All Things Digital

Amateur Radio for the 21st Century

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Slow Scan Television (SSTV): Part 3—APT 101

Detailed reference material is available on my website so only the most important features, developments, and applications are covered herein. Several different variations of weather satellite [analog SSTV] automatic picture transmission (APT) systems existed over the past six decades so the generic term "APT" is used to mean all versions, regardless of their often subtle differences.

INTRODUCTION

American humourist Mark Twain's good friend, newspaper editor Charles Dudley Warner wryly wrote "While everybody talks about the weather, nobody seems to do anything about it!" That 19th century aphorism (Twain "borrowed" and popularized it) is still true today. The number one most talked about, searched for or trending topic in cyberspace isn't "sex", "food" or the "Kardashians"—it's the weather—and we still can't do anything about it! In this century, we seem to have a total reliance on (some would say addiction to) the internet for our daily information (or bread) including weather. But what do we or can we do when everything within 1000 km is knocked down and blanketed by layers of heavy wet snow and ice, disrupting all commercial communication systems? Can you do something about 'it' and provide basic terrestrial and/or satellite based weather information to first and second responders, or any concerned third parties during devastating extreme weather or other environmental emergencies (real or simulated)?

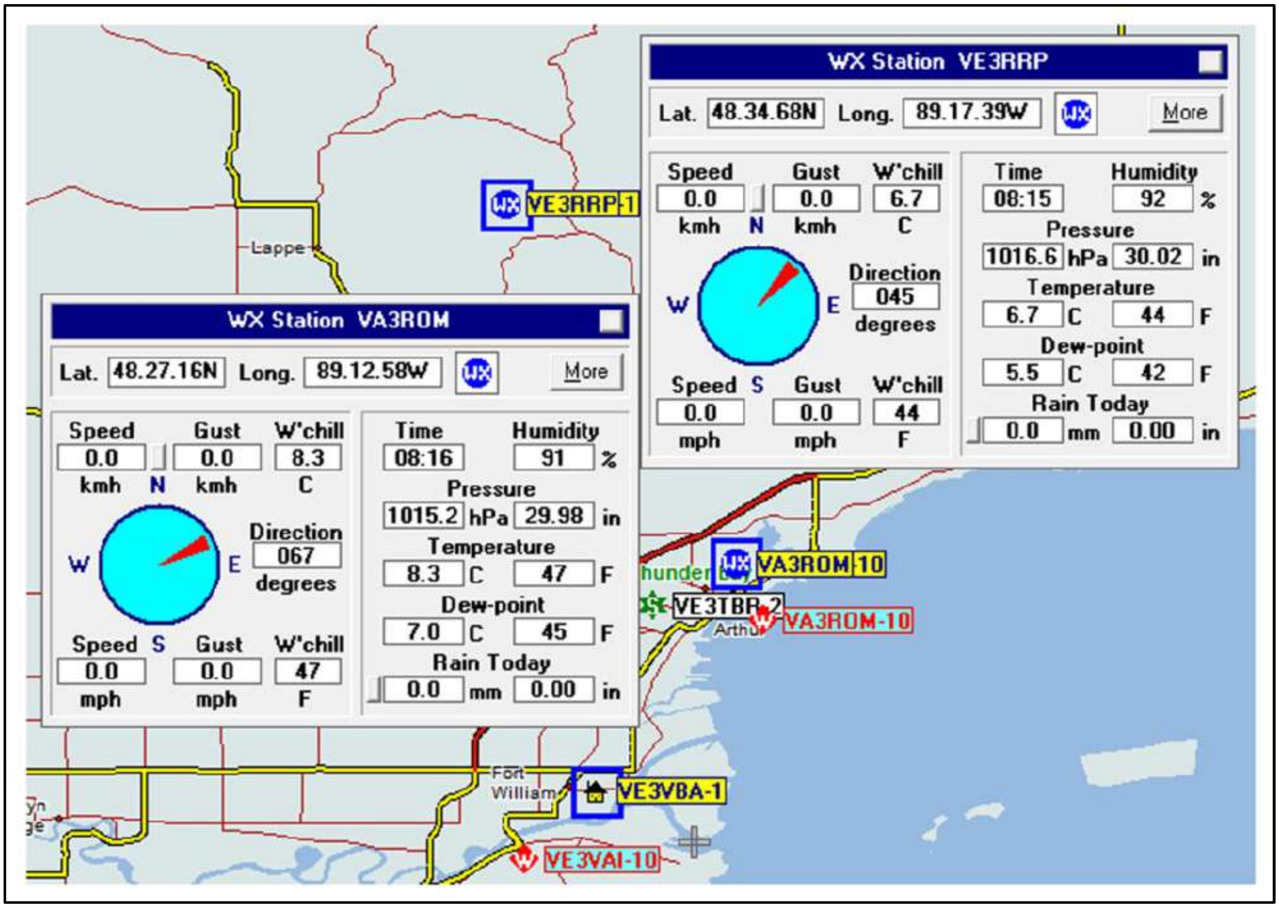


FIGURE 1: *Local Thunder Bay APRS/CWOP PWS transmit data on simplex FM 144.390 MHz (in North America). The data is decoded and displayed graphically using free software. The U.S. National Weather Service is also an active participant sending/extracting data to/from the system.*

Many Amateurs and other like-minded hobbyists have solar/battery powered personal weather stations (PWS) feeding data into various weather related web servers, or emergency communications (EmComm) mesh networks, and/or other radio based systems (Figure 1) such as the Citizen Weather Observer Program (CWOP) or the Automatic Packet Reporting System (APRS), Weather Underground, Weather Bug, et al. Some also receive APT weather satellite maps and telemetry then redistribute them (Figure 2, next page). Why not integrate these valuable resources into your local EmComm “what if” scenarios? “If you fail to plan, you plan to fail.” is a well-known saying, and thinking that it “will never happen here” is a 100% guaranteed failure plan!

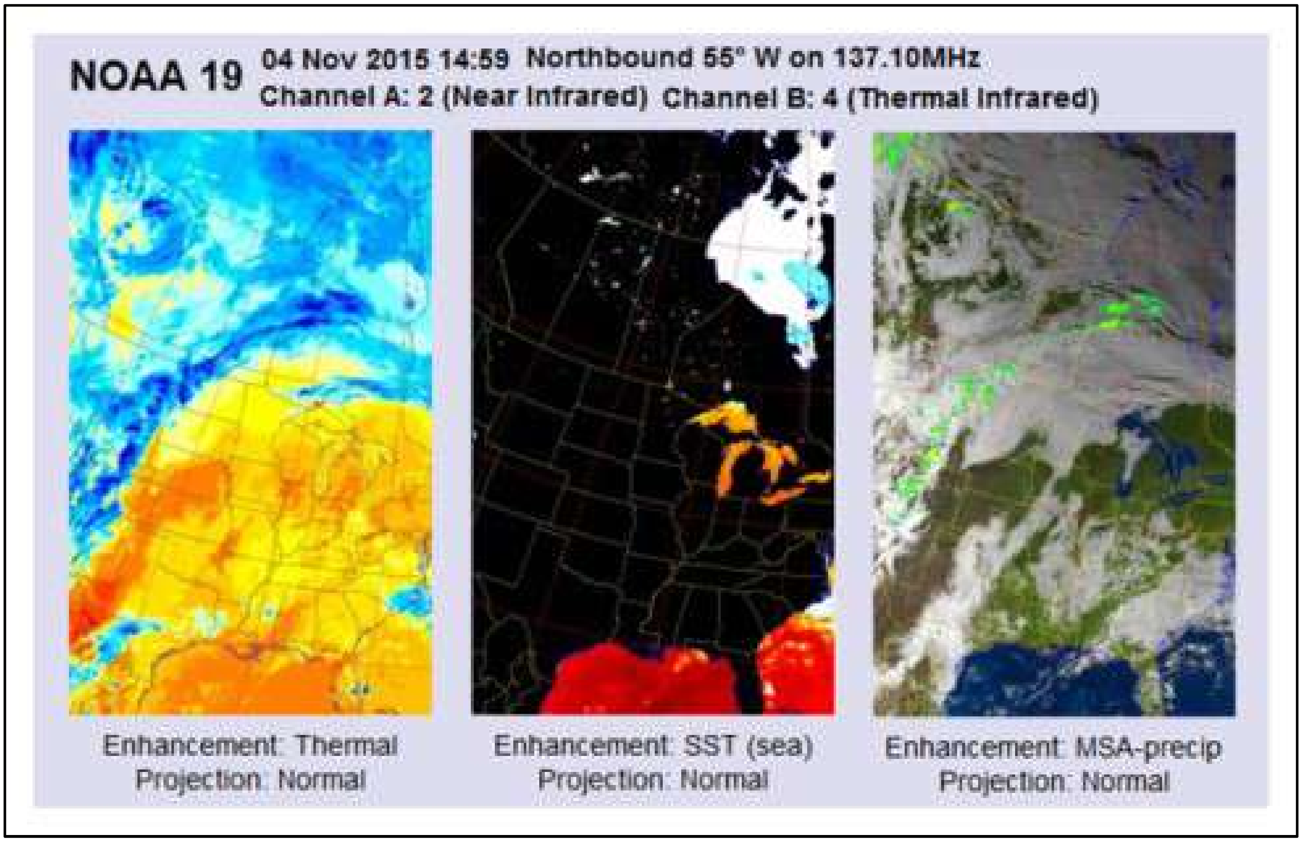


FIGURE 2: *Early morning (well before sunrise) APT infrared (IR) images received from NOAA-19 using free processing software plus a Realtek software defined radio (RTL-SDR) USB dongle. Various processing and colourization method using colour lookup tables (CLUTs) delineate various parameters and features.*

THE PAST

In 1960, the National Aeronautics and Space Administration (NASA) launched the first experimental weather imaging satellite or "bird" called the television Infrared observation satellite (TIROS-1) to test out a novel new (or crazy) idea that artificial satellites could be used for civilian/peaceful purposes to study global climate—perhaps even more. TIROS-1 "grabbed" a single video frame (at 30 second intervals) using a fixed nadir (straight down) looking vidicon camera, converted the frame to an audio signal, saved it to magnetic tape, and later transmitted it (on command) to a ground control station (store and forward). The operation took 200 seconds to transmit one frame at a time so this method left huge gaps between images and required multiple passes over any area before enough overlapping images created a useful composite picture.

It was TIROS-8 in 1963, and the later Nimbus satellite series when real-time APT images from vidicon cameras, then fixed radiometers, and later on, scanning radiometers could be freely received "in the clear" by any person, agency, or country using a VHF radio, and without a command ground control station involved in the process (Figure 3).

Note: A vidicon is a cathode ray tube (CRT) video imaging analog device used in the early days of broadcast television. A radiometer measures (meters) levels of radiation/radiance (radio) at different energy (flux) levels of the electromagnetic force (EMF) spectrum, which is composed of light-speed sub-atomic particles called "photons" (Greek "phos" or light).

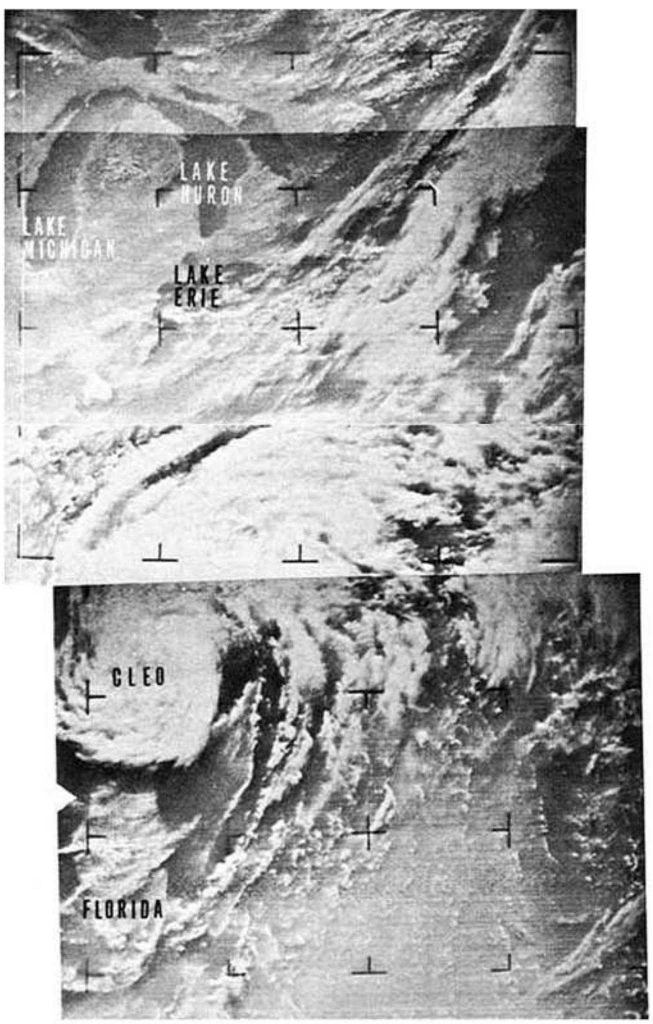
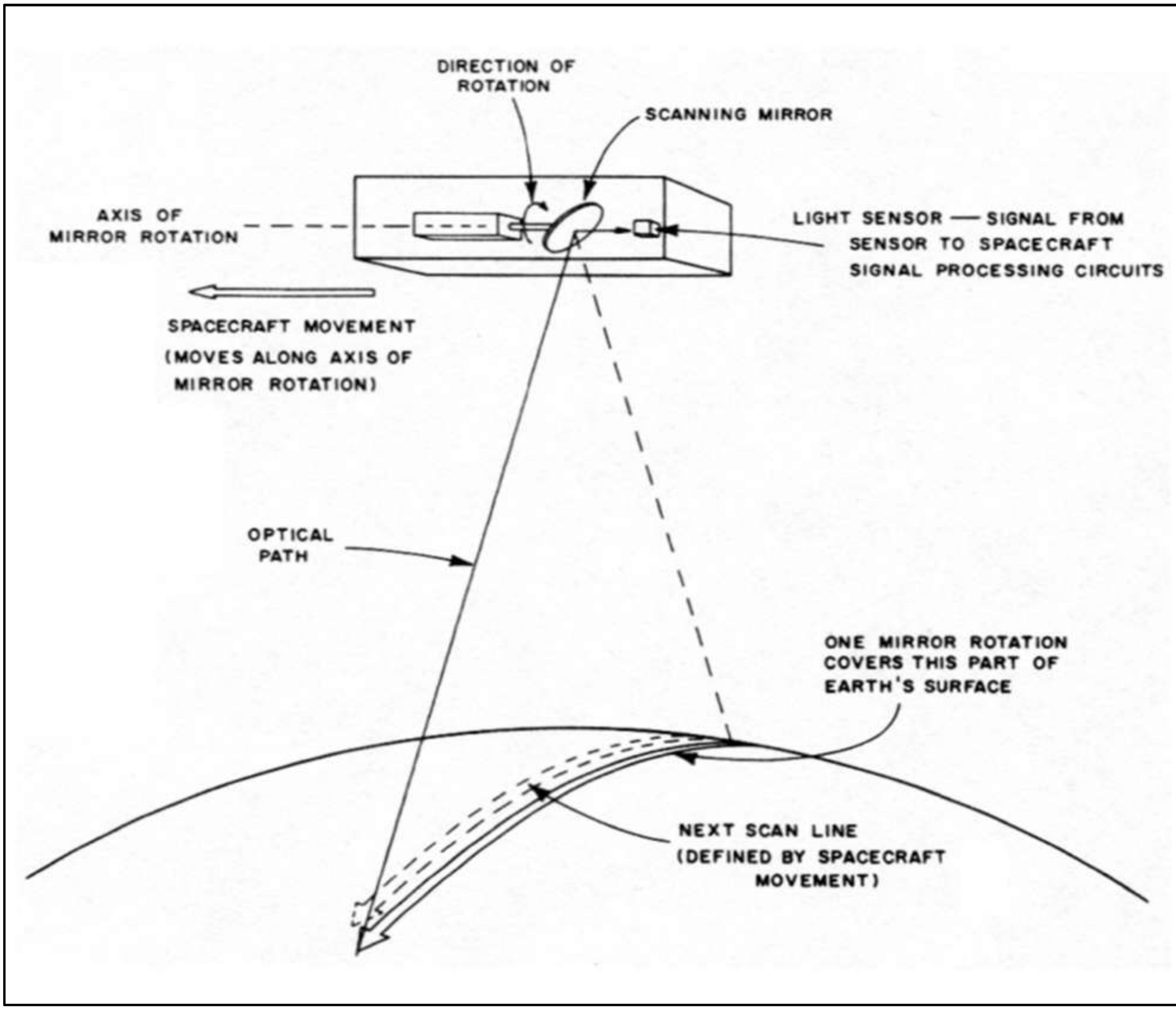


FIGURE 3: *Visible light (vidicon) APT images captured by several Nimbus-1 satellite passes over eastern North America showing category 4 [major] hurricane Cleo in August 1969. Cleo caused the deaths of 156 people, but satellite images helped minimize the loss of life (and property damage) by providing advanced warnings and hurricane path tracking to the public. (Courtesy of NASA)*

Weather satellites image the EM spectrum we call "light" (visible and invisible). Fixed radiometers have a straight down or nadir view of the Earth; scanning radiometers (SRs) use a rotating reflecting mirror with a much wider field of view (FOV) on either side of nadir. So instead of swinging the camera, we move the light from side-to-side! See figure 4, next page.

FIGURE 4: WEATHER SATELLITE SCANNING RADIOMETER

This is how a scanning radiometer works to continuously image the Earth's surface as a series of video scan lines. (Courtesy Weather Satellite Handbook, 5th edition)



Early APT (vidicon type) weather satellites transmitted a 100% compatible weather facsimile (WEFAX) signal and therefore could be used by direct readout (printout) stations already located at major weather centres—a VHF receiver and antenna system was just added. But at $32000 new and $5000 used (in 1960's dollars!) for a complete APT ground receiving and printing station, they were just too cost prohibitive for "civilians". However, technically savvy SSTV enabled Amateurs and other hobbyists started building their own equivalents (using thermal paper or photographic film) for a lot less (Figure 5, next page) but this method never caught on with the "masses" (still too technically difficult and pricey even at "only" $1000).

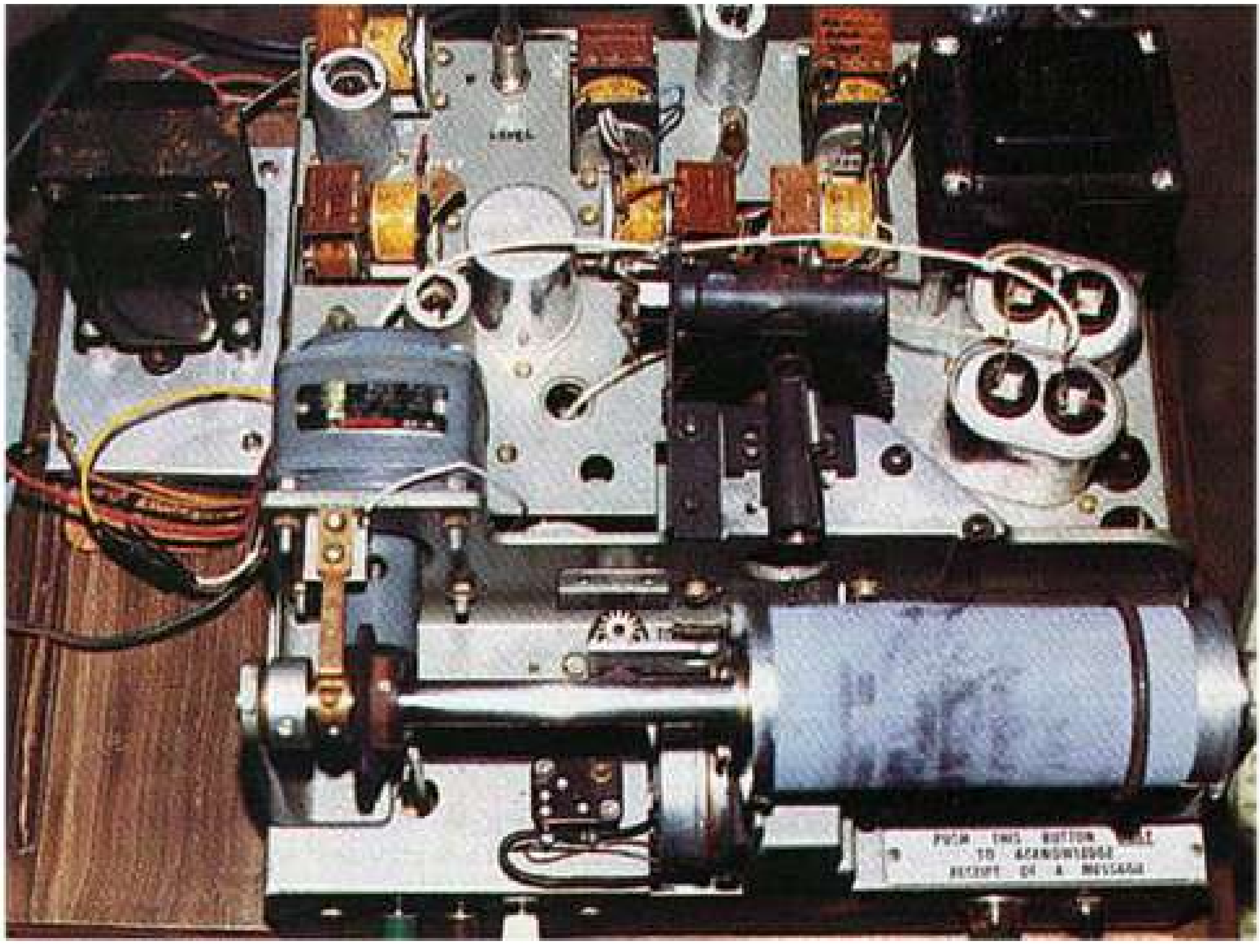


FIGURE 5: HOME-BREW APT/WEFAX DIRECT READOUT STATION (1960's)
It would take about 25 years before the personal computer (PC) revolution and advances in software/hardware made hobbyist APT both affordable and practicable. (Courtesy 73 Magazine)

In 1970, NASA transferred control of all [civilian] weather satellites and their various programs to the newly created National Oceanic and Atmospheric Administration (NOAA). There are satellite command and data acquisition (SCDA) ground centres located at Fairbanks (Alaska) and Wallops Island (Virginia), providing (24/7) monitoring, maintenance and control of all NOAA satellites (Figure 6, next page).

FIGURE 6: WALLAOPS ISLAND NOAA SCDA FACILITY *(Courtesy Google Earth)*

THE PRESENT

NOAA APT birds (currently three) fly in sun-synchronous (polar) looping low-Earth orbit (LEO) averaging 850 km high, travelling in the opposite direction to the Earth's rotation (retrograde) with a close-up view of every spot on the globe at least twice a day or every 12 hours (visible (VIS) and various infrared (IR) wavelengths). They belong to the Polar-orbiting Operational Environmental Satellites (POES) program for meteorology, climatology and oceanography use, and provide free non-visible data collection to all users (Figure 7, next page).

FIGURE 7: HOBBYIST APT RECEIVING STATION

Late 20th and early 21st century APT station setup used by most Amateurs and other hobbyists: QFH (quadrifilar helix) or turnstile (crossed dipoles) antenna, VHF preamplifier, analog VHF FM receiver, remote weather station (optional), computer (desktop/laptop), and some free software. (Courtesy WRASSE Electronic and Davis Instruments)

On the other hand, the digital geostationary operational environmental satellites (GOES) have a very high and wide angle "birds-eye" FOV (pun intended) of what's going on below them. They are forever locked into one spot, spaced around the equator, 35, 800 km above the Earth's surface, but with this type of orbit they can only "see" about 70% of the total surface area below them, while the LEO polar orbiters can image nearly 100%.

But because they remain over one spot, you don't need to calculate satellite position and availability (tracking) and they continuously stream (24/7) very high resolution digital data in real time ("now-casting").

Up to 2010, NOAA launched LEO weather satellites with both the digital High Resolution Picture Transmission (HRPT) and analog APT modes, and made plans for HRPT only birds in the future, however, HRPT has higher start-up costs and isn't compatible with APT equipment, and many "high-profile" users took a very dim view in having to trash perfectly useable gear to reinvest in HRPT equipment. NOAA had predicted that only one APT equipped satellite (out of the five at the time) would be operating by year 2015, but no one really realized how "tough" and "stubborn" the old analog birds are because three (NOAA-15, NOAA-18, and NOAA-19) are still flying high (as of 2017) and still providing invaluable data. NOAA-15, launched in 1998, is showing definite signs of "old age", but barring any serious system failures, at least one of the three should still be working well into the 2020's (NOAA-19 was launched in 2009; Figure 8).

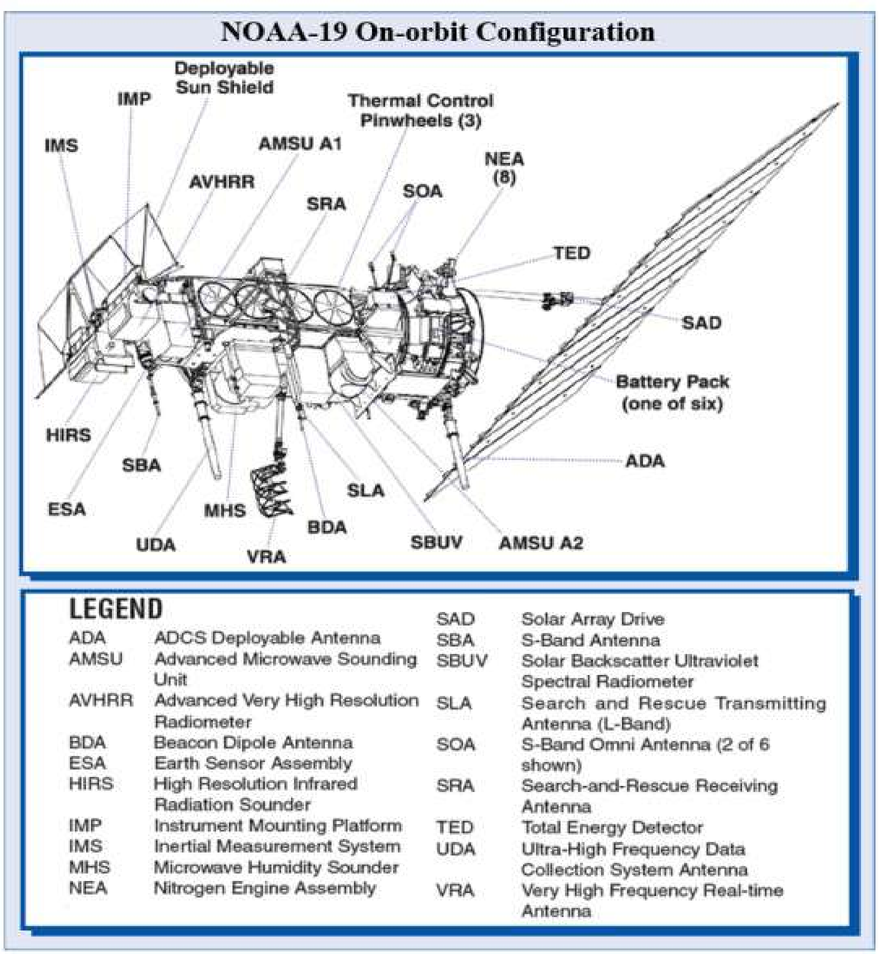


FIGURE 8: *NOAA-19 is the last POES to fly with APT capability; it has long surpassed its minimum 2-year service life. "Granny" NOAA-15 is still "chugging" along after 19 years of continuous service so these "ancient" analog APT satellites may be still around for quite a while longer! (Courtesy NOAA)*

TRANSMISSION FRAME /TELEMETRY FORMAT

Note: I'm glossing over this topic since the APT decoding software handles all the "translation" of APT video and telemetry signals.

AVHRR/3 Channel Characteristics			
Channel Number	**Resolution at Nadir**	**Wavelength (um)**	**Typical Use**
1	1.09 km	0.58-0.68	Daytime cloud and surface mapping.
2	1.09 km	0.725-1.00	Land-water boundaries.
3	1.09 km	1.58-1.64	Snow and ice detection.
4	1.09 km	3.55-3.93	Night cloud mapping, sea surface temperature.
5	1.09 km	10.30-11.30	Night cloud mapping, sea surface temperature.
6	1.09 km	11.50-12.50	Sea surface temperature.

Modern analog APT transmissions are derived from the 3rd generation all-digital SR called the advanced very high resolution [scanning] radiometer (AVHRR/3). It provides six spectral channels of HRPT digital video/telemetry (see above, courtesy NASA) transmitted on 1.7 GHz (L-band) using binary phase-shift keying (BPSK). The AVHRR/3 has 1.1 km/pixel (10-bit) resolution with a narrow but detailed FOV while the converted digital to analog APT image has 4 km/pixel (8-bit) resolution with a wider (aspect angle corrected) but less detailed FOV transmitted on the 137 MHz FM "satellite" band. The AVHRR/3 signal (Figure 9, next page) is only composed varying shades of black and white (256-level greyscale); any colour is applied afterwards in post-processing by using colour lookup tables (CLUTs).

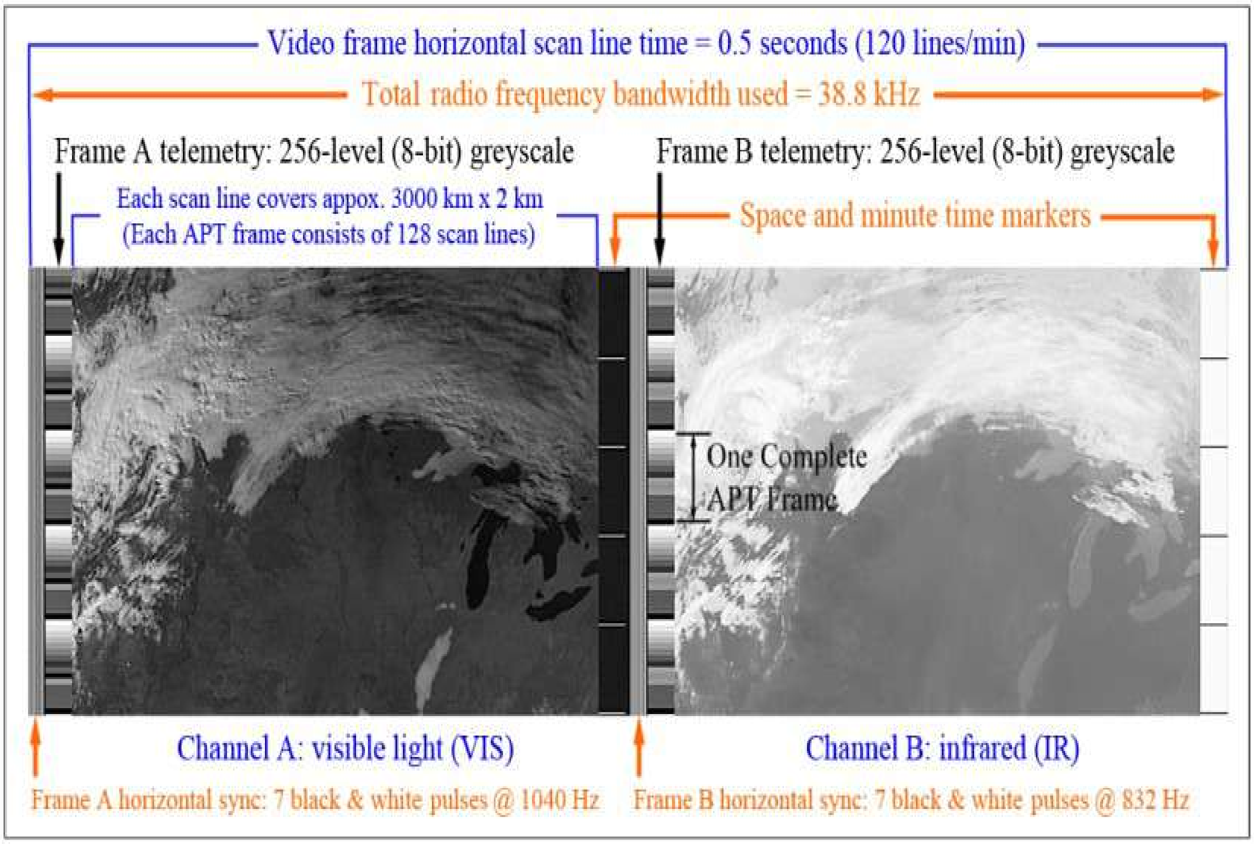


FIGURE 9: APT FRAME AND TELEMETRY FORMAT

This is a five minute segment of a NOAA-19 daytime flyby to the west of the Great Lakes. With NOAA IR imaging, the colder an object is the whiter it appears, and the warmer an object is the darker it appears (the Russian birds do the IR opposite!). Black signal level is 5% modulation and white signal level is at 87% modulation (+/- 5%). APT signals have a very distinctive "tick tock" sound because of their horizontal synchronization (square wave) pulses. (Courtesy NOAA)

A separate APT analog video/telemetry signal is created from two of the AVHRR/3's six channels, converted to analog voltages (Figure 9, next page) and amplitude modulate a 2400 Hz subcarrier (SCAM). This feeds a 37 dBm (5-watt) 137 MHz FM (17 kHz peak deviation) transmitter connected to a right-hand circular polarized (RHCP) helical or "corkscrew" antenna. Modern APT radio frequency (RF) approximate bandwidth is defined by Carson's [FM] bandwidth rule:

$$CBR = 2(\Delta f + f\ m) \text{ or } 2 \times (17 \text{ kHz} + 2.4 \text{ kHz}) = 38.8 \text{ kHz}$$

Note: Early APT used 15 kHz deviation.

During flybys with sufficient sunlight illumination, the visible light channel (Channel A) and one near/mid-IR channel (Channel B) are automatically selected; at night, two different (usually mid and thermal) IR channel wavelengths are selected.

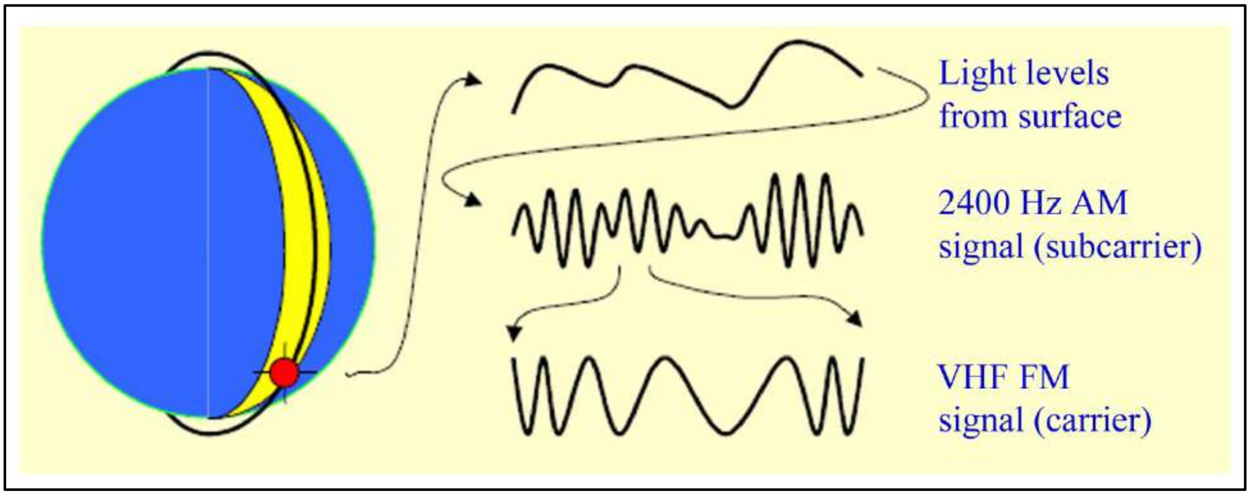


FIGURE 10: 2400 HZ SCAM/VHF FM TRANSMISSION

SCAM FM injects a 2400 Hz audio tone into a keyed VHF FM transceiver and varies the tone's loudness (modulates) up and down to indicate varying voltage (reflected visible and infrared light) levels. All analog signals are composed of an infinite number of points but 8-bit ADC can only quantify 256. This represents a continuous range of possible analog temperatures as digital values ranging from -127 °C to +127 °C, in 1 °C increments. (Courtesy Princeton University)

THE FUTURE

Because HRPT isn't compatible with APT equipment, a new and different digital imaging mode called Low [data] Rate Picture Transmission (LRPT) is the planned replacement. It's still SSTV, and slowly paints video images (in three tall, narrow strips using separate light wavelengths scan line by line on your monitor, but LRPT has the same 1.1 km/pixel resolution as HRPT and can use most current APT equipment! The AVHRR/3 can stream both digital modes, and NOAA had planned to use LRPT for its future LEO weather satellites, but in 2010, the U.S. government decided differently and cancelled this plan. However, the Russians have already launched two LRPT equipped "Meteor-M" satellites with another one in the works so the current APT users are very happy about this, especially in the third-world countries often ignored by the west (politics as usual).

The LRPT birds share the same frequency segment (137 MHz), fly in polar orbiting LEO, and transmit 5-watt RHCP signals, but they use quadrature phase-shift keying (QPSK) with a bandwidth of 120 kilohertz (kHz) at a data rate of 72 kilobits per second (kbps). They transmit huge amounts of image data easily exceeding 100 megabytes [MB] per pass (see Figure 11). In comparison, APT is a “turtle” at 4.16 kbps, resulting in much smaller amounts of data (less than 20 MB) per pass.

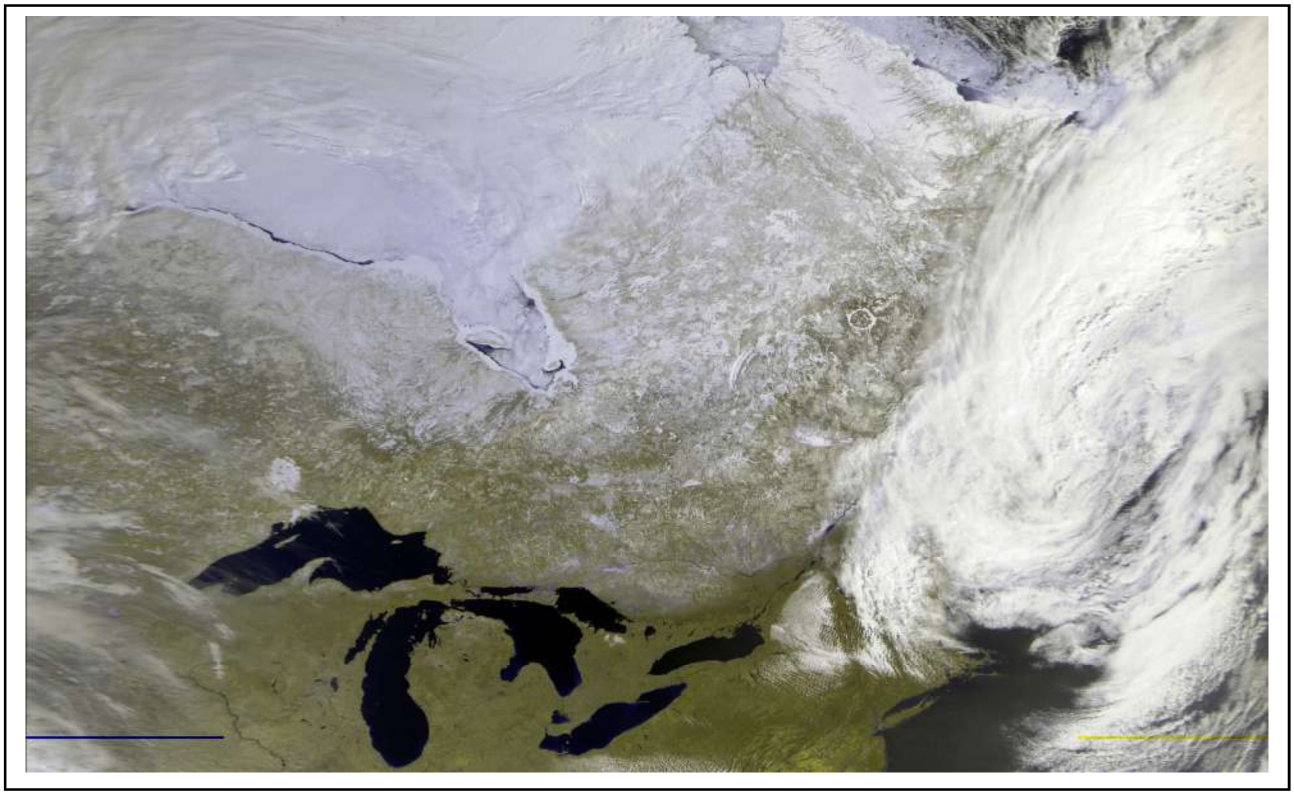


FIGURE 11: *Portion of a digital LRPT Meteor-M2 image morning pass east of the Great Lakes (late March 2016 and ice free). The famous 210+ million year-old Manicouagan annular (ring) meteor impact crater in Quebec is visible (enlargement below); at 100 km in diameter, it’s easily imaged from space. Higher LRPT resolution allows for extreme enlargements of smaller sections.*

Hobbyists have created free LRPT signal decoding and processing software, and have written “how-to” tutorials on using those ubiquitous and inexpensive SDR USB dongles. Adding LRPT to my existing APT receiving station just involved swapping out the old analog FM receiver ($300) for a new SDR dongle ($20) then installing the free LRPT software alongside the old APT software, but my VHF turnstile antenna, preamp/preselector, and old dual-core XP laptop stayed! You can easily see why LRPT is the future of hobbyist weather satellite reception—thanks to the Russian weather service.

MY FINAL

Part 4 looks at using SDR dongles and free digital signal processing (DSP) software to capture/process APT video images/telemetry, with the option to stream them via internet/mesh network for public/personal or ARES specific uses.—73

REFERENCES AND RESOURCES

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http://tinyurl.com/ohydbrs

***QST* Archive**
http://www.arrl.org/qst

VA3ROM: All Things Digital
http://tinyurl.com/og2acxq