<u>Improving the ADF5355 synthesizer board (Version with Touch-Display)</u>

Matthias, DD1US, March 24th 2018, rev 1.1

Hello,

Searching for a way to extend the frequency range of my test equipment I decided to buy a ready-made kit from Ali Express in China.

<u>Introduction:</u>

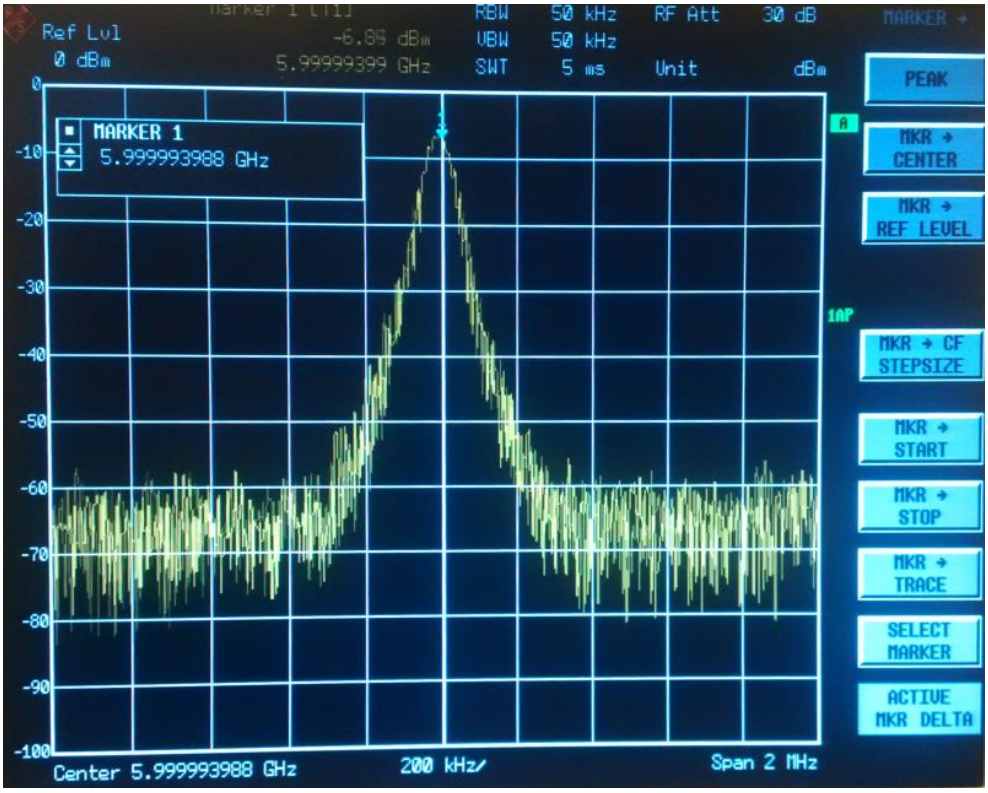
It is a board with the ADF5355 synthesizer IC, which covers the frequency range from 54 MHz to 13.6 GHz, a 125 MHz crystal oscillator and an 32bit ARM based microcontroller STM32F103 RCT6. A second PCB is included which is sandwiched on top and included a resistive color touch display which provides a simple user interface. The price is approximately 110 USD.

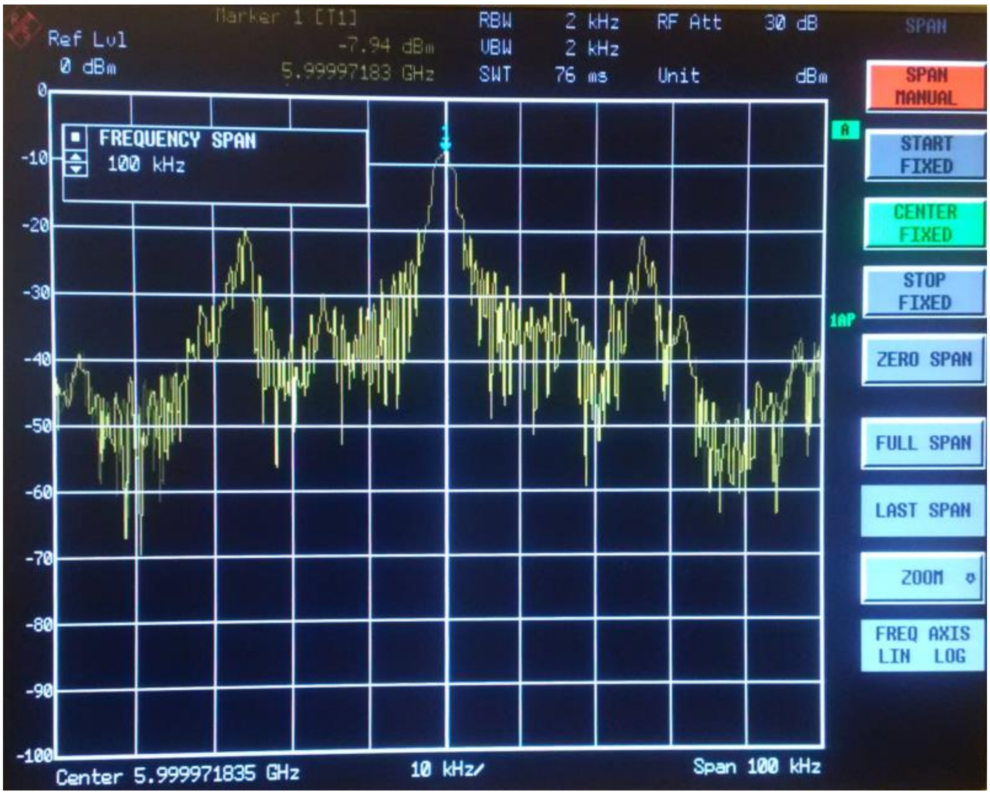
Here is how is looks and what was included:

The board is powered by the mini-USB port or via 5V which need to be supplied to a respective socket next to the mini-USB-port. When I got the board, it powered up properly and at a first glance provided the specified output signals in the full frequency range.

First detailed measurements:

When checking the signal quality more in detail with a spectrum analyzer, I found that the signal was badly contaminated by noise. Here are 2 screen shots of the poor output signal at 6 GHz.

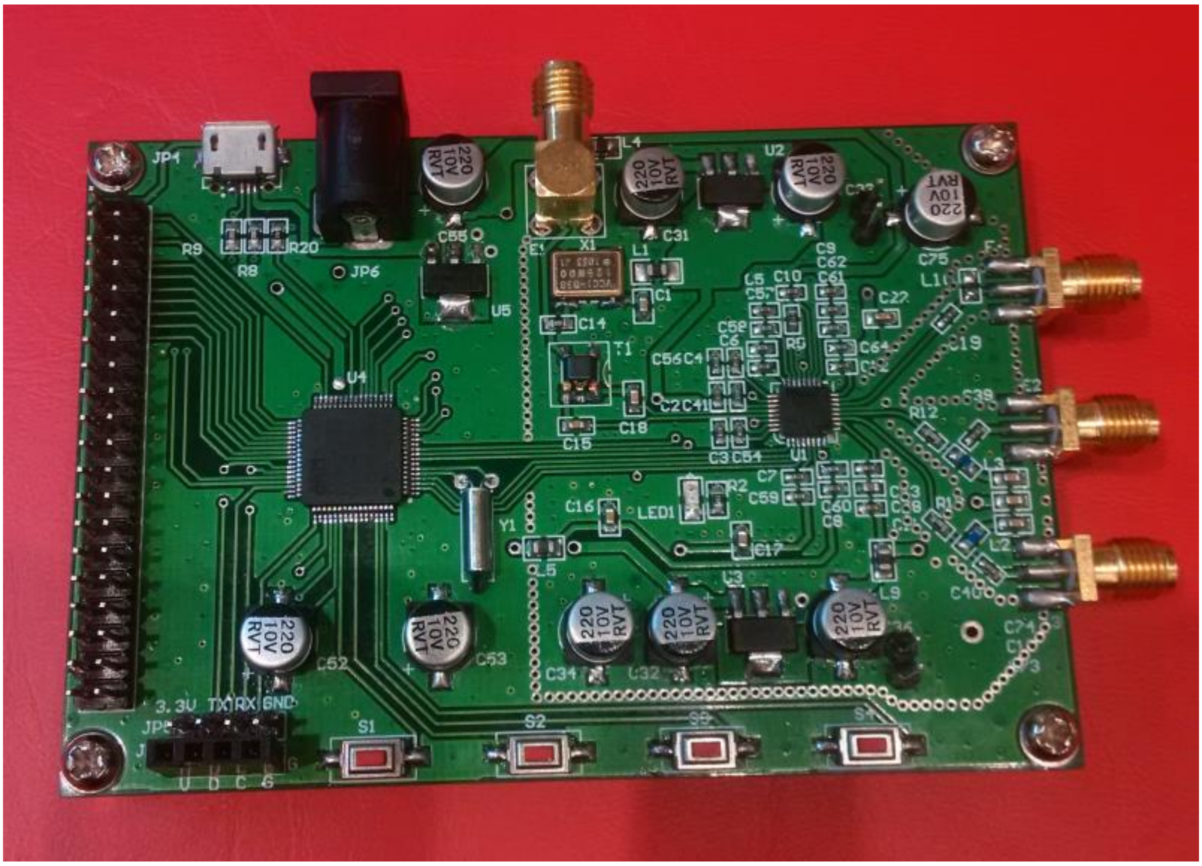


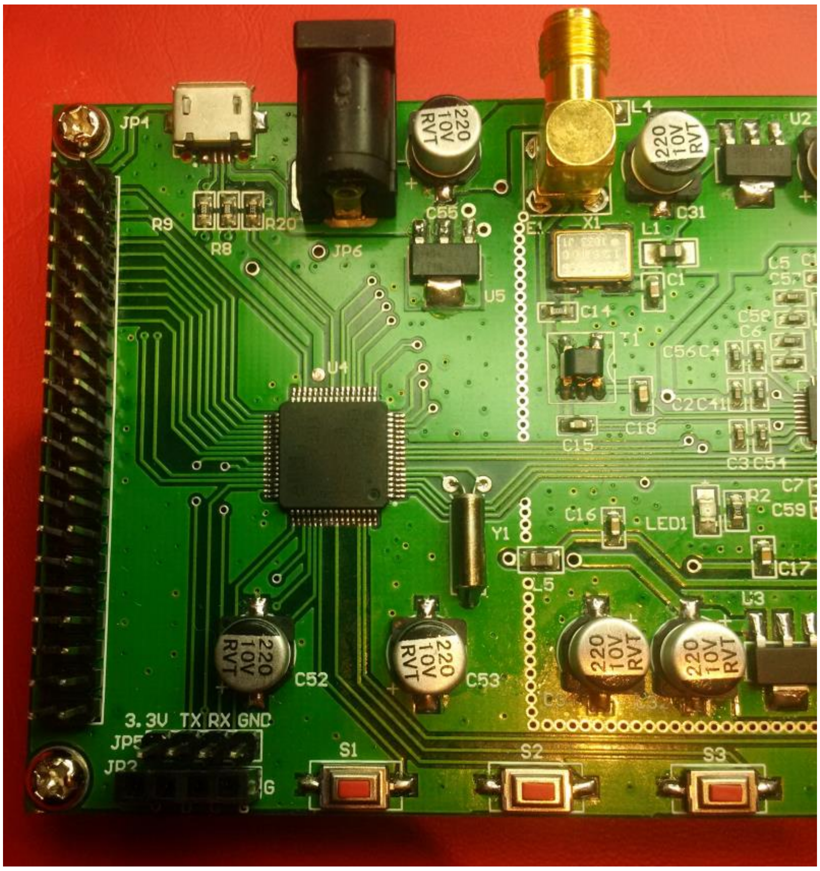


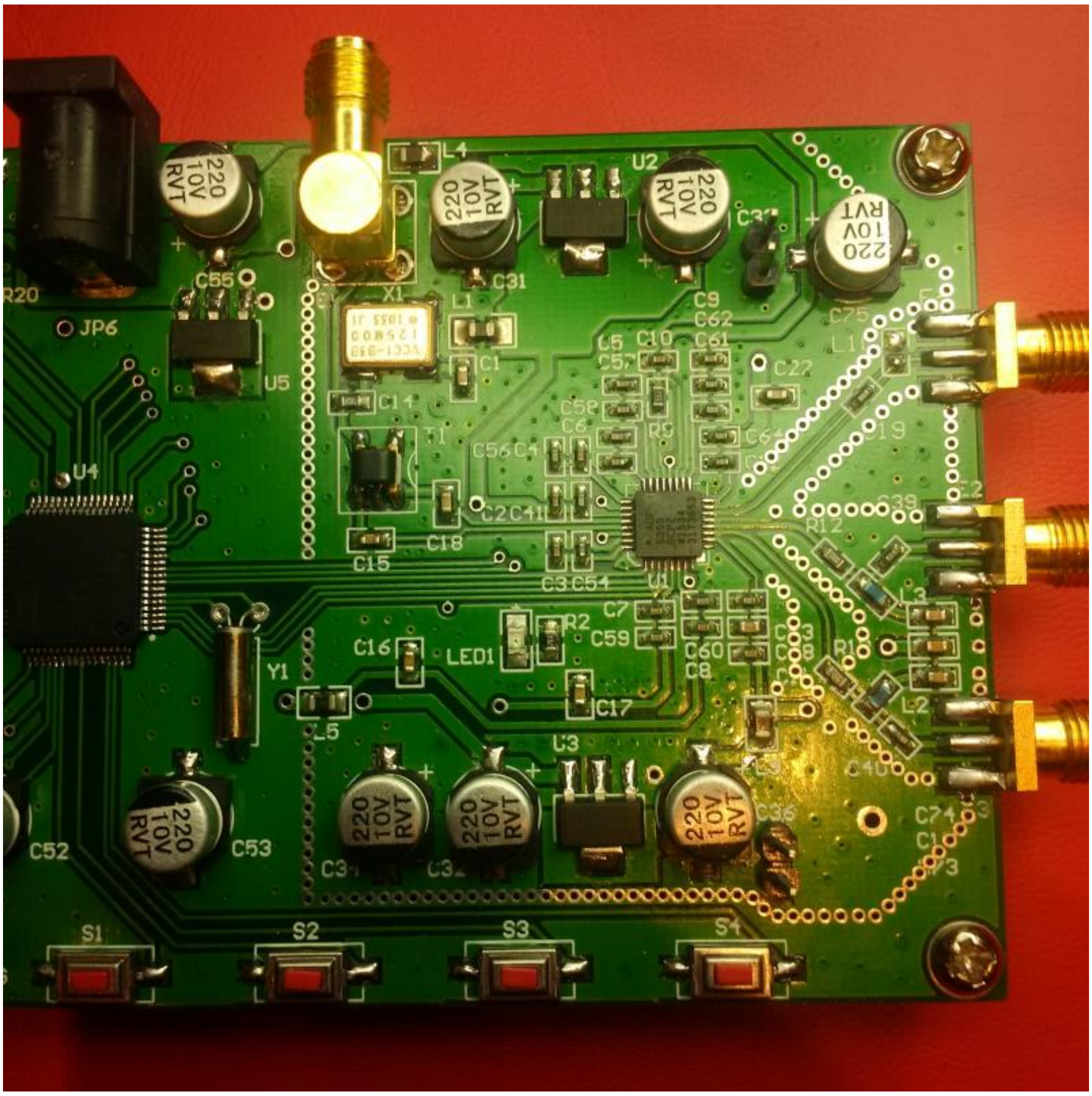
Rechecking the website of the seller I found various spectrum plots but all with a span of 20 MHz which of course do not reveal such a poor signal quality close to the carrier.

Pictures of the board:

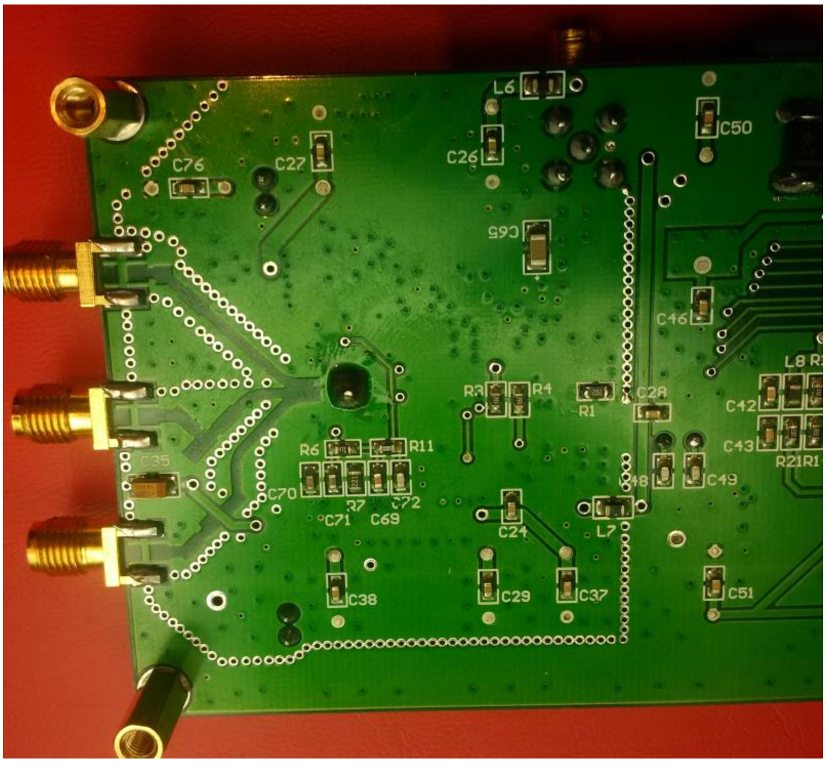
Here are some pictures of the synthesizer board before doing any modifications:



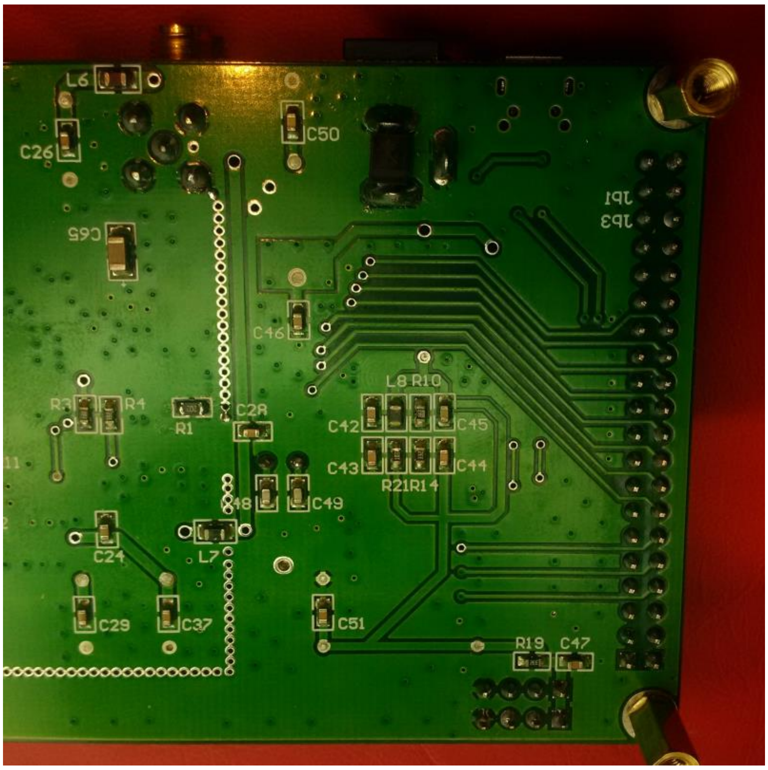




220
10V
RVT
C55
JP6
U5
U4
X1
L1
L4
C31
U2
C9
C62
C75
C14
C15
C18
C16
LED1
R2
C17
Y1
L5
U3
C7
C59
C60
C8
R12
R1
L2
L3
C40
C74
C52
C53
C34
C32
C36
S1
S2
S3
S4



L6
C50
C76
C27
C26
C65
C46
L8
R3
R4
R1
C28
C42
C43
R6
R11
C35
C70
C71
C69
C72
R7
C24
L7
C48
C49
C38
C29
C37
C51



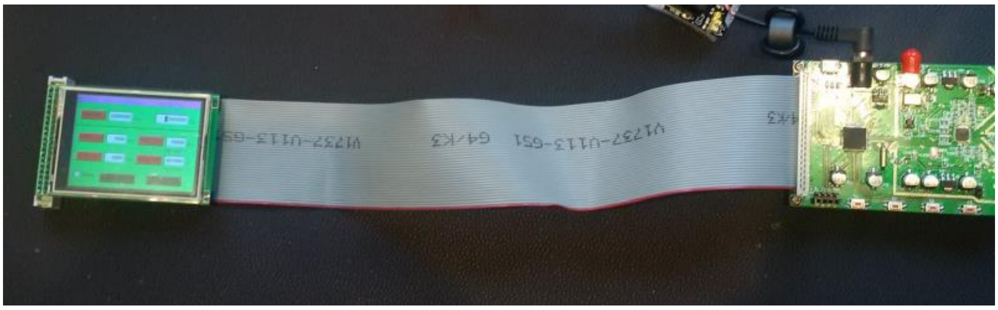
Analysis of the PCB:

I analyzed the board and was first positively surprised that quite some good RF practice was used in the layout. However, I was shocked when I noticed, that the supply voltage for the VCOs was directly supplied from the external power supply. Only other (less critical blocks) were supplied by some on board regulators. There are some inductors and capacitors for blocking the 5V DC voltage for the VCO but when consulting the datasheet and application notes from Analog Devices it became clear, that special care has to be taking with respect to the power supply for the ADF5355. Even though the synthesizer chip has 4 fully integrated VCO and uses several clever tricks to improve the signal quality, the tuning sensitivity of the VCO is specified with 15 MHz/V. A disturbing signal of 1 mV would thus result in an unwanted modulation of the VCO of 15 kHz.

Searching the internet, I found an excellent article from Brain Flynn GM8BJF. Here is a link to his website where you can find the article and many more helpful information about synthesizer boards based on the ADF4xxx and ADF5xxx series: https://gm8bjf.joomla.com/articles

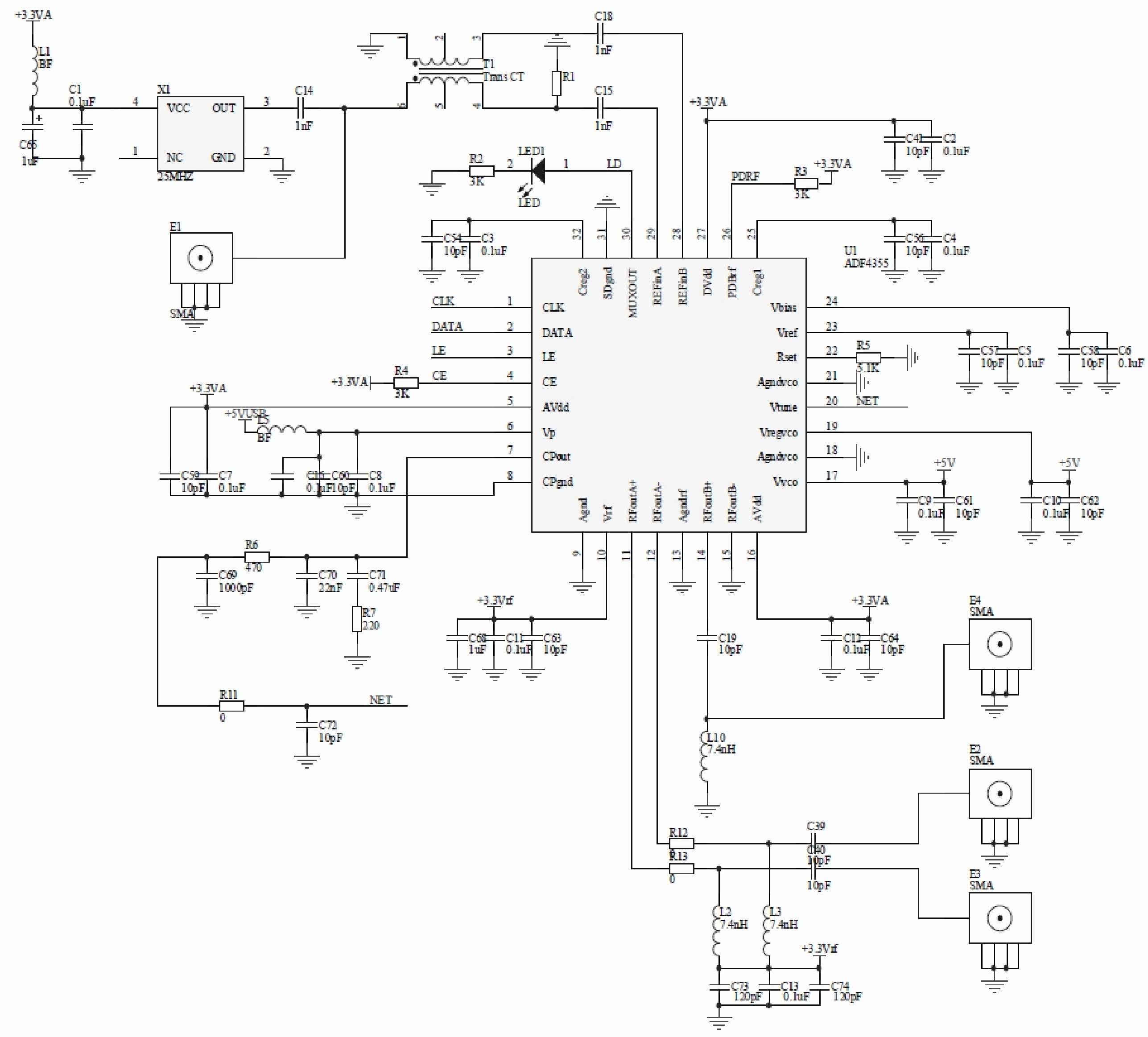
Thanks to this information and subsequent frequent Email exchanges with Brian, I decided to optimize the power supply of my board. Unfortunately, I have a different board compared to the two Brian has been experimenting with. As there is no schematic of my board publicly available I analyzed the board and made my own sketch of the schematic.

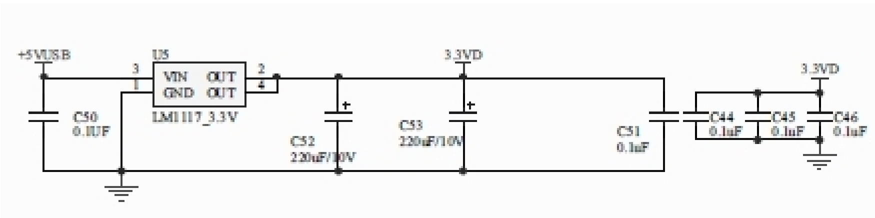
In order to be able to operate the board and perform measurements on it I had to move the display board aside. I was also suspecting that some of the interference of the RF signal might come from intercoupling between the 2 stacked boards. Thus, I prepared a ribbon cable and separated the boards.

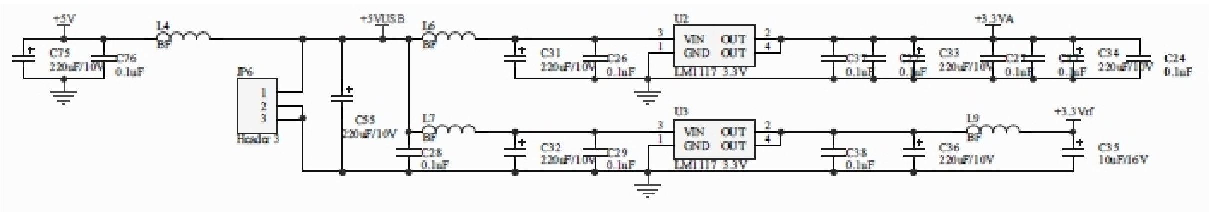


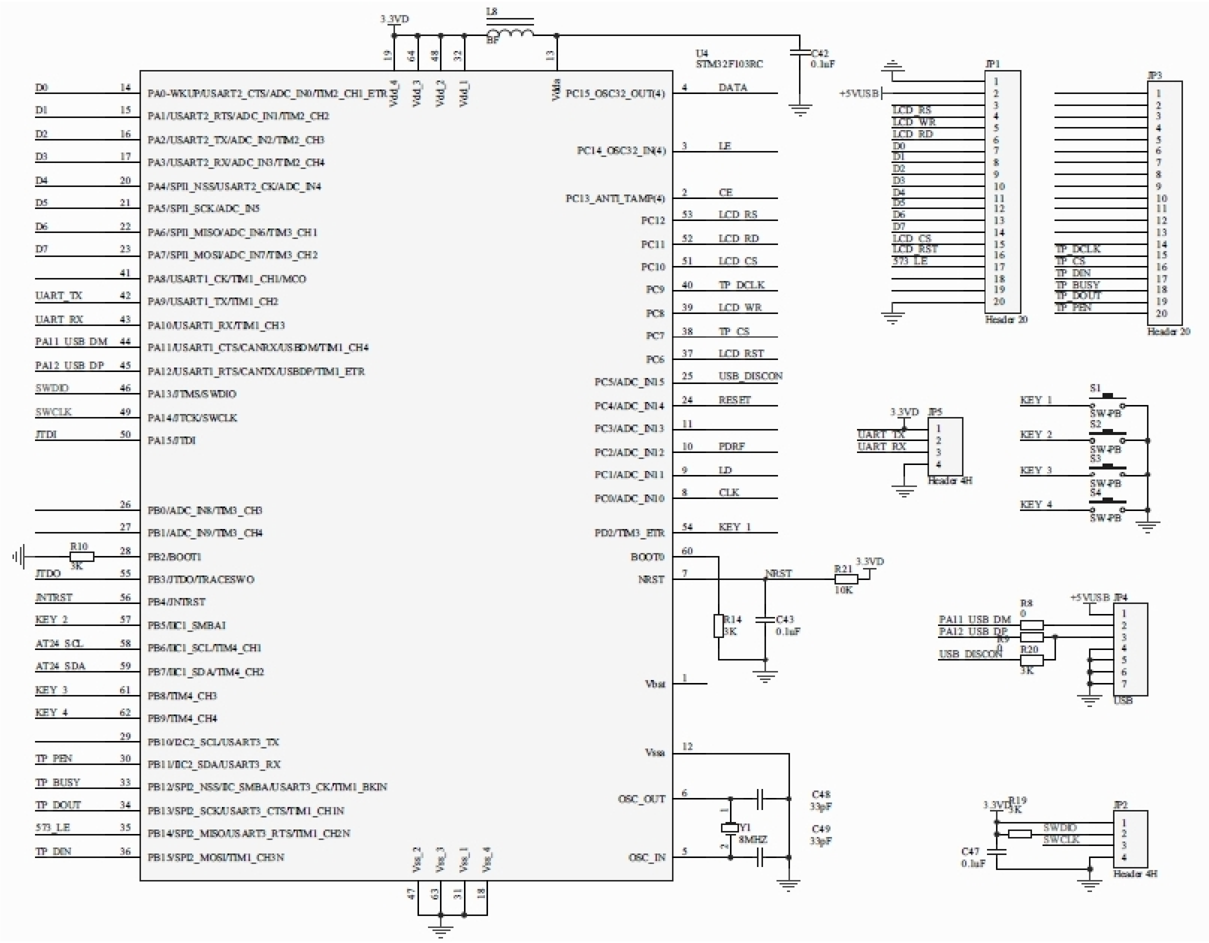
In later investigations it turned out that the display board is not generating additional interference when plugged directly to the synthesizer PCB.

Later I received enclosed schematics of the synthesizer board from Reinhard, DL3BR, which I enclose below.









How to improve the performance:

I focused especially on the various power supply domains. Besides the 5V supply which is needed for some critical circuitry there are 3 voltage regulators for 3.3V supplies on the board. All are using AMS 1117 regulators. Comparing the output noise performance of various available 5V voltage regulators showed that the respective output RMS noise performance in the frequency range 10Hz to 100 kHz varies a lot:
A standard L7805CV regulator has for instance 200uV noise, the AMS1117 (5V) is specified with 150uV (from 10Hz to 10kHz), the LT1761-5 and LT1763-5 are already much better with 20uV. Looking on the recommended ultra-low noise voltage regulators ADM7150 ACPZ-5.0 showing astonishing 1.6uV.

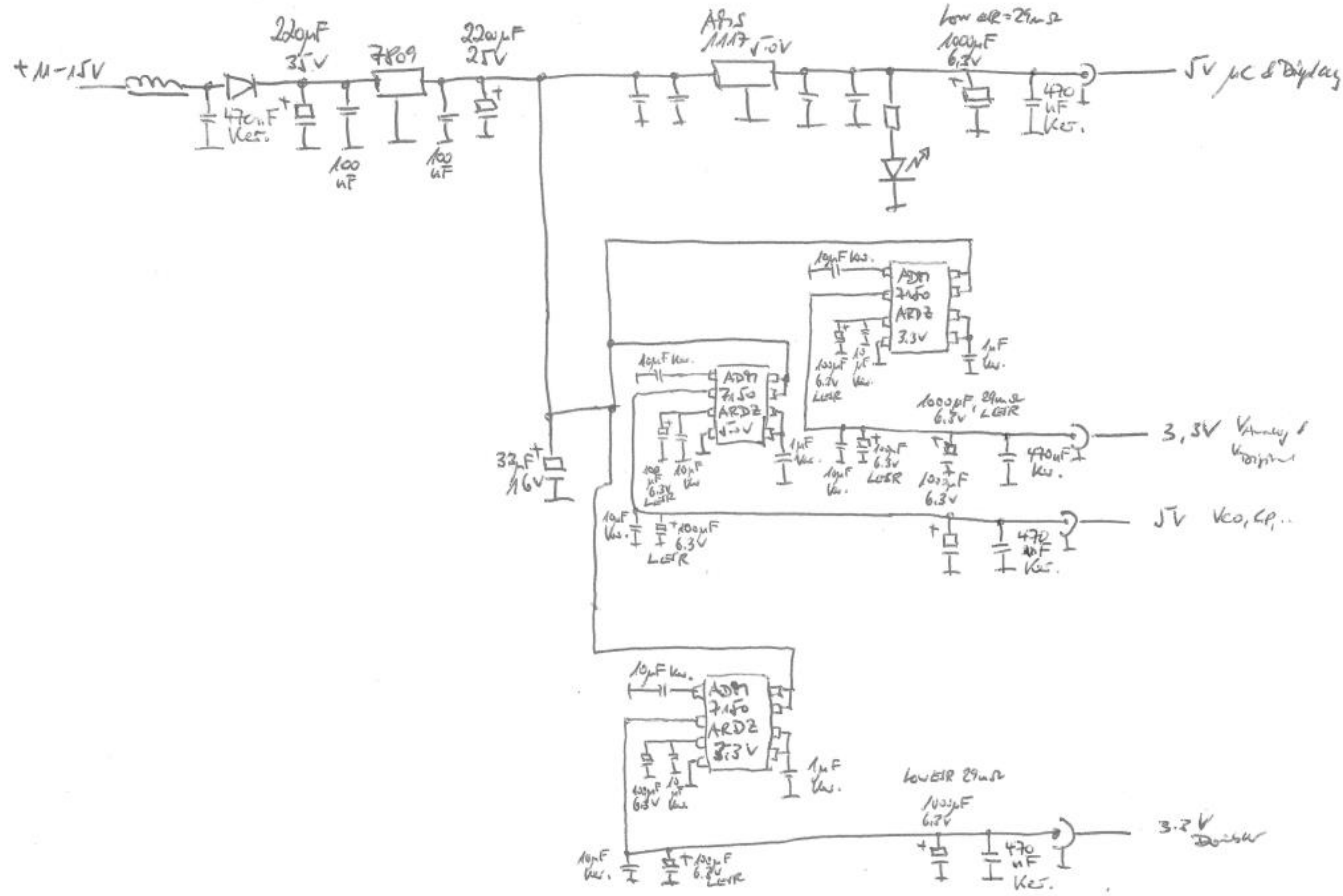
Talking with Brian about this it turned out that he was already preparing a power supply board with 1 piece of ADM7150 ACPZ-5.0 and 2 pieces of ADM7150 ACPZ-3.3 voltage regulators. He was kind enough to provide me a blank PCB and thus I assembled and used this for my purpose. On that board I used the following low ESR 100uF / 6.3V capacitors from Vishay: T55B107M6R3C0035. They feature a ESR of only 35mOhms. The other blocking capacitors are ceramic type.

In addition, I needed another 5V supply domain for the touch display board and decided to use a small PCB which I had at hands using an AMS1117. On the synthesizer board also the 3.3V supply for the microcontroller is derived.

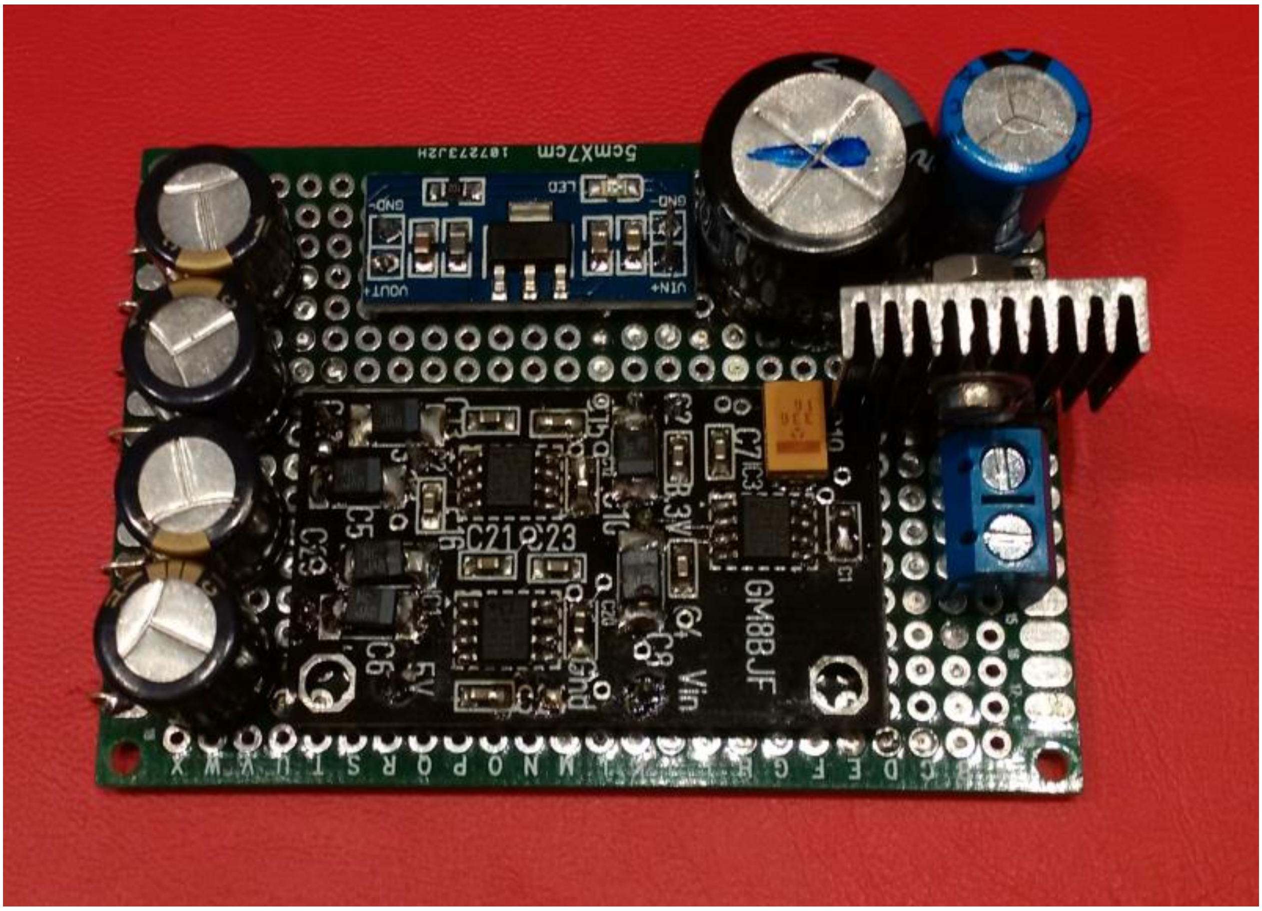
To reduce the power dissipation in the regulators and provide additional decoupling from the external power supply I added a 9V regulator which powers all following 5V and 3.3V regulators. The nominal external supply voltage range is 12V. The possible supply voltage range is 11V to 20V, limited by the heat dissipation of the 9V regulator which is mounted only on a small heat sink.

I assembled the complete power supply comprised of the 2 boards, the primary 9V regulator, reverse supply protection diode and some additional Low ESR capacitors on a carrier board.

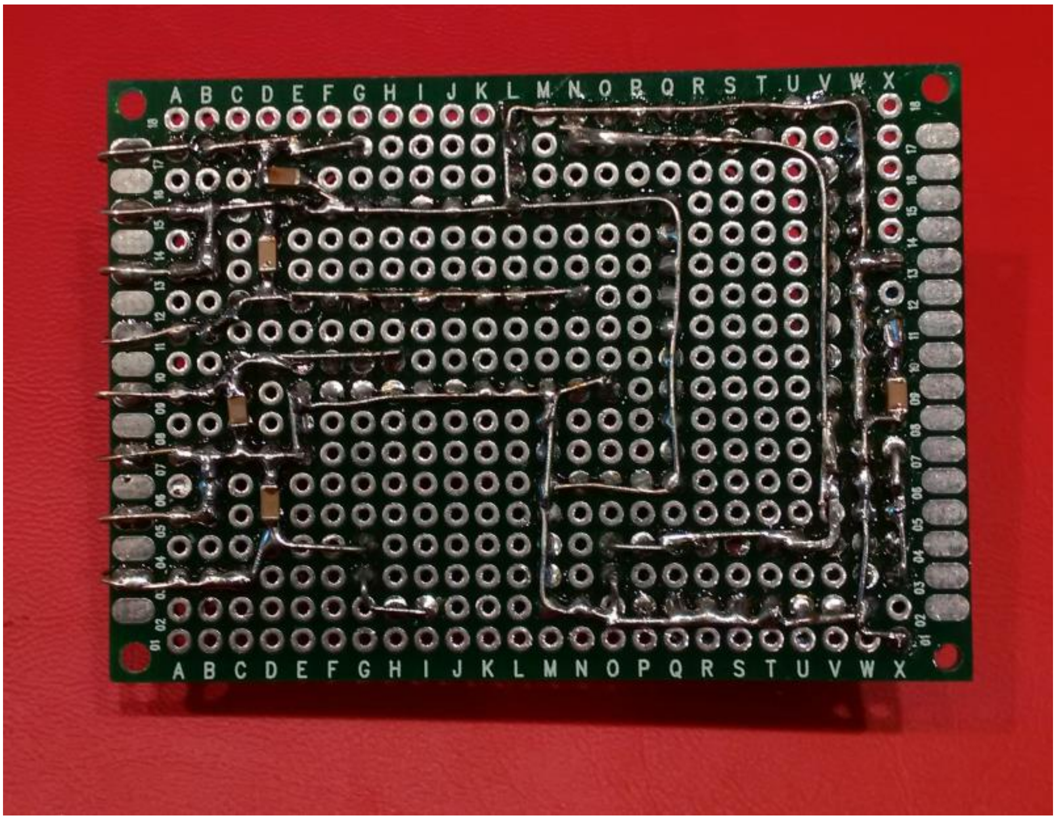
Here is a sketch of the schematic of the complete power supply board:



On the next page you will find some pictures of the power supply board:

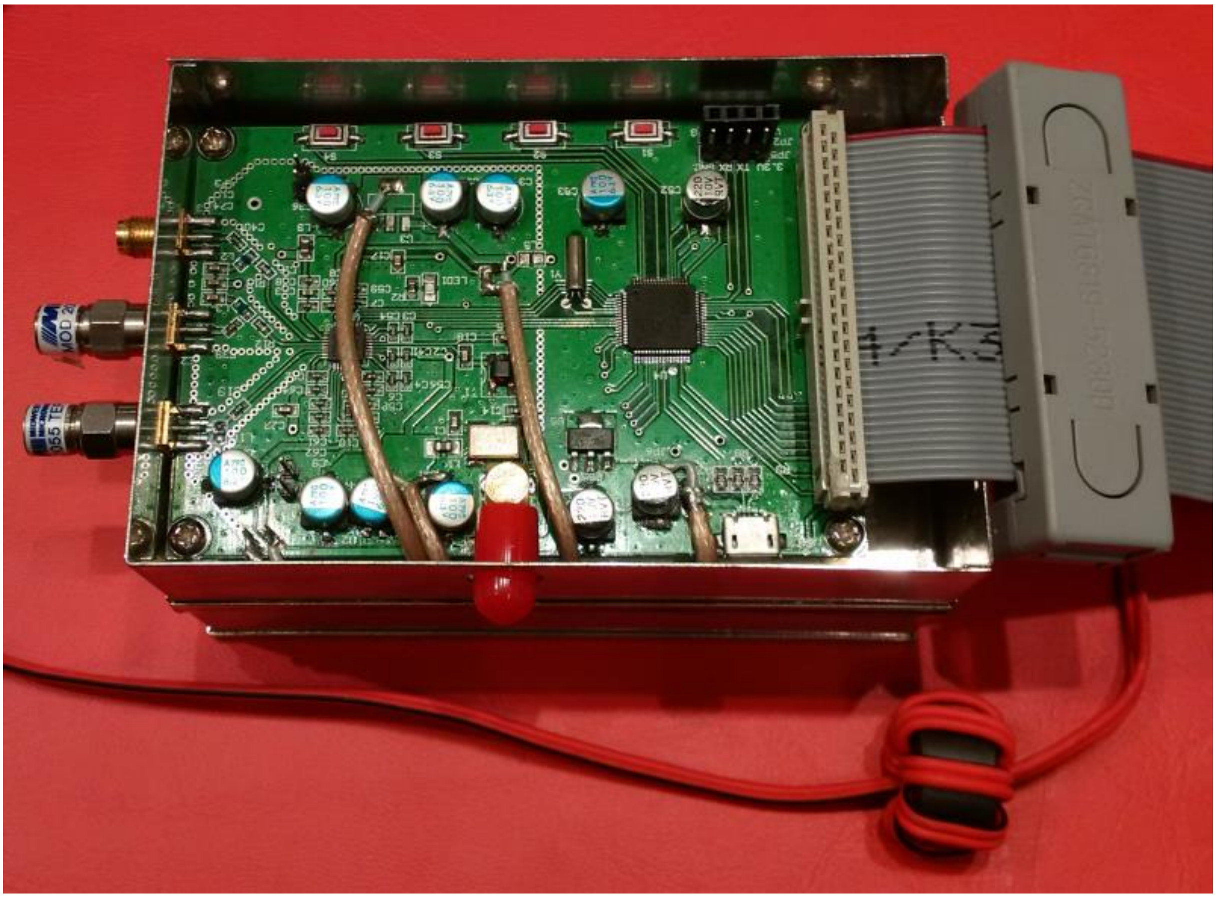


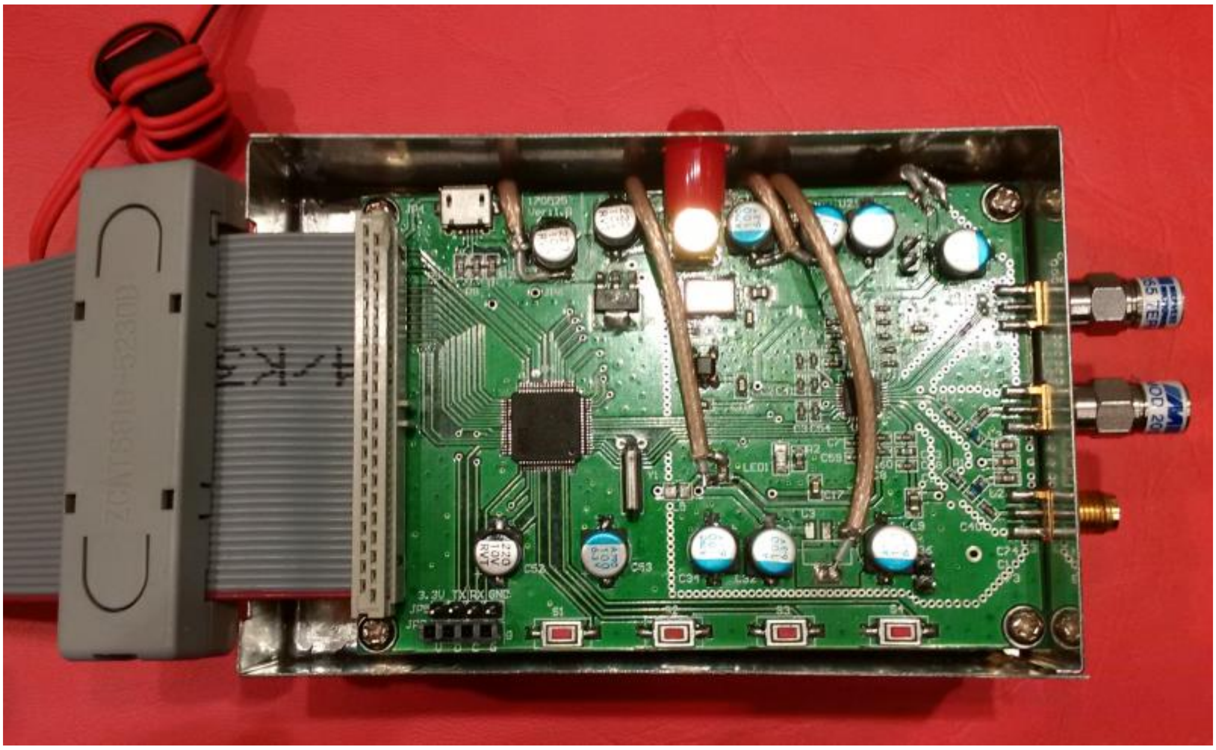
On each output of the power supply board I added a big low ESR 1000uF/6.3V capacitor and I parallel a ceramic 470nF capacitor.



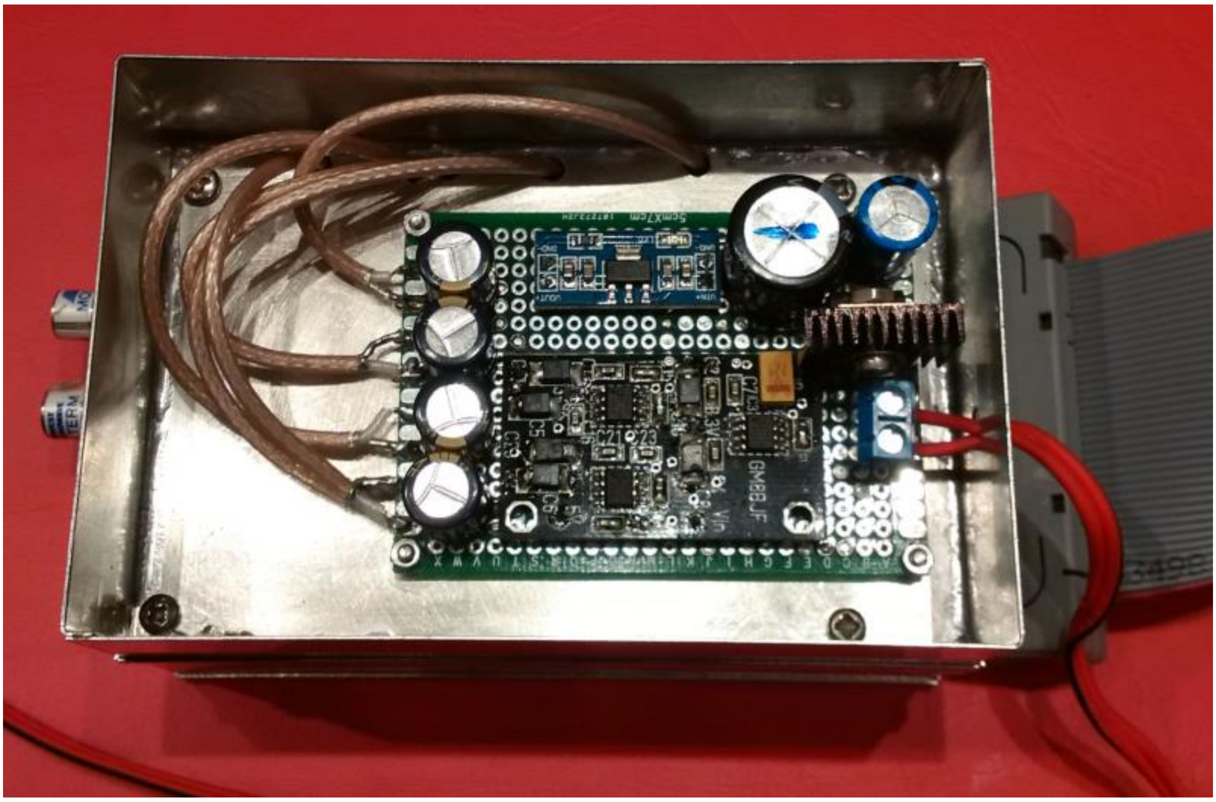
In addition, I decided to mount both, the RF synthesizer board and the power supply each in separated tin-plated cabinets to shield them properly from any possibly interferences. Here are pictures of the metal cans which are stacked on each other:

Next you can find some pictures with the boards assembled in the metal cases. The power supply connections between the power supply board and the synthesizer board are implemented using thin Teflon based coaxial cables. This shielding should avoid unwanted intercoupling from / to those lines. Before that all voltage regulators except the 3.3V regulator for the microcontroller had been removed from the PCB. In addition, the two inductors marked L4 and L5 were removed to disconnect the VCO supply from the 5V supply of the display board. Finally, I also removed the power supply jack and used the space to add an additional 100uF/6.3V Low-ESR capacitor.



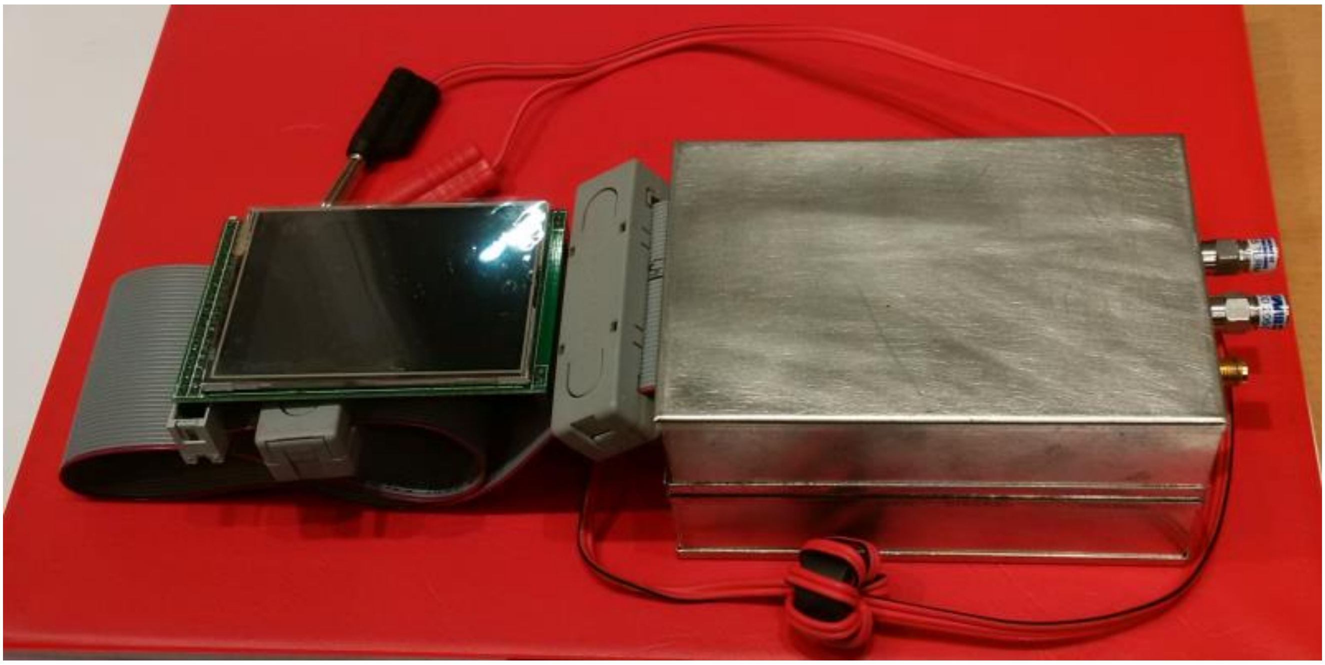


You might have noticed that the color of the round electrolyte capacitors changed. I replaced most of the original capacitors by a 100uF/6.3V type capacitor from PXA with a low ESR of 27mOhms (exact part number is APXA6R3ARA101MF55G). On the backside of the PCB I replaced the Tantal capacitor buffering the power supply for the output stage of the synthesizer with a low ESR 47uF / 6.3V capacitor from Vishay. This T55A476M6R3C0070 features a low ESR of only 70 mOhms.




GM8BJF
Vin
5cmX7cm

I plan to assembly the synthesizer with the display and additional accessories, such as a ALC (automatic level control) unit and a switchable attenuator, in a nice enclosure. Therefore, I wanted to keep the display separate from the RF board to have optimum flexibility where to place the RF unit relative to the touch-display which has to go into the front panel. I added ferrite RF chokes on each end of the ribbon cable to suppress possible interference in the future setup.



Measurement results:

On the next pages you will find various measurement results of the modified setup.

There are 3 sections with measurements performed on 3 GHz, 6 GHz and 12 GHz.

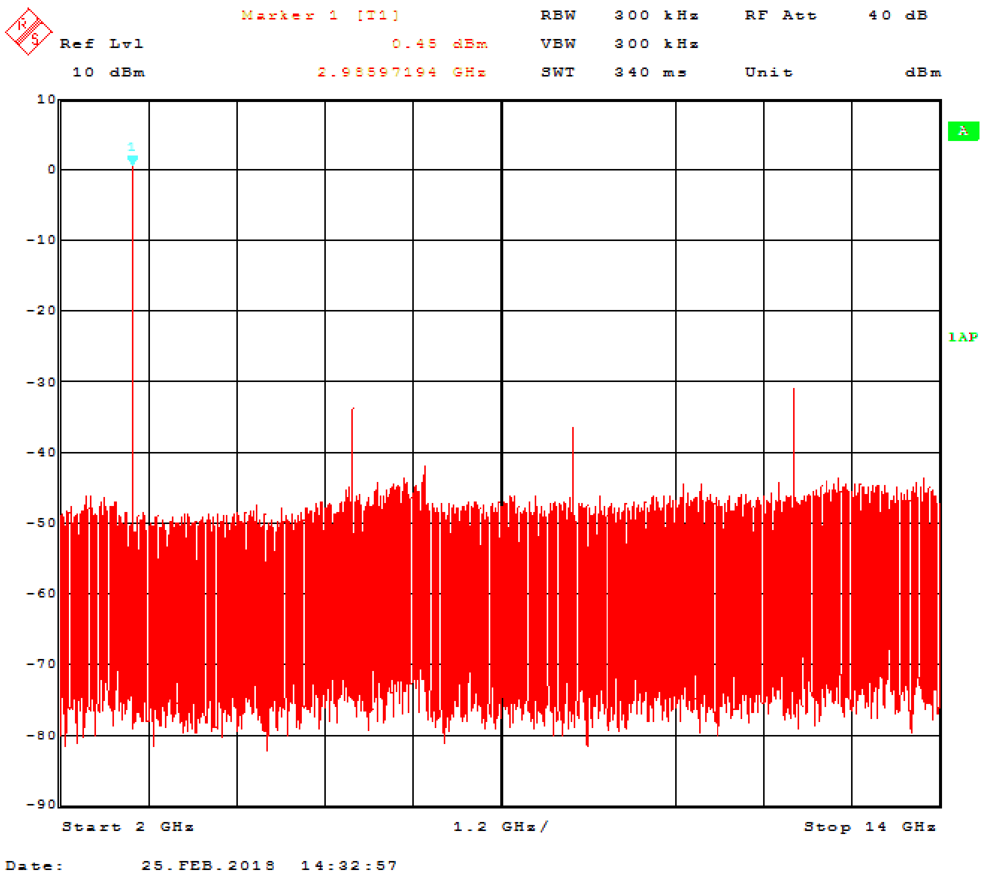
In each section you will first find a wideband spectrum plot showing the harmonics and at the doubler-output also showing the subharmonic.

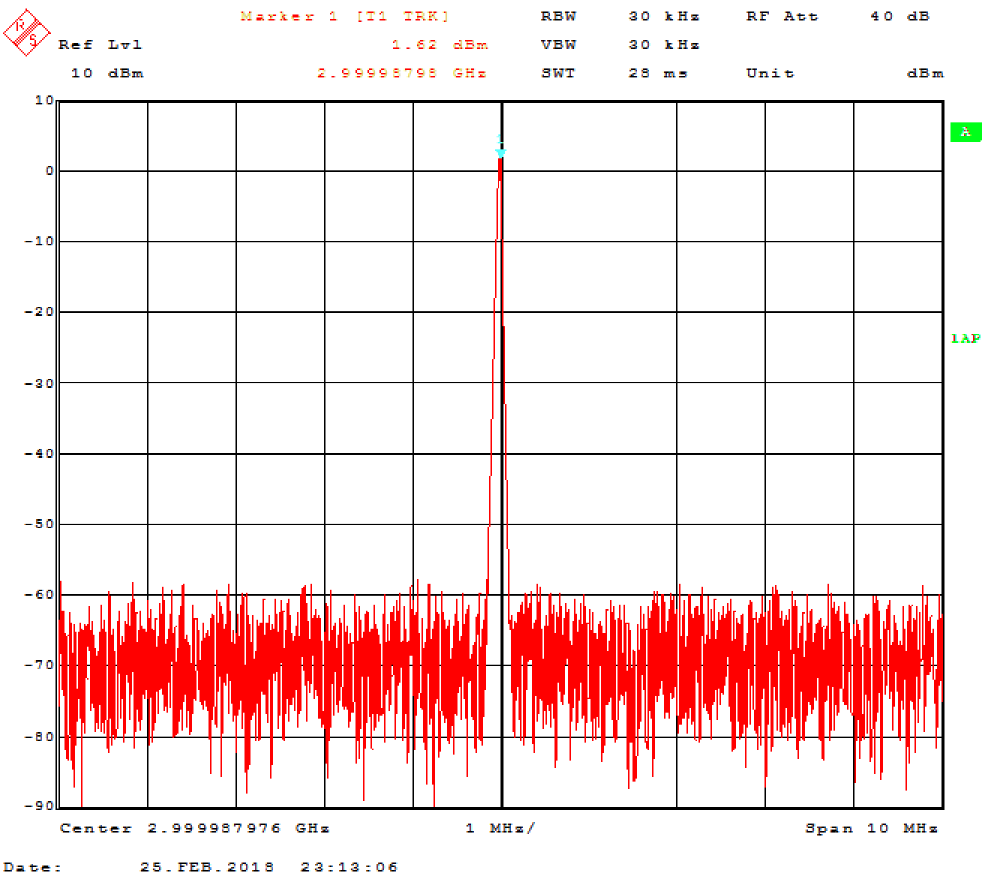
Then you find spectrum plots with the carrier centered and spans of 10 MHz, 1 MHz, 100kHz and 10 kHz.

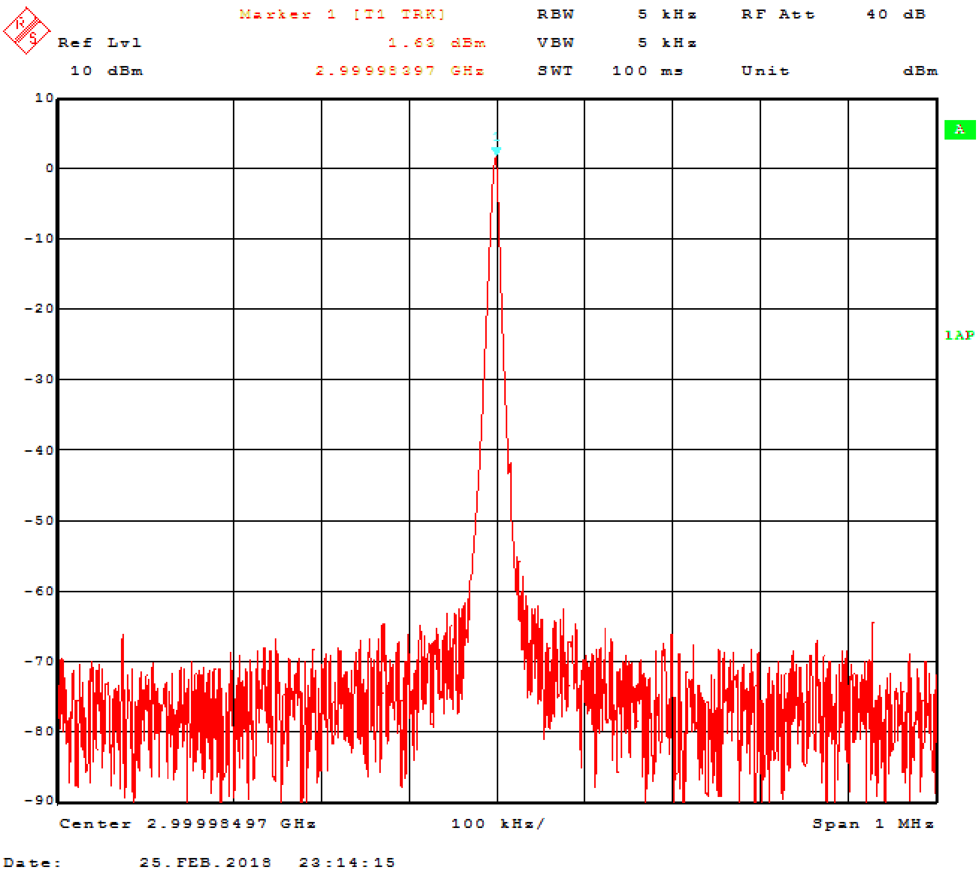
Finally, you will find a plot of the measured phase noise.

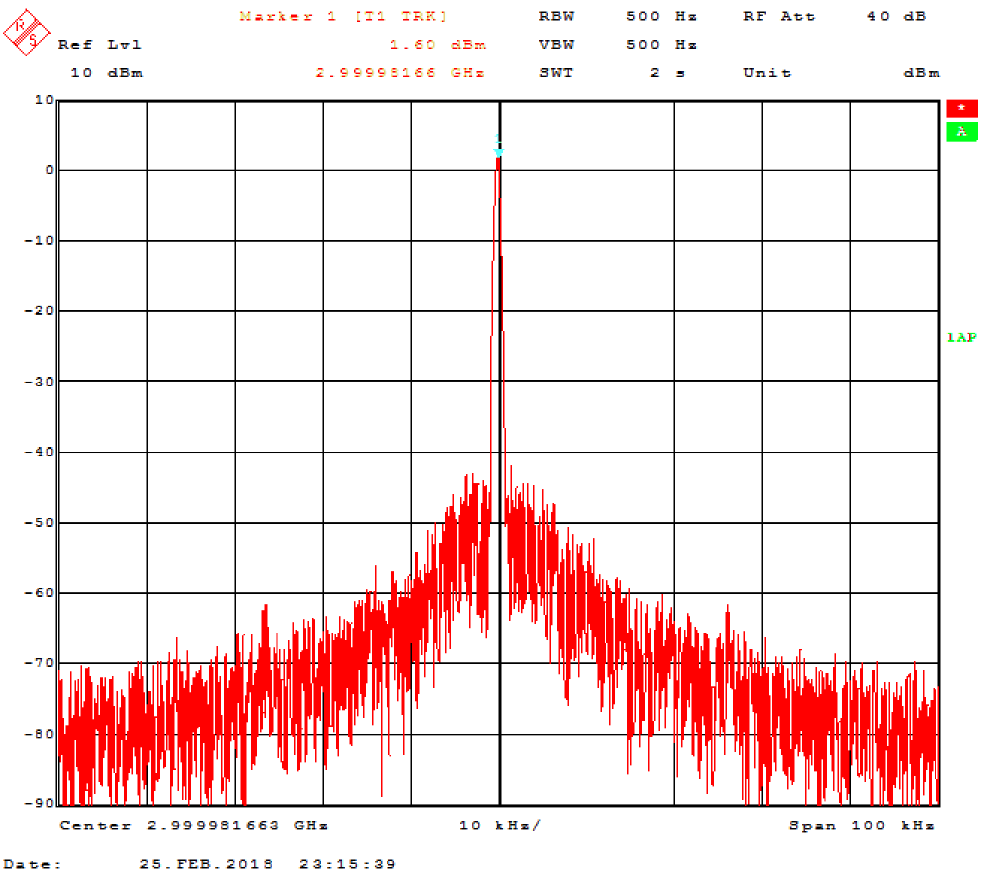
The measurements at 3 GHz and 6 GHz were performed at the output port A+, the measurements at 12 GHz at the doubler-output. Unused RF ports were terminated with a 50 Ohm load.

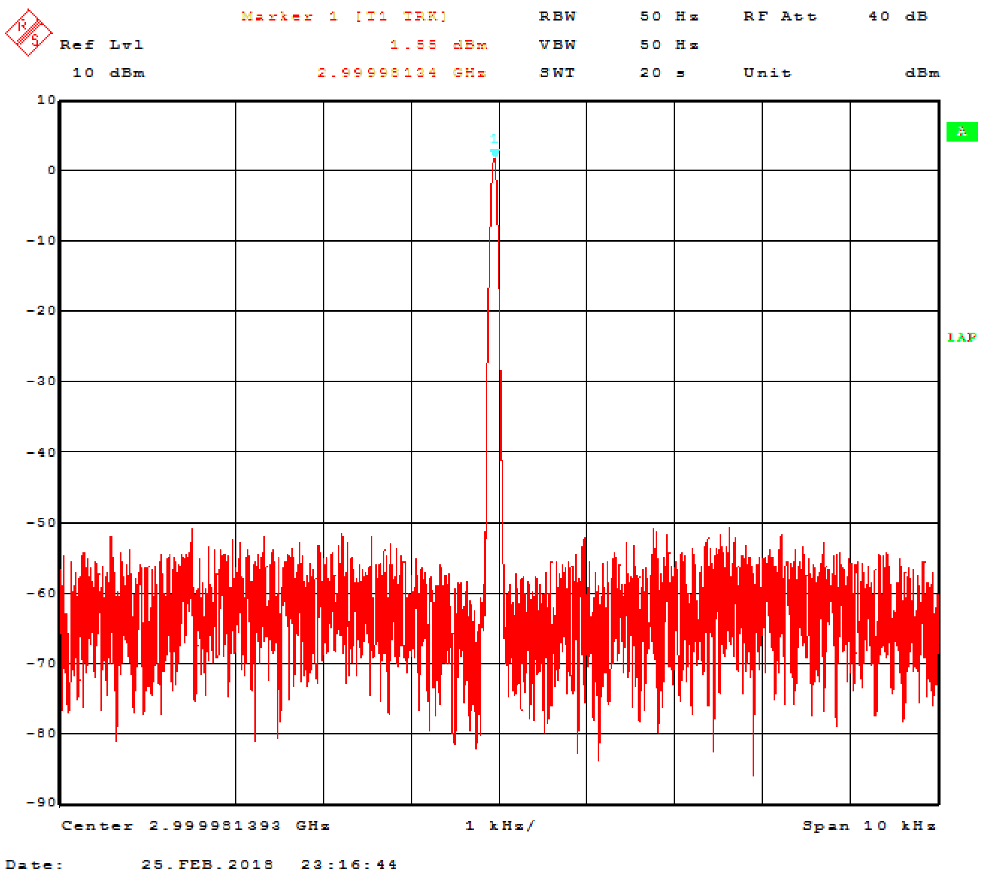
a) 3 GHz measurements:

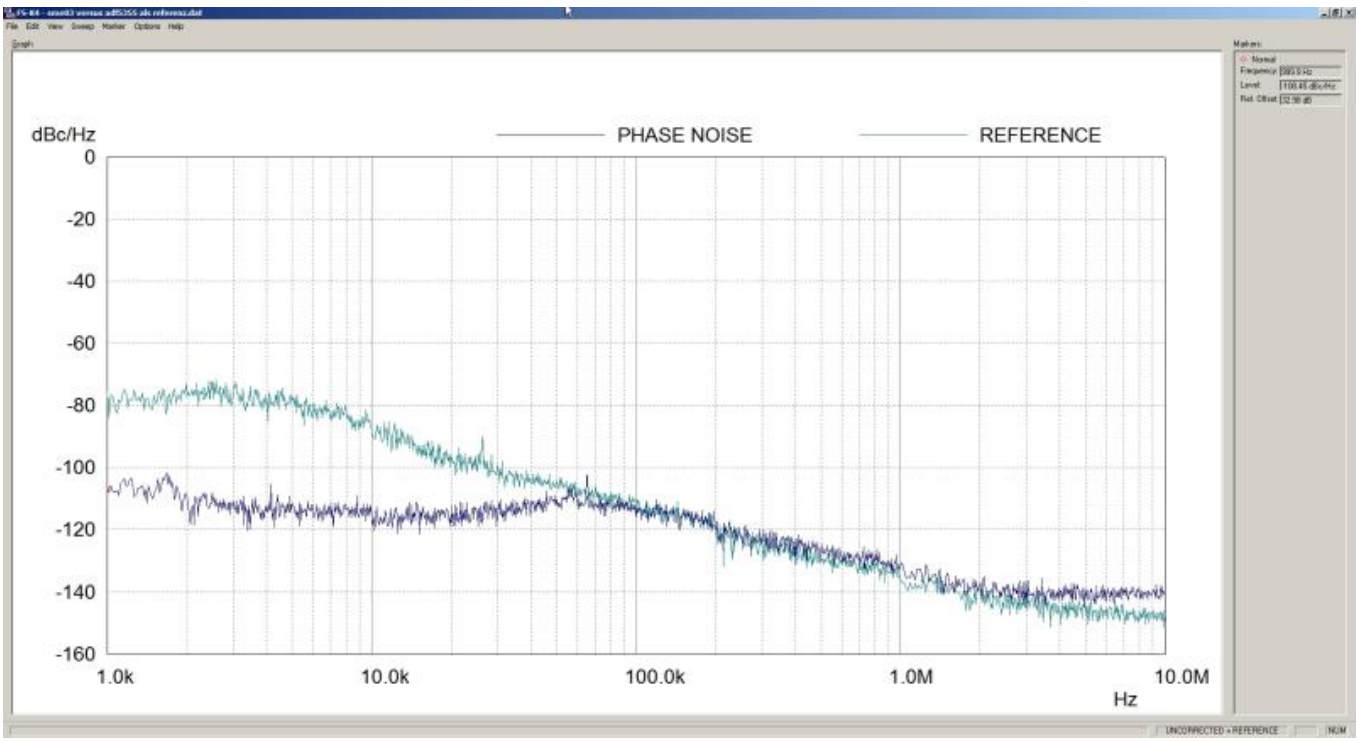





Marker 1 [T1 TRK]
RBW 5 kHz
RF Att 40 dB
Ref Lvl
1.63 dBm
VBW 5 kHz
10 dBm
2.99998397 GHz
SWT 100 ms
Unit dBm
1AP
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
Center 2.99998497 GHz
100 kHz/
Span 1 MHz
Date: 25.FEB.2018 23:14:15

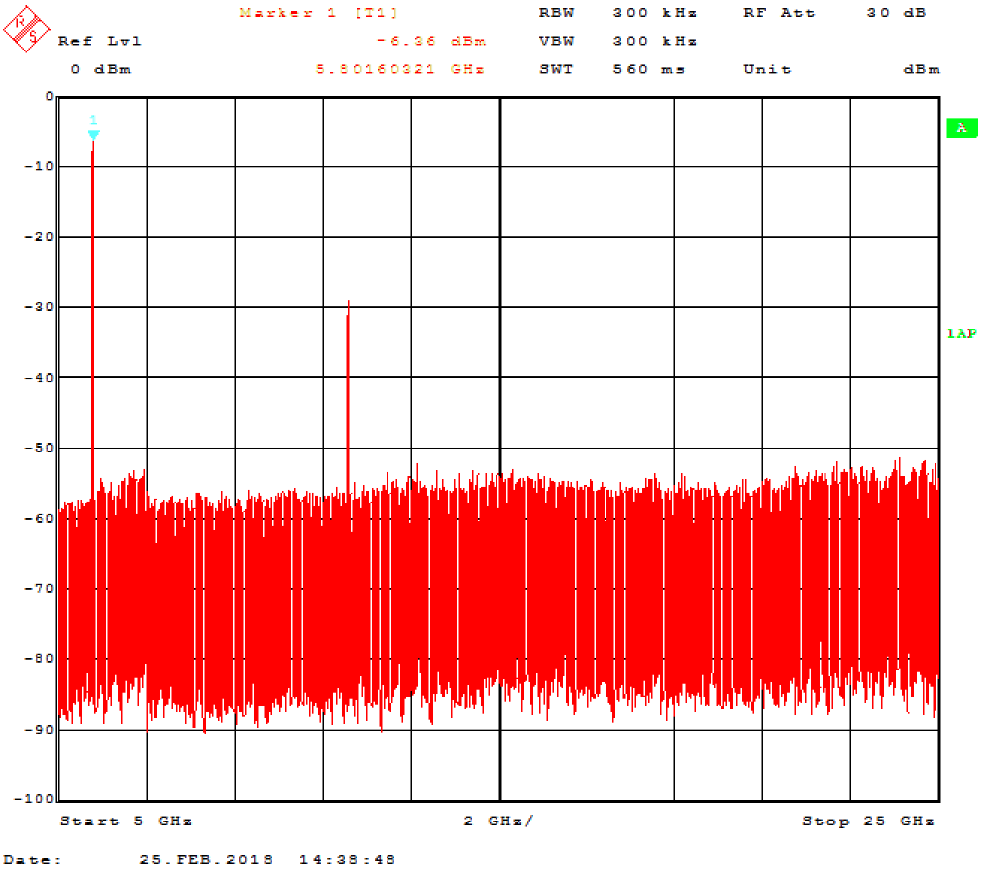

Marker 1 [T1 TRK]
RBW 500 Hz
RF Att 40 dB
Ref Lvl
1.60 dBm
VBW 500 Hz
10 dBm
2.99998166 GHz
SWT 2 s
Unit dBm
1AP
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
Center 2.999981663 GHz
10 kHz/
Span 100 kHz
Date: 25.FEB.2018 23:15:39

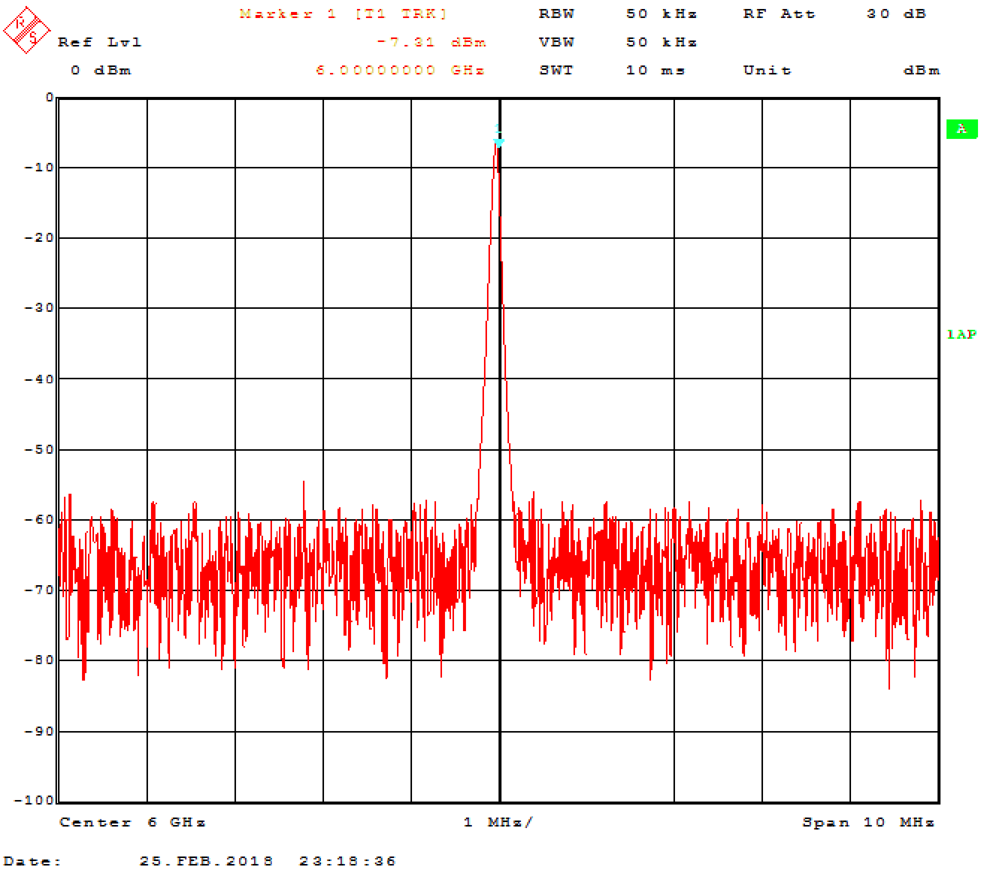


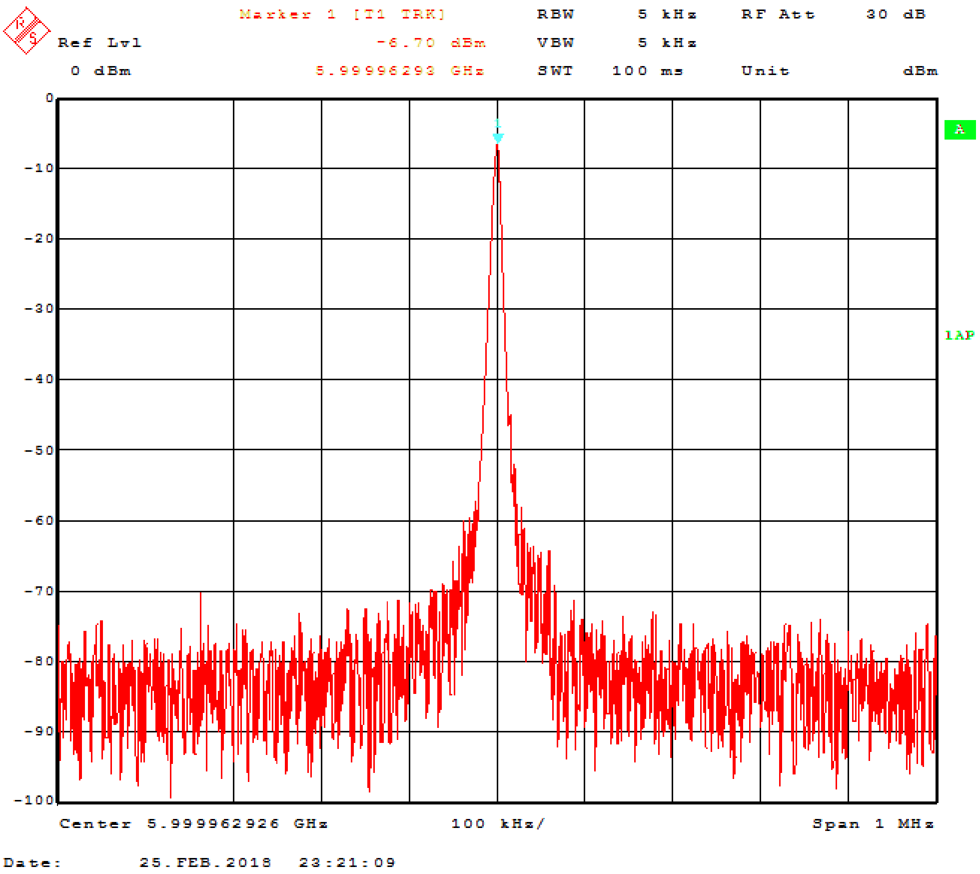


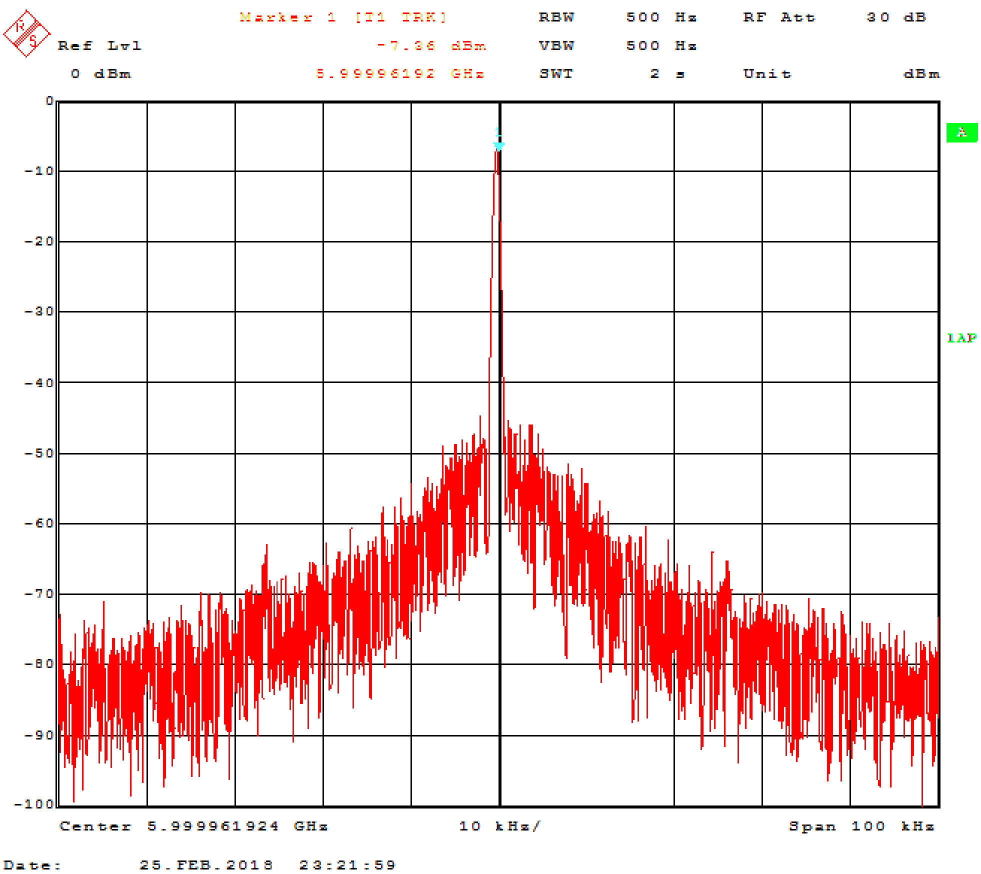
The reference line in the last plot s the phase noise of a R&S SME03 signal generator operating at its maximum frequency of 3 GHz. Below 60 kHz offset the SME03 is significantly better.

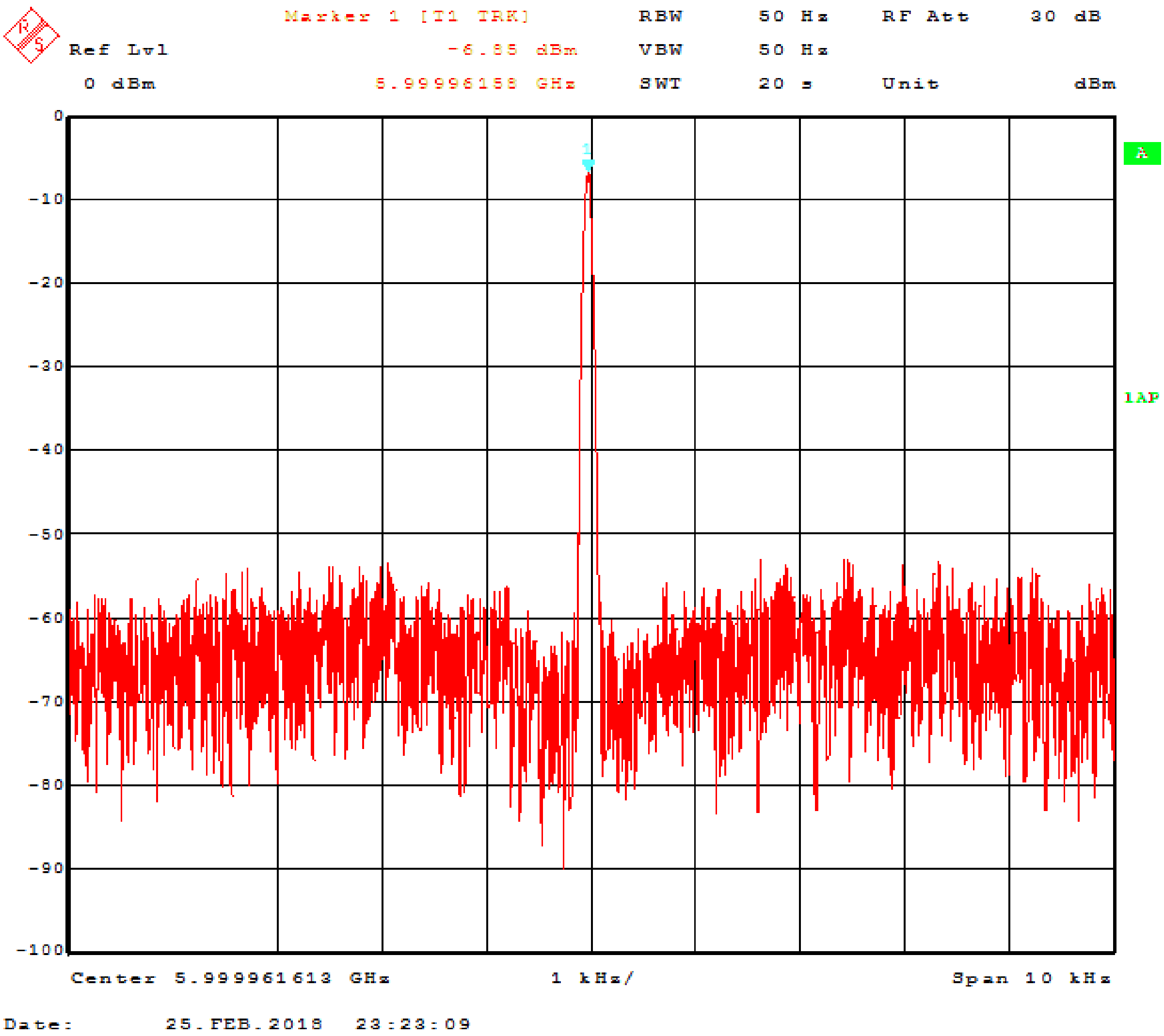
b) 6 GHz measurements:

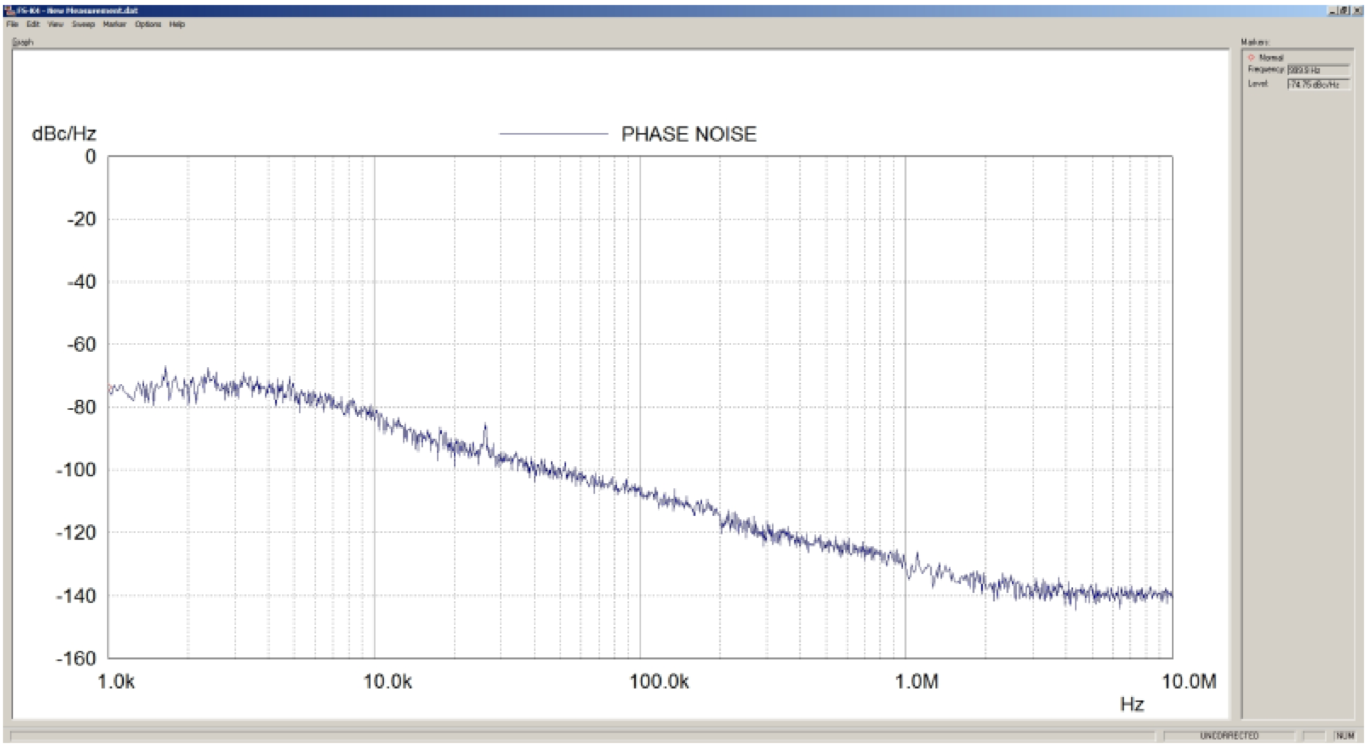




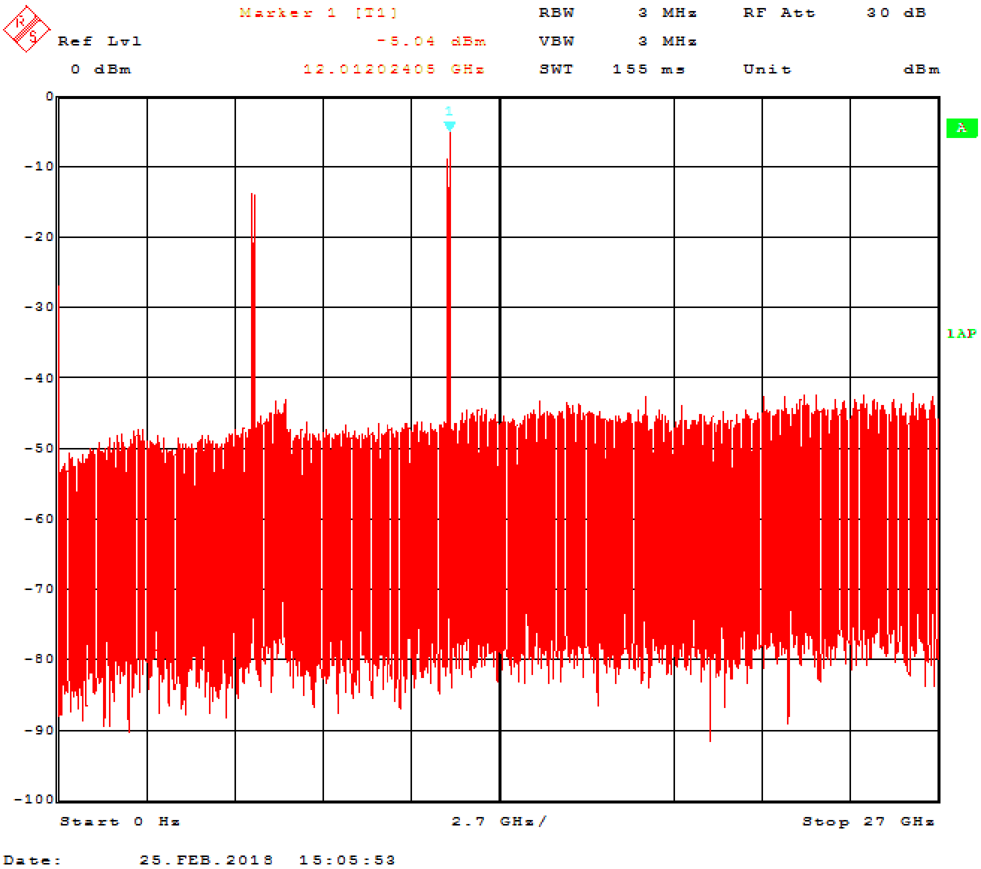

Marker 1 [T1 TRK]
RBW 5 kHz
RF Att 30 dB
Ref Lvl
-6.70 dBm
VBW 5 kHz
0 dBm
5.99996293 GHz
SWT 100 ms
Unit dBm
A
1AP
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
Center 5.999962926 GHz
100 kHz/
Span 1 MHz
Date: 25.FEB.2018 23:21:09

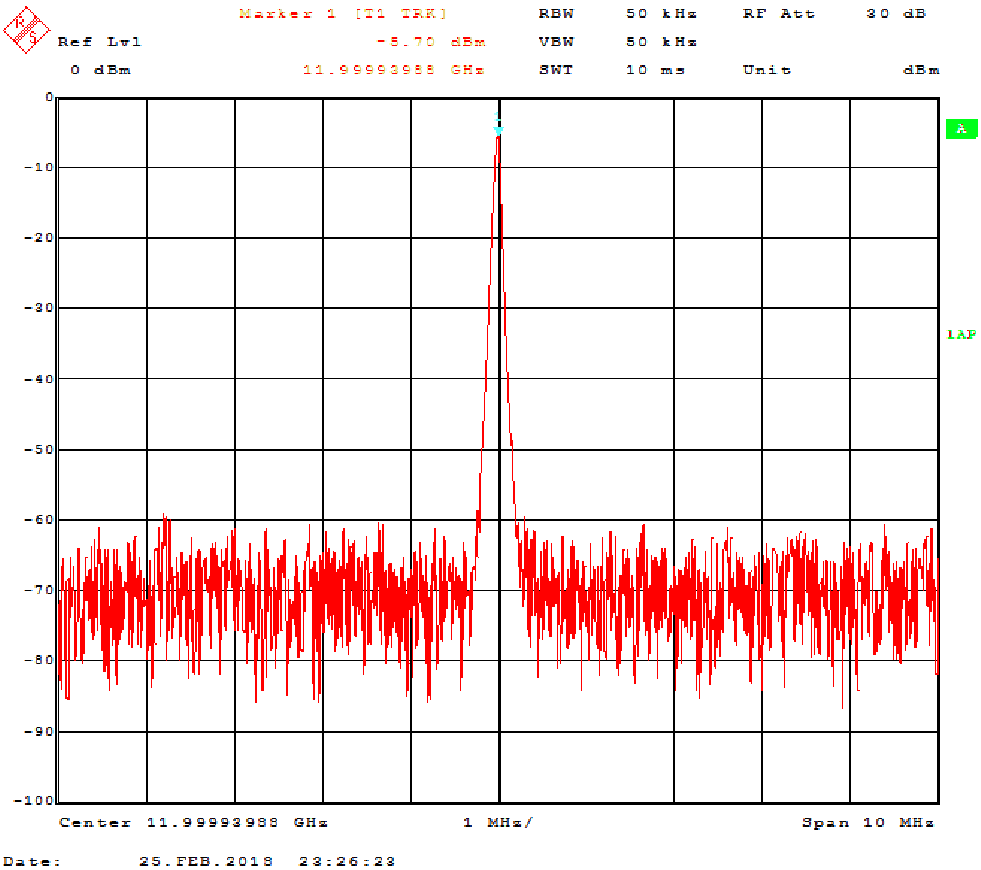

Marker 1 [T1 TRK]
RBW 500 Hz
RF Att 30 dB
Ref Lvl
-7.36 dBm
VBW 500 Hz
0 dBm
5.99996192 GHz
SWT 2 s
Unit dBm
A
1AP
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
Center 5.999961924 GHz
10 kHz/
Span 100 kHz
Date: 25.FEB.2018 23:21:59

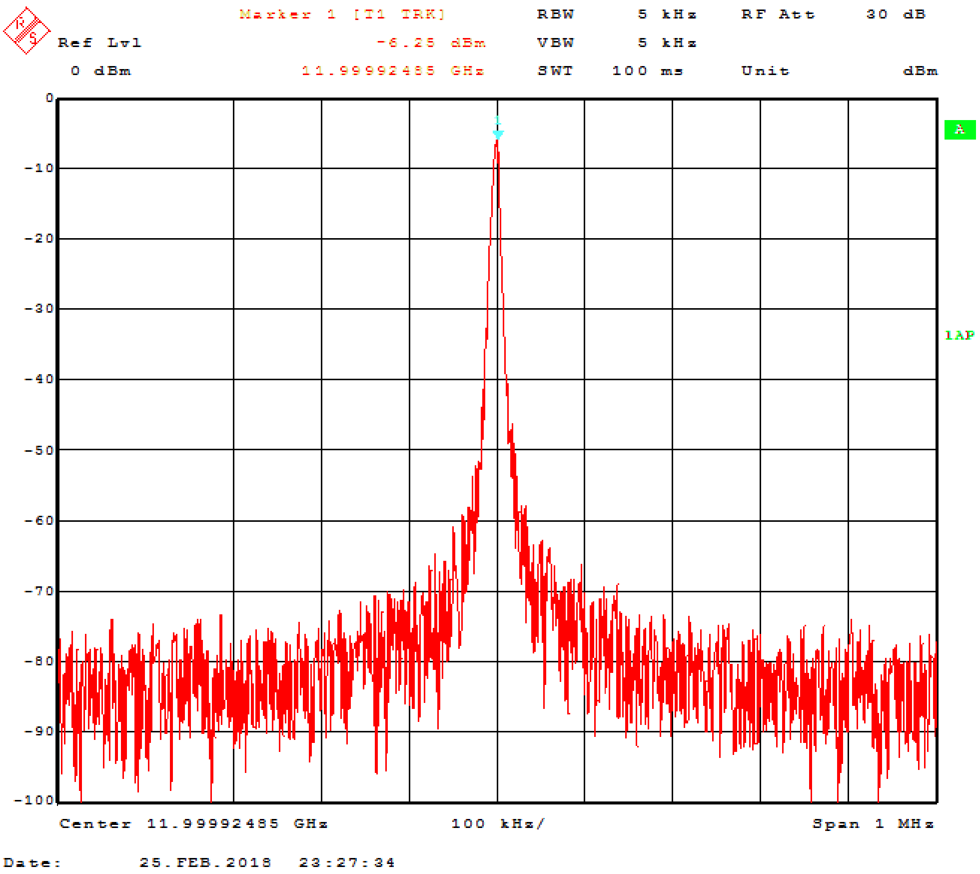

Marker 1 [T1 TRK]
Ref Lvl
0 dBm
-6.85 dBm
5.99996158 GHz
RBW 50 Hz
VBW 50 Hz
SWT 20 s
RF Att 30 dB
Unit dBm
A
1AP
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
Center 5.999961613 GHz
1 kHz/
Span 10 kHz
Date: 25.FEB.2018 23:23:09

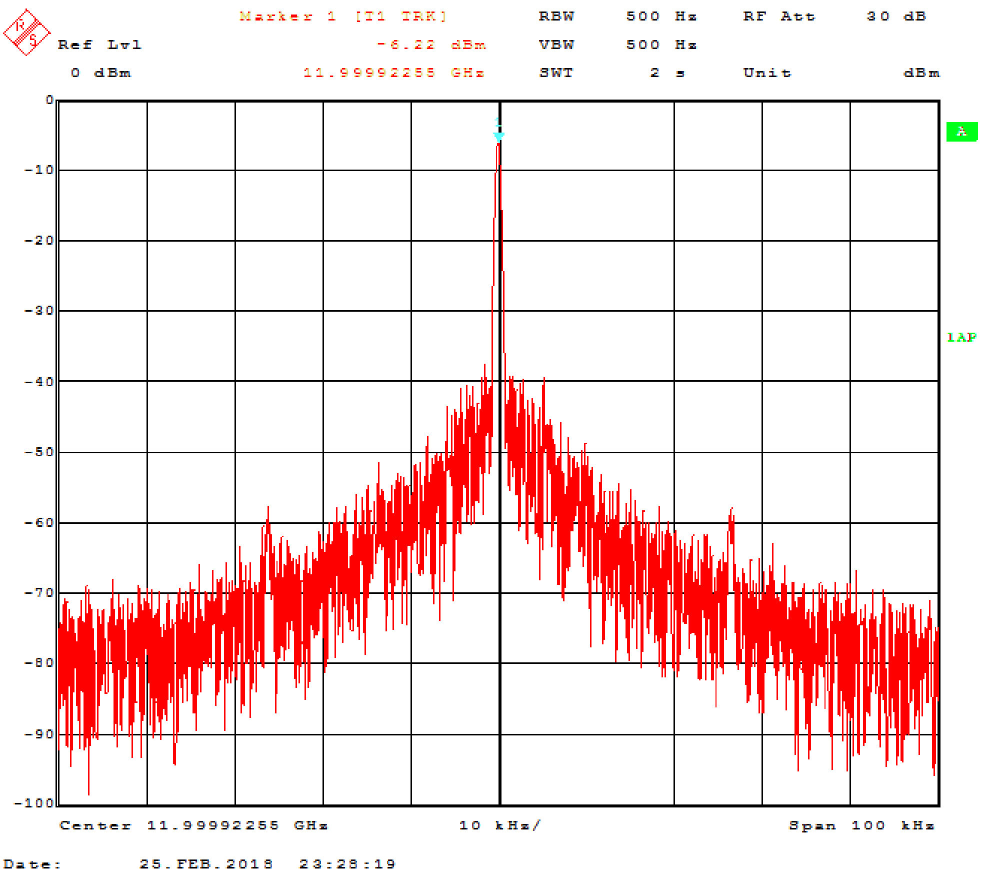

PHASE NOISE
dBc/Hz
0
-20
-40
-60
-80
-100
-120
-140
-160
1.0k
10.0k
100.0k
1.0M
10.0M
Hz

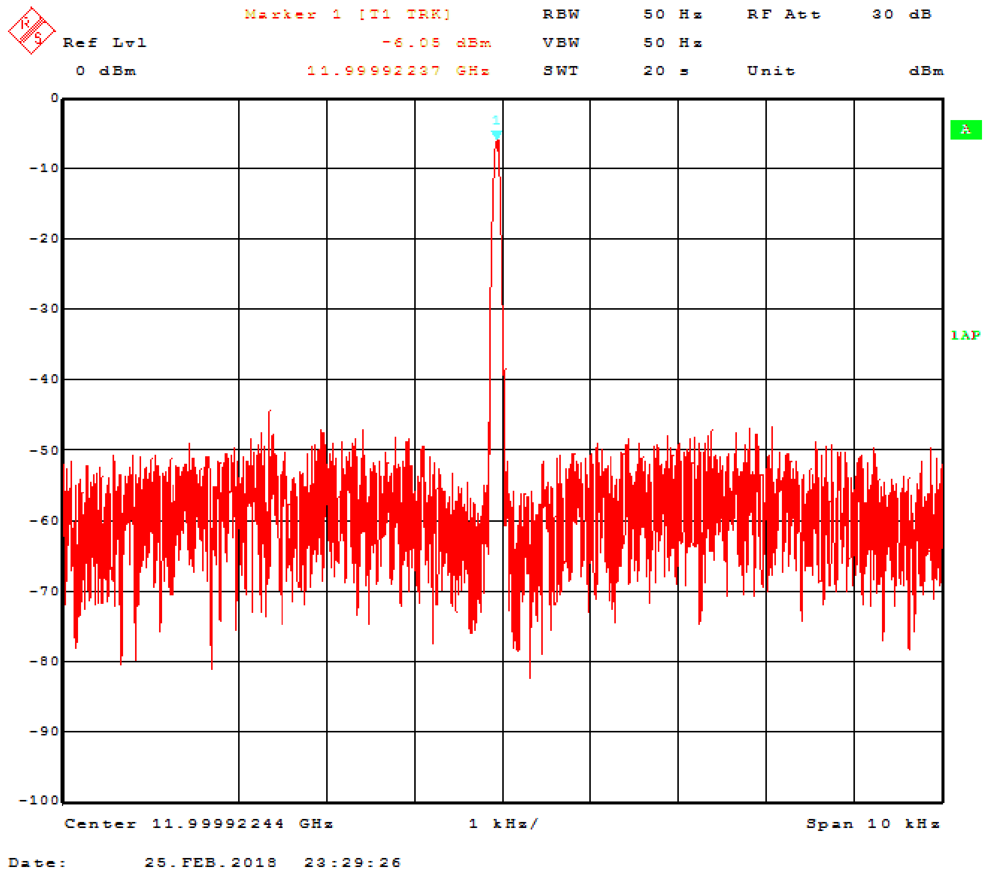
c) 12 GHz measurements:

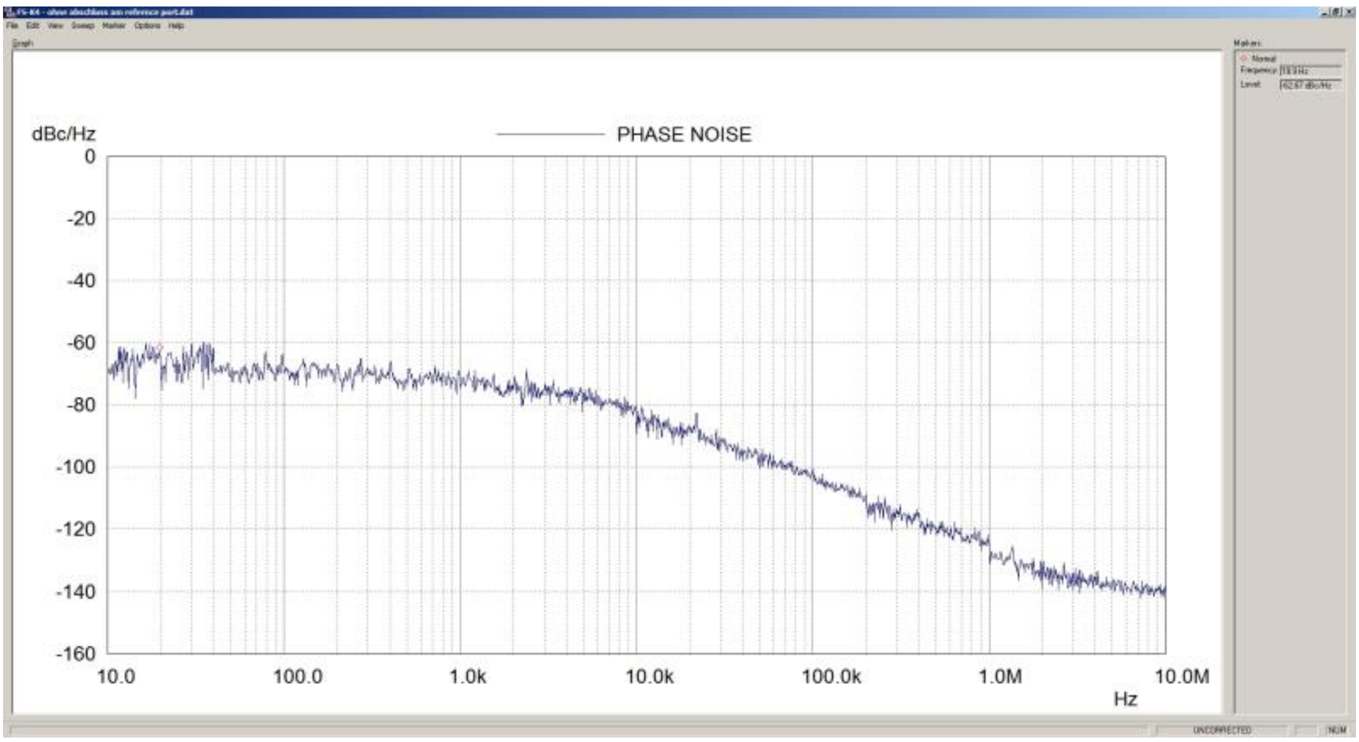





Marker 1 [T1 TRK]
RBW 5 kHz
RF Att 30 dB
Ref Lvl
-6.25 dBm
VBW 5 kHz
0 dBm
11.99992485 GHz
SWT 100 ms
Unit dBm
A
1AP
Center 11.99992485 GHz
100 kHz/
Span 1 MHz
Date: 25.FEB.2018 23:27:34


Marker 1 [T1 TRK]
RBW 500 Hz
RF Att 30 dB
Ref Lvl
-6.22 dBm
VBW 500 Hz
0 dBm
11.99992255 GHz
SWT 2 s
Unit dBm
A
1AP
Center 11.99992255 GHz
10 kHz/
Span 100 kHz
Date: 25.FEB.2018 23:28:19


Marker 1 [T1 TRK]
RBW 50 Hz
RF Att 30 dB
Ref Lvl
-6.05 dBm
VBW 50 Hz
0 dBm
11.99992237 GHz
SWT 20 s
Unit dBm
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
A
1AP
Center 11.99992244 GHz
1 kHz/
Span 10 kHz
Date: 25.FEB.2018 23:29:26


dBc/Hz
PHASE NOISE
0
-20
-40
-60
-80
-100
-120
-140
-160
10.0
100.0
1.0k
10.0k
100.0k
1.0M
10.0M
Hz

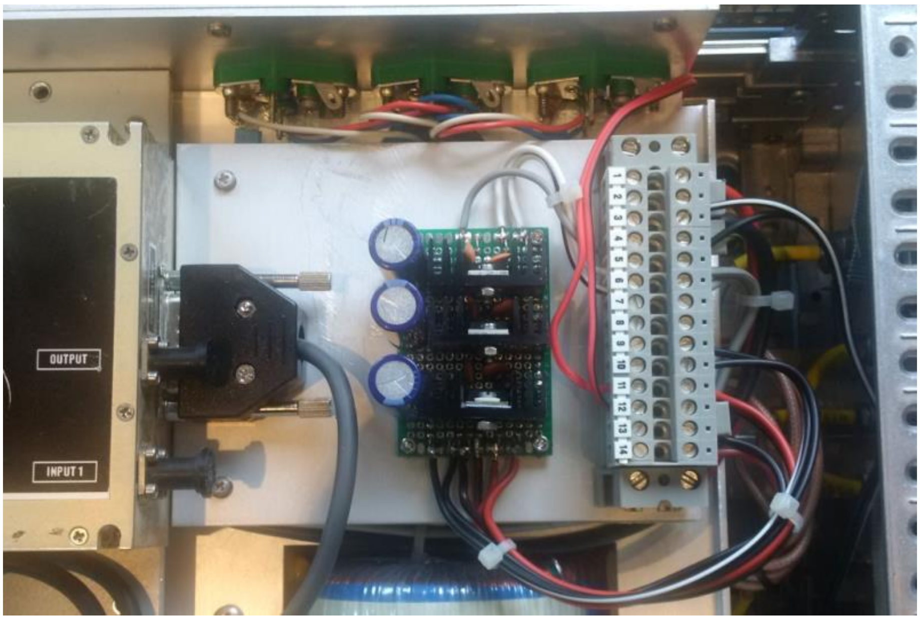
Additional notes on other components used on the PCB:

The crystal oscillator is a VCC1-B3B-125M00 from Vectron. It provides a single ended 125 MHz output signal. The oscillator operates from a 3.3V supply voltage with a current consumption of max. 50mA. The oscillator can drive loads up to 15 pF. The enable/disable pin is left open and due to the internal pull-up resistor, the oscillator is therefore always running when the supply voltage is applied to the board. It could be disabled if the Enable/Disable pin is connected to ground. The temperature stability of the device is specified with ± 50 ppm in the temperature range from -40 to +70 degree C.

The microcontroller STM32F103 RCT6 is based on an 32bit ARM-cortex-M3 core and features 256 kByte embedded flash and 48 kByte SRAM memory. It uses a 64 pin LQFP package. Thanks to the flash the code and latest settings can be restored. Thus, the board always starts with the settings like frequency such as it had been used before powering it down. The supply voltage range in this application is 3.3V. The specified temperature range of the microcontroller is -40 to +85 degree C.

Adding a nice encasing, mains supply and filter:

After optimizing the synthesizer module I decided to integrate it in an old encasing from R&S, which I had bought some years ago. I could reuse the mains power supply in that encasing which delivers +5V, +15V and -15V. I added a switched filter module FB120-MPS which removes the harmonics when using the outputs A+ and A- respectively the subharmonics when using the output B. As the synthesizer module needs +12V and the filter module needs +12V, -12V and +5V added another voltage regulator board. The filter module is not yet activated as I need some control circuits to switch the various frequency bands.



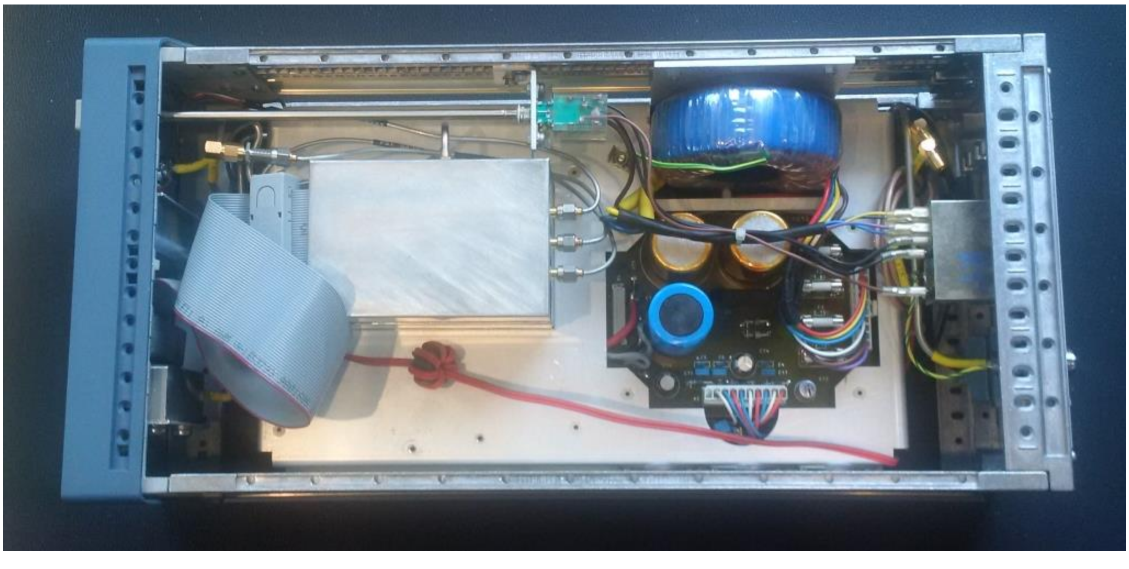
1	2	3	4	5	6	7	8	9	10	11	12	13	14
+5V	+5V	Gnd	Gnd	+15V	-15V	n.c.	n.c.	-12V	Gnd	+12V	Gnd	Gnd	+12V

Switched Filter Bank FB-120-MPS						
No.	Frequenzbereich	Input	D	C	B	A
0	0.01-1.00 GHz	1	L	L	L	L
1	1.00-1.60 GHz	2	L	L	L	H
2	1.60-2.35 GHz	2	L	L	H	L
3	2.35-3.40 GHz	2	L	L	H	H
4	3.40-4.85 GHz	2	L	H	L	L
5	4.85-7.00 GHz	2	L	H	L	H
6	7.00-10.0 GHz	2	L	H	H	L
7	10.0-12.6 GHz	2	L	H	H	H
8	12.6-15.9 GHz	2	H	L	L	L
9	15.9-20 GHz	2	H	L	L	H

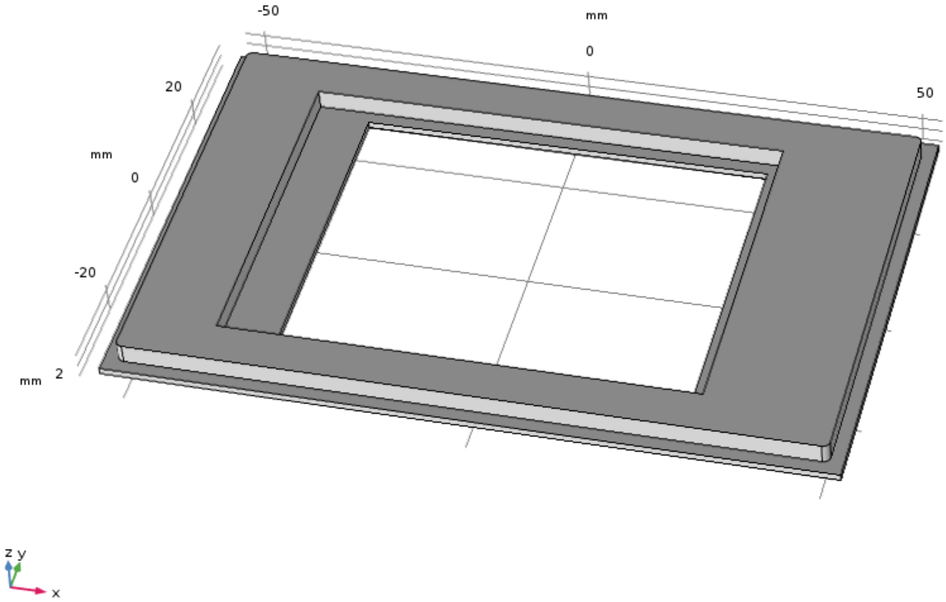
1	2	3	4	5	6	7	8	9	10	11	12
	-12V		Gnd	Gnd	Gnd	Gnd		+12V		+12V	
Ausgänge											
Spannungsreglerplatine							7912		-12V out		
							7812		+12V out		
							7812		+12V out		
Eingänge											
1	2	3	4	5	6	7	8	9	10	11	12
-15V		+15V			Gnd		Gnd				


SWITCHED FILTER BANK
FREQ: 10 MHz - 20 GHz
MODEL: FB-120-MPS
FSCM: 00H86
OUTPUT
INPUT 2
INPUT 1

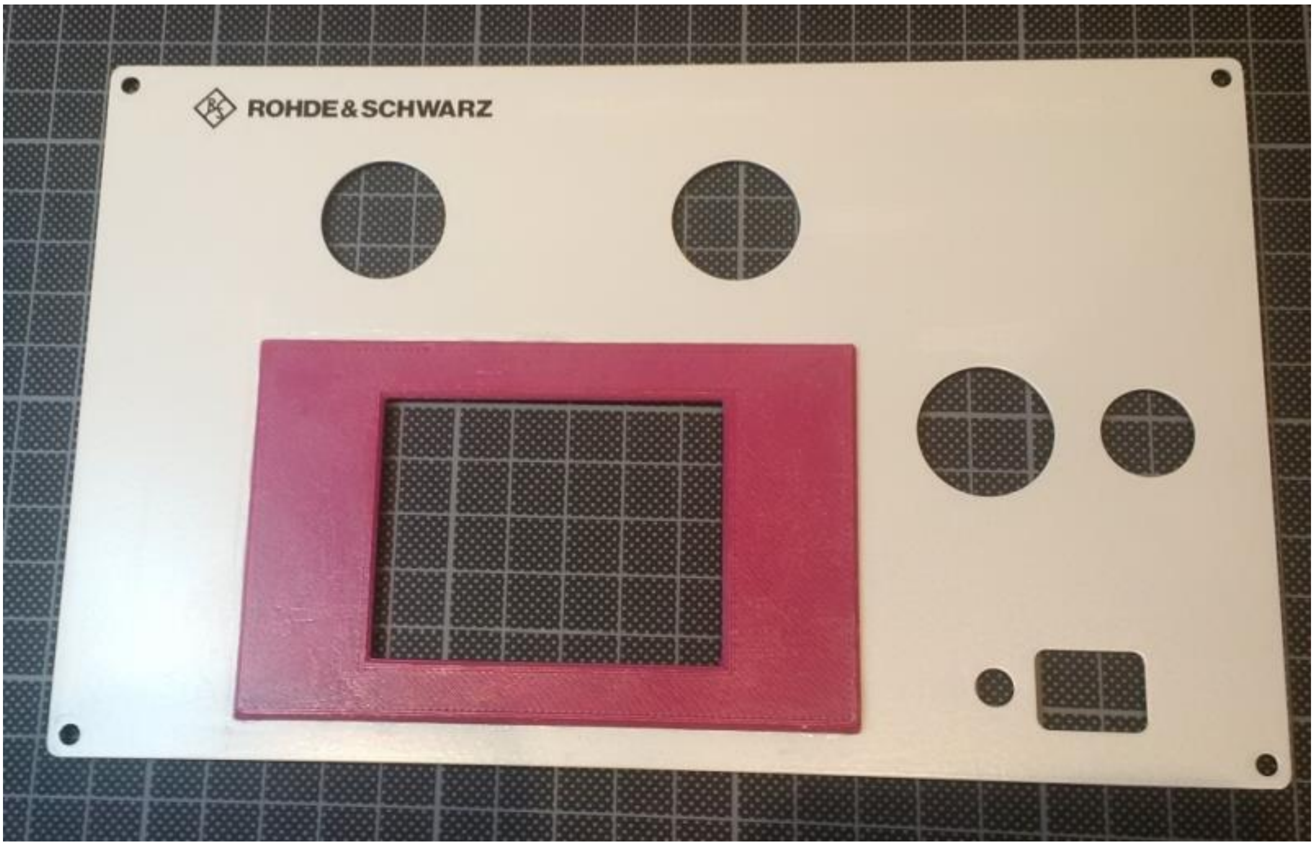

SWITCHED FILTER BANK
FREQ: 10 MHz - 20 GHz
MODEL: FB-120-MPS
FSCM: 00H86



In order to mount the touch display in the front cover of the encasing a friend designed a 3D printable frame. Many thanks to Edgar, DF2MZ for the kind help. I got the frame printed by www.3damberger.de. They are very nice people and delivered very quickly for a very reasonale price. BTW the color was chosen so it matched the frames of other R&S test equipment I have in the same test equipment rack.Here is a sketch and pictures of the frame:



In the next picture you can see the3D printed frame glued into the front-plate.



Finally, here are some pictures of the complete unit after integrating the touch-display.

Summary:

I now have a very nice synthesizer which I can use to generate signals up to 13 GHz which extends my measurement capabilities. The synthesizer can be used as a fixed frequency source and also for sweeping to measure for instance the frequency response of amplifiers and filters.

The phase noise results in the frequency offset range below 10 kHz are not on par with the results Brian Flynn had achieved and measured. He reported that optimizing the charge pump output current allowed him to reduce the phase noise in the loop bandwidth. As I do not have access to the source code of the controller board I am not able to perform such optimizations. In the future I hope to get access to a UART-Interface board will try to control the synthesizer by a PC. I will then see, whether I can improve the performance by tweaking internal control registers of the synthesizer.

Also, the switched filter module needs to be controlled, preferably also by the UART-Interface.

I would like to thank Brian Flynn GM8BJF for his excellent articles, his advice and the PCB for the optimized power supply, Reinhard Beck DL3BR for the schematics of the synthesizer board and Edgar Kaiser DF2MZ for designing the 3D printable frame for the touch-display.

I always appreciate feedback. Please send it to the Email address given below.

Many thanks in advance.

Best regards

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