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Satellite Image Acquisition Using SDR

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ABSTRACT: Low Earth Orbit (LEO) satellites are mainly used for amateur radio communications by ham operators around the world. A few of these satellites were launched in their orbits for the express purpose of weather monitoring by taking pictures of the earth. For the reception of these signals Software Defined Radio was used along with appropriate antennas. Numerous enhancements can be made to the raw satellite images by intelligently comparing images from two different wavelengths in the IR and visible spectra. The paper thus provides a way to use this information in myriad of domains to get a better perspective in understanding variations in weather.

KEYWORDS: Weather satellite imaging, Software defined radio, NOAA, Quadrifilar Helical Antenna (QFH), Wxtoimg

I. INTRODUCTION

From the unique vantage point of space, sophisticated Low Earth Orbit satellites (LEO) satellites bring us information about cloud movements, precipitation amounts, land and sea surface temperatures, ocean currents, drought and floods and other factors that affect our daily lives[1]. Using a Software Defined Radio (SDR) dongle, this information can be received and decoded to form detailed satellite images.A home brew receiving station like this enables anyone to receive the direct readout satellite transmissions with just a basic working knowledge of antennas. The National Oceanographic and Atmospheric Administration, which is a United States governmental institution has been launching weather satellites since 1960[2].Among the polar orbiting satellites, NOAA 15, NOAA 18 and NOAA 19[3] are the only ones fully functional as of now. On reception and decoding of these transmissions, clear and detailed images are created. The NOAA provides various enhancement curves to represent application oriented information more vividly. Thermal heat maps, cloud precipitation levels, sea surface temperatures can be shown on the raw images using these curves. Colour Lookup Tables are also available which are used to form true colour images from the original grayscale ones.

II. TECHNICAL BACKGROUND

The primary scanning instrument in these satellites is the Advanced Very High Resolution Radiometer (AVHRR)[4]. This instrument is designed to detect five channels of radiant energy from the surface of earth ranging from the visible spectrum, the near-infrared, and infrared spectra. Data from these 5 channels are transmitted directly in a high speed digital format known as High Resolution Picture Transmission (HRPT). The analog Automatic Picture Transmission (APT) signal is derived from the original digital data and is multiplexed so that only two of the original channels appear in the APT format. This is accomplished on the satellite by using every third scan line of the digital HRPT data.The satellite uses frequency modulation to broadcast the signal on a 137 MHz carrier. It transmits various other environmental data that are measured with a wide range of instruments on board the satellite. On this 137 MHz carrier, the APT is transmitted on a 2.4 KHz amplitude modulated subcarrier.

The analog APT system was designed to produce real-time video images that can be received and reproduced by low cost satellite ground stations. This data stream is produced by amplitude modulating a 2400 Hz sub-carrier with the 8 most significant bits of the 10 bit digital AVHRR data. This results in an analog signal with the amplitude varying as a

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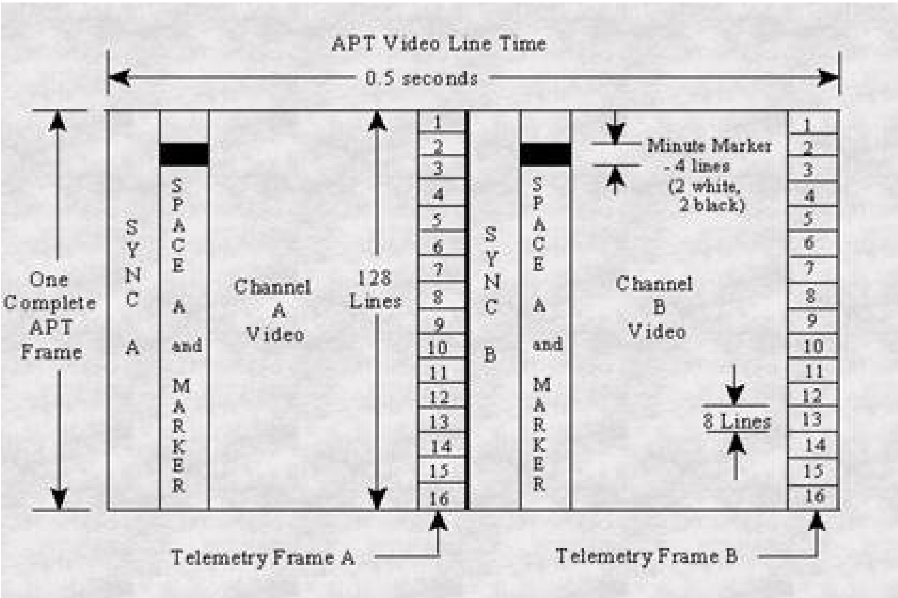
function of the original AVHRR digital data. Two of the six possible AVHRR spectral channels are multiplexed so that channel A APT data is obtained from one spectral channel of the first AVHRR scan line and channel B from another spectral channel contained in the second AVHRR scan line. The third AVHRR scan line is omitted from the APT before the process is repeated. The two spectral channels are determined by ground command and are not selectable by the user.[5]

III. APT FRAME FORMAT

The most important step before jumping to decoding satellite transmissions is to know in which format are they sent. The success of the decoding and it's accuracy mainly depend upon how well you interpret the signal with reference to it's frame format. As in previous cases, this information too is given by NOAA and should be studied in detail before anyone can think of decoding them.

Figure 1: APT Frame format



IV. IMPLEMENTATION

Technological advances in microelectronics and computer software applications over the past decades have made it rather simple to assemble and use a basic direct readout ground station.

The implementation of this system is done in two stages. The first stage covers the hardware aspects of the system widely termed as the antenna subsystem while the second stage involves the setting of up software programs to decode the APT signal received from the antenna.

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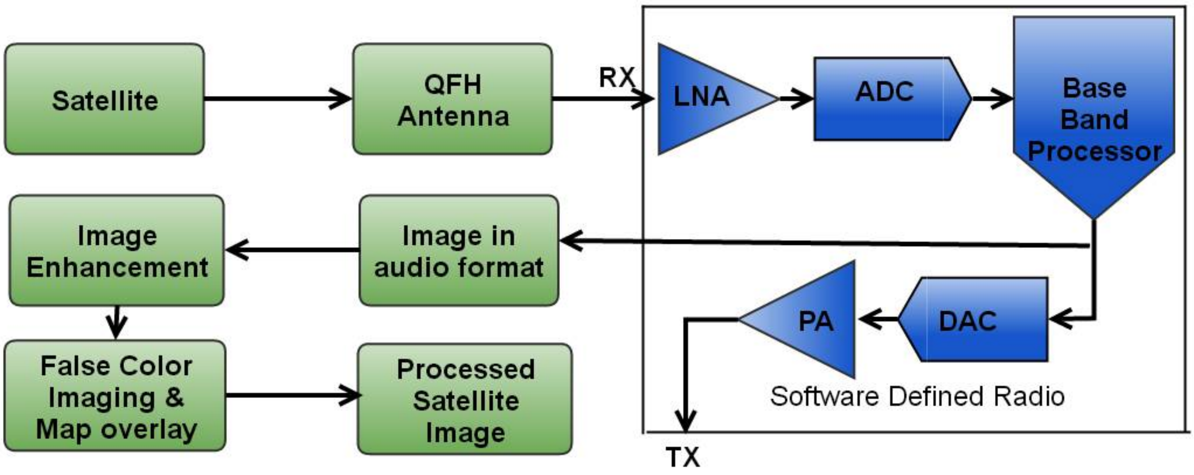

Figure 2: System block diagram

V. RECEIVING SUBSYSTEM

A. Antenna Equipment

Considering the frequencies, signal strength, and polarization factors of the transmissions, a number of antenna designs can accomplish adequate APT reception. These designs include bothomnidirectional antennas and higher-gain beam antennas. The Quadrifilar Helix Antenna is an excellent antenna for APT reception for the main reason that the NOAA satellites have the same antennas on board for transmission of APT signal. It is a special type of omnidirectional resonant antenna that provides a much better radiation pattern compared to the other APT antennas , and does not suffer from the loss of signal strength exhibited in other alternatives such as the simple turnstile antennas . The quadrifilar helix usually consists of four 1/2-turn helices equally spaced around the circumference of a common cylinder[6]. The radiation pattern is omnidirectional in the plane perpendicular to its main axis. Radiation of the signal is nearly circularly polarized over the entire hemisphere irradiated[7]. This makes it almost ideal for receiving signals from polar orbiting weather satellites. Well designed quadrifilar helix antennas often exhibit inherent gain from 3 dB to 5 dB. The quadrifilar antenna will provide virtually noise free reception once the satellite reaches an elevation of 5 to 10 degrees above the horizon. The turnstile will provide slightly less performance at lower elevations levels.

The QFHA constructed is a self-phasing antenna consisting of a smaller loop and a bigger loop.The dimensions of the antenna decide the resonant frequency while the diameter of the conductor used to form the loops decides the input impedance of the antenna.[8] PVC pipes are used to form the mast and arms of the antenna. These pipes form the skeleton of the antenna providing it rigidity and keep the filars of the antenna in the desired helical shape. RG 6 coaxial cable is used in an infinite balun configuration to form the two vertical loops. To use the coaxial cable as a single conductor simply short circuit the center conductor and the braiding[9]. Proper construction of the antenna alone does not guarantee satisfactory performance of the antenna as environmental factors play a major role in signal reception.While mounting the antenna the effect of ground planes must be taken into consideration as placing the antenna too close to such a surface will affect the antenna radiation pattern thereby leading to deterioration in signal quality.

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B. Software Defined Radio (SDR)

SDR is a radio in which the physical layer functions are software defined. Traditional hardware based radio devices limit cross-functionality and can only be modified through physical intervention. This results in higher production costs and minimal flexibility in supporting multiple waveform standards.The hardware required for a receiver is thus relatively easy. A major point of concern in any receiver is the quality of the signal. As the received signal is processed entirely in the digital domain, the signal quality remains commendable and due to all these advantages, the SDR becomes the obvious choice for NOAA APT reception. The figure below gives a broad perspective as to how an SDR works.

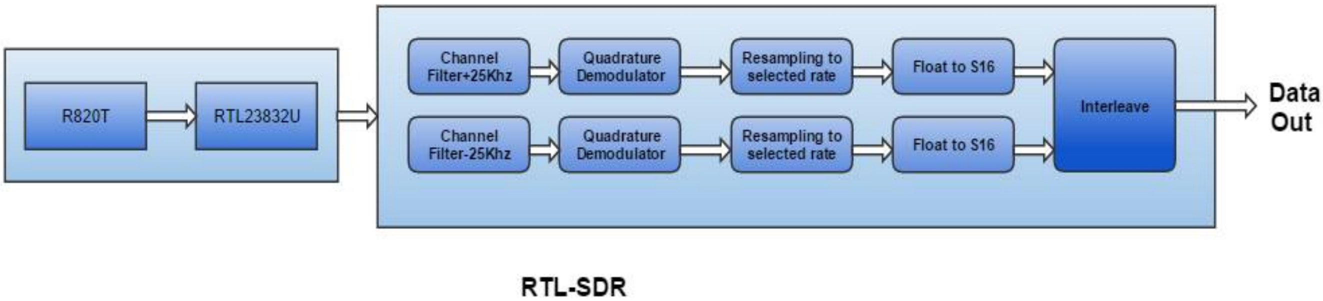

Figure 3 : RTL-SDR block diagram

This software defined solution for observing a wide range of frequencies is made all the more attractive to amateur radio operators by implementing it on a chip making it portable. The SDR used here contains an RTL23832U digital processor and an R820T digital tuner which combined with low noise amplifiers and filters make it a complete package. So the RTL-SDR is in short a Direct Video Broadcast TV tuner USB dongle used in conjunction with a digital processor to make a cheap computer based radio scanner [8].

VI. SOFTWARE SUBSYSTEMS

The AVHRR is a radiometer which in layman's terms can be said to act like a line image sensor. As the satellite passes over a region, it senses the radiations emitted by the earth's surface in five different wavelength ranges. The intensities of these radiations are arranged to form an intelligible image. It is these intensities that are modulated through a 2400 Hz subcarrier which in turn is modulated on a 137 MHz carrier. Thus it is of paramount importance to note that the satellite does not directly transmit images, it transmits intensities through an audio signal which are then assigned 8-bit gray scale values to result in a final grayscale image. Keeping this in mind, the first step the receiver has to perform is to extract the 2400 Hz sub-carrier from the 137 MHz main carrier.

A. RF Frontend

The Software defined radio is a USB dongle as seen in previous paragraphs. This hardware component requires a software counterpart that can control it's software defined parameters like modulation techniques, filter orders, gain, easy to adjust receiver center frequency and a UI that makes observation of a wide range of frequencies an easy job. There are quite a few open source softwares that satisfy the requirements of an SDR, one of them being SDRSharp.

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B. Satellite tracking

The NOAA satellites being LEO, orbit the earth about 4 to 5 times a day and hence they need to be tracked. The APT signal is available only when the satellite is within line of sight of the antenna and above some minimum elevation, generally up to 8-10 degrees. To make this seemingly complex task of tracking the location of a satellite, various softwares are used some of which are gpredict and orbitron. Orbitron is essentially used for satellites have significant doppler shift in their transmission frequencies. For these LEO satellites however, the doppler shift is quite small, and hence continuous automatic adjustments to SDR receiver center frequency are not required. The footprint of the satellite is enough to judge the time at which signal is to be received, and better the elevation, better will be the signal. With the help of these softwares, the time of Acquisition of signal (AOS) and Loss of signal (LOS) is obtained. These two times form a time interval in which the signal is going to be the strongest. The SDR along with other equipment is used in that precise time period to get a clear image.

C. APT Decoding

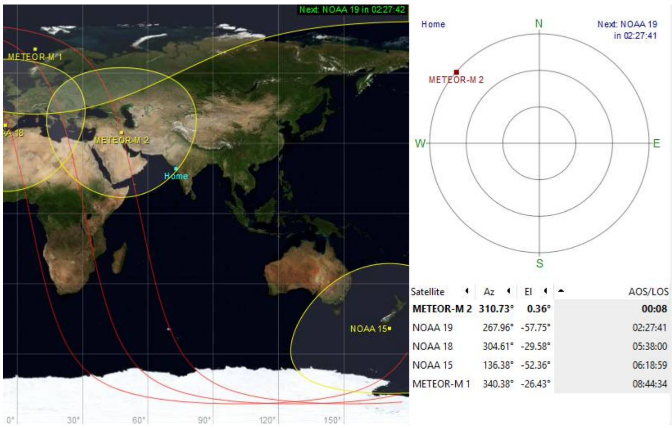

Figure 4 : Gpredict

To obtain an image from the recorded wav file we require special softwares to decode the information present in the audio files. APTDecoder, SatSignal and WxToImg are the three most widely used APT decoding softwares. WXtoImg has more than sufficient features for the beginner.

WXtoImg is a fully automated APT and WEFAX weather satellite decoder, it can also tell you the times and frequencies of the NOAA satellites passing overhead. The software supports recording, decoding, editing, and viewing on all versions of Windows, Linux, and Mac OS X. WXtoImg supports real-time decoding, map overlays, advanced colour enhancements, 3-D images, animations, multi-pass images, projection transformation (e.g. Mercator), text overlays, automated web page creation, temperature display, GPS interfacing, wide-area composite image creation and computer control for many weather satellite receivers, communications receivers, and scanners. There is also a paid version of WXtoImg which can unlock more features, however it is not required for use with RTL-SDR. WXtoImg makes use of the 16-bit sampling capabilities of soundcards to provide better decoding than is possible with expensive purpose-designed hardware decoders.

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VII. RESULTS

The APT signals were decoded into high resolution images using WxtoImg working with SDRSharp. The location of the antenna plays a major role in determining the performance of the system. By experimenting with different locations of the antenna, it was seen that open spaces with not many high-rises elevated with respect to ground gave the best results. The outdoor setup was therefore installed on a terrace about 50 feet away from the indoor one, and this length of coax cable led to a negligible loss not more than 1 dB. The images as seen here, were found to be clearer and more descriptive than the INSAT-3C images from Indian Meteorology Dept.

The signal was found to be sufficiently strong to form an image when the satellite was approximately above 15 degrees elevation. It was observed that the image was noise-free for SNR more than 20 dB.. Also, the antenna constructed was found to be omnidirectional owing to it receiving the signal for the complete duration of the satellite pass. Figure 5 shows how the antenna is mounted at the terrace of the college building. The helical shape of the antenna elements conform with the fact that the performance of the antenna was found to be the best. The coax cable is used as a transmission line to feed the signal to the indoor setup as shown in figure 6.

Figure 5: Outdoor Setup

Figure 6: Indoor Setup

VIII. CONCLUSION

An inexpensive satellite imaging earth station was thus constructed using readily available raw materials. The QFH antenna was proved to be the best suited for APT reception which is why a proper construction of this antenna was of paramount importance to this system. These noise free high resolution images can be used in a wide variety of remote sensing applications. Measuring albedo of earth surface, making heat maps, forecasting weather, extracting precipitation levels of clouds are some of the few applications where these images can be put to use.From figures 7 and 8 it is clearly evident that an image with much higher spatial resolution is obtained using our setup than that from INSAT satellite which is a geostationary satellite. Despite the area covered in the image in figure 8 being more than that in figure 7, the cloud detail is observed to be much better in figure 7. This is because the Low Earth Orbit Satellite

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used by us to get an image is much nearer to earth's surface than INSAT 3C. This is evident in the images shown which is why APT images from LEO satellites, and not images from INSAT 3C, are used for weather monitoring purposes.

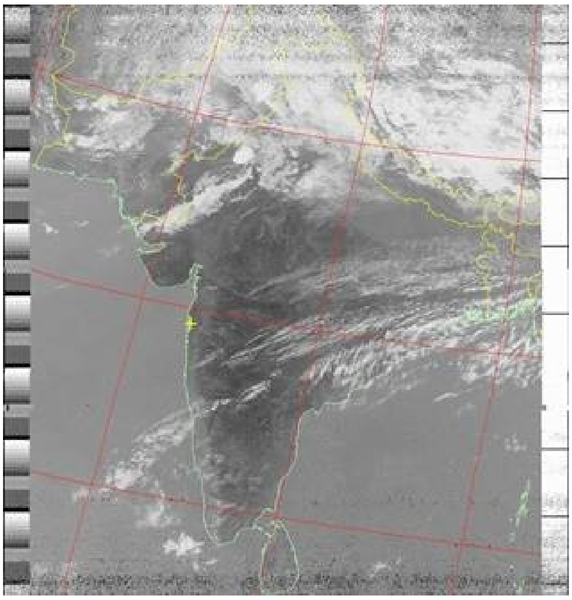

Figure 7: APT Image received by our setup

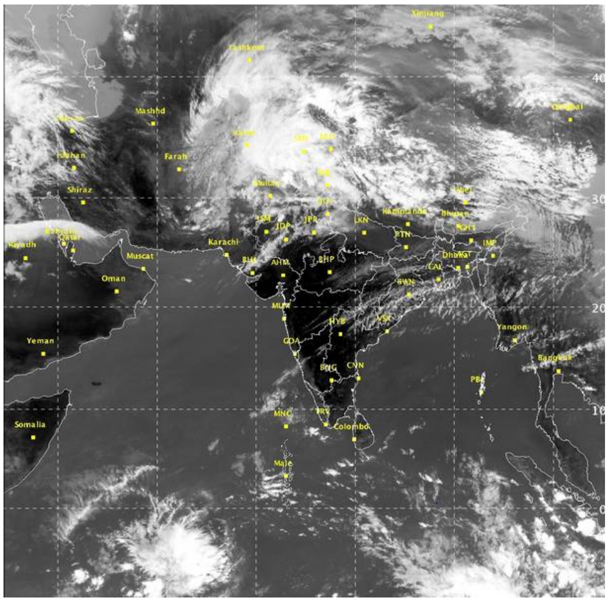

Figure 8: INSAT image from IMD website

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