A Comparative Study of RTL-SDR Dongles from the Perspective of the Final Consumer

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***Abstract*—Electronic low-cost devices are an important part of the market nowadays. This trend has reached several products, that in the past just were available for academic institutions or the industry. In this regard, software-defined radio (SDR) is an important part of them. A clear example of the last statement is the consumption of RTL-SDR dongles. These electronic devices are an option for receiving an RF signal on a computer or a cell phone for around $20 USD. However, the manufacturers of RTL-SDR dongles do not provide a complete description or a data sheet for their products, causing uncertainty among the consumers. In this work, we make a comparative study of some RTL-SDR dongles to provide insightful information about the real behavior of these devices. Our results show how some dongles are more sensible for perceiving signals on some bands than others, especially those with metal enclosures. Also, it is shown how dongles of a known manufacturer have an average cost and are well supported. Nevertheless, one can be able to obtain good results with generic dongles at a lower price.**

I. INTRODUCTION

Software Defined Radio (SDR) is a concept that has revolutionized the communication systems. The idea of SDR consists of a radio in which some or all of the physical layer functions are defined by software [1]. This concept represents important advantages; for example, with SDR it is not necessary to design a new transceiver for communicating over several frequency bands. Moreover, SDR has helped to support technologies such as cognitive radio [2]. SDRs are based on field-programmable gate array (FPGA), SDRs early versions were expensive and not easy to use. Thus, SDRs were just available for the scientific community and the industry.

In this regard, the Universal Software Radio Peripheral (USRP) platform developed for the company Ettus was one of the first commercial options for getting an SDR [3]. These products account with several customizable characteristics such as transceiver frequencies, power transmission, among others. GNU Radio, which is the software to program SDRs, is intuitive and attractive for users [4]. However, for some people the price of Ettus devices is high, and this represents a great disadvantage for experimenting with them. There are additional options for SDRs platforms on the market, but for similar reasons, there is not a considerable amount of consumer users interested in acquiring them [5].

On the other hand, due to the apparition of Digital Video Broadcasting - Terrestrial (DVB-T), some electronics products are left without the ability to receive this type of signal. Several dongles for receiving DVB-T signals appeared on the market. Such dongles allow tuning DVB-T on a computer or cell phone at very affordable cost. The latter characteristic allowed Antti Palosaari, Eric Fry and Steve Markgraf to develop software tools and open the DVB-T device, leaving the signal received available to the final user [6]. In this way, the RTL-SDR dongle has been introduced which permits to configure by means of software the received frequency. Such a device operates by receiving signals over a wide range of frequencies and puts them on a USB port [7]. Thanks to the dongles low-cost, they are used in multiple applications and the number of users has considerably increased in the last years.

Although there are several brands of RTL-SDR dongles, none of them provides a complete product specifications sheet. In general, the only available information is about product details. This is probably because manufacturers assume that the data sheet of the integrated circuit (IC) included in the electronic device is the same as the product integration. Nevertheless, it is mandatory to include additional information about the behavior of the dongle as a final product. This is because as a consumer, there are still several questions with no answer. For example, how dongles respond after a long continuous time of use? Is there any difference between the dongles made with plastic or aluminum enclosure? Why the price is different if they come with the same circuits inside and the same manufacturer?

In order to decide which RTL-SDR dongle is the best well suited according to the needs of each final consumer, a precise description of each device on the market is needed. To date, most of RTL-SDR dongle choices are based on the cost or user recommendations. However, choosing a particular dongle should be made based on measured information of the device. To reduce the uncertainty of RTL-SDR dongle consumers, it is fundamental to provide more useful data about the behavior of these products. On the Internet, there are several comparisons among dongles, but none them compares the signal measured at the same time under an equitable setup [8].

Under these observations, this paper provides information about the real behavior of some RTL-SDR dongles. Here, similar dongles are tested under the same scenario. All of them measure the same bands at the same time, considering the antennas provided by the manufacturer or the seller. The latter is done to compare directly the product as it is sold in the market. In Section II, the characteristics of each dongle examined are presented. In Section III, the methodology and the scenario for the comparison are described. Section IV presents the results obtained. Finally, Section V sketches our conclusions.

II. Description of RTL-SDR dongles tested

We present in this section a brief overview of the RTL-SDR dongle's features with the information provided by each manufacturer. Then, the most important ICs included in the RTL-SDR dongles are described.

A. Tuner Rafael Micro RT820T/2

This IC is basically the fundamental part of the RTL-SDR dongles. There exist two versions of it, the first one (now obsolete) RT820T, and the current RT820T2 [7]. However, it is not clear how much the new version of the tuner is better compared with its predecessor. This IC is built with several circuits such as filters, voltage regulator, and low noise amplifiers, among others. Also, the data sheet mentions that in this IC a smart power detector is included to work on different scenarios. In this work, we consider both tuners since dongles with the RT820T are still on sale.

B. Demodulator RTL2832U from Realtek

This circuit interprets the signal coming from the tuner in order to forward it to the USB port. Among several features, the demodulator cancels impulse noise, supports intermediate frequencies, and it is compatible with some digital TV standards [9].

C. Temperature compensated crystal oscillator (TCXO)

This crystal is considered in several communication systems because of its ability of stabilizing the frequency according to temperature changes. A device that includes this component has a better performance in case of warming. TCXOs are implemented in several electronic devices, and so there exist multiple techniques. In the case of the tested dongles, there are not precise details about which TCXO technique is implemented [10].

D. Connectors and Antennas

There exist two types of connectors in the dongles tested: SMA and MCX. Both connectors operate on the frequencies tuned by the stick. All dongles consider telescopic antennas and some of them include UHF and ISM antennas. However, in this paper, just the telescopic and the UHF antenna of the NESDR Mini are used for the comparison.

Table I presents a summary of the characteristics provided for the manufacturer of each dongle. In this table, it is possible to appreciate similar parameters among these dongles and at the same time, several differences in prices. For example, the NEWGEN.RTL2832 SDR is very similar to the NESDR SMArt from Nooelec. However, the cost of the latter is about double compared with the first one, but the last has an unknown producer. The NESDR Mini dongle is the only one that still uses the RT820T tuner. Most of the dongles have the same perception frequency range, the exception is the DVB-T+FM+DAB+SDR which indicates that it is able to perceive starting from 500 kHz. The dongles with an unknown manufacturer were bought on Aliexpress [11], [12]. The rest of the dongles was acquired directly from Nooelec [13]. A picture of all dongles considered in this work is presented in Figure 1.

Fig. 1. RTL-SDR dongles studied in this work.

III. Comparison scenario

Nowadays RTL-SDR dongles are used in a wide range of applications such as research or amateurs activities [14], [15]. RTL-SDR dongles have a similar response to a spectrum analyzer [16]. Therefore, they have been considered in several low-cost projects [17]. RTL-SDR dongles are considered for teaching courses related to electronic communications [18], [19]. Also, these devices are used as receivers in some frequency bands such as emergency services, aircraft traffic, radio astronomy, TV broadcast, FM, among others. The comparing measurements of the dongles were performed on frequency bands assigned to some of these services. In the next, the comparison process is described.

A. Setup scenario

Each device is set considering the antenna and cables provided by the manufacturer. Some dongles are sold with more than one antenna. However, for the comparison, we choose the telescopic antenna since it is common among dongles. In this regard, there are two exceptions. The first one is the NESDR Mini, which includes a monopole antenna. The second one is the NEWGEN.RTL2832; this device does not add any antenna. For such a reason, it is tested with an antenna from an NESDR SMArt.

TABLE I
CHARACTERISTICS PROVIDED FOR THE MANUFACTURER OF THE RTL-SDR DONGLES CONSIDERED IN THIS STUDY.

Number	Commercial dongle name	Manufacturer	Frequency range	Housing	Input	TCXO (PPM)	Accessories	Cost (USD)
1	NESDR SMArt	Nooelec	25 MHz - 1.75 GHz	Aluminum	SMA	0.5	Telescopic metal antenna, 433MHz antenna and UHF antenna.	$29.95
2	NESDR Mini 2 +	Nooelec	25 MHz - 1.75 GHz	Plastic	MCX	No	Telescopic metal antenna and remote control.	$22.95
3	NESDR Nano 2 +	Nooelec	25 MHz - 1.75 GHz	Plastic	MCX	0.5	Telescopic metal antenna and remote control	$22.95
4	NEWGEN.RTL2832 SDR	Unknown	25 MHz - 1.76 GHz	Aluminum	SMA	0.5	None	$15.86
5	DVB-T+FM+DAB+SDR	Unknown	500 kHz - 1.7 GHz	Plastic	SMA	1	Telescopic metal antenna	$19.02
6	NESDR Mini	Nooelec	25 MHz - 1.75 GHz	Plastic	MCX	No	Telescopic metal antenna and remote control	$18.95

All devices are plugged to a hub included on a desktop computer. The source code is developed in Python to capture the 8-bit I/Q produced by the dongles at the same time. The signals of the six dongles considered in this work are saved to a *.csv* file and then they are plotted in Matlab. In order not to lose samples for all sticks, the sample rate considered is 2.4 MHz. The gain of all dongles is fixed on an intermediate value, which for this case is 25.4 dB. Here, just the power spectrum is studied, where the size of the discrete Fourier transforms is 2048 points. As it can be seen in Figure 2, all dongles' antennas are located with the magnet of the antennas base to a similar distance among each other over a metallic platform.

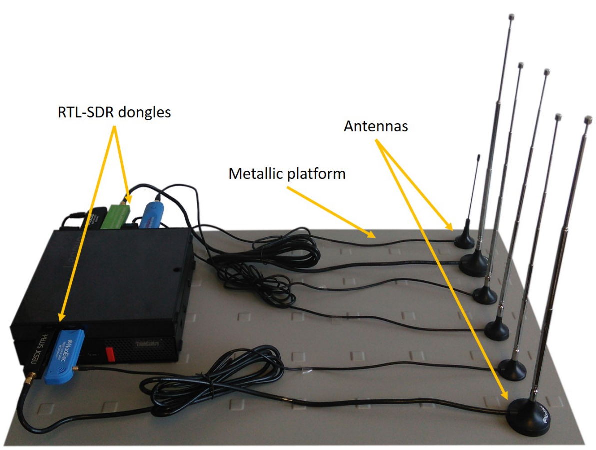

Fig. 2. The measurements scenario with the RTL-SDR dongles, antennas and a PC.

Under this scenario, five minutes of each of the next frequency bands are measured. The total bandwidth size of 2.4 MHz is considered for the measurements. Then, the *.csv* file is averaged in order to get a general vision for each band. In each case, the measurements start with dongles on the ambient temperature in order to avoid heating by the time of use. The frequency spectrum bands measured are radio astronomy and spatial research, FM broadcast, radiolocation, radio communication, and mobile phone bands. More frequency power spectrum measurements were performed; however, the bands presented are some of the most used by RTL-SDR consumers.

IV. RESULTS

The results of the examined frequency bands are shown in Figure 3. In general, there is a difference in the reception of each RTL-SDR dongle. Also, each dongle has a different behavior according to the frequency band tested. Thus, the response of the product mismatches with the indicated by the manufacturers. Next, a detailed description of the figures is provided.

Figure 3(a) shows the frequency band of 39 MHz measured by the dongles. Here, we can appreciate the difference in the sensing of each dongle. The NESDR Mini 2+ has the highest power gain, its signal is followed by the NESDR SMArt and NESDR Nano 2+. Signals received by the two devices with unknown manufacturers are almost the same. The NESDR Mini is the dongles with the lowest sensitivity. It is important to point out how all captured signals have similar behavior, then the main difference among them is the gain.

In Figure 3(b), it is shown part of the frequency bandwidth assigned to FM broadcast observed during this study. In this case, the most sensitive RTL-SDR dongle is the NESDR SMArt, followed by the NEWGEN.RTL2832 SDR. These two sticks have a considerable gain among the others. An important characteristic of both and different from the rest is that the two dongles come with an aluminum enclosure. On the contrary, the two fewer sensitives are NESDR Mini and NESDR Mini 2. For these two devices, the frequency of 94.8 MHz does not exist, as can be seen in the red ellipse area. Thus, for the users wanting to capture FM signals, these two devices are not recommended.

The band allocated to radiolocation and radio communication services is at 421 MHz. The measurements obtained with the dongles on this space appear in Figure 3(c). In this figure, a fairer sensitive scenario is shown. Here, almost all dongles exhibit the same noise floor and the power spectrum presence. NESDR SMArt and NEWGEN.RTL2832 SDR show a gain reduction among the other dongles. However, the device with the lowest precision is the NESDR Mini. This dongle presents a frequency displacement compared to the rest. For the whole band measured, the signal observed by this stick appears some MHz shifted; some examples are pointed out with the red ellipses. Also, we can observe a signal of noise at a superior level compared with the rest of the signals.

Finally, Figure 3(d) shows the signals observed by the dongles at the frequency of 852 MHz. The result is similar to the last figure presented. Also, the dongles have comparable levels of sensitivity. The NESDR SMArt is the only one with a few increases in the signal measured. In this case, the NESDR Mini shows the same displacement on frequency. However, in this frequency, the NESDR Mini does not perceive an important quantity of signals, as can be seen on the continuous yellow line in Figure 3(d).

V. Conclusion

The reduction of economic cost on several electronic devices has helped several enthusiastic people to make experiments in an easy way. Some devices such as the RTL-SDR dongles are now available for everybody. This trend contributes to all fields, especially, research and education. Nevertheless, it also has a great impact on the market, because RTL-SDR dongles represent an important part of electronics consumption. However, the manufacturers of these devices do not provide accurate information about the behavior of their products. This causes uncertainty on the consumers of RTL-SDR dongles.

In this work, a comparison of some RTL-SDR dongles was provided. The result showed how apparently all dongles have similar characteristics. However, under similar circumstances, the signals obtained exhibit considerable differences. According to the results, the NESDR SMArt dongle offers the best reception, but it also has the highest price. A very similar perception signal can be obtained with the NEWGEN.RTL2832 SDR dongle; a great advantage of this product is its price, while its main disadvantage is that the unknown manufacturer. Probably the less recommendable dongle is the NESDR Mini since it presents a poor behavior and has an obsolete tuner.

As part of our future work, the set of studied RTL-SDR dongles will be wider. Also, it is necessary to know the behavior of these devices under a large operation time. This is because it is essential to appreciate the TCXO response effects on long-term spectrum measurements.

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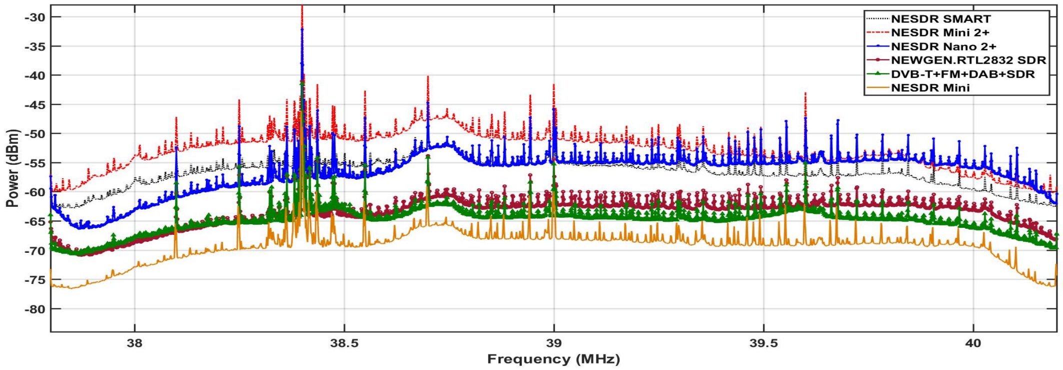
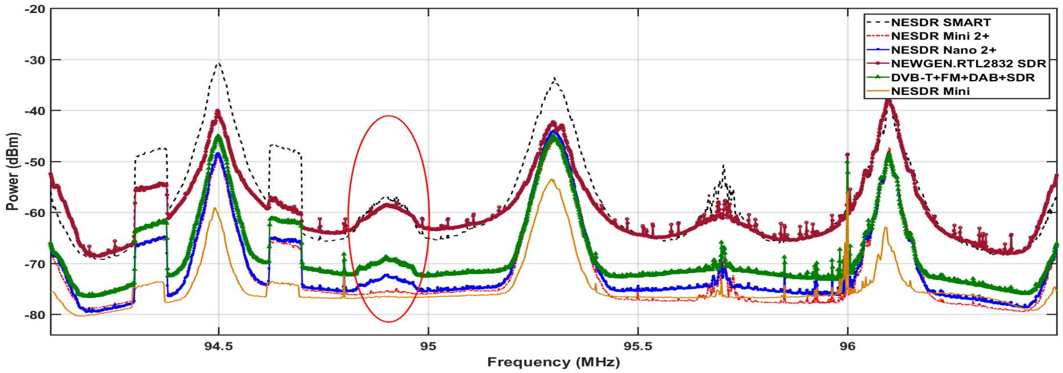
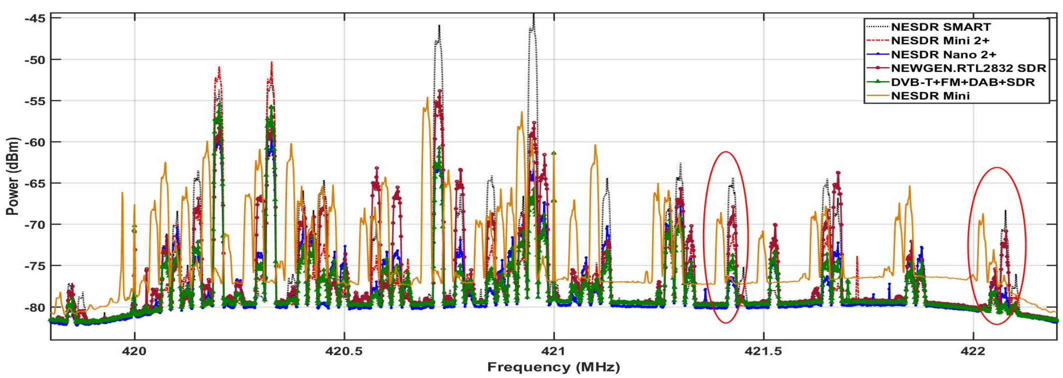


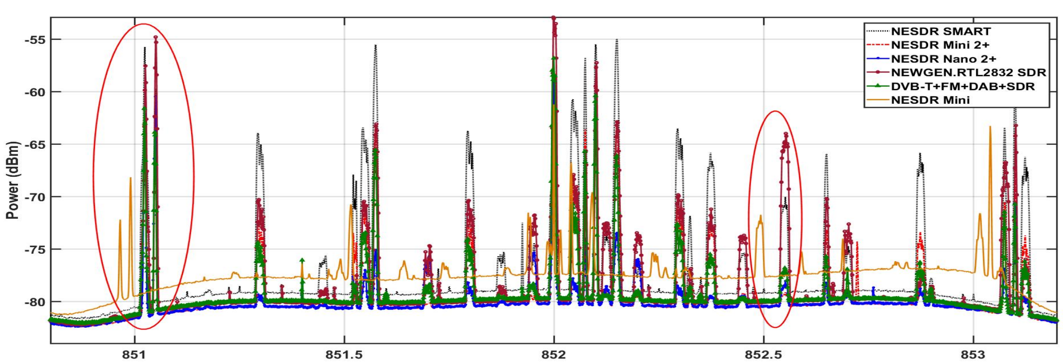
(a) Frequency bands of 39 MHz, corresponding to radio astronomy and spatial research.



(b) Frequency bands of 95.3 MHz, corresponding to FM broadcast.



(c) Frequency bands of 421 MHz, corresponding to radiolocation and radio communication.



(d) Frequency bands of 852 MHz, corresponding to mobile phone bands.

Fig. 3. Average of five minutes of frequencies bands measured with the studied RTL-SDR dongles.