

SDR based Design of a system for meteorological image acquisition through NOAA satellite

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Abstract--- Software Defined Radio is a logical evolution, and convergence of digital radios and software technologies. It offers practical, effective, and inexpensive solutions. In this paper, we present SDR based design of a system for meteorological image acquisition through NOAA satellite. These satellites are equipped with a radiometer, which scans the earth in five channels; its scanner is able to map the clouds and vegetation, to measure the temperature and the humidity in the atmosphere and on the earth.

The idea behind this study is to create a database of meteorological parameters to serve all Algerian researchers

Keywords--- Software defined radio, SDR, RTL-SDR dongle, NOAA, Wxtoing, SDRSharp, gr-gsm

I. INTRODUCTION

The concept of software-defined radio was emerged in the American defense sector, resulting from military research on multi-mode radios operating in VHF and UHF bands (US Air Force's ICNIA program), In 1979 [1].

In 1984, E-SYSTEMS, which called now "Raytheon", coined the term "radio software" in a corporate bulletin. It referred to a prototype digital base band receiver equipped with a set of processors that performed adaptive filtering for interference cancellation and demodulation of wideband signals [2].

After that, an RFI (Request For Information) on software defined radio for mobile telephony marked the starting point of increased activity in the field. In 1996, the MMITS (Modular Multifunctional Information Transfer System) Forum was launched, renamed in 1998 as the Software Defined Radio Forum, then as the Wireless Innovation Forum in 2009. Its objective is to promote and develop software radio technology, the deployment and use of open architectures for advanced wireless systems, also to stimulate and guide innovation and standards [3].

Software-defined radio has revolutionized the communications industry by providing a high level of flexibility. Despite the military origins of the SDR, today the radio equipment industries are investigating this trail,

and changing their hardware architectures. The SDR became popular and applicable in various fields such as defense, mobile telecommunications, limited production devices and cognitive radio, broadcast radio, etc..

Due to its adaptability and flexibility, the software-defined radio mainly used in wars, such Americans JTRS program [4]. It considered a major element in the tactics of centered network conflict; it allows remote exchange at the battlefields, with the possibility of transmission in the HF to UHF bands, with a high rate using specific WNW waveforms (Wideband Networking Waveform). In the field of electronic warfare, this technology offers strategic support due to SCA (Software Communications Architecture) standards. During an attack, the Electronic Counter Measure (ECM) device receives, then transmits radio-electric transmissions to intercept and / or scramble the interchanged information in the environment, while taking into account the unforeseen improvement of military equipment, in order to protect his camp. This technology also allows the detection of the enemy by radar while controlling the electromagnetic spectrum by exploiting and / or preventing communication as well as the management of material equipment [5].

Software radio technology remains a choice for more innovation in the broadcasting field, known for its standard character. It also presents an alternative economic for telecommunication operators. Some companies use this technology because of its standards that define the interfaces of radio control equipment (RCE), based on digital links. This choice is justified by the possibility of putting the RCE on the top floor as well as in the basement [5].

According to Mitola, software radio is incorporated with model-based reasoning in this type of radio. This approach, called "cognitive radio" [3] improves and diversifies software radio and its functionalities, following a state of consciousness and using the information received by sensors, with a possibility of reconfiguration.

Moreover, SDR is used in the NASA Space Telecommunications Radio System (STRS), demonstrating

a partnership with the OMG and the SWG (Space Working Group) to create an independent platform model based on API (Application Programming Interface) to support special space equipment as well as certain functions [5].

In this paper we present the SRD utilization in meteorological image acquisition through the NOAA satellite. Every day, NOAA satellites send APT data to land with frequencies around 137 MHz. This data could be acquired by a system based on software-defined radio, using a PC and "RTL-SDR" attached to a suitable antenna for reception, and equipped with two software "SDRSharp" to record the APT signal, and "WXtoImg" to decode the signal into a metrological image

The paper is organized as follows. In section 2 we present The SDR concept and its development tools used in this work while, section 3 illustrates proposed architecture, where we detailed the antenna design and we describe the RTL-SDR dongle. Finally, a conclusion is presented in section 4.

II. AUTOMATIC PICTURE TRANSMISSION (APT)

Observation satellites are equipped with a scanning radiometer, a system comprising several sensors, lenses and mirrors controlled by motors. The radiometer scans the surface of the earth line by line and as it moves 120 lines are transmitted every minute forming a complete image. In figure, we observe from left to right: a synchronization band, a time marker, the image itself and a telemetry band. This succession is repeated twice, on the left the visible image and on the right the infrared image. Each time an image frame is received, the synchronization appears as lines vertical blacks to the left of the image while the telemetry data is presented as "corners" carrying calibration and other information. The markers are an alternation of black and white horizontal traces for the visible channel, white and black for the infrared channel, the synchronization is an alternation of vertical bands and the telemetry is an alternation of grayscale bands serving as a reference to decode the 'image [6]

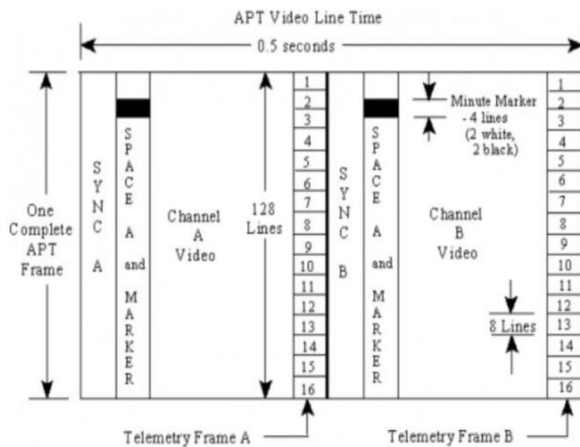


Fig. 1. APT format

III. SDR

A. Review

Generally, traditional radios consist of an integrated circuit transceiver developed using dedicated equipment. The main components used are mixers, amplifiers, filters, modulators/demodulators and converters [7]. In parallel with this approach, an innovative concept has appeared "Software Defined Radio" (SDR) which represents a radio communication system structurally different from traditional radios; it implements most of its features by software instead of a hardware implementation. The SDR Forum quotes: "The SDR is a radio in which some or all of the functions of the physical layer are defined by software" [8]. SDR consists of two subsystems: a hardware subsystem and a software subsystem. Its components include Digital Signal Processors (DSP), Field Programmable Gate Array (FPGA) and General Purpose Processors (GPP). Figure 2 illustrates Hardware /software division in software-defined radio.

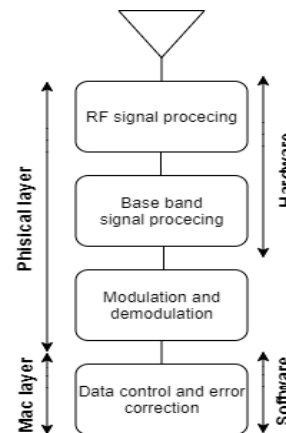


Fig. 2. Software/Hardware division in SDR [7]

B. Development tools

1) SDRSharp (SDR#) software

Currently, SDRSharp is the most popular SDR software, used with the RTL-SDR key (dongle). It is free, easy to set up and easy to use in radio reception to listen and view received signals.

The figure 3 illustrates its interface, which consists of four main windows:

1. Define demodulation mode and its parameters.
2. Adjust the desired frequency and volume.
3. View the spectrum in real time.
4. View the waterfall.

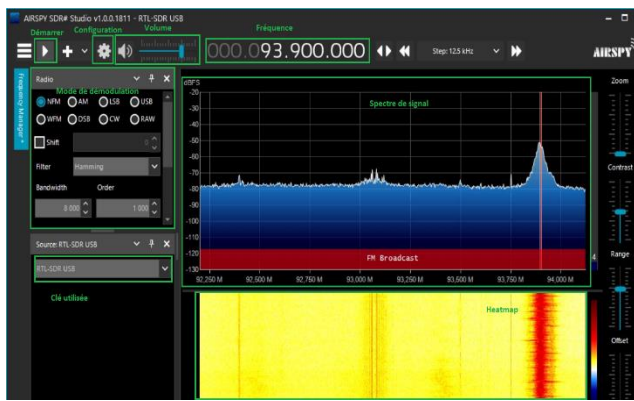


Fig. 3. Screen shoot of SDRSharp interface

2) Matlab/Simulink

Matlab/Simulink defines a hardware support package for RTL-SDR, with a library that contains different blocks compatible with the RTL-SDR dongle. The user is able to scan, and view in real time the signal's spectrum captured by the dongle and implement any type of digital signal processing under Matlab/Simulink.

The block of RTL-SDR Receiver shown in the figure 4 sets a direct communication with any RTL-SDR connected to the computer; it has many parameters such as frequency center, sample rate f_s , and tuner gain to adjust. In addition, a frequency correction value (ppm) can be set to compensate for any hardware tolerance issues associated with the R820T

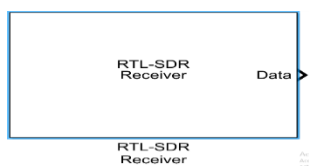


Fig. 4. RTL-SDR Receiver bloc

The figure 5 illustrates a GSM receiver designed on Matlab/Simulink using a RTL-SDR dongle. It is able to receive:

- FM radio with frequencies ranging from 88 MHz to 108 MHz.
- GSM for frequencies ranging from 800 MHz to 1000 MHz.

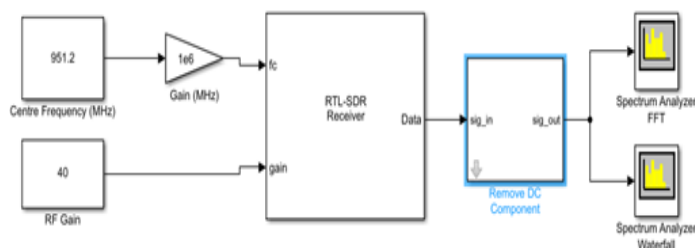


Fig. 5. GSM Receiver based on SDR

After running the simulation, the RTL-SDR's block receiver establishes a connection with the RTL2838U dongle, while setting the center frequency to 951.2 MHz and the RF gain to 40 dB.

The received signal is formed of 8 bits encrypted and encoded data stream, these samples are transmitted to the block "Remove DC Component" whose role is to find the average value of a data frame and remove the DC peak presented in the spectrum.

Then the signals pass through the two spectrum analyzer blocks. The first one configured to display a Fast Fourier Transform (FFT) of the received signal, which has a bandwidth of a sample rate of 2.4 MHz, defined by the RTL-SDR dongle. The spectrum analyzer (waterfall) configured to display the spectrogram using a short time Fourier transform.

The figures below illustrate some downlink GSM channels, captured at the 951.2 MHz frequency, as well as their waterfall.

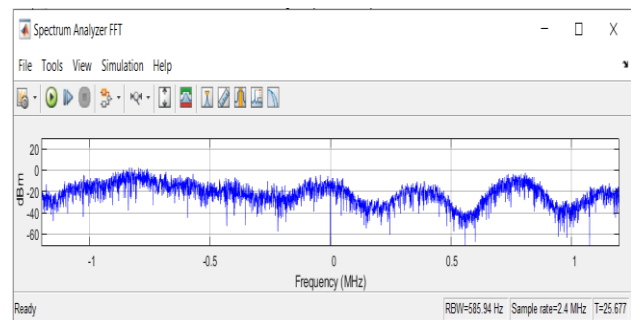


Fig. 6. Spectrum analyzer FFT for 951.2 MHz

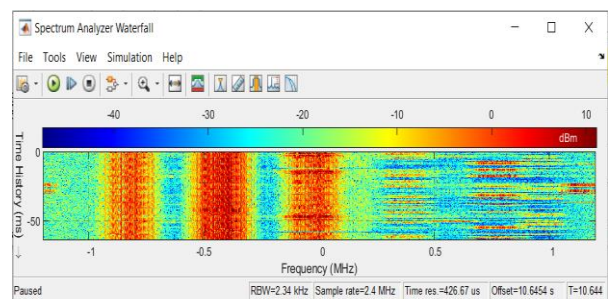


Fig. 7. Spectrum analyzer Waterfall for 951.2 MHz

3) gr-gsm

Matlab / Simulink only allowed us to visualize the GSM frequency spectrum, however with gr-gsm we can do flow capture, visualization, decoding, as well as data extraction.

To do this application, we used gr-gsm, which is a free project developed by Piotr Krysiak, it is only available on Linux. Gr-gsm provides tools for receiving, decoding and decrypting GSM flow. It consists of the following five programs:

1. `grgsm_scanner`: used to scan the GSM band and display the surrounding BTS information.
2. `grgsm_livemon`: a graphical tool to monitor transmitted data on a given frequency in real time.
3. `grgsm_channelize.py`: useful when voice communication uses frequency hopping. It separates a broadband capture into several files, where each one contains an ARFCN (Absolute Radio-Frequency Channel Number).
4. `grgsm_capture.py`: requires only two arguments: frequency or ARFCN and an output file.
5. `grgsm_decode`: requires only two arguments: frequency or ARFCN and a capture file.

```

cherry@cherry-virtual-machine: ~
cherry@cherry-virtual-machine:~$ kal -s GSM900
Found 1 device(s):
0: Generic RTL2832U OEM

Using device 0: Generic RTL2832U OEM
Found Rafael Micro R820T tuner
Exact sample rate is: 270833.002142 Hz
[R82XX] PLL not locked!
kal: Scanning for GSM-900 base stations.
GSM-900:
r82xx_read: i2c wr failed=-9 reg=00 len=1
r82xx_set_freq: failed=-9
Tuning to 937000000 Hz failed!
r82xx_write: i2c wr failed=-9 reg=1a len=1
r82xx_set_freq: failed=-9
Tuning to 937200000 Hz failed!
chan: 34 (941.8MHz - 28.552kHz) power: 102290.50
chan: 36 (942.2MHz - 27.617kHz) power: 85369.76
chan: 47 (944.4MHz - 28.458kHz) power: 106992.08
chan: 81 (951.2MHz - 27.902kHz) power: 56710.79
chan: 109 (956.8MHz - 28.572kHz) power: 46434.90
chan: 112 (957.4MHz - 28.799kHz) power: 57108.88
...chan 120
Difference of offsets between channels is >1kHz. This likely means
that the correct PPM is too far away and you need to provide a rough
estimate using the '-e' option. Try tuning against a local FM rad
to or other known frequency first.
cherry@cherry-virtual-machine:~$
    
```

Fig. 9. Screenshot of surrounding frequencies

Figure 8 illustrates the diagram of the acquisition cycle and the steps of the GSM network investigation.

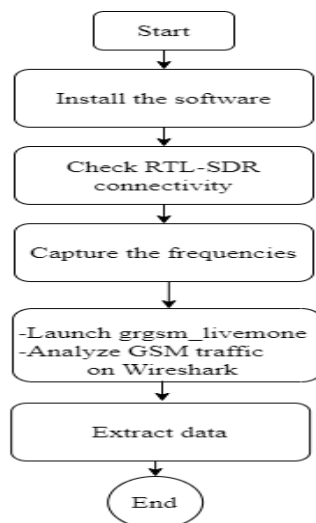


Fig. 8. GSM flow investigation flowchart

After installing the software and checking the connectivity between the dongle and the laptop, we start the scan in order to catch the frequencies used by the surrounding BTS (Base Transceiver Station) in real time. Figure 9 illustrates them, where each one is defined by channel number and power.

After that, we run `grgsm_livemon` in order to monitor transmitted data on a given frequency in real time. We have chosen the same frequency (951.2 MHz) used before on Matlab/Simulink to see the deferent.

The downlink transmitted data are presented by encrypted packets; their spectrogram is shown in the figure bellow.

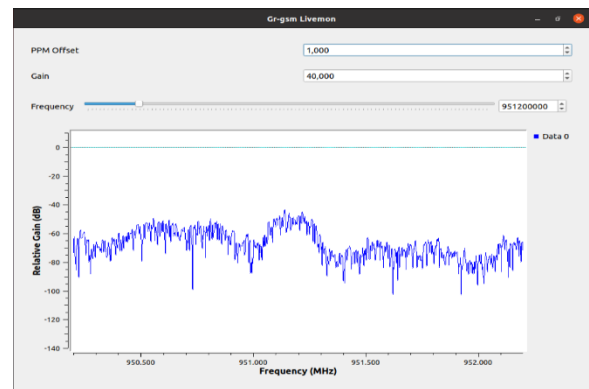


Fig. 10. Spectrum centered at 951.2 MHz

Finally, we launch Wireshark in order to extract cellular data, while `grgsm_livemon` sends data in the GSMTAP format over the UDP port, Wireshark runs automatically with a filter of GSMTAP packets. As a result, we could take out, slot number 0, mobile country code (MCC) which equal 603, mobile network code (MNC) that identify the network of mobile operators represented by: 01,02,03 (Mobilis, Djezzy, Ooredoo), and absolute Radio-Frequency Channel Number (ARFCN) equal 47.

IV. PORPOSED ARCHITECTURE

A. NOAA satellite

The National Oceanic and Atmospheric Administration (NOAA) satellites are American meteorological satellites in polar orbit at an altitude of around 850 km, they transmit images continuously about 540 miles above the earth. The first NOAA satellite launched in 1970, and currently the NOAA 15, NOAA 18, NOAA 19 and NOAA 20 satellites are in service.

The satellites are equipped of a radiometer for monitoring cloud masses, to measure sea or continental surface temperatures, an infrared sounder providing atmospheric temperature and humidity profiles and a diffuso-meter for determining wind direction and speed over marine surfaces [8]. AVHRR (Advanced Very High

Resolution Radiometer) sweeps through six channels, distributed between the visible and the infrared, with a wavelength between 0.58 and 12.50 micrometers, with an instantaneous footprint of 1.1 km at the sub-satellite point. The scanner on this radiometer used to map vegetation and cloud formations and to measure temperature and humidity in the atmosphere and on earth [9].

The ATP signals of the NOAA satellites are in a sound format, we opted for the WXtoImg, which is a fully automated decoder for the APT weather satellite. The software supports recording, real-time decoding of satellite image data, map overlays, advanced color enhancements, image editing and visualization for many weather satellite receivers, communication receivers and scanners.

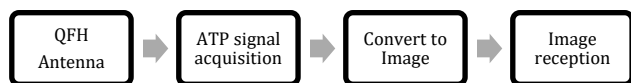


Fig. 11. WXtoImg operating principle

The reception of NOAA images is done through the two software. SDR-Sharp to receive the APT signal from NOAA satellites and transmit it to WXtoImg to decode it and then convert it into weather images

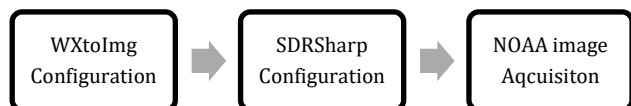


Fig. 12. Steps of NOAA image acquisition

Once the satellite positioned in our orbit, the decoding of the image begins automatically and the image will appear gradually. The decoding operation and the enhancement of its quality last about 15mn.

B. Antenna design

Quadrifilar Helicoidal antenna (QFH), is a good one for satellite waves reception, it is composed of two vertical loops arranged in a helix of 1/2 turn, and spaced around the perimeter of a common cylinder. These loops promote a right circular polarization (RHC) allowing to generate a current with a phase shift of 90 degrees. it uses different sizes of loops that make the current inductive in one and capacitive in the other with a general reactive nature [10].

We have chosen a model of a helical four-wire antenna, taking into consideration these parameters for its realization:

L: length of helical components of a half loop

L_{ax} : Length of the cylinder axis.

R: radius of cylinder.

These dimensions depend of the value of λ and the frequency ≈ 137 MHz. In the table below, we mentioned the dimensions of the two loops and legs of QFH antenna as a function of λ [27].

TABLE I. DIMENSION OF QFH FOR 137 MHz

Dimensions	Big loop	Small loop
Height	0.26λ	0.238λ
Diameter	0.173λ	0.156λ
Leg size	0.56λ	0.508λ

To design it we have used 2 meters 50 mm PVC pipe, 5 meter long 8mm copper tubing, 5 meters of 50 Ω coaxial cable and a junction box with four inputs.



Fig. 13. QFH antenna

C. RTL-SDR

RTL-SDR is an inexpensive software defined radio USB dongle that is able of receiving signals with good acquisition accuracy. This device used as a DVB-T (Digital Video Broadcast-Terrestrial) USB receiver based on the Realtek RTL2832U chip (demodulator chip) which is responsible of digital signal processing. The dongle is able to scan and receive a wide frequency spectrum ranging from 25 MHz to 1.75 GHz, Where the maximum sampling frequency is theoretically is 3.2 MHz.

V. RESULTS AND DISCUSSION

The received images are presented below; they are automatically enhanced by the WxtoImg software, depending on the quality of the ATP signal recorded. The images are composed of a color palette, whose vegetation appears greenish and the sea is colored blue, the ground in brown and the cloud masses in grey, however in figure 14 sea appears grey due to low reflectance in visible channels.

The quality can be improved by choosing an adequate emplacement for acquisition and also through a sophisticated SRD USB dongle,

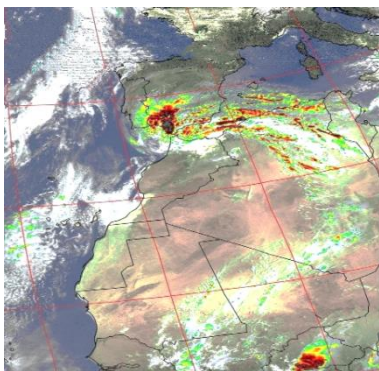


Fig. 14. Image NOAA 18 (28/06/21)

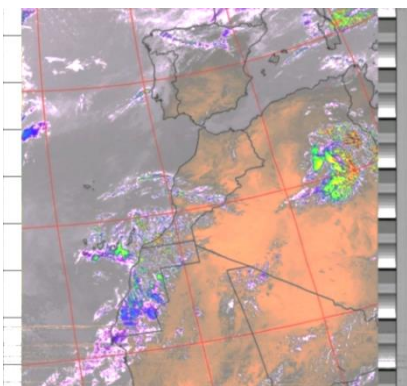


Fig. 15. Image NOAA 15 (28/06/21)

VI. CONCLUSION

In this work we have presented an architecture design of metrological images through NOAA satellite and using RTL-SDR dongle. The results show the reliability of system. However, the design can be improved and extended to an extraction of a metrological database through development of Python program

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