Receiving weather satellite signals using SDR

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About me

- KK6VXV -- Licensee since Aug 2015 (General)
- Background in Computer Science
- Interested in space/astronomy since long
- Interested in RF since couple of years
- SDR combines software & RF!
Outline

- Types of weather satellites
- Signal acquisition -- passes, antennas, radios
- Signal processing -- analysis, demodulation, decoding
- Going further
Types of satellites

- **Polar Orbiting Environmental Satellites (POES)**

- Sun-synchronous orbit (400-600 mi)
- Orbital plane rotates as earth orbits the sun (~1° per day)
Types of satellites

- **Geostationary Orbiting Environmental Satellites (GOES)**
  - GOES-13 (2006, 75° W, “east”)
  - GOES-14 (2009, 105° W, on-orbit storage)
  - GOES-15 (2010, 135° W, “west”)

- Geosynchronous equatorial orbit (22,236 mi)
Relevant direct readout services

- **Automatic Picture Transmission (APT)**
  - Analog transmission on VHF (137 MHz, ~38 KHz wide)
  - Used since 1960s
- In use on remaining NOAA POES satellites
- Transmits measurements of AVHRRR instrument
- FM and can be RX’d *without* SDR
Relevant direct readout services

- **Low-Rate Picture Transmission (LRPT)**
  - Digital transmission on VHF (137 MHz, ~150 KHz wide)
  - Used since 2000s
- Present on METOP-A, but disabled after launch
- In use on METEOR-M satellites
- QPSK modulated
Relevant direct readout services

- **(Adv.) High-Resolution Picture Transmission ((A)HRPT)**
  - Digital transmission on L-band (~1700 MHz, 4.5 MHz wide)
  - Used since 2000s

- In use on NOAA, METOP, METEOR satellites

- BPSK or QPSK modulated
Sat Apr 11th 2015, 3PM, NOAA-19, HRPT, RX by @usa_satcom
Satellite passes

- Any orbit can be described by “orbital elements”
- Encoded in Two-Line Element sets (also: TLEs)
- Orbits cannot be predicted indefinitely
- Update TLEs every ~week (see CelesTrak.com)
Satellite passes

- Find out your position (GPS or lookup online)
- Compute passes of any object over your location
- Typical resulting parameters:
  - Acquisition of signal (when appears over horizon, also: **AOS**)
  - Loss of signal (when disappears over horizon, also: **LOS**)
  - Azimuth at AOS
  - Azimuth at LOS
  - Azimuth at maximum elevation
  - Maximum elevation
Satellite passes

- Gpredict (Linux, right)
- WXtrack (Windows)
- Heavens-Above.com (Web)
- SkyView Satellite Guide (iOS)
- Many, many more…
Antenna

- No experience with L-band yet, maybe next year…
- Only focusing on 137 MHz here (APT, LRPT)
- Signal has Right-Hand Circular Polarization (RHCP)
- Two categories: with/without tracking
Antenna: tracking

- Tracking only needed for gain antennas
- Crossed Yagi or normal Yagi (-3dB)
- Helical antenna (corkscrew)
Antenna: no tracking

- No tracking means omnidirectional antenna
- A regular 2 meter vertical won’t do it… (only terrestrial)
- More prone to interference (e.g. ACARS)
- Most frequently used designs:
  - Crossed dipole (also: turnstile)
  - Quadrifilar Helix Antenna (also: QFH)
Antenna: at my QTH

- First used Arrow Yagi, with “manual” tracking
- Built QFH (soft copper conductors, PVC body)
- 80ft of RG-58/U (~5dB loss)
- Bias-T in shack, LNA at antenna (LNA4ALL)
Software Radio

- APT is 38 KHz wide, LRPT is 150 KHz wide
- SDRs only capture baseband signal, don’t do processing
- Often advertised with frequency range & bandwidth
- For example:
  - RTL-SDR, 24-1700 MHz, 2.4 MHz b/w (~$20)
  - AirSpy, 24-1800 MHz, 10 MHz b/w (~$200)
  - HackRF One, 1-6000 MHz, 20 MHz b/w (~$300)
  - USRP, 0-6000 MHz, up to 56 MHz b/w (~$1100)
Radio Software

- Always need software to control these SDRs
- Tune, configure bandwidth, LNA/IF gain
- Most software can also mix/filter/demodulate
- For example:
  - GNU Radio (Linux, OSX)
  - GQRX (Linux, OSX)
  - SDRsharp (Windows)
  - HDSDR (Windows)
GQRX receiving 2.5 MHz centered on 137.5 MHz (using AirSpy)
NOAA-18 APT at 137.9125 MHz, Jan 18th 2016, 4PM, RX by KK6VXV
Recording

Tuned frequency

Demodulation

Translated frequency

Spectrum of demodulated signal

Waterfall of entire band

40 KHz band pass

412.900 kHz
Recording

- Either record baseband data directly…
  - 2.5M samples/sec x 2 (I & Q) x 2 bytes (16 bit integer) = 10MB/sec
  - Good pass (15 minutes) = ~9GB

- … or translate and filter on the fly:
  - APT baseband (~38 KHz): 40K x 2 (I & Q) x 2 bytes = 160KB/sec
  - Good pass (15 minutes) = ~144MB

- … or also apply frequency demodulation:
  - APT audio (~ 11 KHz): 11K x 2 bytes = ~22KB/sec
  - Good pass (15 minutes) = ~20MB
APT: Analyzing the signal

- 137.5 MHz center
- 2.5 MHz wide
- 15 minutes
- NOAA-18
  - APT
  - 137.9125 MHz
  - Jan 19th 2016
  - 6AM pass (quiet)
APT: Analyzing the signal

- Zoom on carrier
- Doppler shift
- +/- ~3KHz
- Freq. shift translates to DC offset
APT: Analyzing the signal

- Zoom on time
- 137.9115 MHz
  - -2 KHz offset
- FM’d of signal
- AM’d on
- 2400 Hz carrier
APT: Analyzing the signal

- Let’s listen (if we have audio here)
  - “tick, tock, tick, tock, …” (two tick-tocks per second)
- Let’s look
  - Recognize the signal’s envelope
APT: Demodulation

- Easiest to do “live” in SDR software; record WAV file
- Otherwise, you can use GNU Radio (for example), to:
  - Shift baseband to center APT carrier
  - Apply band pass filter to +/- 20 KHz
  - Decimate signal (e.g. 2.5 MHz to 50 KHz)
  - FM demodulate
  - Write RAW or WAV signal to disk
APT: Processing

- Signal contains 2 channels, 1040 pixels wide each
- Sync preamble on every line (for slant correction)
APT: Processing

- Many programs available for decoding APT signals
- For example:
  - WXtoImg; feature rich, channel combinations, map overlay
  - apt137; written by myself, open source, synchronizes & normalizes
Mon Jan 18th 2016, 2PM, NOAA-19, APT, RX by KK6VXV
WXtolmg, HVC “false color” enhancement, map overlay
LRPT: Analyzing the signal

- 137.5 MHz center
- 2.5 MHz wide
- 15 minutes
- METEOR-M N1
  - LRPT
  - 137.1 MHz
  - Jan 19th 2016
  - 8AM pass
LRPT: Analyzing the signal

- Zoom on carrier
- 150 KHz wide
- Doppler present but hardly visible
- QPSK looks like broadband noise
LRPT: Acquisition

- Easiest to do “live” in SDR software; record raw I/Q data
- Create 150 KHz filter around 137.1 MHz
- Otherwise, shift/filter/decimate in GNU Radio (like APT)
LRPT: Processing

- Carrier tracking to lock onto real frequency
- Synchronization, error correction, framing
- Baseband to locked QPSK constellation / bit stream:
  - LrptRx (Windows only)
  - GNU Radio flow graph
- Bit stream to data:
  - LRPToffLineDecoder (Windows only)
LRPT: Processing
Closing thoughts

- APT won’t be around forever
- All direct readout services will be digital
- Moving to L-band and X-band (8 GHz)
- Pick up APT while you can, easy and fun!
- LRPT more involved, but doable!
Links

- World Meteorological Organization -- Satellite index
  - [http://www.wmo-sat.info/oscar/spacecapabilities](http://www.wmo-sat.info/oscar/spacecapabilities)

- QST, October 2009, The Quadrifilar Helix as a 2 meter Base Station Antenna

- Future NOAA Polar Orbiting and Geostationary Satellite Systems
  - [http://noaasis.noaa.gov/NOAASIS/ml/future.html](http://noaasis.noaa.gov/NOAASIS/ml/future.html)
Tools

- Gpredict
- GQRX
- Waterfall (https://github.com/pietern)
- Audacity
- apt137 (https://github.com/pietern)
- WXtoImg
- LrptRx
- LRPToffLineDecoder