gr-satellites

A collection of GNU Radio decoders for Amateur satellites

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About the speaker

- PhD in Mathematics
- Day job: in GMV (Madrid) as a GNSS engineer, developing GNSS receivers and simulators, especially for Galileo
- Independent researcher in radio communications, radio science, space systems and other topics
- Amateur radio operator: EA4GPZ (Spanish callsign), M0HXM (UK callsign)
- Blog `http://destevez.net`
- Twitter @ea4gpz

Outline

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gr-satellites

- A GNU Radio out-of-tree module with a collection of telemetry decoders for Amateur satellites
- Input: IQ RF samples (from SDR, conventional radio or recording)
- Output: packets in hex or parsed telemetry values
- Currently supports more than 80 different satellites
- More than 70 custom blocks, many of them implemented in Python
- Project goal: providing an open-source solution for decoding every satellite that transmits on Amateur bands
- Essentially a one man's project, but I'm eager to collaborate with other people

Origins of the project

- Started in 2015 as experiments to decode some Amateur satellites which nobody had decoded before (other than the satellite owners). These often involved some reverse-engineering.
- Motivations:
  - Learning and fun
  - ITU Radio Regulations state that Amateur transmissions “shall not be encoded for the purpose of obscuring their meaning”. This means that all Amateur transmissions should have a readily available decoder or public specifications.
- People started to find these experiments useful, so the idea to collect them under a comprehensive collection gave rise to gr-satellites
- Since then, I have been adding support for newer Amateur satellites as they get launched

Usual development workflow

- A new satellite gets launched
- Amateurs do some recordings of the signal
- I work with the recordings and documentation available online to see what protocols/specifications are used
- Usually the documentation is incomplete or inexistent: do reverse-engineering or try to get in touch with the satellite team to ask questions
- If all goes well, eventually we figure out all the specifications
- Write a decoder, put up a blog post

A few words about documentation

- Currently there is an ongoing discussion in the Amateur community about the importance of publishing documentation and specifications about the signals used by Amateur satellites
- We are trying to get things more strict: complete specifications must be publicly available at some point before launch
- If you are designing a satellite that will use Amateur radio spectrum, please do:
  - Get in contact with the Amateur community. We are here to help
  - Write and publish good and complete specifications for your protocols

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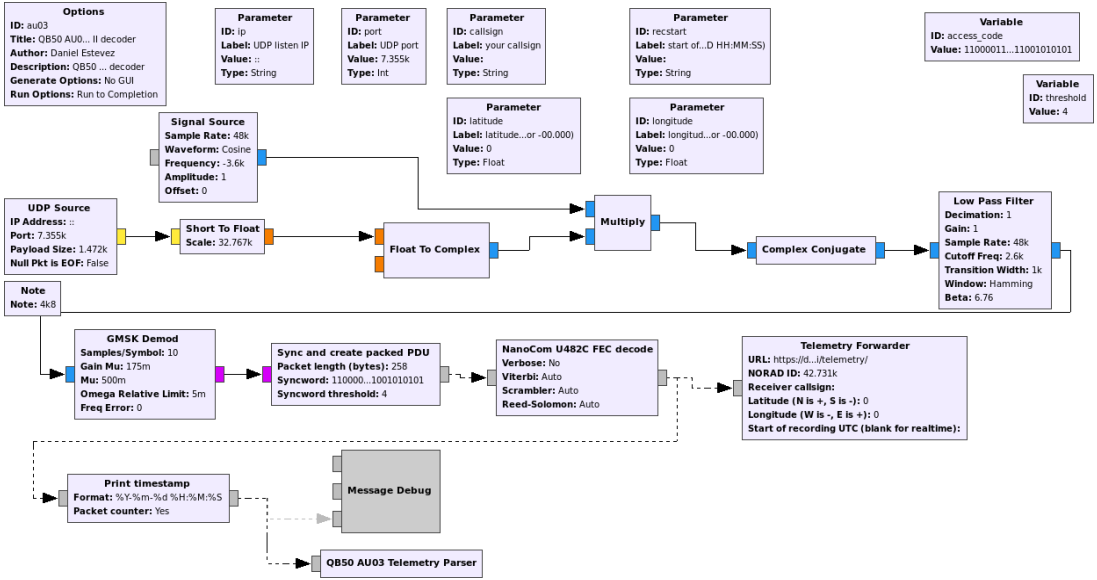
Structure of the project

- Each satellite has its own flowgraph
- Basic information about each flowgraph is included in the README
- The flowgraph contains the telemetry decoder (from IQ to PDUs) and telemetry parsers, image decoders and telemetry submitters as appropriate
- No GUI
- Some configuration parameters. Designed to run as a `.py` script from the terminal.
- Output gets printed to the terminal, or passed on via sockets or files

Input format

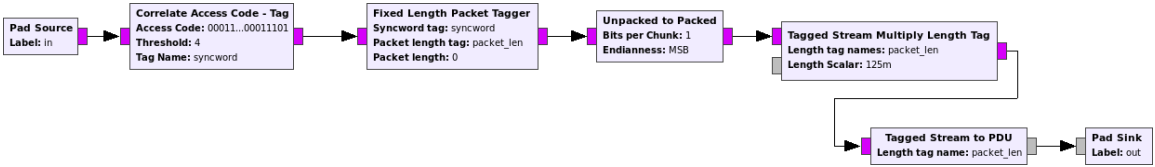
- Supporting different input formats can be cumbersome
- I settled on real time UDP input with a (real) `float32` signal at 48ksps.
- Reasons:
  - Many people have 48ksps audio recordings from conventional radios or SDRs
  - GQRX can stream audio with UDP using this format
- Depending on the modulation, something different is expected:
  - FM/FSK. FM demodulated audio
  - Narrow bandwidth linear (e.g. 1k2 BPSK). Conventional SSB audio (0-3kHz) with signal centred at 1.5kHz.
  - Wide bandwidth linear (e.g. 9k6 BPSK). Wide SSB audio (0-24kHz) with signal centred at 12kHz.
- Ways to feed input:
  - GQRX
  - gr-frontends: UDP streamers from WAV recordings, audio source, and some SDR hardware
  - Build your own using netcat


Options
ID: au03
Title: QB50 AU0... II decoder
Author: Daniel Estevez
Description: QB50 ... decoder
Generate Options: No GUI
Run Options: Run to Completion
Parameter
ID: ip
Label: UDP listen IP
Value: ::
Type: String
Parameter
ID: port
Label: UDP port
Value: 7.355k
Type: Int
Parameter
ID: callsign
Label: your callsign
Value:
Type: String
Parameter
ID: recstart
Label: start of...D HH:MM:SS)
Value:
Type: String
Variable
ID: access_code
Value: 11000011...11001010101
Variable
ID: threshold
Value: 4
Parameter
ID: latitude
Label: latitude...or -00.000)
Value: 0
Type: Float
Parameter
ID: longitude
Label: longitud...or -00.000)
Value: 0
Type: Float
Signal Source
Sample Rate: 48k
Waveform: Cosine
Frequency: -3.6k
Amplitude: 1
Offset: 0
UDP Source
IP Address: ::
Port: 7.355k
Payload Size: 1.472k
Null Pkt is EOF: False
Short To Float
Scale: 32.767k
Float To Complex
Multiply
Complex Conjugate
Low Pass Filter
Decimation: 1
Gain: 1
Sample Rate: 48k
Cutoff Freq: 2.6k
Transition Width: 1k
Window: Hamming
Beta: 6.76
Note
Note: 4k8
GMSK Demod
Samples/Symbol: 10
Gain Mu: 175m
Mu: 500m
Omega Relative Limit: 5m
Freq Error: 0
Sync and create packed PDU
Packet length (bytes): 258
Syncword: 110000...1001010101
Syncword threshold: 4
NanoCom U482C FEC decode
Verbose: No
Viterbi: Auto
Scrambler: Auto
Reed-Solomon: Auto
Telemetry Forwarder
URL: https://d...l/telemetry/
NORAD ID: 42.731k
Receiver callsign:
Latitude (N is +, S is -): 0
Longitude (W is -, E is +): 0
Start of recording UTC (blank for realtime):
Print timestamp
Format: %Y-%m-%d %H:%M:%S
Packet counter: Yes
Message Debug
QB50 AU03 Telemetry Parser

A very useful block: Sync and create (packed) PDU

- Most satellites transmit packets of a fixed size or with a (small) MTU
- Packets are marked by a syncword at the beginning
- Sync and create PDU extracts a PDU of fixed size whenever the syncword is detected
- “Overlapping packets” are allowed. Useful for shorter packets or false syncword detections

Sync and created packed PDU

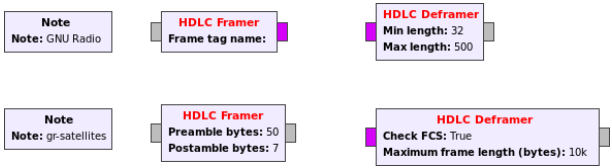


- Fixed Length Packet Tagger is a custom Python block. It outputs a packet and `packet_len` tag whenever it sees a syncword tag.
- Maybe I should be using Protocol Parser for this?

Working with KISS files to store packets

- The KISS protocol was originally designed to interface a TNC (packet radio modem) and a host
- It is a way of marking frame boundaries and sending control commands
- These days is often used to delimit frame boundaries in files, TCP streams, etc.
- Very simple protocol: one frame-delimiter byte to mark frame boundaries, one escape byte to escape the frame-delimiter byte or the escape byte if they occur in the data

Custom HDLC Framer and Deframer



- Implemented in Python
- They do not have NRZ-I built in. Sometimes HDLC is used without NRZ-I (usually a bad idea).
- Framer can add a preamble and postamble of arbitrary length. Long preamble important for clock recovery in the receiver.
- Deframer can skip CRC-16 check. Useful for debugging.

Some other useful components

- Decoders for GOMspace radios U482C and AX100. Many satellites use these.
- Texas Instruments CC11xx and SiLabs Si4463 decoders.
- Several FEC decoders:
  - CCSDS Viterbi
  - CCSDS or general Reed Solomon (uses Phil Karn's libfec)
  - Reed Solomon decoder with rscode (perhaps redundant)
  - BCH decoder
  - Golay decoder
- Several descramblers:
  - G3RUH asynchronous
  - CCSDS synchronous
  - IESS-308 asynchronous
  - PN9 synchronous (TI and SiLabs variants)
- Several CRC checkers

Outline

Latest developments

- June. Contract with SatRevolution to adapt gr-satellites to decode their Światowid and KRAKsat satellites
- July–September. ESA Summer of Code in Space: Athanasios Theocharis (Univ. of Thessaloniki) adding blocks for the CCSDS Space Packet, TM Space Data Link and TC Space Data Link protocols

On the roadmap

- Port to GNU Radio 3.8 and Python 3
- Rearchitecture:
  - More modularity in the decoders: easier to add a satellite, easier to change some component in all applicable satellites
  - Flexibility in selecting the outputs: selecting different kinds of outputs, ability to output different things to files
  - Flexibility in selecting the inputs: UDP IQ realtime input, WAV file at faster speed
  - Perhaps optional GUI elements
  - What other features would be useful?
- Including FSK demodulators by David Rowe
- Adding tests. End-to-end tests with sample recordings from `satellite-recordings`.
- Not yet 100% sure on how to go about these, so comments are welcome
- Remember that gr-satellites is my largest project, but it is also a kind of “side project”. It only gets perhaps 10% of my time. Remaining 90% goes to other varied smaller projects or experiments.

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