

The Never Ending Story Of The SDR Continues

Examination of a DVB-T Stick with an R820T tuner and RTL2832U decoder as a receiver

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The exact behaviour and the operation of a DVB-T Stick with an E4000 Tuner was studied very closely in [1]. In the meantime the prices for these Sticks have significantly increased, but for those with the R820T tuner have fallen. Therefore this device has been put under the microscope. The conclusions are described below as well as ground breaking information about the different practical uses of the two versions.

1 Procurement

Thanks to The Internet, this is not a problem. If you enter “R820T RTL2832” in the search bar of Ebay you will find many offers from China with a lowest price of approximately €6 (but with no antenna and no remote control). This immediately goes up to €20 to include an antenna, remote control and CD. Payment is no problem via PAYPAL and the parts usually arrive through your letterbox within a week.

2 Preparation of the Sticks for the measurements

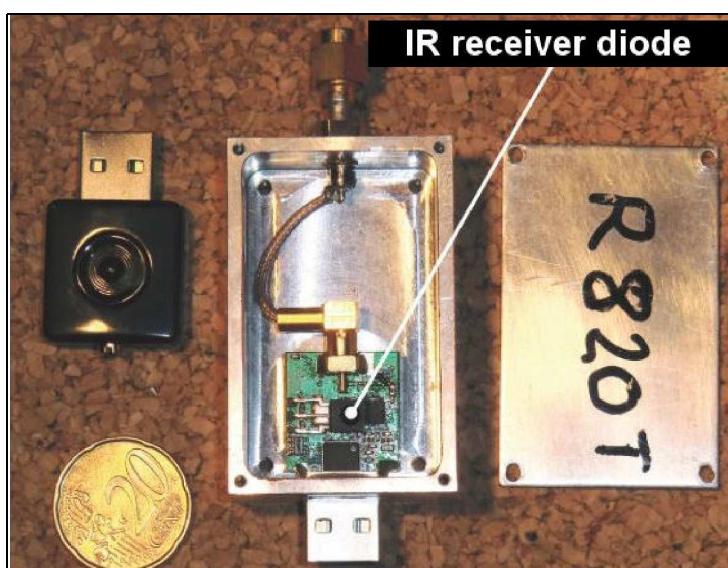


Fig 1: Before and after removing cover so that you can see the hardware

Fig 1 shows what you should look for when ordering. The version with an additional infra-red remote control (the IR receiver diode is clearly visible in the centre of the board) plus this latest generation of Stick is significantly smaller than its predecessors. A 20 cent piece is shown for size comparison.

By the way: The current E4000 receiver looks exactly the same but at least for double the price.

The aerial socket has been shrinking therefore it is no longer easy to unsolder and you have to search for a matching plug including the thin Teflon cable. Fortunately this MCX mini plug is increasingly found on most modern communication devices and is also available from retail

stores. Of course anyone who has been digging in boxes at HAM Radio flea markets for years could have acquired a supply of these at very little cost.

The Stick was fitted into a machined aluminium housing and secured with UHU-plus (epoxy resin) at the USB end. An electrical seal was made with conductive silver paint. The antenna was connected with a piece of semi rigid cable (outer diameter = 3.6mm) with an SMA connector soldered into a special brass threaded bush made on the lathe. This is the only way to get an electrically sealed housing (with a solid cover bolted on).

Testing for any RF leaks is simple: you set the Stick to the FM radio band e.g. at 100MHz, switch to WFM (wideband FM) and "Tuner-AGC" = ON in the configure menu. The computer display should show nothing except for one or two noise lines generated in the tuner itself (spikes) also the speakers should only be whispering. Approaching the antenna socket with the index finger without touching the housing you should hear an FM station in the noise; weak and noisy but audible.

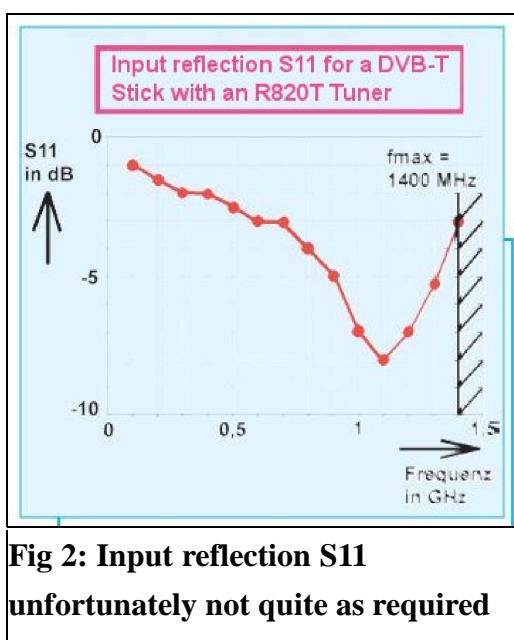
3 The software

There is no need to discuss this again:

"SDR#" (SDR sharp) is the most suitable for the narrowband receiver behind a filter to be investigated or as a special converter or as a spectrum analyser. Go to the appropriate home page [2] and load the latest version. Download the zipped file version and install it (cautious people delete the previous version before installation).

The stick should be connected to the computer with a well shielded USB cable and the driver called "zadig.exe" installed. When the driver opens choose "options" then "list all devices", now choose "Bulk-In, Interface (interface 0)". If this is successful a message "driver installed successfully" will be displayed. Then start the program "sdrsharp.exe". If the correct driver was found by the program, click on the play / stop button in the upper left corner of the screen and the "RTL-SDR / USB" should be recognised. Full operating instructions were published in [1].

4 What is new?



The first striking difference of the R820T tuner over the E4000 version is that the frequency range of the R820T is continuous from 24MHz to 1400MHz without any gap! Some people have used them to over 1500MHz but the PLL oscillator shows sudden dropouts above 1500MHz. It is reasonable to be satisfied with 1400MHz. By comparison the E4000 starts at 50MHz and has a gap between 1100MHz and 1235MHz. But it can be operated without any problems and with excellent data up to 2200MHz.

Fig 2 shows the measured input reflection S11 from 100MHz to 1400MHz. Not exciting and the E4000 did slightly better. This could have been improved because the high impedance FET inputs are not matched correctly.

The AGC behaviour and gain settings are significantly different for the R820T. These are found in the "configure" menu.

With the Tuner-AGC switched off, the tuner gain can be set with the "RF Gain" slider to no less than 50dB (exactly 49.7dB). The E4000 was only about 35dB. However, when the Tuner-AGC is checked the "device" goes to full gain and grabs an additionally 10dB of gain on top of that! This can be a bad thing under certain circumstances because this increases the sensitivity by 10dB but the danger of clipping goes up. This action is pointless if the residual noise of the tuner is already clearly displayed on the screen and is near to the quantisation noise of the AD converter. The present 8 bit converters have a theoretically dynamic range only approximately 57dB and in this case the additional amplification brings no benefit to the signal to noise ratio. Thus there is an overload danger, therefore switch it off. The tuner amplification is better set to a reasonable value by hand using the slider.

The practical approach is shown in a series of images:

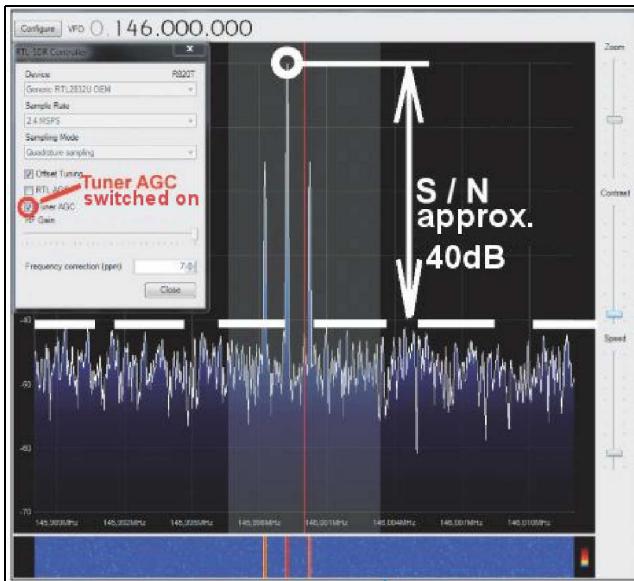


Fig 3: This is the screen display with the setting shown giving full gain.

Fig 3 shows the spectrum of a 102dBm AM signal at a frequency $f = 146\text{MHz}$ with 30% amplitude modulation by a 1kHz tone. The Tuner-AGC is enabled by the check mark and therefore the carrier exactly reaches the top of the chart with zero dB. The signal-to noise ratio is approximately 40dB.

Now uncheck the Tuner-AGC and the AGC will be removed, set the RF gain control to maximum (= 49.6dB). As expected the receiver noise is reduced by 10dB but the signal-to noise ratio remains the same, see **Fig 4**.

Now reduce the gain by 30dB to 19.7dB. The carrier level is also reduced by 30dB but the tuner noise is higher due to quantisation noise. Therefore the signal-to noise ratio deteriorates massively (**Fig 5**).

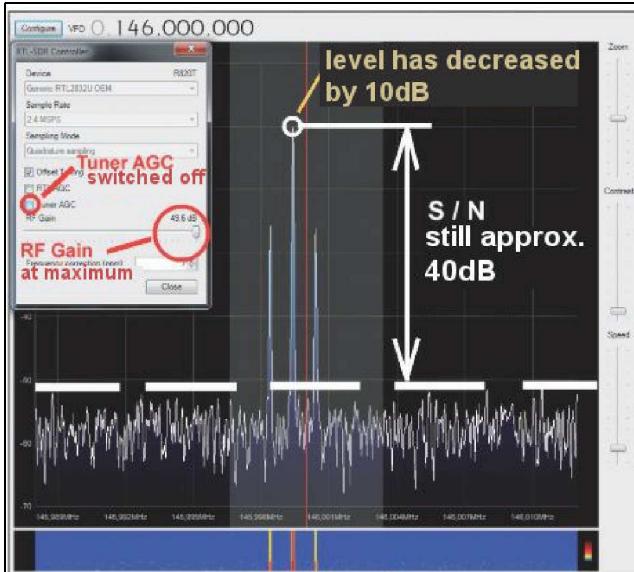


Fig 4: Switching off the Tuner-AGC reduces the total noise by exactly 10dB at maximum RF gain

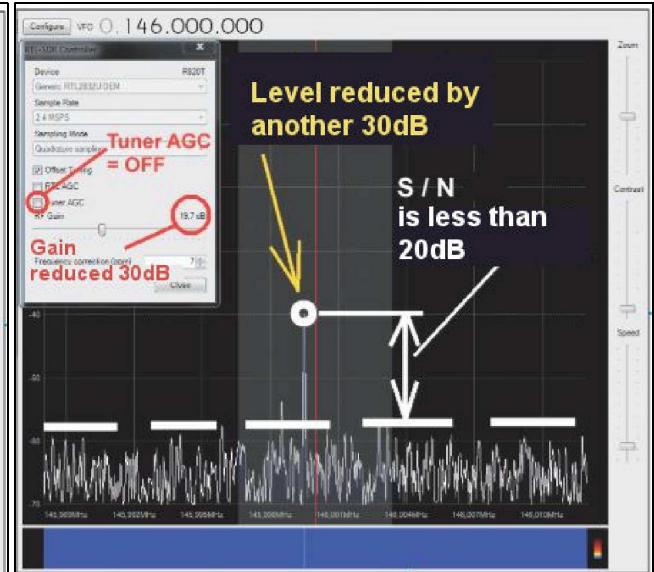


Fig 5: A reduction of the RF gain from approx. 50dB to approx. 30dB (this reduces the S/R ratio by 20dB)

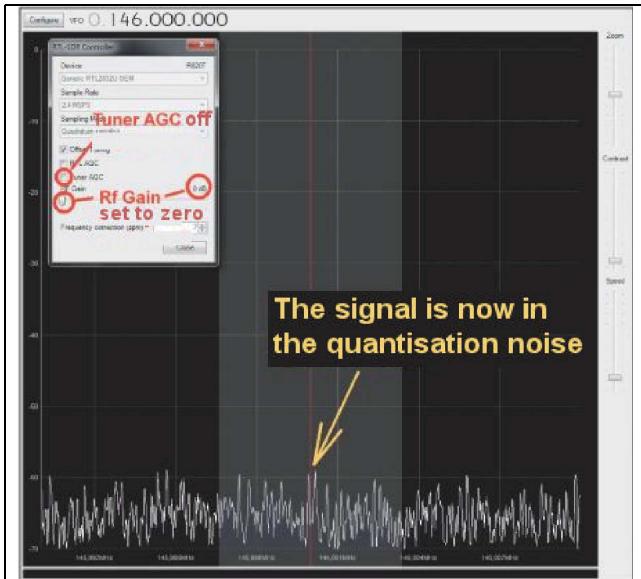


Fig 6: A further reduction by 20dB to a total of 50dB reduction and the signal has disappeared into the noise

Finally reduce the gain by almost 50dB (RF Gain = 0dB) and the signal finally disappeared into the quantisation noise (**Fig 6**).

5 Frequency response and input sensitivity

This is a simple task using two proven precision measuring instruments, HP8640B and HP8657B. A carrier output level of 120dBm was used at each frequency this corresponds to $0.224\mu\text{V}$. An AM modulation of 30% gives acoustical feedback to help control.

The HP8640B was used for the range of 20MHz up to 200MHz; the behaviour up to 1400MHz was a task for the HP8657B. The carrier amplitude is displayed on the spectrum displayed of the PC screen and the peak noise can be read at each selected frequency.

Determining the optimum setup settings for the best signal to noise ratio with the highest displayable dynamic range was really tricky to achieve. Here are the final values that were used; they can be found in the left half of the screen:

a) Radio menu

Operating mode:	AM
Shift:	Null
Filter type:	blackmann-Harris 7
Filter bandwidth:	6800Hz
Filter order:	450
Step size:	1kHz, Correct IQ

b) Audio

48000 samples per second

Filter audio = ON

c) AGC

Use AGC

Use hang

Threshold : - 56dB

Decay: 93 ms

Slope: 0

d) FFT Display

View: both

Window: blackmann-Harris 7

Resolution: 131 072

Range: was 0... -70dB, adjusted

(All remaining adjustments in central position)

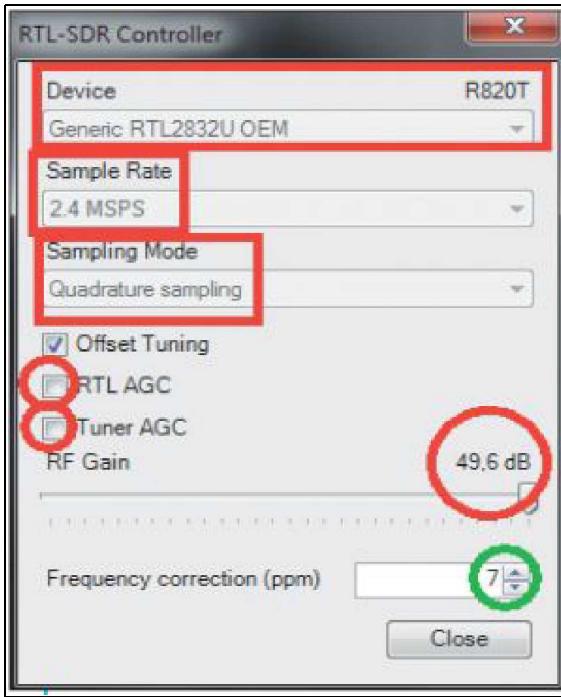


Fig 7: The Configure Menu requires great attention and care, if the results are to be reproducible (see text)

The "Configure Menu" is, of course, the most important and therefore is shown in **Fig 7**. To achieve this some explanations are required:

The Stick recognised is at the top "Device = R820T" and the converter / decoder-type "Generic RTL2832U OEM"

Sample rate 2.4 mega samples per second (best compromise regarding the S/R ratio and sudden, internally produced noise spikes) and the Sample type "Quadrature Sampling" (Note: this can be changed when the play button is pressed, the program will be stopped).

Offset tuning is switched on; RTL-AGC and Tuner-AGC are switched off.

The RF gain is set to the maximum value of 49.6dB.

The green "Frequency correction (ppm)" only makes sense if the transmitter signal has the highest stability and absolute accuracy is required.

The results are shown in **Fig 8** (for the range from 24 to 200MHz) and **Fig 9** (for the range from 200 to 1400-MHz) and indicate no major problems - except the joy

that no frequency bands are missing and you can choose any arbitrary frequency in this range.

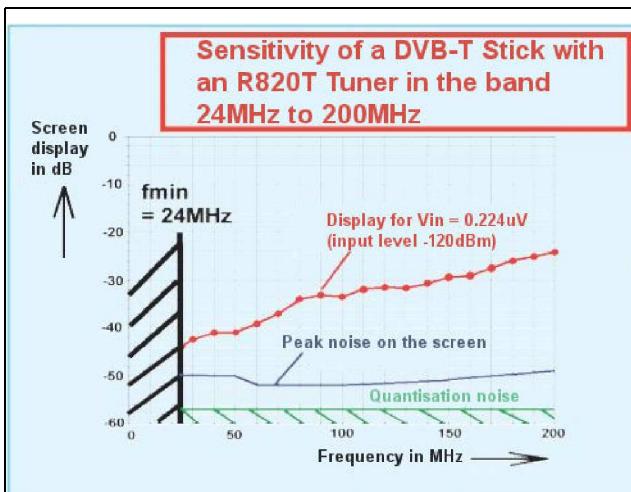


Fig 8: The sensitivity from 24MHz to 200MHz

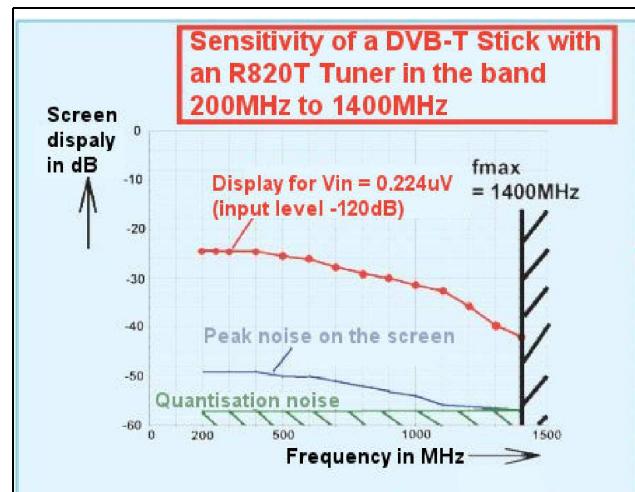


Fig 9: The sensitivity from 200MHz to 1400-MHz with no blocked frequencies

6 Determining the dynamic range as a spectrum analyser

The result shown in **Fig 10** is very interesting but cannot be explained it without pondering and puzzling.

It was at the frequency $f = 146\text{MHz}$ but there is an internal fault line of the tuner in the vicinity of 145MHz. The conditions for **Fig 10** were:

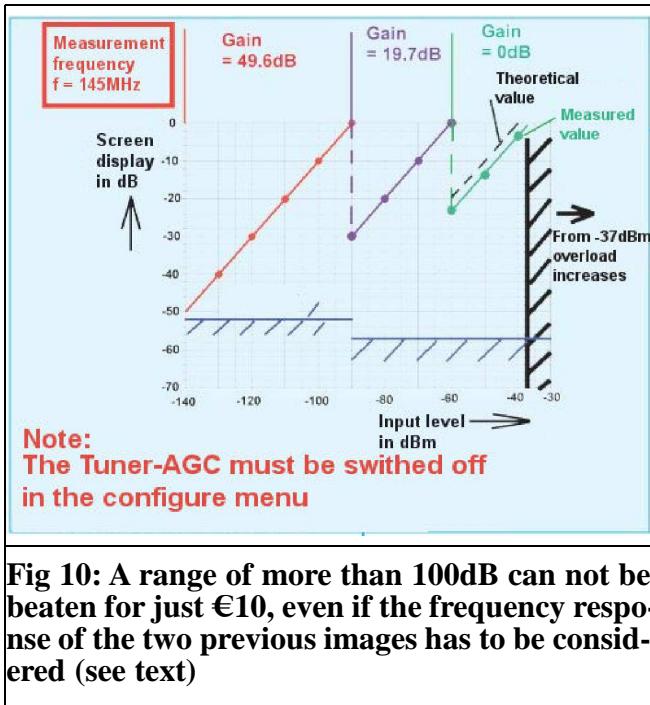


Fig 10: A range of more than 100dB can not be beaten for just €10, even if the frequency response of the two previous images has to be considered (see text)

- a) The Tuner-AGC is always off
- b) For very small input levels (below -90dBm) the gain was set to maximum i.e. 49.6dB, giving a display range of about 50dB.
- c) If the spectral line is over the top of the screen, reduce the RF gain to 19.6dB or a sensitivity of 30dB. So, you can represent levels up to 60dBm.
- d) If that's not enough, you can turn the RF gain to 0dB. The amplitude of the spectral line is now reduced by 20dB, unfortunately it is approximately 23dB (programmer take note more closely). **Fig 10** shows the theoretical and practical results.

Looking at these results, suddenly the maximum possible measuring range is 100dB - for less than 10 euros!

By the way:

This dynamic behaviour applies to the entire frequency range. It only needs to be corrected at the measurement frequency by the amplitude values shown in **Figs 8 and 9**.

Otherwise precautions mentioned in the E4000 article are valid: be careful of excessive levels at the input. When several signals are applied the same time these Sticks are not particularly good for intermodulation and overload. Don't worry this is noticeable; the screen will be awash with a forest noise lines if this happens. The gain can be reduced and use the Tuner-AGC or RTL-AGC as little as possible.

7 Conclusion

As so often in life, the rule is that one must respect and know the limitations that apply. This means if you can only have one of the two Sticks you must decide which to choose or preferably you should always have both in the drawer.

To work with either, first check the warnings and the recommendation; always use the maximum possible gain. These Sticks can only be used as a complete "system" following a preamplifier, a filter or a converter. You will get a lot of pleasure and save a lot of development work.

Thinking of ideas can be dangerous: Thoughts go through the fantasy stage and countless projects come to mind for such a "fine toy". Hopefully the projects suggested by my friends on the phone can come true. "When will there be Sticks for 5.8GHz? I have got a camera with an ISM module output at this frequency?".

8 Literature

- [1] Gunthard Kraus, DG8GB, The DVB-T Stick With E4000 Tuner Measuring Receiver, UKW Berichte issue 3/2013, page 131 to 148 and page 177-187
- [2] <http://sdrsharp.com/downloads/sdrinstall.zip>