All Things Digital

Amateur Radio for the 21st Century

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Slow Scan Television (SSTV): Part 4–APT 102

APT WEATHER SATELLITE RTL-SDR RECEIVING STATION (THEORY AND PRACTISE)

Figure 1 depicts the components of an Automatic Picture Transmission (APT) weather satellite receiving station built around the Realtek software designed radio (RTL-SDR) USB dongle and supporting software. It's a fully automatic, low-cost, battery/solar powered, easy to setup/breakdown portable system you can use at home, for classroom demonstrations, for field work, and/or emergency communications (EmComm) with/without internet or mesh network connectivity.

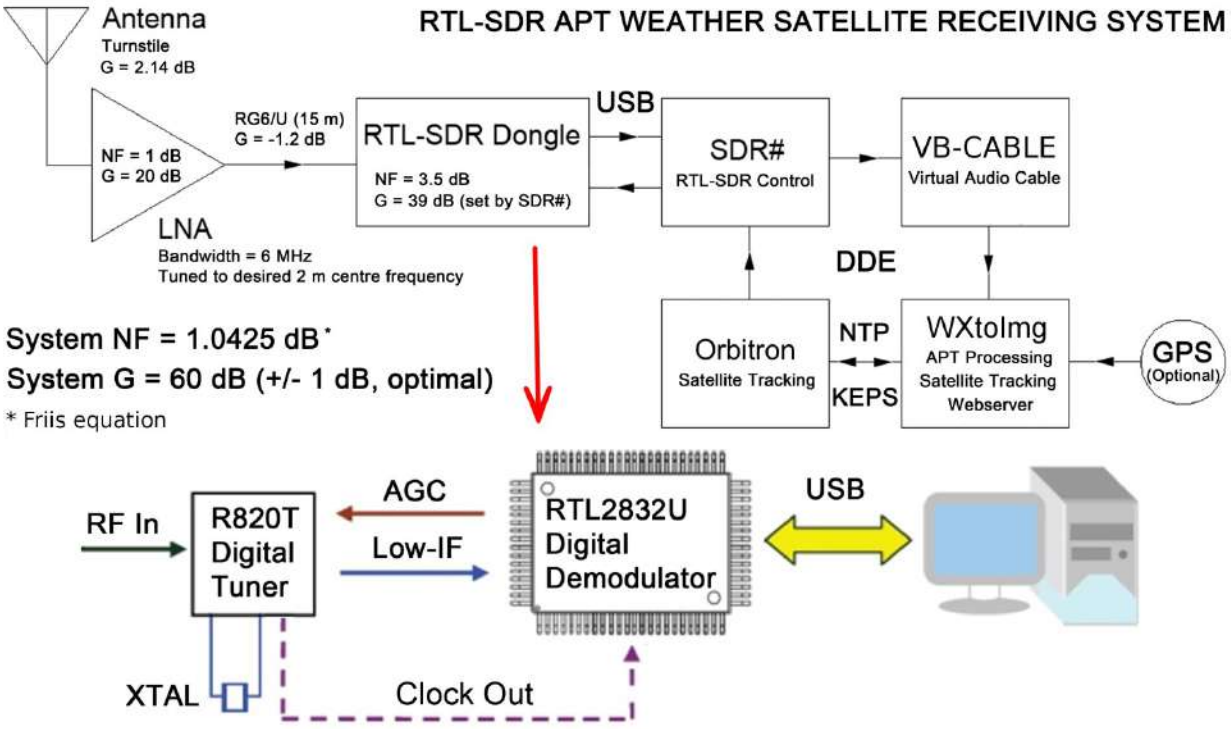

FIGURE 1: *RTL-SDR block diagram courtesy Realtek*

1. ANTENNA

Modern APT signals are continuously transmitted at 37 dBm (5 watts) using a right-hand circular polarized (RHCP) helical or "corkscrew" antenna (Figure 2). Early satellites first tired horizontal and then vertical polarity with so-so results because the Faraday effect causes linearly polarized radio signals to rotate and shift in phase as they travel through and interact with the ionosphere. The ionosphere is an atmospheric upper layer created by incoming solar UV ionizing radiation "blasting" molecules and ripping away their electrons. In addition, the rapidly changing position and distance of the satellite's antenna with reference to a ground station causes fading and noise as the radio signal rotates between horizontal and vertical polarities.

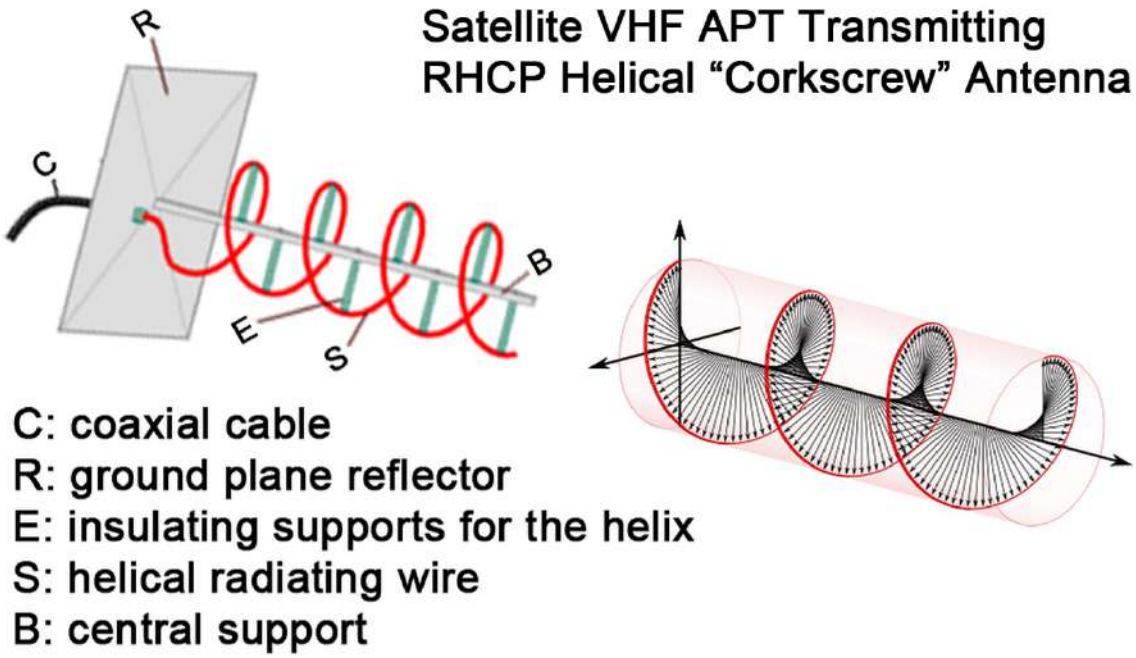

FIGURE 2: *Courtesy Wikipedia*

But if a satellite uses a circularly polarized (CP) antenna, it significantly reduces these problems. *Note: As radio frequency increases the Faraday effect decreases (inversely proportional) and it disappears altogether above 1 gigahertz (GHz).*

When receiving radio signals, the most important factor is the antenna's directivity (reception pattern) and its effect on the incoming signal-to-noise ratio (SNR or S/N) measured in decibels (dB). Antenna gain (meaning power gain) or efficiency is relatively unimportant because both signal and noise are equally affected so this ratio remains the same and can only be degraded by adding noise. We want the highest SNR possible using the minimum amount of gain required. Antenna gain (defined as directivity times efficiency) is unimportant unless the receiving system overall gain is so low that system noise (thermal or "white") dominates. Increasing antenna gain increases directivity making it more directional, and this requires you to move the antenna to follow satellites across the sky else all you will hear is really loud noise most of the time.

Many hobbyist satellite ground receiving stations use simple dual-purpose omnidirectional (RHCP) low-gain antennas such as the quadrifilar helix (QFH) or other "eggbeater" type loop antennas, or the turnstile antenna (Figure 3). They don't require height to work well since satellites are sky high, but mounting antennas at least three metres above ground level (AGL) and well away from any surrounding obstructions minimizes any signal reflections which cause fading and add noise.

FIGURE 3: *APT Turnstile or crossed dipole antennas (homemade and commercial)*

2. LNA

The primary purpose of a low noise amplifier or LNA (Figure 4) is to reduce the overall system noise factor (F) or the ratio of how much system noise is added to the incoming SNR. It is expressed as noise figure (NF) in dB.

$$F = SNR_{IN} / SNR_{OUT} \text{ and } NF\ (dB) = 10\log_{10}(F)$$

Most system noise is added by the first RF amplifier stage because it's literally the "hottest" thing in the receiver chain (at this point) and heat means energy and energy means noise. However, because of a quirk of physics/electronics, cascading (adding) an RF amplifier with a lower noise figure ahead of (preferably at the antenna feed point) a receiver's or another amplifier's input significantly reduces the system NF (Friis noise factor equation refers).

FIGURE 4: LOW NOISE APT AMPLIFIERS

To calculate this, we must convert all noise figures to noise factors, and all power gains to power ratios. This is the simplified Friis equation for cascading two RF amplifiers:

$$F_T = F_1 + (F_2 + 1) / A_{P1} \text{ where power ratio AP} = 10^{(G/10)} \text{ and F} = 10^{(NF/10)}$$

The LNA's other purposes are to decrease free space path loss (FSPL) measured in dB, which varies with distance/frequency, and to reduce normal (not excessive) coaxial feedline attenuation losses (keep the line as short as possible).

$$\text{FSPL (dB)} = 20\log_{10} (\text{distance in km}) + 20\log_{10} (\text{freq. in MHz}) + 32.44$$

A "high-Q" tuned (sharp, narrow bandwidth) LNA with a 1 dB NF and 20 dB gain is a good match for and won't overload our RTL-SDR dongle with its so-so 48 dB dynamic range. Dynamic range is the difference (in dB) between the weakest received signal before it's too noisy, and the strongest received signal before it's too distorted.

You have two choices for providing LNA power: run a separate DC battery/solar (no AC/DC noisy "wall warts") fused power line alongside your coax (simple and easy method) or add a "bias-T" circuit (capacitor/inductor) to insert a DC voltage into the feedline at the receiver and extract DC voltage at the LNA (sometimes called a "power injector"). The bias-T has some insertion loss and will add some system noise, and they are also frequency specific so one designed for HF use isn't suitable for VHF. *Bias-T caveats: Some antenna designs are DC short circuits (like the QFH) and accidentally connecting it to a bias-T powered feedline is not good thing. Or, if you use an antenna switch and absentmindedly switch it to the "grounded" position, poof goes the bias-T! Been there, done that.*

3. FEEDLINE

RTL-SDR dongles are designed for (European) digital FM/TV reception and have 75-ohm input impedance. In receive-only systems, the receiver determines the system input impedance because it is the “load” and the antenna is the “transmitter” and 75-ohm RG-6 type (dual or quad-shield) coax is a perfect match, but keep the run as short as possible. Dual-shield is adequate for VHF/UHF frequencies but quad-shield is better suited for microwave (> 1 GHz) frequencies.

4. RTL-SDR

It was discovered (early 2010) that these inexpensive RTL digital (European format) FM/TV dongles (Figure 5) could be easily reprogrammed and combined with digital signal processing (DSP) programs to turn them into multi-mode, wide-receive frequency (24-1700 MHz) SDRs and other useful electronic devices (spectrum analyzers, panadapters, etc.).These devices have infinitely variable software controlled gains and bandwidths with a 3.5 dB noise figure. However, their dynamic range is limited to about 48 dB because they use 8-bit analog-to-digital conversion (ADC) so we have to be very careful about using too much gain because they easily overload. Pricier SDRs use 10-bit (or higher) ADC and their dynamic range increases dramatically (roughly number of bits times 6). In comparison, low-priced ($1,000) commercial analog APT receiving systems have at least a 1 dB NF with a 80 dB dynamic range and very sharp (extremely high-Q) RF bandpass filters in both the receiver and LNA.

There is a lot of local terrestrial RF in and around the 137 MHz satellite sub-band, especially from high powered paging systems, Iridium communications satellites, and Russian Meteor-M digital weather birds. In addition, the wideband receive capability of the RTL-SDR dongles makes them very prone to strong out-of-band interference—more so if you “crank” up the gain.

FIGURE 5: *RTL-SDR USB dongle, housings, and USB cable with ferrite chokes*

The SDR dongle communicates over and is powered by a USB cable connected to your computer (laptop, desktop, or netbook). However, computer USB power is very "dirty" and "noisy" so never plug any SDR dongle directly into a USB port; instead use a short cable (six inches or so) with a ferrite choke or two. Cheap cables have poor shielding and hobbyists often wrap them with copper or aluminum tape and put their dongles inside metal enclosures. SDRs with temperature controlled crystal oscillators (TCXOs) are becoming more common and preferred because they have low parts-per-million (ppm) frequency errors (typically 0.5 to 1.0 ppm) and low frequency drift. They reach electronic thermal equilibrium quickly, and stay frequency stable even if the ambient air temperature varies (metal housings really help to keep this constant).

SDR#

SDR# pronounced “SDRSharp” (Figure 6) is the “heart and soul” of the system; it interfaces with the SDR and other software using “plugins” (custom program modules) to enhance existing, or add new features and functions. One plugin provides access to and controls the R820T’s three internal RF amplifiers: LNA, variable gain amplifier (VGA) and mixer amplifier. This overrides the RF automatic gain control (AGC) to the RTL2832U digital demodulator, minimizing any added noise by independently adjusting each amplifier’s gain levels. A satellite tracking client plugin connects with several different tracking programs to automatically switch (at the right time) to the required frequency, and also compensate for Doppler effect or frequency shifting caused as a satellite rapidly approaches/recedes to/from your station by keeping the satellite’s signal centred in the SDR’s adjustable intermediate frequency (IF) passband for the entire satellite pass; this also keeps the SNR high. The plugin has a simple scripting control allows you to customize it for any (not just APT) satellites of interest (name, frequency, mode, bandwidth, and so on).

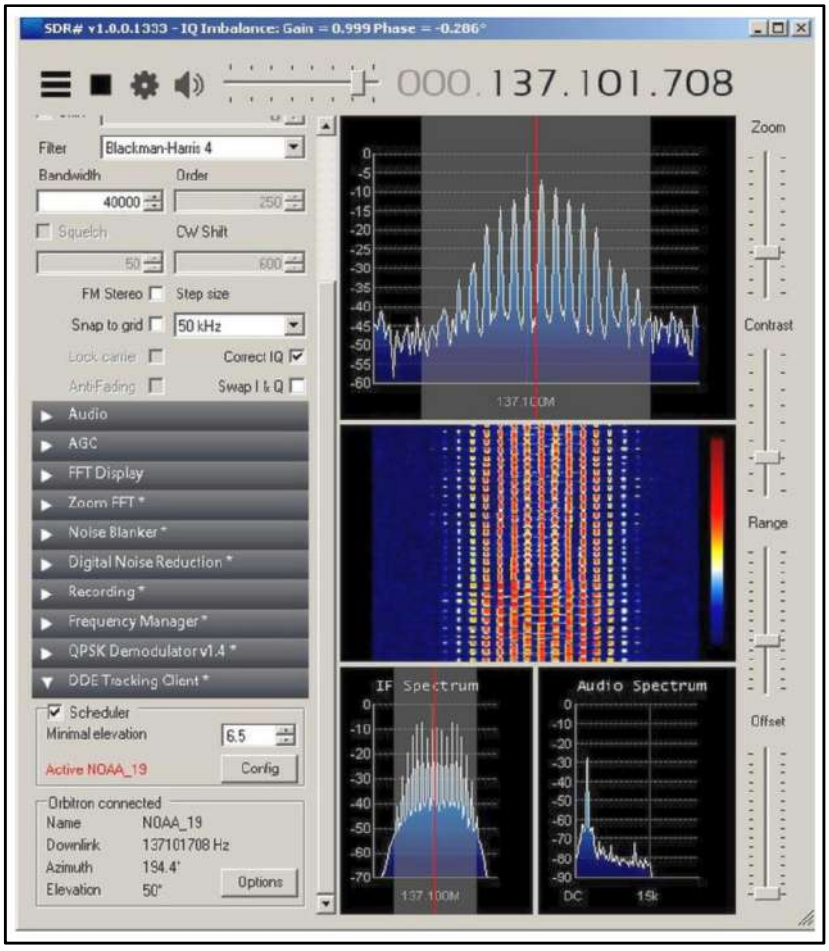

FIGURE 6: SDR#

Here's what the APT signal “looks” like in the SDR# spectrum display (top) and waterfall (just below) along with the IF and audio spectrum views (bottom left and right) indicating 30+ dB SNR. We need at least 24 dB SNR for noise free APT images and also block out any weaker, interfering signals (as much as is possible).

6. ORBITRON

The satellite tracking plugin supports three popular programs: Orbitron, SatPC32, and WxTrack. On startup, my customized Orbitron (Figure 7) connects to an internet network time protocol (NTP) server, synchronizes the computer's real-time clock (RTC) and updates (if required) its internal satellite database with the latest orbital elements or Keplerians ("Keps"). Then it loads SDR#, activates the satellite DDE tracking client, and waits for the first scheduled satellite to trigger an acquisition-of-signal (AOS) alert. Whew! Orbitron continually updates satellite tracking position/frequency information to SDR# in real-time.

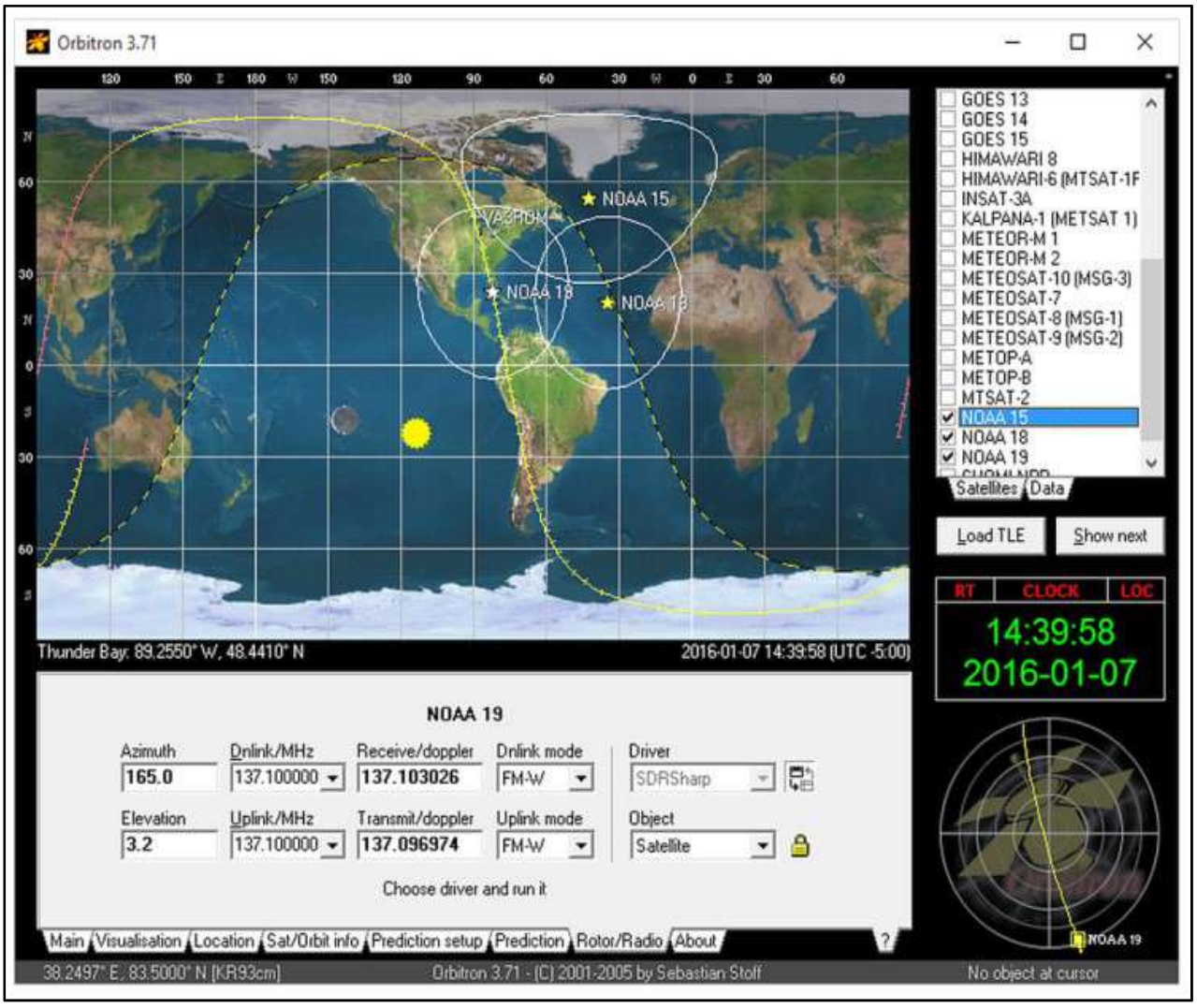

FIGURE 7: ORBITRON SATELLITE TRACKING DDE SERVER

Because of their orbital "dances", you may only be able to use two of the three active APT satellites at the same time else their overlapping radio footprints can cause Orbitron to switch frequencies from one to the other during a pass.

7. VB-CABLE

VB-CABLE is a virtual audio cable (VAC) or software audio transporter, and it eliminates external audio cables between the SDR, sound card, and DSP software by keeping all processes in the "digital domain" after the initial ADC is performed; this eliminates back-and-forth analog-digital-analog conversions with your sound card, resulting in faster and less lossy (added noise) signal processing.

8. WXTOIMG

WXtoImg or "Weather to Image" (Figure 8) is available in three free (as of late 2016) versions: basic, standard, and professional. It supports several operation systems (Windows, Linux, and Apple) and is probably the most popular of the other Windows APT processing programs (APTDecoder and SatSignal). It connects to an NTP but can also use an external GPS for time synchronization in the field, and also updates (if required) its internal satellite Keps database via the internet.

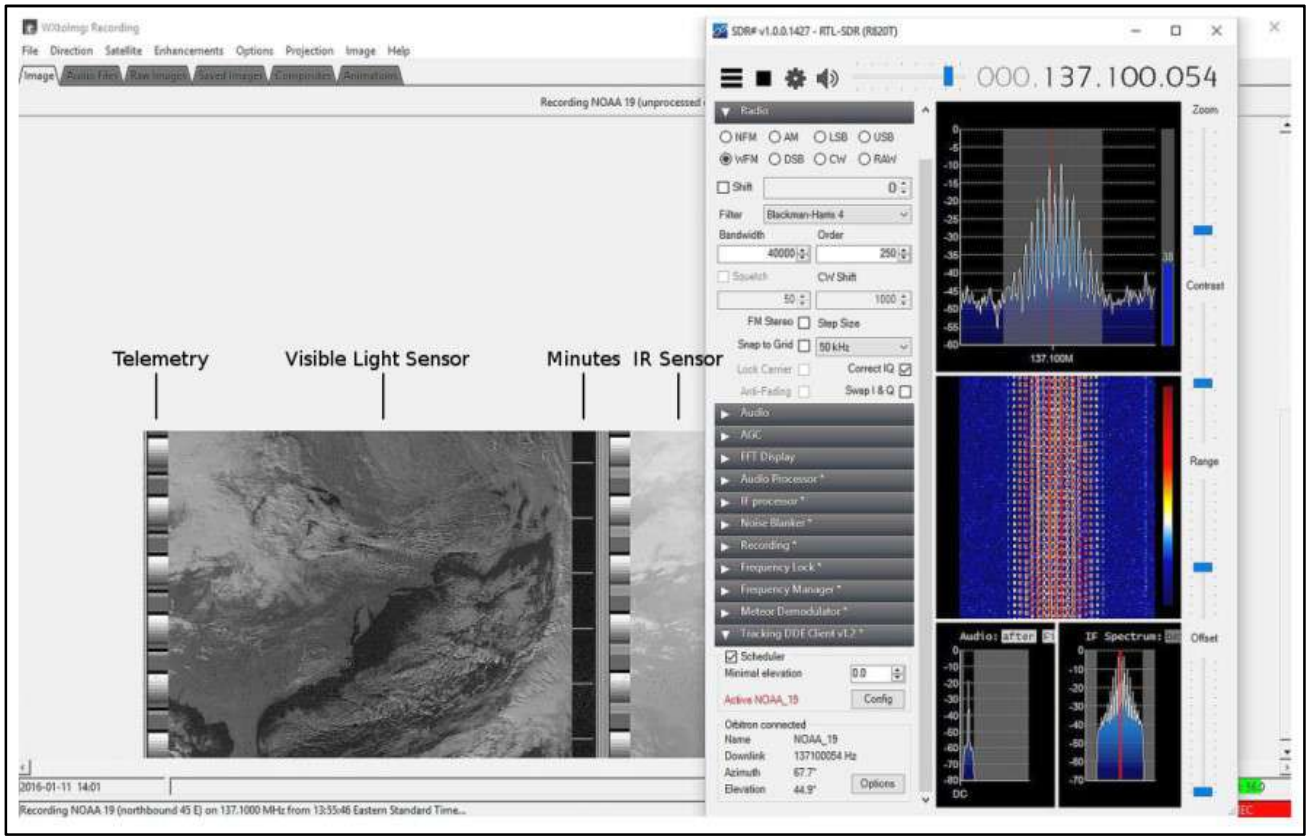

FIGURE 8: WXTOIMG AND SDR#: *Over five minutes into a real-time, raw digital-to-analog (DAC) converted SSTV/APT video drawn slowly, scan line by scan line on your display as it passes from south to north (afternoon/evening passes).*

If an internet connection isn't available, the Winlink 2000 radio messaging system (WL2K RMS) can be used to get the latest Keps for use by both your satellite tracking program and WXtoImg. You can also request various satellite images via the WL2K system, but these are rather large files (40-50 kilobytes) and take time to download via radio. A great way to demonstrate what the WL2K RMS can do for providing EmComm weather services (text and images).

Once an APT satellite pass is over, the job of creating weather maps and adding colour begins, and accurate timekeeping is essential else map/graphical overlays won't align with the received telemetry (no more than 250 millisecond time error allowed). WXtoImg standard and professional versions can also "stitch" several sequential satellite passes together to produce spectacular colour composites (Figure 10). These images give you a good idea of the antenna directivity and overall system performance.

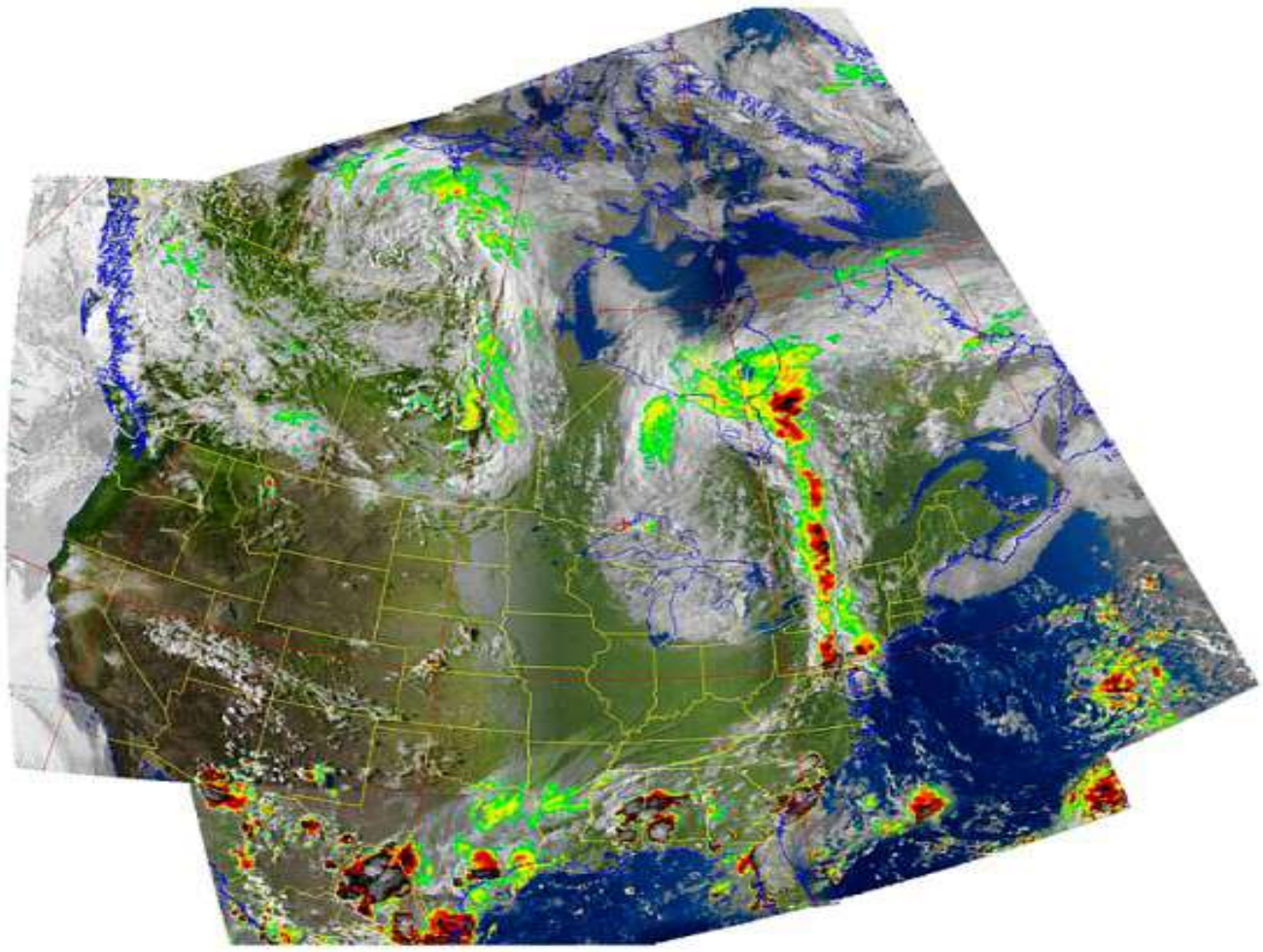

FIGURE 10: *WXtoImg MSA-precip summer time APT composite [daylight] image*

Figure 10 (previous page) is a multispectral analysis with precipitation (MSA-precip) composite daylight APT image centred on my location (Thunder Bay, Ontario). We are in the "wrong" time zone and have an artificial double daylight saving time with summer sunsets after 2200 local time (physically well inside the Central zone, but politically and economically "inside" the Eastern or "Toronto" time zone). The composite image reveals how well my RTL-SDR USB dongle, feedline, LNA and turnstile antenna are performing. WXtoImg automatically analyzes received telemetry, calculates cloud top temperatures then indicates the probability of precipitation and/or intensity by colouring the cloud tops accordingly using a colour lookup table (CLUT).

WXtoImg can create hypertext markup language (HTML) webpages by encapsulating generated weather map images (thumbnails and full-size) with text, then upload everything to an internet web server so you can share with the world. Or you can store everything on a local drive directory on your computer, and set it up as an Amateur Radio mesh server to feed data to other mesh users in EmComm situations (simulated or real).

MY FINAL

You can also use SDRs and ancillary devices to receive many other data modes such as ACARS, ADS-B, AIS, APRS, SSTV, LRPT, et al just by swapping out decoding software and/or changing antennas, as required. Joining a specific Yahoo user group can really help you navigate through this "brave new" SDR DSP world.

My next column looks at a nifty 10 MHz reference radio signal device you can build that is a very handy tool to have in your shack.–73

REFERENCES AND RESOURCES

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http://jcoppens.com/ant/qfh/index.en.php

Friis Equation

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Hardware and Helps

http://www.rtl-sdr.com
http://www.geo-web.org.uk/index.php/
http://www.amsat.org
http://www.wraase.de

Receiving NOAA Weather Satellites

http://tinyurl.com/kjqtkyy
https://www.youtube.com/watch?v=drliNzdtQZw

SDR#

http://tinyurl.com/p6wzgzm

Software: APT

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Software: Satellite Tracking

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http://tinyurl.com/johlstr

VB-CABLE

http://tinyurl.com/myzjf54

VA3ROM: All Things Digital

http://tinyurl.com/og2acxq