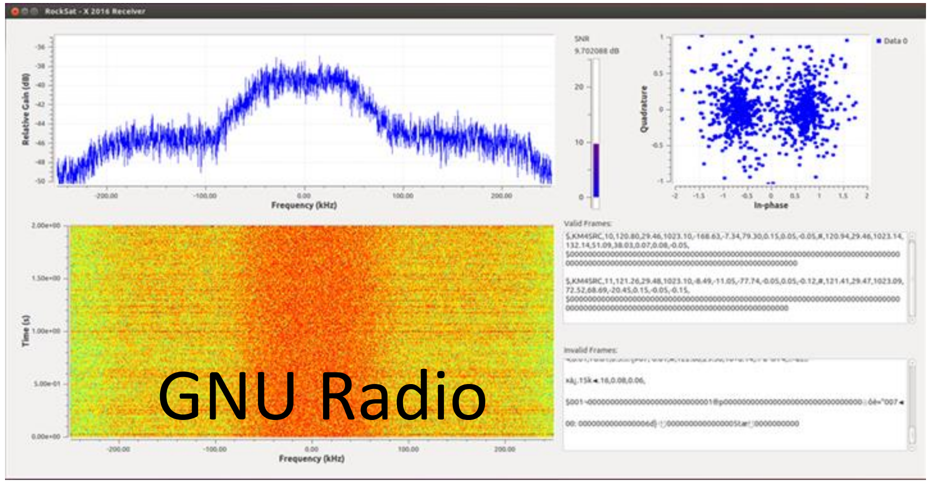
Receive Only

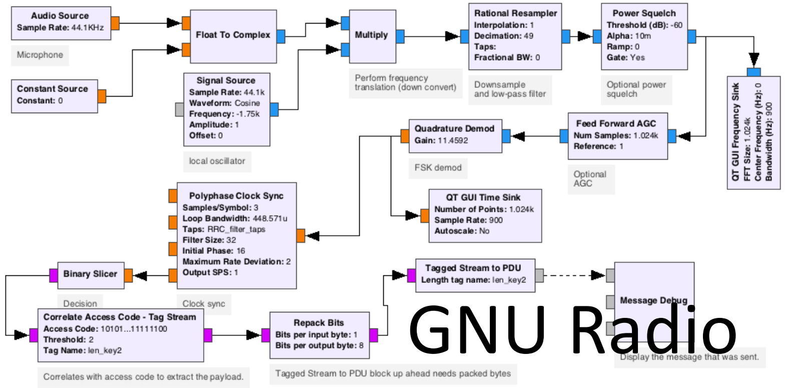
Transceivers (TX & RX)

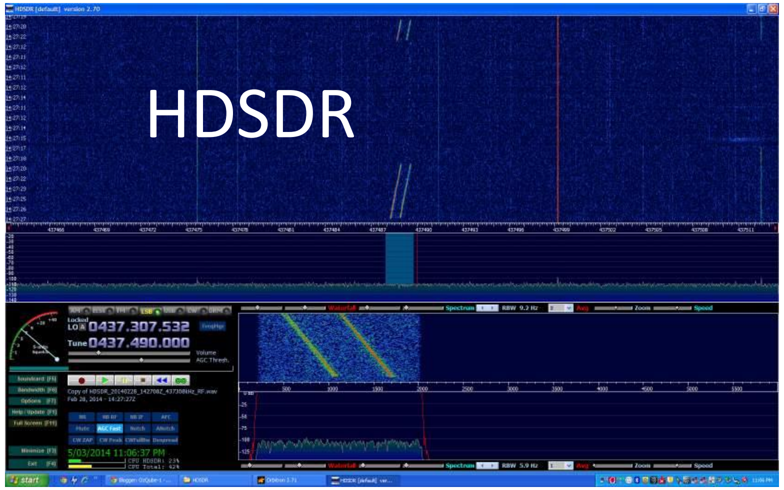
See for more: https://www.rtl-sdr.com/roundup-software-defined-radios/

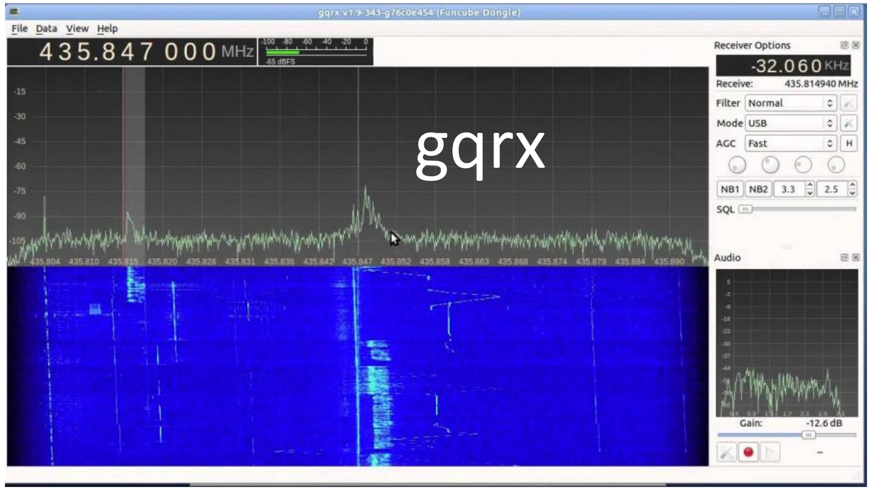
The 'S' in SDR?...here are a few...

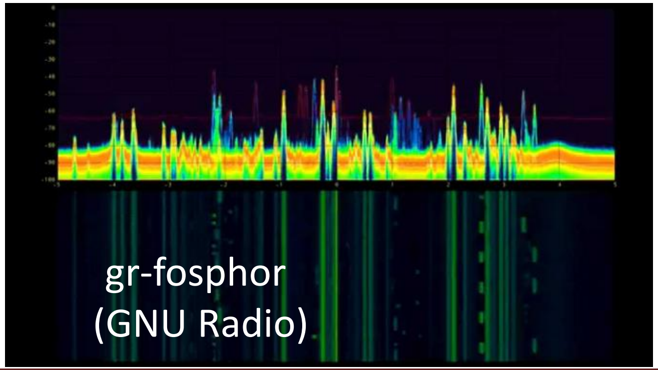












Putting it all together

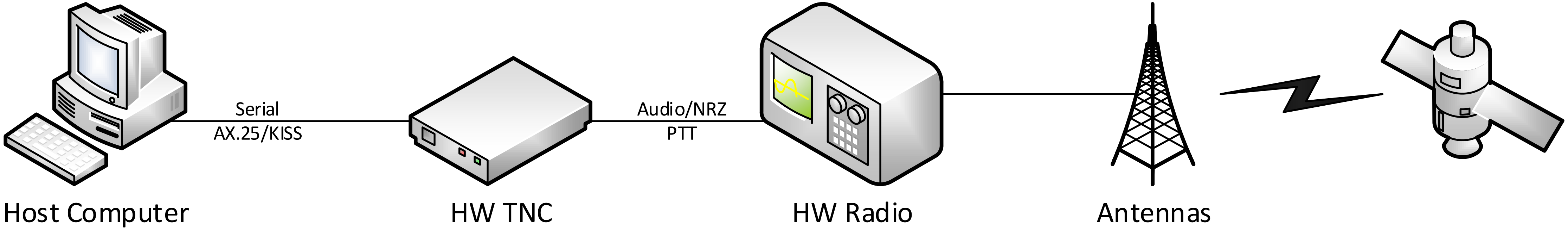
LOTS of options exist……..

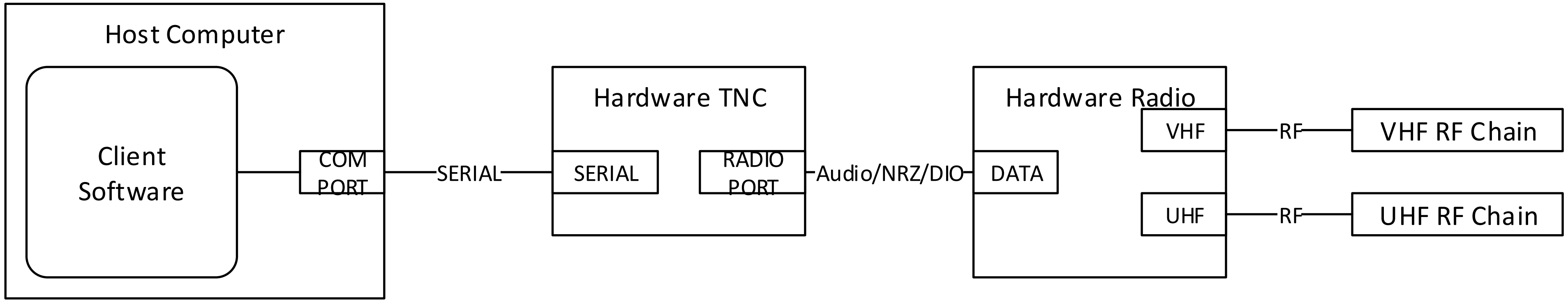
….and combinations of options…

….how to decide?!?!?!…..

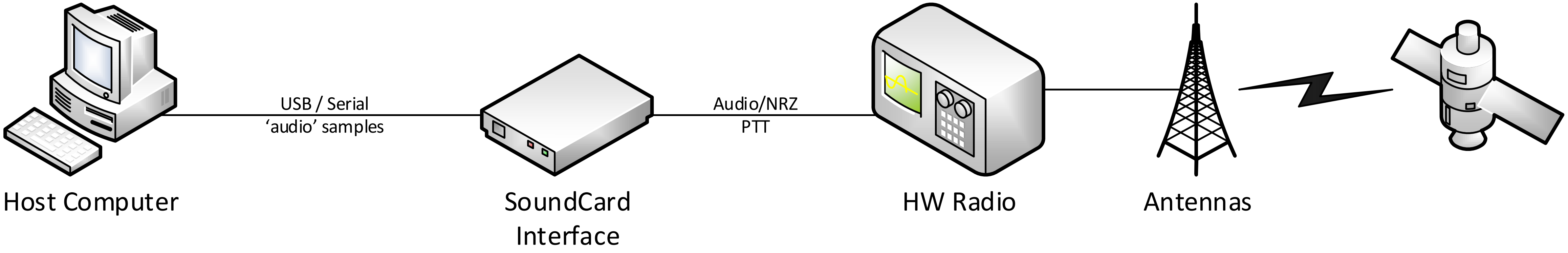
….Lets go over some fundamentals……..

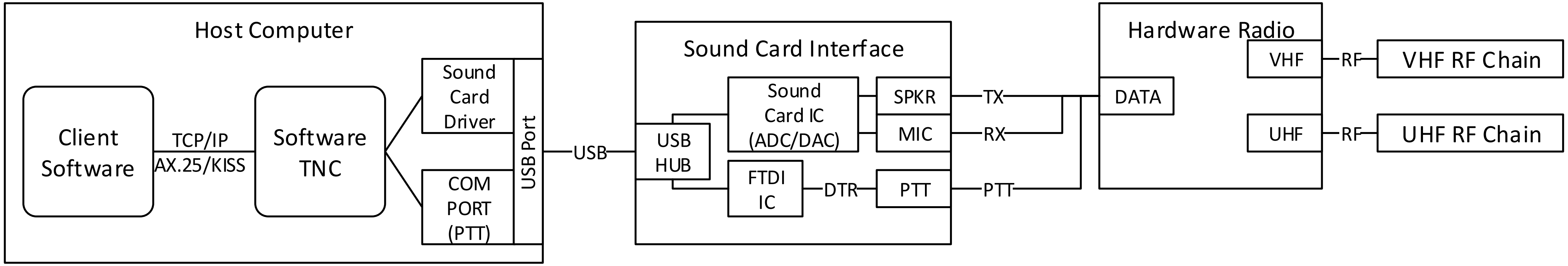
Hardware TNC Ground Station



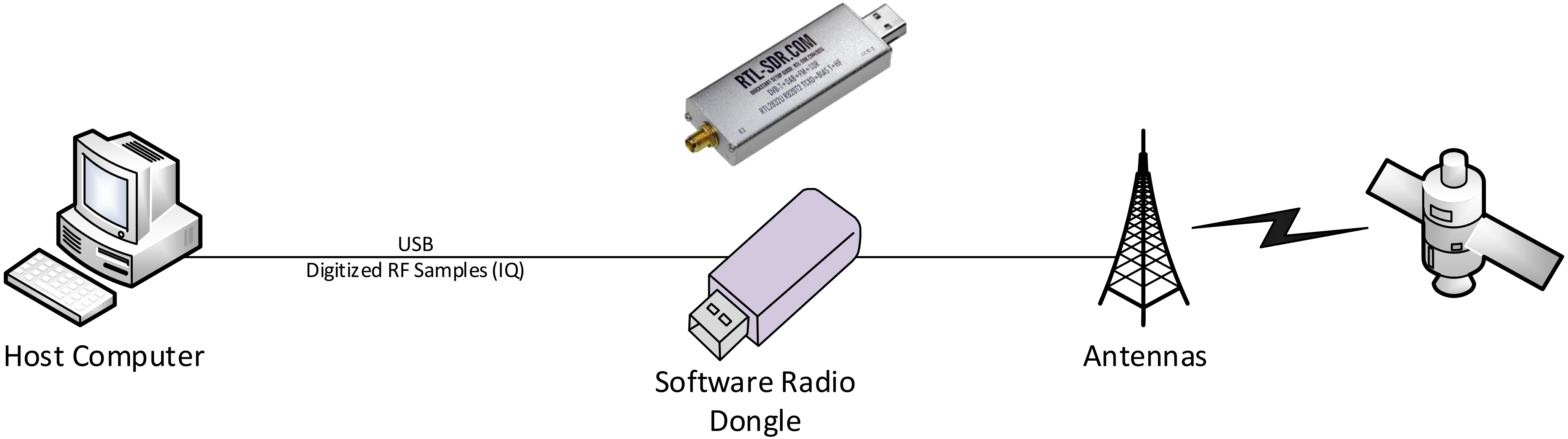


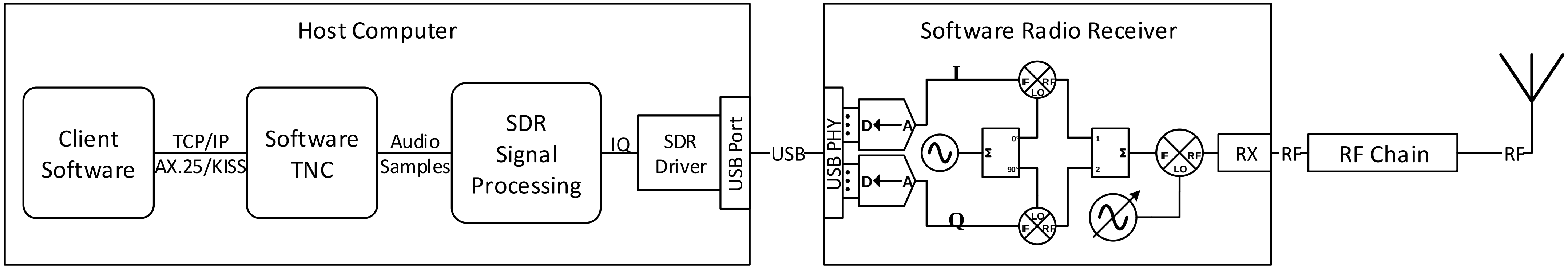
Software TNC + Sound Card Ground Station



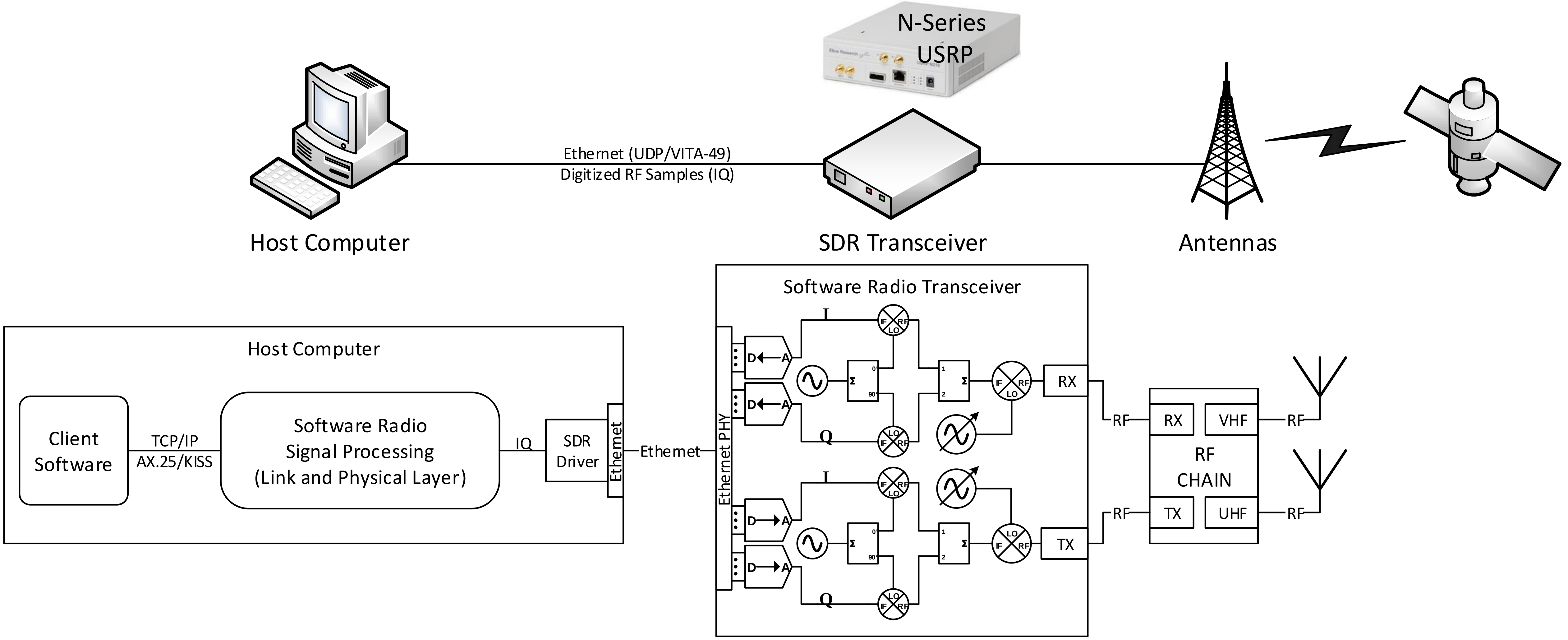


Software Defined Radio Receiver





Software Defined Radio Transceiver



NOTE: This is basically the chosen VTGS architecture

TNC Connection Overview

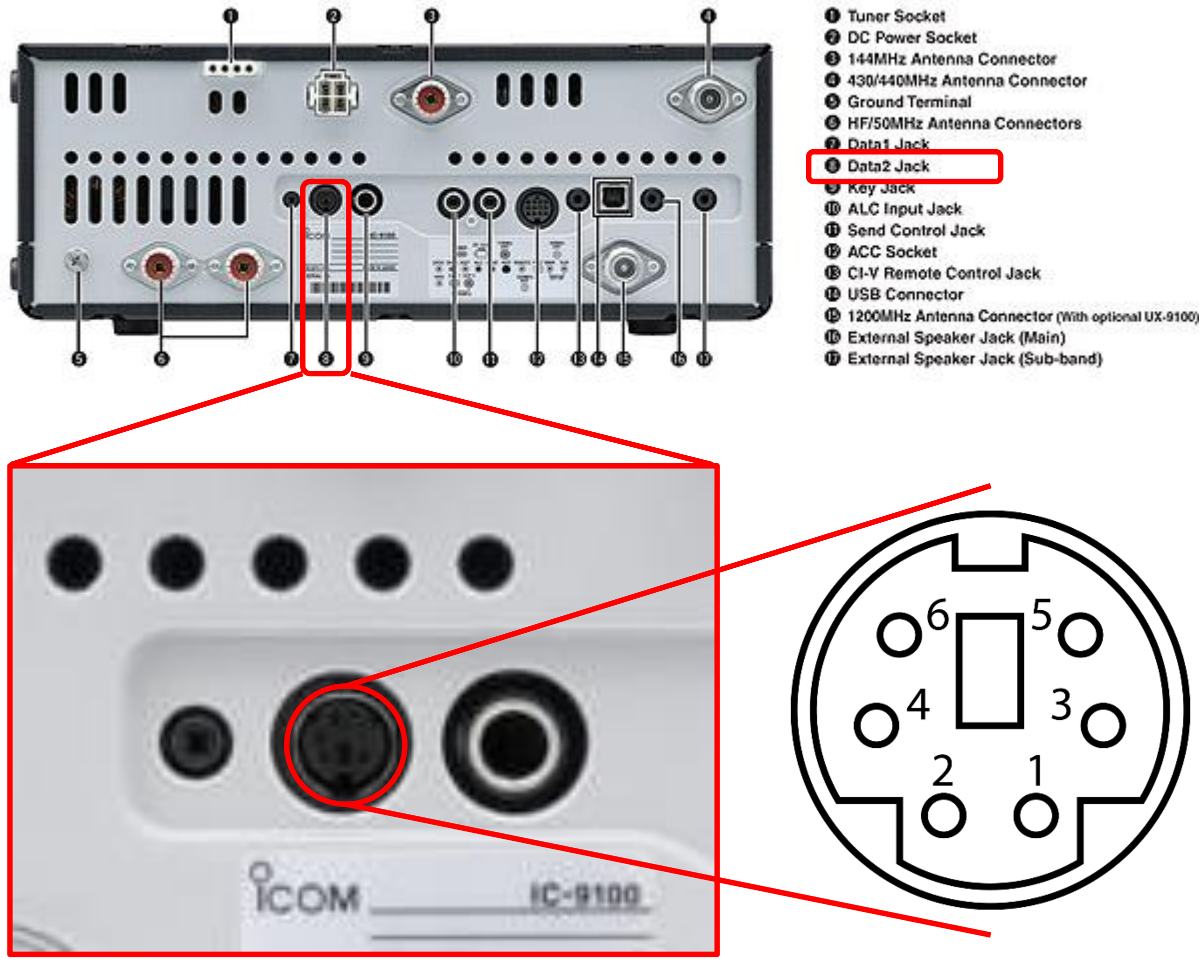
TNC Implementation Types

Hardware Radio DATA Jack

Specific Interface Examples

Hardware Radio DATA Jack

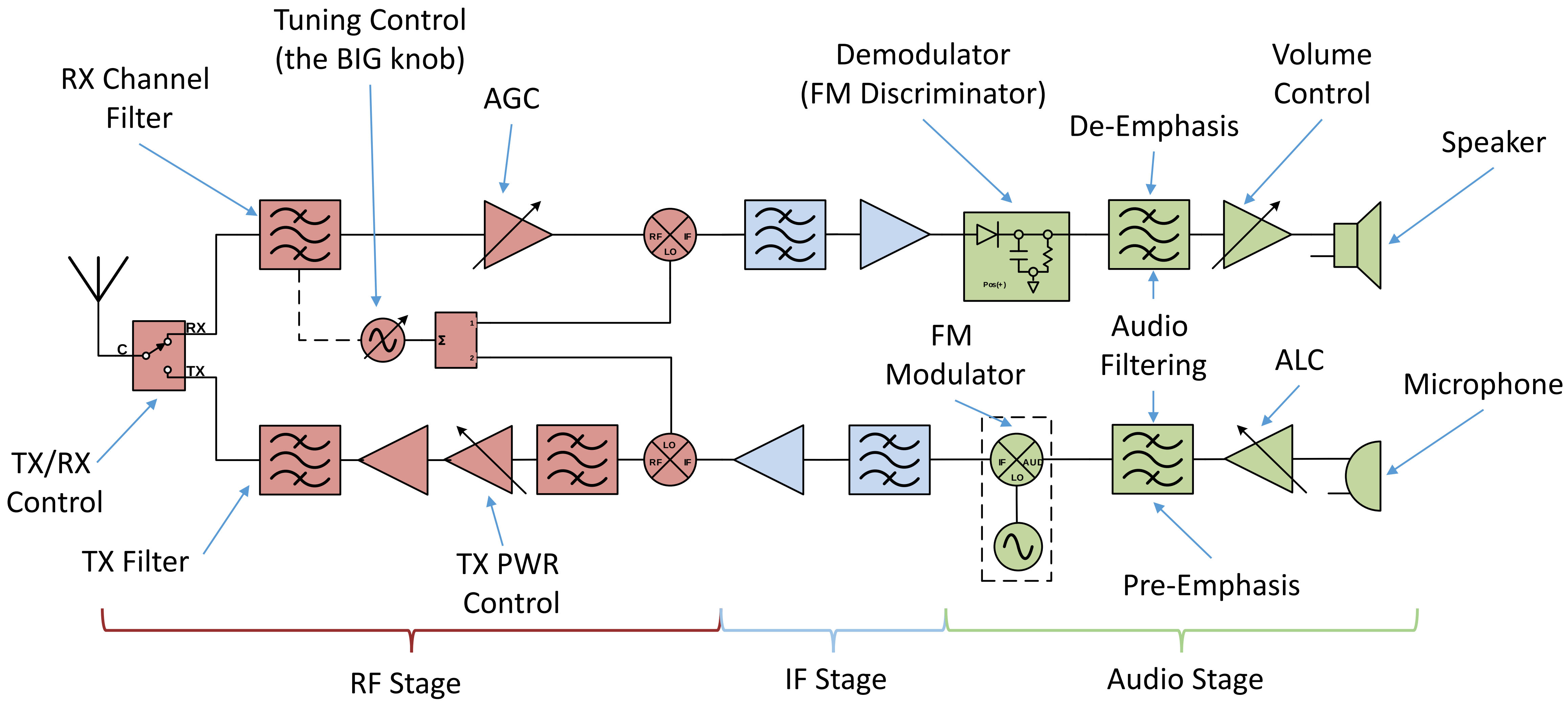
ICOM-9100 Example



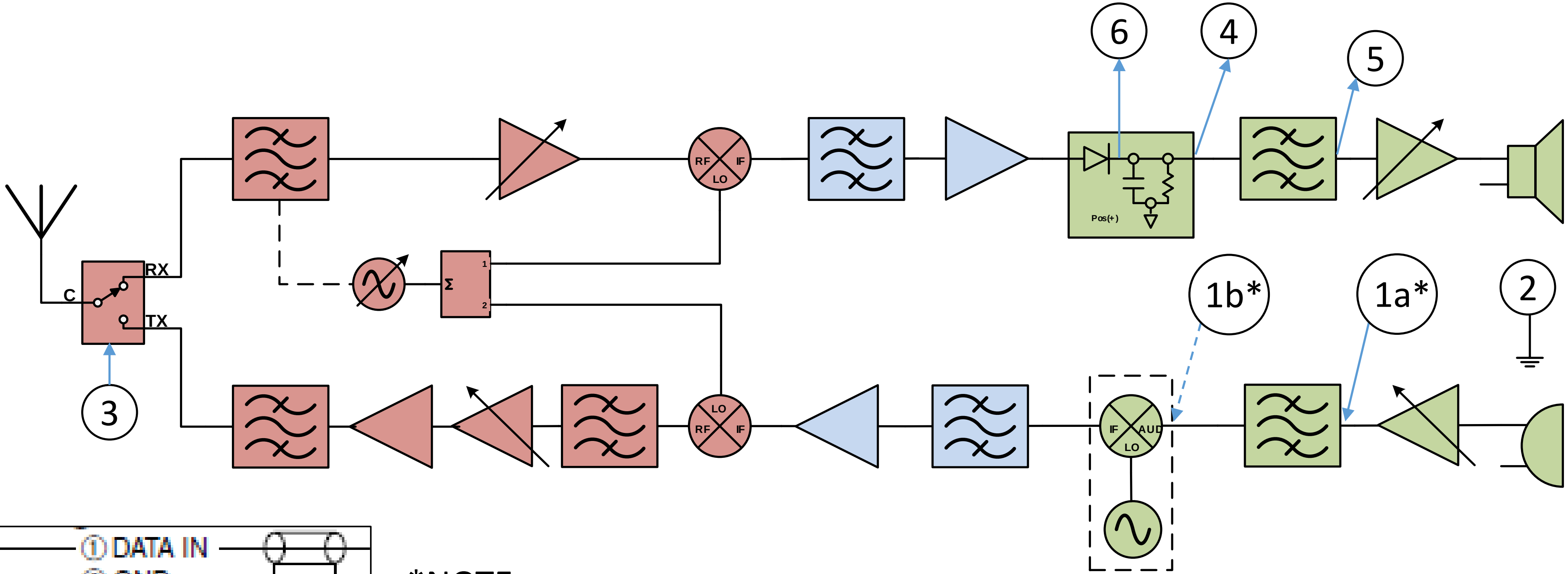
What is it for?

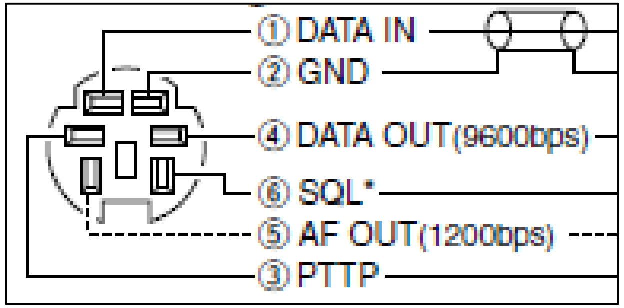
- Used for packet operations.
- Bypasses audio filtering (which can distort digital communications).
- Standardized PS-2 Connector and pinouts across vendors.
- High speed (9600 baud) and low speed (1200 baud) packet access.
- Connects to ‘Radio Port’ on TNC.

FM Transceiver (simplified)



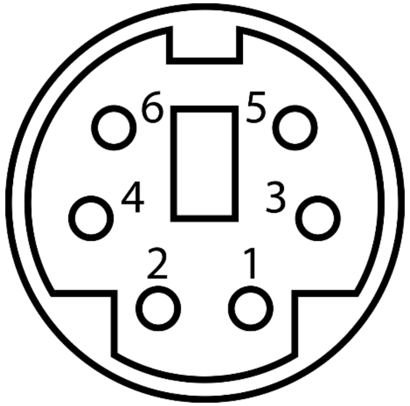
FM Transceiver – DATA Jack Tap Points



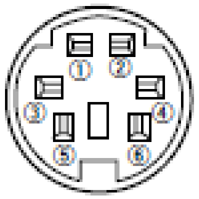


*NOTE:

- Selecting 1200 Baud packet mode on radio menu connects 1a tap point
- Selecting 9600 Baud packet mode on radio menu connects 1b tap point
- Unsure if pins 4 and 5 are affected by this menu selection. (TEST!)



Hardware Radio DATA Jack

DATA2	PIN No.	NAME	DESCRIPTION	SPECIFICATIONS
 Rear panel view	1	DATA IN	Input terminal for data transmit. (1200 bps: AFSK/ 9600 bps: G3RUH, GMSK)	Input level (1200 bps) : 100 mV Input level (9600 bps) : 0.2 to 0.5 Vp-p
	2	GND	Common ground for DATA IN, DATA OUT and AF OUT.	———
	3	PTTP	PTT terminal for packet operation. Connect to ground to activate the transmitter.	Input voltage (High) : 2.0 V to 20.0 V Input voltage (Low) : –0.5 V to +0.8 V
	4	DATA OUT*	Data out terminal for 9600 bps operation only.	Output impedance : 10 kΩ Output level : 1.0 Vp-p
	5	AF OUT*	Data out terminal for 1200 bps operation only.	Output impedance : 4.7 kΩ Output level : 100–300 mV rms
	6	SQL*	Squelch out terminal. This pin is grounded when the transceiver receives a signal which opens the squelch. • To avoid interfering transmissions, connect squelch to the TNC to inhibit transmission when squelch is open. • Keep RF gain at a normal level, otherwise a “SQL” signal will not be output.	SQL open : Less than 0.3 V/ 5 mA SQL closed : More than 6.0 V/ 100 μA

* The pin 4 (DATA), pin 5 (AF) and pin 6 (SQL) output capabilities are for the MAIN Band’s AF and squelch by default. You can change this setting in “DATA AF/SQL Select” of the Set mode. (p. 166)

From IC-9100 Manual

Probably want MAIN assigned to uplink so that when PTT is triggered, the radio transmits on the Uplink Frequency. SUB would then be assigned to Downlink noting the comments below. *Could be totally wrong about this, especially if IC-9100 has a ‘satellite mode’ of operation that overrides these settings.*

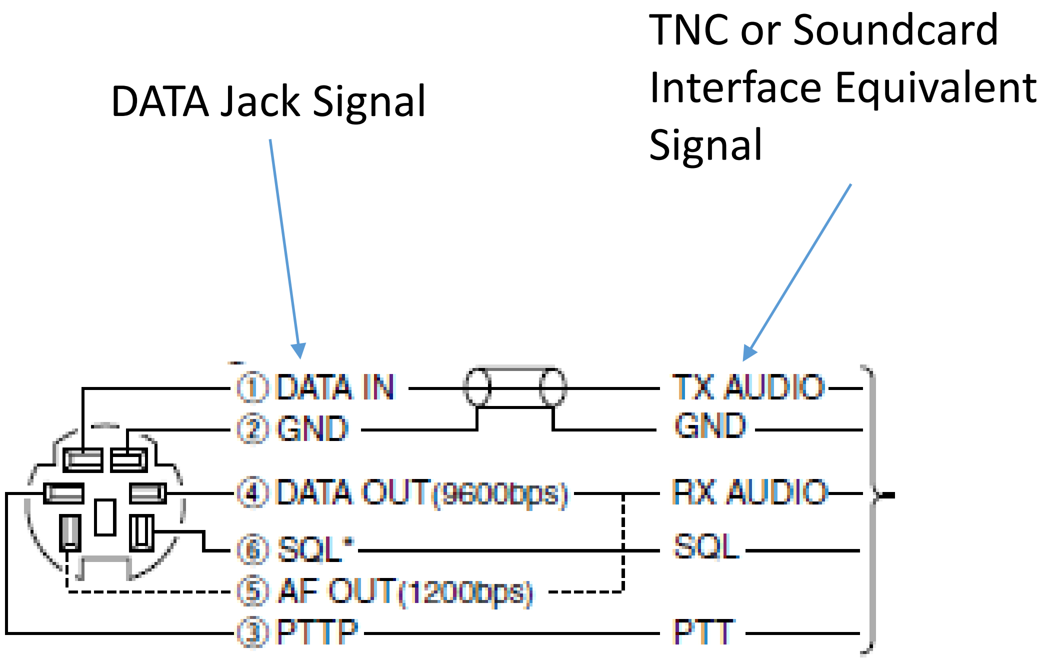
52. DATA AF/SQL Select **(Default: MAIN)**

Set the [DATA2] socket’s pin 4 (DATA), pin 5 (AF) and pin 6 (SQL) output usage.

- MAIN : Sends the MAIN Band’s receive audio and squelch.
- SUB : Sends the SUB Band’s receive audio and squelch.

Hardware Radio DATA Jack

DATA Jack to TNC Pinout/Cabling



TNC or Soundcard Notes

- Each vendor is different.
- Different connector styles, different pinouts, different settings.
- Must consult the manufacturer documentation to properly configure and fabricate interface cable.
- Some TNC/Soundcard vendors sell pre-fabricated radio specific interface cables.
- MUST pay attention to signal levels (volume control) on DATA IN (1), DATA OUT (4), and AF OUT (5) pins to avoid signal distortion (lost packets).

Hardware Radio DATA Jack – Additional Notes

VIRGINIA TECH

Volume Control

- The AF OUT (5) and DATA OUT (4) Pins bypass the majority of the audio conditioning circuitry. This is to avoid distortion. This means that the VOLUME control knob on the radio has no effect on the voltages output on these pins. The human operator can set the volume of the radio speaker to a comfortable level for monitoring without affecting the voltages output on these pins. Most TNCs have a configurable 'input gain control' (or similar) setting to set this at an optimal input level for the TNC. Most sound card interfaces have an 'RX knob' which is essentially a volume control for the same purpose.

Squelch Pin (6)

- SQL (6) connection is optional. Purpose is to inhibit Transmit when open (signal detected). **For satellite work, recommend leaving disconnected so that the squelch can be completely opened on the radio.** This will allow a human operator to listen to signals too weak to decode (like near AOS/LOS) to monitor system performance without inhibiting transmit (uplink) capability.
- This pin is most useful for Terrestrial APRS use when in a cluttered RF environment (many transmitters on same frequency and bursty). This pin is usually connected to a 'Data Carrier Detect' Pin on the TNC to inhibit TX when signals are detected on the channel in order to avoid packet collisions.

Hardware Radio DATA Jack – Additional Notes

Push To Talk (PTT)

- The PTT (3) pin is used to enable transmit on the radio.
- It is tempting to connect directly to the TNC (that's what the manual says to do right!?!?).
- For satellite work, usually this is not actually desirable because there are multiple devices that need to 'see' the PTT signal to switch the entire system (not just the radio) into a transmit state.
- Devices that need to see the PTT pin include the Low Noise Amplifiers, The High Power Amplifiers, the Radio and sometimes additional devices (such as coax relays) depending on the specifics of the ground station design.
- Normally, this pin out of the TNC is used to trigger a device called a 'sequencer' that has multiple PTT output channels with configurable delays between each channel. The radio PTT signal on the DATA jack is usually the LAST PTT signal to be enabled.
- More on Sequencing later……..its important!

TNC Connection Overview

TNC Implementation Types

Hardware Radio DATA Jack

Specific Interface Examples

Some Examples

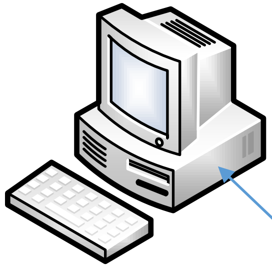
- Hardware TNC And Radio: KPC-9612+ TNC & ICOM-9100
- Sound Card Interface and ICOM-9100
- Software TNC Examples (for sound card interfaces)
- Software Radio Receiver Example
- ‘Client Software’ Examples

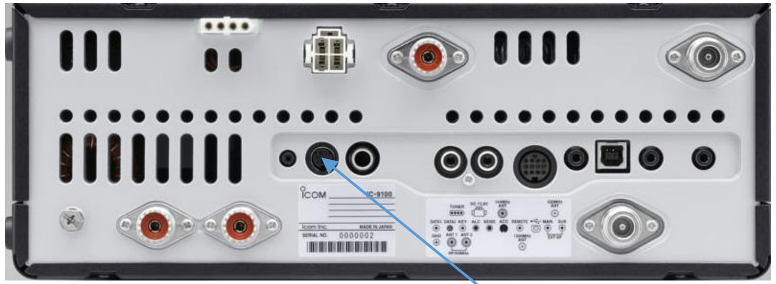
HW TNC To HW Radio Example

KPC-9612+	ICOM-9100

- Port 1 – Low Speed (AFSK1200)
- Port 2 – High Speed (FSK9600)
- Computer = Serial

HW TNC To HW Radio Example

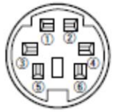




Terminal Name	KPC-9612 Plus Terminal Number	Computer Terminal Number (DB-25)	Computer Terminal Number (DB-9)
FG	1	1	N/A
TXD	2	2	3
RXD	3	3	2
RTS	4	4	7
CTS	5	5	8
DSR	6	6	6
SG	7	7	5
DCD	8	8	1
DTR	20	20	4
Shield	Shield	Shield	Shield

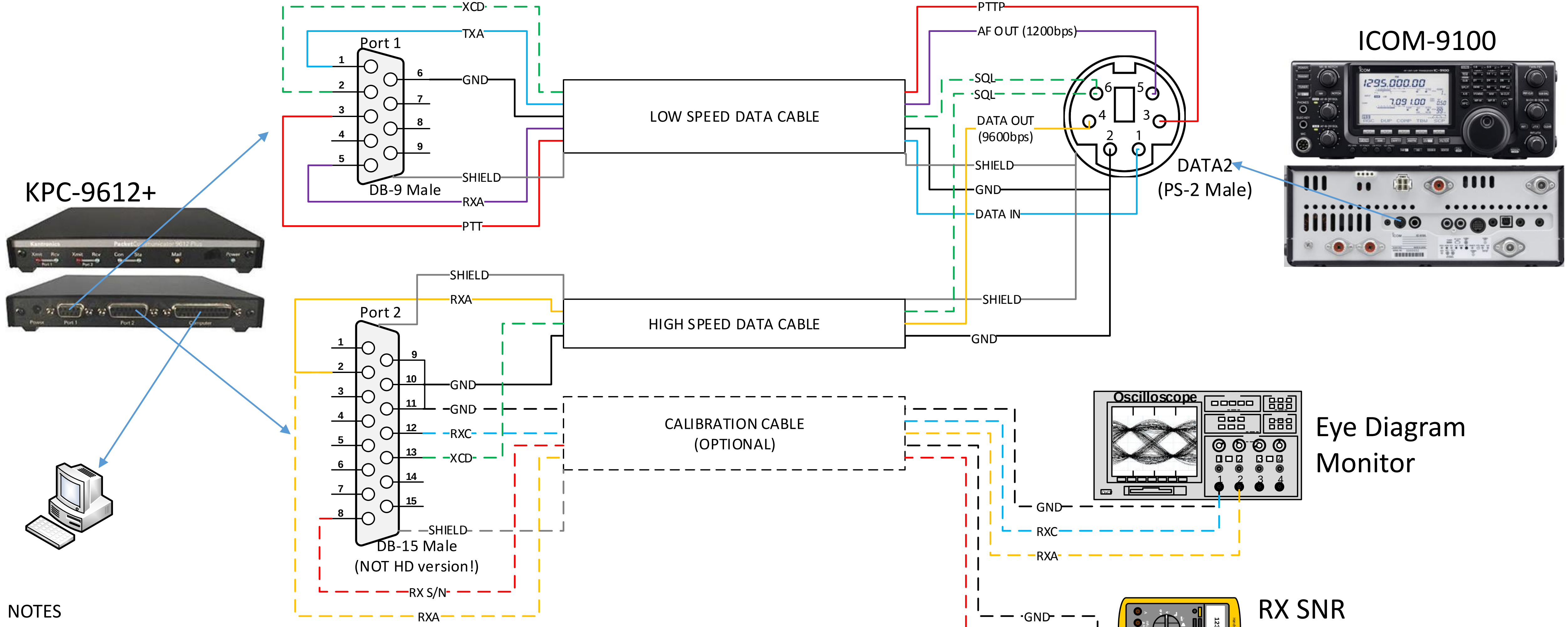
Terminal Nr	Nomenclature	Function
1	TXA	Transmit audio (AFSK out)
2	XCD	External carrier detect
3	PTT	Push-to-Talk
4	CTLB(1200)	Control line B (1200 Port)
5	RXA	Receive audio (AFSK in)
6	GND	Ground
7	EXT-IN	External input for Power/Reset*
8	CTLA(1200)	Control line A (1200 Port)
9	GND/RESET	Ground (may be configured as external reset)*
Shield	Shield	Shield

Terminal Nr	Nomenclature	Function
1	PTT	Push-to-Talk (output)
2	RXA	Receive signal (input)
3	TXA	Transmit signal (output)
4	RXD	Receive signal (digital input)
5		(not used)
6	CTLA 9600	Control line A (output) (High Speed Port)
7	CTLB 9600	Control line B (output) (High Speed Port)
8	RX S/N	Receive quality (output)
9	GND	Ground
10	GND	Ground
11	GND	Ground
12	RXC	Receive clock (output)
13	XCD	External carrier detect (input)
14	ANØ	Buffered A/D (input)
15	AN1	Buffered A/D (input)
Shield	Shield	Shield

DATA2	PIN No.	NAME	DESCRIPTION
 Rear panel view	1	DATA IN	Input terminal for data transmit. (1200 bps: AFSK/ 9600 bps: G3RUH, GMSK)
	2	GND	Common ground for DATA IN, DATA OUT and AF OUT.
	3	PTTP	PTT terminal for packet operation. Connect to ground to activate the transmitter.
	4	DATA OUT*	Data out terminal for 9600 bps operation only.
	5	AF OUT*	Data out terminal for 1200 bps operation only.
	6	SQL*	Squelch out terminal. This pin is grounded when the transceiver receives a signal which opens the squelch. • To avoid interfering transmissions, connect squelch to the TNC to inhibit transmission when squelch is open. • Keep RF gain at a normal level, otherwise a "SQL" signal will not be output.

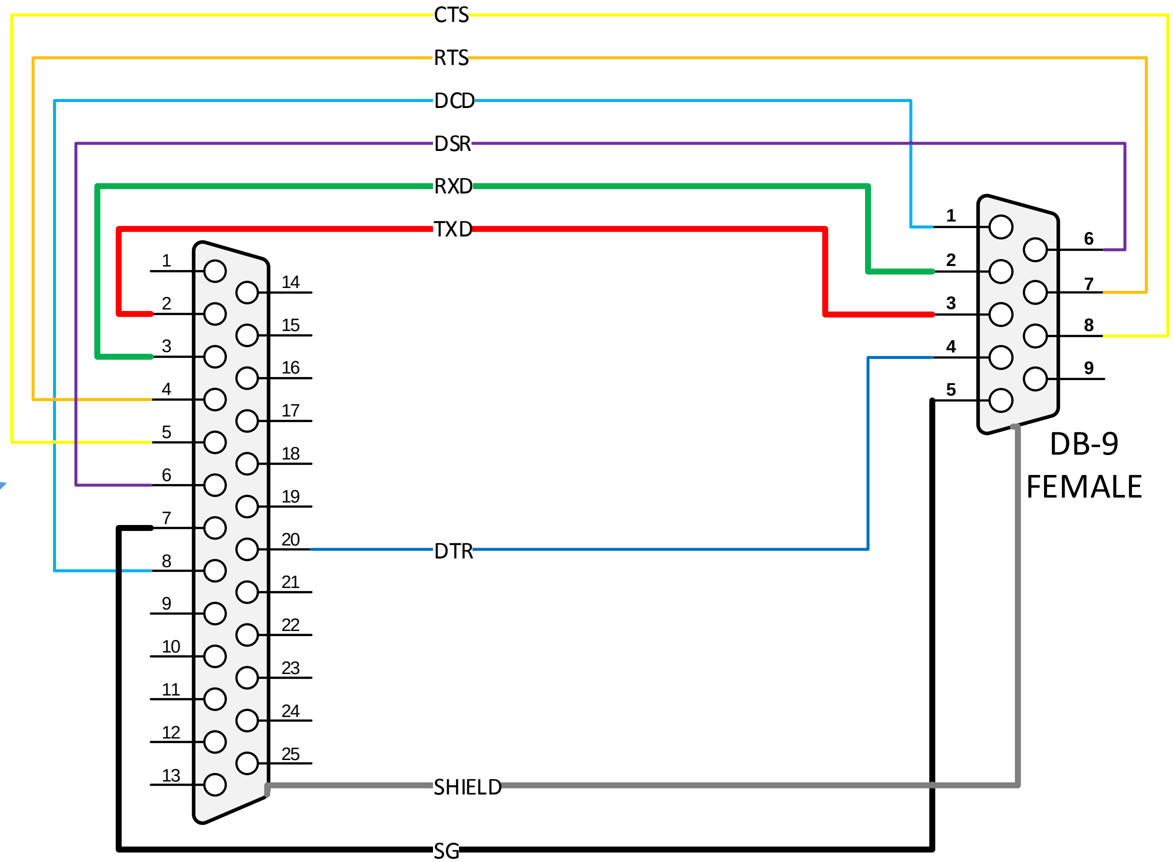
Cable Fabrication Time!

KPC-9612+ TNC to ICOM-9100 DATA Cable

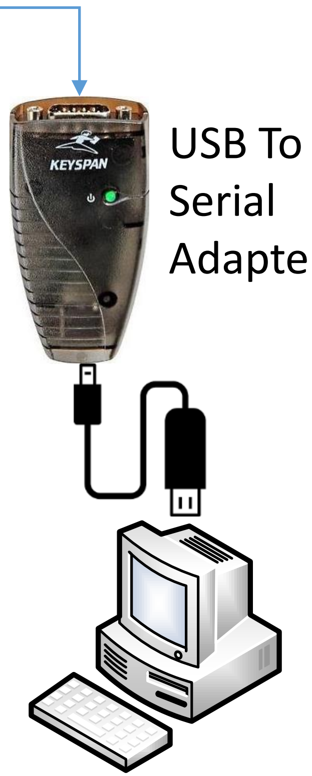


NOTES
1. Port 1 (AFSK1200) Controls Transmit (PTT) Since this is the uplink rate.
2. Port 1 (AFSK1200) Can also Receive (not needed, but useful for testing, related to KISS Protocol).
3. Recommend NOT Connecting Squelch (SQL/XCD) Lines to Data Jack (used For TX inhibit).
4. Dashed Lines are optional (SQL to DATA and Calibration equipment).

KPC-9612+ TNC to HOST Computer Cable



DB-25 Male
RS-232 - DCE



USB To Serial Adapter**

NOTES:

1. SG/TXD/RXD/Shield Are Required!
2. Other Signals are optional.
3. FTDI Converters can cause EMI/RFI and 'splatter' receiver front ends.

**Keyspan USA-19HS USB to Serial to converter is a recommended 'known quiet' device.

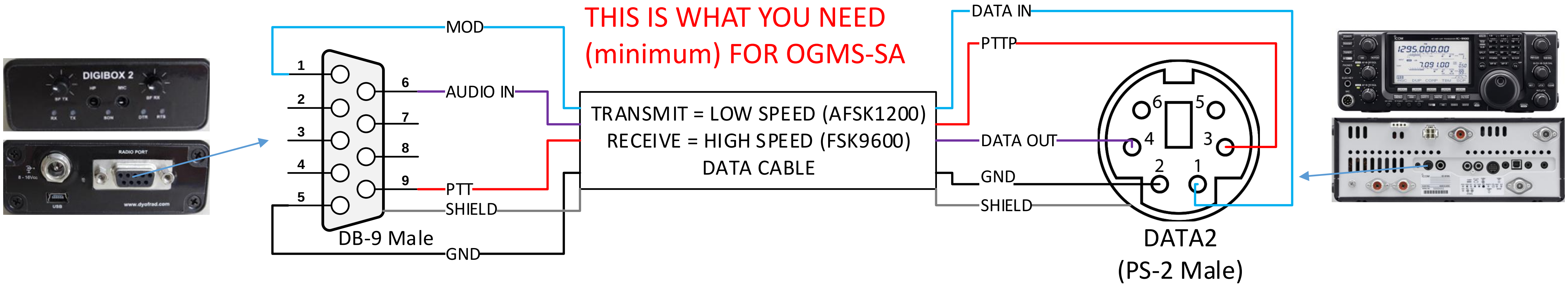
SoundCard Interface To HW Radio Example

DIGIBOX2	ICOM-9100

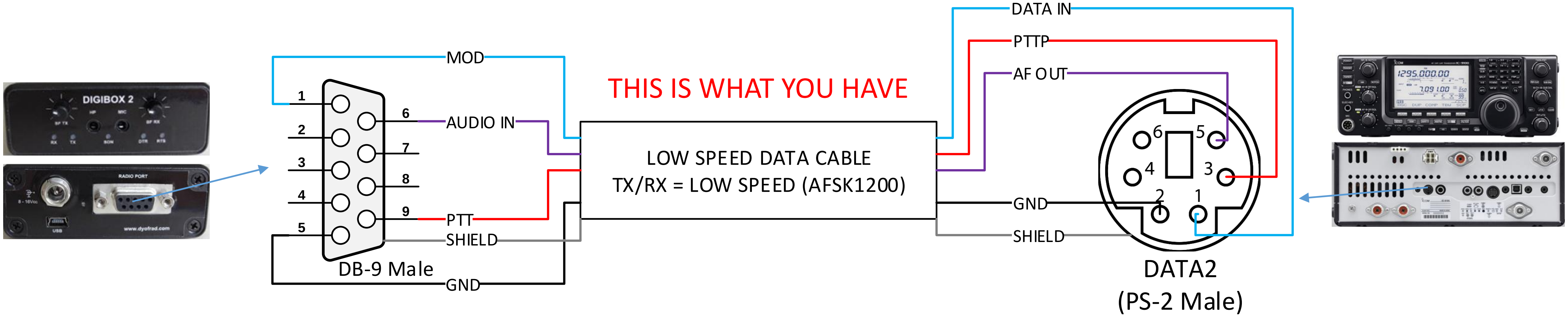
FRONT

REAR

Digibox2 Interface To HW Radio Example

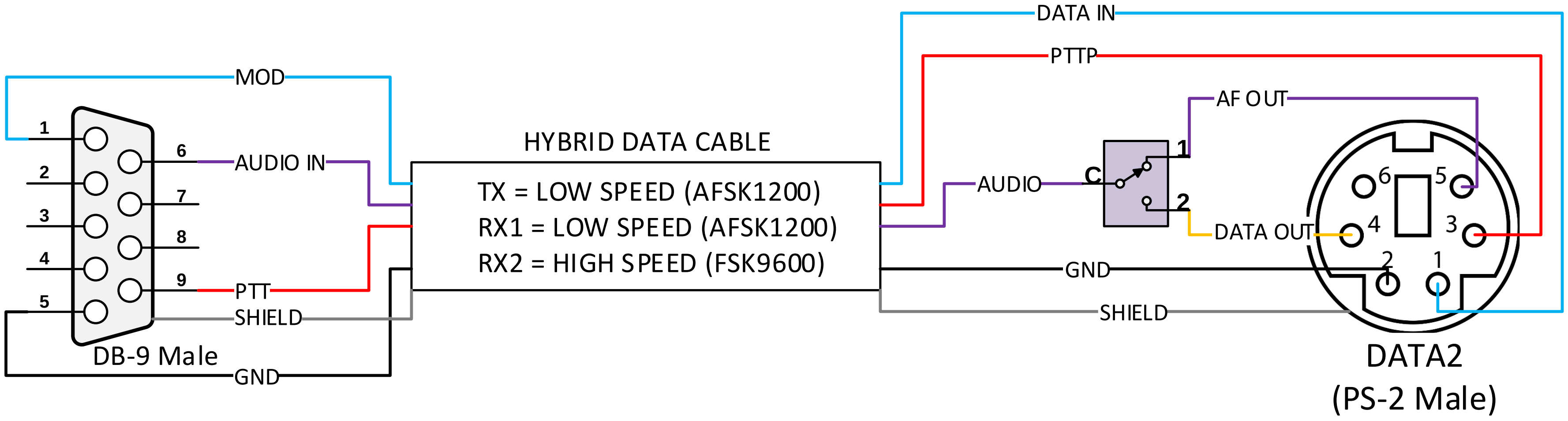


NOTE: In order to test this connection you need an FSK9600 Transmit reference signal. CANNOT use this cable with local APRS transmissions for testing.



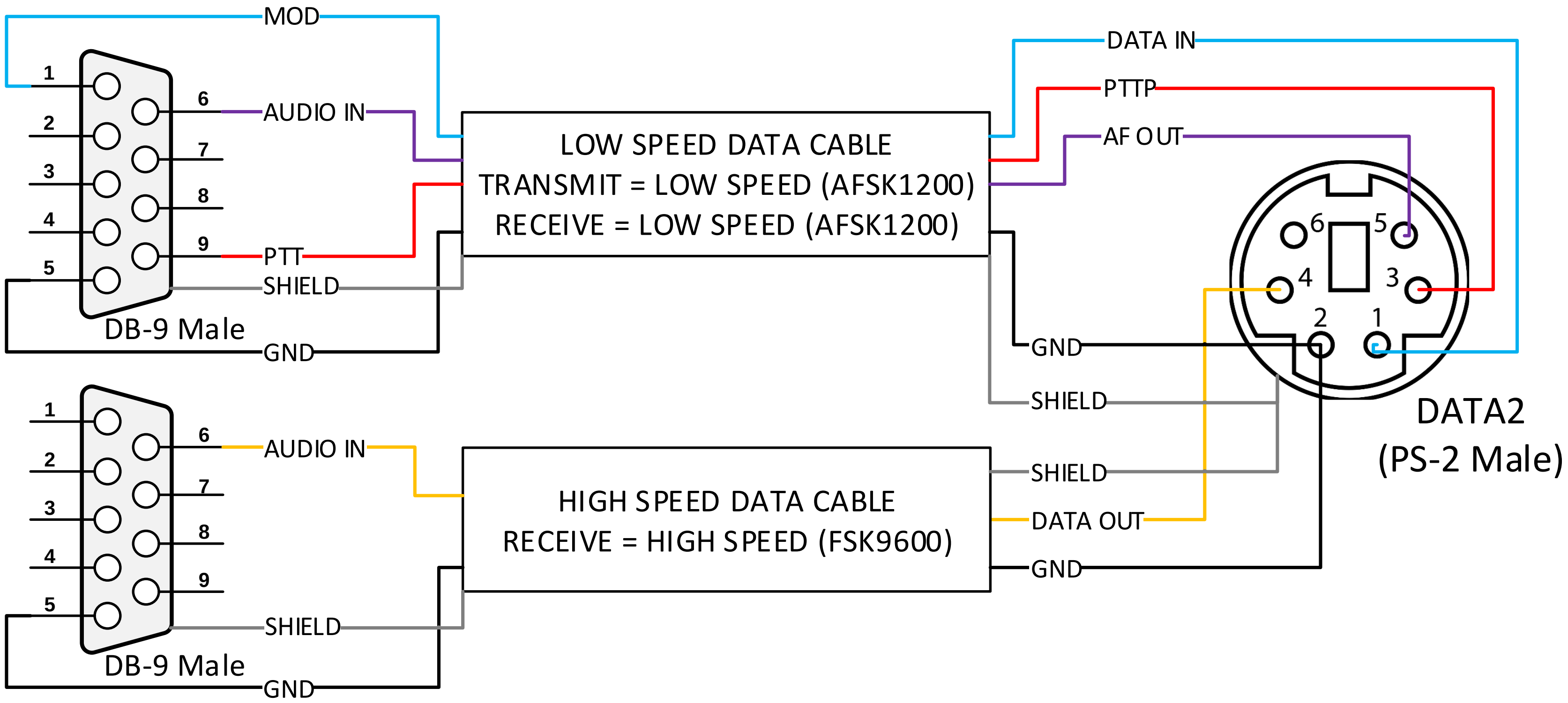
NOTE: Can test this configuration with local Terrestrial APRS signals (useful for testing higher layer AX.25/KISS interfaces).

Digibox2 Interface To HW Radio Example - Hybrid

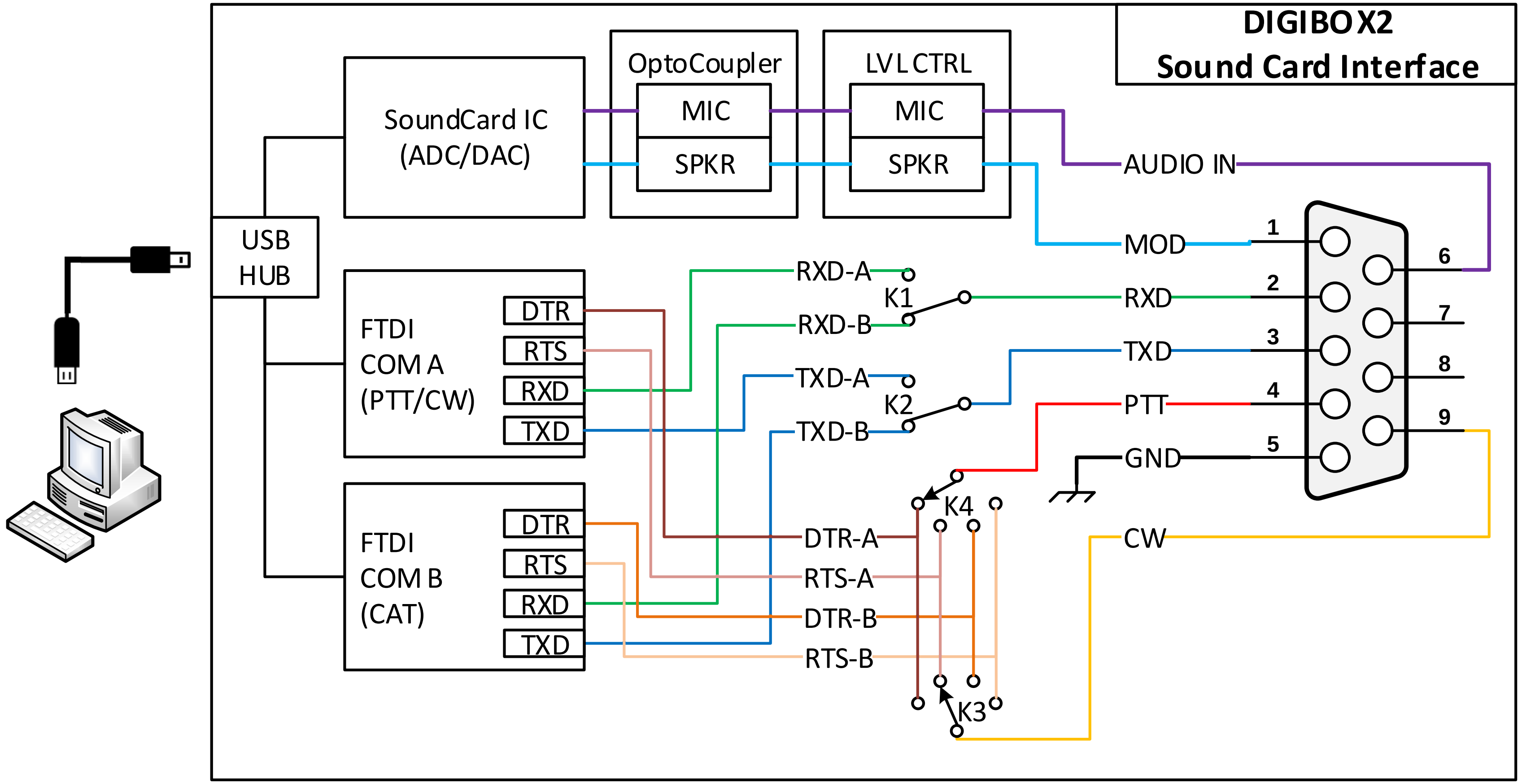


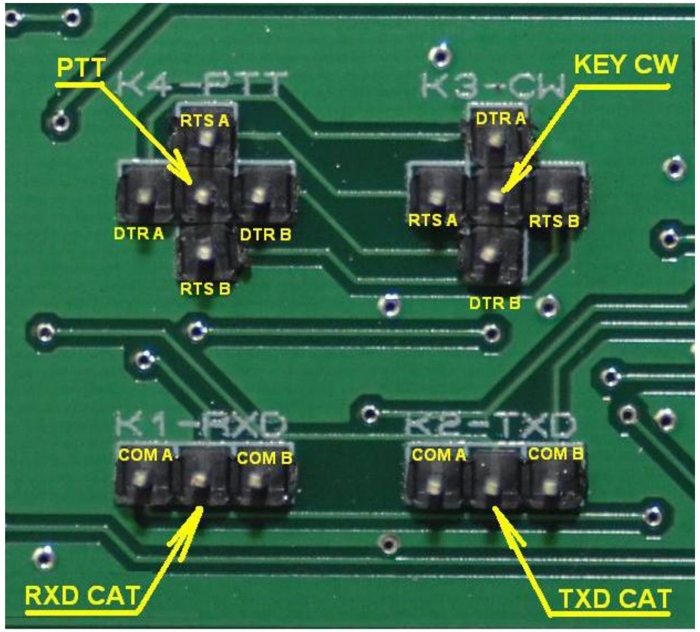
- Option for switchable low speed or high speed connection
- Can select RX1 (AFSK1200) for low speed testing with terrestrial APRS signals. Can also use to test other system functionality against satellites (doppler control, antenna pointing, etc.).
- Once confident with higher level AX.25/KISS processing and satellite tracking (Doppler, pointing) can then switch to RX2 (FSK9600) for testing against 9600 baud satellites.
- NOTE: This is a logical diagram, fabrication details are left to the experimenter to decide.

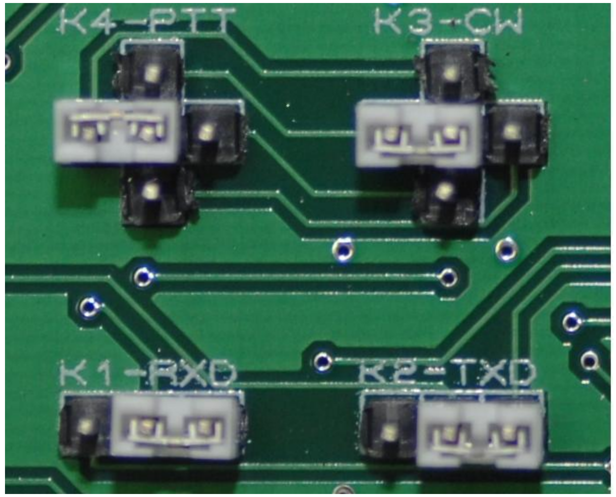
Dual Digibox2 Interface To HW Radio Example



Digibox2 COM Ports (Not Soundcards!)







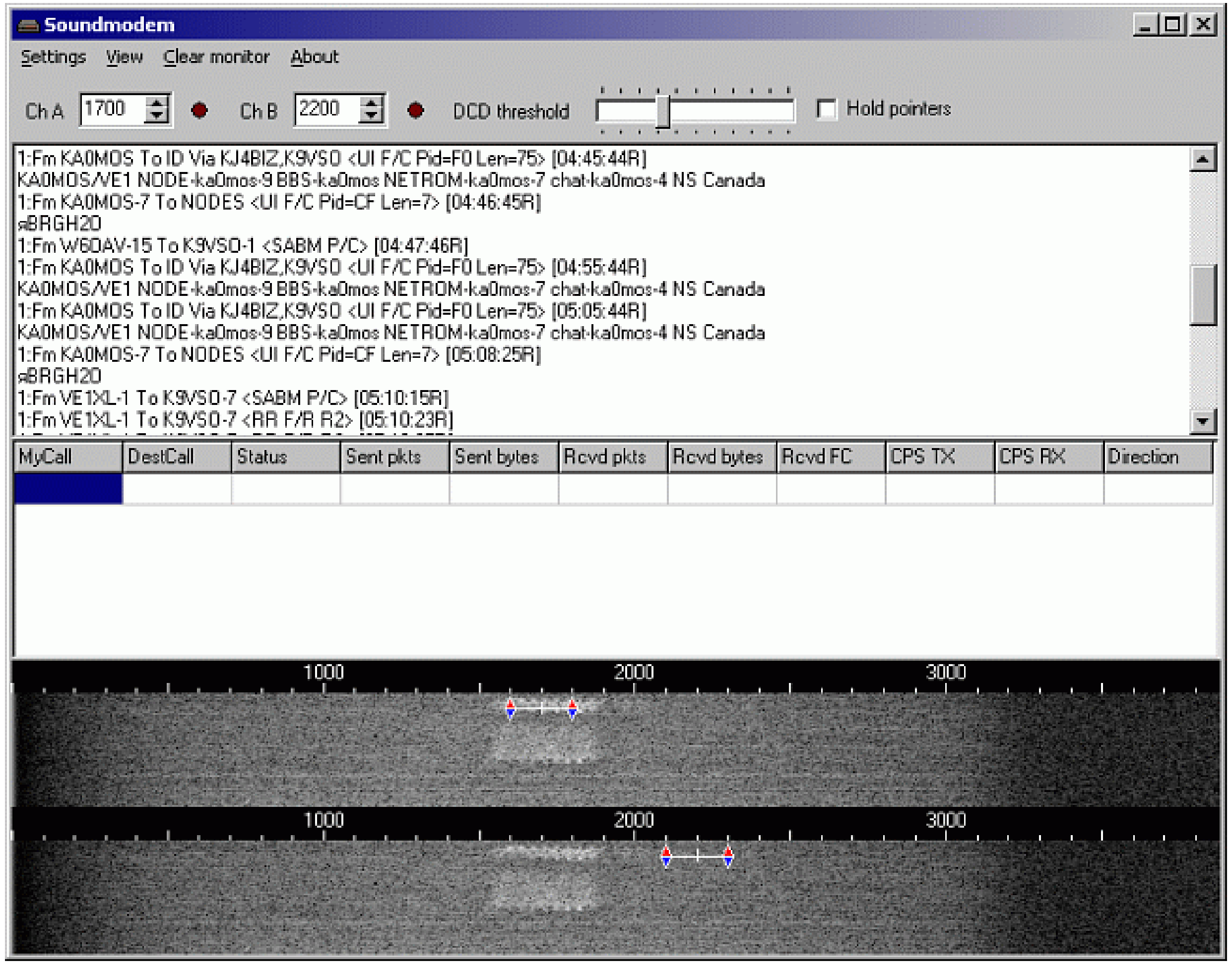
Jumper positions for this Example:

COM A = PTT/CW Key Control (Transmit Signal)

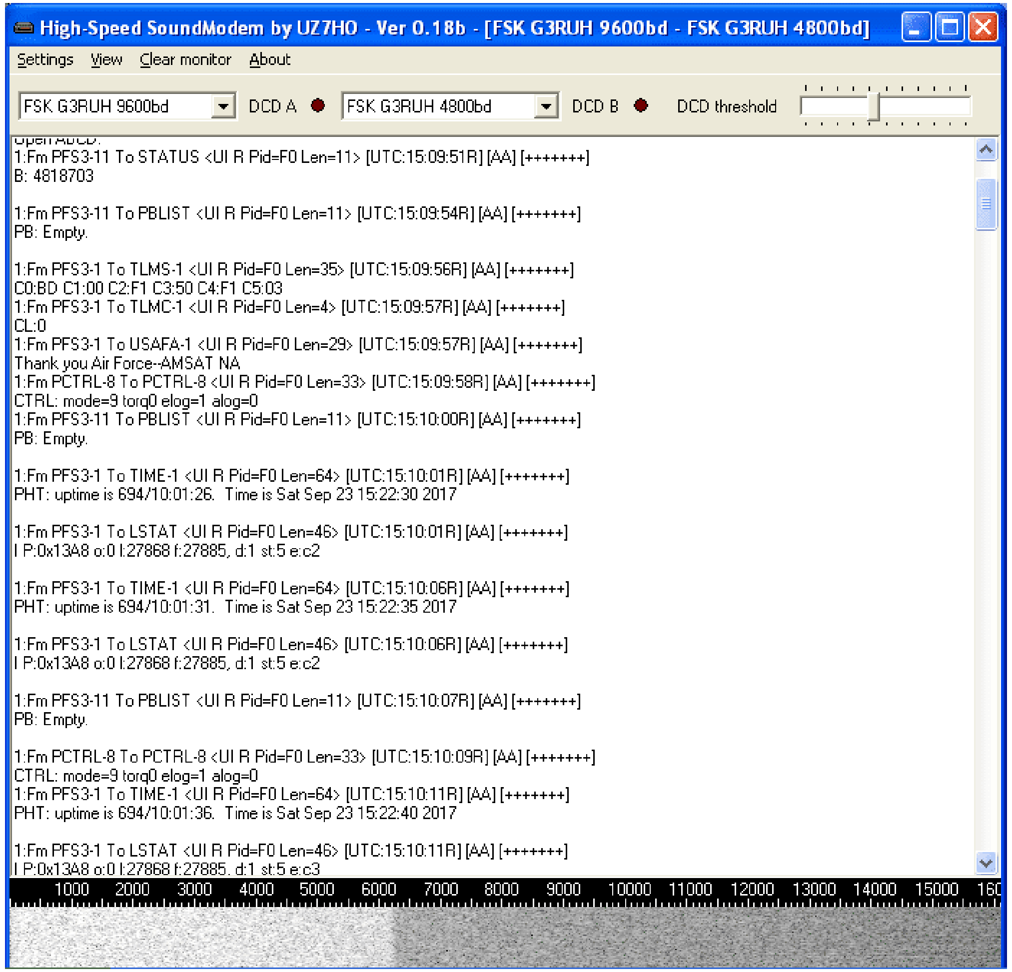
COM B = Yaesu's Computer Aided Transceiver (CAT) = ICOM's CI-V = Computer Tuning Control

Software TNCs (for soundcard interfaces)

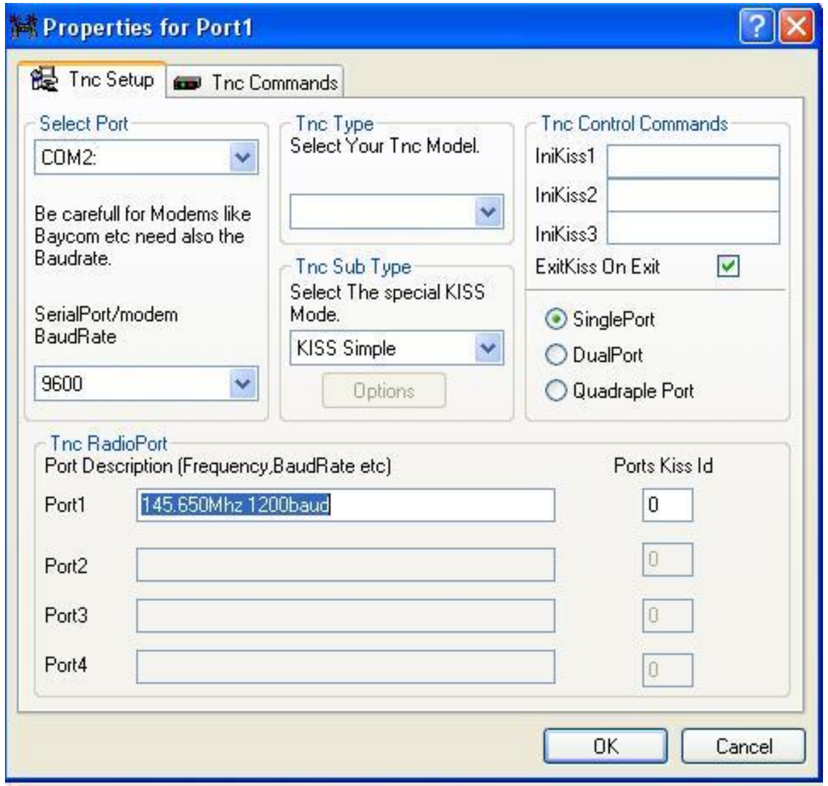
SoundModem (AFSK1200)

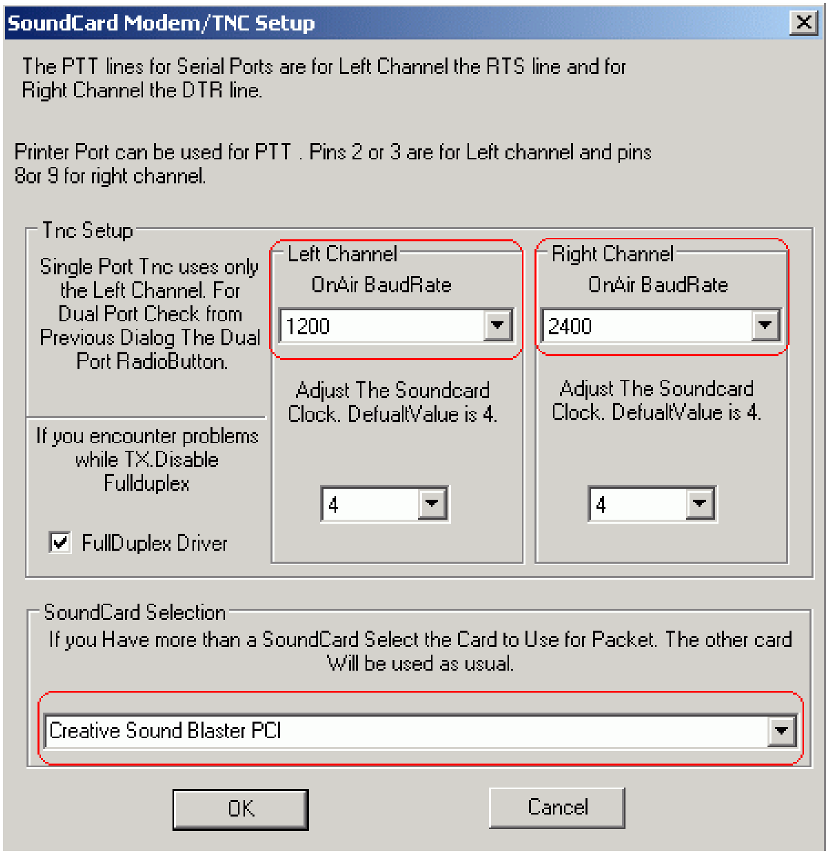


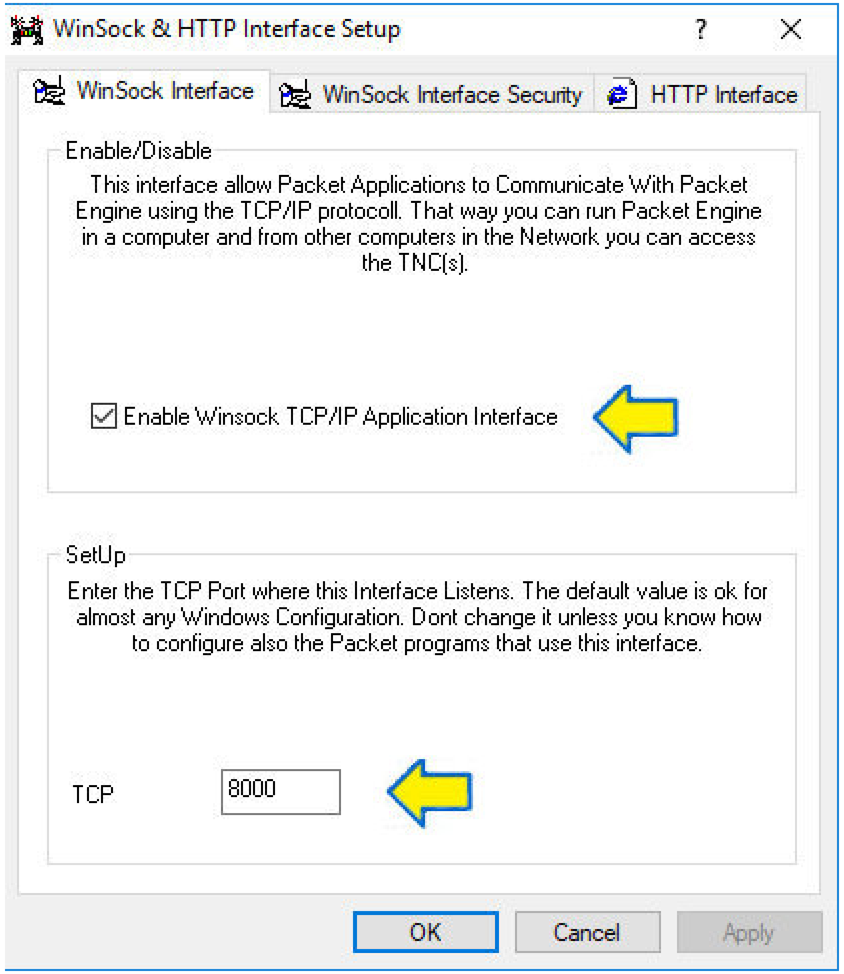
High Speed Soundmodem (FSK 9600)



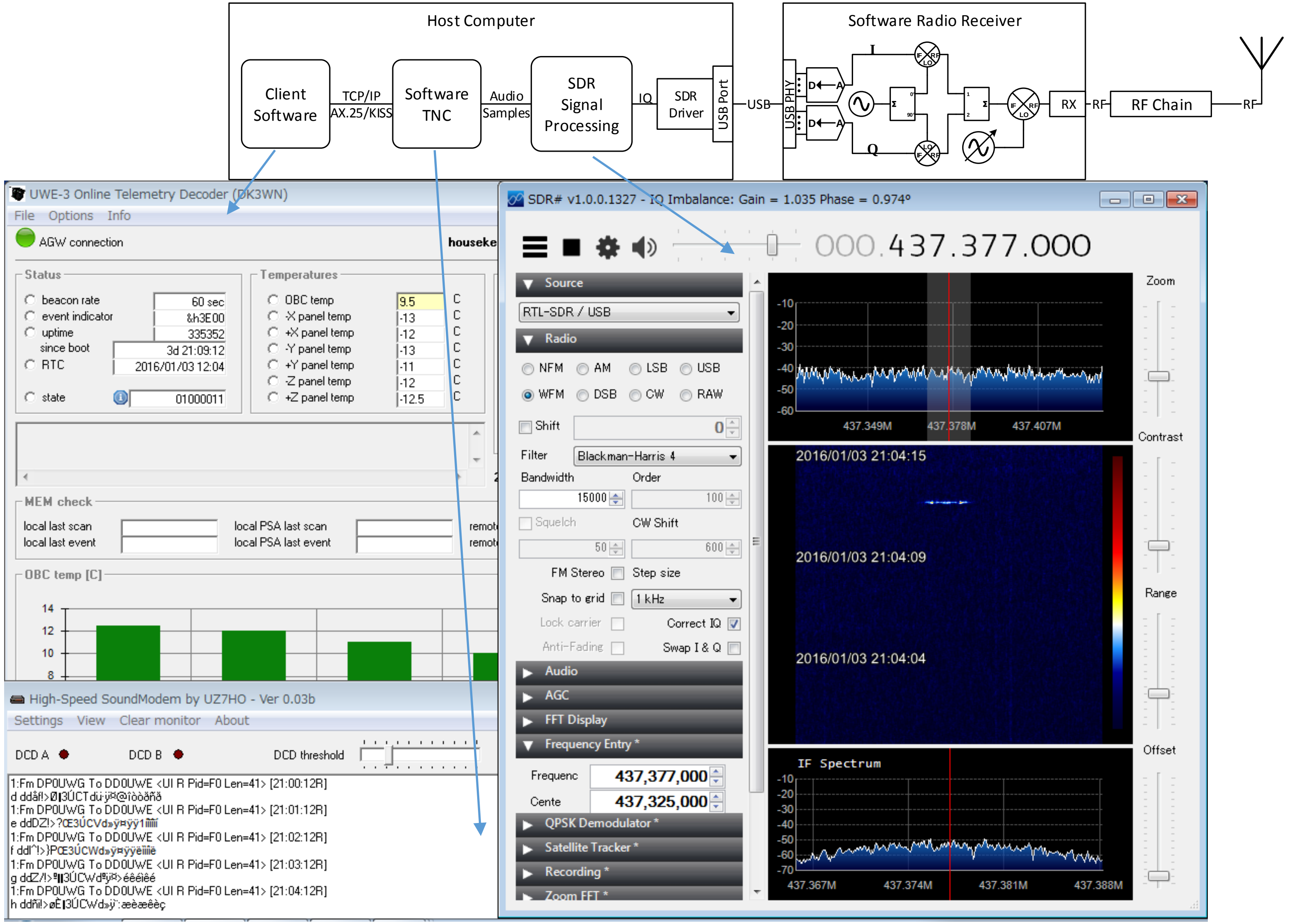
Software TNC - AGW Packet Engine



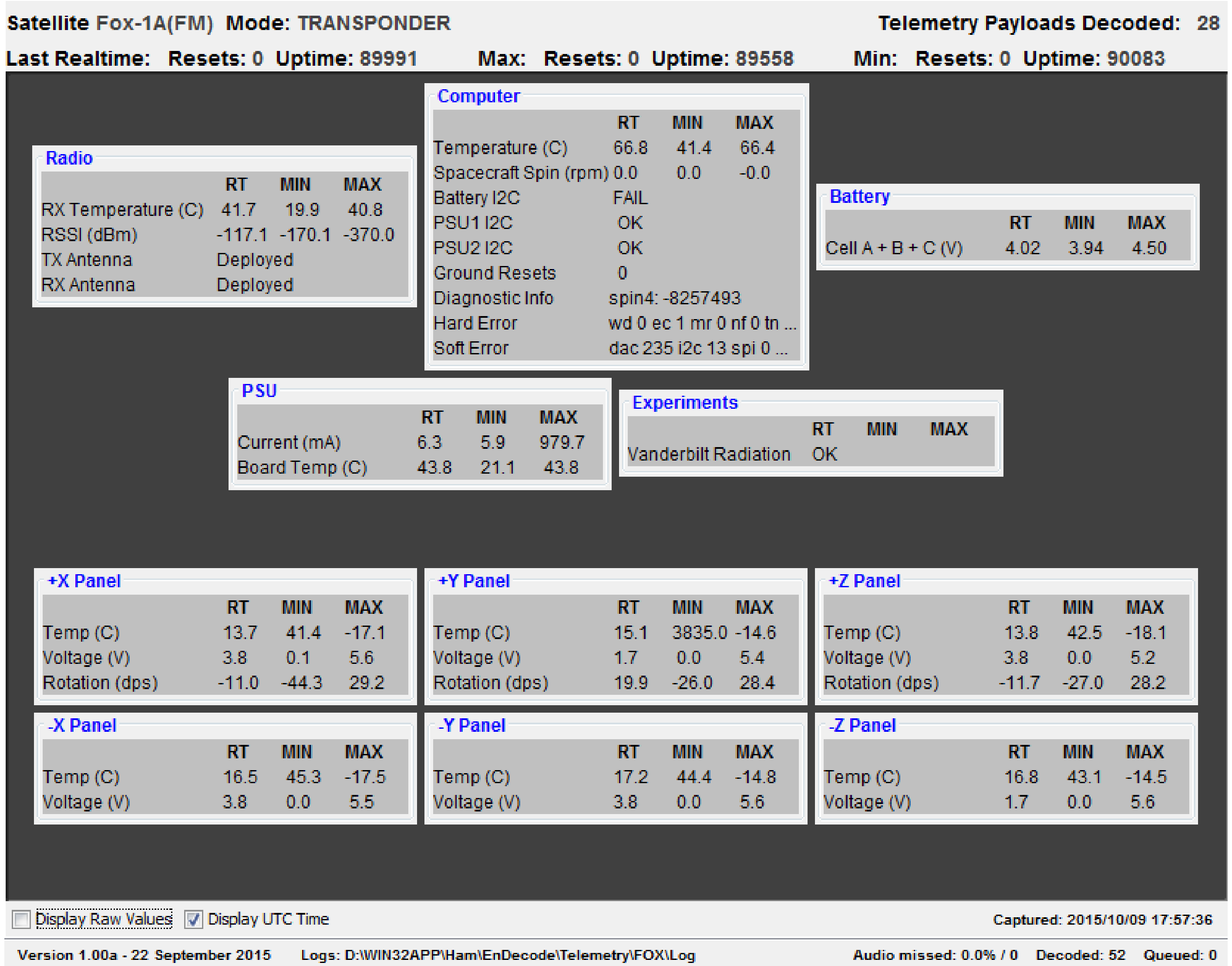




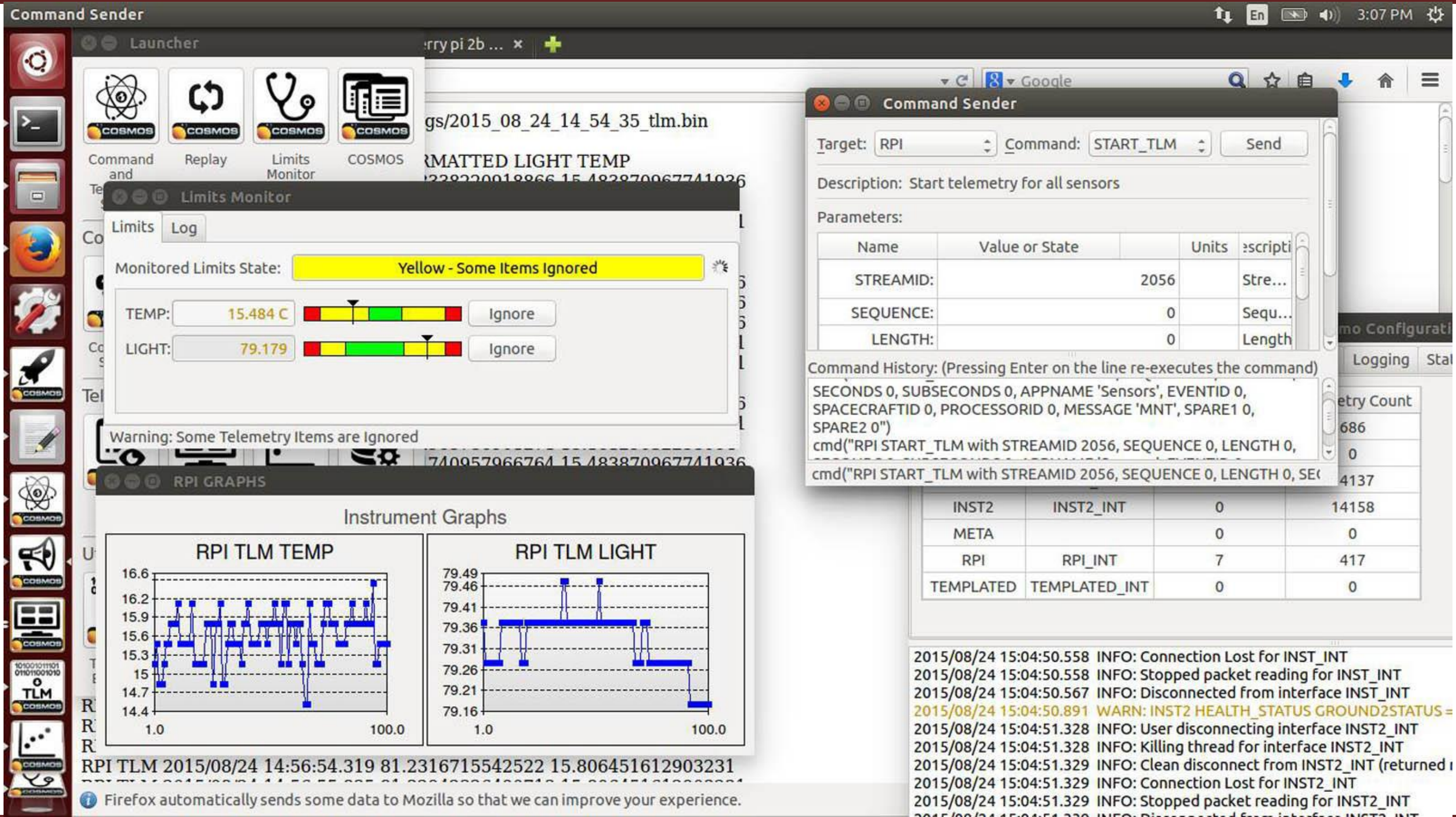
Software Defined Radio Receiver - Example



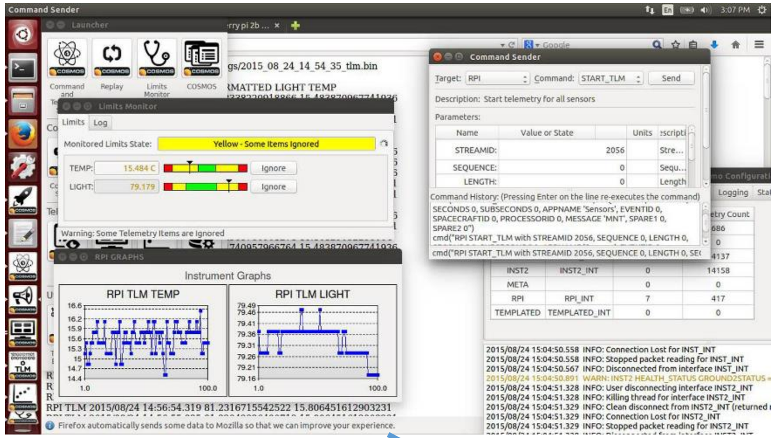
Client Software Examples – AMSAT FOX Software

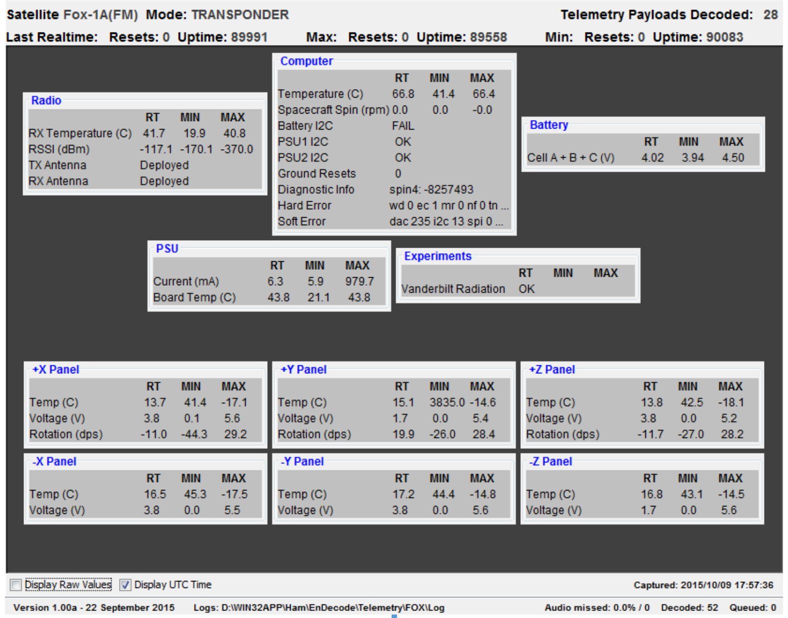


Client Software Examples – COSMOS!



****Client Software – The Point!****





Satellite
XYZ
Telecommand (TC)
And
Telemetry (TM)
Software

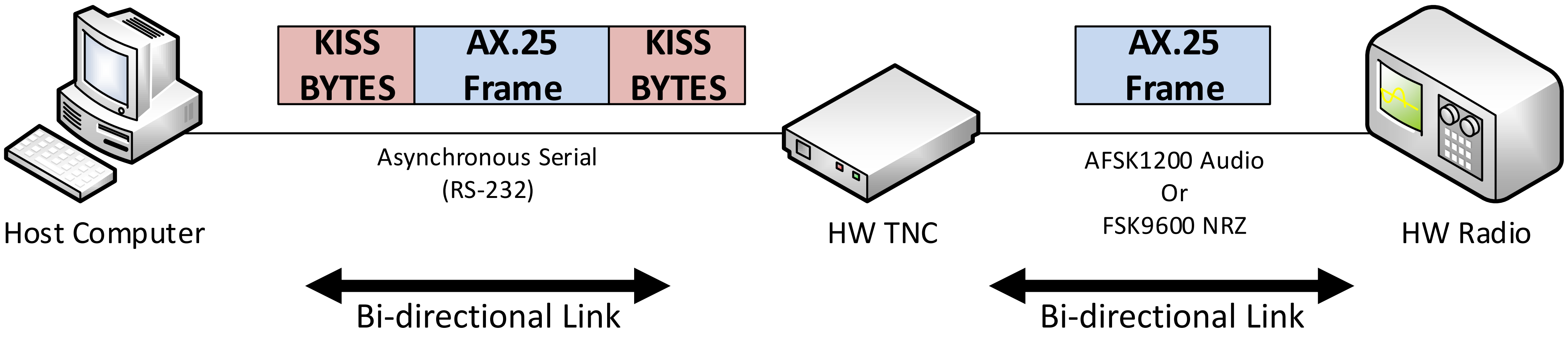
AX.25/KISS Frames

Come Out (TX/Uplink) and
Go In (RX/Downlink)

KISS Protocol

Keep It Simple, Stupid (KISS) Protocol

- "KISS (keep it simple, stupid) is a protocol for communicating with a serial terminal node controller (TNC) device used for amateur radio. This allows the TNC to combine more features into a single device and standardizes communications. **KISS was developed** by Mike Chepponis and Phil Karn **to allow transmission of AX.25 packet radio frames** containing IP packets **over an asynchronous serial link**, for use with the KA9Q NOS program." -- https://en.wikipedia.org/wiki/KISS_(TNC)



KISS Protocol – Only 3 Extra Bytes!

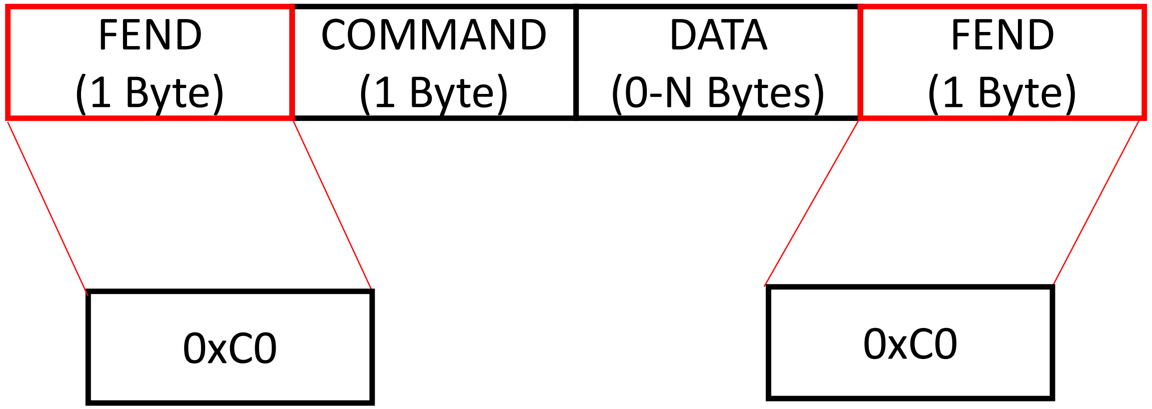
FEND (1 Byte)	COMMAND (1 Byte)	DATA (0-N Bytes)	FEND (1 Byte)
START Control Character	KISS COMMAND Character	DATA for over the Air TX (AX.25 Frame)	STOP Control Character

Special KISS Characters		
Hex value	**Abbreviation**	**Description**
0xC0	FEND	Frame End
0xDB	FESC	Frame Escape
0xDC	TFEND	Transposed Frame End
0xDD	TFESC	Transposed Frame Escape

<u>Why Special Characters?:</u>

- FEND Used to Mark Start/Stop of a KISS Frame (kind of like HDLC Flag bytes)
- If the FEND or FESC codes appear in the data to be transferred, they need to be escaped.
- If DATA contains:
  - FEND → FESC, TFEND replaces in byte stream
  - FESC → FESC, TFESC replaces in byte stream
- (kind of like HDLC bit stuffing, but at the byte level)

KISS Protocol – FEND Byte



FEND (0xC0) is used to mark the start and stop of a FRAME

KISS Protocol – COMMAND Byte

FEND (1 Byte)	COMMAND (1 Byte)	DATA (0-N Bytes)	FEND (1 Byte)

Port Index (Hi Nibble*)	CMD (Lo Nibble*)

Commands for control of TNC

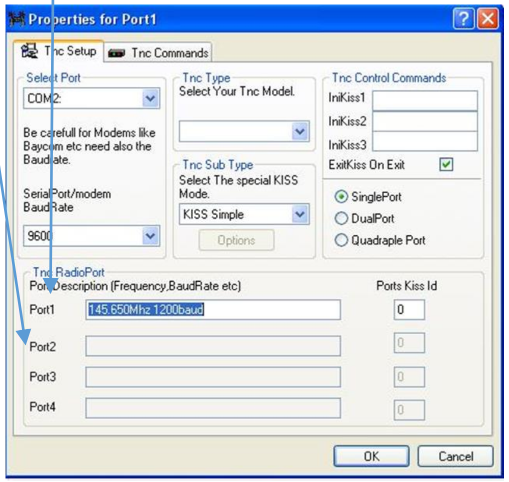
Port Index of TNC

1 0

0

1

Remember this guy?



*NOTE:
1 Nibble = 4 bits
1 Byte = 2 Nibbles = 8 bits

KISS Command Codes			
Hex value	**Name**	**Bytes**	**Description**
0x00	Data frame	Varies	This frame contains data that should be sent out of the TNC. The maximum number of bytes is determined by the amount of memory in the TNC. **This is the only allowed command code for a RECEIVED frame**
0x01	TX DELAY	1	The amount of time to wait between keying the transmitter and beginning to send data (in 10 ms units).
0x02	P	1	The persistence parameter. Persistence=Data*256-1. Used for CSMA.
0x03	SlotTime	1	Slot time in 10 ms units. Used for CSMA.
0x04	TXtail	1	The length of time to keep the transmitter keyed after sending the data (in 10 ms units).
0x05	FullDuplex	1	0 means half duplex, anything else means full duplex.
0x06	SetHardware	Varies	Device dependent.
0xFF	Return	1	Exit KISS mode. This applies to all ports and requires a port code of 0xF.

KISS Protocol – DATA Byte

FEND (1 Byte)	COMMAND (1 Byte)	DATA (0-N Bytes)	FEND (1 Byte)

AX.25 Transfer Frame Header (128 bits)				Information Field
DESTINATION ADDRESS	SOURCE ADDRESS	Control Bits	Protocol Identifier	
56	56	8	8	0-2048

Client Software Outputs/Inputs The AX.25 Frame inside the KISS DATA Field

Note ONLY the AX.25 Frame, NOT the HDLC pieces, are inside the KISS Frame

AX.25/HDLC Protocol

AX.25 Protocol - Overview

- The ‘A’ means ‘Amateur’
- Layer 2 (Link Layer) Specification.
- Derived from HDLC (flags, framing, bit stuffing, NRZ-I encoding)
- Most common amateur radio packet protocol
- Relatively large protocol, with only a small subset of details relevant to satellite
- References:
  - https://www.tapr.org/pdf/AX25.2.2.pdf ← Full AX.25 specification (July 1998, almost 20 years old!)
  - https://www.qb50.eu/index.php/tech-docs/category/17-up-to-date-docs
    - 11- QB50-EPFL-SSC-SCS-ICD-AX.25-TFF-3-1.pdf ← This one describes the relevant pieces of AX.25 for satellite work
  - http://destevez.net/2016/06/kiss-hdlc-ax-25-and-friends/ ← additional useful details and mapping to Physical layer (AFSK, GMSK, etc.)

AX.25 Protocol – Initial Details

- Octets (Bytes) are sent Least Significant Bit (LSB) first:

MSB							LSB
7	6	5	4	3	2	1	0

- Frames are sent Most Significant Byte First (Flag, then Dest, then Src, …. One exception!)
- All fields in between flags are subject to HDLC bit stuffing (more later)
- Satellites use AX.25 Unnumbered Information Frame (UI-Frame)
- UI-Frames are Connectionless
- AX.25 UI-Frame Structure:

	AX.25 Transfer Frame Header (128 bits)						
FLAG	DESTINATION ADDRESS	SOURCE ADDRESS	Control Bits	Protocol Identifier	Information Field	Frame Check Sequence	FLAG
8	56	56	8	8	0-2048	0-2048	8

AX.25 Protocol – Flag Field

	AX.25 Transfer Frame Header (128 bits)						
FLAG	DESTINATION ADDRESS	SOURCE ADDRESS	Control Bits	Protocol Identifier	Information Field	Frame Check Sequence	FLAG
8	56	56	8	8	0-2048	16	8

Flag (8 bits)							
0	1	1	1	1	1	1	0

Flag (8 bits)							
0	1	1	1	1	1	1	0

- Used to mark beginning and end of frame
- Helps receiver synchronize
- Usually many are sent before and after frame
- Not subject to HDLC Bit Stuffing (more later)
- Fixed Value: **01111110 (0x7E)**
- ***Technically this is NOT part of the AX.25 Frame, its part of the HDLC encapsulation (a detail but important for implementers)!***

AX.25 Protocol – Destination & Source Addresses

	AX.25 Transfer Frame Header (128 bits)						
FLAG	DESTINATION ADDRESS	SOURCE ADDRESS	Control Bits	Protocol Identifier	Information Field	Frame Check Sequence	FLAG
8	56	56	8	8	0-2048	16	8

DESTINATION ADDRESS																								
C1 (8 bits)								...	C6 (8 bits)								SSID (8 bits)							
X	X	X	X	X	X	X	0		X	X	X	X	X	X	X	0	0	1	1	S	S	I	D	0

SOURCE ADDRESS																								
C1 (8 bits)								...	C6 (8 bits)								SSID (8 bits)							
X	X	X	X	X	X	X	0		X	X	X	X	X	X	X	0	0	1	1	S	S	I	D	1

- 6 Callsign octets + 1 SSID Octet
- 6 Callsign octets are 7 bit ASCII, but left shifted one bit.
- Last bit of each octet indicates whether there is more data or not:
    - 0 = More Address Data
    - 1 = End of Address Data

This is the only last bit with a value of 1

- SSID[7:5] fixed bits → **011**
- SSID[4:1] → 16 bit integer value, usually 0000
- NOTE: 2 to 4 addresses are allowed in AX.25; Destination and Source are required with up to 2 additional ‘paths.’ Usually, for satellites, only the source and destination fields are present. A notable exception to this are the APRS repeater satellites (ISS, PSAT, NO-44, etc.) that include additional ‘digipeat paths’ (According to the APRS protocol).

AX.25 Protocol – Control and Protocol ID

	AX.25 Transfer Frame Header (128 bits)						
FLAG	DESTINATION ADDRESS	SOURCE ADDRESS	Control Bits	Protocol Identifier	Information Field	Frame Check Sequence	FLAG
8	56	56	8	8	0-2048	16	8

Control (8 bits)							
0	0	0	0	0	0	1	1

Protocol ID (8 bits)							
1	1	1	1	0	0	0	0

Control Bits:

- Indicates what type of AX.25 Frame is being sent
- Unnumbered Information Frame → Shall be fixed: **00000011 (0x03)**

Protocol Identifier:

- Indicates what type of layer 3 protocol
- No layer 3 protocol implemented → Shall be fixed: **11110000 (0xF0)**

AX.25 Protocol – Information Field

FLAG	AX.25 Transfer Frame Header (128 bits)				Information Field	Frame Check Sequence	FLAG
	DESTINATION ADDRESS	SOURCE ADDRESS	Control Bits	Protocol Identifier			
8	56	56	8	8	0-2048	16	8

- Integer multiple of octets
- Maximum Length of 256 octets
- Contains the DATA!!!
  - Telecommand (TC)
  - Telemetry (TM or TLM)
  - Mission Data
- This is where higher layer definitions come into play. QB50 for example elected to use CCSDS packet formats *within* the Information Field. APRS is an ASCII based protocol that defines this field for APRS messages. ***This can be completely custom, but MUST be defined (ICDs recommended)!***

AX.25 Protocol – Frame Check Sequence

FLAG	AX.25 Transfer Frame Header (128 bits)				Information Field	Frame Check Sequence	FLAG
	DESTINATION ADDRESS	SOURCE ADDRESS	Control Bits	Protocol Identifier			
8	56	56	8	8	0-2048	16	8

- 16-CCITT based CRC (Cyclic Redundancy Check)
- Used to *detect* bit errors (doesn't correct them!, some limited tricks are possible)
- Usually if errors are detected packet is discarded and not passed up the OSI stack for higher level processing.
- NOTE: The FCS is sent least significant byte FIRST!!!! This can be confusing for implementers.
- ***Technically this is NOT part of the AX.25 Frame, its part of the HDLC encapsulation (a detail but important for implementers)!***

HDLC (AX.25) Protocol – Bit Stuffing

FLAG	AX.25 Transfer Frame Header (128 bits)				Information Field	Frame Check Sequence	FLAG
	DESTINATION ADDRESS	SOURCE ADDRESS	Control Bits	Protocol Identifier			
8	56	56	8	8	0-2048	16	8

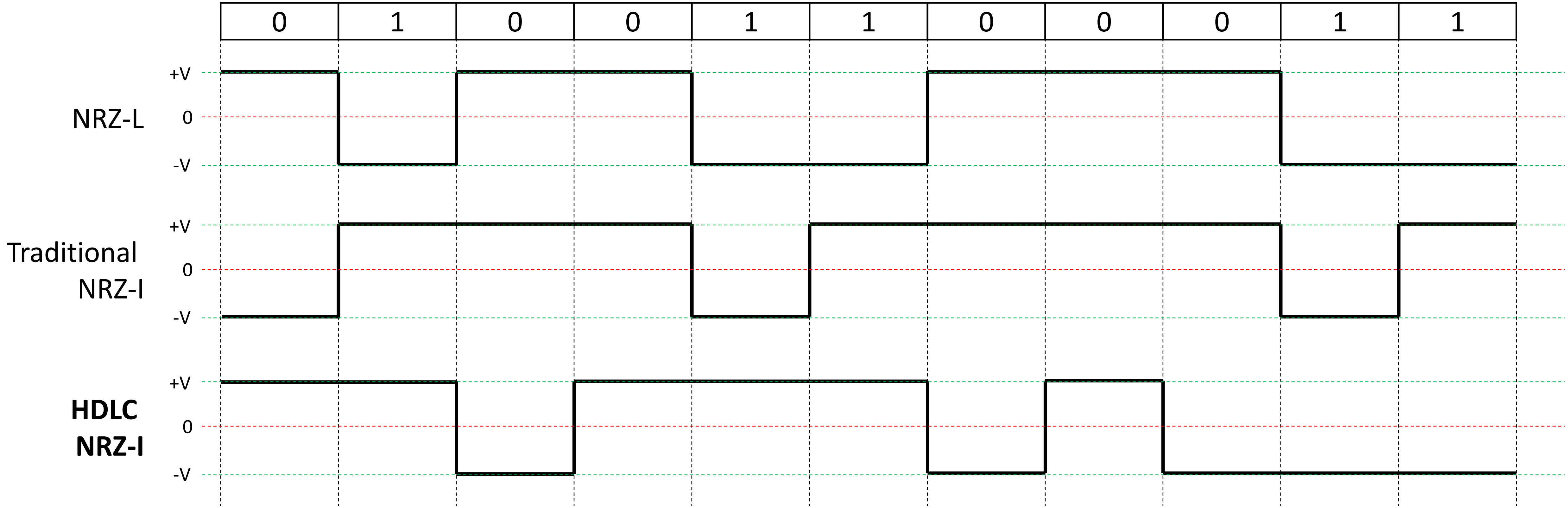
Flag (8 bits)							
0	1	1	1	1	1	1	0

Subject to bit stuffing

Flag (8 bits)							
0	1	1	1	1	1	1	0

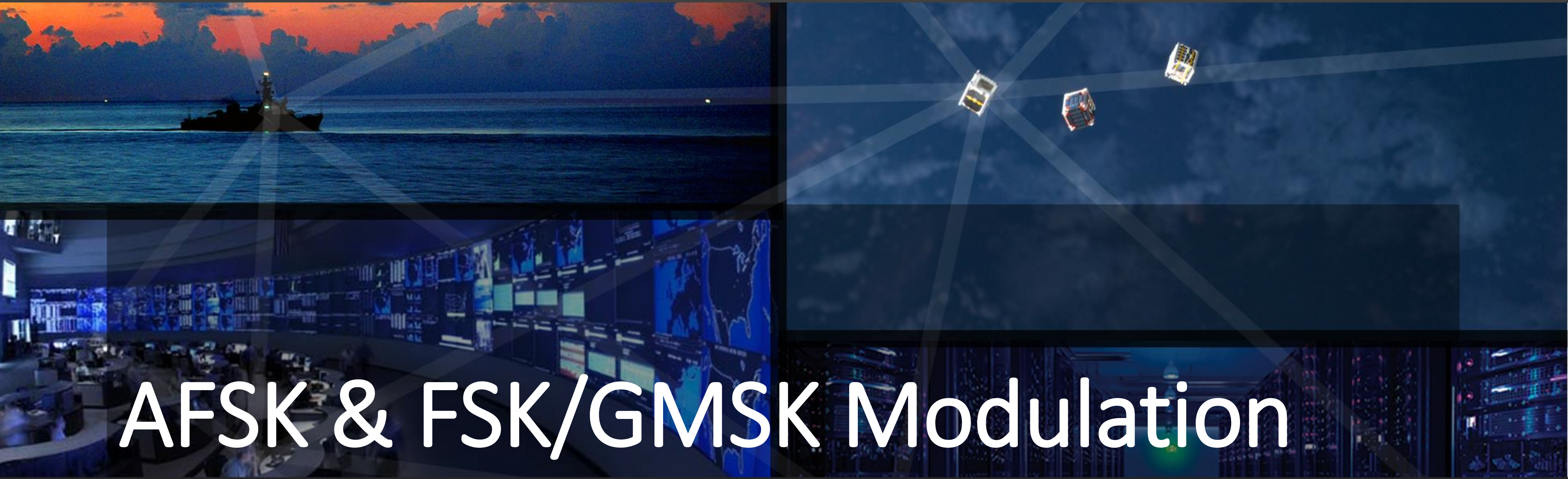
- Flags are special…its how the receiver detects an AX.25 frame in the bit stream.
- It is entirely possible (likely) that 6 consecutive 1s will appear in the data stream of an AX.25 frame. If nothing is done about this, then a false flag detection will occur, resulting in a failed CRC check, resulting in a discarded frame.
- Bit Stuffing to the rescue!
    - As the AX.25 frame is being sent into the modulator, the number of consecutive 1s is monitored.
    - If 5 consecutive 1s are detected in the bit stream, a 0 is inserted.
    - On the receiver side, if 5 consecutive 1s are detected and then the next bit is a 0, the 0 is discarded from the bit stream ('un-stuffed'). If the next bit is a 1, the receiver should expect a following 0, indicate a FLAG has been received.

HDLC (AX.25) Protocol – NRZ-I Line Encoding

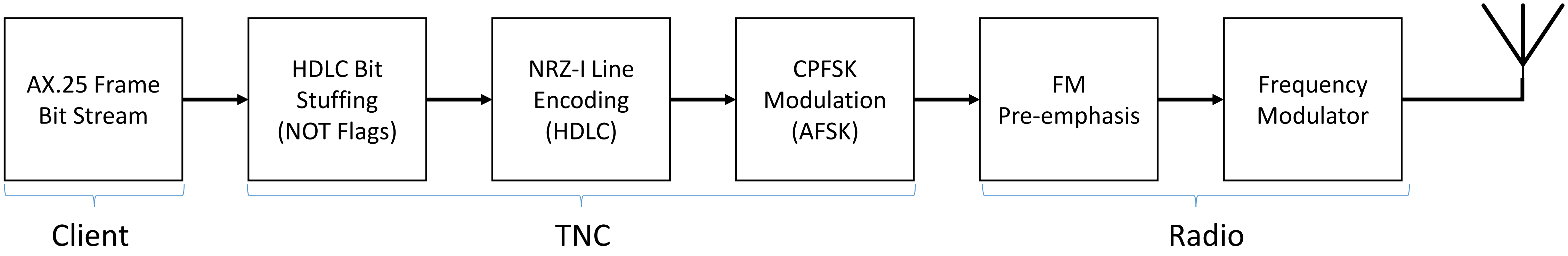


- The Use of Non Return to Zero Inverted (NRZ-I) means that modulations don't care about the actual symbol state (say a positive or negative frequency). What matters is the *change* or *lack of change* of a symbol to represent the bit value.
- NOTE: HDLC/AX.25 uses an inverted form of NRZ-I.
  - 0 → Transition
  - 1 → No Transition

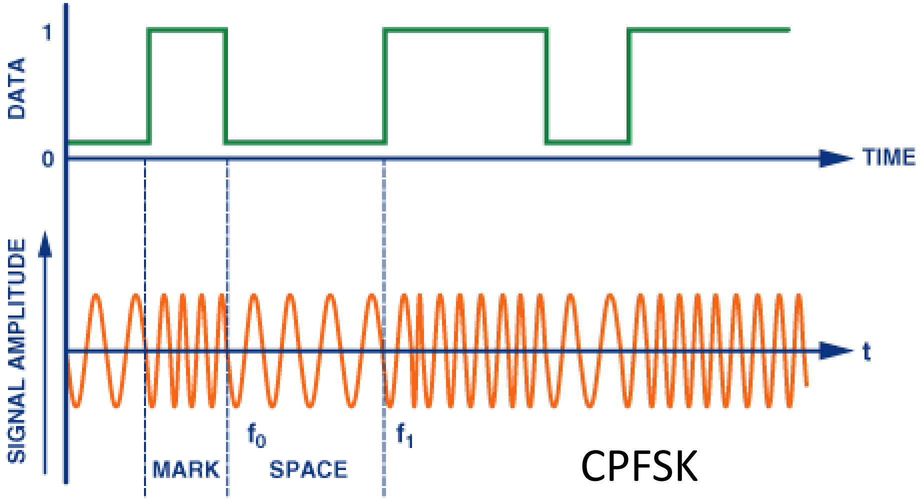
AFSK & FSK/GMSK Modulation



AFSK and FM Modulation

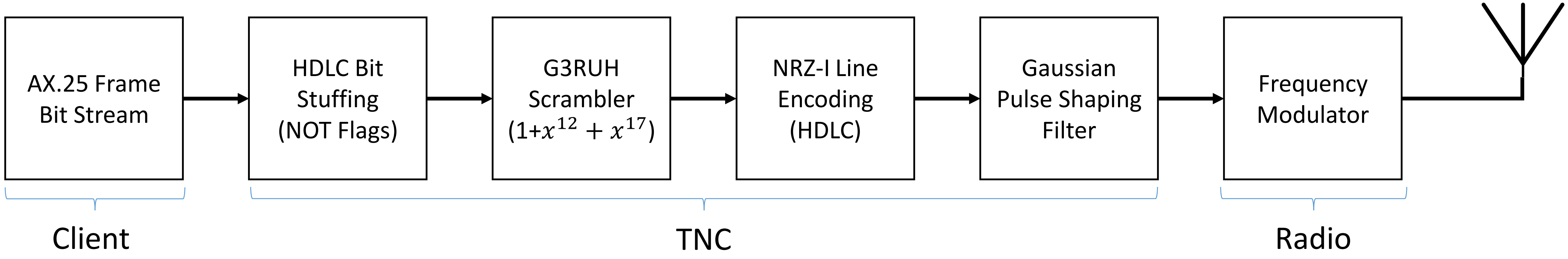


- AFSK = Audio Frequency Shift Keying
- Uses audio tones at 1200 Hz (Space) and 2200 Hz (Mark).
  - Derived from Bell 202 dialup modem standard, which is why a ‘burst’ sounds like an old modem.
- NRZ-I bits are used to alternate (or not) between the tones.
- Continuous Phase Frequency Modulation used to generate AFSK
  - No instantaneous phase change → reduced signal bandwidth.
- Audio is then piped into an FM transmitter.

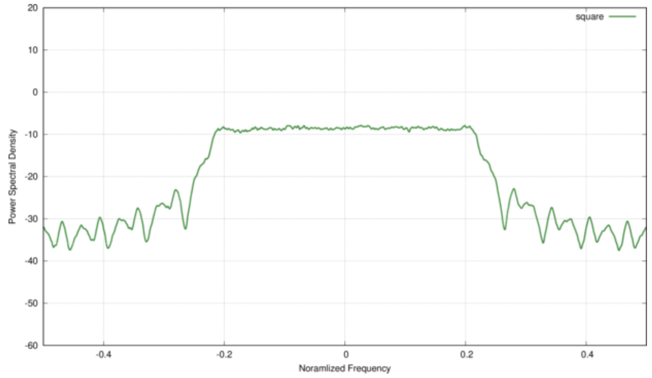


CPFSK

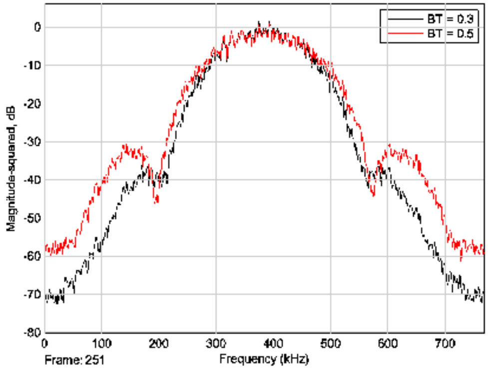
G3RUH FSK/GMSK Modulation



- FSK = Frequency Shift Keying
- GMSK = Gaussian Minimum Shift Keying
- Modulating signal (the 'message') bypasses the FM pre-emphasis/de-emphasis circuitry of hardware radio and is applied directly to the FM Modulator (varactor) to produce FSK.
- If the NRZ-I signal is passed through a *Gaussian* pulse shaping filter before it is sent to the radio then GMSK is produced.
- More on next slide for pulse shaping

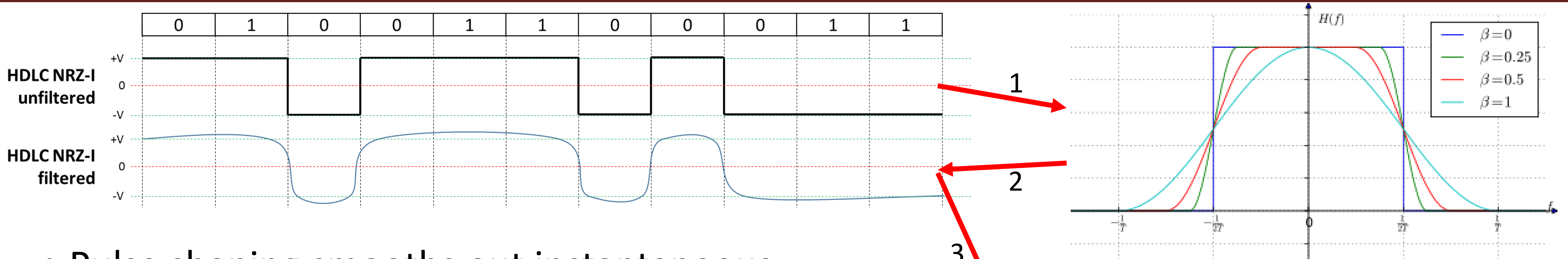


FSK PSD

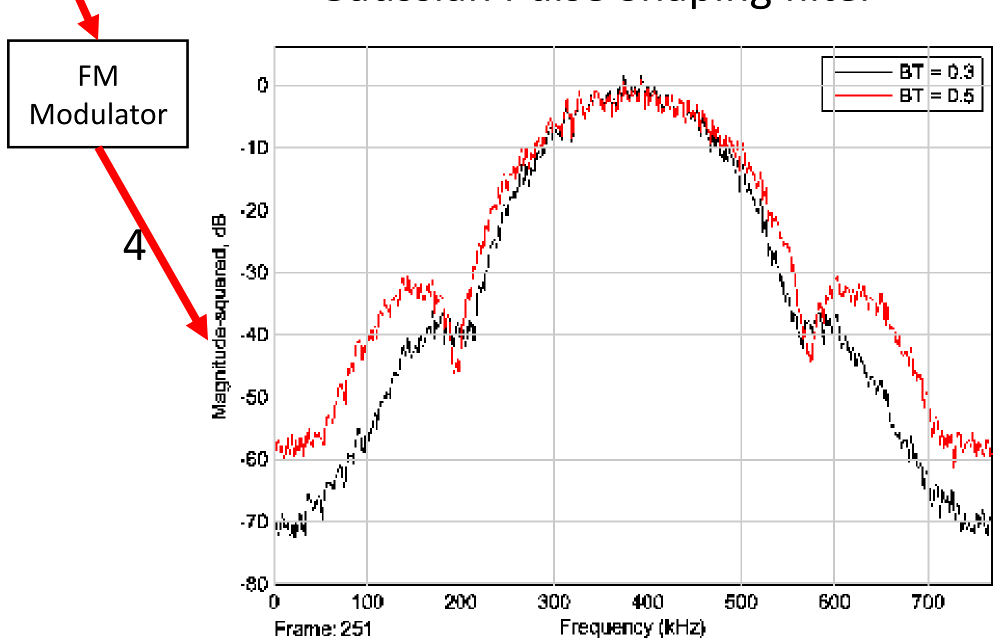


GMSK PSD

GMSK and Pulse Shaping Filter – more details



Gaussian Pulse Shaping filter



GMSK Power Spectral Density

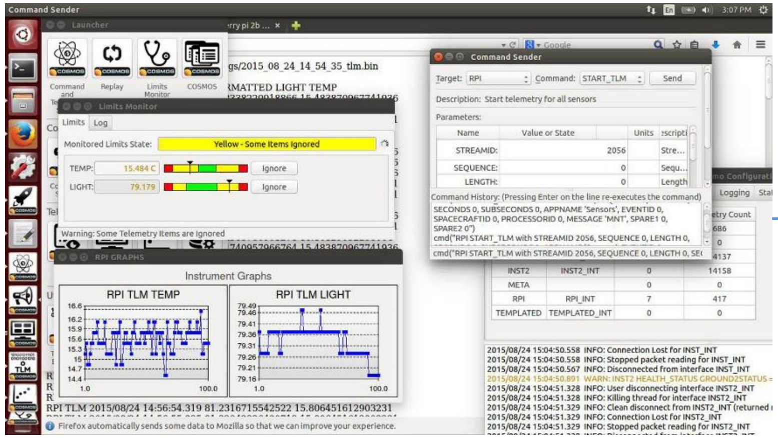
- Pulse shaping smooths out instantaneous transitions, which reduces side lobes in the produced signal.
- Rolloff factor of pulse shaping filter controls ‘smoothness’ of curves. Is between 0 and 1 where 0 is a rectangular filter (i.e. no different than no filtering). Sometimes called β, sometimes α, sometimes BT.
- For Amateur Satellites, BT = 0.5 is common.

Summary of process so far……

Uplink Only Scenario (for simplicity)

Agnostic to what type of TNC/Radio interface is used

Client Software (Satellite TC/TM Software)



①

AX.25 Transfer Frame Header (128 bits)				Information Field
DESTINATION ADDRESS	SOURCE ADDRESS	Control Bits	Protocol Identifier	
56	56	8	8	0-2048

②

FEND (1 Byte)	COMMAND (1 Byte)	DATA (0-N Bytes)	FEND (1 Byte)

③

TCP Socket

OR

Serial Port

1. Client Software generates a properly formatted AX.25 Frame with Telecommand in Information Field.
2. Client Software *encapsulates* the AX.25 Frame inside the DATA field of a KISS Frame
3. Client Software writes the KISS Frame to the TNC via Serial or TCP/IP

TNC KISS Processing

4

FEND (1 Byte)	COMMAND (1 Byte)	DATA (0-N Bytes)	FEND (1 Byte)

5

TNC Parameter Control Functions & Port Routing

AX.25 Transfer Frame Header (128 bits)				Information Field
DESTINATION ADDRESS	SOURCE ADDRESS	Control Bits	Protocol Identifier	
56	56	8	8	0-2048

6

HDLC Processing

4. TNC Receives the KISS FRAME (Serial or TCP), removes/replaces escaped bytes if necessary, discards the FEND Bytes
5. The command byte is passed off for TNC parameter control and port routing. It is REMOVED from the byte stream.
6. The DATA field, which contains an AX.25 frame, is extracted and passed off to HDLC steps

TNC HDLC Processing

7

AX.25 Transfer Frame Header (128 bits)				
DESTINATION ADDRESS	SOURCE ADDRESS	Control Bits	Protocol Identifier	Information Field
56	56	8	8	0-2048

8

AX.25 Transfer Frame Header (128 bits)					
DESTINATION ADDRESS	SOURCE ADDRESS	Control Bits	Protocol Identifier	Information Field	Frame Check Sequence
56	56	8	8	0-2048	16

9

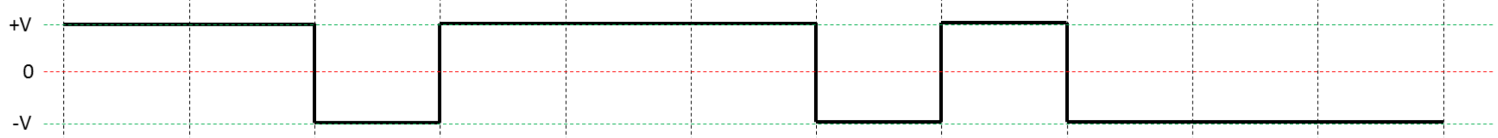
	AX.25 Transfer Frame Header (128 bits)						
FLAG	DESTINATION ADDRESS	SOURCE ADDRESS	Control Bits	Protocol Identifier	Information Field	Frame Check Sequence	FLAG
8	56	56	8	8	0-2048	16	8

9

0	1	0	0	1	1	0	0	0	1	1

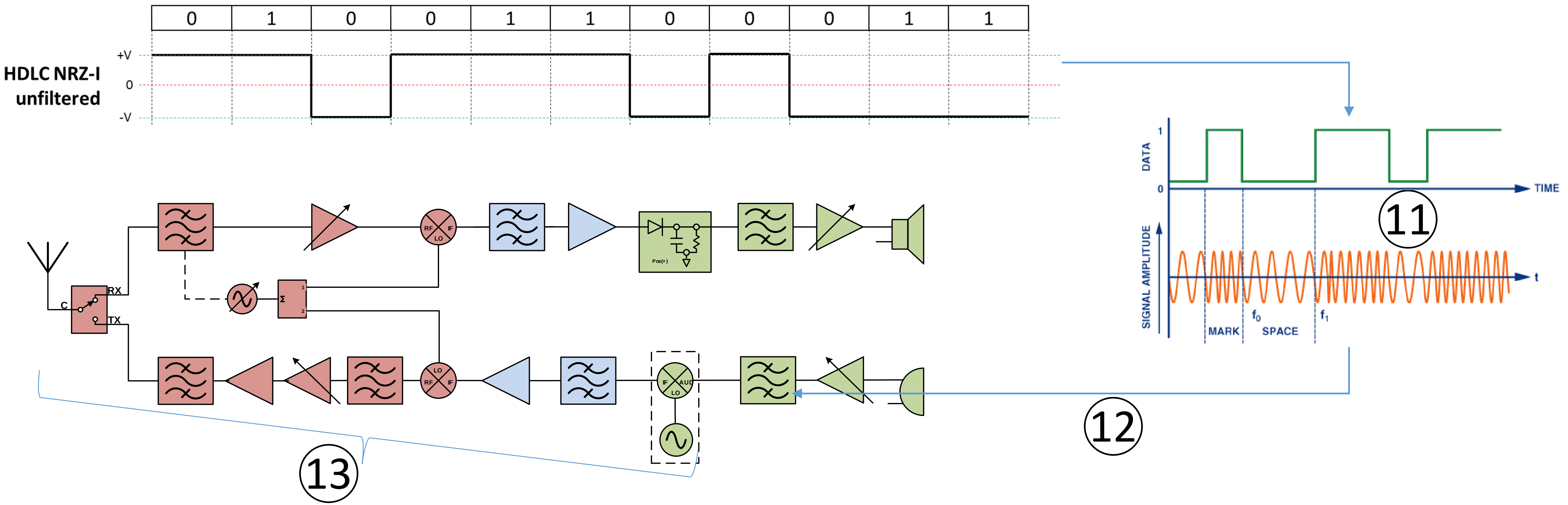
10

HDLC NRZ-I unfiltered



7. HDLC Processing receives the AX.25 Frame
8. Frame Check Sequence is computed and appended to the Frame, Bit stuffing occurs (not depicted)
9. FLAGs are appended and prepended to the Frame (usually many flags on both ends)
10. Bit stream of frame is line encoded (HDLC NRZ-I), Most significant byte first (except FCS, flipped), LSB first

AFSK Modulation

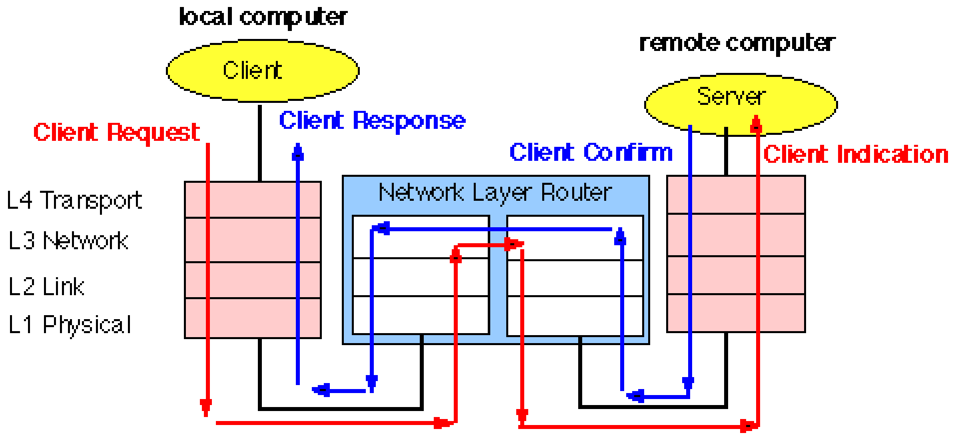


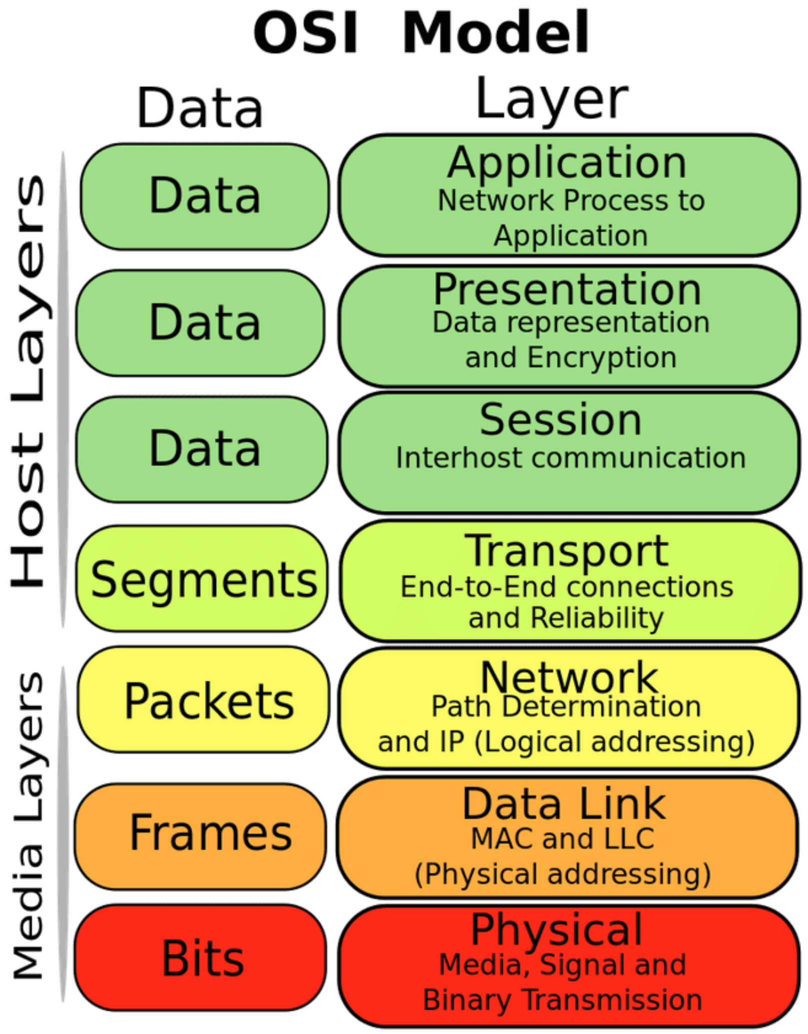
11. HDLC NRZ-I encoded bit stream is input to the AFSK Modulator; CPFSK modulation is used to produce an output AFSK signal
12. TNC triggers push to talk (PTT) line to place radio in transmit mode; AFSK Signal is passed into the DATA IN port of the radio on the DATA JACK (packet mode 1200 tap point)
13. AFSK signal is sent through the FM Modulation process and radiated out of the radio.

Open Systems Interconnect Model

Open Systems Interconnect (OSI) Stack

- Devices logically communicate at the relevant layers
- Encapsulation
- Headers
- Standards (for interchangeable layers)

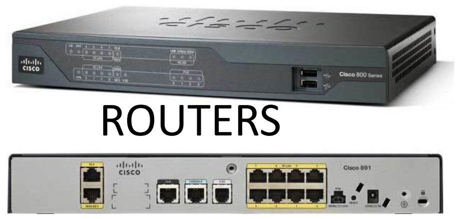


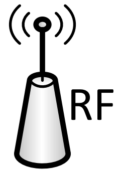


OSI Stack – Simple Web Browsing Example

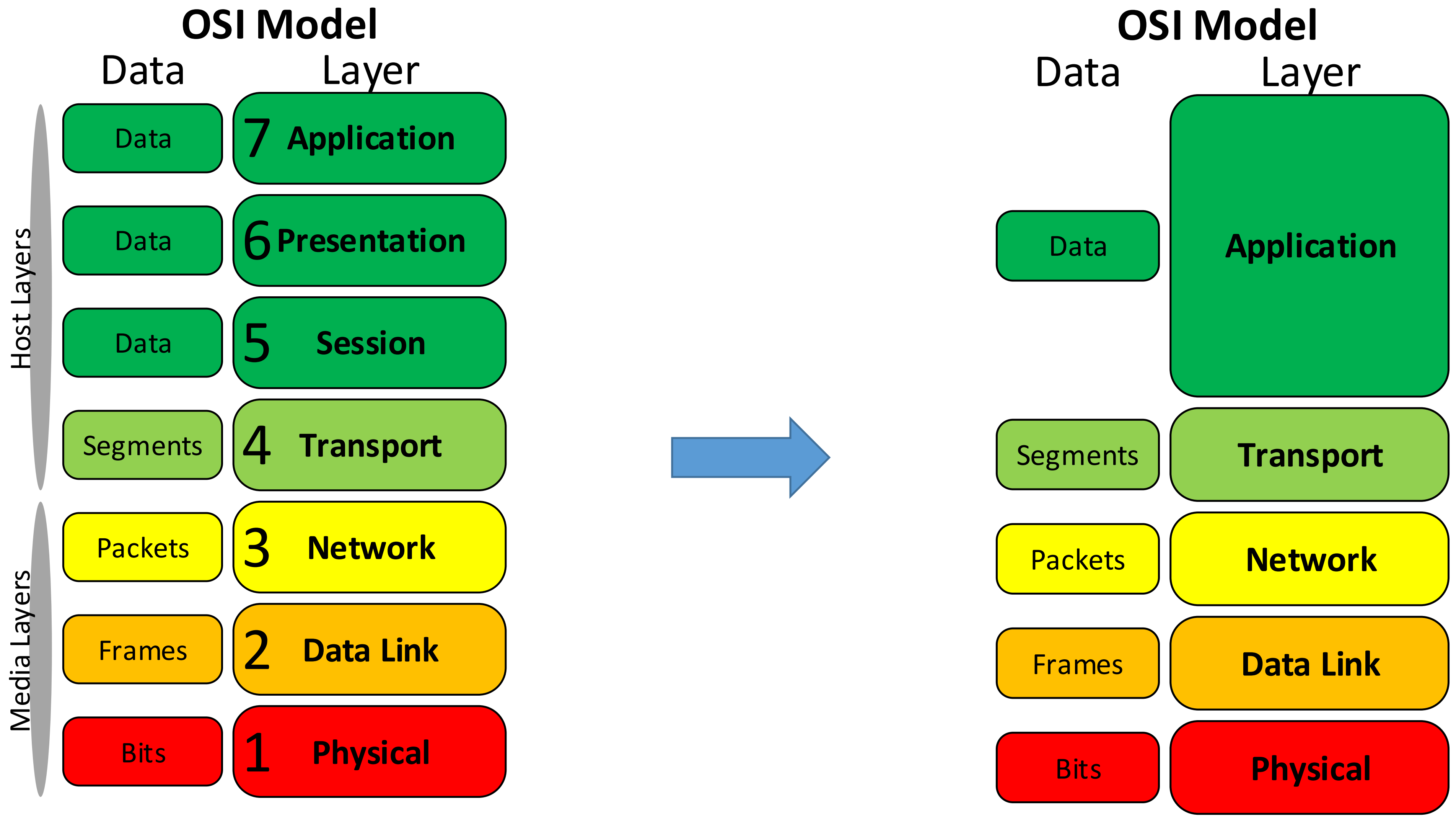
OSI Model

	Data	Layer	
Host Layers	Data	7 **Application**	HTTP (Web Browser)
Host Layers	Data	6 **Presentation**	
Host Layers	Data	5 **Session**	
Host Layers	Segments	4 **Transport**	TCP
Media Layers	Packets	3 **Network**	IP
Media Layers	Frames	2 **Data Link**	MAC
Media Layers	Bits	1 **Physical**	


ROUTERS

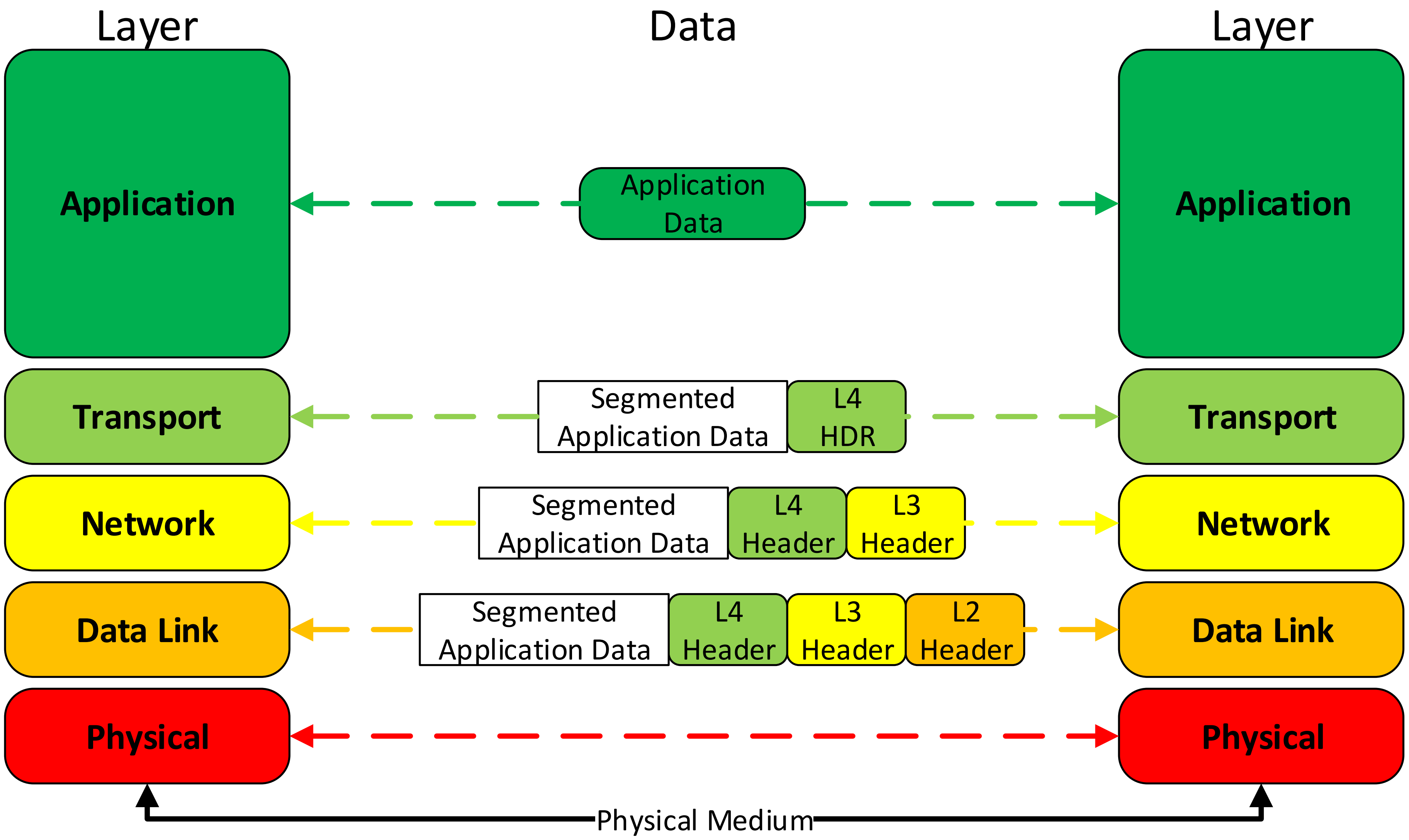


Before We Proceed—a simplification



This is a common simplification which we will use for the rest of this presentation

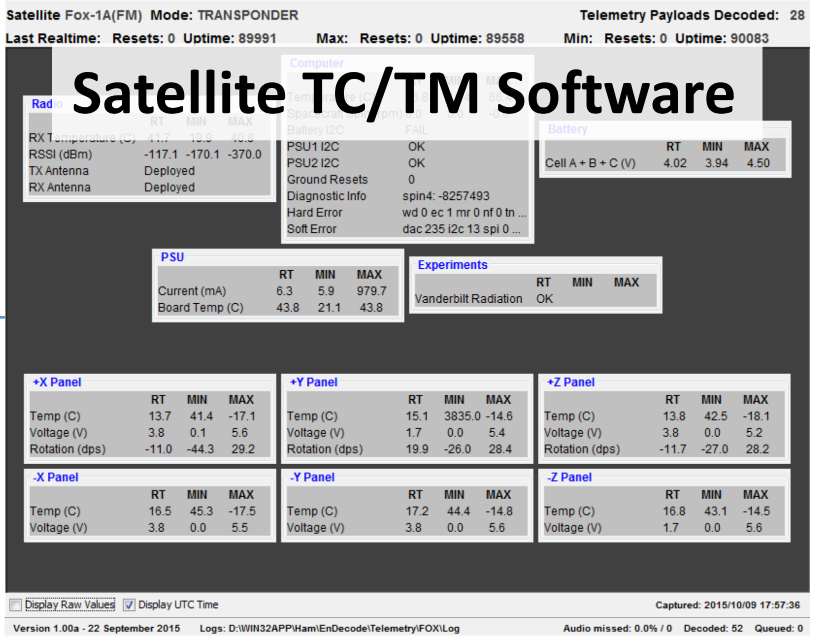
OSI Stack Logical Communication



OSI Stack – Smallsat Comms Example

Data	Layer	
Data	**Application**	Client Application
Segments	**Transport**	TCP
Packets	**Network**	IP
Frames	**Data Link**	MAC /KISS/AX.25/HDLC
Bits	**Physical**	RS-232/AFSK/FSK/GMSK

VPN



Remote Connection

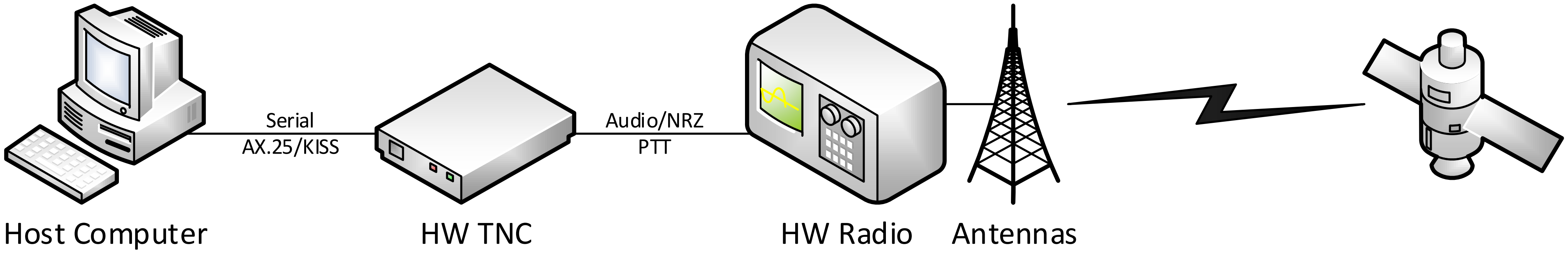
Bring it all together!

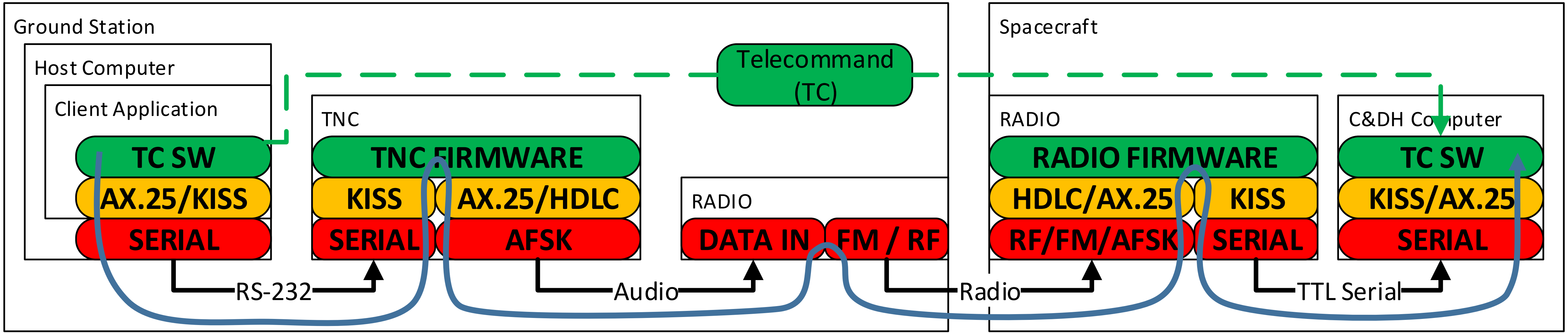
Information overload---what's the point?

- TCP
- IP
- VPN
- KISS
- HDLC
- AX.25
- AFSK
- OSI
- G3RUH GSMK/FSK

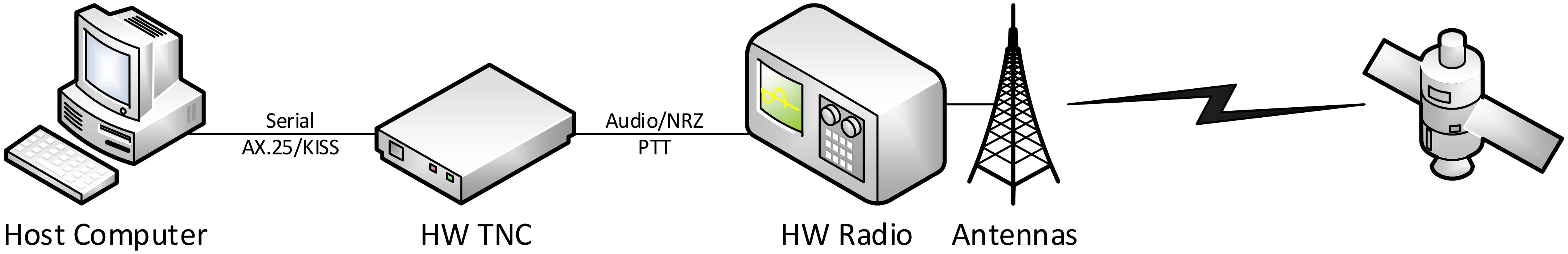
Once again............

OSI Stack for AFSK Uplink – Hardware TNC

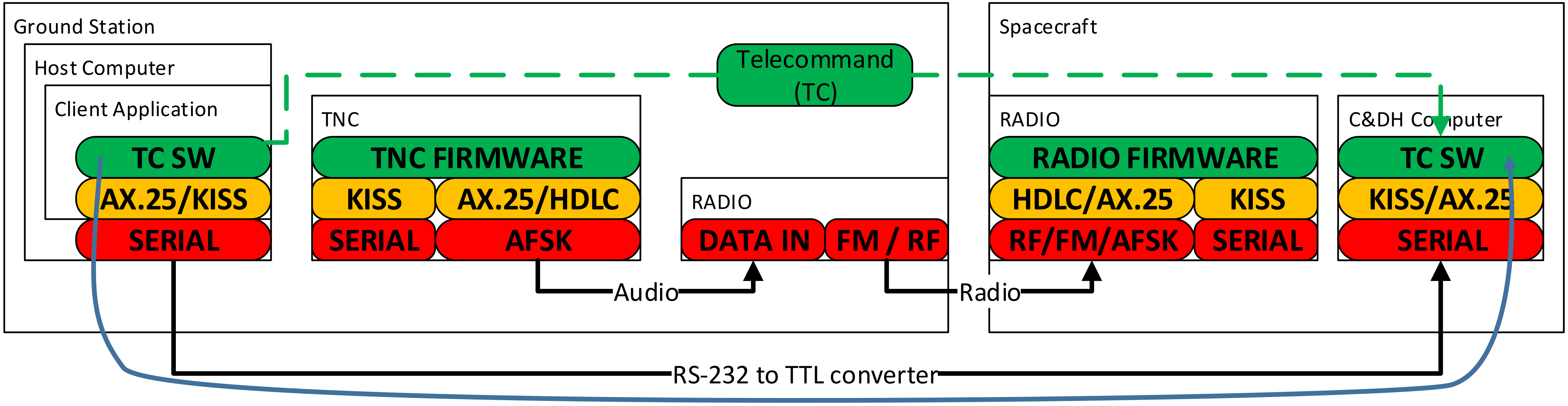




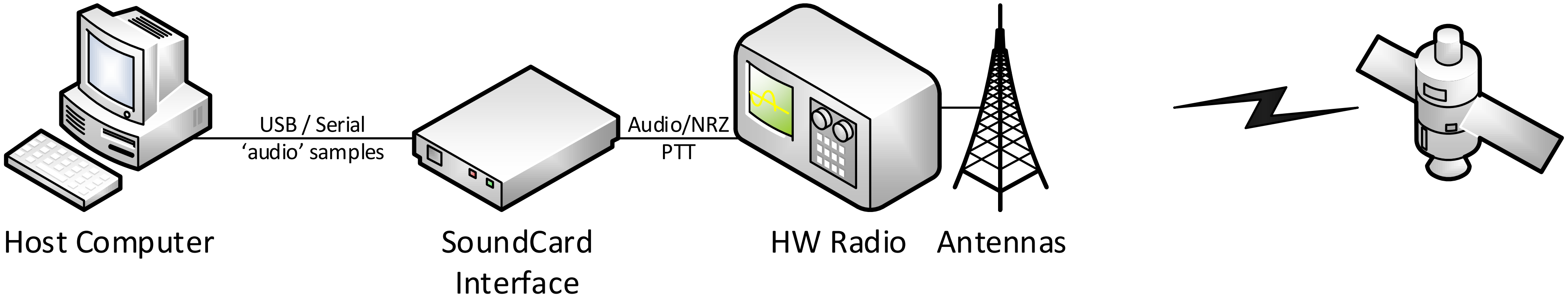
Slight tangent - If you are still developing/testing

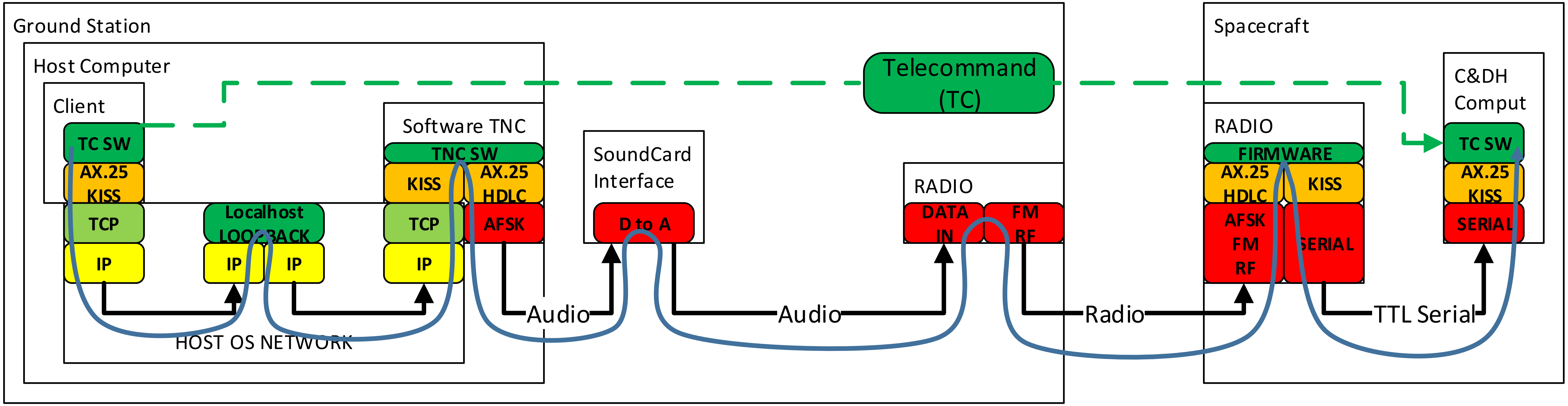


This is the power of adhering to the OSI Model!

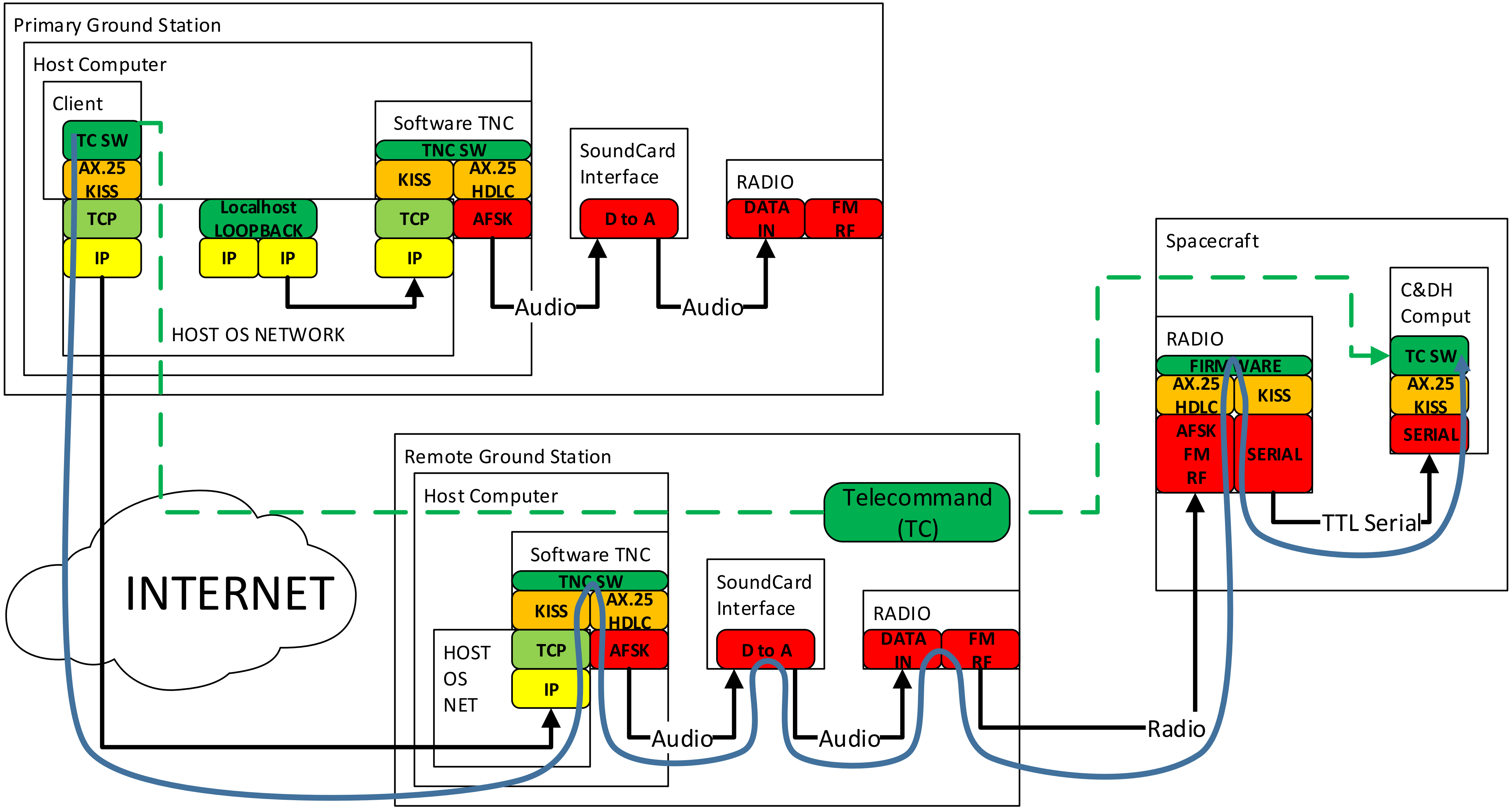


OSI Stack for AFSK Uplink – Software TNC



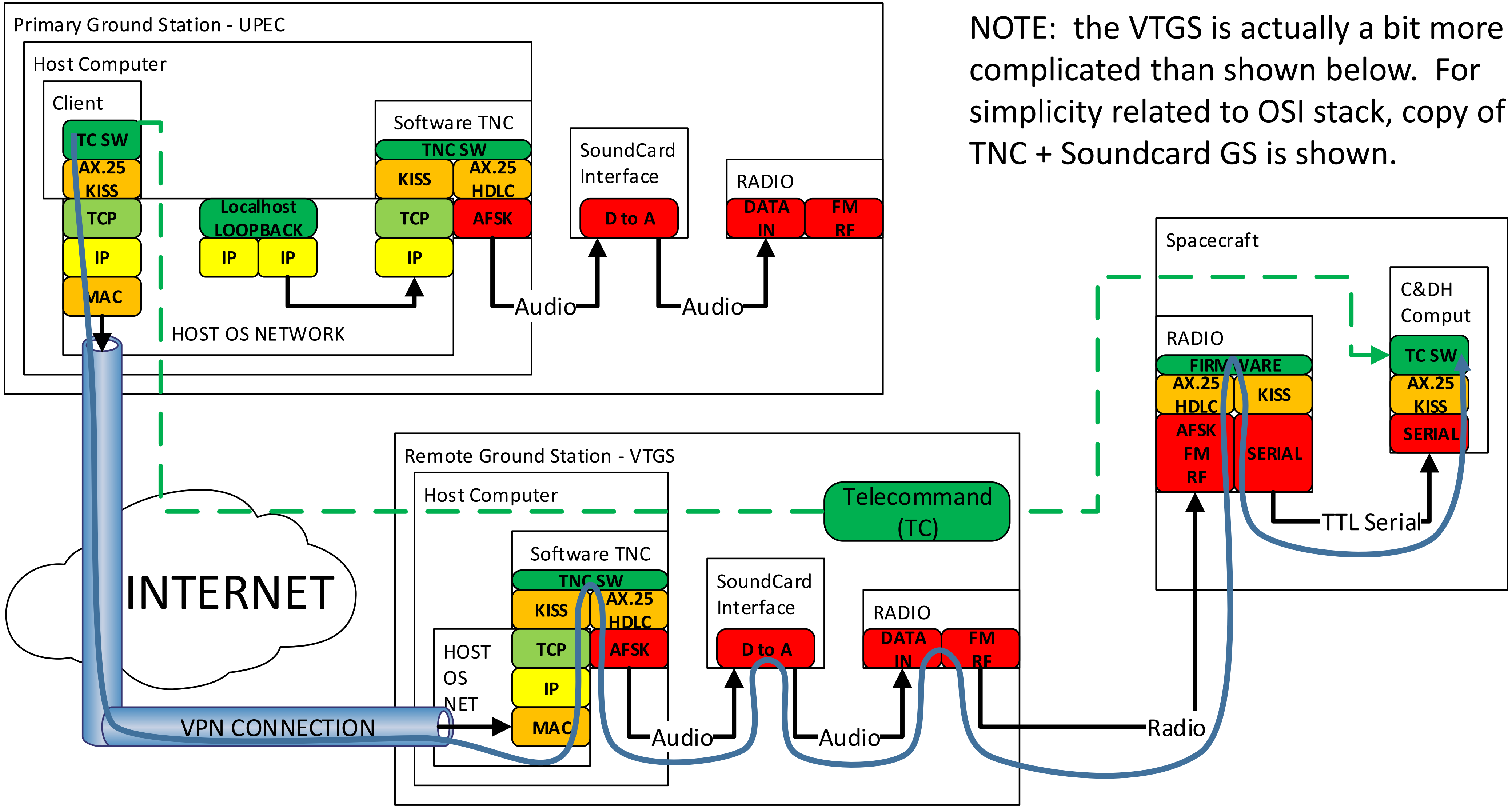


OSI Stack for AFSK Uplink – Remote Connection



OSI Stack for AFSK Uplink – VTGS Connection

NOTE: the VTGS is actually a bit more complicated than shown below. For simplicity related to OSI stack, copy of SW TNC + Soundcard GS is shown.



Summary

The Key things to remember

Summary – Key points to remember

- Telemetry (TM) processing and Telecommand (TC) generation software specific to the satellite must be written if it does not already exist.
- The structure of the of the Information Field for TC/TM must be defined (ICDs).
- **The TC/TM Software must output an AX.25 Frame encapsulated in a KISS Frame for uplink and expect to receive a KISS Frame containing an AX.25 Frame from downlink.**
- It is **HIGHLY** recommended that the TC/TM software utilize TCP/IP sockets for transport of KISS Frame. This interface is common with software TNCs and is necessary for the Internet based remote connection to the VTGS.
- I am NOT an expert on the IC-9100. I've given some pointers on the cable fabrication and testing process…..but double checking functionality and configurations specific to the IC-9100 (Menu settings) need to be done at UPEC.
- This presentation is pretty specific to TNC Interfacing (with relevant deviations). Topics not addressed for full ground station design and implementation would have resulted in at least double the slide deck length…(link analysis, antenna design, noise characterization, amp design, tracking, sequencing, message passing, data storage, metadata generation, etc. etc.)……..

Thank You!

And remember…..Don’t Panic!.....It’s all gonna work!