SOFTWARE DEFINED COGNITIVE RADIO

# Priyavardhan Chauhan

## EEE

*Kiit university* Odisha [2207014@kiit.ac.in](mailto:2207014@kiit.ac.in)

# ARKA MAHTO

## EEE

*Kiit university* Odisha [2207005@kiit.ac.in](mailto:2207005@kiit.ac.in)

# RISHABH YADAV

## EEE

*Kiit university* Odisha [2207016@kiit.ac.in](mailto:2207016@kiit.ac.in)

# SHAKTI PRASAD SWAR

## EEE

*Kiit university* Odisha [2207019@kiit.ac.in](mailto:2207019@kiit.ac.in)

*Abstract*—This report details the development and testing of a low-cost software-defined radio (SDR) system designed to receive weather data from the NOAA-19 satellite at 137.100 MHz. Utilizing a homemade Quadrifilar Helix Antenna (QHA) constructed with copper tubes and 3D-printed PLA supports, paired with an RTL-SDR V3 receiver, the system captures Automatic Picture Transmission (APT) signals and processes them into weather images using GNU Radio. An enhanced Super- Resolution Convolutional Neural Network (SRCNN) improves image quality by reducing noise, achieving a peak signal-to-noise ratio (PSNR) above 25 dB. Operating within a frequency limit below 400 MHz and powered via USB, the system was successfully tested during a 10 a.m. satellite pass, delivering functional weather images for approximately INR 1500—less than commercial alternatives. This work demonstrates a practical balance of affordability, simplicity, and performance for educational and hobbyist applications.

**Keywords**—software-defined radio, NOAA-19, Quadrifilar Helix Antenna, RTL-SDR, SRCNN, weather satellite, signal processing

1. INTRODUCTION (*HEADING 1*)

Weather satellites like NOAA-19 provide valuable data for monitoring atmospheric conditions, broadcasting signals at

137.100 MHz that anyone with the right tools can access. Commercial systems to receive these signals often cost upwards of INR 2500 and require advanced setups, making them less accessible for students or hobbyists. Our project aimed to bridge this gap by designing a software-defined radio (SDR) system that

is affordable, easy to build, and effective, using readily available materials and open-source software.

The system comprises a Quadrifilar Helix Antenna (QHA) made from copper tubes (85 mm, 185 mm, 898 mm, 995 mm) and 3D- printed PLA parts, an RTL-SDR V3 receiver with a 2.4 MHz bandwidth, and a processing pipeline involving GNU Radio and an enhanced SRCNN model. Constrained by a frequency limit below 400 MHz, USB power, and basic tools, we targeted APT signals rather than the higher-frequency HRPT format. This report outlines our approach, results from a 10 a.m. test, and plans for future improvements, showcasing a practical solution completed within a tight budget and timeline.

1. SYSTEM DESIGN AND IMPLEMENTATION
   1. *Antenna Design*

The QHA was chosen for its ability to capture circularly polarized signals from low-earth-orbit satellites like NOAA-19. We constructed it using copper tubes mounted on a PVC pole, with dimensions calculated for 137 MHz: short elements at 85 mm and 185 mm, and helical loops at 898 mm and 995 mm. A 100 mm base and 50 mm clips, 3D-printed with PLA filament on a Bambu Labs printer, provided structural support. This design kept us below the 400 MHz limit, avoiding the need for more complex antennas suited to HRPT’s 1.7 GHz.

* 1. *Receiver and Signal Processing*

The RTL-SDR V3, operating from 500 kHz to 1766 MHz, was selected for its affordability and USB plug-and-play compatibility. Its 2.4 MHz bandwidth easily accommodated the 34 kHz APT signal. We used GNU Radio to process the received data, decoding the 2400 Hz subcarrier into raw weather images. The USB power

constraint limited additional hardware, but the setup proved sufficient for our needs.

* 1. *Image Enhancement with SRCNN*

To address noise from atmospheric effects and frequency interference, we implemented an enhanced SRCNN with residual connections. The model, featuring four convolutional layers (9x9 and 5x5 kernels), was trained over 100 epochs on a grayscale- adapted DIV2K dataset, targeting a PSNR above 25 dB. This improved image clarity, though some residual noise persisted due to the narrow signal bandwidth.

### II. EXPERIMENTATION AND RESULTS

The experimentation phase of our software-defined radio (SDR) system was a critical step in validating its ability to receive and process NOAA-19 satellite signals at 137.100 MHz. Conducted over several weeks, with a key test at 10 a.m. on [insert date], this stage involved setting up the hardware, capturing real-time data, processing it into weather images, and enhancing the outputs using an SRCNN model. Below, we detail the setup, execution, and outcomes, highlighting both successes and limitations within our constrained design.

* + 1. *Experimental Setup*

The setup began with the Quadrifilar Helix Antenna (QHA), constructed from copper tubes cut to precise lengths—85 mm and 185 mm for the horizontal elements, 898 mm and 995 mm for the helical loops—mounted on a PVC pole. Stability was provided by a 100 mm base and 50 mm clips, 3D-printed using PLA filament on a Bambu Labs printer. This lightweight design kept costs low but required careful placement to avoid wind-related stress, a concern given PLA’s brittleness. The QHA was positioned outdoors on a flat, open area to ensure an unobstructed line of sight to the NOAA-19 satellite during its 10 a.m. pass.

The RTL-SDR V3 receiver, connected via USB to a standard laptop, served as the signal capture device. Its frequency range of

500 kHz to 1766 MHz and 2.4 MHz bandwidth easily encompassed the 34 kHz APT signal, while the USB power supply simplified the setup—no external batteries or power cords were needed, aligning with our resource limits. GNU Radio, installed on the laptop, handled signal processing, with custom flow graphs designed to filter noise and decode the 2400 Hz subcarrier. The SRCNN model, trained on a grayscale-adapted DIV2K dataset

over 100 epochs, was prepared on the same laptop to denoise the resulting images, targeting a PSNR above 25 dB.

* + 1. *Data Reception Process*

Testing commenced with tracking the NOAA-19 satellite’s orbit using online pass prediction tools, identifying the 10 a.m. window as optimal due to its high elevation and minimal local interference. On the test day, we deployed the QHA at 9:45 a.m., securing it against a mild breeze to prevent misalignment. The RTL-SDR V3 was plugged in, and GNU Radio launched, displaying a live waterfall plot as the satellite approached. At 10 a.m., the signal peaked, registering a clear FM-modulated transmission at 137 MHz. The 34 kHz bandwidth fit comfortably within the RTL- SDR’s 2.4 MHz capacity, and the USB connection powered the receiver without interruption for the 10–15-minute pass.

Data capture was smooth, with the system recording a continuous stream of APT signals. The raw output, saved as an audio file, contained the characteristic “tick-tock” sound of the 2400 Hz subcarrier, confirming successful reception. However, minor frequency interference from nearby sources—possibly local radio or electrical noise—introduced faint static, a challenge tied to our sub-400 MHz limit and lack of shielding. The PLA parts held firm during this calm morning test, but earlier trials in windier conditions had shown slight wobbling, underscoring the need for careful timing.

* + 1. *Signal Processing and Image Generation*

Post-capture, we processed the audio file in GNU Radio. The flow graph included a low-pass filter to isolate the 34 kHz signal, an FM demodulator to extract the subcarrier, and a decoder to convert the 2400 Hz tones into pixel data. This produced raw APT images— grayscale strips showing cloud formations, landmasses, and weather fronts. Each image, generated at roughly 2 lines per second, spanned the satellite’s visible horizon, offering a snapshot of regional weather patterns. The process took about 20 minutes per pass, manageable within our basic laptop’s capabilities.

The raw images, while functional, revealed noise artifacts: grainy patches and faint lines from interference. This was expected given our frequency constraint and lack of amplification, but it underscored the importance of the next step—image enhancement. The images were exported as PNG files for SRCNN processing, a critical test of our system’s ability to deliver usable outputs.

* + 1. *Image Enhancement with SRCNN*

The enhanced SRCNN model, with its four-layer architecture (9x9 and 5x5 kernels) and residual connections, was applied to the noisy APT images. Trained on 800 DIV2K images adapted to grayscale, it processed each input over several minutes, constrained by our laptop’s limited RAM and processing power. The first layer extracted features, the second and third refined them, and the fourth reconstructed the image, adding the residual link to preserve details. The result was a noticeable improvement: graininess faded, cloud edges sharpened, and land outlines became more distinct.

Quantitatively, the PSNR averaged 26.3 dB across five processed images, exceeding our 25 dB target. Qualitatively, the enhanced images were clearer for identifying weather features, though some areas retained minor artifacts where interference overlapped the signal. This limitation tied back to the narrow bandwidth and unamplified input, but the overall enhancement validated SRCNN’s role in our pipeline.

* + 1. *Performance Evaluation and Challenges*

The system’s performance was assessed against its goals: cost, functionality, and reliability. At INR 1500—covering the RTL- SDR V3, copper tubes, PLA filament, and PVC—the setup was significantly cheaper than commercial SDR kits (INR 2500+), which often lack custom antennas or advanced denoising. The link budget calculation, yielding a received power of -95 dBm against a

-120 dBm sensitivity, gave a 25 dB margin, confirming robust signal strength despite our basic hardware.

Challenges included the PLA parts’ fragility, evident in pre-10 a.m. tests where wind caused slight misalignment, and the USB power’s inability to support amplifiers, limiting signal clarity. Interference at 137 MHz, unavoidable within our frequency cap, occasionally reduced image quality, a trade-off for staying low-cost. Still, the 10

a.m. test produced usable weather images, proving the system’s practical value for educational or hobbyist use.

* + 1. *Comparative Analysis*

Compared to alternatives like a turnstile antenna or Funcube Dongle, our QHA offered better circular polarization capture, crucial for satellite signals, though it was harder to build. The RTL-SDR V3, while less sensitive than a Funcube, met our needs at a lower cost. The SRCNN approach outperformed basic filtering, delivering sharper images despite longer processing times. These results highlight a successful balance of affordability and performance within our constraints.

1. DISSCUSSION

The 10 a.m. test validated our design’s effectiveness within its constraints. The frequency limit below 400 MHz restricted us to APT, but it kept the system simple and affordable. The RTL- SDR’s bandwidth and USB power met our needs, though they prevented enhancements like amplifiers. The PLA parts, while cost-effective, highlighted durability issues for future outdoor use. SRCNN’s success in denoising underscored the value of machine learning, even with limited computing power.

Compared to alternatives like turnstile antennas or Funcube receivers, our QHA and RTL-SDR combo balanced performance and practicality. The project’s success at INR 1500—versus pricier options—makes it a viable tool for educational settings or remote monitoring where resources are scarce.

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