Langenbrettach, September 29th 2013
Matthias Bopp

A precise reference frequency not only for your ham radio station
Rev 1.1

A ham radio station needs a stable reference frequency if you want to move to very high frequencies or operating modes with very narrow bandwidths. Probably the worst case is reached if both aspects combine like it is the case in deep space satellite communication:
1.) Due to the very high distances between the satellite and the ground station the operating frequency is moved up to make use of high gain antennas with a reasonable size.
2.) At the same time the bandwidth of the signal is reduced to achieve higher S/N ratios.

I intend to prepare myself for the reception of deep space satellite signals as the next generation of ham radio satellites is in design and will hopefully be launched in the next 2 years. Therefore recently I started to work on a suitable concept for the local oscillator generation of my system.

I decided for a surplus Rubidium Frequency Standard and selected the model FE-5680A from Frequency Electronics Inc. I bought it from Guy Ovadia (guy@orcon-tech.com) who provided a very professional and kind service.

I have chosen a version of the FE-5680A module, which includes a DDS (direct digital synthesis) IC AD9830A from Analog Devices and thus provides a sinusoidal output signal of approx. 6 dBm with a user specified output frequency from 1 Hz to 20 MHz. This "Option 2" allows the remote adjustment of the output frequency by a computer through an RS-232 interface. Please note that there are multiple different versions of the FE-5680A available. This module has the size .98 x 3.47 x 4.92 inches respectively 25 x 88 x 125 mm. The input power of 15 V DC is supplied through a 9-pin Sub-D connector. The current consumption is approx. 2 A during the start-up time and once the operating temperature of the module is reached it is reduced to 0.75A. My module did not supply the RF signal outside the module nor was the RS232 connection externally available. You will find instructions on the necessary modifications later in this article.

Rubidium Frequency Standard FE-5680A

Please note, that there seem to be multiple versions of this unit for sale (for instance on Ebay), where the pinout might be different. You will find additional information at the end of this paper.

Here is the pin-out of the 9 pin SUB-D connector:

PIN	FUNCTION	NOTES
J1-1	+15V	DC power input
J1-2	GROUND	Provides DC return, RS-232 return
J1-3	Loop Lock Indicator	Indicates whether or not the output frequency is stabilized to the Rb atomic reference. Low output means it is locked. It should go low a few minutes after power up (it takes longer when the unit is cold). If you connect a 5-10 kOhm resistor from J1-1 to the anode of a LED and connect the cathode of the LED to J1-3, the LED will go on when the unit is locked.
J1-4	NOT USED	Applying +5V at pin4 does activate RFout at pin7
J1-5	GROUND	Provides DC return, RS-232 return
J1-6	1 PPS output	1 pulse per second output signal
J1-7	NOT USED	Applying +5V at pin4 does activate RFout at pin7
J1-8	RS-232 Rx	True RS-232 signal with ±12V
J1-9	RS-232 Tx	True RS-232 signal with ±12V

The parameters of the serial connection are: 9600 baud, 8 bits, one stop bit, no parity, no flow control.
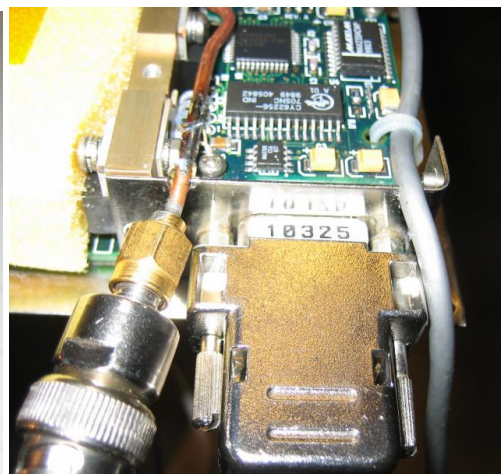
Here are the technical data of my FE-5680A module:

PARAMETER	SPECIFICATION
Output Frequency	Programmable from 1 Hz to 20 MHz with a resolution of $<1\text{x}10^{-12}$ Hz
Type	Sinusoidal
Amplitude (minimum)	0.5 Vrms into 50 Ohm (+7dBm)
Adjustment Resolution	$<1 \text{ x } 10^{-12}$ over range of $3.8 \text{ x } 10^{-5}$
C-field potentiometer Resolution	$1 \text{ x } 10^{-11}$ over range of $3 \text{ x } 10^{-9}$
Drift	$2 \text{ x } 10^{-9}$ / year respect. $2 \text{ x } 10^{-11}$ / day
Short Term Stability: 1 sec $\leq$ 100 sec	$1.4 \text{ x } 10^{-11}$ t
Retrace	$5 \text{ x } 10^{-11}$
Phase Noise (fo = 10 MHz)	-100 dBc @ 10 Hz, -125 dBc @ 100 Hz, -145 dBc @ 1000 Hz
Input Voltage Sensitivity	$2 \text{ x } 10^{-11}$ / (15V to 16V)
Frequency vs. Temperature	$\pm 3 \text{ x } 10^{-10}$ (@ -5°C to +50°C)
Spurious Outputs	-60 dBc
Harmonics	-30 dBc
Loop Lock Indication	> 3Vdc = unlocked, < 1Vdc = locked
Input Power (@ 25°C)	11 watts steady state, 27 watts peak
DC Input Voltage/Current	15V to 18V @ 1.8A peak and 0.7A steady-state
Ripple	+15V: <0.1 Vrms
Warm-up Time	< 5 minutes to lock @ 25°C
Size	25 x 88 x 125 mm / .98 x 3.47 x 4.92 inches
Weight	434 grams respectively 15.3 oz.

As my module did not supply the RF signal outside the module nor was the RS232 connection externally available I modified the module and routed these signals out. You can find pictures of the modification on the next pages.
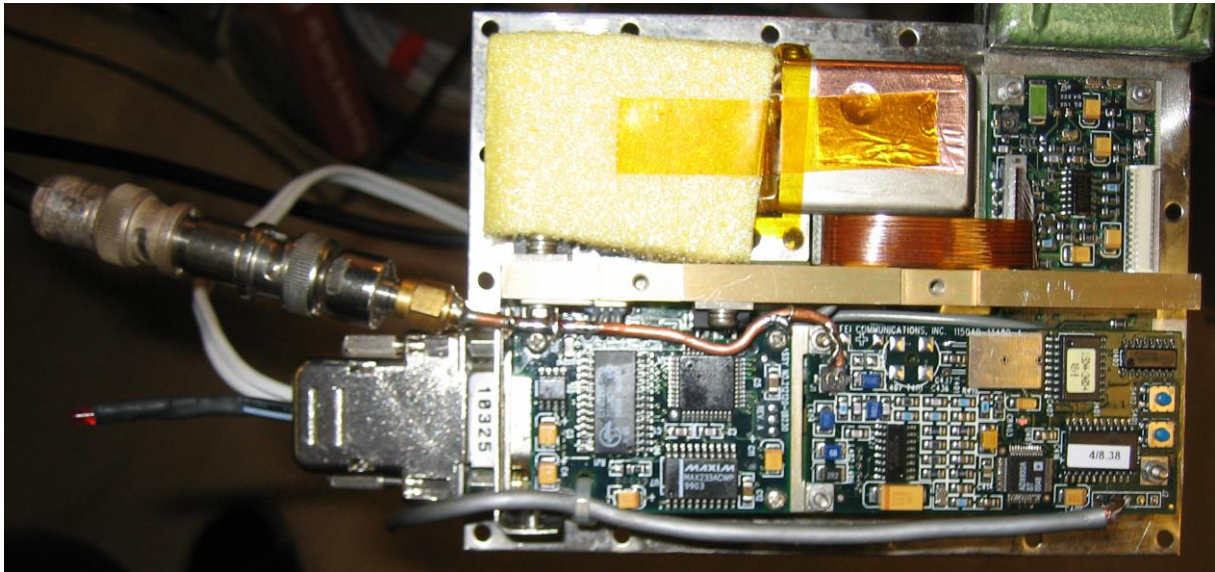
To route the signals outside the modules I had to make some modifications. I started with the lid of the cabinet where I added 2 openings around the Sub-D connector to route 2 additional cables to the outside.

**Modified lid to route the RF and RS232 signals out**   **Left RF semi-rigid cable, right RS232 cable**

Top view of the open FE-5680A module with the additional RF semi-rigid and RS232 cables
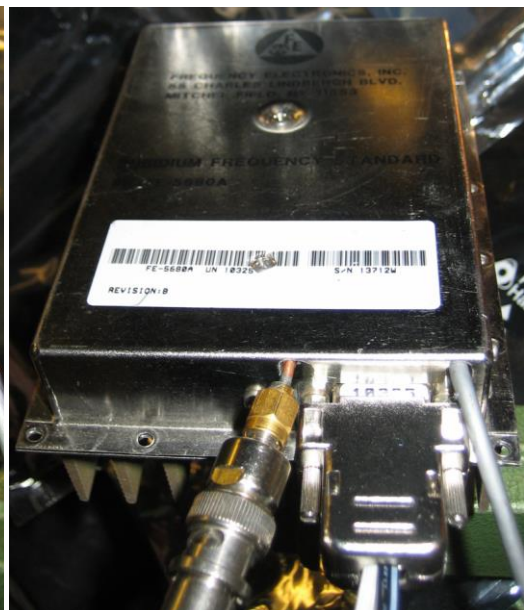
On top you see the physics package covered by foam for thermal insulation. On the bottom right you see the DDS (Direct Digital Synthesis) board where you find the RF- and the RS232 signals which are routed outside.
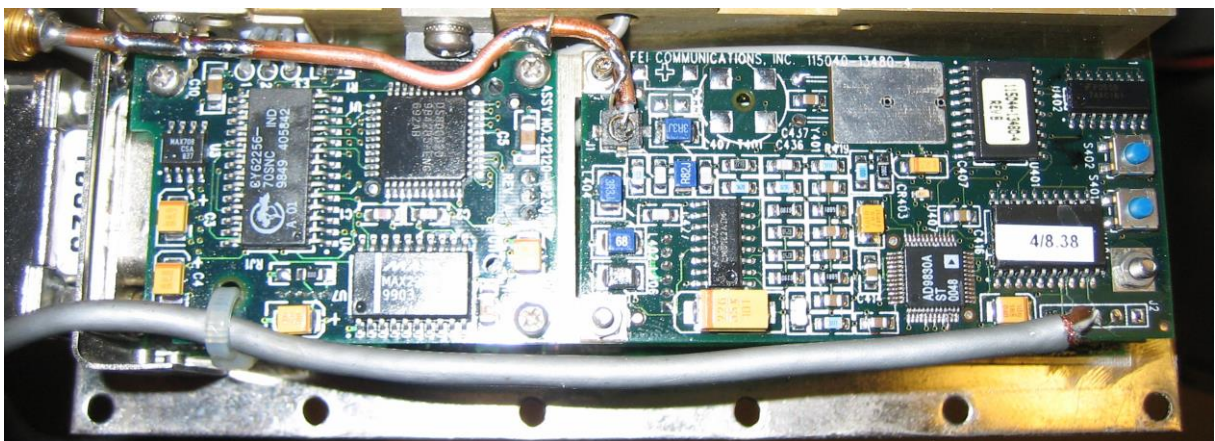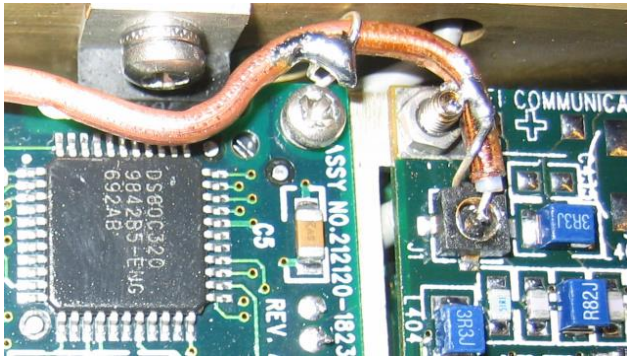

Detailed view of the DDS board where the 2 cables are connected to the PCB
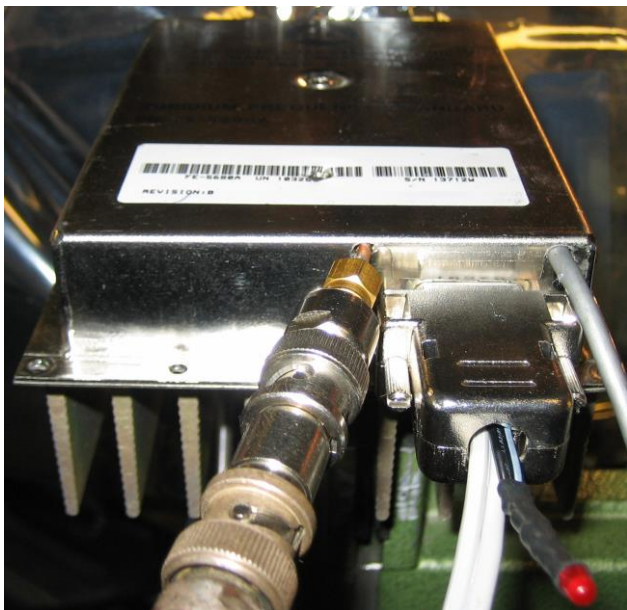
Front view with closed lid and lock LED

Front view with closed lid

**Detailed view, where to tap the RF signal**   **Detailed view of the RS-232 connection**

The centre pin of the semi-rigid cable is soldered to the centre pin of the Hirose RF jack. The shield of the semi-rigid cable is soldered to multiple ground connections of the PCB. Ian VK3XID suggests to solder the centre of the coaxial cable not to the centre pin of the Hirose jack but to one of the 4 pads around the Hirose connector (3 of the 4 pads are ground, one is connected to the centre pin. He found this much easier to implement.

The RS-232 signals are available at a 5 pin connector on the lower right of the DDS-PCB. Only the 3 leftmost pins are used. The signals at the connector, which I removed to solder the wires directly to the board, are from left to right:

PIN	FUNCTION	NOTES
1	GND	goes to Ground of the computer which is pin 5 on a female 9-pin Sub-D connector
2	TXD	goes to RXD of the computer which is pin 2 on a female 9-pin Sub-D connector
3	RXD	goes to TXD of the computer which is pin 3 on a female 9-pin Sub-D connector
4	+5V	don't connect it
5	+5V	don't connect it

Now it is time to verify that an output signal is available. Below please find the measured output spectrum of my module after start-up (when it is locked). As you can see, the default frequency is 8.388608 MHz (2^{23} Hz).
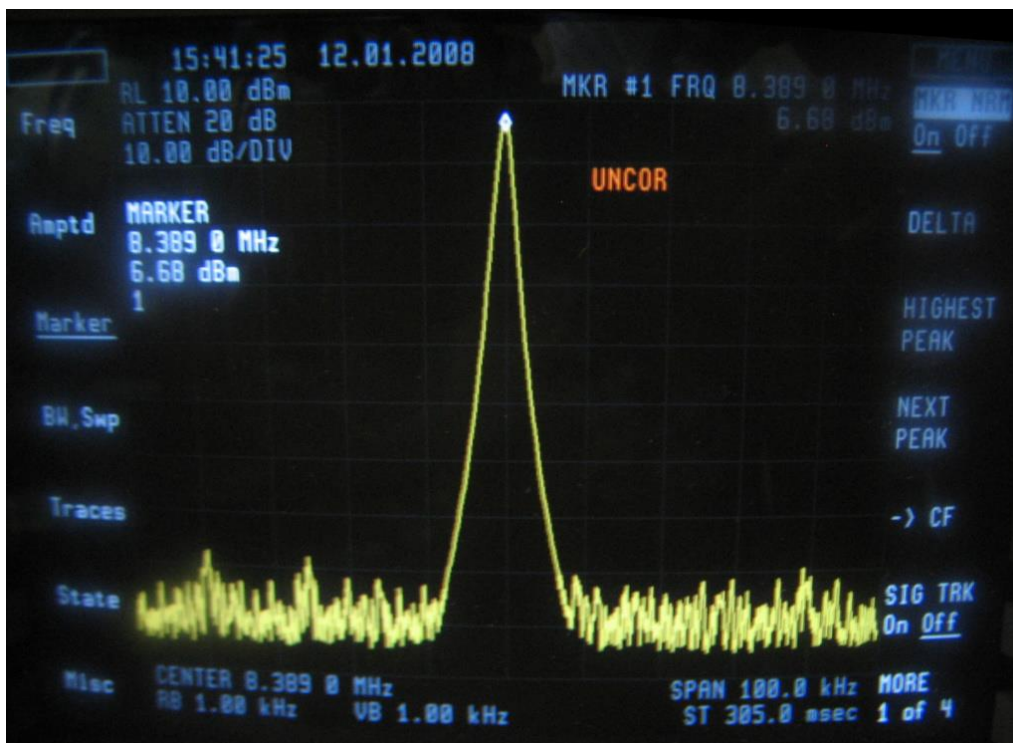
Measured output spectrum of FE5680A

Next the output frequency can be programmed. The instructions below for programming the unit were found on the internet in an article from Don Latham (see http://www.leapsecond.com/museum/fei5650a/). All credits are due to him for figuring out the commands and to Guy Ovadia (guy@orcon-tech.com) for providing them to me.

With the power supply disconnected you should connect the RS232 cable to the computer and the to the FE-5680A module. Now reconnect power to the device. Open a terminal program such as window's HyperTerminal. Configure the terminal program to open the COM port, which you connected the cable to. Set the terminal to 9600 baud, no parity, 8 data bit, 1 stop bit and no flow control.

Enter a capital "S" to the terminal, and press Enter. You should get a response similar to this:
R=50255057.012932Hz F=2ABB504000000000
If you don't get it, make sure your terminal program is set to output CR / LF characters when pressing Enter.

The command structure for setting the frequency is F=abcdefgh (+Enter).
Abcdefgh is a 4-byte hex word, such as 32AB56DF.

The output frequency is given by: $N / (2^{32}) * Fref$
Where:
"N" is the 4-byte hex word you entered (ranging from 0 to $2^{32}-1$)
"Fref" is a reference frequency of approximately 50.255 MHz.

The reference frequency is given by the R=xxxxx response to the "S" command you entered. You can also measure the reference frequency yourself. It is available at a test point at the top of the DDS board.

Here are the values I derived and used for my device:
R=Fref=50255056.353937 Hz
An output frequency of 8,388608 MHz with a level of 7,0 dBm was the result of F=2ABB503E3D4E4400.
An output frequency of 8,9733 MHz with a level of 7,0 dBm was the result of F=2DB5503E3D4E4400.
An output frequency of 10,000000 MHz with a level of 6,6 dBm was the result of F=32F0AB000000.

A more detailed description about the programming of the DDS IC AD9830A can be found in the respective datasheet, which you can download from the Analog Devices website.

In practice, it seems that the unit only likes frequencies somewhat close to the originally set frequency. There is probably a band-pass filter somewhere on the board that attenuates the signal for frequencies far from the original one. It has been reported by others that a frequency range of 1.5 MHz to 15 MHz gives a decent measurable output. I have not yet verified this myself. If you can find out where this bandpass filter is and how to change or remove it, it may be possible to get a wider frequency range – although it is probably limited by the Nyquist frequency of about 25 MHz. Please share your findings with me and I will be happy to add it to this little documentation.

Finally there is an "E" command that stores the frequency settings in a non volatile memory in the unit. It works fine and avoids the need to reprogram the unit after each power up unless you want to change the frequency.

To make life for all of us a bit easier, Duane C. Johnson (redrok@redrok.com) wrote a nice little program to conveniently operate the FE-5680A. He was kind enough to share it with us – thank you very much Duane.

The program is written in BASIC. Duane used Borland's Power Basic as this will also support COM4. You could also run it using native BASIC if you use only COM1 or COM2. Please note that the program will only start when the FE-5680A unit is properly connected and powered up.

The program includes:
1.) Native BASIC .bas source-code
2.) A compiled .exe executable
3.) A .cfg configuration file for selecting the com port and a preset frequency. Please make sure that this file resides in the same directory as the .exe file.
4.) Some notes in a .txt text file.

You can download the 4 files in a ZIP-archive named "FE5860A.ZIP" from Duane's website at http://www.redrok.com. The archive can also be accessed directly at http://www.redrok.com/FE5680A.zip. In case you might have trouble to access his website I will be happy to send you my latest copy by Email.

Additional information:

1.) Duane C. Johnson also found out that you can greatly lower the acceptable minimum output frequency by soldering an electrolytic capacitor across the chip capacitor shown in the picture of the DDS board to the right. He used a 33uF capacitor because it was the smallest he could fit in the box but suggests that larger caps would be even better. Please note the polarity as marked in the picture !

I have not yet tried the modification myself but will certainly do so whenever I will open my module next time.
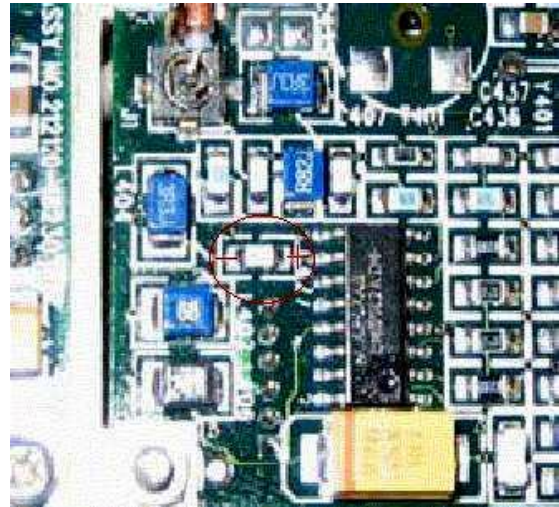
Capacitor to be modified on DDS board

2.) Kurt Poulsen reported to me, that he bought a unit on Ebay from "flyingbest" with a built in RS232 output (factory fitted option 1). In his unit the RS-232 RX is pin 7 and not pin 8 as I have used. In his unit pin 8 is reserved for EFC according to the manufacturer's datasheet.

3.) Donald R. Frayer reported to me, that he bought multiple units where the RF signal was available at pin 7 when he applied +5 Volt at pin 4.
I verified this approach at a second FE-5680A unit (FEI P/N 217400-30352-1), which I recently bought. The +5V supply current to pin 4 is about 70 mA. The RF output at pin 7 is a clean sinusoidal signal (in my case 10 MHZ) with an amplitude of 1.2Vpp measured with a high impedance probe. This option makes the above mentioned modification obsolete (routing the RF signal with a semi-rigid cable outside).

4.) Bernd DF1YW reported to me, that the units he bought had the same part number as the ones reported from Donald Frayer. His units are not programmable but fixed to 10 MHz output. The MAX232 chip is available but did not respond to his commands. Also his unit uses an AD9832 instead of the AD9830.

5.) Dick G8BNR reported to me, that he has multiple units which look the same like the ones I described but have already their own 5 Volt regulator built-in. It is an MIC2920A-5.0BS voltage regulator and thus his units do not need +5V connected to pin 4 of the 9 pin connector. At his units the 10 MHz output is active without the +5V externally supplied to pin 4.

6.) In spring 2013 I received a detailed analysis and modifications from a nice fellow called Detlef. As this is quite a detailed work I have attached his work as appendix #1 to this document. Detlef asked me not to publish his Email-address but I will be happy to forward questions and feedback to his work to him.

I always appreciate feedback and suggestions for improvements. Please send it to my Email address below.

Many thanks in advance.

Best regards

Matthias

Email: DD1US@AMSAT.ORG   Homepage: http://www.dd1us.de

FE-5680A - Detailed Description and Modifications

The Unit I have bought

My FE-5680A Rubidium Frequency Standard comprises neither frequency output nor RS-232 interface on the Sub-D 9-pin connector, but only the supply input (+15 VDC and Gnd, of course) and Lock and 1-PPS (1 pulse per second) output.

The unit is marked as 'Revision:B' on its label (lower left corner). I think this is important (you may recognize this in product pictures in internet offers) as these units are - or at least my unit is equipped with a

- DDS (Direct Digital Synthesizer) Board with AD9830 IC and its own RS-232 interface as described in many descriptions I have found in the internet.
- Adjustment Board with DALLAS microcontroller DS80C320 (8052 µC, ROM-less) and an additional RS-232 interface. I believe that the function of this board is OPTION 02 (frequency fine tuning) as described within the original manufacturer's FE-5680A data sheet.

My Modifications

Intention

I want to use the FE-5680A as a universal high-precise, programmable synthesizer with a selectable output frequency range of at least 10 Hz to 20 MHz. The frequency output as well as the RS-232 interface should be available on the Sub-D 9-pin connector.

Original Circuit Diagram

The original DDS Board is shown here:
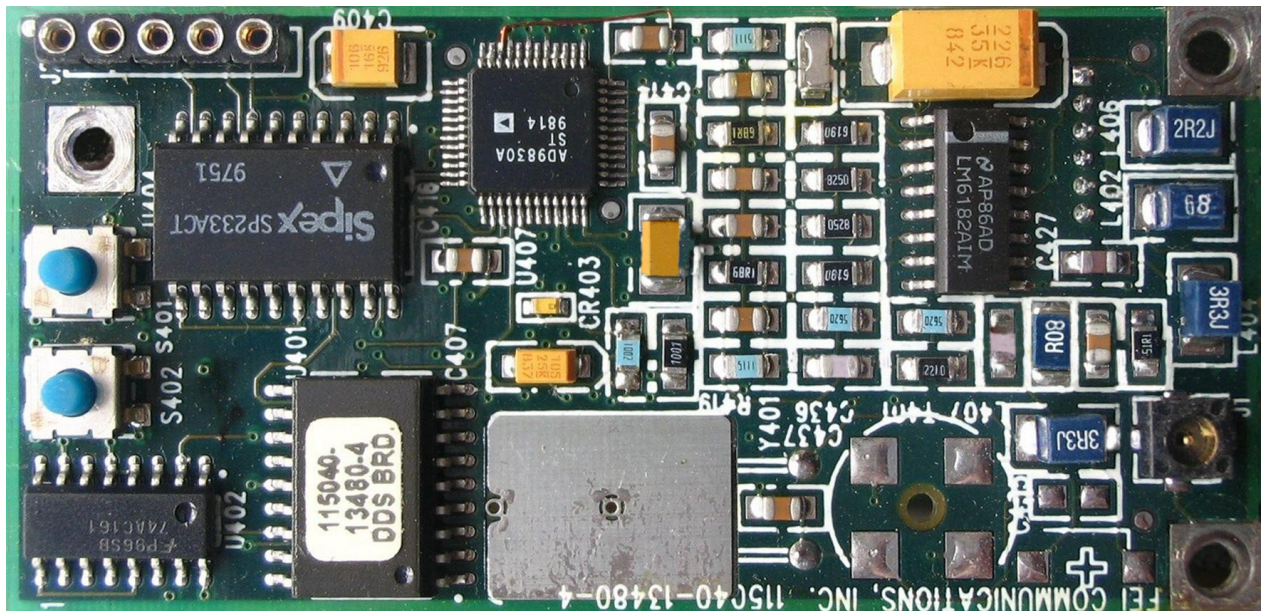
DDS Board – Top view

I have examined the filter and amplifier section; the results can be seen here:
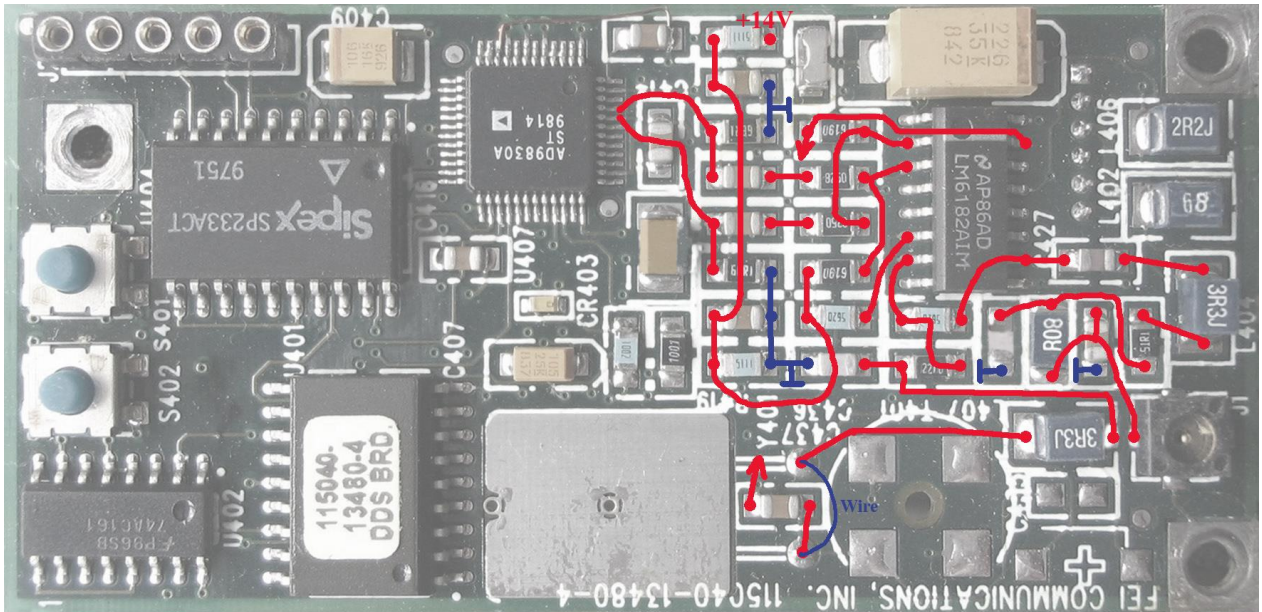
DDS Board – Layout Amplifier & Filter

The resulting circuit diagram is enclosed here:
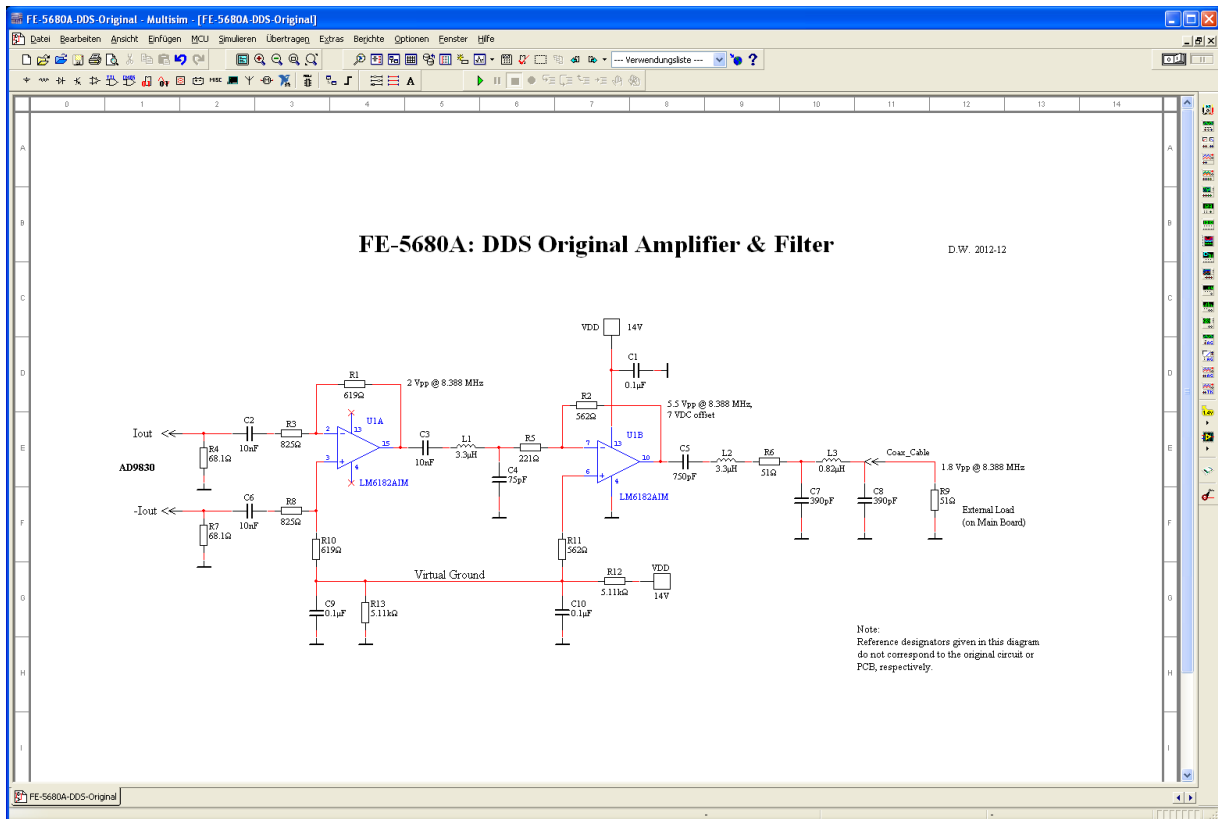
DDS Filter Circuit

Please note that the capacitor values of the second filter stage are measured within the circuit and thus, cannot be guaranteed to be 100% exact.

Note: this and all other diagrams can be found in a magnified version attached to the end of this document !

Simulated Filter Frequency Response and Simulated Modifications

I have simulated the frequency response of the original FE-5680A filter and amplifier circuit by means of a SPICE simulation. You can see the results for each filter stage here:
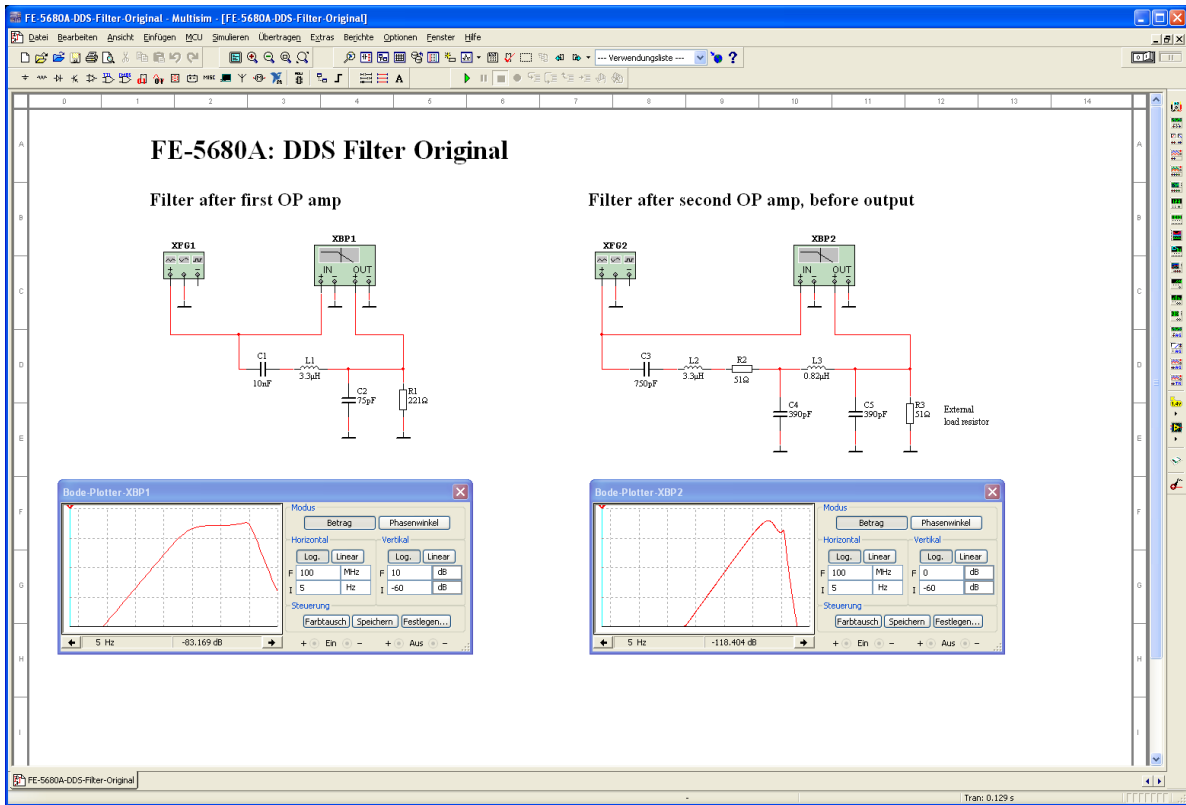
DDS Original Filters

The simulation result for both filters together (and the op amp between them) is shown here:
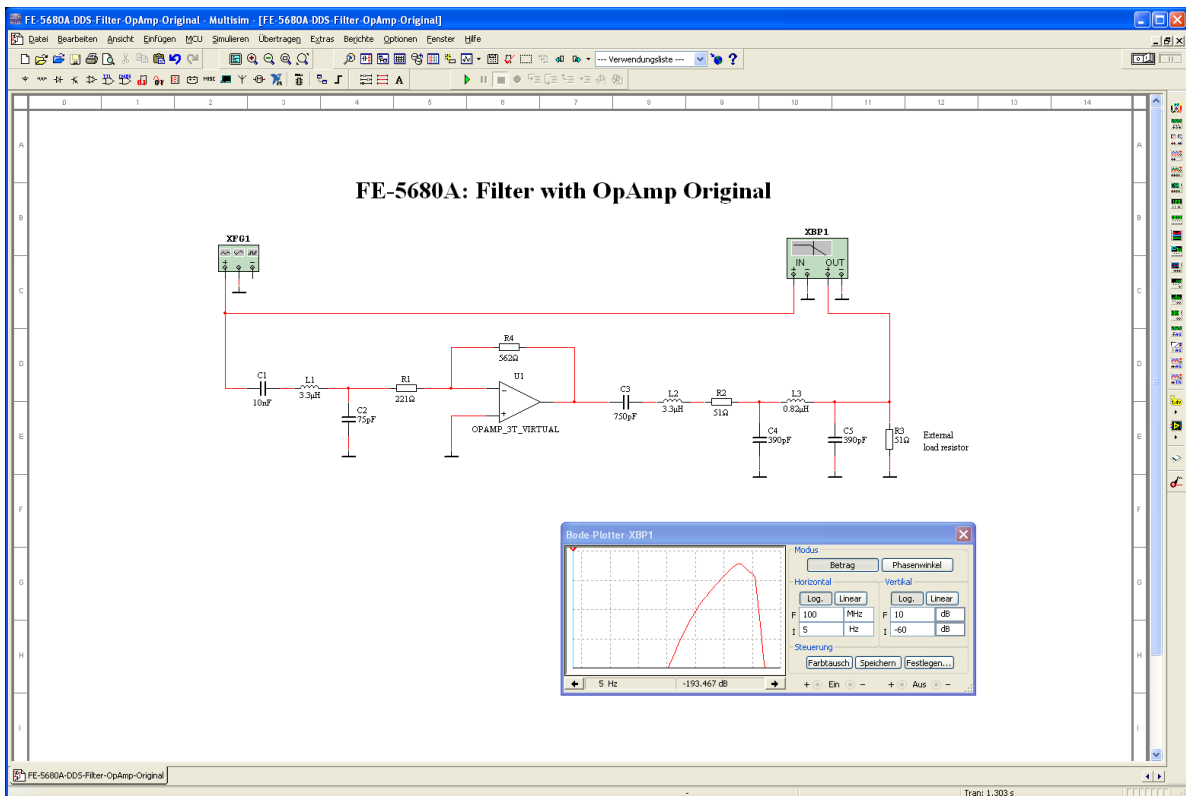
DDS Original Filters & Op Amp

With further simulations I have tried to alter the (simulated) filter components to gain an extended low-frequency response. You can find the results below:
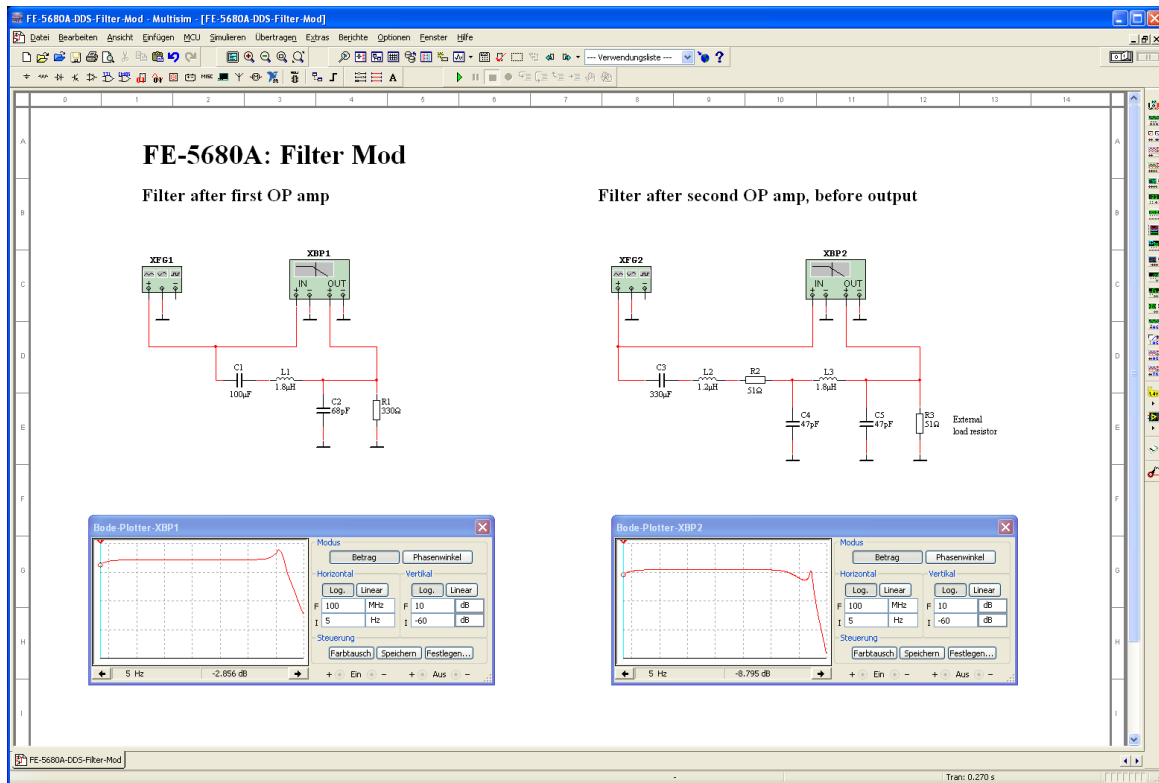
DDS Filters Mod
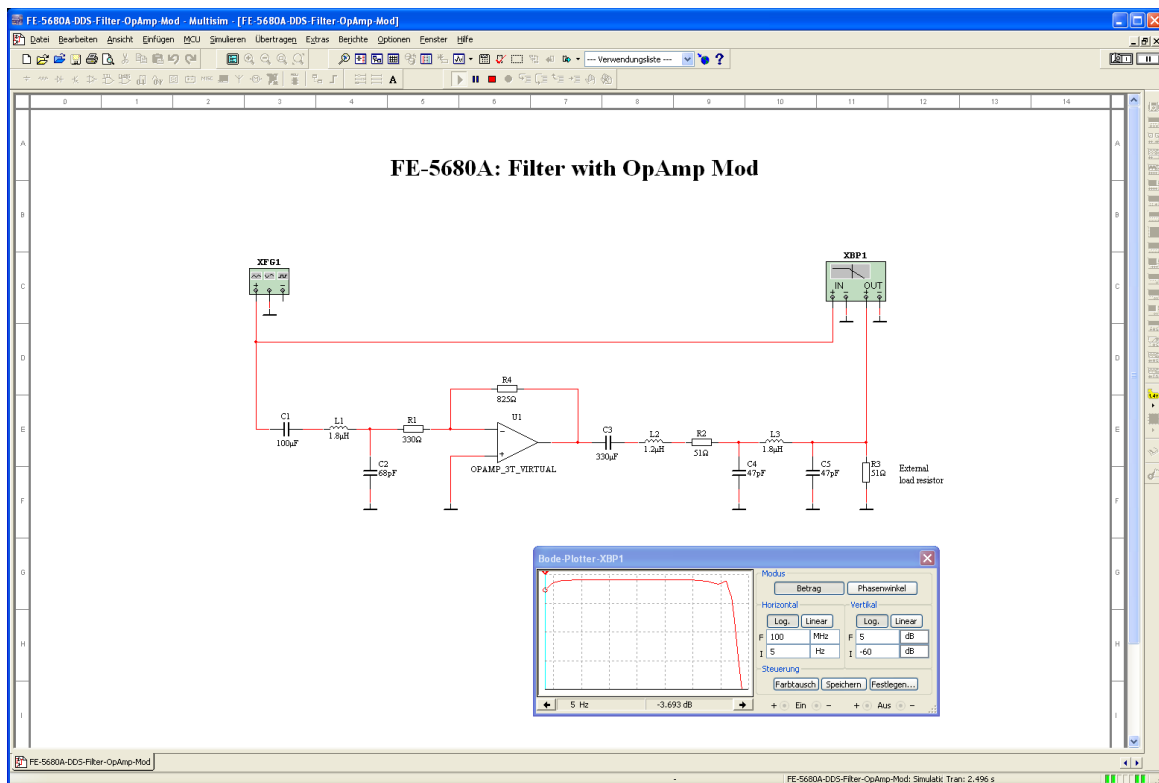
DDS Filters & Op Amp Mod

Modified DDS Board

As not only the filters has to be modified but because also the coupling capacitors of the first amplifier stage have to be extremely enlarged to gain the desired low-frequency response, I decided to re-design the first

amplifier stage to get a high input impedance. Further on I do not use the internal filter but routed-out the signal after the first amplifier (with 75 Ohm back-terminated coax cable) - with the necessity or possibility, respectively to use external filter circuitry and additional external amplifiers.

Suitable filter designs may be found in the internet. Again I have simulated two filter circuits with my SPICE simulator; the results are given here:

DDS Filter ELV Elektronik

Please find the circuit diagram with my modifications and the additional output below:

DDS Modified Circuit

As can be seen, the first amplifier is no longer wired as differential amplifier. Instead I use the positive op-amp input as high-impedance input for signal amplification. Note that the coupling capacitor (10 µF) is a miniature ceramic type. The first amplifier stage is configured as cable driver for the (AC-coupled) output coax cable RG-179. To compensate this heavier load for the first amplifier, I increased the input resistance of the second amplifier stage (from 221 to 330 Ohm). I also replaced the resistor divider of the original design with an IC - TLE2426LP, called 'Rail Splitter' by Texas Instruments, to get a stable virtual ground with low impedance even at low frequencies.

Note that the 1 PPS output function was not changed by my modifications; after power-on my modified FE-5680A outputs it as it did in original state.

A picture of the modified DDS Board is shown below:

Modified DDS Board

"Hanging" on the upper edge of the board, you may see the TLE2426LP ("rail splitter"). The black cable is the RS-232 interface cable; I soldered it to the RS-232 connector from the bottom side of the PCB. Onto a free copper-clad field, as can be seen in the picture at the bottom edge of the DDS Board, I glued a small piece of PCB which now carries the three coupling capacitors for the output and at the same time the solder joint of the output cable (RG-179). Note that the solder pad, I used to mount the 75 Ohm resistor, had to be isolated by removing the copper trace connected to it.

Modification of Adjustment Board

To gain access to the Sub-D 9-pin connector, I removed the Adjustment Board together with the cooling aluminium angle (with attached plastic IC - or whatever it is) by removing the nut (and washer) from the screw at the center cooling block of the FE-5680A. I cut off the three wires connecting the Adjustment Board with the Main Board and soldered a connector made of three pins of an IC socket into the solder pads of the board. As mating connector, again I used three pins of an IC socket with the three wires soldered into the socket holes.

As I didn't find a connector mating the RS-232 connector of the Adjustment Board, I once more used an IC socket, glued onto the board. The function and arrangement is the same as it is with the connector at the DDS Board: Gnd, TxD (output from) and RxD (input to the Adjustment Board). This can be verified with the help of the RS-232 interface SP233ACT data sheet. The remaining two pins of the original connector are routed to Vcc (not used here).

The described modifications are shown in the next two pictures:

Adjustment Board Top View

Adjustment Board Bottom View

Modification of Sub-D 9-pin Connector

I cut off the solder pins of the original connector and removed it. The remaining pins could easily be de-soldered from the upper side of the Main Board (without removing the FE-5680A's base plate of housing). Then I mounted a Sub-D 9-pin connector with straight PCB solder pins. The advantage is that these pins can either be soldered with wires to the board (in different arrangement compared to the original wiring, see below) and on the other hand, can be used as connector pins for IC sockets. That's what I did for the frequency output as well as for the RS-232 interface. To get two adjacent pins for the connection of the coax cable I slightly re-arranged the assignments of the Sub-D 9-pin connector as follows:

Pin	Function
1	Power Supply +15 VDC
2	GND (Power Supply and RS-232)
3	Frequency Output (10 Hz ~ 20 MHz, 75 Ohm)
4	Frequency Output RTN (Cable Screen)
5	GND (Power Supply and RS-232)
6	1 PPS Output
7	Lock Indicator (CMOS, Low = locked)
8	RS-232C - RxD (into FE-5680A)
9	RS-232C - TxD (from FE-5680A)

The modifications of the Sub-D 9-pin connector and its connections can be seen in the picture below:
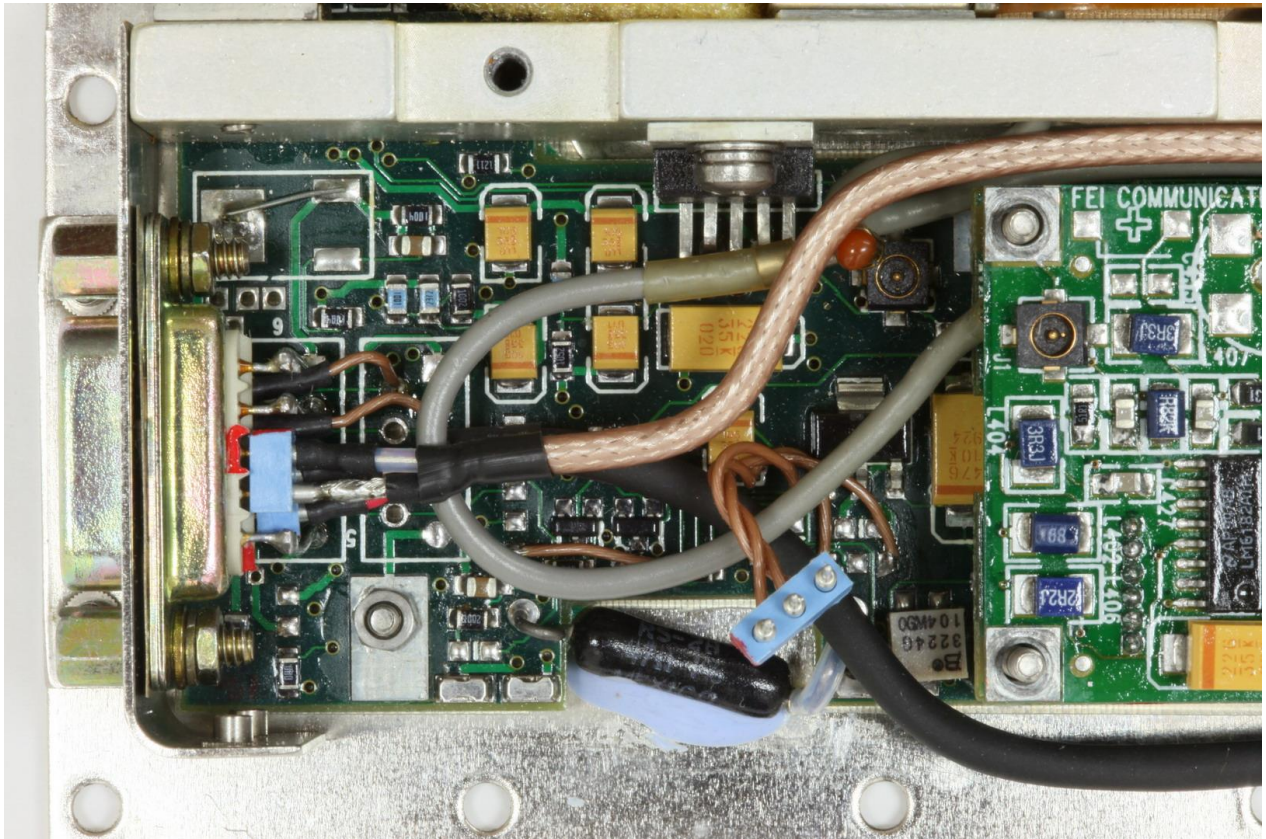
Modified Sub-D Connector

Conclusion

As described above, I successfully modified my FE-5680A Rubidium Frequency Standard to get a random programmable output frequency between 10 Hz and 20 MHz with a amplitude of approx. 1.1 Vpp at 75 Ohm. A sine reconstruction filter and associated amplifiers have to be added externally.

Please send feedback and remarks to Matthias at DD1US@AMSAT.ORG.

Best regards

Detlef

Note: Appended to this document you can find magnified versions of all diagrams.
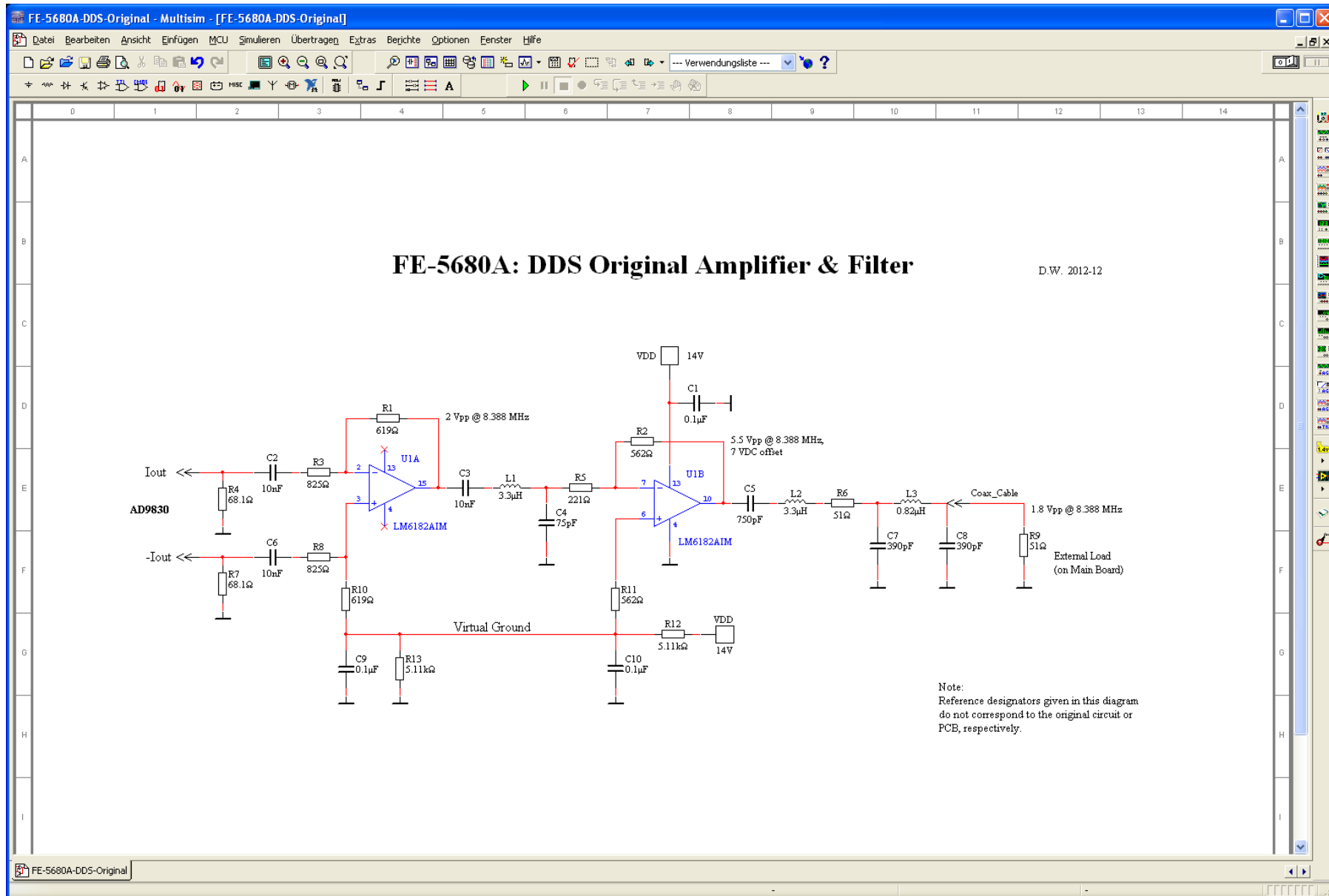
--- Verwendungsliste ---

FE-5680A: DDS Original Amplifier & Filter

D.W. 2012-12

VDD 14V

C1
0.1µF

R1
619Ω

2 Vpp @ 8.388 MHz

U1A

R2
562Ω

5.5 Vpp @ 8.388 MHz,
7 VDC offset

U1B

Iout

C2
10nF

R3
825Ω

C3
10nF

L1
3.3µH

R5
221Ω

C5
750pF

L2
3.3µH

R6
51Ω

L3
0.82µH

Coax_Cable

1.8 Vpp @ 8.388 MHz

AD9830

R4
68.1Ω

C4
75pF

LM6182AIM

LM6182AIM

C7
390pF

C8
390pF

R9
51Ω

External Load
(on Main Board)

-Iout

C6
10nF

R8
825Ω

R7
68.1Ω

R10
619Ω

R11
562Ω

Virtual Ground

R12
5.11kΩ

VDD
14V

C9
0.1µF

R13
5.11kΩ

C10
0.1µF

Note:
Reference designators given in this diagram
do not correspond to the original circuit or
PCB, respectively.

FE-5680A-DDS-Original

Datei Bearbeiten Ansicht Einfügen MCU Simulieren Übertragen Extras Berichte Optionen Fenster Hilfe

--- Verwendungsliste ---

FE-5680A: DDS Filter Original

Filter after first OP amp

Filter after second OP amp, before output

XFG1   XBP1
IN OUT

C1
10nF

L1
3.3µH

C2
75pF

R1
221Ω

XFG2   XBP2
IN OUT

C3
750pF

L2
3.3µH

R2
51Ω

L3
0.82µH

C4
390pF

C5
390pF

R3
51Ω

External
load resistor

Bode-Plotter-XBP1

Modus
Betrag   Phasenwinkel

Horizontal
Log. Linear
F 100 MHz
I 5   Hz

Vertikal
Log. Linear
F 10   dB
I -60 dB

Steuerung
Farbtausch Speichern Festlegen...

5 Hz   -83.169 dB

+ ● Ein ● –   + ● Aus ● –

Bode-Plotter-XBP2

Modus
Betrag   Phasenwinkel

Horizontal
Log. Linear
F 100 MHz
I 5   Hz

Vertikal
Log. Linear
F 0   dB
I -60 dB

Steuerung
Farbtausch Speichern Festlegen...

5 Hz   -118.404 dB

+ ● Ein ● –   + ● Aus ● –

FE-5680A-DDS-Filter-Original

Tran: 0.129 s

FE-5680A: Filter with OpAmp Original

Datei Bearbeiten Ansicht Einfügen MCU Simulieren Übertragen Extras Berichte Optionen Fenster Hilfe

--- Verwendungsliste ---

FE-5680A: Filter Mod

Filter after first OP amp

Filter after second OP amp, before output

XFG1

XBP1

IN OUT

C1
100μF

L1
1.8μH

C2
68pF

R1
330Ω

XFG2

XBP2

IN OUT

C3
330μF

L2
1.2μH

R2
51Ω

L3
1.8μH

C4
47pF

C5
47pF

R3
51Ω

External
load resistor

Bode-Plotter-XBP1

Modus
Betrag   Phasenwinkel

Horizontal
Log. Linear
F 100   MHz
I 5   Hz

Vertikal
Log. Linear
F 10   dB
I -60 dB

Steuerung
Farbtausch Speichern Festlegen...

5 Hz   -2.856 dB

+ ◉ Ein ◉ −   + ◉ Aus ◉ −

Bode-Plotter-XBP2

Modus
Betrag   Phasenwinkel

Horizontal
Log. Linear
F 100   MHz
I 5   Hz

Vertikal
Log. Linear
F 10   dB
I -60 dB

Steuerung
Farbtausch Speichern Festlegen...

5 Hz   -8.795 dB

+ ◉ Ein ◉ −   + ◉ Aus ◉ −

FE-5680A-DDS-Filter-Mod

Tran: 0.270 s
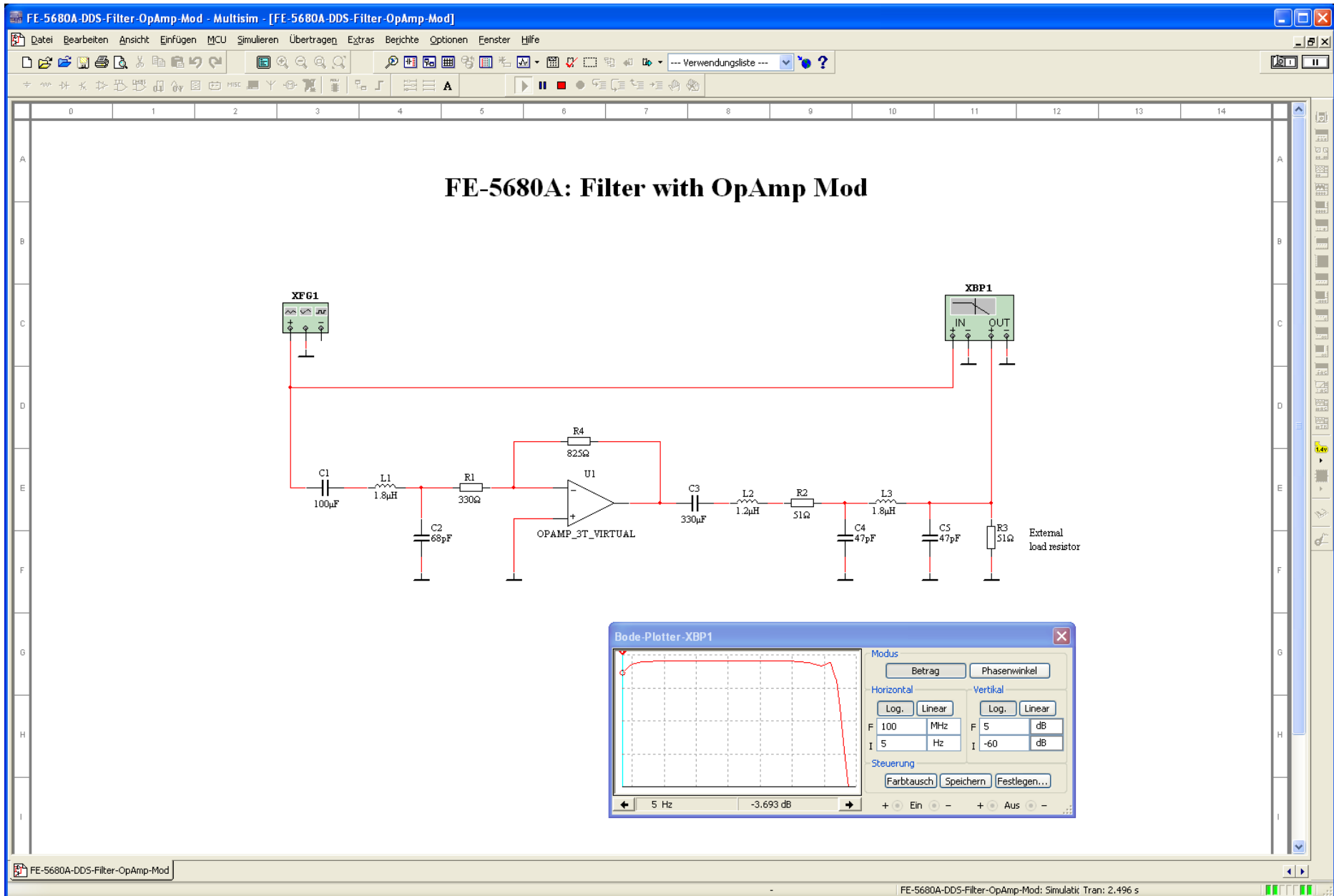
FE-5680A: Filter with OpAmp Mod

Datei   Bearbeiten   Ansicht   Einfügen   MCU   Simulieren   Übertragen   Extras   Berichte   Optionen   Fenster   Hilfe

--- Verwendungsliste ---

Filter "20 MHz DDS-Board DDS 20",
ELVjournal 05/2002

Filter "20 MHz Funktionsgenerator",
Elektronik 14/1997

XFG1   XBP1
IN   OUT

XFG2   XBP2
IN   OUT

R4   L1   L4   L5
390Ω   4.7µH   4.7µH   4.7µH

C7   C2   C1   C6   R1
8.2pF   39pF   39pF   8.2pF   470Ω

C10   C12   C13   C11
4.7pF   6.8pF   6.8pF   4.7pF

R2   L2   L6   L3   L7
120Ω   2.2µH   2.2µH   2.2µH   2.2µH

C3   C8   C4   C5   C9   R3
22pF   47pF   47pF   47pF   22pF   240Ω

Bode-Plotter-XBP1

Modus
Betrag   Phasenwinkel
Horizontal   Vertikal
Log.   Linear   Log.   Linear
F 100   MHz   F -0   dB
I 5   Hz   I -60   dB
Steuerung
Farbtausch   Speichern   Festlegen...
←   5 Hz   -5.248 dB   →   + ◉ Ein ◉ −   + ◉ Aus ◉ −

Bode-Plotter-XBP2

Modus
Betrag   Phasenwinkel
Horizontal   Vertikal
Log.   Linear   Log.   Linear
F 100   MHz   F 0   dB
I 5   Hz   I -60   dB
Steuerung
Farbtausch   Speichern   Festlegen...
←   5 Hz   -3.522 dB   →   + ◉ Ein ◉ −   + ◉ Aus ◉ −

DDS-Filter-ELV-Elektronik

Tran: 0.344 s

FE-5680A: DDS Modified Amplifier & Filter
with additional 75 Ohm Output 10 Hz ~ 20 MHz

D.W. 2012-12