

Hardware and Software Considerations to Use NOAA Images

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Abstract – *The techniques of weather satellites images reception has quickly evolved in the last decade. At the beginning, the operation of building a reception station required considerable means, and only specialized institutions had access to these techniques. Nowadays, because of the recent development of micro-computers and signal processing, it is now possible for even a small institution to have its own station able to receive net images from certain meteorological satellites such as NOAA and METEOSAT satellites with affordable costs. A reception station for certain meteorological satellites has been mounted and operated in our laboratory. A description of this station and of the set of software necessary for the reception and the processing of the APT images is given. Indications of the use of some software as well as their application for processing a sample of the received images are presented. We point out that the station allows image processing in real time*

Résumé – *Les techniques de réception des images venant des satellites météorologiques sont rapidement évoluées durant la dernière décennie. Dans le passé, l'opération de construire une station de réception satellitaire demandait des moyens considérables et seules les institutions spécialisées pouvaient accéder à ces techniques. Grâce au développement récent de l'informatique et le traitement du signal, il est maintenant possible même pour les petites institutions d'avoir leur propre station capable de recevoir des images nettes transmises par certains satellites météorologiques tels que les satellites NOAA et METEOSAT avec des coûts abordables. Une station de réception pour certains satellites de météorologie a été montée et mis en œuvre dans notre laboratoire d'université. Une description de cette station et les logiciels nécessaires pour la réception des images de format APT ainsi que leur traitement est donnée dans cet article. Des indications concernant l'utilisation ainsi que leur application sur un échantillon des images reçues a été aussi présentée. La station permet aussi le traitement des images en temps réel.*

Key words: Polar orbiting satellites — Satellite reception – Meteorological images – VHF transmission – APT signal – AVHRR NOAA system – Surface temperature – Image processing.

1. INTRODUCTION

The complete operational geostationary system includes hundreds of satellites. Among them we may mention the European satellite METEOSAT, the two American satellites GOES, the Japanese satellite GMS and the Russian satellite GOMS. All these satellites are in the equatorial plan, at about 36 000 km from the Earth surface. They are disposed in order to ensure an optimal observation of our planet. The Polar Orbiting Satellites evolve at much lower altitude (a few hundred km), consequently, their period of revolution is shorter (approximately 102 minutes for an altitude of 850 km). The orbit of these satellites has often an inclination of 99°, for Helios synchronism reasons. The NOAA and METEOR satellites, as well as the future METOP satellites (programmed by EUMETSAT) belong to the category of the Polar Orbiting Satellites. In this article, we describe how to build a reception station for some meteorological satellites and how to use some necessary software to track, receive and treat the rough images sent every day by these polar satellites.

Most weather satellites offer two kinds of picture services, a digital transmission format with high resolution data (named HRPT or PDUS) and an analogical transmission format of lower resolution (APT, WEFAX, SDUS). This later transmission format needs limited technical resources for reception and decoding. We have mounted and operated a reception station for the APT weather satellites pictures. This station is able to receive the APT pictures from several satellites like the Russian METEOR3-5 satellites and the new US NOAA17 satellite. The received images are treated by our own program PCSATWIN [1] and other programs like SATSIGNAL [2] and WXTOIMG [3].

2. DESCRIPTION OF THE STATION

Our polar satellites images reception station is a system of remote sensing which is based on the technique of the AM and FM modulation. It includes two parts (hardware and software). The hardware part consists of :

1. Omnidirectional aerial turnstile antenna, whose diagram of radiation without hole, and which is quit high quality device for the reception of NOAA APT VHF signal. The QFH (QuadriFilar Helix) Antenna is another type of antenna was also used.
2. Receiver with a bandwidth IF (Intermediate Frequency) from 30 to 45 kHz,
3. VHF preamplifier with gain of 32 dB, fixed under the antenna,
4. Computer equipped with a Analogical/Digital converter.

The software part consists of :

1. Software to predict the tracks of meteorological satellites both as paths above the earth, and as images produced by these satellites when scanning the ground, like WXTRACK [4].
2. Software for decoding the analogical format of the APT signal (Automatic Picture Transmission), like WXSAT [5].
3. Different image processing programs like PCSATWIN, SATSIGNAL and WXTOIMG

2.1. Orbital Characteristic

The mathematical basis of satellite orbit determination has been known since the work of Kepler and Newton in the 17th century. For nearly 400 years, this knowledge was applied to the movement of heavenly bodies such as the planets and their natural satellites. Only in the last half century, the same basic laws have been applied to the new artificial satellites in earth orbit. Through observation, Kepler discovered three basic laws of orbital dynamics and established what have become known as the Keplerian Orbital Elements, which utilize six parameters (some illustrated in the diagram below) to fully define the position of a satellite in space. These are defined in such a way that five of the six are quasi-stable over time, leaving only a single parameter varying with time. This is a computational advantage which makes the orbital elements a near-universal tool used by space agencies to describe the orbits of their satellites [6].

2.2. Geostationary satellites (GMS-GOES-METEOSAT)

A geosynchronous satellite whose circular orbit lies in the plane of the Earth's equator remains fixed relatively to the Earth. The satellite circles the earth once each day. The time it takes for a satellite to orbit the earth is called the period. For a satellite's orbit period to be one sidereal day, it must be approximately 35,786 kilometers (19,323 nautical miles or 22,241 statute miles) above the earth's surface [7]. Since 1998, satellite systems in operation include METEOSAT (from EUMETSAT), GMS (Geostationary Meteorological Satellite of Japan), GOMS-N1 (Geostationary Operational Meteorological Satellite of Russia) and GOES (Geostationary Operational Environmental Satellite from the USA). The current GOES

satellites are of an advanced design first flown in 1995. Next, Japan launched a new satellite design, MTSAT, and EUMETSAT launched the first of its METEOSAT Second Generation (MSG) satellites series. The main characteristics of current planned geostationary meteorological satellites are given in reference [8].

2.3. Polar orbiting satellites (NOAA-METEOR)

These satellites are placed in low orbits and transmit their information in real time. The images obtained require a geographical repositioning for each orbit. The NOAA (National Oceanic and Atmospheric Administration) is an American administration in charge of the exploitation of the meteorological satellites with low orbits (approximately 800km in altitude).

These satellites are known as:

- *heliosynchronous* (their revolution is done on a constant level compared to the sun),
- *circumpolar* (their orbit passes close to the poles), and with streaming (the radiometer which is revolving, gives a continuous analysis of terrestrial surface).

The POES satellite system offers the advantage of daily global coverage, by making nearly polar orbits roughly 14,1 times daily. Since the number of orbits per day is not an integer, the sub orbital tracks do not repeat on a daily basis, although the local solar time of each satellite's passage is essentially unchanged for any latitude. Currently, in orbit, we have a morning and afternoon satellite, which provide global coverage four times daily. The POES system includes the Advanced Very High Resolution Radiometer (AVHRR) and the Tiros Operational Vertical Sounder (TOVS). Because of the polar orbiting nature of the POES series satellites, these satellites are able to collect global data on a daily basis for a variety of land, ocean, and atmospheric applications. Data from the POES series supports a broad range of environmental monitoring applications, including weather analysis and forecasting, climate research and prediction, global sea surface temperature measurements, atmospheric soundings of temperature and humidity, ocean dynamics research, volcanic eruption monitoring, forest fire detection, global vegetation analysis, search and rescue, and many other applications. Their period is of approximately two hours and they shift approximately 25 degrees of longitude per revolution. The data transmitted by this satellite can be received several times per day according to the number and the orbit of the satellites in service. With each passage, it gives several simultaneous images, one into visible and others in various wavelengths from the infra-red channel.

2.4. Analogue transmission of geostationary meteorological satellites (WEFAX)

The International WEFAX system for transmission of image data in analogue format is another success story for the Coordination Group for Meteorological Satellites (CGMS). WEFAX is a standard data transmission specification used by operators of geostationary meteorological satellites to transmit satellite images and other data in analogue form to low-cost user stations. The format is a derivative of the Automatic Picture Transmission (APT) originally developed for transmission from the polar satellites of the USA. This common heritage also helps to keep costs down. The international standard broadcast frequency for WEFAX transmissions is 1691,0 MHz. Some systems, such as EUMETSAT's METEOSAT, also transmits WEFAX on 1694,5 MHz. The structure of the standard WEFAX format is shown on figure 1, transmitted as lines of data in analogue format over a total period of about three and a half minutes. This format includes synchronization signals at the beginning and the end, together with further synchronization signals at the start of every line. Although the transmissions are in analogue format throughout, digital header information is encoded in the analogue signal at the start of the signal, so that user software can determine which image is being transmitted [9]. WEFAX has served the user community well for over 20 years and will be replaced by a new standard, the Low Rate Information Transmission (LRIT) system. LRIT

has the advantage that it is completely digital and will be able to transmit images that can be used in a more quantitative way than the current analogue WEFAX images.

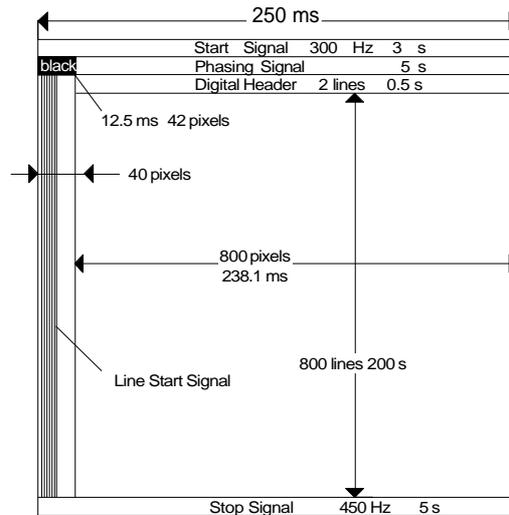
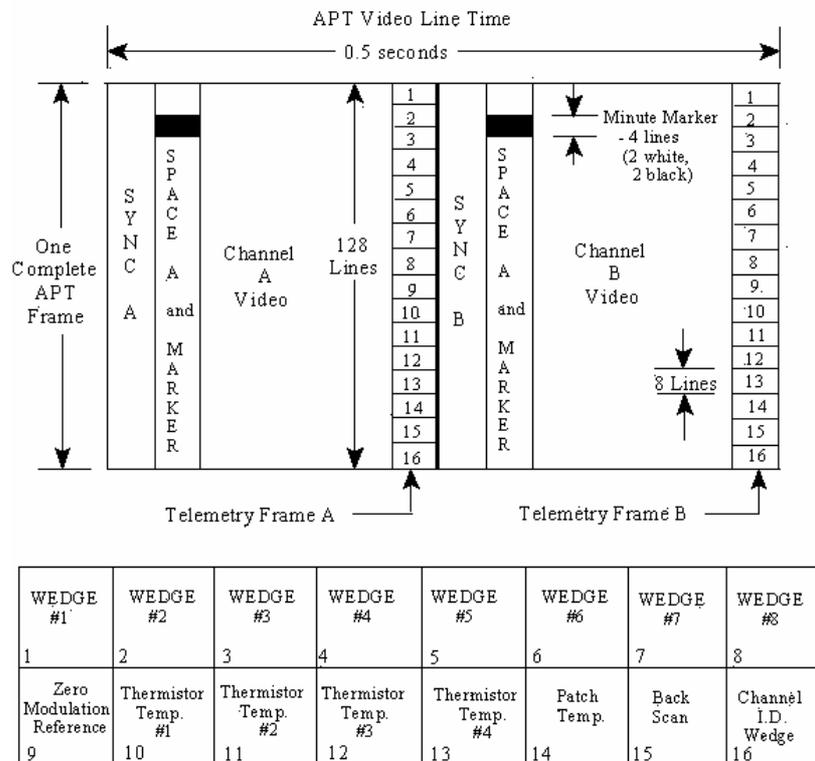


Fig. 1: The standard WEFAX format

2.5. APT format for POES

APT data, that we receive daily, are transmitted continuously as an analogue signal using amplitude modulation of a 2400 Hz carrier. A new line of data is transmitted each half second, containing a line of image data from two AVHRR channels together with supporting information (figures 2 and 3).



Notes:

- 1) Each telemetry frames consists of 16 points
- 2) Telemetry frame rate is 1 frame per 84 seconds
- 3) Each telemetry point is repeated on 8 successive APT video lines

Fig. 2: The APT frame format

As each image frame is received, synchronization patterns show up as vertical black lines to the left of each image, while telemetry data are shown as gray scale wedges carrying calibration and other information. Any two of the AVHRR channels can be chosen by the NOAA ground station for dissemination. A visible channel is used to provide visible APT imagery during daylight, and one IR channel is used constantly (day and night). A second IR channel can be scheduled to replace the visible channel during the night-time portion of the orbit [10].

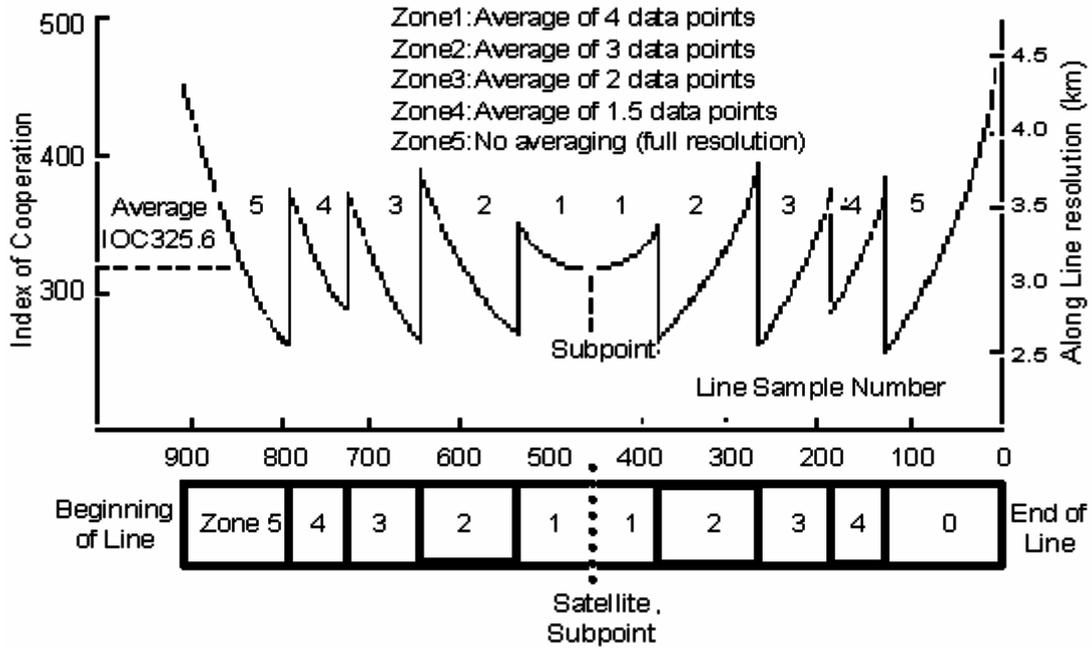


Fig. 3: Cross-scan linearization scheme

The on-board sampling scheme uses every third line of the AVHRR instrument data and samples each line as shown in figure 1 to provide cross-track linearization. This gives quasi-constant resolution across and along track of around 4 km. The characteristics of the transmitted signal remain unchanged in the NOAA KLM satellite series from those in the TIROS-N series (NOAA-8 to NOAA-14), while there is a minor change in the data format to account for the modified channel-3 on the AVHRR instrument. APT will not be transmitted by the METOP satellites (flown by EUMETSAT since 2003). These satellites will use the newer LRPT digital standard.

3. OPERATIONAL REQUIREMENT

To receive data from VHF-APT transmissions, a ground station is required. A block diagram of a minimum ground station components is presented in figure 4.

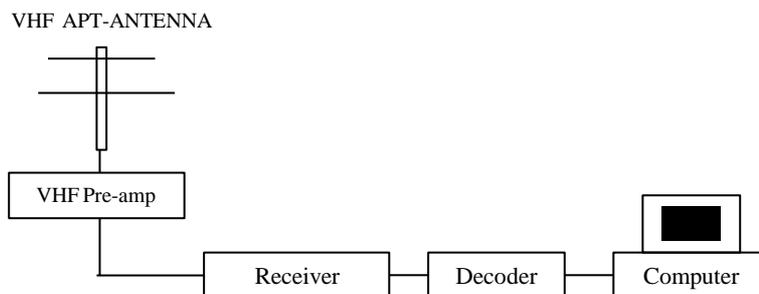


Fig. 4: APT station realized.

The antenna for the APT system consists of an omnidirectional and circularly polarized beam. A preamplifier is necessary because the signal transmitted by the satellites is weak (about 4 Watts). The receiver then converts the radio signals into audio tones, and the decoder converts the audio tones, which represent analogue voltage levels generated by the sensors, into digital data. The computer receives these data through an analogue to digital converter. It is necessary to have an orbital prediction program and current orbital elements for the satellites to determine when they will be visible from the ground station. In the APT system, the predictions tell the operator when to have the system active, and any slight error is generally not important.

4. SOFTWARE FOR TRACKS PREDICTION

Since the satellites fly over the same terrestrial area approximately four times per day, it is necessary to predict the tracks of weather satellites both as paths above the earth. For that, there are many applications which simulate the movement of the satellites in universal real time.

Among this software, we find:

- WXTRACK
- ITRACK
- FOOTPRINT
- J-TRACK

Figure 5 gives the menu of software WXTRACK that we currently use :

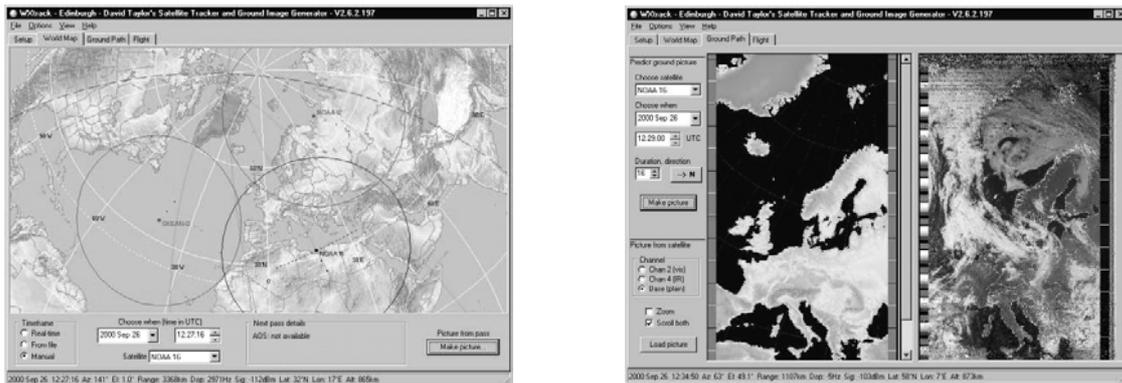


Fig. 5: WXTRACK software (a) The Worldmap menu , (b) ground path.menu

The main feature of WXTRACK is the ability illustrated in figure 6.b, the prediction of the image that a pass should produce. The program allows us to put side-by-side the predicted image with an actual satellite pass so that areas that are unclear or cloud covered may be determined.

5. SOFTWARE FOR THE APT FORMAT DECODING

WXSAT, that we use, is a software intended to decode the APT weather images transmitted by the polar orbiting satellites and geostationary (in AM and FM modulation). We use also, other software like WXTOIMG and SATSIGNAL.

6. REALIZATION

6.1. Quadrifilar Antenna

The quadrifilar antenna improves on traditional APT antenna performance in two ways. Firstly, the quadrifilar is a true circularly polarized antenna. This exactly matches the antenna pattern from the satellite and also serves to reject linearly polarized earth based signals. Secondly, the gain pattern of a quadrifilar closely matches the received signal level from the satellite, resulting in nearly constant received signal quality from horizon to horizon.

Theoretical design is calculated through helical wires model (figure 6), the calculation of the radiation fields from helical wires utilizes the expansion of phase factors in the current integral for the fields into a series of Bessel.

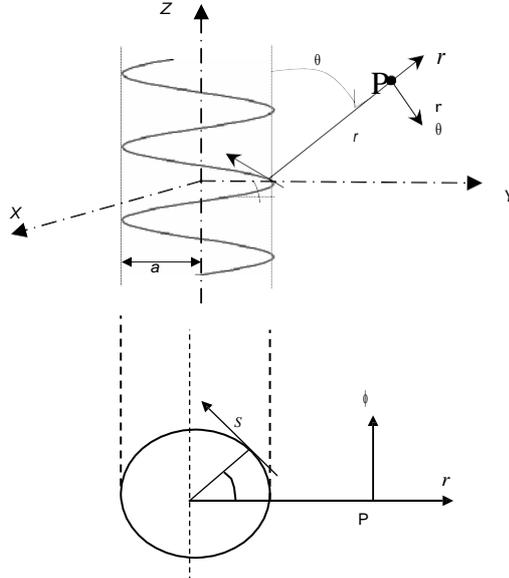


Fig. 6: Orientation of one helical wire of a volute.

The field components E_ϕ , E_θ are then computed from a rapidly converging series obtained by term-wise integration. The radiation wave field \vec{E} at a far-field point P .

$$\vec{E} = (i\omega\mu_0 / 4\pi R) \int [r' \times (\vec{r} \times \vec{s})] I_s e^{-ikr} ds \quad (1)$$

where r is the distance of P from the current or wire element and R is the distance of P from the origin, ω is the angular frequency of the source current and field, $k = \omega/c$ is a propagation constant, c being the speed of wave propagation and μ_0 the permeability of the free space. This field can be resolved into two locally orthogonal components:

$$\left\{ \begin{aligned} E_\phi &= -\frac{i\omega\alpha\mu_0 I_0 e^{-ikR}}{4\pi R} \int_{-\phi_0}^{\phi_0} \cos\psi e^{ika\sin\theta\cos\psi} e^{i[ka\alpha\cos\theta - \beta]\psi} d\psi \\ E_\theta &= -\frac{i\omega\alpha\mu_0 I_0 e^{-ikR}}{4\pi R} \left\{ (\tan\theta \sin\theta) \int_{-\phi_0}^{\phi_0} \cos\psi e^{ika\sin\theta\cos\psi} e^{i[ka\alpha\cos\theta - \beta]\psi} d\psi + \cos\theta \int_{-\phi_0}^{\phi_0} \sin\psi e^{ika\sin\theta\cos\psi} e^{i[ka\alpha\cos\theta - \beta]\psi} d\psi \right\} \end{aligned} \right. \quad (2)$$

where I_0 is the magnitude of the assumed sinusoidal current propagating along the helical wire and meaning of other symbols can be found in figure 6. Due to the factor in the form of $e^{i(\cdot)\cos\psi}$ in the integrand, all integrals in (2) are expressible as infinite series of Bessel functions, and the field component E_ϕ, E_θ can be evaluated with rapid convergence.

6.2. Antenna preamplifier

The amplifier designed is specially used to be connected to an unbalanced antenna input for reception of signals in a narrow band of about 2MHz. It was originally designed for weather satellite reception, in the range of 137-138 MHz. This amplifier uses two stages of BFR91 device, has a low noise figure and a power gain of 32 dB. It is powered with a 12 V dc supply, fed down through the coaxial cable.

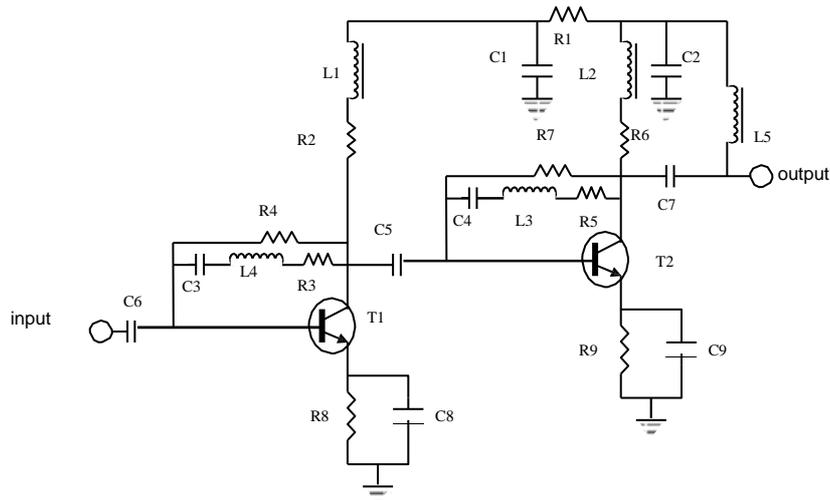


Fig. 7: Electronic schematic of the preamplifier.

6.3. APT receiver

The receiver of the APT waveform that we use is based on the frequency demodulation with double change of intermediate frequency technique. An FM waveform carries its information in the form of frequency changes, so the amplitude is constant. Thus, the information is held in the zero crossings. The FM waveform can be clipped at a low level without loss of information, and additive noise has less effect on zero crossings. Receivers therefore often clip, or limit the amplitude of the received waveform prior to frequency detection. This produces a constant amplitude waveform as an input to the discriminator. This clipping has the effect of introducing higher harmonic terms which are rejected by a *post-detection low-pass filter*. A more sophisticated system is shown in figure 8.

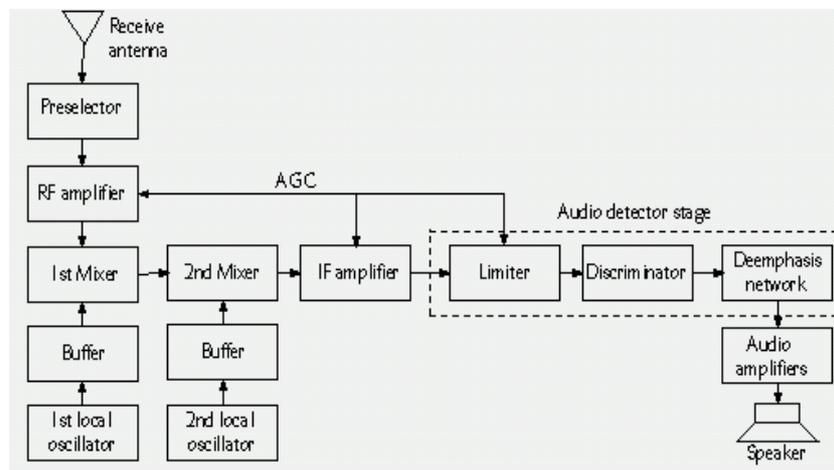


Fig. 8: Diagram of the APT receiver

7. RESULTS

7.1. Validation of the WXSAT software

By simulation, we applied a sound signal (of .WAV extension) generated from one PC, to the input of the sound card of another PC, the corresponding image decoded by the WXSAT software is given in the figure 9. The image obtained shows well that signal APT is collected from a station located in the south of England. The signal is emitted in the visible channel of radiometer AVHRR/2 of NOAA14, and the spatial resolution of the image is 4 km.

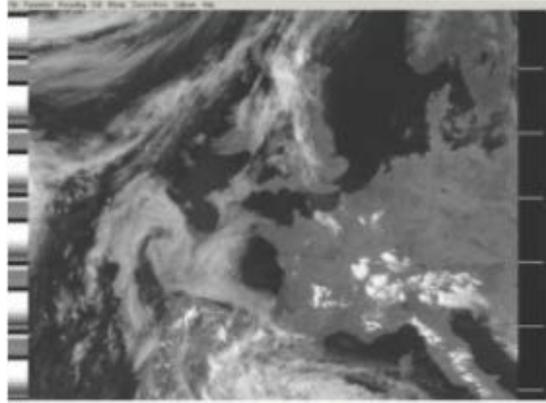


Fig. 9: Image of test decoded by the WXSAT software.

7.2. Results of reception

The image below on the left (figure 10), is among about hundred images collected by our station since September 2nd 2002, and was emitted by the new satellite NOAA17 (put into orbit on June 24, 2002), the APT frequency of reception is 137.62 MHz.

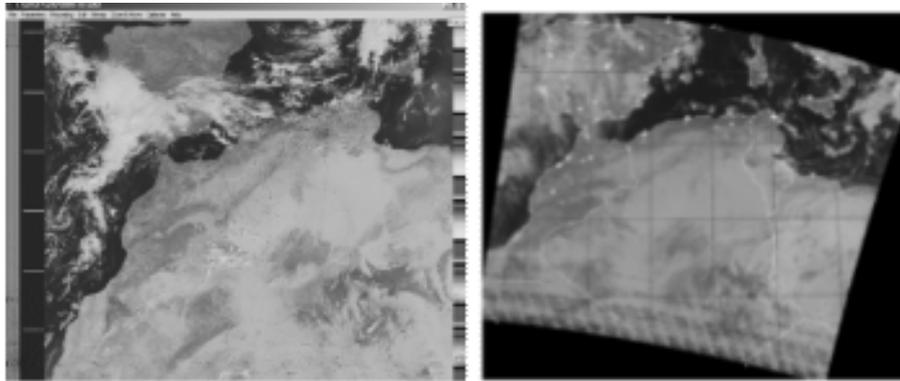


Fig. 10: Image Processed

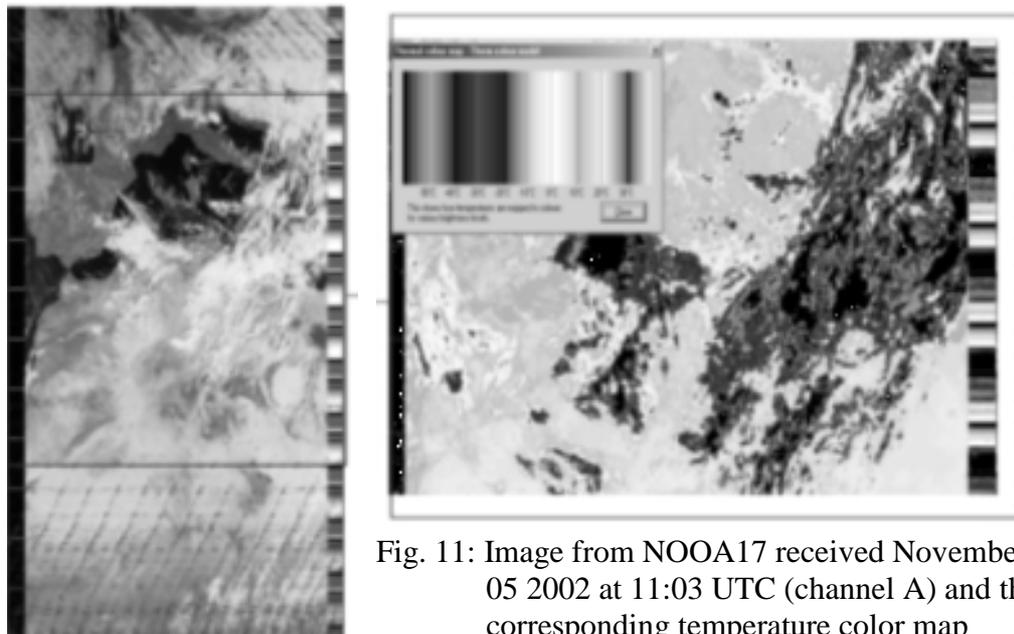


Fig. 11: Image from NOAA17 received November 05 2002 at 11:03 UTC (channel A) and the corresponding temperature color map image processed by Sat signal

8. TREATMENT

After elimination of telemetry and synchronization data, we applied the geometrical correction to the received image by using our PCSATWIN software (Figure 10), the resulting image is given on the right. To locate the areas, we applied a mask showing country, state boundaries, latitude and longitude. On this image, the point with a marking " + " on the top, locates our station of reception (Oran city, North-West of Algeria, $0^{\circ} 35' W$, $35^{\circ} 50' N$).

To display the temperature distribution, we have used SATSIGNAL software. When a NOAA APT signal is correctly decoded, it should be presented with three additional tabs on the image display labeled Channel A (channel 2 in the AVHRR instrument), Channel B (channel 4 in the AVHRR instrument) and False Color. The last tab, is used to display the distribution of the level temperature in the picture (figures 10 and 11).

9. CONCLUSION

The techniques of weather satellites images reception has quickly evolved in the last decade. At the beginning, the operation of building a reception station required considerable means, and only specialized institutions had access to these techniques. Nowadays, because of the recent development of micro-computers, it is now possible to have a reception station from some meteorological satellites with affordable equipments. We have built a reception station of APT weather satellites which gives high quality brute images. The daily received images are stored in a data base, in order to be available at any time for image processing (like geometrical correction, localization of the borders, temperature of surface, etc...). It is also possible to do this processing in real time.

NOMENCLATURE AND ABBREVIATION

AGC: Automatic Gain Control	RAM: Random Access Memory
AM: Amplitude Modulation	UTC: Universal Time Co-ordinate
APT: Automatic Picture Transmission	VHF: Very High Frequency
AVHRR: Advanced Very High Resolution Radiometer	WEFAX: Weather Facsimile
NOAA: National oceanic and Atmospheric Agency	FM: Frequency Modulation
ω : angular frequency of the source current and field (s^{-1})	μ_0 : permeability of the free space.
c : speed of wave propagation ($m s^{-1}$)	$k(\omega, c)$: propagation constant (m^{-1})
a : semi major axis of the elliptical orbit (m),	e : eccentricity of the orbital ellipse,
i : inclination of the orbit with respect to the equator($^{\circ}$),	
Ω : Right ascension of the ascending node describes the rotation of the orbit with respect to the true anomaly $\gamma(^{\circ})$	
ϖ : argument of the perigee defines how far the orbit is turned within its own plane($^{\circ}$),	
γ : true anomaly defines the position of the satellite with respect to $\omega(^{\circ})$	
θ : angular position of the satellite on its orbit ($^{\circ}$)	

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