# A low cost signal generator for 54 MHz to 13.4 GHz



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Microwave & EME Symposium in Gajow / Poland,
June 9th 2018

# Agenda

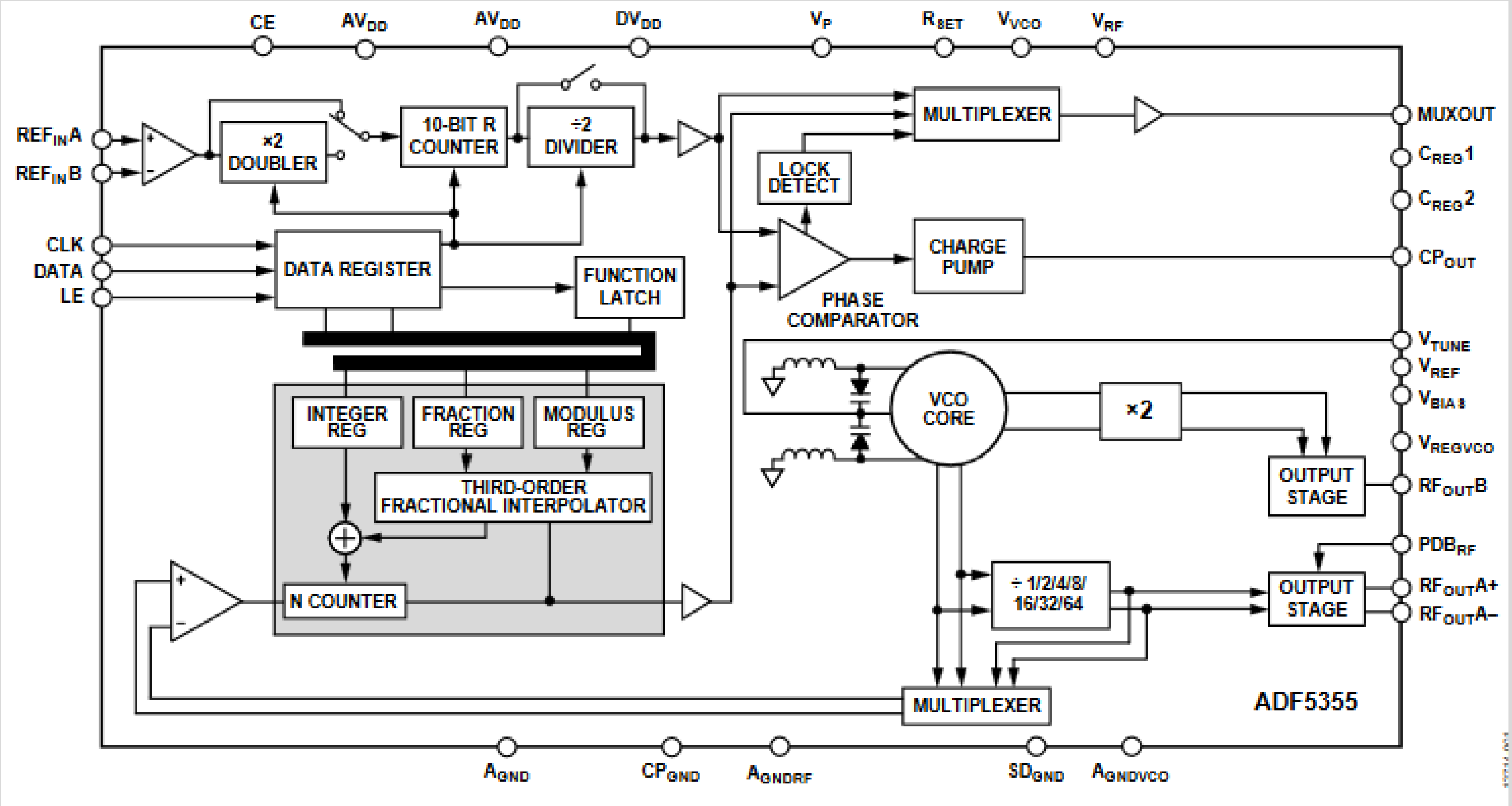
- Motivation
- ADF5355 IC
- Chinese low cost modules
- Module including touch display
- Analysis of the board
- Improvements
- Integration
- What‘s next ?
- Acknowledgement

# Motivation

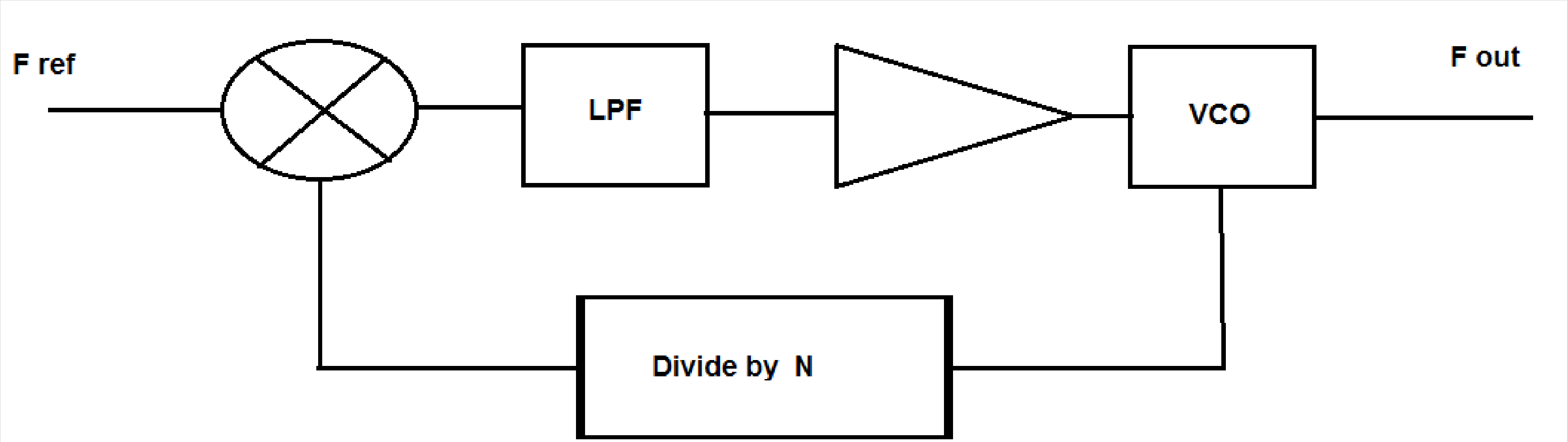
- My signal generator frequency range was limited up to 3 GHz
- As I intended to expand my activities also to the higher Microwave bands I need a source up to at least 11 GHz
- Commercial signal generators, even second hand, are quite expensive and the very old ones quite bulky
- I wanted to have a source which can be controlled with a simple user interface (without the need of a PC)

# ADF5355 Synthesizer IC

- Fractional-N synthesizer IC with integrated VCOs



# Frac-N PLL




$$Fout = \mathrm{N}\,.\,Fref$$

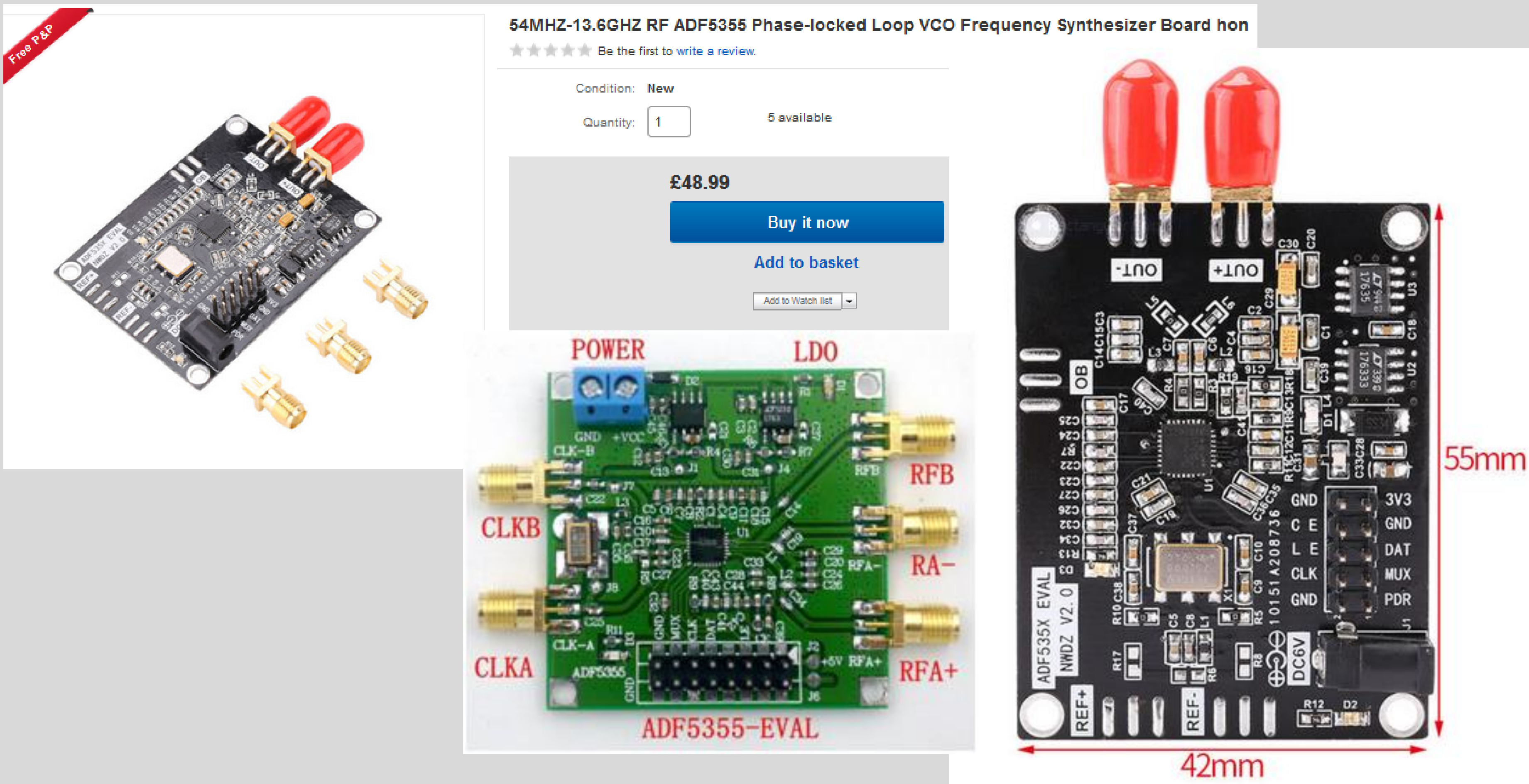
N need not be an integer and can be a fractional number. This opens up useful possibilities for the design of the PLL.

# Fractional-N possibilities

- Can use a higher PFD frequency.
- N = INT + $FRAC/MOD$ can be made a much smaller number.
- Less multiplication of phase noise on reference frequency.
- Useful for PLLs at microwave frequencies.
- Potential for better phase noise performance.
- Allows smaller tuning steps than Integer-N.

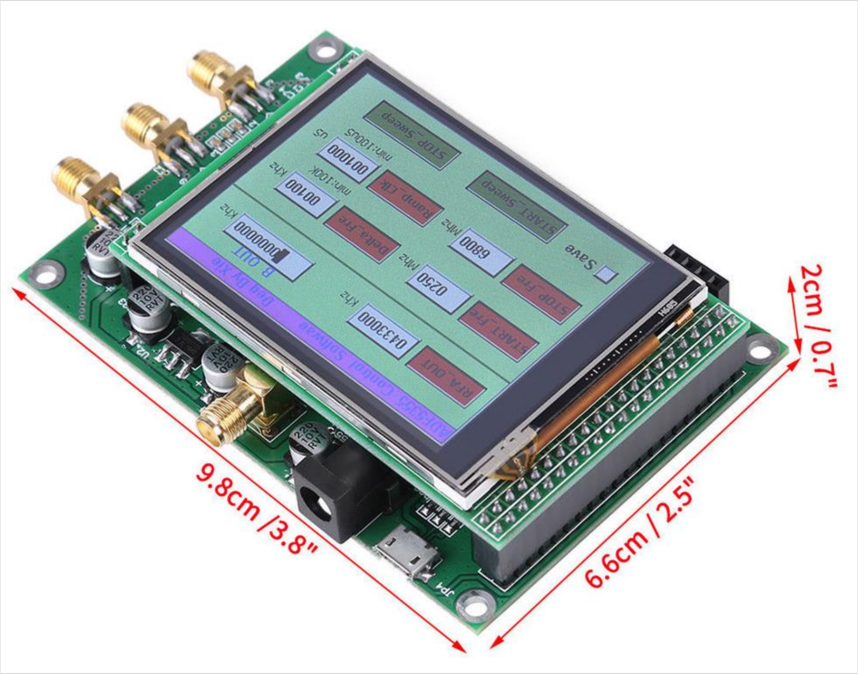
# Chinese low cost boards

- There are multiple versions of chinese low cost boards available



# Module including touch display

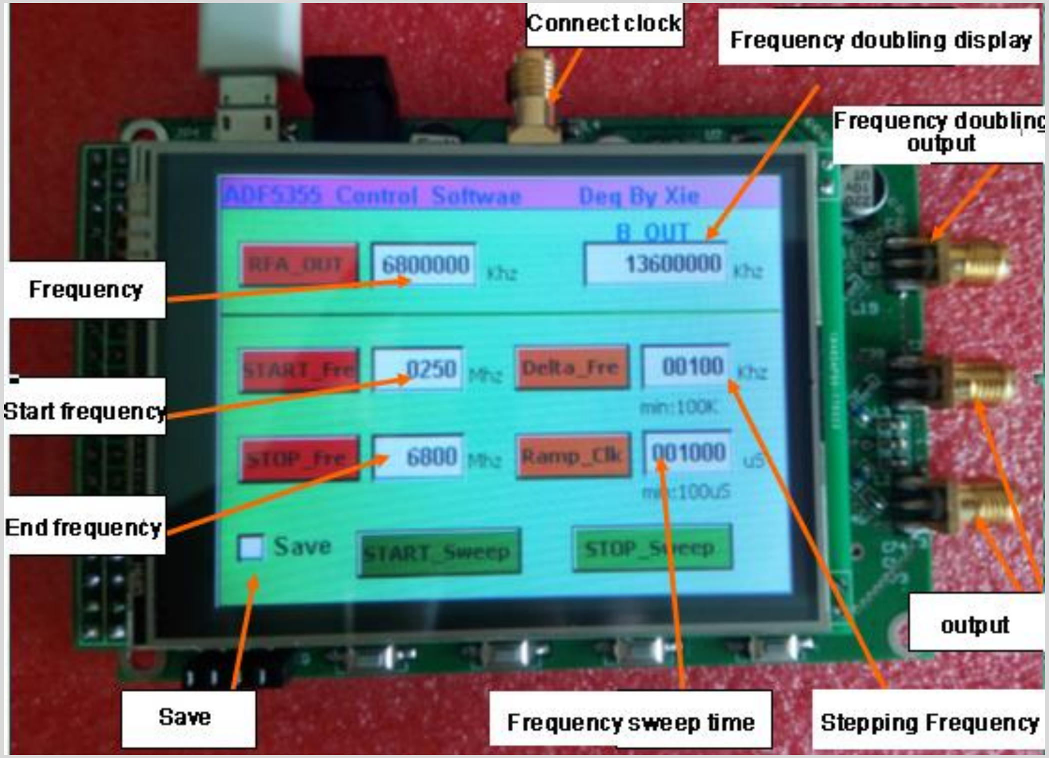
- This board is available on Ebay and Ali Express, price ~ 100 USD




- Based on 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.

# Module including touch display

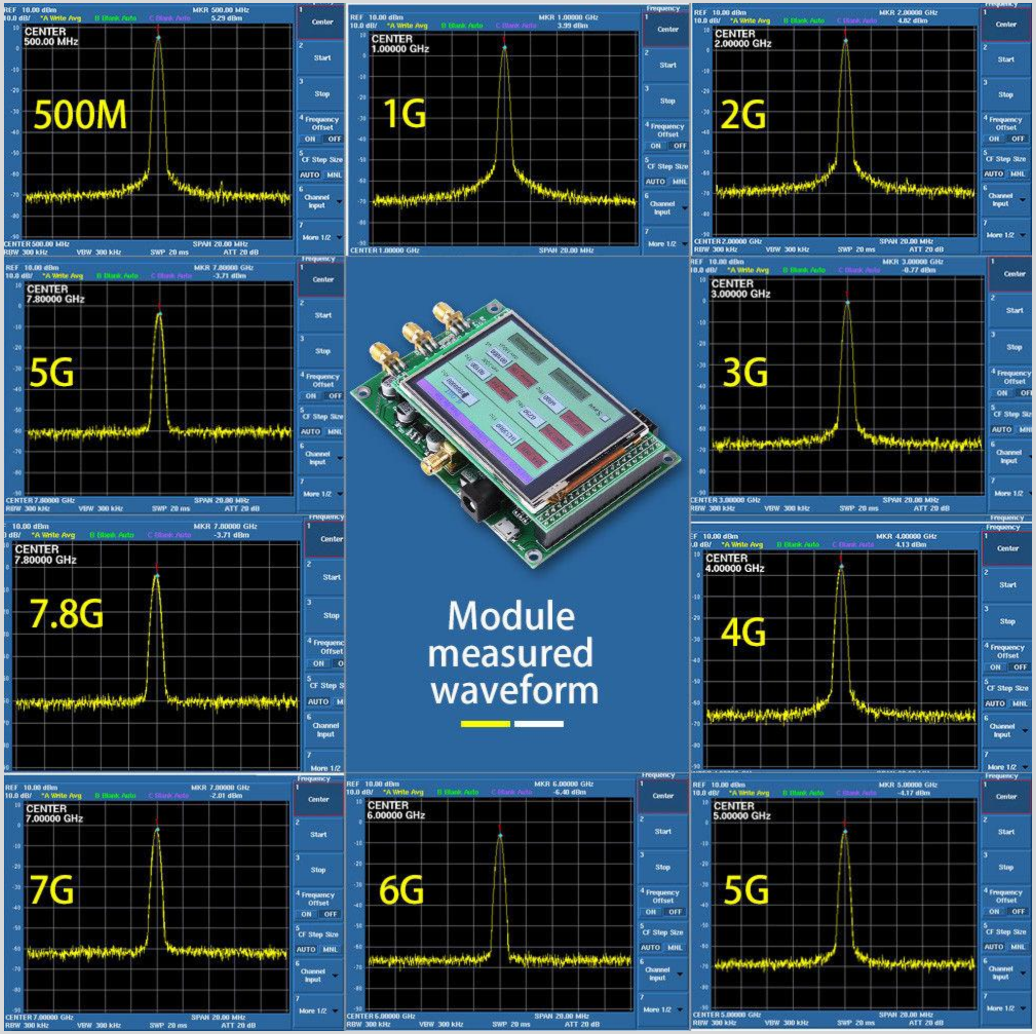
- The board is powered by the mini-USB port or via 5V which need to be supplied to a respective socket next to the mini-USB-port.



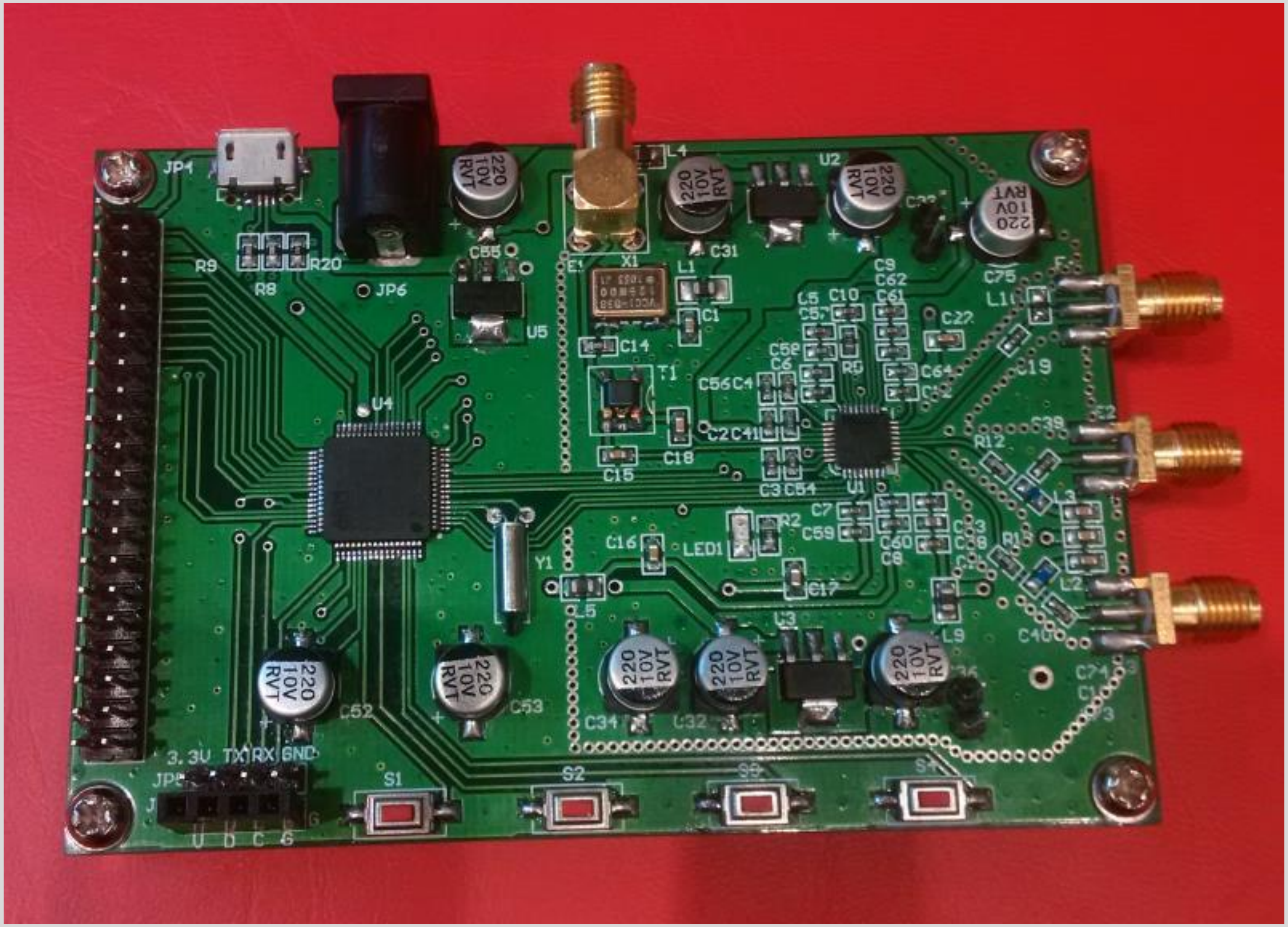

- When I got the board, it powered up properly and at a first glance provided the specified output signals in the full frequency range.

# Module including touch display

- Measurements from the seller are all with a span of 20 MHz:

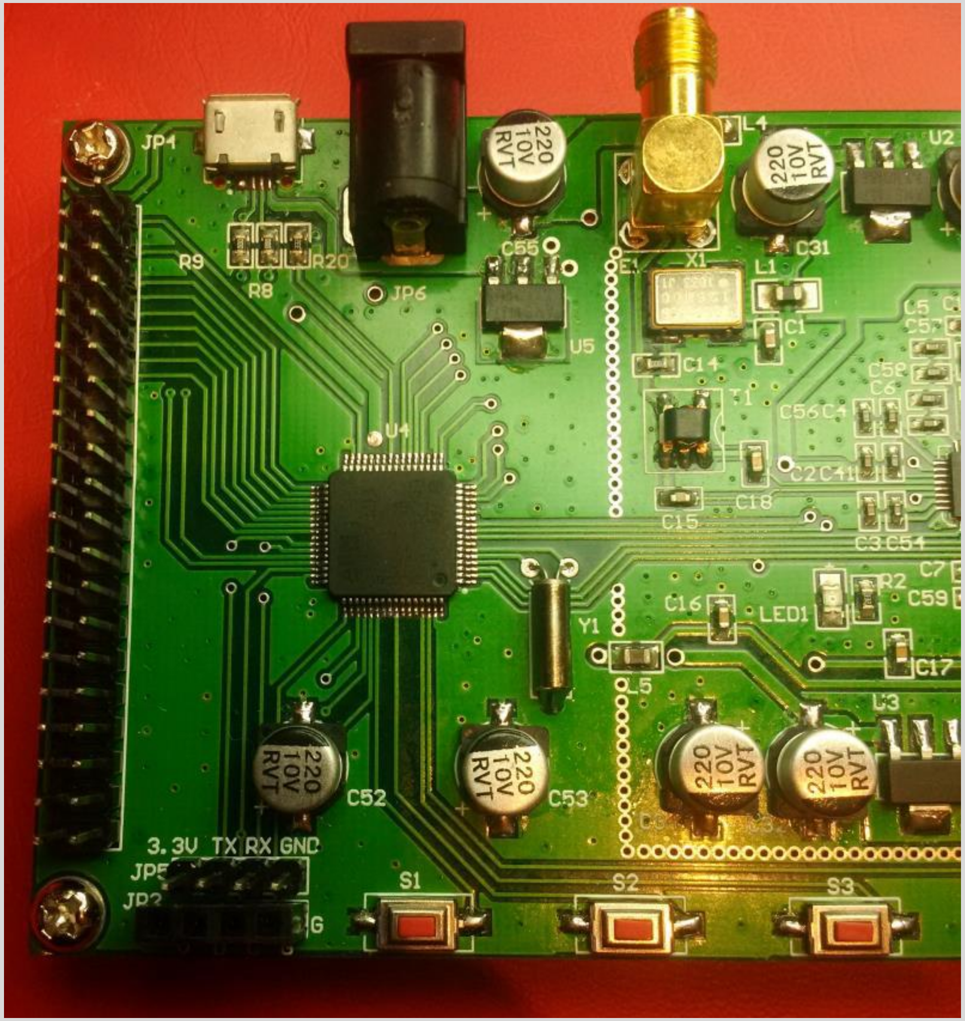


# Pictures of the PLL board



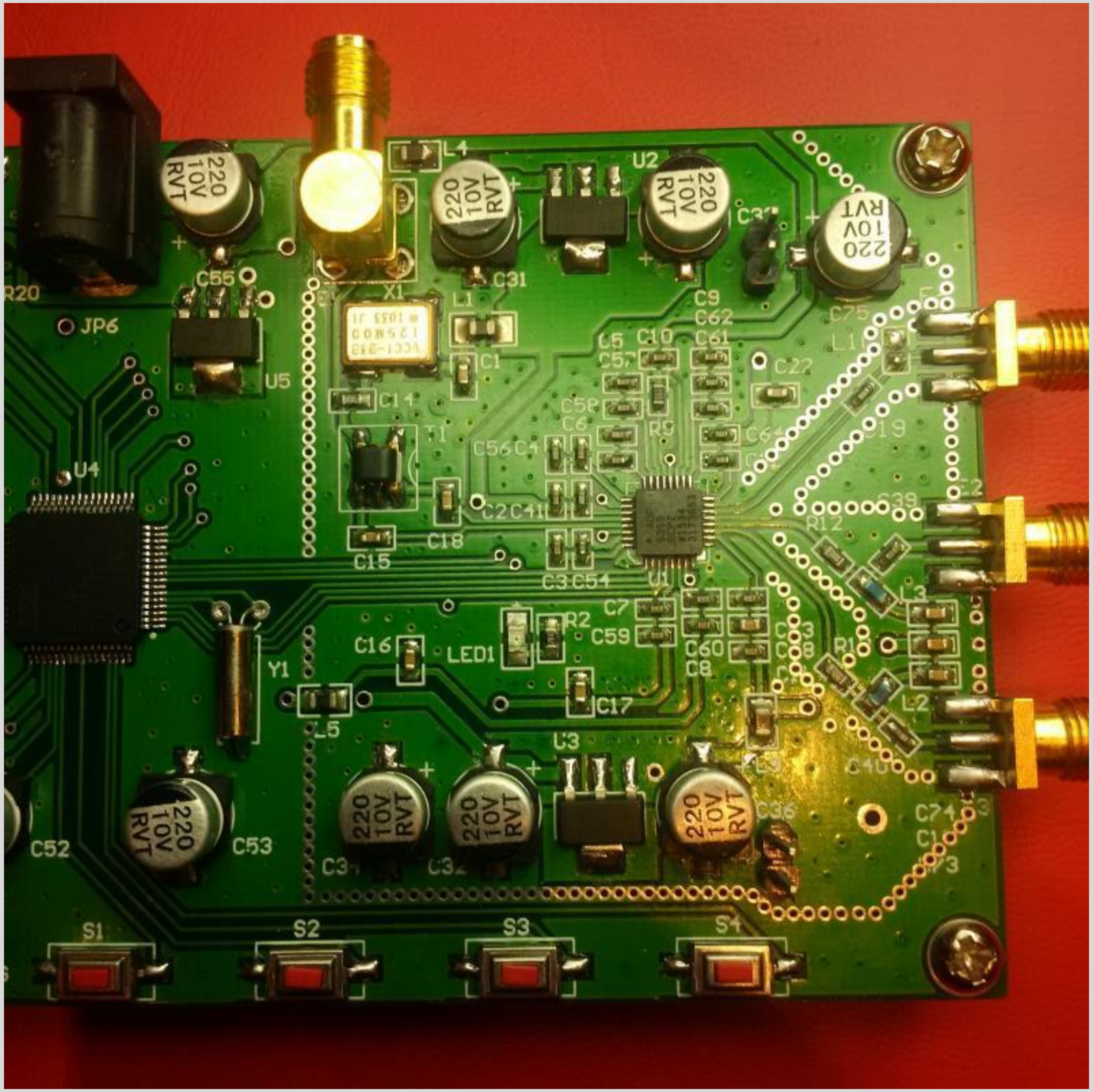
I analyzed the board and was first positively surprised
that quite some good RF practice was used in the layout.

# Pictures of the PLL board



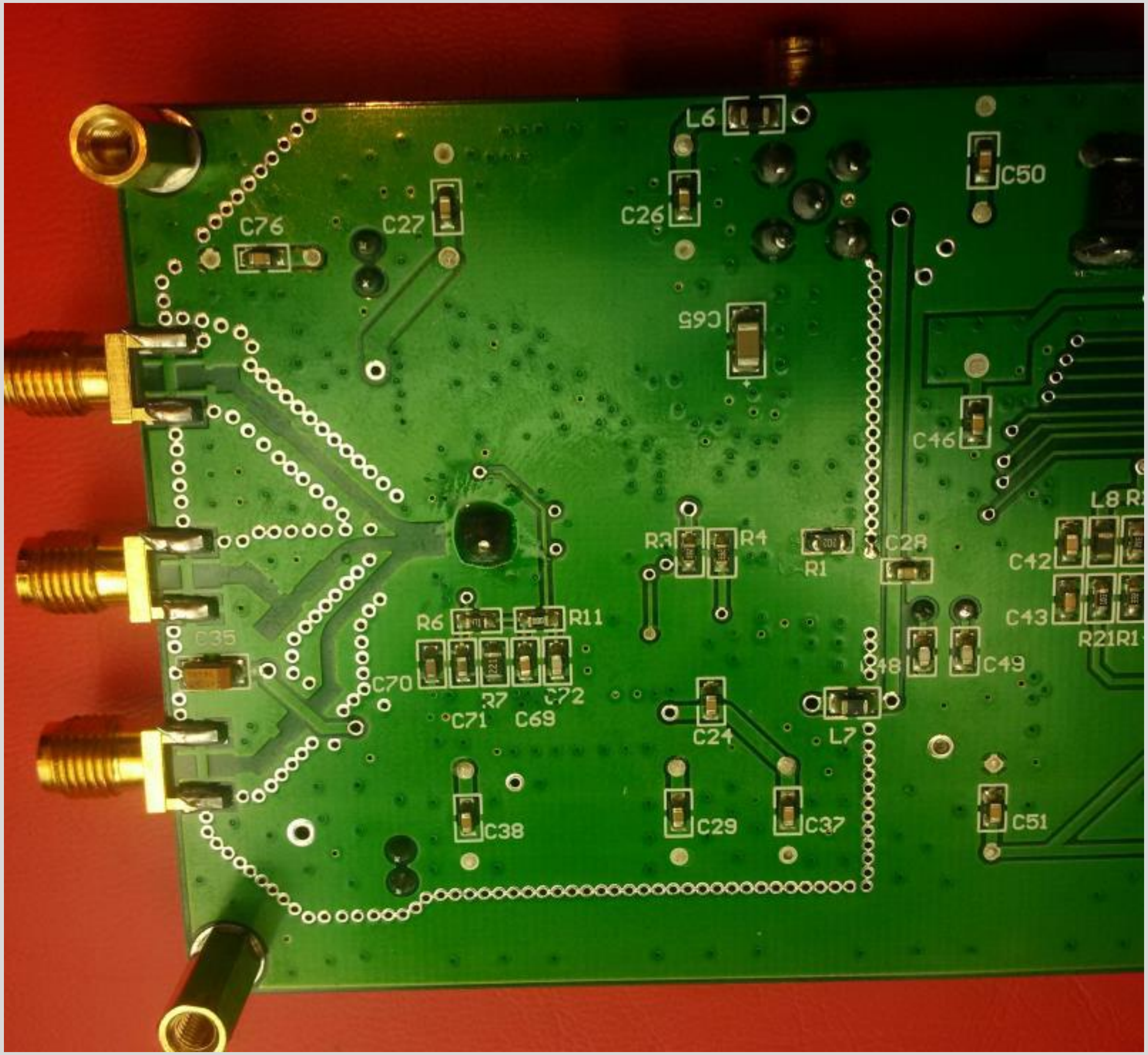

The digital part (left) with the ARM microcontroller
is isolated from the analog/RF-part (right)

# Pictures of the PLL board



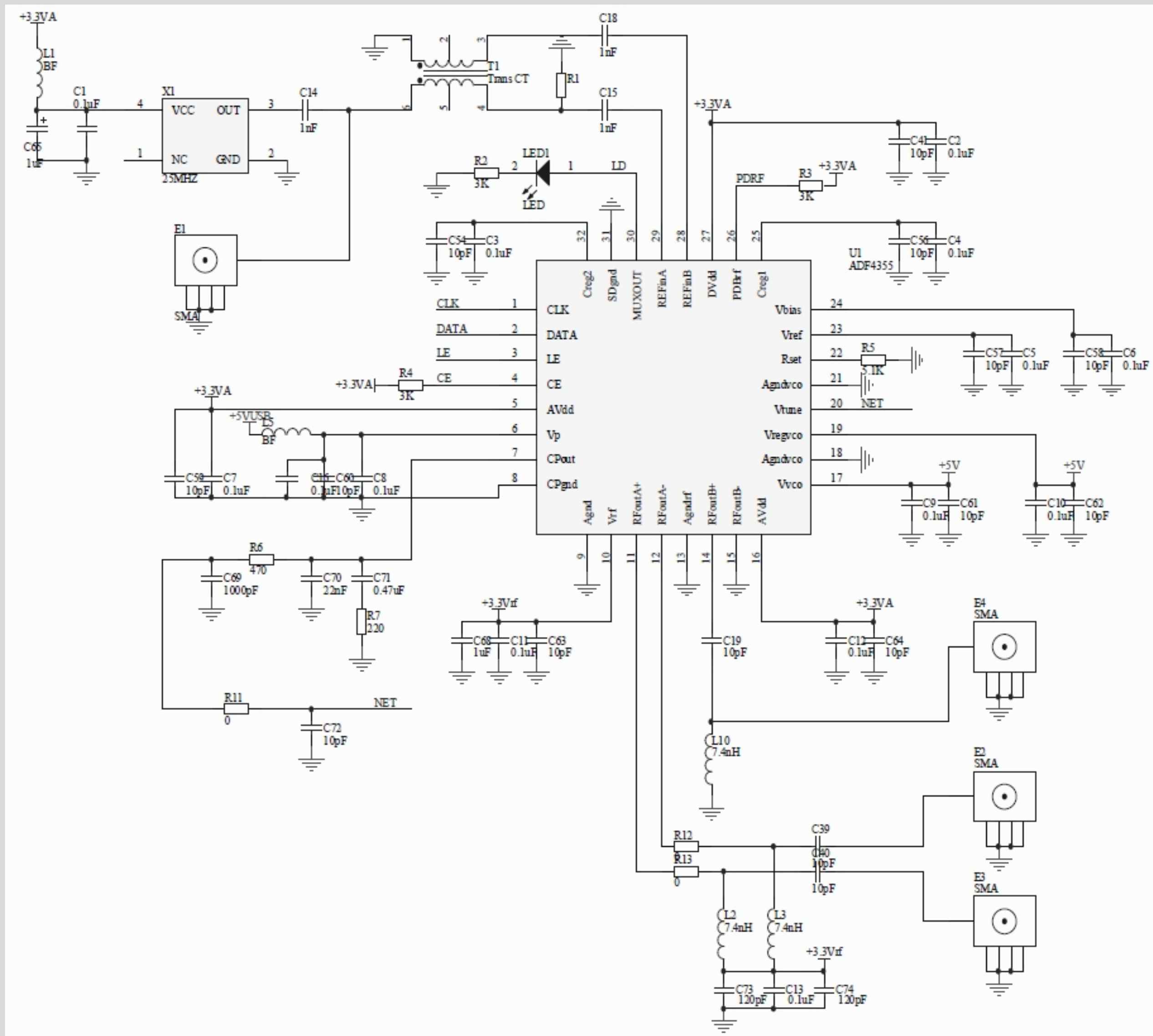

RF part with the ADF5355 synthesizer IC

# Pictures of the PLL board




The ADF5355 synthesizer IC has a ground pad on the back

# Analysis of the PLL board

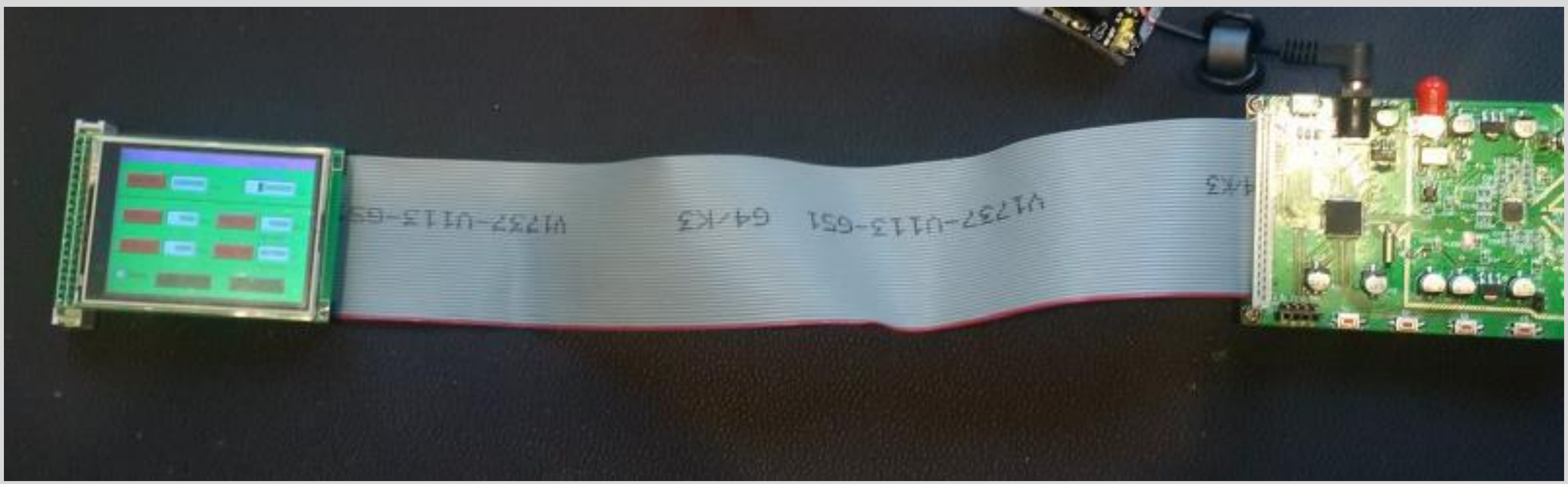


# Analysis of the PLL board

- 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.

# Analysis of the PLL board

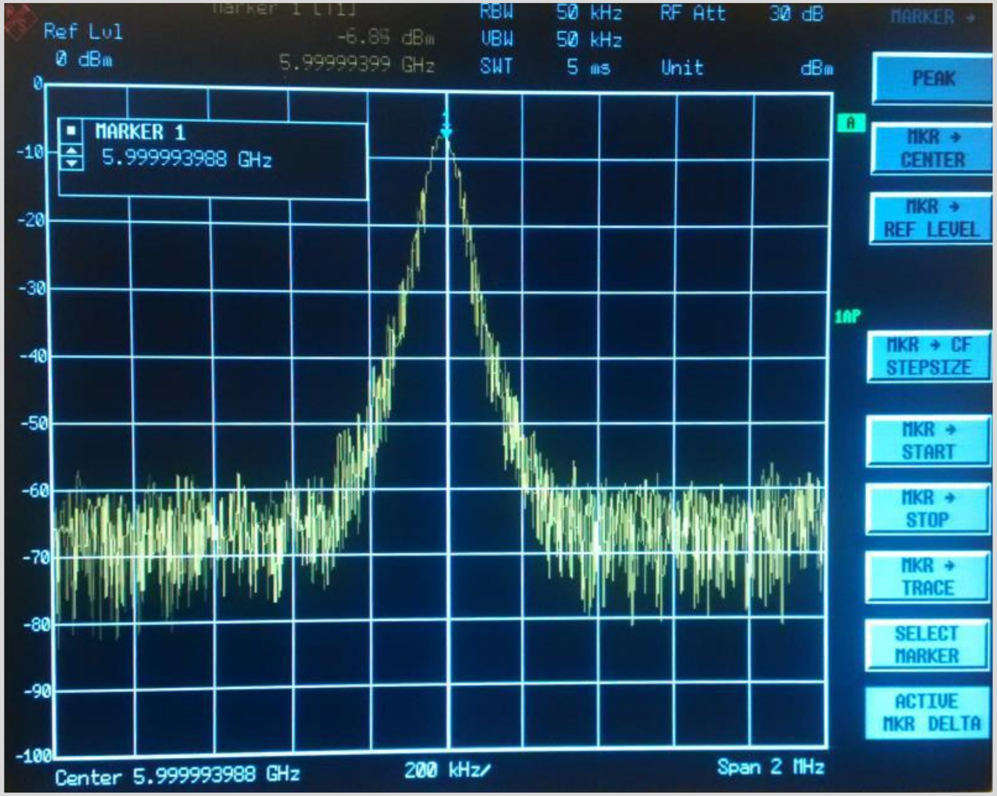
- In order to be able to operate the board and perform measurements on it I had to move the display board aside.
- I was also suspecting that some interference of the RF signal might come from intercoupling between the 2 stacked boards. Thus, I prepared a ribbon cable and separated the boards.



- It turned out, that the display board is not generating additional interference when plugged directly to the synthesizer PCB.

# Analysis of the PLL board

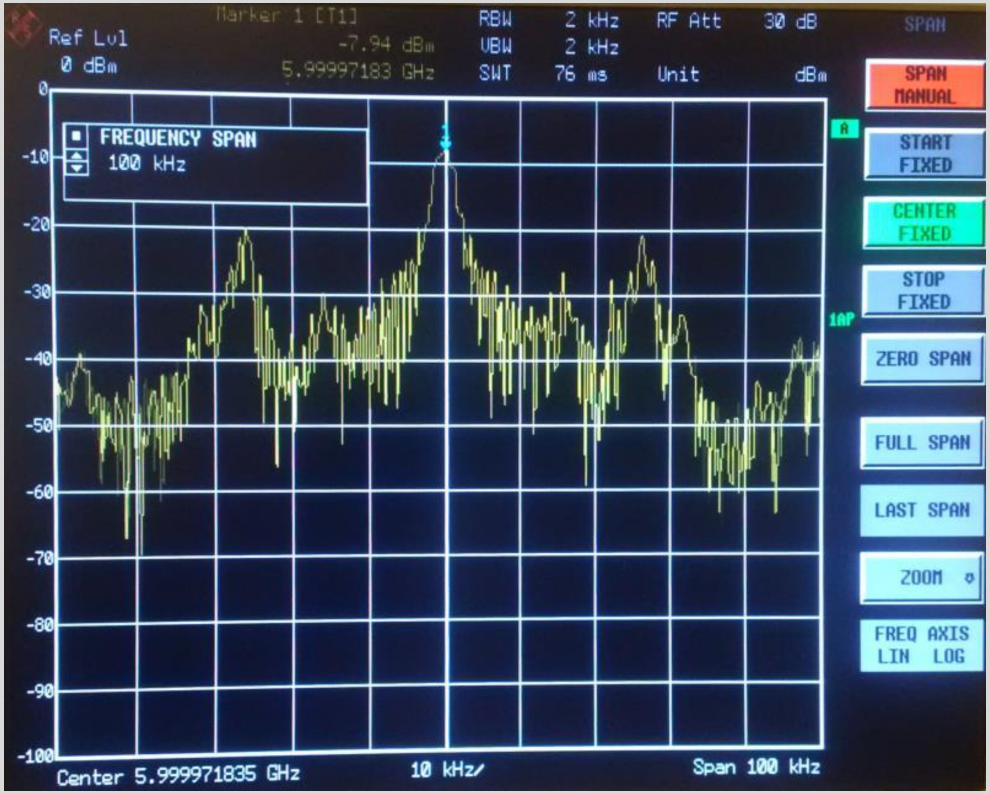
- This is my own measurement of the output signal at 6 GHz, horizontal scale is 200kHz/div, vertical scale is 10dB/div




- No, this signal is not intentionally modulated !

# Analysis of the PLL board

- This is my own measurement of the output signal at 6 GHz, horizontal scale is 10kHz/div, vertical scale is 10dB/div



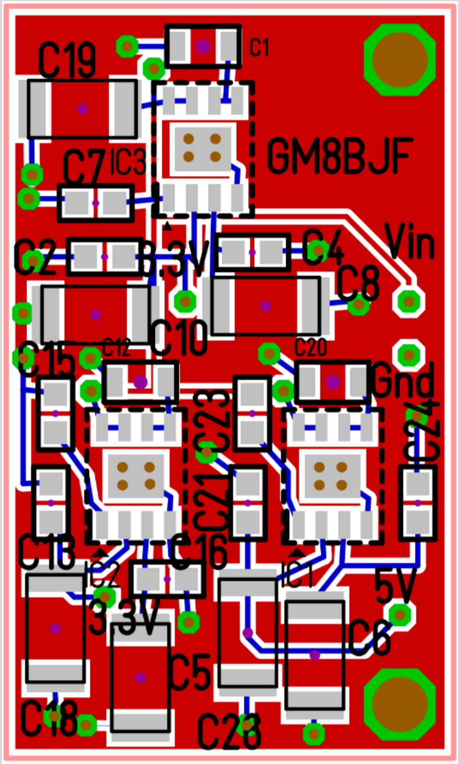

- This looks really ugly !

# Improvements

- 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.
  The ultra-low noise voltage regulators ADM7150 ACPZ-5.0 show astonishing 1.6uV.
- So it was clear I wanted to use the ADM7150 regulators.

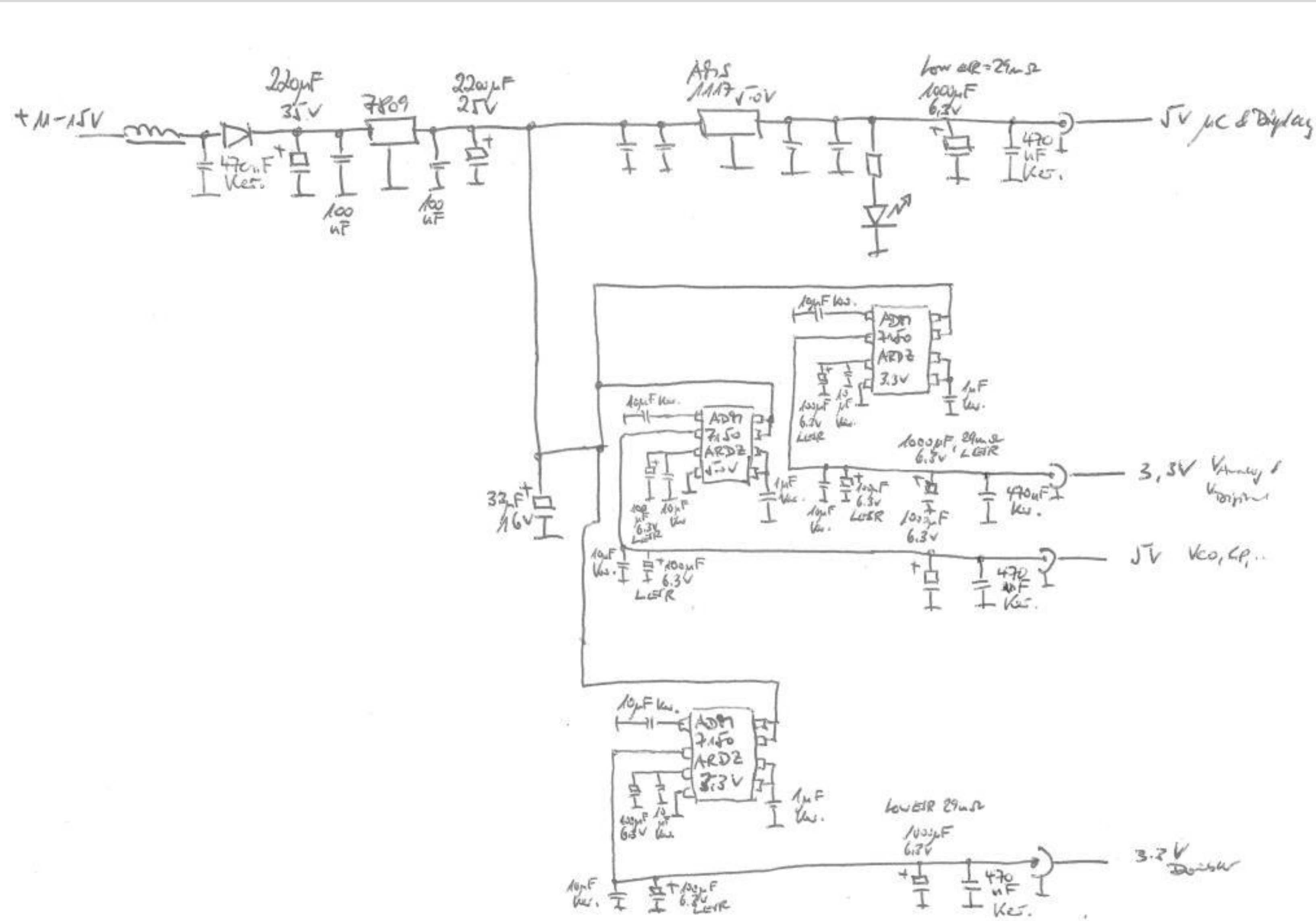
# Improvements

- Talking with Brian GM8BJF 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.

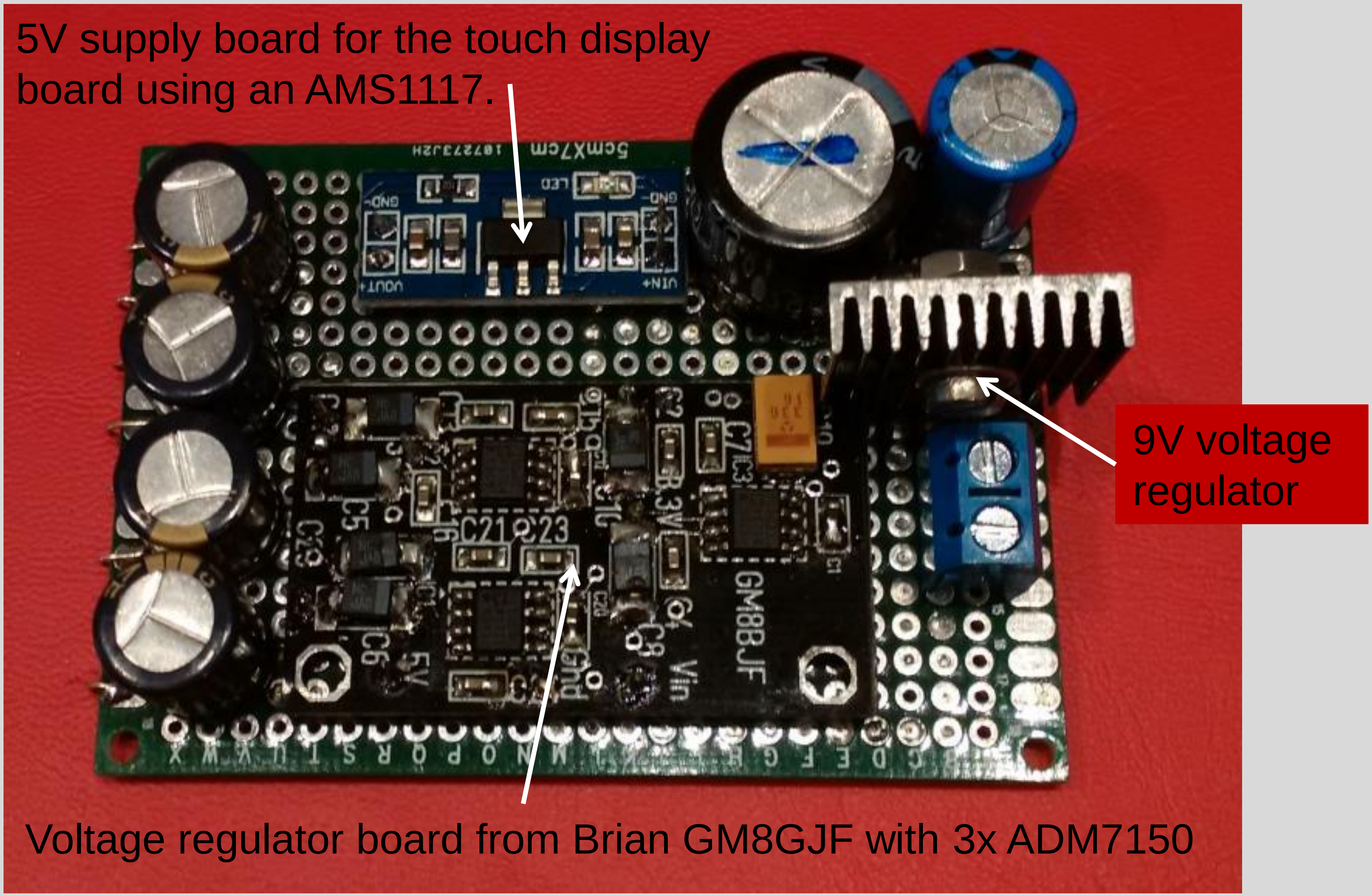



- In addition, I needed another 5V supply domain for the touch display board and decided to use a small PCB which I had at hands using an AMS1117. On the synthesizer board also the 3.3V supply for the microcontroller is derived.
- To reduce the power dissipation in the regulators and provide additional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

# Improvements



# Improvements




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.

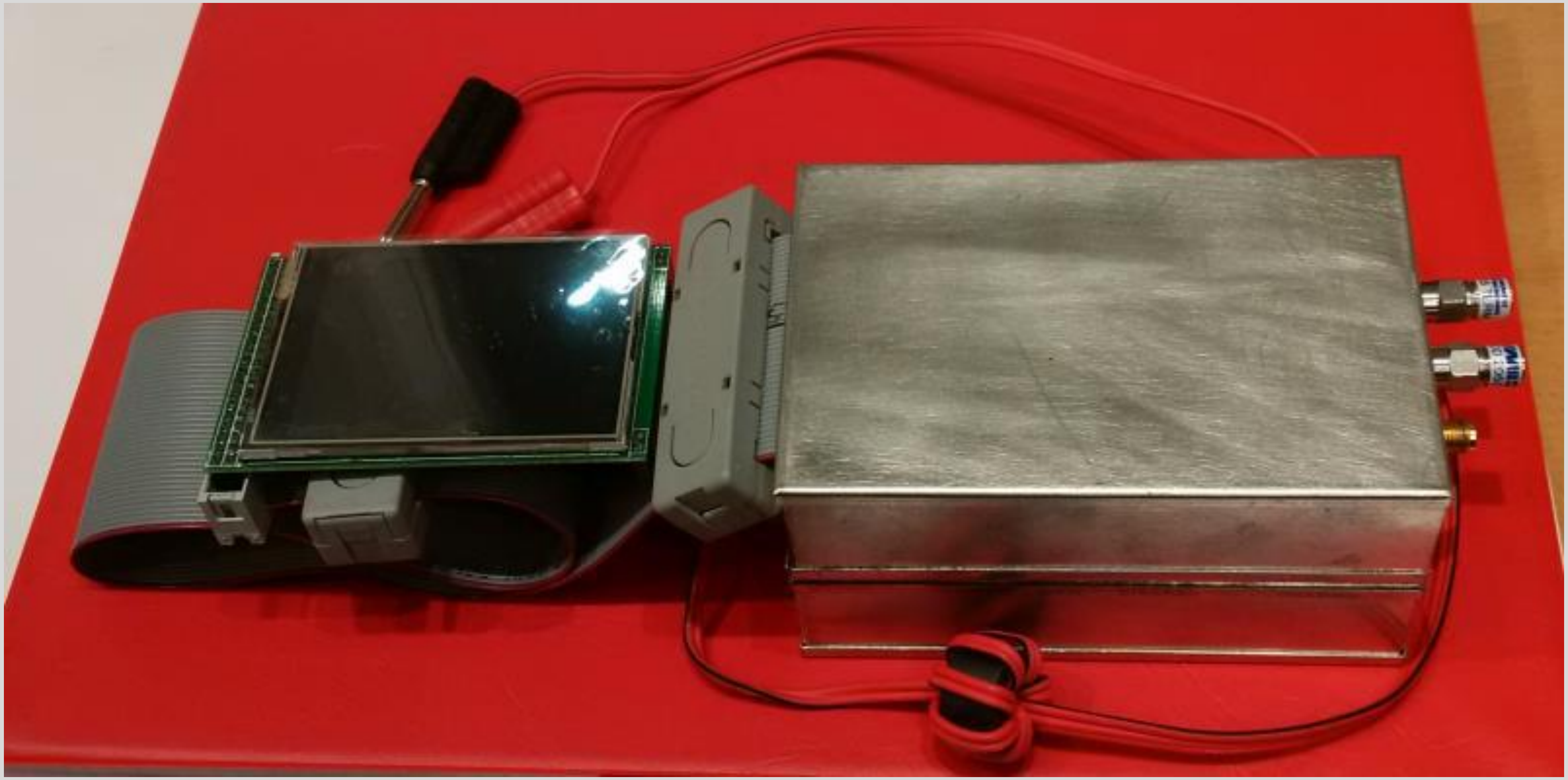
# Improvements


I put the power supply board in a shielded box and
routed all supply with shielded cables to the synthesizer board

# Improvements

I removed all voltage regulators except the 3.3V regulator for the microcontroller. In addition, the two inductors marked L4 and L5 were removed to disconnect the VCO supply from the 5V supply of the display board. I also removed the power supply jack and used the space to add an additional 100uF/6.3V Low-ESR capacitor.

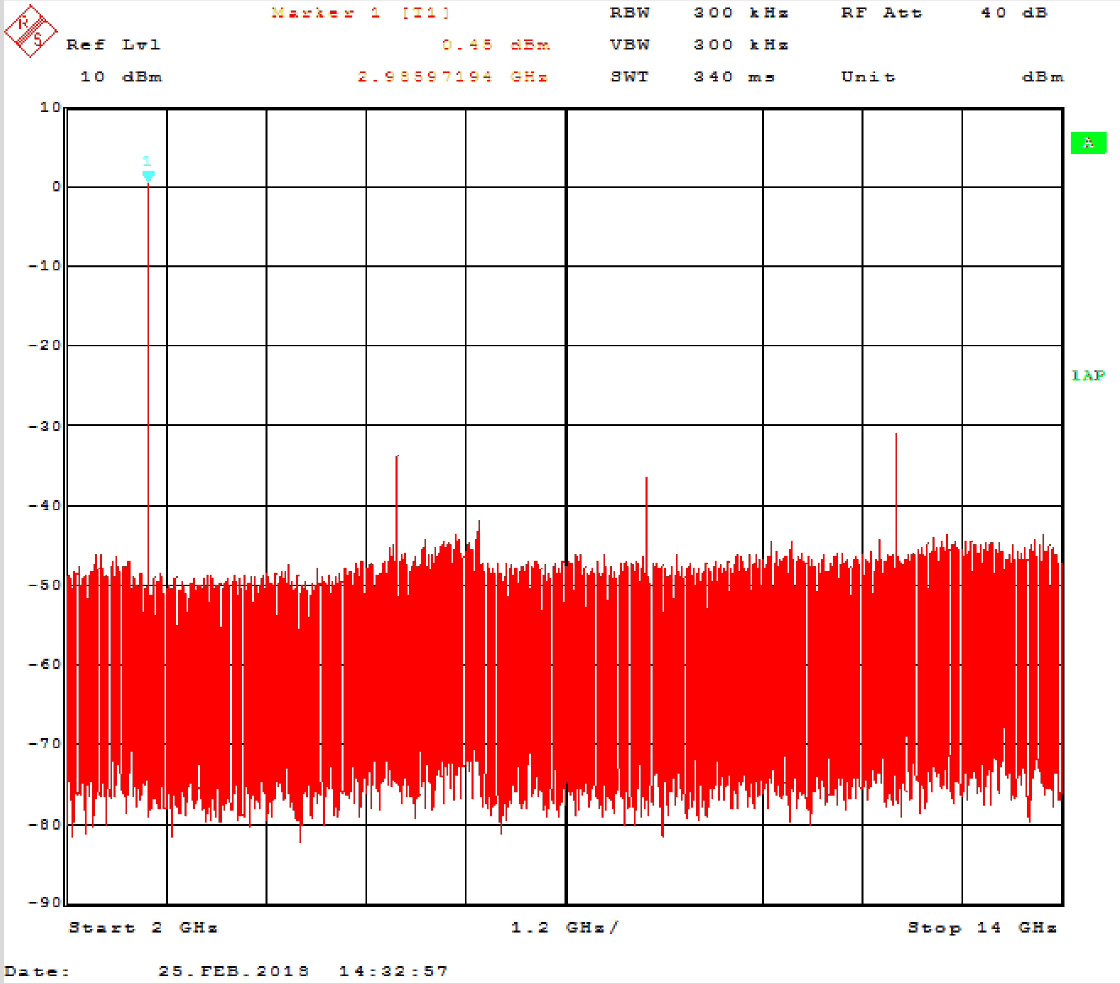
# Improvements



In order to avoid any intercoupling / interference the synthesizer board and the power supply board are in 2 separate shielded boxes. I added ferrite RF chokes on each end of the ribbon cable to suppress possible interference from the touch display.

# Results after Improvements

Measurements with the synthesizer set to 3 GHz.
a) <u>wideband</u>, b) span of 10 MHz, c) 1 MHz, d) 100kHz and e) 10 kHz



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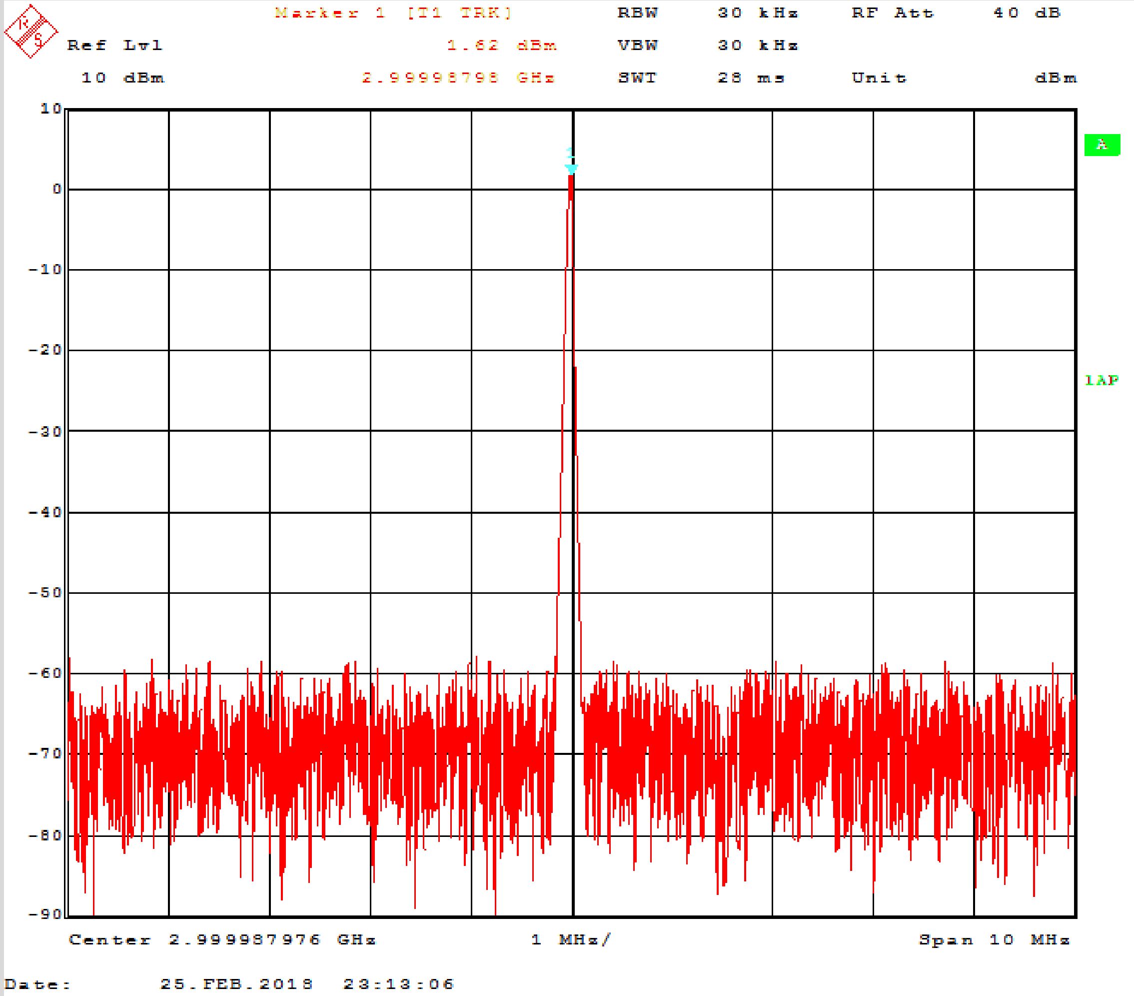

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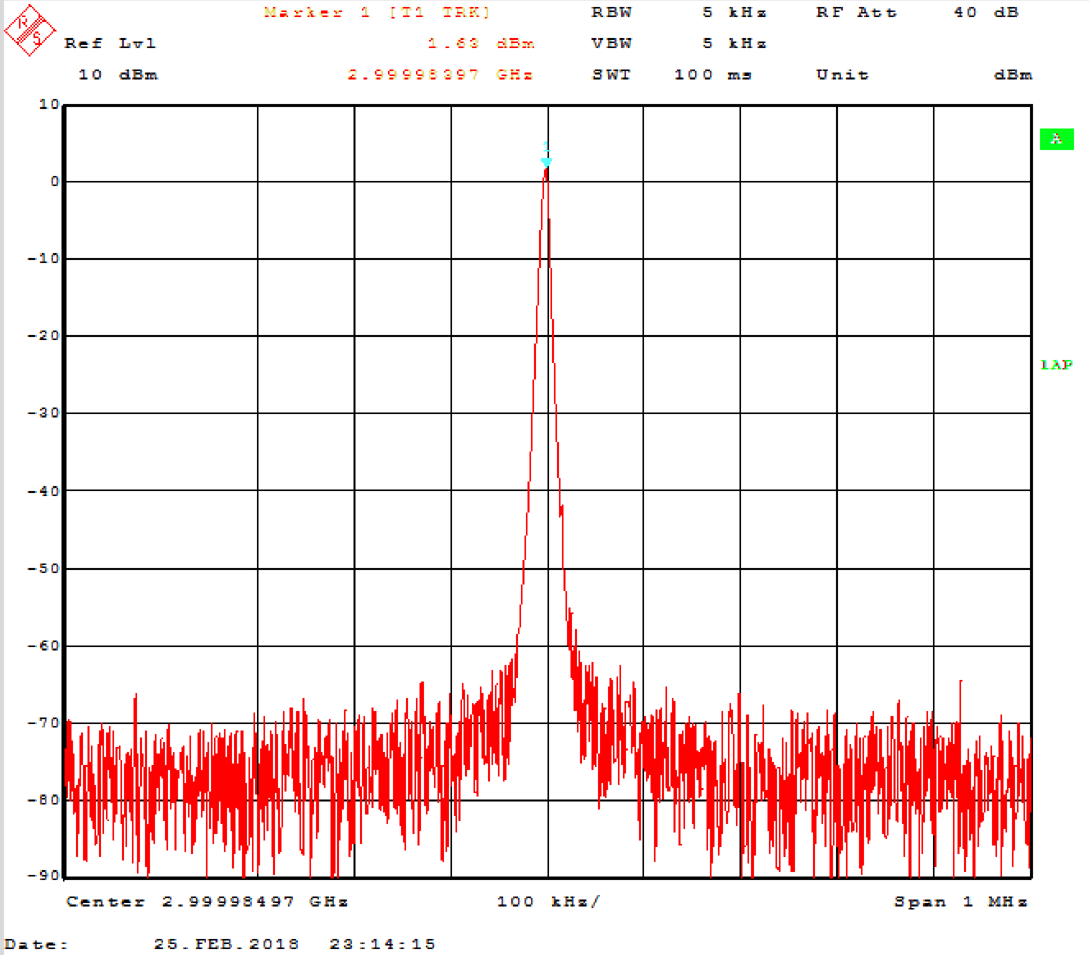

# Results after Improvements

Measurements with the synthesizer set to 3 GHz.
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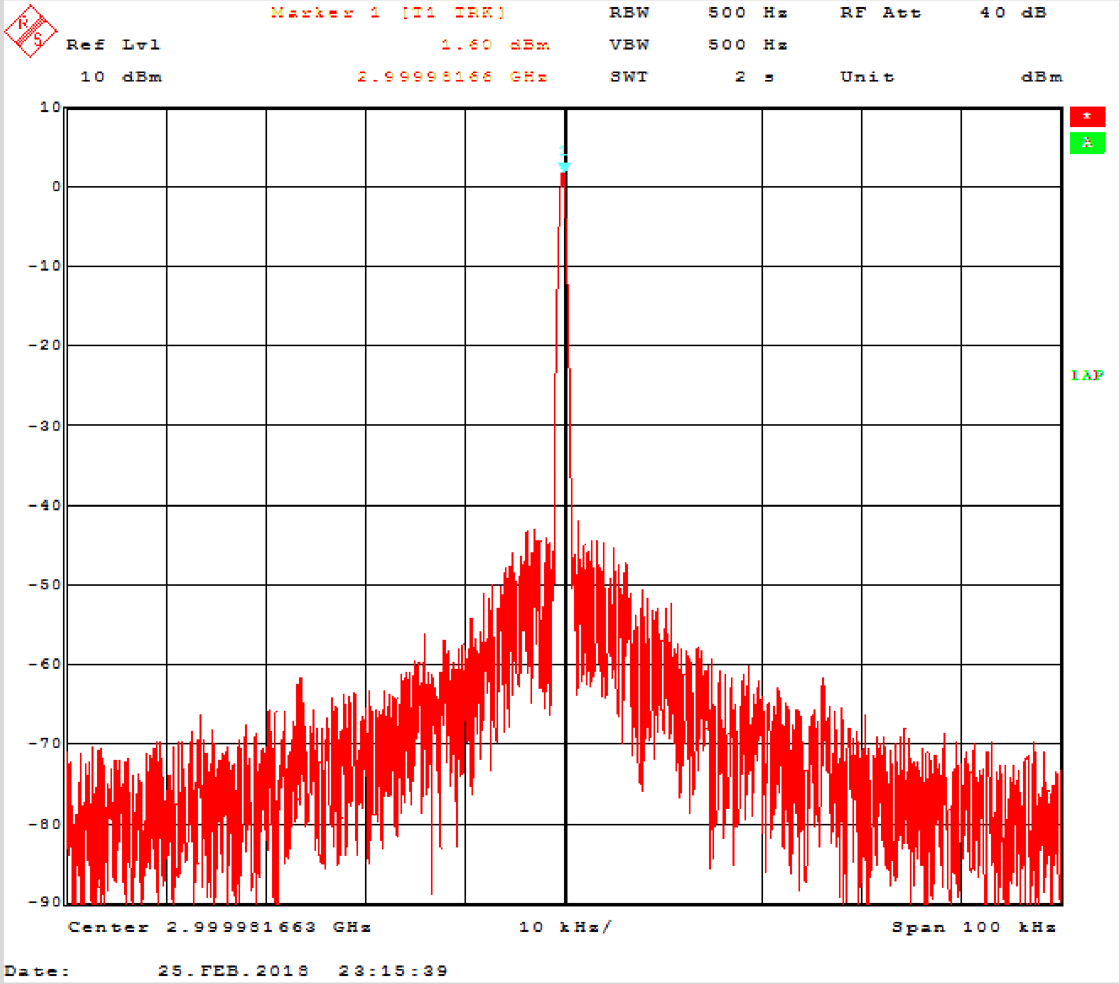
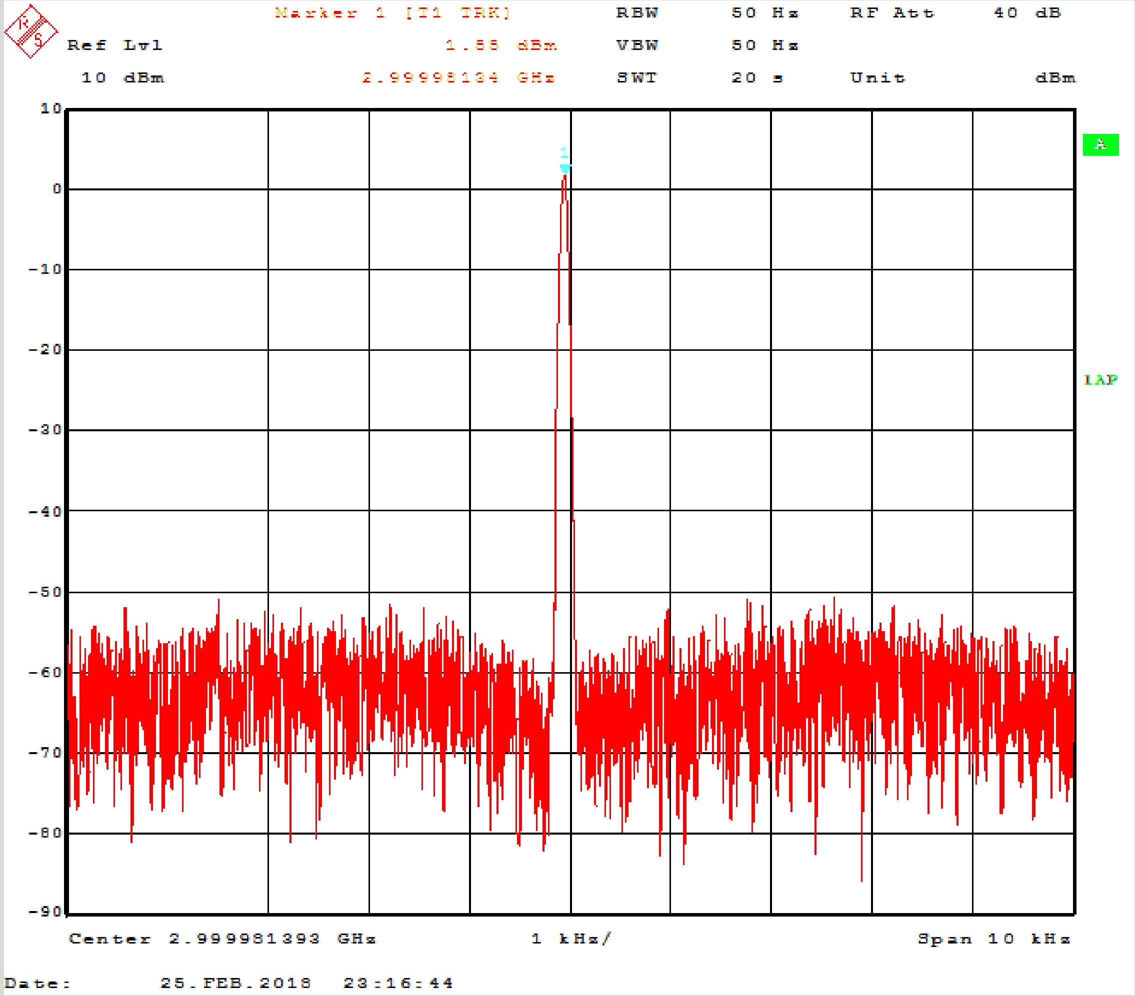


# Results after Improvements

Measurements with the synthesizer set to 3 GHz.
a) wideband, b) span of 10 MHz, c) 1 MHz, d) 100kHz and e) <u>10 kHz</u>



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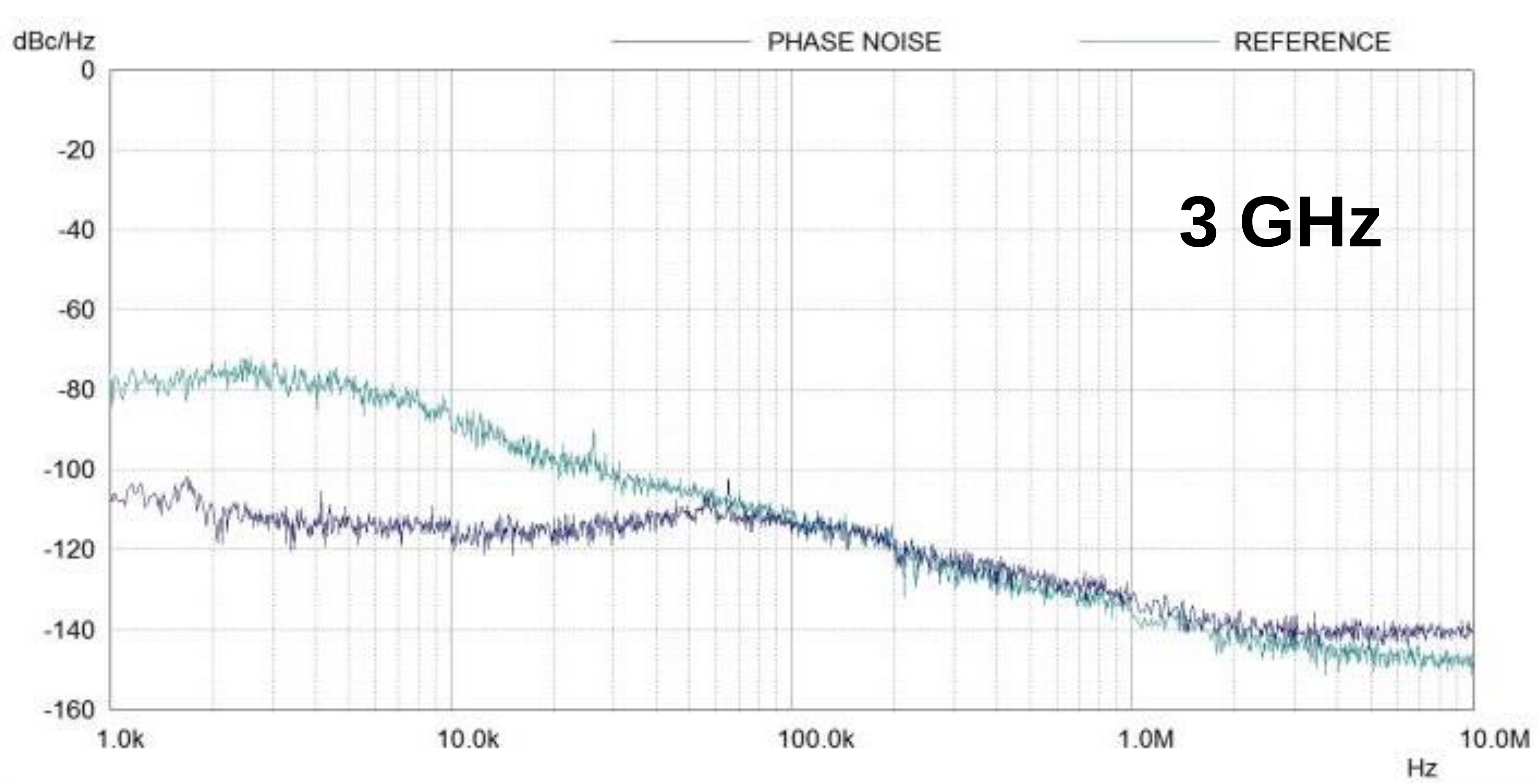
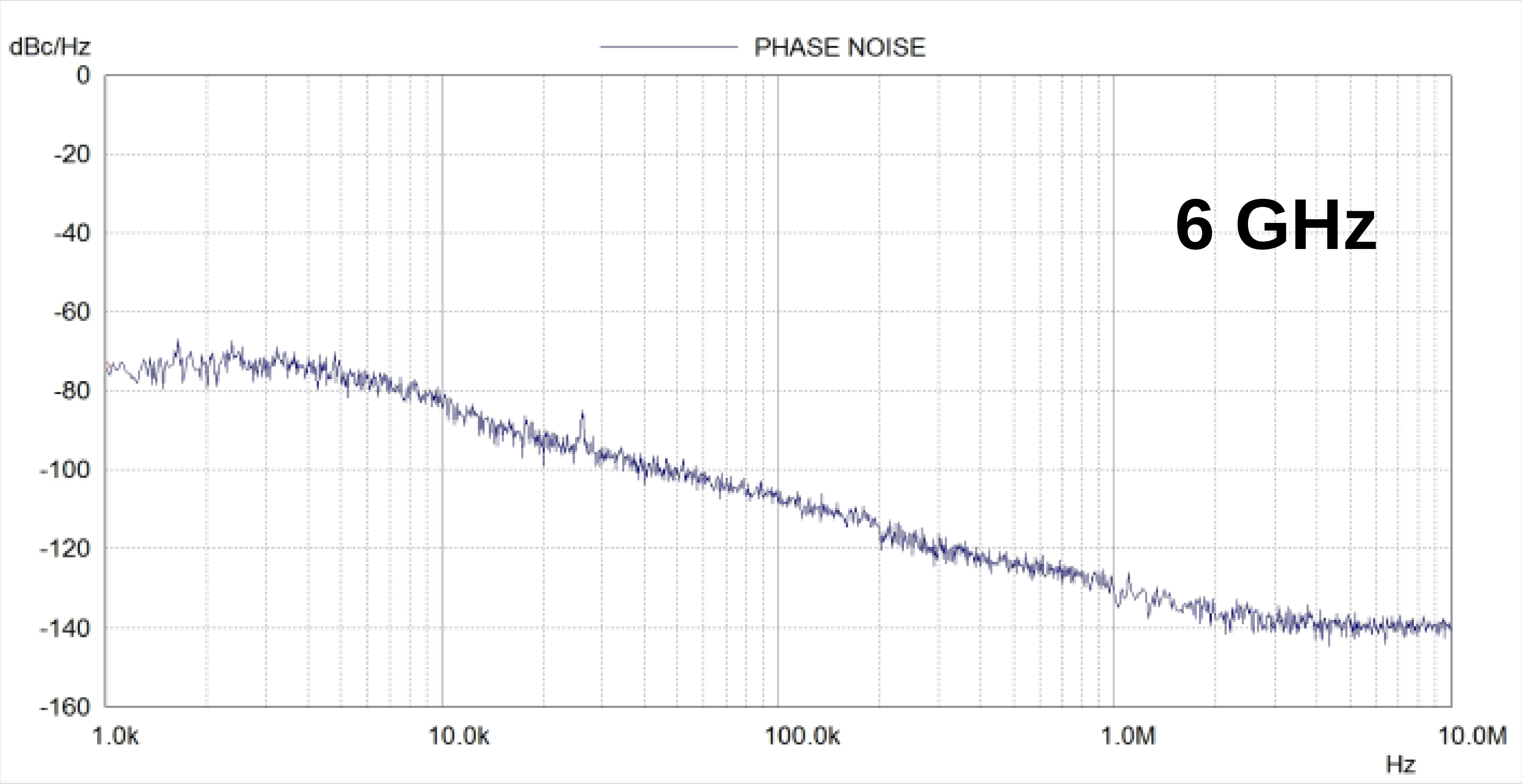



The reference line is the phase noise of a R&S SME03 signal generator operating at its maximum frequency of 3 GHz. Below 60 kHz offset the SME03 is significantly better, above 2 MHz the ADF5355 is better.

# Results after Improvements



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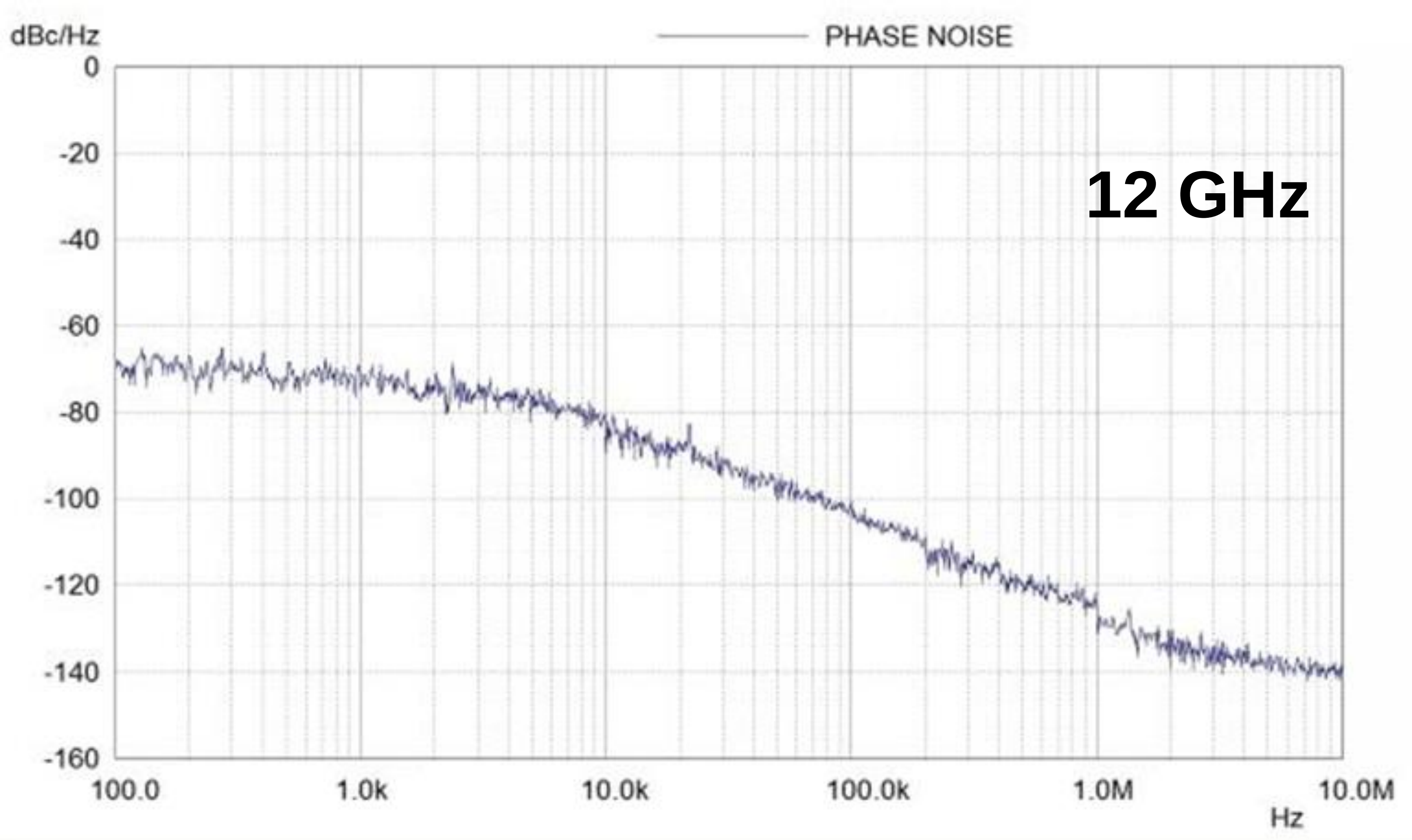
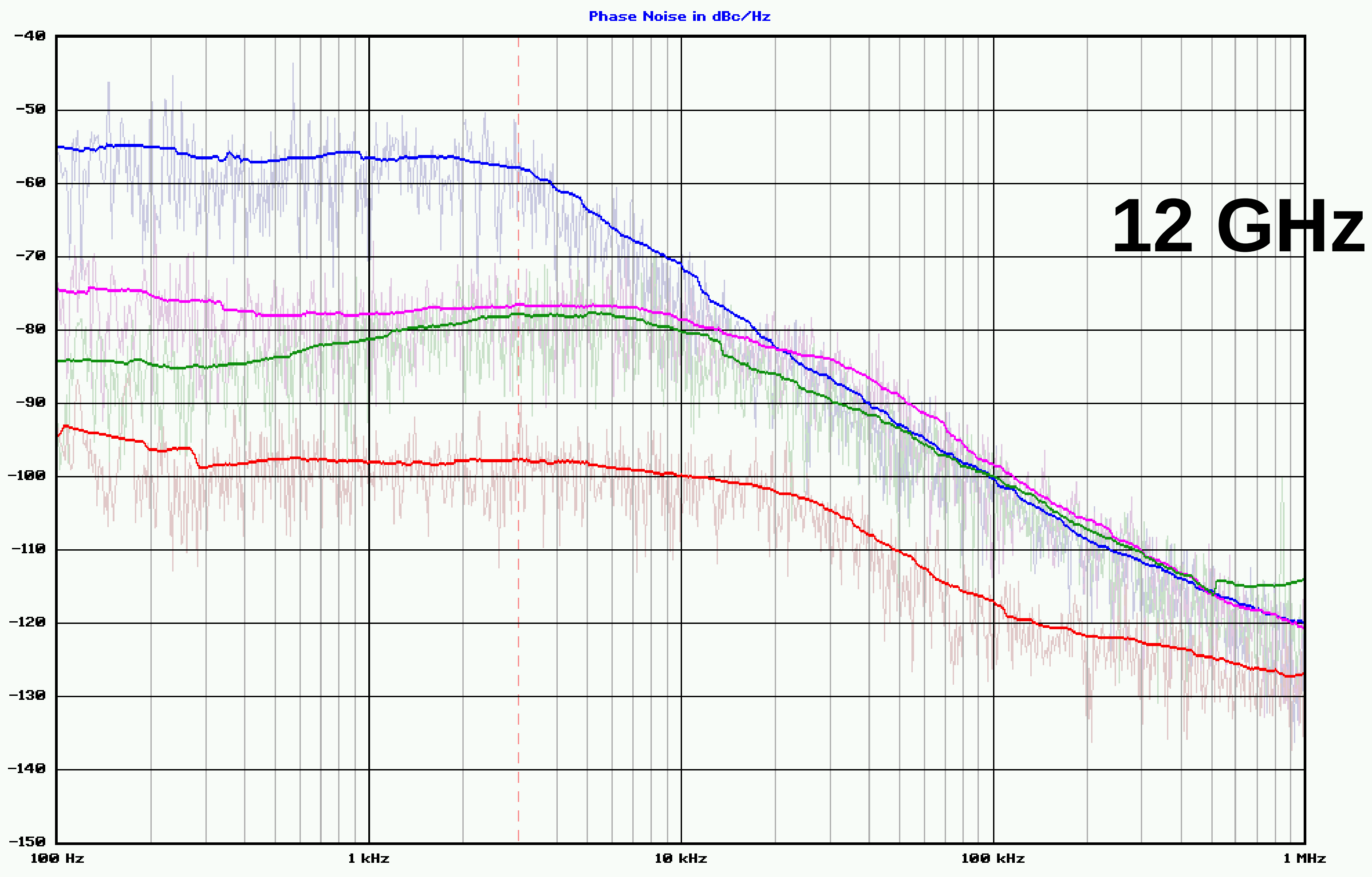


# Results of Brian Flynn GM8GJF




| Trace | Carrier Hz | Carrier dBm | dBc/Hz at 3000 Hz | Time/Date | Instrument | Rev |
|---|---|---|---|---|---|---|
| adf5355 (Icp=0.3mA) vs CTI-Herley 12.575GHz | 575 700 150 | -11.20 | -57.9 | 21/12/2017 17:38:14 | HP8566B | 2639 |
| adf5355 (Icp=4.8mA) vs CTI-Herley 12.575GHz | 575 701 250 | -11.20 | -76.5 | 21/12/2017 17:42:43 | HP8566B | 2639 |
| 11.6GHz DFS120 vs CTI-Herley 12.575GHz | 975 499 000 | -14.20 | -77.7 | 21/12/2017 18:12:30 | HP8566B | 2639 |
| Phase noise floor (100MHz Cal) | 100 000 000 | -11.20 | -97.6 | 21/12/2017 17:50:26 | HP8566B | 2639 |

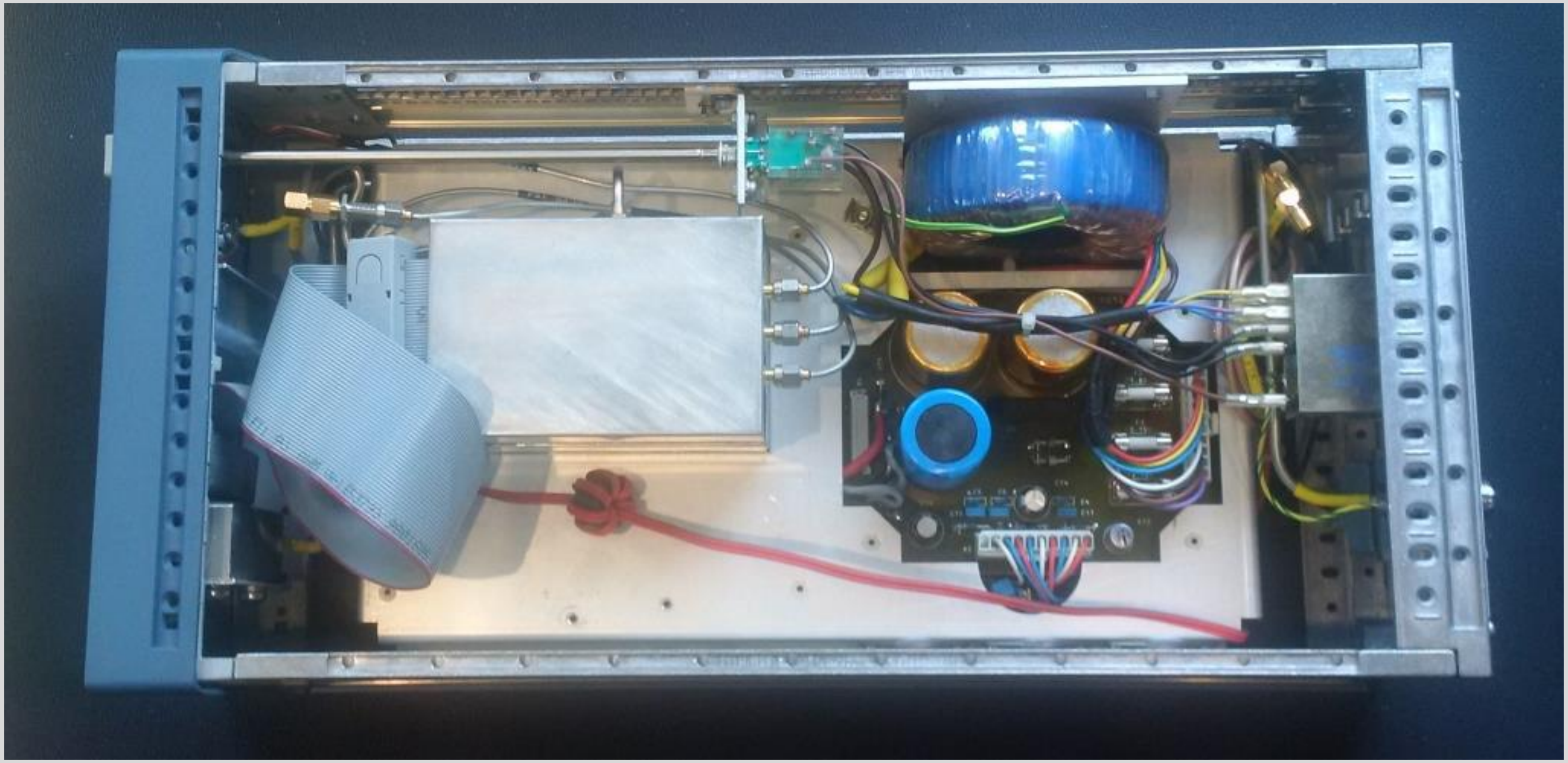
# Summary

- 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 GM8GJF had achieved and measured. At 12 GHz with an offset of 1kHz his measured phase noise is about 5dB better.
- He showed 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.

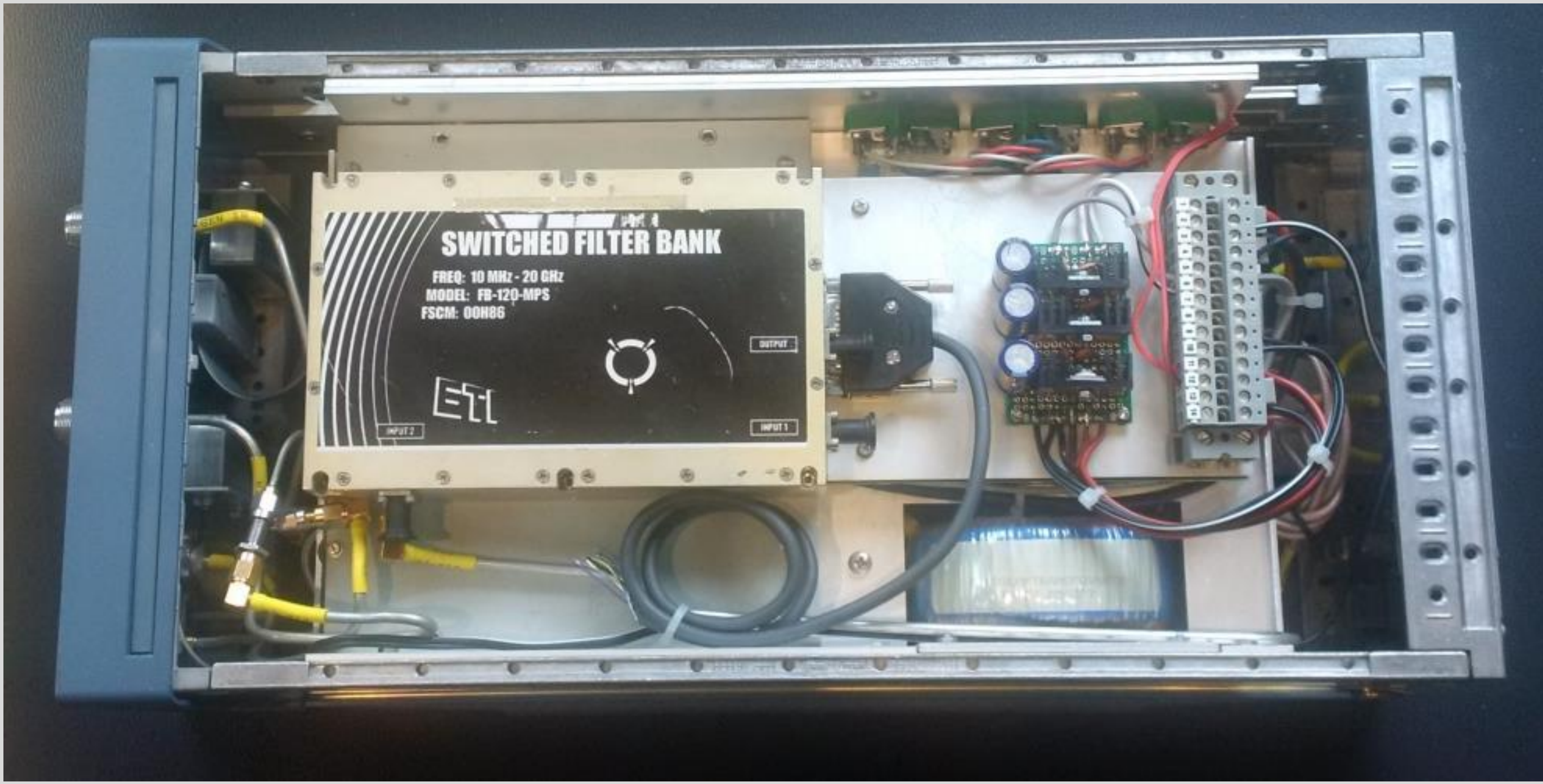
# Integration

- 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 I added another voltage regulator board.
- The filter module is not yet activated as I need some control circuits to switch the various frequency bands.

# Integration

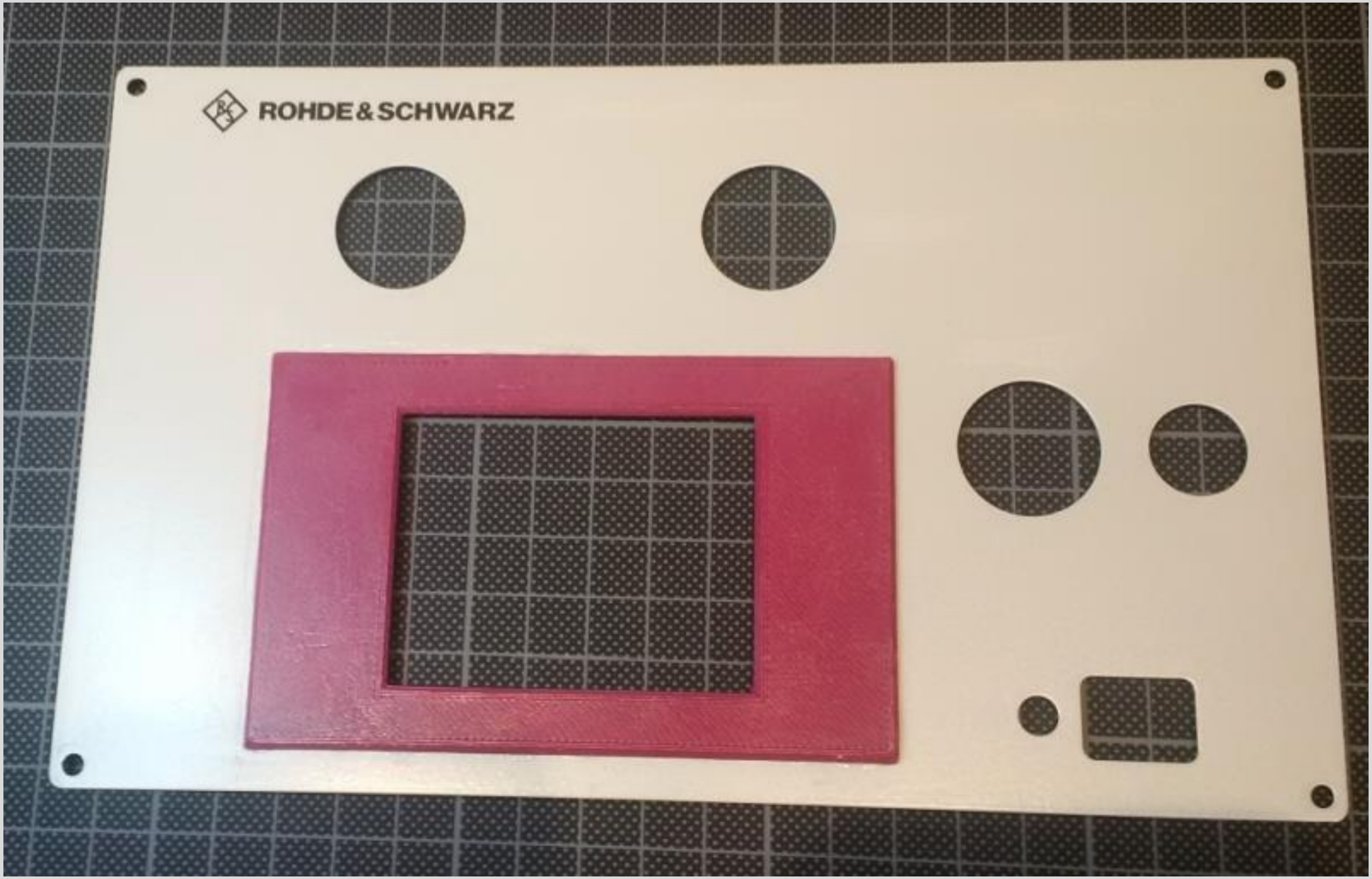


# Integration




A detailed analysis of the switchable filter bank can be found at my website www.dd1us.de

# Integration




I reused / modified the existing front plate and added a 3D printed frame for the touch-display

# Integration

# Integration

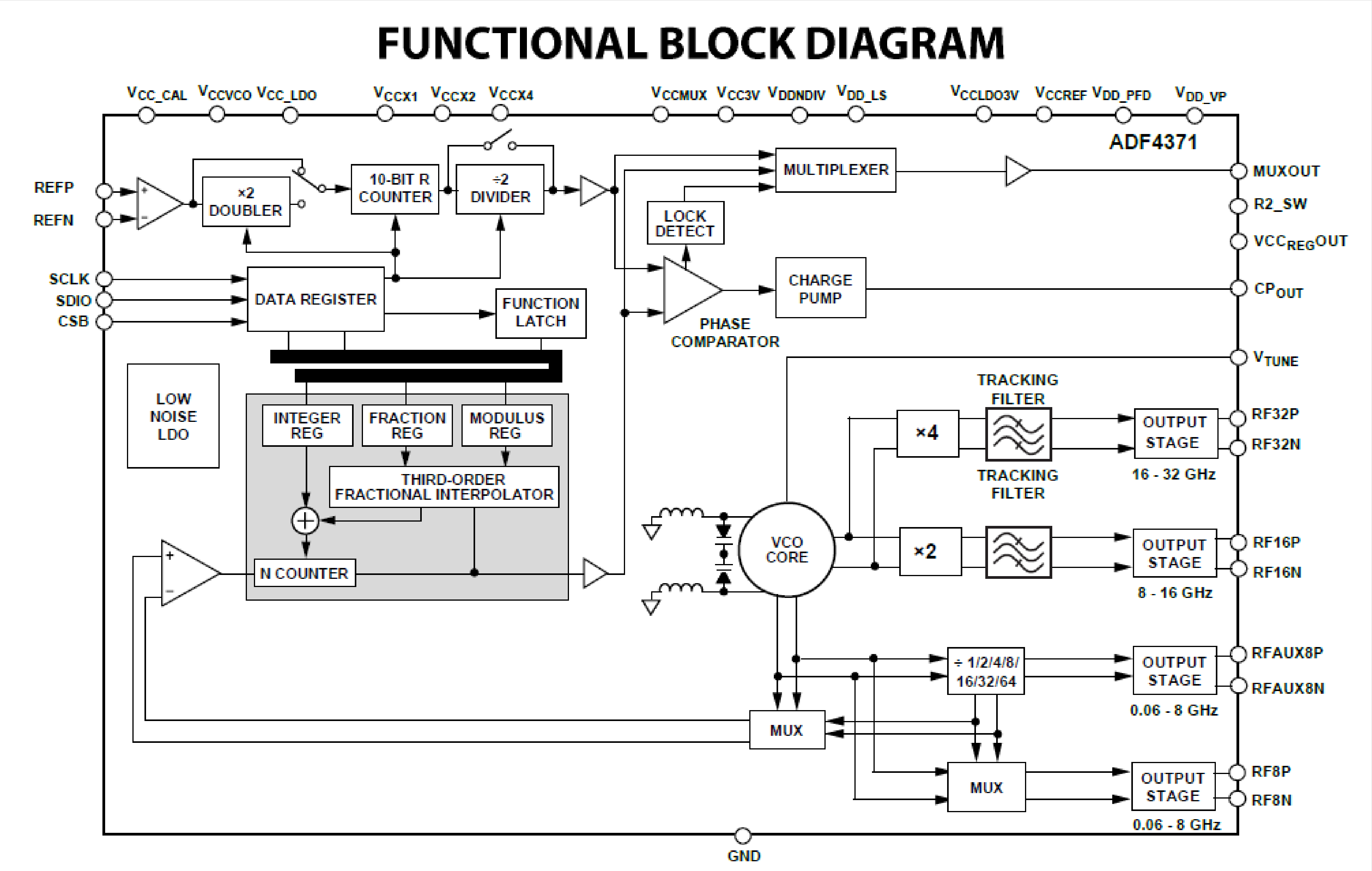
# What‘s next ?

The Switched Filter needs to be controlled, preferably by sniffing the communication between the ARM controller and ADF5355

Analog Devices released an improved version of the ADF5355, the ADF5356 which is pin compatible but promises a 6dB improved phase noise.

2 weeks ago Analog Devices annouced a new generation synthesizer IC ADF4371, covering the frequency range 62.5 MHz up to 32 GHz

# What‘s next ?


FUNCTIONAL BLOCK DIAGRAM
ADF4371
REFP
REFN
×2 DOUBLER
10-BIT R COUNTER
÷2 DIVIDER
MULTIPLEXER
LOCK DETECT
CHARGE PUMP
PHASE COMPARATOR
SCLK
SDIO
CSB
DATA REGISTER
FUNCTION LATCH
LOW NOISE LDO
INTEGER REG
FRACTION REG
MODULUS REG
THIRD-ORDER FRACTIONAL INTERPOLATOR
N COUNTER
VCO CORE
TRACKING FILTER
×4
×2
OUTPUT STAGE
16 - 32 GHz
8 - 16 GHz
÷ 1/2/4/8/ 16/32/64
0.06 - 8 GHz
MUX
MUXOUT
R2_SW
VCCREGOUT
CPOUT
VTUNE
RF32P
RF32N
RF16P
RF16N
RFAUX8P
RFAUX8N
RF8P
RF8N
GND

# Acknowledgement

I would like to thank

Brian Flynn GM8BJF for his excellent articles and presentations which he kindly allowed me to reuse, his advice and the PCB for the optimized power supply

Reinhard Beck DL3BR for the schematics of the synthesizer board

Edgar Kaiser DF2MZ for designing the 3D printed frame for the touch-display.

# Thank you for your attention !

You can find this presentation and further information on this project as well as many other articles on my website at www.dd1us.de

If you have questions please feel free to contact me by Email at dd1us@amsat.org