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SDR Based Ground Station for Image Reception from Weather Satellites

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Abstract

From the specific view of space, sophisticated Low Earth Orbit (LEO) satellites provide us with information on cloud movements, precipitation, land and sea surface temperatures. These satellites are fascinating as they continuously transmit an image signal that is easy to decipher of what they are actually looking at. This data is useful to predict weather and rainfall. The main purpose of this work is to develop an inexpensive ground station for receiving the images from these satellites and give a rough prediction of weather and rainfall. Software Defined Radio (SDR) was used for the reception of these signals along with V-Dipole, QFH Antenna and several open source software's. So far this work is successful in receiving signal from 40+ satellite passes of the National Oceanic and Atmospheric Administration's (NOAA) and METEOR-M2 satellites over the location Bangalore, India (Grid: MK83SC) and decoded the same to obtain real time images as seen by the satellite. The images obtained were further analyzed for rough weather predictions over the above mentioned location.

Keywords: Automatic Picture Transmission (APT), Low Rate Picture Transmission (LRPT), Software Defined Radio (SDR), Quadrifilar Helix (QFH) Antenna.

1. INTRODUCTION

The National Oceanic and Atmospheric Administration's (NOAA) is an American scientific agency which has launched 19 satellites that focuses on forecasting changes in climate, weather, oceans and coasts. At present NOAA-15, NOAA-18 and NOAA-19 are geosynchronous satellites active with Automatic Picture Transmission (APT) feature, orbiting at an altitude around 830km. These satellites are equipped with series of instruments and one of the sensor which is AVHRR (Advanced Very High-Resolution Radiometer) has a feature to detect the reflection of electromagnetic waves by clouds, surface waters and objects on the surface of the earth. The AVHRR has 6 detectors operating on a channel of wavelengths ranging from visible to thermal infrared. The live weather images are broadcasted by the APT signals. METEOR-M2 is a Russian weather satellite launched to monitor atmosphere, sea temperatures, humidity, ice conditions and clouds. Meteor-M2 is currently active with LRPT (Low Rate Picture Transmission) feature. The objective is to set up a low cost base station by using a Software Defined Radio (SDR) along with a suitable antenna (Quadrifilar Helix Antenna, V Dipole Antenna) to receive the signals from NOAA and Meteor-M2 satellites and decode the same using several open source software's (SDR#, WxToImg, Orbitron, LRPT Decoder) to obtain real time images when the satellite is overhead.

2. AUTOMATIC PICTURE TRANSMISSION(APT)

The Automatic Picture Transmission (APT) is an analog transmission system developed to get data in the form of pictures from weather satellites. Over five decades, it has helped to get real-time image data for low-cost base stations across many parts of the world. APT system has 2 image channels i.e. Infrared and Near Infrared/Visible Channel. The image reception starts when the receiver is within the radio range. For about 8-15 minutes the satellite is within the radio range. When both, the receiver and satellite frequencies are matched, with the help of unsophisticated receivers the final output is obtained.
Frequency range – 137-138 MHz

Bandwidth - 35 KHz (to overcome Doppler Shift) Modulation – Wideband FM (WFM)
Currently, there are only 3 NOAA satellites i.e. NOAA-15, NOAA-18 and NOAA-19 which transmit APT signals.

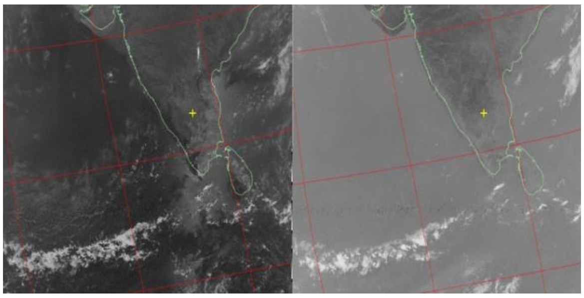

Fig 1: The 2 channel APT image system

3. LOW RATE PICTURE TRANSMISSION (LRPT)

The Low Rate Picture Transmission (LRPT) is a digital transmission system, which is used by the Meteor-M2 satellite to transmit the signal. This system was introduced as a replacement for APT. APT system had only 2 image channels (Infrared and Near Infrared/Visible Channel) which were at reduced accuracy and resolution (8-bit, 4km/pixel, 2 lines/second). LRPT system provides 3 image channels (RGB channels) with better resolution (10-bit, 1km/pixel, 6 lines/second). Frequency range - 137-138 MHz
Bandwidth - 120 KHz (to overcome Doppler Shift) Modulation – Quadrature Phase Shift Keying (QPSK)

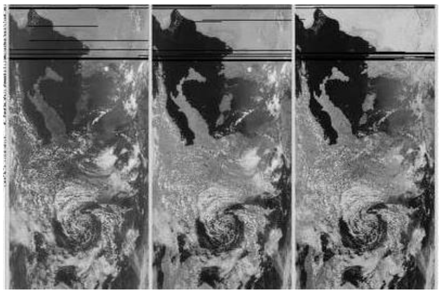

Fig 2: The 3 channel LRPT image system

Compared to APT, LRPT images contain 12 times the resolution and are 4 times more accurate.

4. IMPLEMENTATION

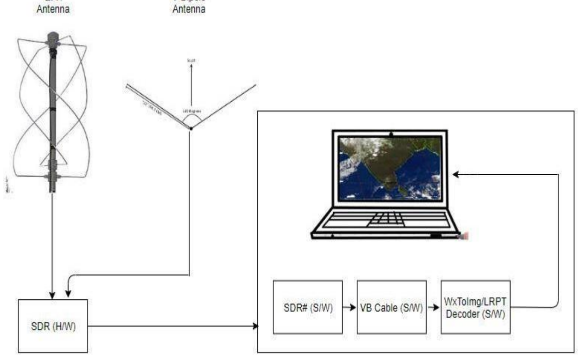

Fig 3: Block Diagram showing the project setup

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The above block diagram shows the implementation of setting up a low-cost ground station for receivingthe signal from the weather satellites and decode the same using open source software's.
Setup consists of an antenna (only one is used at a time) which is connected to the RTL-SDR dongle. A RG-58 coaxial cable is used for the connections, one end of the coaxial cable is soldered to the antenna, the other end is connected to the SDR by means of two connectors viz. BNC male connector and BNC female to SMA male connector. Once these connections are done, the SDR is plugged into the USB port of the PC/Laptop.

A. Hardware Requirements

Based on the investigations done, the appropriate antennas that can be used for receiving APT and LRPT signals are V- Dipole Antenna, QFH (Quadrifilar Helix) Antenna, Double Crossed Antenna and Turnstile Antenna.
Here, the V-Dipole Antenna and the QFH Antenna are used along with a Software Defined Radio (SDR) for the signal reception from the weather satellites.
V- Dipole Antenna:
Initially the signal reception was done using a home-made V- Dipole antenna. A V-Dipole antenna is a simple linearly polarized $\lambda/2$ dipole separated by an angle of 120°. A conducting material such as copper is used for designing the dipole, here a 10 Standard Wire Gauge (SWG) copper wire is used whose length is determined by the formula[11] $L= \lambda/2$ where λ is the wavelength.
The wavelength λ is determined by using the formula $c= \lambda.f$, where c is the speed of light (approximated at 3*10^8m/s), f is the frequency and λ is the wavelength.
Let us choose f= 137.5MHz since the downlink frequencies of NOAA and Meteor-M2 satellites ranges from 137.1MHz to 137.9125MHz. Upon substituting f in the formula $c= \lambda.f$ we get λ=2.1818m. Using this the length of the dipole is determined which is 2.1818/2= 1.0909m. Therefore the length of each leg should be approximately 54cm.

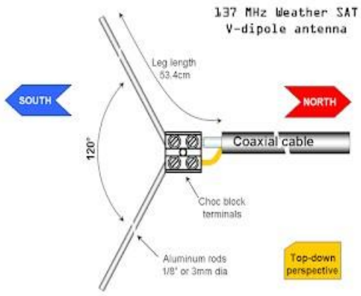

Fig 4: Schematic of the V-Dipole Antenna [11]

Fig 5: Constructed and Mounted V-Dipole Antenna

1. QFH (Quadrifilar Helix) Antenna:

One major drawback with using V-Dipole Antenna was that, depending on the direction of the satellite pass i.e. northbound or southbound, the antenna facing direction had to be changed to receive signal in the direction of the satellite pass. Therefore, to overcome this drawback, a circularly polarized QFH Antenna was built.

The Quadrifilar Helix (QFH) antenna is a Right Hand Circular Polarized (RHCP) antenna used for receiving signals from geosynchronous satellites. It consists of 2 loops whose dimensions are decided by the wavelength of the signal. The formula[10] for calculating the loop elements are:

Big Loop:	Small Loop:
Height= 0.26 λ	Height=0.238 λ
Diameter=0.173 λ	Diameter=0.156 λ
Leg Size=0.560 λ	Leg Size=0.508 λ

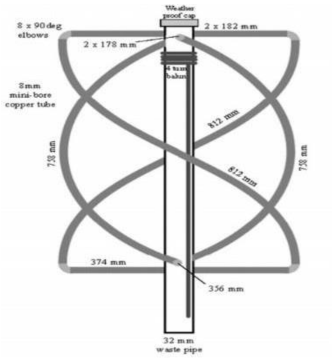

Fig 6: Schematic of the QFH Antenna [10]

The wavelength is calculated by using the following equation c= λ.f. In this equation c is the speed of light (approximated at 3*10^8m/s), f is the frequency and λ is the wavelength.

Since the downlink frequencies of NOAA and Meteor-M2 satellites are ranging between 137.1MHz-137.9125MHz let us choose the frequency f as 137.5MHz. Upon substituting f in the expression c= λ.f, we get λ=2.1818m. Using this value of λ we obtain the height, diameter and leg size of the 2 loops of the QFH antenna using the formulas listed above. A 14 Standard Wire Gauge (SWG) copper tube having outer diameter of 3/8 inch is used along with a PVC pipe for constructing the antenna.

Fig 7: Constructed and Mounted QFH Antenna

2. Software Defined Radio (SDR):

Software-defined radio (SDR) is a system used for radio communication where hardware like amplifiers, filters, mixers, modulator/demodulator etc. implemented by traditional hardware like resistors, capacitors are instead implemented by embedded systems i.e. a chipset fabricated and mounted on a PCB. The SDR used here is a RTL-SDR manufactured by RTL- SDR Blog, it consists of the RTL2832U chipset which gives us access to the radio spectrum thereby enabling us to listen to frequencies ranging from 500KHz-1.5GHz. The RTL- SDR has a maximum sampling rate of 3.2 MS/s (Mega Samples per Second), however for weather satellite image reception it is operated at 2.4

MS/s. The input impedance of the RTL-SDR is approximately 75ohms.

Fig 8: The RTL-SDR Dongle [12]

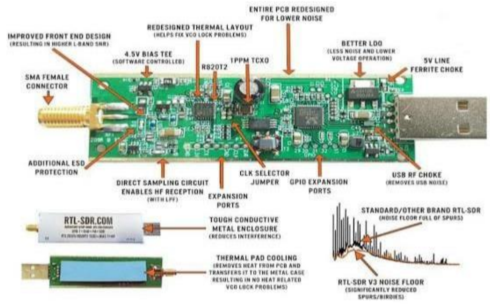

Fig 9: The internal structure of RTL-SDR [12]

B. Software Requirements

All the software's used for the receiving and decoding the signals are open source software's which doesn't require any license for using them.

1. Zadig:

To get the RTL-SDR dongle running on a Windows OS, a driver is necessary for the installation. Zadig is a device driver software used for installing and configuring the RTL- SDR on the PC/Laptop. When the RTL-SDR dongle is plugged into the USB port for the first time, the zadig software has to be run to complete the installation of the dongle.

2. SDR Sharp (SDR#):

SDR Sharp (SDR#) is a PC-based DSP application used for Software Defined Radio (SDR). It is an open source software designed using C# language. The main purpose of using SDR# is to tune the receiving frequency of the SDR. Apart from these other parameters such as modulation type, bandwidth, RF gain, sampling frequency etc. can be varied as required. It also shows a waterfall diagram or frequency spectrum of the signal where the signal pattern can be analyzed.

3. WxToImg:

WxToImg is the software used for decoding the signal i.e. the audio received from the SDR# software is decoded into real time images as seen by the satellite. A 2 channel (Infrared and Near-Infrared/Visible) raw image is obtained which can be enhanced using various enhancement modes like MCIR (Map Colored IR Enhancement), MCIR precipitation, MSA (Multi Spectral Analysis), MSA precipitation, Thermal image, Sea surface Temperature etc.

4. Virtual Audio Cable (VB Cable):

The audio from the SDR# cannot be fed directly into the WxToImg via the PC's mic as the external noises will be also picked up with the actual audio signal from the satellite. To overcome this the VB Cable software is used which pipes the

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audio internally from SDR# to WxToImg so that no external noises are added to the original audio signal.

5. LRPT Decoder:

As the NOAA satellites works on the principle of Automatic Picture Transmission (APT), WxToImg software is sufficient for the decoding of the signal into image. But the Meteor- M2 satellite works on the principle of Low Rate Picture Transmission (LRPT), since WxToImg does not support decoding of LRPT signals, the LRPT Decoder software is used for decoding the Meteor-M2 satellite's audio signal into image. Here a 3 channel (R,G,B or R,G,Infrared) raw image is obtained.

6. Orbitron:

The Orbitron is a satellite tracking software. It can be used to predict the passes of all active satellites over any location. It also gives the status of the satellite like elevation angle, azimuthal angle, maximum elevation, uplink frequency, downlink frequency etc. The Orbitron can also be used to auto-start the decoding by launching the SDR# and WxToImg software's as soon as there is a satellite pass over the specified location with some minimum elevation

.

C. *Procedure for receiving and decoding the signal:*

- The Zadig software is launched in the PC to complete the installation of the RTL-SDR dongle. Now the SDR is configured and it is ready to receive the signal from the antenna.
- Firstly, the Orbitron software is run, which gives the satellite's pass information such as pass start time, pass end time, max. elevation, downlink frequency etc.
- The frequency in the SDR# software is tuned to the downlink frequency of the respective satellite. The required modulation type is selected (WFM for NOAA satellites, QPSK for Meteor-M2 satellite) and bandwidth is adjusted depending upon the signal type to be received. Once the play button is selected, the software starts receiving the signal.
- Along with the SDR#, simultaneously WxToImg

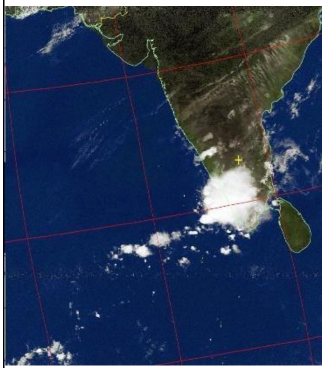
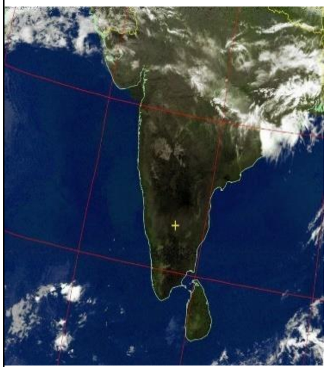
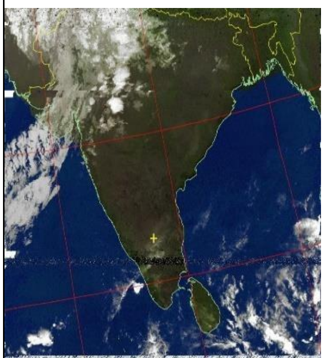
/LRPT Decoder is made to run. The audio output of the PC/Laptop is changed to VB Cable under the Control Panel. When the elevation of the satellite is greater than 10°, the WxToImg/LRPT Decoder starts decoding the audio signal received from SDR# into a raw image. Once the decoding is finished the raw image can be enhanced as per requirements of the user.

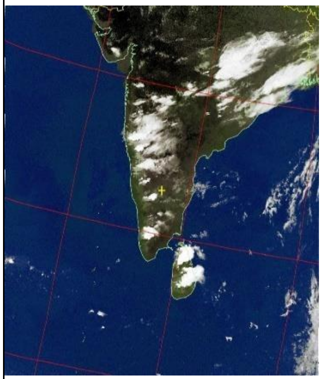
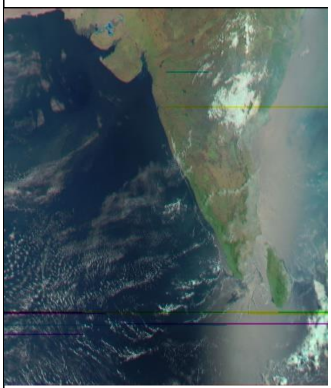
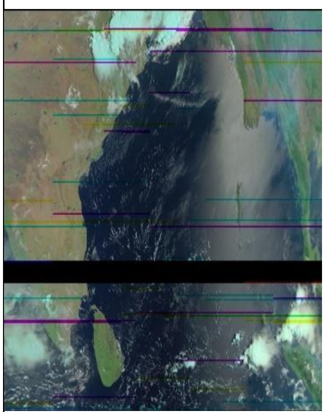
4. RESULTS AND DISCUSSION

Results

Among the 40+ satellite passes that has been attempted to receive signal and decoded to obtain from which received signal gave a good SNR (max. SNR at least greater than 25db) and the decoded image showing vast area coverage are shown in the table below along with the pass details.images, few passes has been selected

Table I. Images Received From Satellites

1)	Antenna used: QFH Antenna Satellite: NOAA-15 Date: 07/04/2020 Pass start: 07:54 IST Max elevation: 46.8° Direction: Northbound Grid: MK83SC (Bangalore, India) Enhancement applied: MCIR (Map colored IR) Enhancement	
2)	Antenna used: QFH Antenna Satellite: NOAA-18 Date: 15/03/2020 Pass start: 21:16 IST Max elevation: 62° Direction: Northbound Grid: MK83SC (Bangalore, India) Enhancement applied: MCIR (Map colored IR) Enhancement	
3)	Antenna used: QFH Antenna Satellite: NOAA-19 Date: 27/03/2020 Pass start: 05:58 IST Max elevation: 83.2° Direction: Northbound Grid: MK83SC (Bangalore, India) Enhancement applied: MCIR (Map colored IR) Enhancement	

4)	Antenna used: V-Dipole Antenna Satellite: NOAA-19 Date: 10/04/2020 Pass start: 17:46 IST Max elevation: 84° Direction: Southbound Grid: MK83SC (Bangalore, India) Enhancement applied: MCIR (Map colored IR) Enhancement	
No.	Pass Details	Image
5)	Antenna used: QFH Antenna Satellite: Meteor-M2 Date: 03/04/2020 Pass start: 08:55 IST Max elevation: 49.1° Direction: Northbound Grid: MK83SC (Bangalore, India)	
6)	Antenna used: V-Dipole Antenna Satellite: Meteor-M2 Date: 21/04/2020 Pass start: 07:55 IST Max elevation: 32° Direction: Southbound Grid: MK83SC (Bangalore, India)	

Discussion

One pass, each from NOAA and Meteor-M2 satellite is considered, and the detailed analysis of the image received is as shown below.

Considering the NOAA-15 satellite pass dated 07/04/2020
at 07:54 IST having a maximum elevation of 46.8° and heading northbound, shown below are the images obtained after applying different enhancement methods to the raw image received from the decoded audio signal via the WxToImg software.

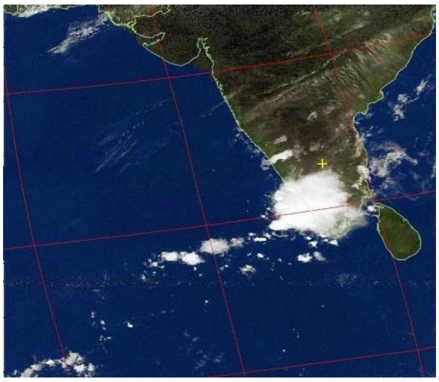


Fig 10: MCIR (Map Colored IR) Enhancement

Fig 10 shows the MCIR Enhancement applied to the raw image. Through this MCIR enhancement a colored image is obtained which is near equivalent to what is seen by the satellite in the real time. A cloud formation is seen over the southern parts of India roughly covering parts of Kerala, Tamil Nadu and Karnataka.

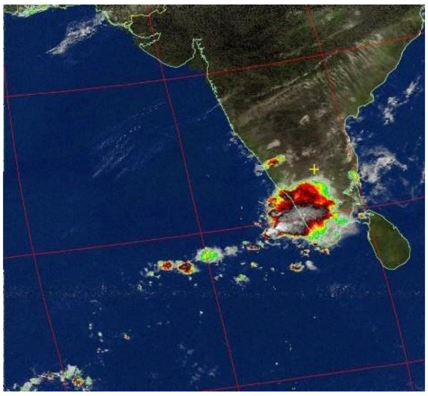


Fig 11: MCIR (Map Colored IR) Precipitation Enhancement

Fig 11 shows the MCIR Precipitation Enhancement applied to the raw image. The MCIR Precipitation Enhancement shows us the accumulation of water in the clouds through various shades of red spots. A dark red spot means a very dense cloud having more amount of water accumulation. From the image it is evident that parts of Kerala, Tamil Nadu and Karnataka is covered by these dense clouds.

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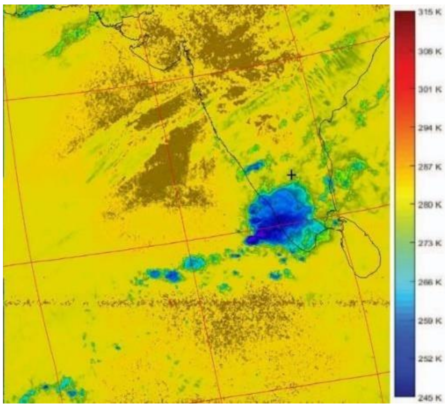

Fig 12 shows the Thermal Enhancement along with the heatmap scale. The blue spots on the thermal image shows a cooler/ low temperature over regions of Kerala, Tamil Nadu and Karnataka. From the above shown images, it can be inferred that the chances of rainfall is more in the regions of Kerala, Tamil Nadu and Karnataka when compared to the other parts of India at that moment of time. Let us consider one image received from Meteor-M2 satellite pass shown below, dated 03/04/2020 at 08:55 IST having a maximum elevation of 49.1° heading northbound.

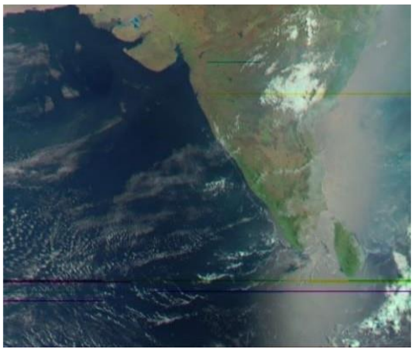

Fig 13: Image received from Meteor-M2 satellite

The image obtained by decoding the LRPT signal from Meteor-M2 satellite looks much more realistic than the images received from NOAA satellites. But unlike the images received from NOAA satellites, the enhancements such as MCIR, MSA and Thermal Imaging cannot be applied to the images received from Meteor-M2 satellite. The rainfall or temperature is tough to predict unless it is viewed by a weather or a meteorological expert. Factors like cyclone formation (if any) and direction of heading can be inferred from the Meteor-M2 satellite images.

CONCLUSION AND FUTURE SCOPE

A. Conclusion

The objective of this paper to build a cost effective base station for receiving images from weather satellites and making a rough weather predictions through these images is successful.

At first, the work was limited only to get signals from the active NOAA satellites which transmits APT signals, using a simple homebrew V-Dipole Antenna. But then, certain ambiguities were experienced. The antenna had to be faced towards north or south with respect to the direction of satellite pass, also the area coverage and quality of the image received was not up to the mark. To overcome this the QFH Antenna was constructed, which is a circular polarized antenna. The quality and area coverage of the image was better when compared to V-Dipole antenna. Later the work was enhanced by trying to pick up signals from Meteor- M2 satellite which transmits LRPT signal. The signal was successfully received using the same setup and decoded to get much more realistic image than received from NOAA satellites. Through the images received, a rough prediction of weather and rainfall over the location Bangalore, India has been done. These images can serve for greater research purpose to weather experts and weather enthusiasts to monitor the climatic conditions and give accurate weather and rainfall predictions.

B. Future Scope

- The received images can be used for greater research purpose for more accurate weather prediction.
- The same project set up with a suitable antenna can be used to receive signals from geostationary satellite like GOES-16, and the same signal can be decoded to obtain images with a much vast coverage, covering almost half of the earth.
- To record near space images or videos without the help of satellites, a high-altitude weather balloon can be manually launched with a payload consisting of a high-resolution camera. Also, few sensors can be interfaced with a microcontroller and put in the payload to measure parameters like pressure, altitude, temperature wind speed etc. in real time. Once the high-altitude weather balloon reaches certain height it explodes causing the payload to be dropped at a random location. With the help of a RF transmitter mounted on the payload, by using the SDR (Software Defined Radio), the payload can be tracked and recovered.
- The same project setup can be used to receive the ADS-B (Automatic Dependent Surveillance- Broadcast) signal transmitted by the aircrafts, and it can be decoded to obtain parameters related to aircrafts such as distance travelled, heading direction, call-sign, speed, altitude, route etc.
- The SDR along with an appropriate antenna can be used to listen to the HAM bands.

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