Receiver construction using 50 ohm modules (gain blocks)

Part 2: 70cm version

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1. Introduction

After the successful development of the 2m receiver (see part 1 of the article in [4]), it was natural to take full advantage of the low-priced DVB T Sticks with the R820T tuner. The experience and measurements showed that coverage up to 1400 MHz without any restriction, quality loss or any other problems was possible. In addition the PLL may tune and lock at frequencies up to 1700MHz depending on the stick temperature and manufacturing variations. This was not reliable; reception only works reliable up to 1400MHz.

At HAM Radio 2016, there was an interesting conversation with one of SDR#'s program developers, who moaned about the problem and provided the explanation: at these high frequencies, the currents in the charge pumps of the PLL are slowly changing in the microampere region. It is difficult to maintain the necessary setting precision caused by temperature and other influences.

The current sticks are now fitted with the R820T2 tuner chip, which improves many things, including operation up to 1700MHz. There is more to be said later.

But back to reception in the 70 cm and the 23 cm bands. For this purpose, only two components shown in **Fig 1** need to be changed: The LNA and the bandpass filter must be revised or re-developed for these two ranges. Both the calibrator component and the DVB-T component can be transferred directly from part 1.

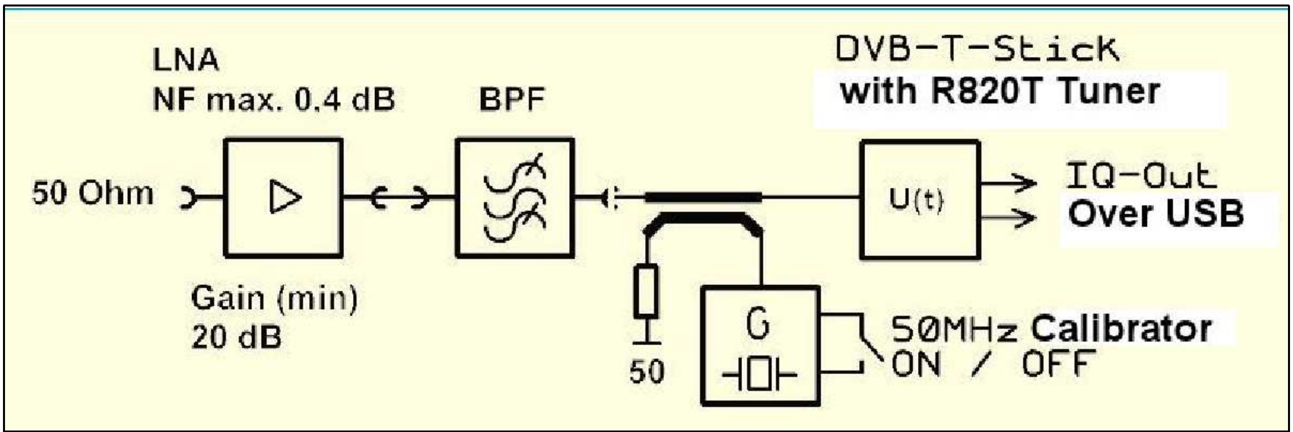


Fig 1: The overview diagram of the receiver remains unchanged, only two blocks have been changed

2. Reception to 70cm

This chapter describes the preamp and the bandpass filter for the 70 cm band.

2.1. The low-noise preamplifier

For this purpose, the circuit of the LNA [5] was used. The modified circuit diagram is shown in **Fig 2.** The reasons for the change can be shown with the help of the new network analyser VNWA3 as follows:

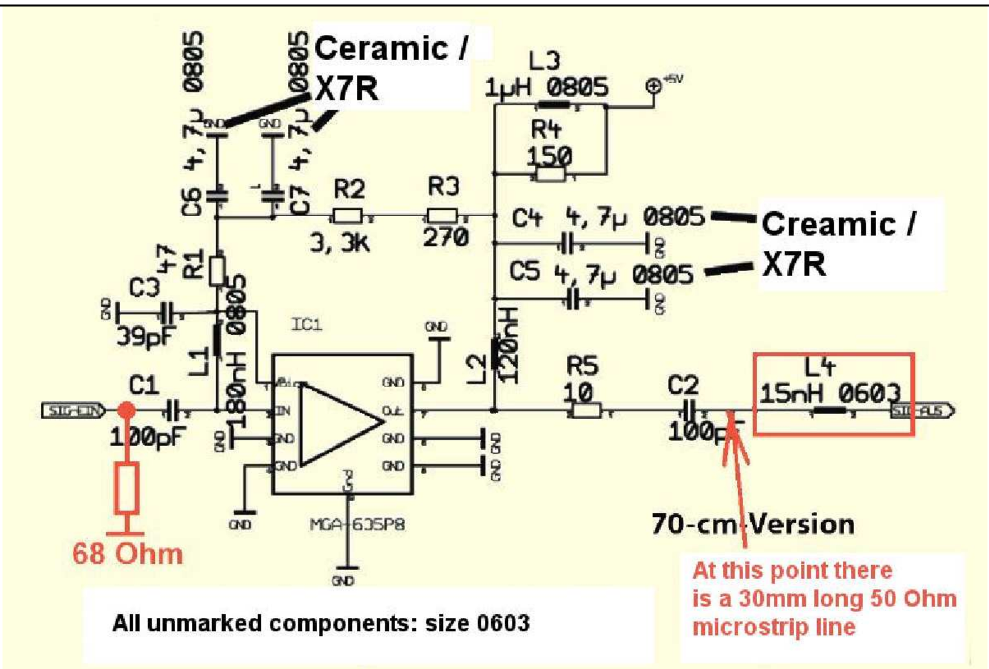


Fig 2: These are the few changes to a successful LNA development that can be easily adapted to all tasks in the range of 100MHz to 3GHz

The original state of the input reflection S11 can be seen in **Fig3**. It is typical for the use of high-impedance PHEMTs in the input stage of a tuner, with the manufacturer often providing internal chip corrections to improve S11 above 500MHz.

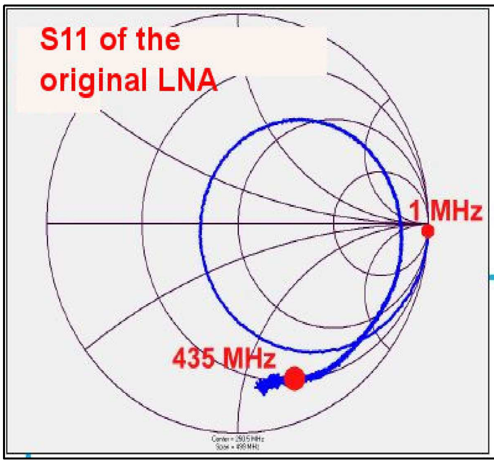


Fig 3: This is the starting point of S11 at the input, it should be better

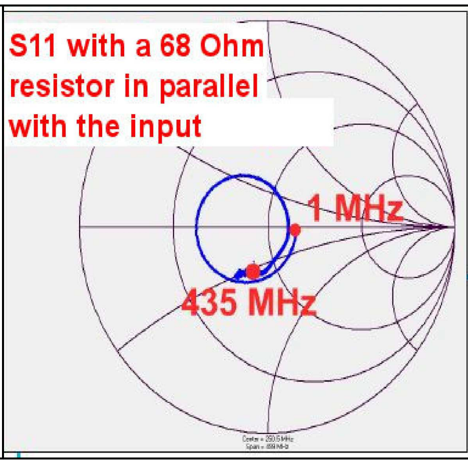


Fig 4: With this simple trick (additional parallel resistor on the input) S11 is much better

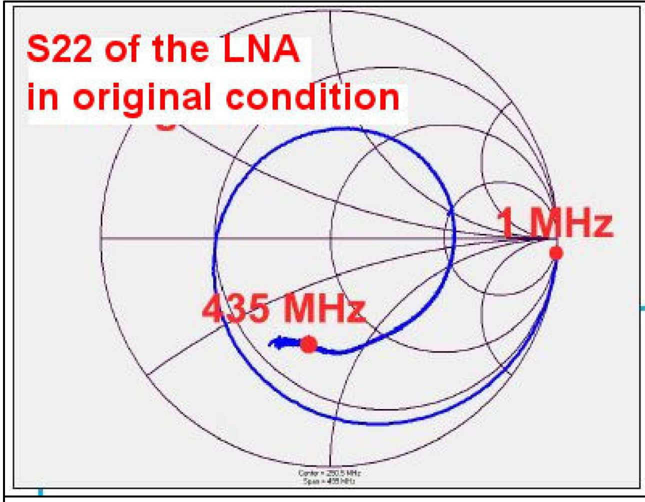


Fig 5: Also S22 at the output leaves something to be desired

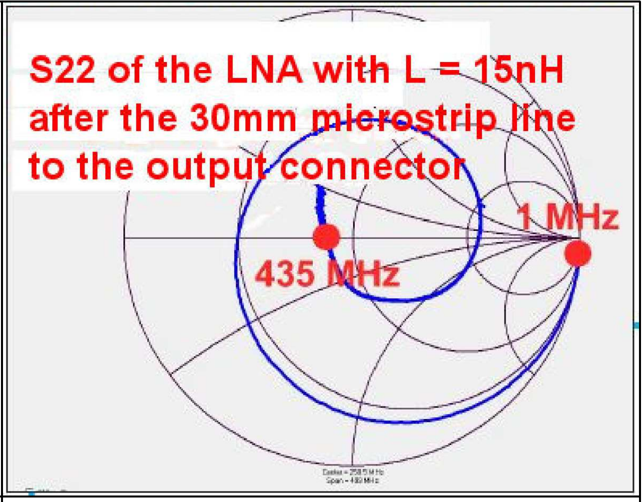


Fig 6: The circuit change on the board (after much prior evaluation of the Smith chart) is a resounding success to S22

A 68Ω parallel resistor was connected directly to the input jack with the effects shown in **Fig 4.** The output (S22) was also examined (**Fig 5**). At 435MHz it was well below the horizontal axis in the capacitive area. This was with a Z = 50Ω microstrip line on the board between the output point of the amplifier stage and the SMA output socket. The length is slightly more than 30mm, so a small additional inductance (L = 15nH) at the end of the line was required to lift the point for f = 435MHz up to the horizontal axis (**Fig 6**); S22 is significantly improved S21 was 24.3dB at 435MHz as shown in **Fig 7.**

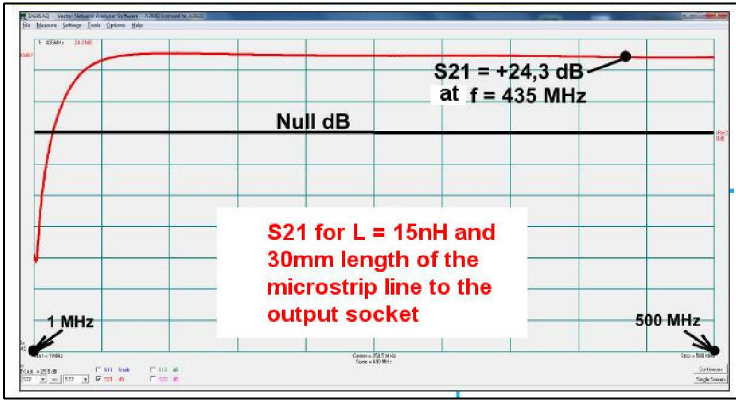


Fig 7: You can be satisfied with 24.3dB for S21 at 435MHz

For information, S12 was determined with the same settings as S21 - this result is also reassuring (**Fig 8**). The measurement of the noise figure gave a value of NF = 0.4dB (previously 0.35dB) in the range of 420 to 450MHz.

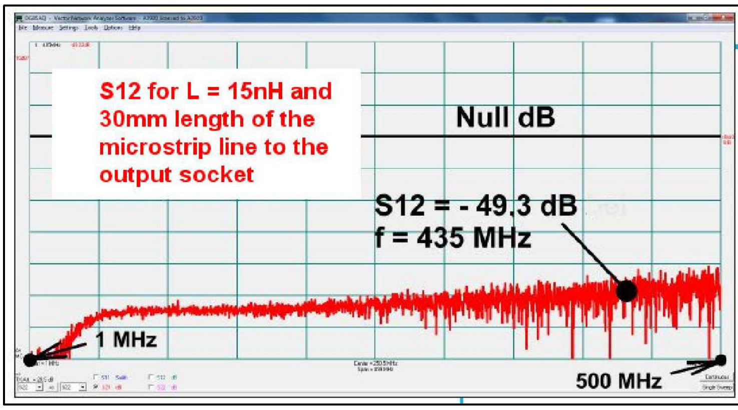


Fig 8: And S12 is so low that no tendency to oscillate is expected

The finished amplifier in its housing is shown in **Fig 9.**

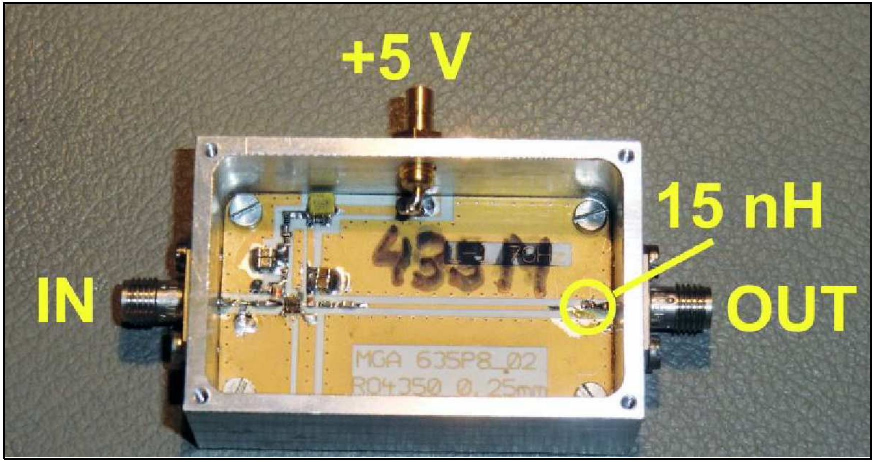


Fig 9: The overall circuit is so small that my "standard housing" leaves a lot of room spare

2.2. The bandpass filter for 435MHz

This development turned out to be somewhat difficult because of my own specifications, such as a high quality bandpass filter around 500MHz AND the chosen housing size restricted the possibilities.

LC filters could not be used in the small aluminium housing because such small coil diameters and low wire thicknesses would not give the Q required. Of course, one could realise Q = 400 using large 8cm diameter coils and 8mm copper wire thickness (best silver plated)

What else is left?

Microstrip filters made of pieces of line at this frequency are also far too long (because the necessary electrical length of an element with a quarter wavelength is unfortunately 17.2cm at 435MHz). So this solution does not work ...

SAW filters are a good solution because there are many manufacturers for the frequency f = 433.92MHz (ISM - Industrial, Scientific and Medical Band). Unfortunately, these filters are usually narrow-band (only a few MHz) with a transmission loss between 2 and 4dB. However, the stopband attenuation only reaches values of approximately 40dB. Demands for higher stop attenuation or greater bandwidth lead to higher transmission loss and procurement is a problem.

So, as a last resort, only the keyword "helical filter" remained. These are small silver plated coils with inductances below L = 100nH in a silver plated shielding cans. The trick is that only the lower end of the coil is grounded and the upper end of the coil is suspended in the air. This is a winding with capacity to the can (ground!) giving a very high quality resonant circuit. Several such cans with inductive coupling (e.g. using a cutout between the shield cans) will string together to form a small bandpass filter.

TOKO was the best known manufacturer of these helical filters, but they have stopped production. Production has continued by the American company TEMWELL. One delivery option in Germany is TACTRON [3], whose field service engineer is known from earlier times.

His search for a 435MHz TEMWELL helical filter was successful, but a simple two section filter should cost €30!

However, there was a residual stock of nearly 200 pieces of the version for the ISM frequency of 433.92MHz. This helical filter has two tuning cores and can easily be re-tuned to 435MHz. As a result, 10 such filters came into the house at half list price and were used for this experiment.

The data of the filter with the name TDR29 42B-433.92MHz are:

3dB Bandwidth	=	10MHz
Insertion loss	=	3.5dB
Ripple	<	1dB
Selectivity	<	25dBc at +/- 50MHz

If you need something like that (there are currently still about 200 pieces in stock) please contact [3].

First, a printed circuit board of ROGERS R04003 material 30mm x 50mm with a continuous 50Ω grounded coplanar waveguide line in the centre was designed. This line was interrupted at one point and the two section filter inserted. Since the filters are designed for board mounting (long connection feet), you have to "magic" something. **Fig 10** shows this solution and in **Fig 11** you can see S11 and

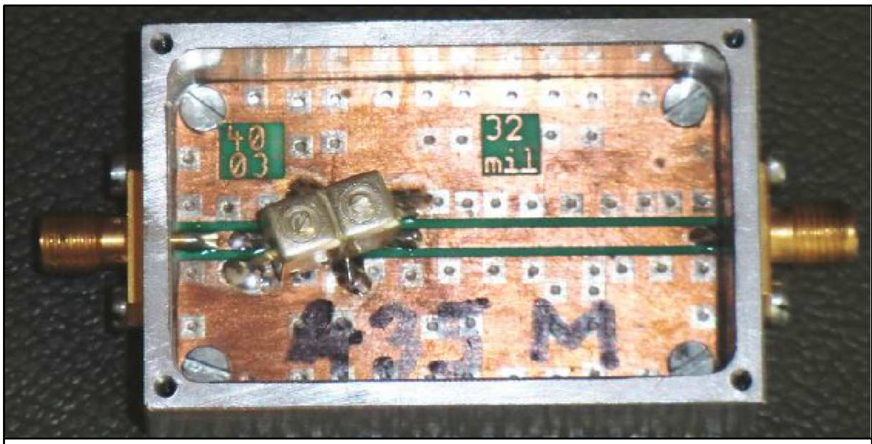


Fig 10: How to get the helical filter into the circuit using some "magic"

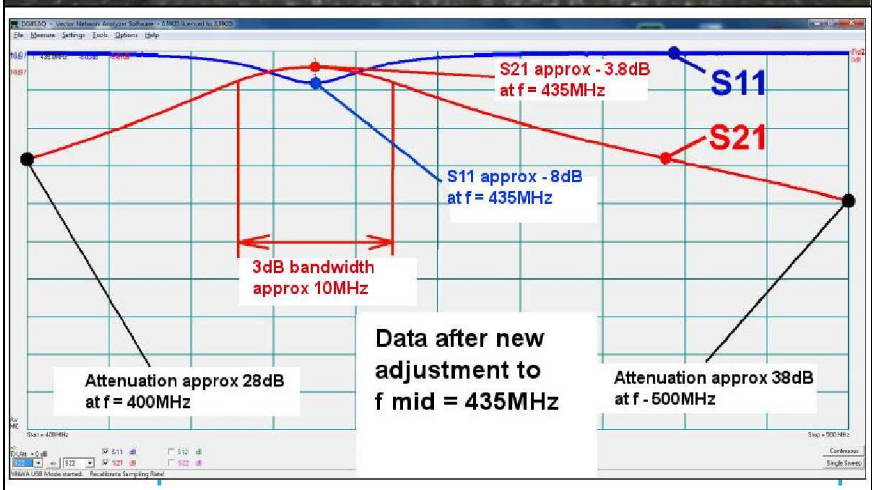


Fig 11: And then there is somet-hing disappointing about the measurements

S21 of the filter newly tuned to 435MHz. Apart from a slight deterioration of the input reflection due to the detuning, they correspond to the data sheet values.

However, neither the near nor the distant rejection values of such a two section bandpass filter are really exciting, although the passband attenuation at 435MHz is only about 4dB. So a four section filter was experimented with in which two of these devices were coupled together by a small SMD trimmer capacitor of 1.2 to 3 pF (**Fig 12**).

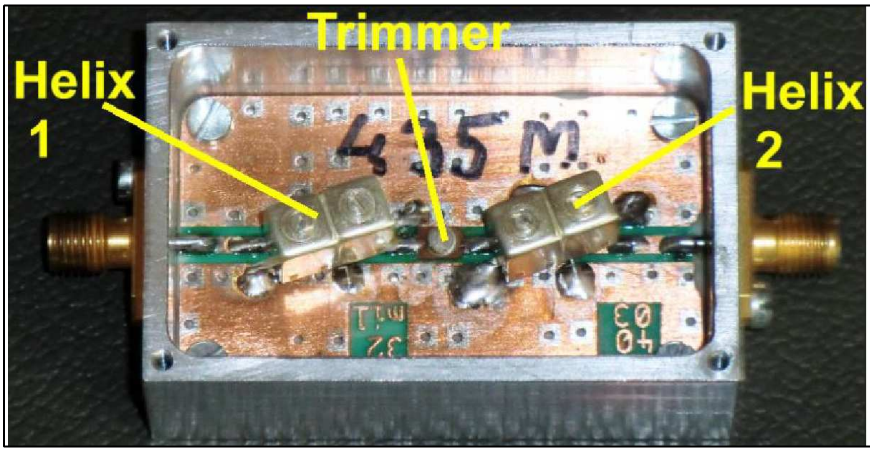


Fig 12: Using the principle "from two make four", two of the helical filters were converted into a four section bandpass filter (see text)

The interesting result was that the amateur radio band plans have a frequency range of 430 to 440MHz (centre frequency = 435MHz) for the region "IARU 1" and for the region "IARU 3" it is the same centre frequency but a band of 420 to 450MHz. And that's how it looked when both were investigated:

a With fixed coupling (trimmer is set to 3pF), the bandwidth of 420 to 450MHz (region IARU 3) required for the complete 70cm band can actually be divided by mathematically adjusting the 4 helix coils. Although the ripple and the input reflection are not great - but you can now easily tune the receiver over the entire band (**Fig 13**). Compared to the two section

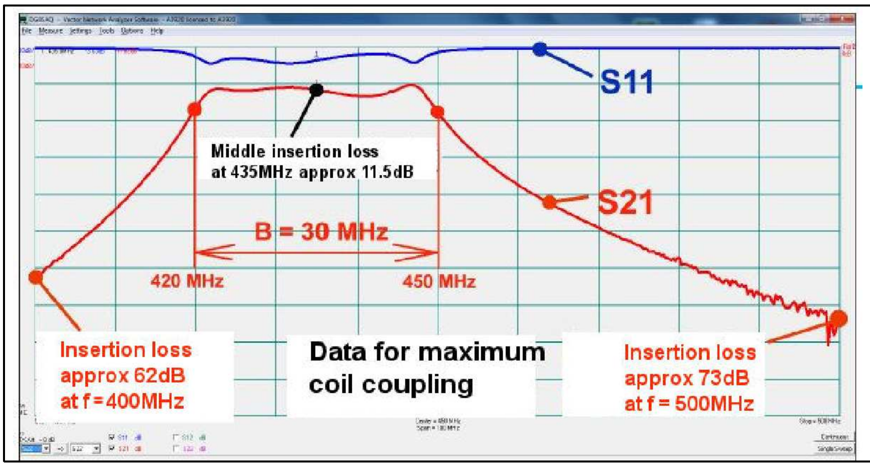


Fig 13: The broadband version shows some ripples and a moderate input match S11

bandpass filter in **Fig 11,** however, far-range rejection is clearly better; SAW filters are no better here. Only the transmission loss of approximately 11dB (centre value) is unpleasantly high.

b With loose coupling (trimmer is at approximately 1.2pF) the desired narrow transmission curve with B = 10MHz is obtained at the centre frequency of 435MHz, combined with good matching by S11 = - 14dB at f = 435MHz (**Fig 14**)

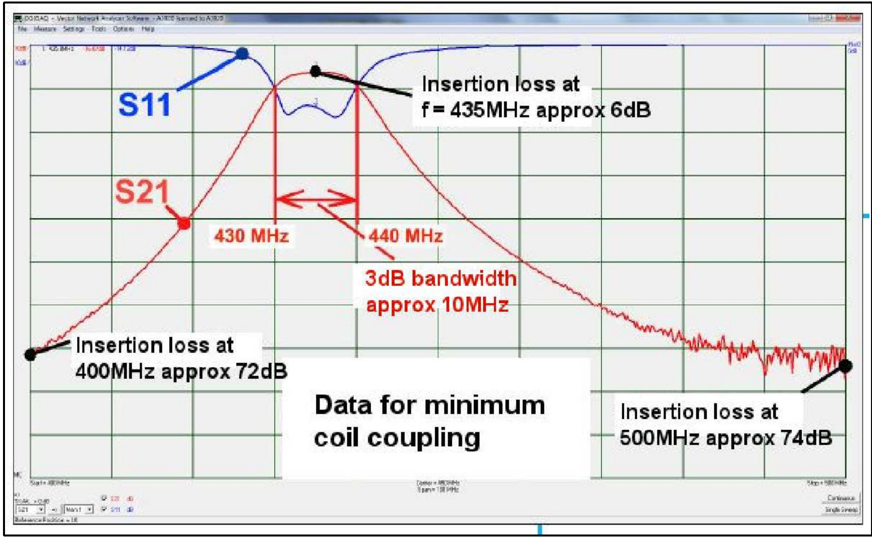


Fig 14: The narrow band version is first class for Europe

The transmission loss increases in the middle of the band, compared to the two section bandpass filter, only about 1.5dB, to about 6dB.

It is probably best to make a narrowband and a broadband version of the four section filter, then you can choose.

3. The Calibrator block

The calibrator remains unchanged. Its principle, properties and details can be taken directly from the corresponding chapter in Part 1 [4].

4. The DVB-T stick

4.1. What's new?

You can only say – a lot! A development of the tuner IC R820T is used in this project; it is now called R820T2 and fortunately is fully compatible. These are the most important innovations:

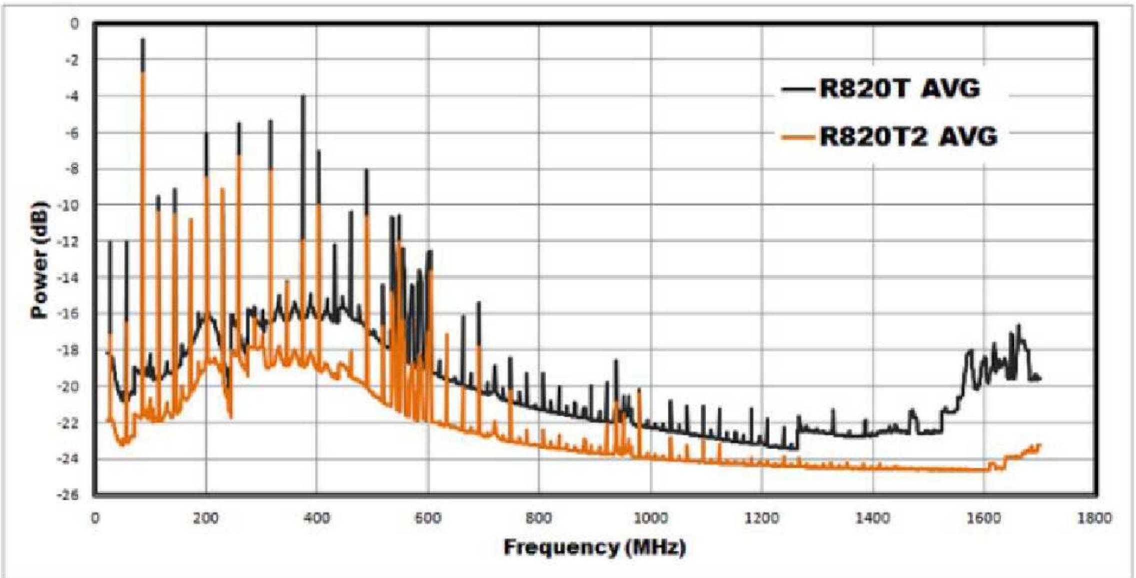
1 The quality of electronically tuneable IF filters at the tuner output has been improved, with bandwidth ranging between 350kHz and more than 2MHz. The filter edges are pleasantly steep (especially for FM or DAB operation). To use the new hardware one needs the newest version 2.76 of the program, "HDSDR" together with "rtl-tcp.exe" and "ExtIO_RTL_TCP.-dll".

2 The sensitivity has been increased or the inherent noise level reduced; **Fig 15** from The Internet illustrates progress. Depending on the working frequency, the improvement is between 1 and 4dB (from [1]).

3 Measurement of S11 with the network analyser compared to the R820T chip measurements shows completely new results leading to a single conclusion:

The RF input of the R820T2 has a 100Ω resistor integrated in parallel to eliminate the high

The first test was a noise floor test. We used rtl_power and ran a noise test with maximum gain and a 50 Ohm terminator connected for 15 minutes over the entire receivable frequency band. We averaged the results over three different R820T dongles and three R820T2 dongles to remove dongle to dongle variances. The results show that noise floor on the R820T2 is around 2-3 dB lower at most frequencies.



Next we tested the SNR with the gain set to zero using a HackRF as the signal source. The results show that the R820T2 is about 2-5 dB more sensitive depending on the frequency. Also, compared to the R820T, the sensitivity seems to be significantly better at 1.5 GHz to 1.8 GHz as all tested R820T units could not even detect the test signal above 1.5 GHz without increasing the gain.

Fig 15: Other users have come to the conclusion that the R820T2 tuner chip produces much less noise

impedance FET input of the previous version to improve the matching!

As mentioned on the internet (and self-investigated!), The stability problems of the PLL in operation up to 1700 MHz seem to have been eliminated.

For further experiments the new stick version is essential. These are already only €7 on The Internet (light blue housing and a side MCX). A Better option is the "RTL-SDR.COM-Stick" for $20 with:

a SMA connector for the RF input

b A nice aluminium housing that not only serves as a shield but also for better heat dissipation (**Fig 16**).

Fig 16: This is what the RTL-SDR.COM stick looks like. It is worth the small extra cost (see text)

c Improved input matching, which results in lower S11 values even at low frequencies (**Fig**

17 shows the measured curve). In addition, examination of the board under a microscope

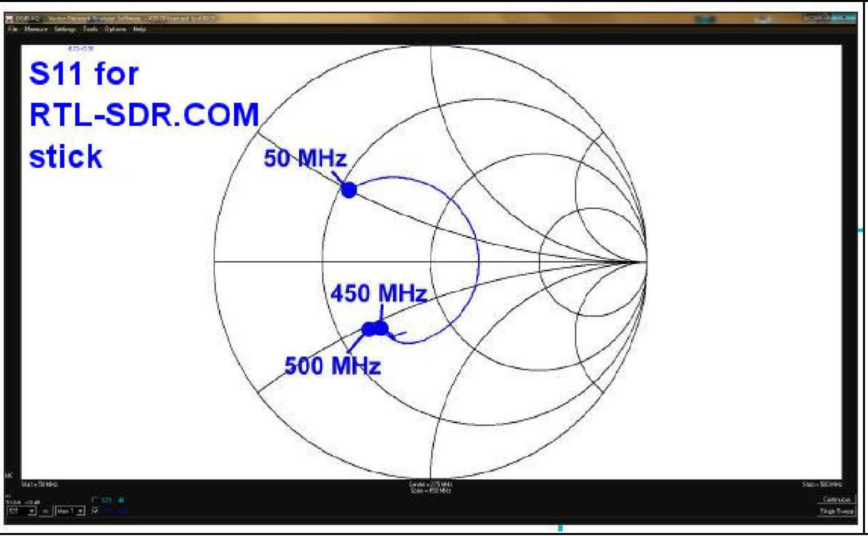


Fig 17: The input matching has improved a lot compared to its predecessor chip

clearly shows a high pass filter with two coils and two capacitors has been inserted at the input to the chip.

d A temperature compensated quartz oscillator (TCXO) with a tolerance of less than 1 ppm.

e The possibility to use a "Bias-T" to feed a preamplifier with the operating voltage of +4.5 V (of course you need a preamplifier that works properly at +4.5V).

f The optional "HF" mode enabling the RTL2832U decoder chip to be used as a "direct sampler of the antenna signal" up to the input frequency of about 14MHz by small changes on the board.

g Guaranteed with the new R820T2 tuner chip, as shown on the label (**Fig 16**).

This makes it better equipped for more demanding applications.

4.2. The new and stable "HDSDR" program version 2.76

Without software such a DVB-T stick is useless and therefore it was a great stroke of luck that the author met the software programmer at the 2016 VHF meeting in Weinheim and got to know him better. In his free time he works on further development of the "HDSDR" program for SDR operation and has not stopped the necessary updates for the new tuner chip.

From the Homepage, "www.hdsdr.de" you can currently download the "stable version 2.76" of "HDSDR". If at some point another newer version is made available you should test it immediately. Many users help with tips and error reports to constantly improve the software.

For operation on a PC you need the "EXTIO_RTL_TCP.dll" as well as the programs "rtl-tcp.exe" and "zadig".

There is something else to note:

At the moment you can find the version "zadig_2.2exe" on The Internet. It is used to determine the current USB port assignment and to install the appropriate driver. But for computers with an early version of WINDOWS 7 this often does not work with the version 2.2, but only with the first version "zadig.exe" These and the other files are currently listed on The Internet.

To make life easier, see [2]:

“Frischer Wind für DVB-T-Sticks und SDRs durch die neue stabile HDSDR-Programmversion (im Moment: 2.76) und den neuen Tunerchip R820T2”.

The five files are needed are shown in the above folder on my web site:

a The current "HDSDR_installer.exe" version 2.76 (which one should update after the installation again and again)

b rtl-tcp.exe

c EXTIO_RTL_TCP.dll

d both versions of "zadig" namely "zadig.exe" and "zadig_2.2.exe"

(there are also direct links to these programs so you can search for newer versions).

After downloading the files, follow the instructions below to use "HDSDR" and a new R820T2 (or an old R820T) stick:

1 First, "HDSÐR" is installed on the home computer and provides an "icon" on the screen (everything goes without problems).

2 Then copy the remaining four files to this "HDSDR folder"

3 For "RTL-TCP" as well as "zadig_2.2" and "zadig.exe" you still need shortcuts on the WINDOWS screen; the result should match with **Fig 18.**

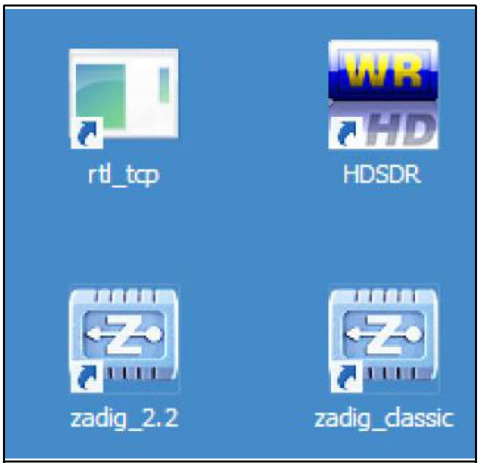


Fig 18: You should have this Icon quartet on your WINDOWS screen after the software installation

Now the SDR-Stick can be plugged into a USB port.

You now start a trial with "Zadig_2.2" by opening it. Under "Options" click on "List all devices". In the appropriate window you look for the stick (usually reported as "RTL28-32U") and install its driver.

Once that is done, start "RTL-TCP". This opens a small DOS window in which you can follow all the currently running processes (**Fig 19**).

If this is not the case repeat the above steps with the older

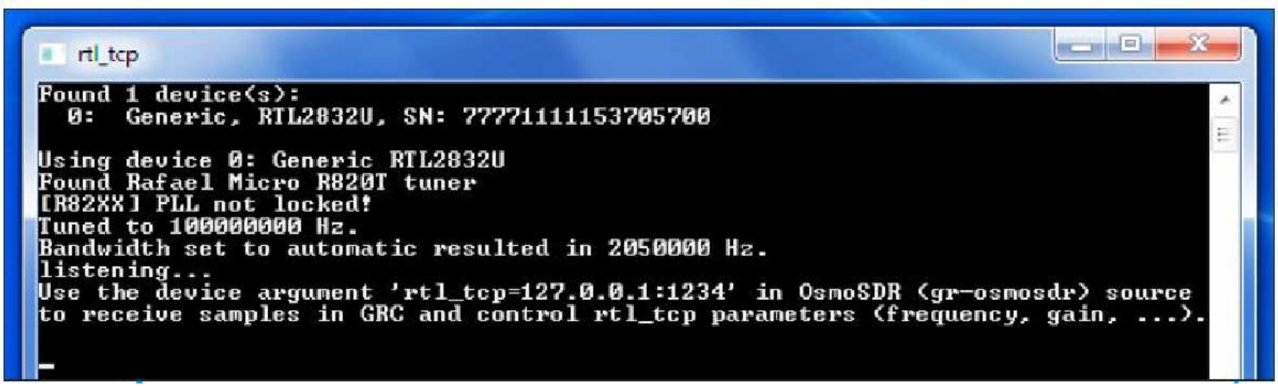


Fig 19: This is what a successful installation looks like: a small DOS window generated by the program "RTL-TCP.exe"

version "zadig.exe". However, it is recommended to restart "WINDOWS" first.

If the DOS window appears stable on the screen, click on "HDSDR”, this activates "EXTIO_RTL_-TCP.dll" and finally starts the program.

As an aid to the operation the download area available in [2] has a "list of keyboard shortcuts" for "HDSDR 2.76".

Note:

This should be enough for the time being because a separate article on this topic should deal with the program, its many options and practical use.

A demonstration of the program is shown in **Fig 20:** It shows the VHF FM screen around 100MHz with a short antenna and a bandwidth of 2050kHz at a sampling rate of 3.2Msps. **Fig 21** demonstrates how bandwidth switching to 350kHz and slight correction of tuning can remove unwanted

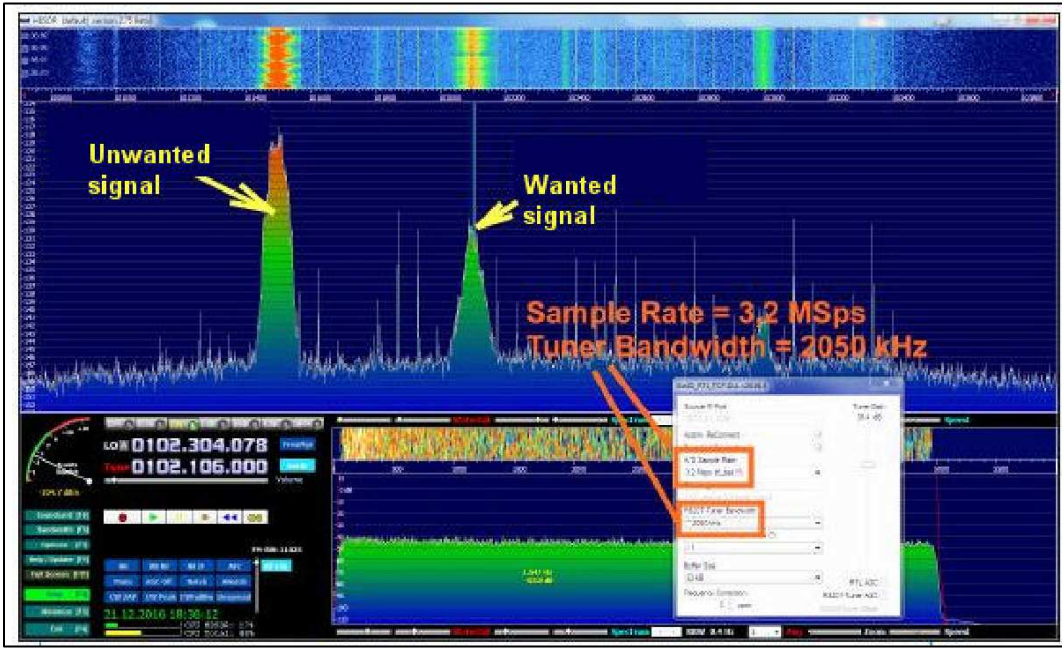


Fig 20: To demonstrate the easily controllable IF filters on the tuner chip output: this is what it looks like with a 2MHz IF filter bandwidth and FM reception

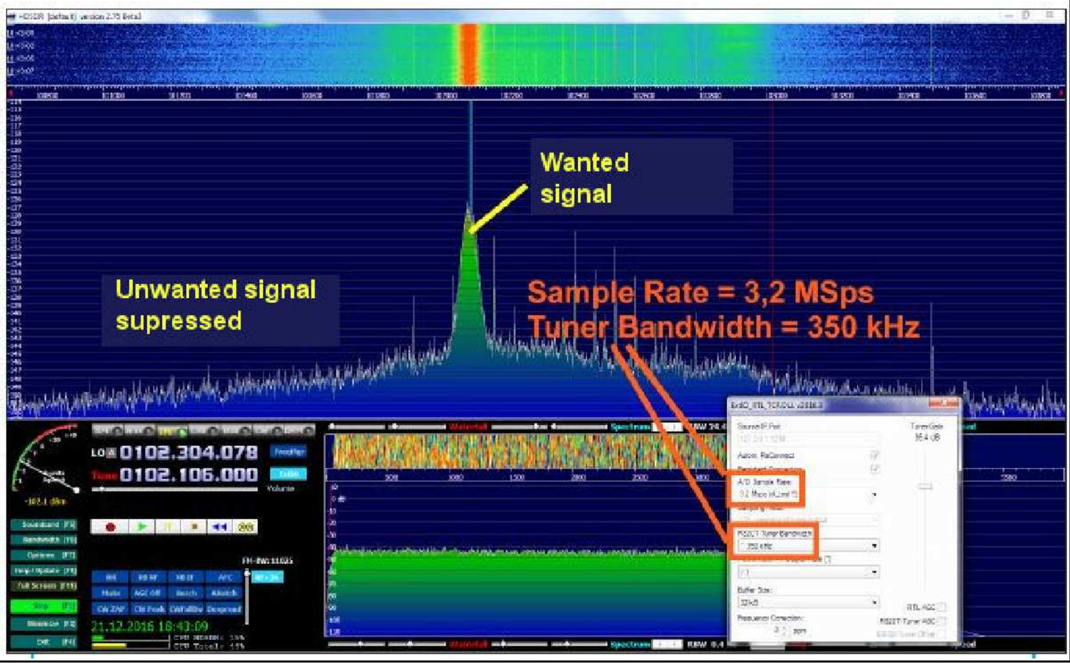


Fig 21: This is the convincing consequence of switching to 350kHz band-width

signals. This can be very useful, especially for weaker stations, with a minimum input sample rate of 1.5Msps. (Note: The maximum adjustable sample rate of 3.2Msps cannot be used yet - as it is in the experimental stage and shows clear dropouts during playback).

Unfortunately, very large computing power is required, so the PC used should have a clock frequency of at least 2GHz, otherwise you will continuously fight dropouts. It is best to try the limit on your own computer using a nice piece of music on FM reception to find out the maximum of the sampling rate.

5. The complete "machine"

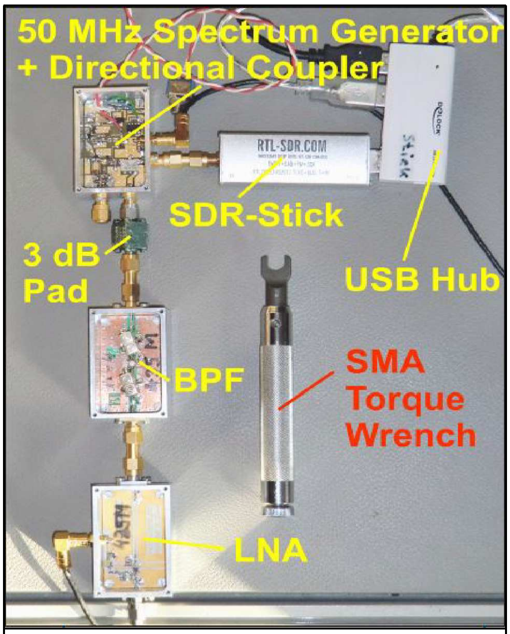


Fig 22: This the complete receiver inc-luding SMA torque wrench

The appearance has changed very little compared to the 145MHz version in Part 1. But now there is a new LNA, a modified filter circuit and of course the much larger "RTL-SDR.COM-Stick" with its metal housing and the SMA input as shown in **Fig 22.** In addition, a 3dB SMA attenuator is inserted between the bandpass filter and the calibrator to improve filter termination. And a special tool is also shown.

There were some bad surprises. Although the sensitivity and reception are virtually identical to the 2m version of Part 1, random switching to the FM band and FM reception at 90MHz, some radio stations suddenly became audible and clearly visible in the spectrum and waterfall. Anyone who has experienced this will sigh compassionately, because that means an endless and tedious search until the radiation is removed. The observed signal levels are in the range of 0.02µV to 0.2µV!

List of all remedial measures taken:

a The SMA connections between the individual components were only "hand tightened". The use of the tool shown in **Fig 22** (official SMA torque wrench) has already brought some improvement. In addition, no shielding covers should be missing and all four cover screws must be tightened correctly.

b The +5V supply voltage fed via an SMB connector and shielded coaxial cable of the preamplifier and calibration module should have a 4.7µF SMD ceramic multilayer capacitor mounted on board (e.g. from the company REICHELT, size 0805 - 16V). The previous decoupling of the supply voltage with a simple LC filter only reduced signals that want to sneak into the module.

The additional 4.7µF capacitor complements the existing decoupling of a wideband Pi circuit and prevents the out of band interference signals picked up by the preamplifier from leaving the module via this path and settle in elsewhere. Yes, yes, this insanely high overall gain ...

c Then the RTL SDR.COM stick was disassembled and examined closely. As a result, the housing and especially the gap between housing and USB connector is now sealed with conductive silver. Then even the SMA input was "Leakey" because the inner toothed washer used for securing under the mounting nut likes to be quite oblique and so a tiny gap remains inside - even if it is tightened well (which unfortunately not all are). The brutal remedy was: omit the toothed washer completely and tighten the nut very well. That is the plan.

d Some small "folding ferrites" from China were ordered on eBay to fit cables with a diameter of 5mm. They were fitted on the USB cable to the PC and on the line to the switch that turns the 50MHz Calibrator on and off.

Now it was quiet and therefore the complete stick could now be filled with insulating thermal grease. This increases the thermal inertia and thus the short-term frequency stability considerably. Thanks to the additional built-in TCXO module in the RTL-SDR-Stick, the set frequency is quite stable after switching on and the deviation drops quickly below 1 ppm.

6. Measurement results

Compared to the 2m version, a number of new insights into the correct operation flowed into the project - especially thanks to constant progress on "HDSDR".

The most important change seems to me to be an extra tiny addition in the upper right corner of the RF spectrum (**Fig 23**). It is a "Clip control of the A to D converter in the RTL2832U chip" and measurements with a precision measuring signal generator show that this transducer is really very nicely dB linear up to the maximum value (**Fig 24**). But exceeding only 1 to 2dB of the maximum allowed value (indicated by the display of !!! Clip!!!) produces a screen full of new interference lines (**Fig 25**) due to saturation. This is of course a nice thing, because you now know exactly how far you have to reduce the "RF Gain" with tuner control off.

Fig 23: Tiny little window with the clipping indicator

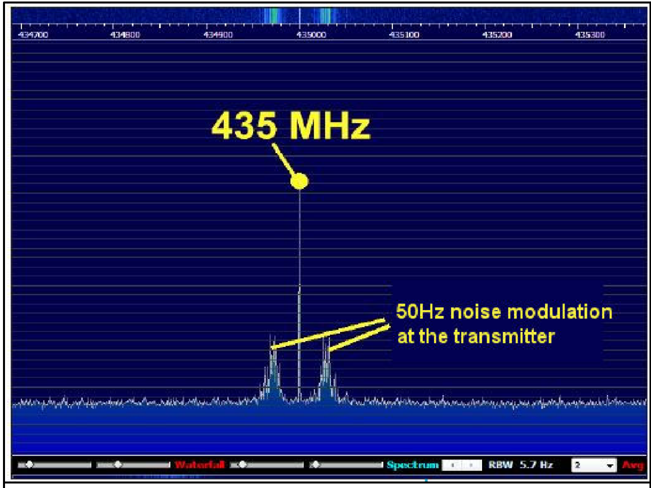


Fig 24: The clipping display is convincing and excellent, at first sight the warning seems to be correct

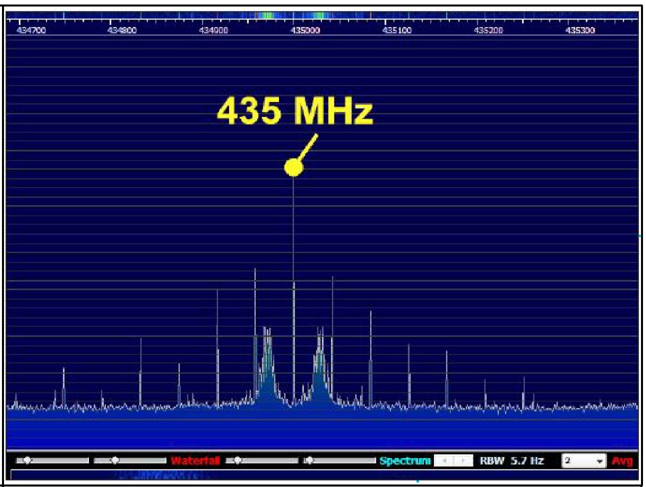


Fig 25: A level increase of 1 to 2dB is sufficient to produce this forest on new spurious lines

A measurement was made to determine the behaviour of the clipping display. It showed that the dB linearity of the R820T2 tuner chip leaves nothing to be desired. In the clipping display, the display is only in step with the S-meter up to 10dB below the clipping point, because for still lower input signals an indication as "green area" is sufficient (from the HDSDR version 2.76 the display becomes "RF <-30dBFS" = 30dB under full scale used). **Fig 26** shows the very good curve of the

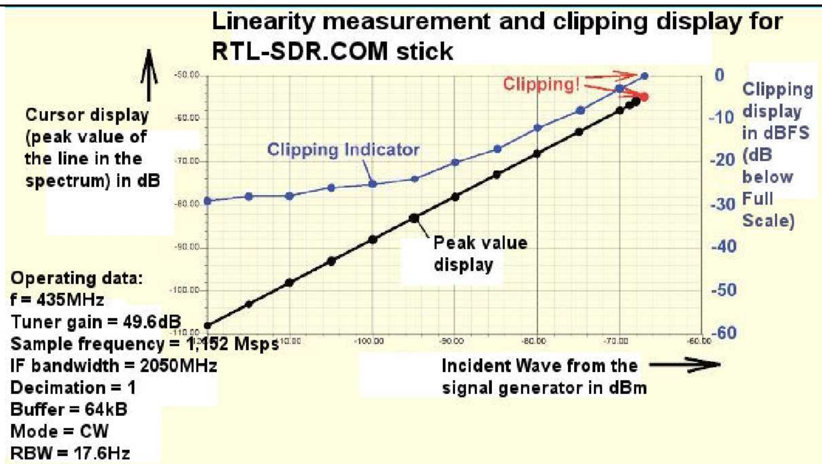


Fig 26: There is nothing like exact measurement. Here you can see how wonderfully linear the AD converter works in the IQ demodulator of the RTL2832. However, the clipping display only runs parallel to the cursor display over an area of up to 10dBFS exactly

stick. Sensitivity is good as shown in **Fig 27.** The transmit signal level is -120dBm (0.22µV) at f =

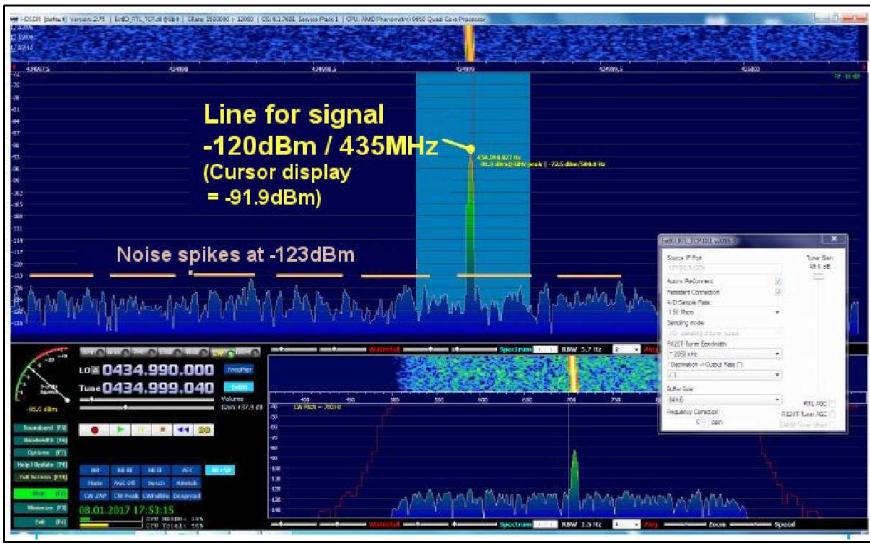


Fig 27: Once again, at an input level of -120dBm (0.22µV) at f = 435MHz, you can reach more than 30dB away from the noise spikes

435MHz and this gives an indication of -91.9dBm on the screen. The peaks of the noise reach a maximum of -123dBm and so you can proudly read a S/R ratio of a good 30dB.

The "EXTIO menu" is where the most important settings can be made, it shows:

a Sampling rate of 1.5 mega samples per second

b A tuner bandwidth of 2050kHz

c A set maximum tuner gain of 49.6dB

d R820T tuner AGC disconnected and RTL AGC off

The operating mode is "CW".

The "Resolution Bandwidth RBW" in the RF spectrum is 17.6Hz.

Here is an important note:

RBW is not the receiver bandwidth but the smallest possible frequency step in the spectrum. It is calculated according to the relationship

Smallest frequency step = RBW = 1 / data collection time in the time domain

If the RBW is reduced it not only improves the frequency resolution of the presentation, but it also drops the "noise floor" and the background noise on the screen. This is of course paid for with a higher computational effort.

The following question was waiting for an answer:

At what input level is the R820T2 tuner chip itself at the limit, even if you reduce the gain (tuner gain) to zero dB?

To do this, start at f = 435MHz with the maximum "Tuner Gain" of 49.6dB (the AGC is off) and increase the signal level up to the clipping display. The level is recorded and then the "Tuner Gain" is gradually reduced via the corresponding slider (note: this is not continuous, but only in the stages that the chip manufacturer intended). Each time the new signal level for "clipping" is read.

Fig 28 shows the result. You can clearly see the linear range - and when the input stage in the tuner chip is getting too much (and who is bothered by the slightly stepped course of the trace in the linear range, the signal level could unfortunately only be changed in 1dB increments).

So you can complete this project satisfied.

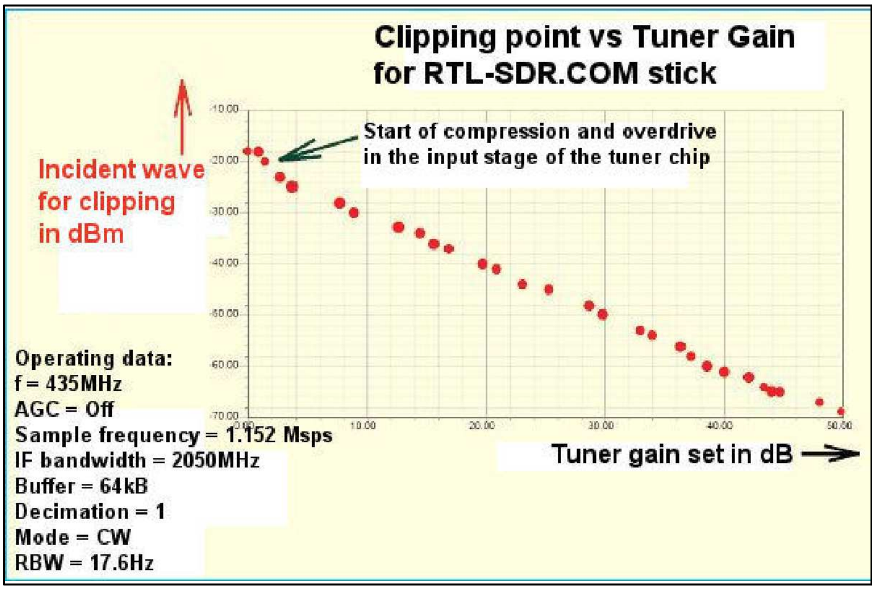


Fig 28: With this trick (via the clipping indicator and tuner gain setting), you can see exactly the input level where the tuner chip is working linearly

References

[1] RTL-SDR.COM – Homepage

[2] On the homepage (www.gunthard kraus.de) there is a folder with the name " Frischer Wind für DVB-T-Sticks und SDRs …” and in that folder there is a list of keyboard shortcuts under “Liste mit den Tastenkombinationen (keyboard shortcut list) für die HDSDR-Version 2.76”

[3] Company TACTRON, Sales: Mr Achim Baier; Tel. +49 7308 811 2026; Fax +49 (0) 7191 3540-15; Email: achim.baier@tactron.de; Web: http: //www.tactron.de

[4] Receiver construction using 50 ohm modules (gain blocks) - Example Application: a low noise 2m receiver using a DVB-T stick. First published in UKW Berichte 4/2016. An English translation is on the VHF Communications web site – www.vhfcomm.co.uk

[5] A low noise preamplifier for the 70cm band with gain of 25dB and noise figure of approximately 0.4dB. Published in VHF Communications Magazine 4/2013