Decoding Earth: APT Signals from NOAA Weather Satellites

1 Introduction

In this lab, you'll use a software-defined radio (SDR) to receive live satellite imagery directly from space. The NOAA Polar-Orbiting Environmental Satellites (POES), such as NOAA-15, NOAA-18, and NOAA-19, continuously broadcast Automatic Picture Transmission (APT) signals as they pass overhead. These transmissions can be received with an RTL-SDR connected to a dipole antenna and Low Noise Amplifier (LNA), allowing you to decode the real-time images of Earth.

The APT signal is a frequency modulated (FM) analog transmission that carries two simultaneous image channels and satellite telemetry data. You'll record the transmission using the SDR++ software and process it using SatDump to reconstruct the full satellite image. Along the way, you'll explore important concepts in satellite orbits, modulation techniques, and radio reception.

Before beginning the lab, please install the following software which will be used to interface with the RTL-SDR, record data, and decode the satellite imagery.

- RTL-SDR V4 Drivers: `https://www.rtl-sdr.com/rtl-sdr-quick-start-guide/`
- SDR++: `https://www.sdrpp.org/`
- SatDump: `https://www.satdump.org/download/`

2 NOAA Satellite Orbit

2.1 Finding the Orbital Period

Before receiving and decoding signals from one of the NOAA weather satellite, it's helpful to first understand how these satellites move in orbit. In this section, you'll calculate how long it takes a polar orbiting satellite like NOAA POES to complete one orbit of Earth using Newton's form of Kepler's 3rd law, Equation 1.

$$T = 2\pi\sqrt{\frac{r^3}{GM}} \tag{1}$$

Here, T is the orbital period [seconds], r is the orbital radius [meters], G is the gravitational constant, and M is the mass of Earth [kg]. The orbital radius (r) is the distance from the satellite to the center of mass of the Earth; this value is the product of the Earth's radius ($R_\oplus$) and the satellite altitude (h):

$$r = R_\oplus + h \tag{2}$$

Use Equations 1, 2, and the given constants to answer the following questions:

1. What is the orbital radius r of a NOAA POES satellite? __________________________

2. Use Kepler's law to calculate the orbital period T in minutes. ____________________

3. Why do polar orbiting satellites pass overhead at different times each day? ________________

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Quantity	Symbol	Value	Units
Earth Radius	$R_\oplus$	6.371×10^6	m
Gravitational Constant	G	6.674×10^{-11}	$\mathrm{m^3\ kg^{-1}\ s^{-2}}$
Earth Mass	M	5.972×10^{24}	kg
Satellite Altitude	h	8.50×10^5	m

2.2 Planning the Pass

NOAA satellites orbit Earth roughly every 102 minutes, passing over different parts of the planet each time. Because these satellites are in polar sun-synchronous orbits, they cover nearly the entire globe over time, but they're only overhead for a few minutes per pass. To successfully record and decode the APT transmission, you'll need to plan your observation window carefully.

1. In your internet browser, go to N2YO.com
2. In the top right search bar, type the name of the satellite (NOAA-15, NOAA-18, or NOAA-19).
3. If prompted, enter your current location.
4. Select 10-day predictions
5. From the list of upcoming passes, find the next one and note the following information.
    (a) Start time and direction: ____________________
    (b) Max altitude and direction: ____________________
    (c) End time and direction: ____________________
6. Select Map and details to visualize which direction the satellite will pass overhead.

3 Equipment Setup

3.1 Hardware

1. Thread the two 1-meter dipole antennas into the tripod base and angle the elements outward at a 45°angle.
2. Thread the short coaxial cable coming from the tripod into the **IN** port of the LNA.
3. Take the longer coaxial cable and connect it to the **OUT** port of the LNA. Connect the other end of the coaxial cable into the input of the RTL-SDR.
4. Plug the RTL-SDR into the USB port of your computer.

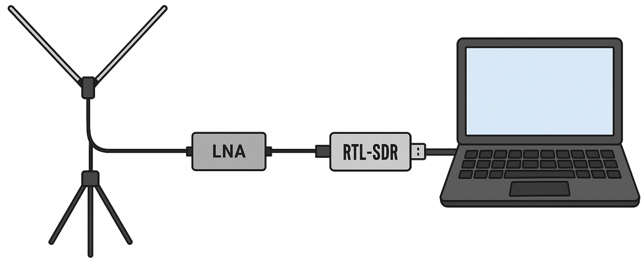

Figure 1: Diagram of the SDR hardware setup

3.2 Software

Before recording the satellite data, you'll need to configure the necessary software to interface with your RTL-SDR and prepare for decoding. This section assumes the software listed in the introduction has already been installed. If not, please return to the Section 1 and follow the installation links.

Satellite	**Frequency**	**Mode**	**Bandwidth**
NOAA 15	137.62 MHz	NFM	50 kHz
NOAA 18	137.9125 MHz	NFM	50 kHz
NOAA 19	137.1 MHz	NFM	50 kHz

Table 1: NOAA satellite transmission parameters.

1. Verify RTL-SDR driver installation

   Ensure that your operating system recognizes the RTL-SDR. On Windows, this typically involves running Zadig to install the correct drivers (full instructions in the Quick Start guide linked in Section 1). On Linux and macOS, drivers are usually pre-installed, but you may still need to confirm access permissions.

2. Launch SDR++

   Open SDR++ while the RTL-SDR is plugged into your computer. Select your RTL-SDR device from the list of available sources. Note that the RTL-SDR may be listed as `[00000001] Generic RTL2832U OEM` or something similar. Press the play button on the top left to verify that the waterfall and spectrum displays respond when the device is active.

3. Configure SDR++ settings for NOAA satellite reception.

   Use the following standard settings to capture an APT signal.

   Source

- Set the correct frequency for the satellite you're observing, Table 1
- Source: RTL-SDR
- Sampling Rate: 2.4MHz

- ✓Bias T
- ✓IQ Correction

  Radio

- Mode: Narrow FM (NFM)
- Bandwidth: 50,000
- Snap Interval: 5000
- ✓IF Noise Reduction → NOAA APT

  Recorder

- ✓Audio
- Select a destination for SDR++ to save the `.wav` file
- Container: WAV
- Sample type: Int16

4 Signal Acquisition

With your satellite pass selected, hardware assembled, and SDR++ configured, you're now ready to record the transmission.

1. Begin Recording

   Open SDR++, confirm your frequency and demodulation settings, and start recording about 1 minute before the satellite is expected to appear above the horizon. Recording too late may cause you to miss the start of the APT signal.

2. Monitor the Signal During the Pass

   As the satellite rises, a narrow FM signal should become visible in the spectrum and waterfall display, similar to Figure 2. When the signal is demodulated into audio, you will hear a characteristic beeping and ticking sound. Each beep is a single line of pixels, transmitting the image line-by-line. If the signal becomes weaker and the audio becomes more noisy, adjust the orientation of the antenna until the signal appears at its maximum intensity. Try to maintain this maximum intensity throughout the observation, as static in the audio will cause static in the image.

3. End and Save the Recording

   After the satellite has passed below the horizon and the signal disappears, stop the recording. Double check that the file was saved correctly <u>before</u> closing SDR++. Make note of the location the recording was saved on your computer for the decoding step.

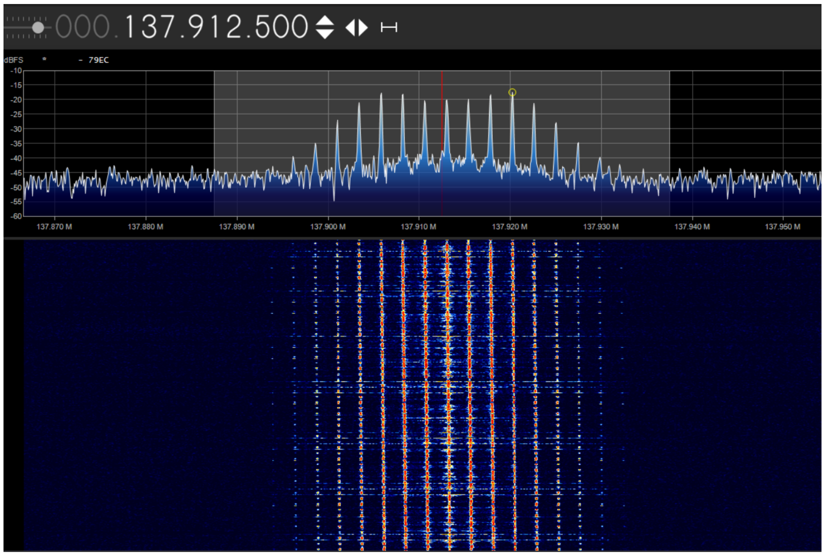

Figure 2: Spectrum and waterfall plot of the APT signal from the NOAA 18 satellite.

5 Decoding the Signal to an Image

Now you're ready to take the audio recording you made during the satellite pass and decode it into an image using SatDump. This software processes the APT transmission and reconstructs the visible Earth image line-by-line.

1. Open SatDump and go to the `Offline processing` tab.
2. In the `Search pipelines` bar, find and select the `NOAA APT` option.
3. Point the `Input File` to the `.wav` you recorded in SDR++.
4. Point the `Output Directory` to the directory you want the images to be saved.
5. Set the `Input Level` to `audio_wav`.
6. Set the `Baseband Format` to `cs16`
7. Set the `Samplerate` to `2.4 Msps`, or whatever sample rate you used to record the signal in SDR++.
8. Set the `NOAA Satellite` to the specific satellite you observed.
9. Press Start.

SatDump will automatically decode the input file into a series of images, and save the results in the output directory.