Rugged 2 m Preamplifier for Tough RF Conditions

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1. Introduction

This article builds on the ongoing low noise amplifier (LNA) work of the authors which was published in previous DUBUS editions [1, 2]. The new preamplifier described here was designed as part of a 144/28 MHz transverter for radio clubs OK2C and OM6A and is a lower cost alternative for functionally similar professional products in the 2 m band [3]. The transverter design was carried through separate LNA, Rx mixer, IF amplifier, Tx mixer, PA and OCXO modules (LEGO style) and will be published in a future DUBUS edition. See Fig. 1. The preamplifier, equipped with RF relays, can also be used alone directly at the antenna.

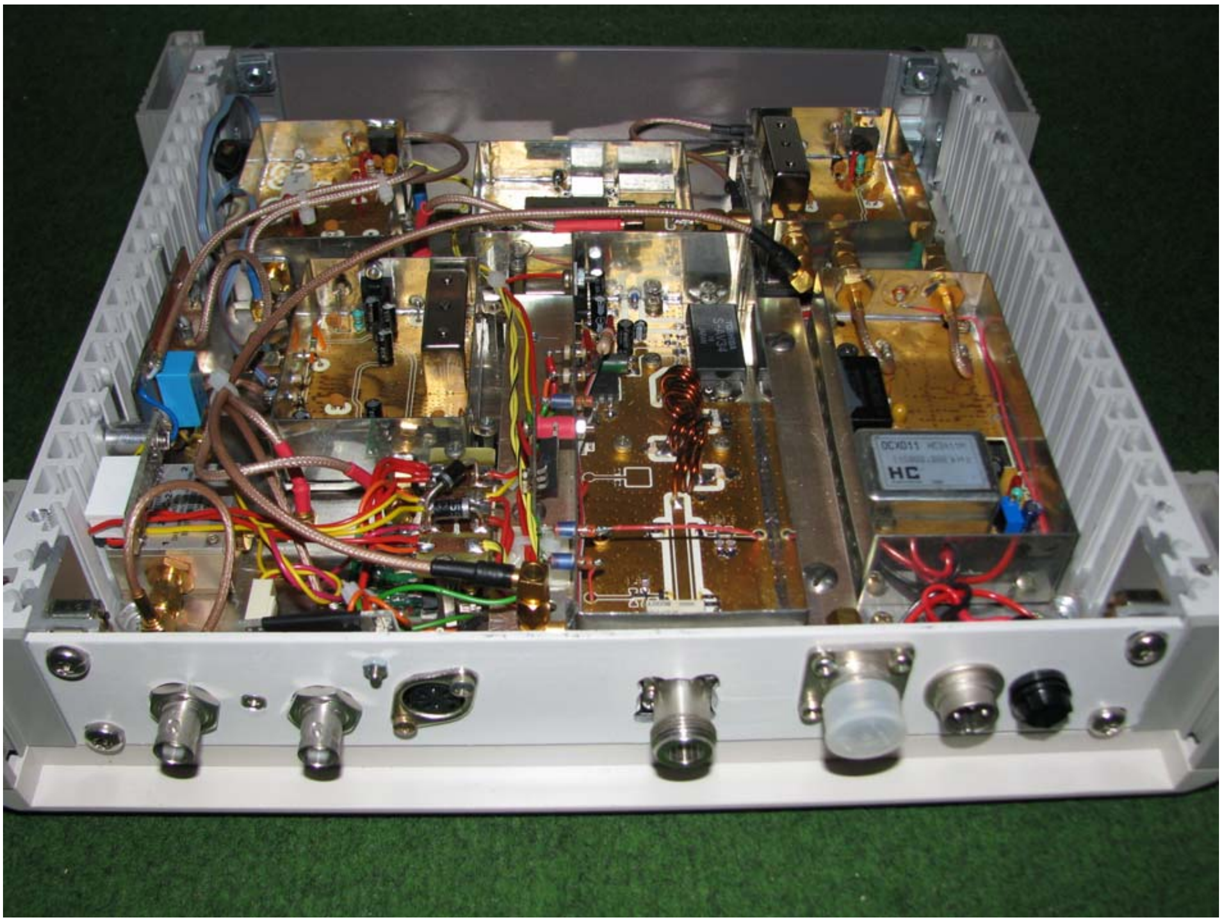


Fig. 1 - 144/28 MHz Transverter

2. LNA RF Operating Parameter Requirements

Operating parameters of a single LNA must accommodate the dynamic range of the system's receiving chain. Receiver dynamic range issues are often described in various publications [4, 5]. Let's now review the calculations for a 3-stage cascaded connection. See Fig. 2.

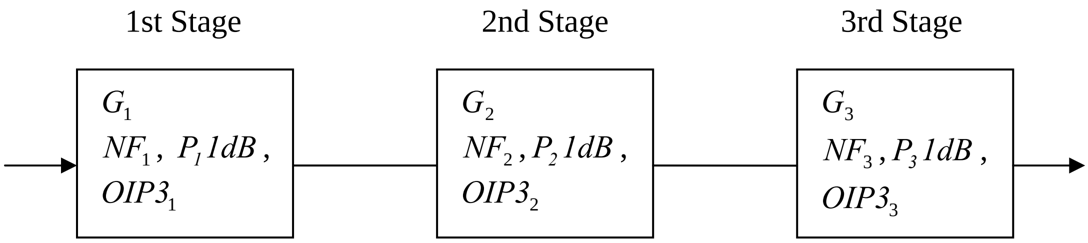


Fig. 2 – A 3-stage cascaded connection. For each stage Gain – *G*, Noise Figure –*NF*, Output Power Compression *P1dB* and Output 3rd-order Intercept Point- O*IP3*

The lower limit of dynamic range is often defined by noise figure. In a 3-stage cascaded system it is given by the well-known Friis formula,

$$NF(\mathrm{dB}) = 10\log\left[NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1 G_2}\right] \tag{1}$$

The upper limit of dynamic range can be defined by the output power compression at 1dB. For three cascaded stages it is given by the formula

$$P1dB(\mathrm{dB}) = 10\log\left[\frac{1}{\frac{1}{P_1 1dB G_2 G_3} + \frac{1}{P_2 1dB G_3} + \frac{1}{P_3 1dB}}\right] \tag{2}$$

Another definition for the upper limit of dynamic range may be made by using the 3rd-order intercept point (*IP3*). The relationship between *OIP3* and the output power compression *P1dB* value is given by a rule of thumb and the difference is statistically 10-12 dB in favor of *OIP3* [6]. However, for accurate analysis of these variables, actual measurements must be performed. The 3-stage cascaded *OIP3* calculation is given by

$$OIP3(dB) = 10\log\left[\frac{1}{\frac{1}{OIP3_1 G_2 G_3} + \frac{1}{OIP3_2 G_3} + \frac{1}{OIP3_3}}\right] \tag{3}$$

Note: Linear values of noise figure and gain must be used for all formulas.

The relationship between input (*IIP3*) and output (*OIP3*) 3rd-order intercept point is given by the formula

$$IIP3 = OIP3 - G \quad (dB) \tag{4}$$

During portable operation, many stations are exposed to very high electromagnetic field levels from their 70cm and 23cm antennas and also from professional TV, FM or GSM transmitters. For example, the FM signal power level at OM6A station's portable QTH on the 2 m antenna is +25 dBm. Specifically because of this condition, we need to have a highly linear front end with good selectivity. Also, contest participation requires a very high dynamic range for the entire Rx chain including the LNA.

The noise figure of an LNA on 2 m is not as critical as on higher bands, since the G_a/T_S ratio (where G_a is antenna gain and T_S is system temperature) is influenced by a relatively higher antenna noise temperature of about 400 – 600° K, nevertheless it should be below 2.5 dB for terrestrial operation and the noise figure of the entire Rx chain should be better than 3 dB. This can be achieved by mounting the LNA at the antenna.

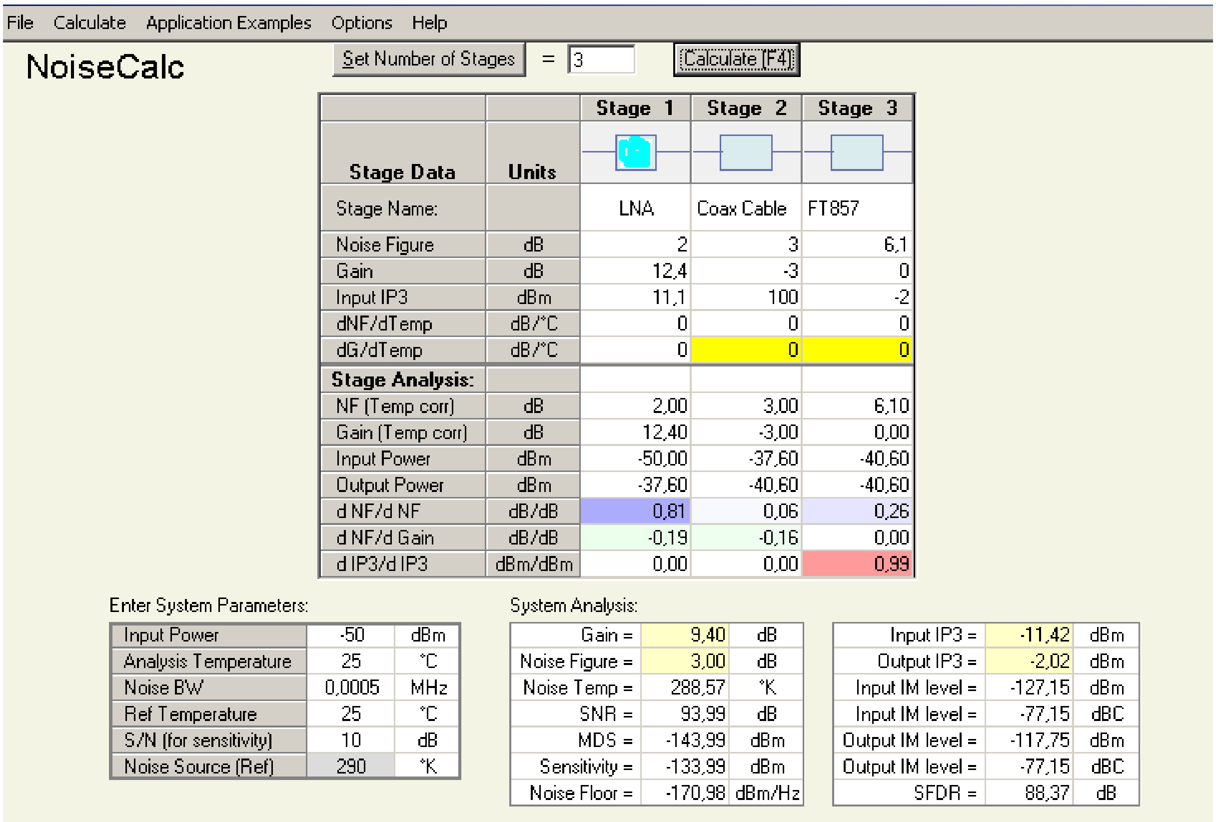
Various circuit calculators have been developed to facilitate the signal system analysis. Suitable for our application is the free software APPCAD [7]. In addition to cascaded *IP3*, *NF* calculations, this software also calculates third order intermodulation products (*IM*), Minimum Detectable Signal (*MDS*) and Spurious Free Dynamic Range (*SFDR*). Definitions of these values may be found in the program.

Example 1.

Using APPCAD software, determine optimum *Gain*, *IIP3*, and *SFDR* (500Hz) for a cascaded system consisting of the described preamplifier mounted at the antenna, feed line having 3 dB attenuation and an FT 857D transceiver, to achieve maximum *SFDR* and Rx chain 3 dB noise figure.

Parameters of LNA are *NF* = 2 dB, *IIP3* = 11.1 dBm,
SFDR = 104.06dB related to *BW* 500 Hz

Parameters of transceiver FT 857D are *NF* = 6.1dB, *IIP3* = -2dBm,
SFDR = 92.59 dB related to *BW* 500 Hz [8]



File Calculate Application Examples Options Help

NoiseCalc

Set Number of Stages = 3 Calculate (F4)

Stage Data	Units	Stage 1	Stage 2	Stage 3
Stage Name:		LNA	Coax Cable	FT857
Noise Figure	dB	2	3	6,1
Gain	dB	12,4	-3	0
Input IP3	dBm	11,1	100	-2
dNF/dTemp	dB/°C	0	0	0
dG/dTemp	dB/°C	0	0	0
Stage Analysis:				
NF (Temp corr)	dB	2,00	3,00	6,10
Gain (Temp corr)	dB	12,40	-3,00	0,00
Input Power	dBm	-50,00	-37,60	-40,60
Output Power	dBm	-37,60	-40,60	-40,60
d NF/d NF	dB/dB	0,81	0,06	0,26
d NF/d Gain	dB/dB	-0,19	-0,16	0,00
d IP3/d IP3	dBm/dBm	0,00	0,00	0,99

Enter System Parameters:

Input Power	-50	dBm
Analysis Temperature	25	°C
Noise BW	0,0005	MHz
Ref Temperature	25	°C
S/N (for sensitivity)	10	dB
Noise Source (Ref)	290	°K

System Analysis:

Gain =	9,40	dB
Noise Figure =	3,00	dB
Noise Temp =	288,57	°K
SNR =	93,99	dB
MDS =	-143,99	dBm
Sensitivity =	-133,99	dBm
Noise Floor =	-170,98	dBm/Hz

Input IP3 =	-11,42	dBm
Output IP3 =	-2,02	dBm
Input IM level =	-127,15	dBm
Input IM level =	-77,15	dBC
Output IM level =	-117,75	dBm
Output IM level =	-77,15	dBC
SFDR =	88,37	dB

Fig. 4 - APPCAD Software Dialog Window

From Fig. 4 it is apparent that for the cascaded system with resulting *NF* =3 dB, the *IIP3* = -11.42 dBm , *SFDR* = 88.37 dB and optimum LNA gain = 12.4 dB. From the calculation it is also obvious, that while the noise figure was considerably improved, other parameter values such as spurious free dynamic range and especially *IIP3* are significantly inferior. When using an LNA, we must particularly take into account its gain and select it to be as small as possible so as not to significantly reduce the *SFDR* value.

Based on the above calculations, we can refute the ham-radio myth that a high *IP3* preamplifier can improve the dynamic range of the entire receiving system at the working frequency.

3. Circuit Design

Our LNA schematic is shown in Fig. 5. The amplifier employs two RFMD MMIC amplifiers, SPF-5122Z [9]. The MMIC amplifiers are coupled together by a pair of two-way 90 degree power combiners with very low insertion loss. This configuration provides a better input impedance match, since the impedance match of these MMIC amplifiers is not very good at lower frequencies. Input selectivity is achieved using triple helical filters customized for low insertion loss. Filter measurements confirmed factory specifications [10]. See Fig. 6. The output selectivity provides the triple helical filter with narrow frequency bandwidth, since the bandwidth performance of helical filters is a tradeoff against insertion loss, but higher insertion loss on the output is made up by MMIC gain. The LNA gain can be adjusted with fixed attenuators on each MMIC amplifier branch. TOKO 1314 output filters, from "GSM junk," were used. See Fig. 7. We had similar filters marked with numbers 1313 and 1315. The S_{21} measurements of all these filters can be found on the OK2ULQ web site [11]. Since these filters are no longer in production, our PC board has been designed for variant assembly so that it is possible to use any TT model of Temwell filters as well. The dual sided PC board is made of ROGERS RO4050B material. The component layout is shown in Fig. 8 -10. The parts list is summarized in Tab. 1. Problems may be encountered with hand-soldering the tiny MMIC package. We had the opportunity to test a professional soldering machine for this purpose. See Fig. 11.

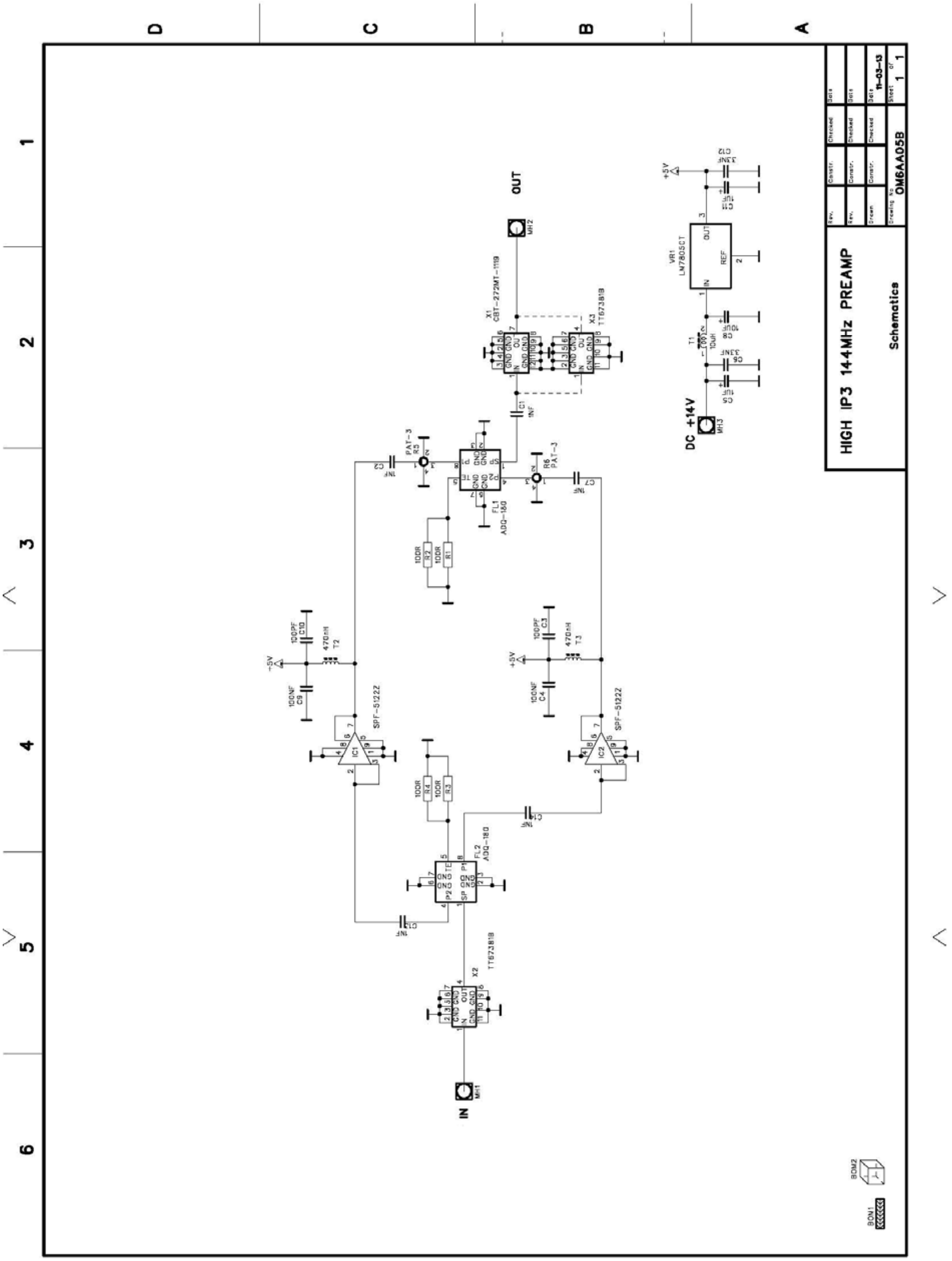


Fig. 5- LNA Schematic

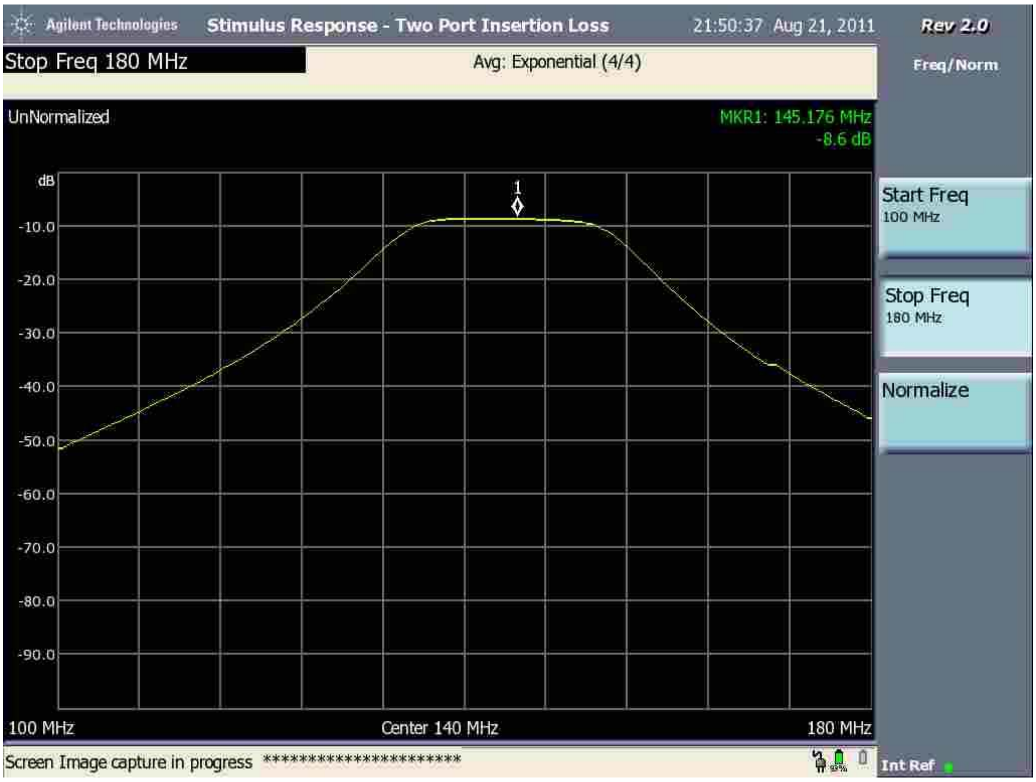


Fig. 6- Two port insertion loss (S_{21} characteristics) of Temwell TT67381B filter. Insertion loss at 145 MHz is 1 dB.

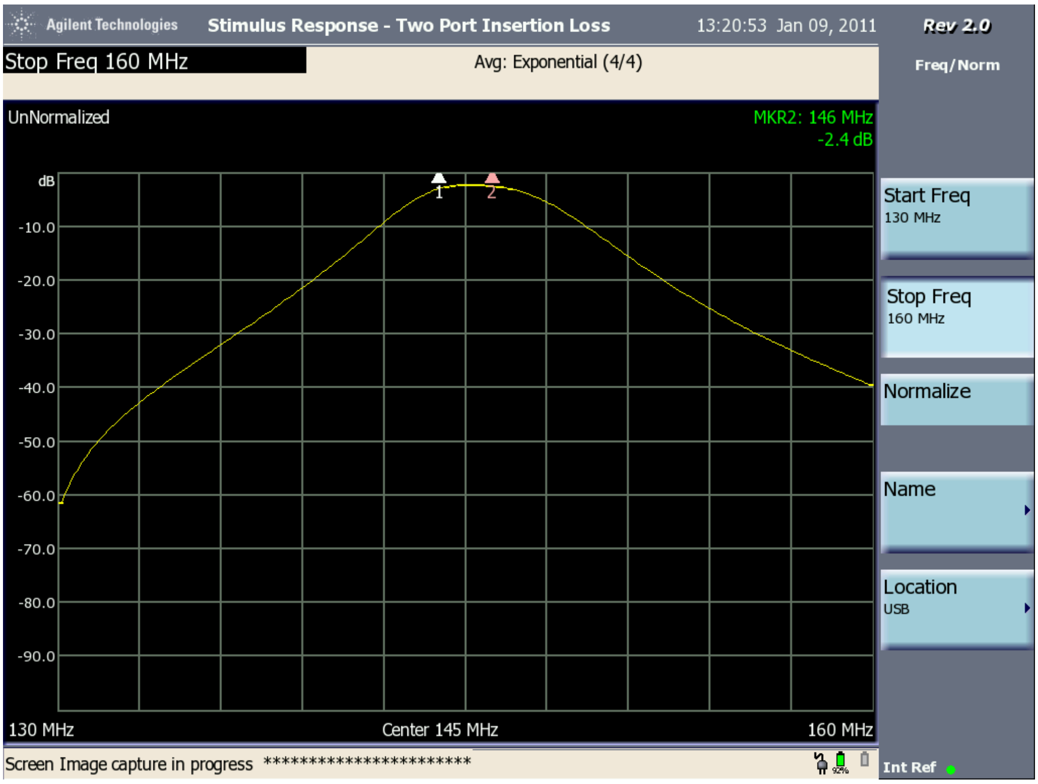


Fig. 7- S_{21} characteristic of TOKO 1314 filter

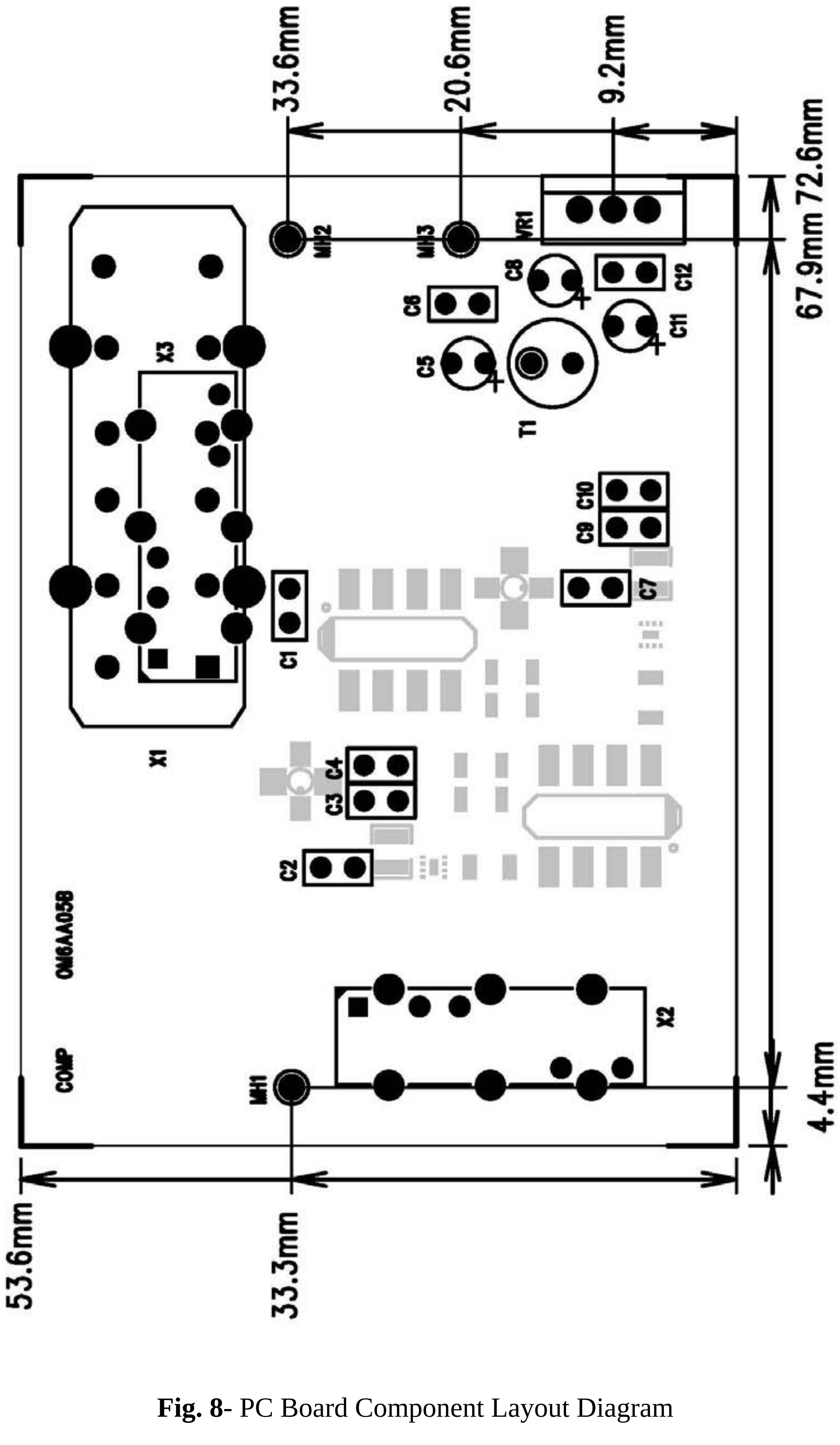


Fig. 8- PC Board Component Layout Diagram

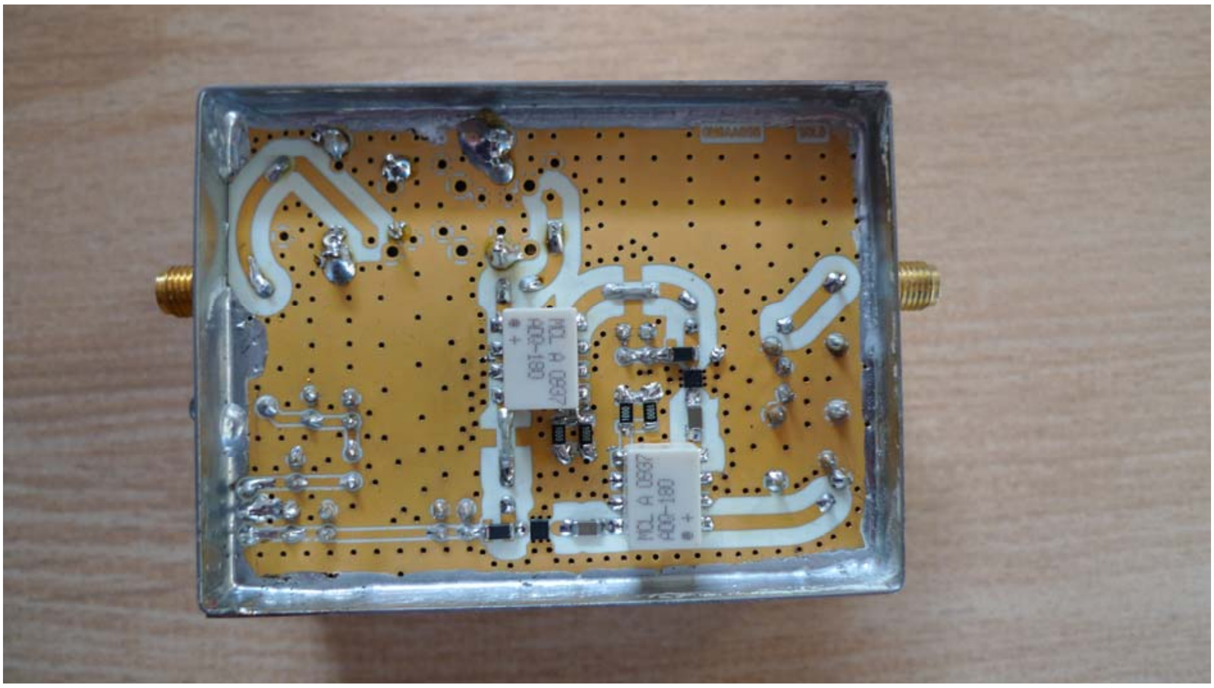


Fig. 9- PC Board Component Layout – bottom view

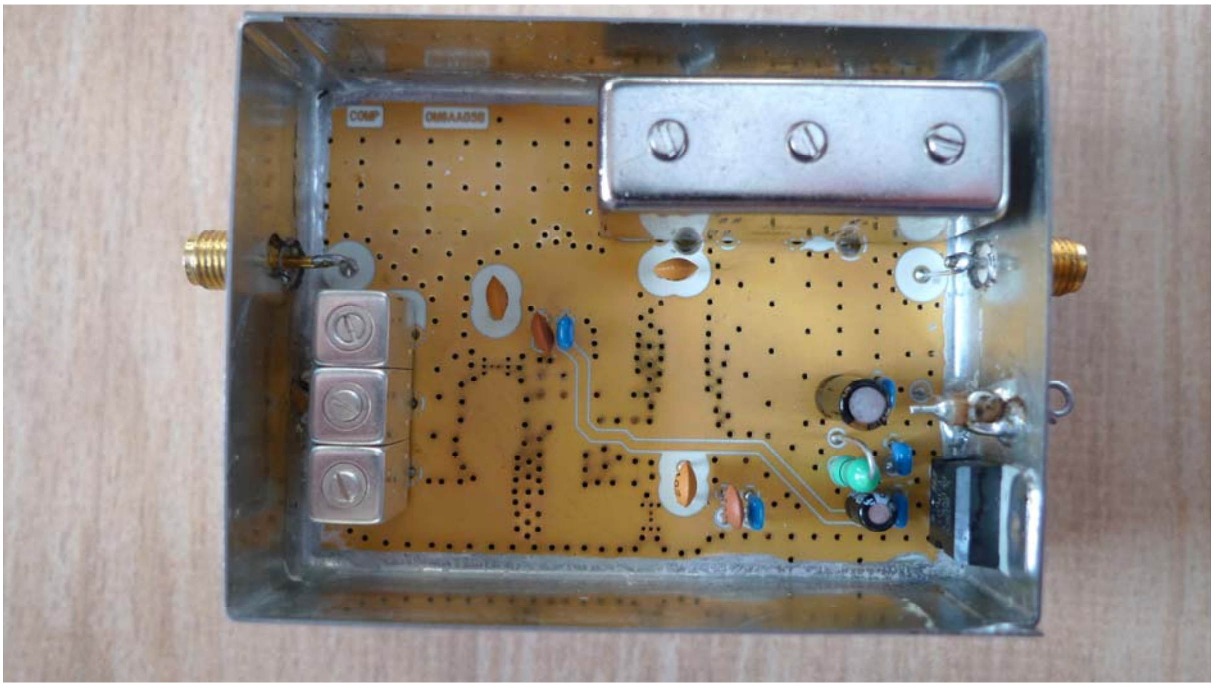


Fig. 10- PC Board Component Layout –top view

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Item	Qty	Reference	PART NUMBER	VALUE	PCG	P-S	ARTC	NOTE
1	2	IC1-2	SPF-5122Z	50-4000MHz	2X2 MM	RFMD		LOW NOISE MMIC AMPLIFIER
2	1	VR1	LM7805CT		TO-220	NATIONAL SEMI.		VOLTAGE REG.
3	2	R5-6	PAT-1		AF320	MINI-CIRCUITS		1W MINIATURE CERAMIC FIXED ATTENUATOR
4	4	R1-4	RC-02HP	100R	1206	PHILIPS		RES.SMD
5	3	C1-2 C7	EGRU RM2.54	1NF	RM=2.54MM	PHILIPS		CERAMIC CAP.
6	2	C4 C9	EGRU RM2.54	100NF	RM=2.54MM	PHILIPS		CERAMIC CAP.
7	2	C3 C10	EGRU RM2.54	100PF	RM=2.54MM	PHILIPS		CERAMIC CAP.
8	2	C6 C12	EGRU RM2.54	33NF	RM=2.54MM	PHILIPS		CERAMIC CAP.
9	2	C13-14	KEFQ	1NF	1206	PHILIPS		CERAMIC CAP. SMD
10	2	C5 C11	TANTAL	1UF	RM=2.54MM	PHILIPS		RADIAL ELYT RM=2.54MM
11	1	C8	ELYT	10UF	RM=2.54MM	PHILIPS		RADIAL ELYT RM=2.54MM
12	1	T1	22R103	10uH	RM=3.1MM			INDUCTOR
13	2	T2-3	3650 1008 5%	470nH	36502C	TYCO		SMT INDUCTOR
14	1	X1	CBT-272MT-(1314)	145MHz	CBT	TOKO		TRIPLE TUNED FILTER
15	2	X2-3	TT67381B	144MHz	7H3B	TEMWELL		VHF,UHF HELICAL FILTER
16	2	FL1-2	ADQ-180	120-180MHz	CJ725	MINI CIRCUITS		POWER SPLITTER/COMBINER
17	1	MH3	HIGH-FREQUENCY SEALED LEADTHROUGH					
18	1	BOM2	WBG-35		55X74X30 MM	DONAU		METAL BOX
19	1	BOM1	RO4350B	ER=3.66	WEIGHT=0.762MM	ROGERS		PCB MATERIAL
20	2	MH1, MH2	SMA Connectors					

Tab. 1- Parts List

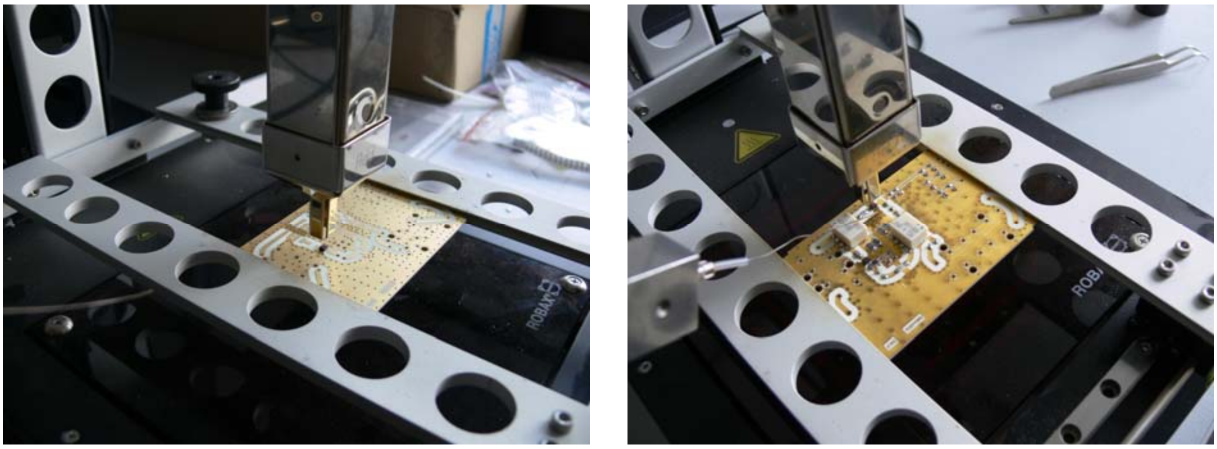

Fig. 11 a, b- Soldering the MMIC`s

4. Measured Parameters

4.1 *S*- Parameters

The *S*-parameters of our LNA were first measured without filters. The results are shown in Fig. 12–15. A Rohde & Schwarz ZVL-6 vector network analyzer was used for these measurements. The *S*-parameters with the output TOKO filter are documented in Fig. 16–19. *S*-parameters of the complete LNA equipped with both filters are plotted in Fig. 20-23. The S_{21} parameter of the complete LNA in the frequency range of 0.05 – 5 GHz is shown in Fig. 24.

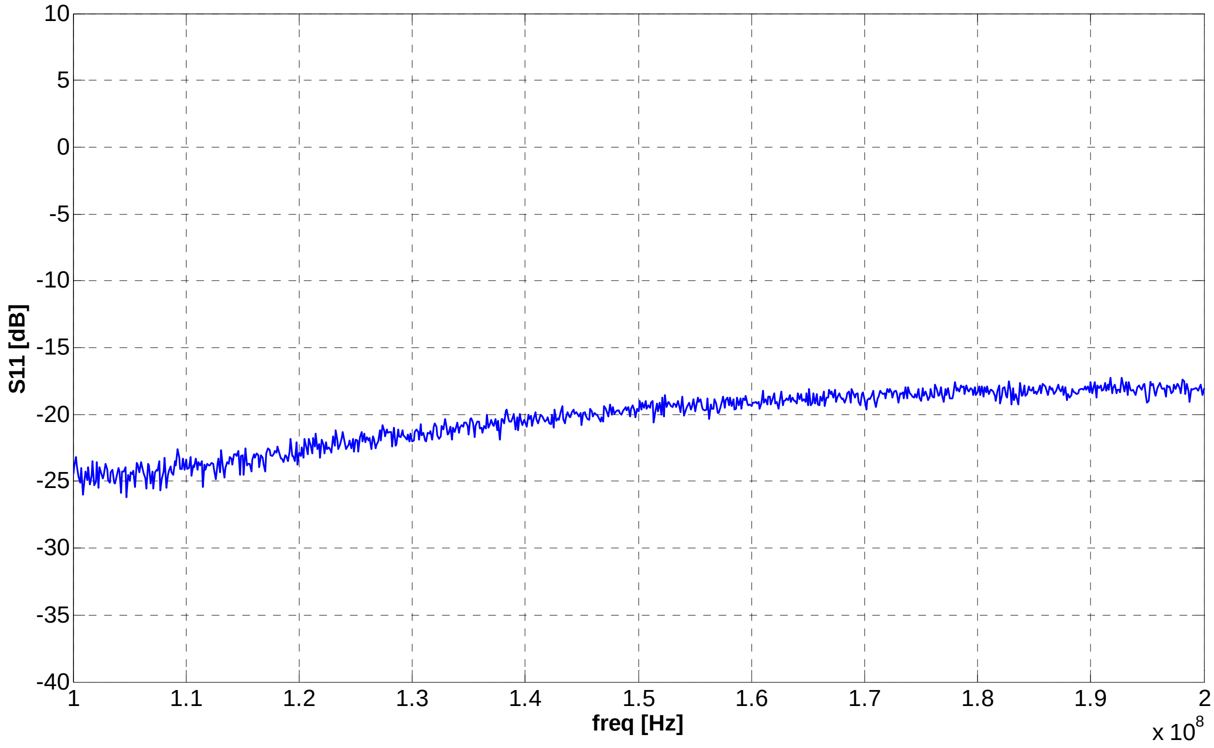

Fig. 12- S_{11} Parameter without filter

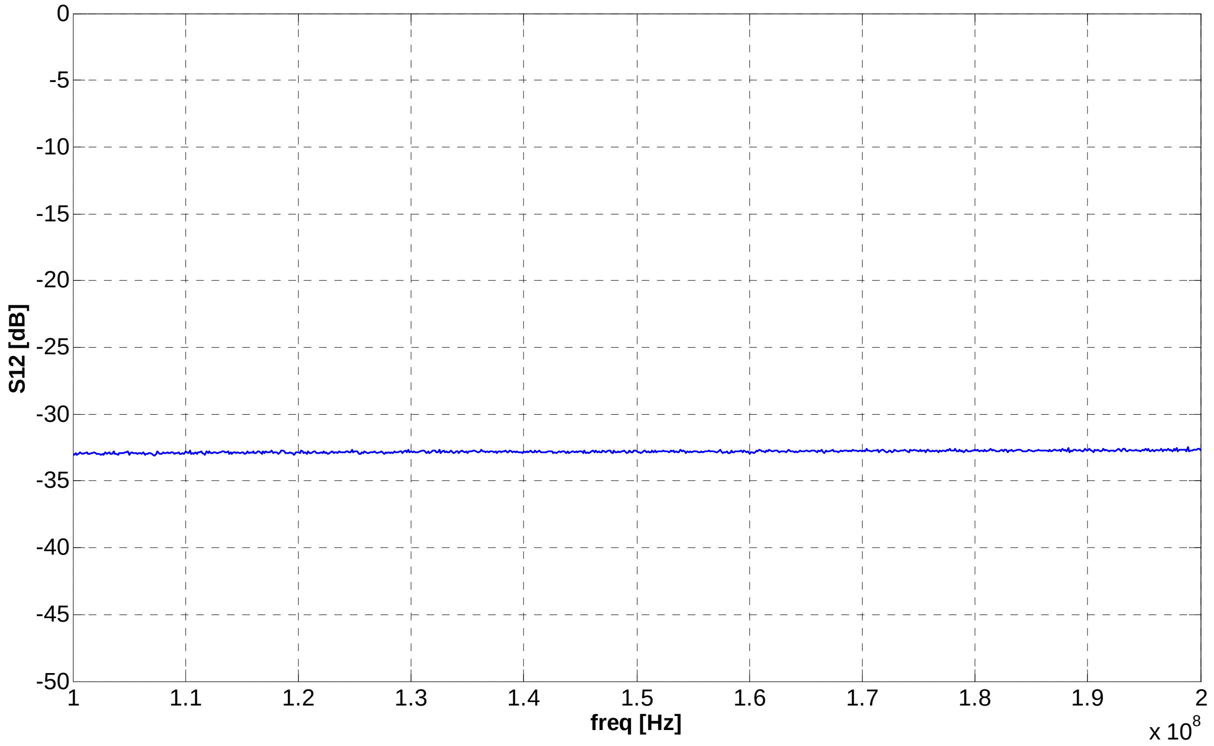

Fig. 13- S_{12} Parameter without filter

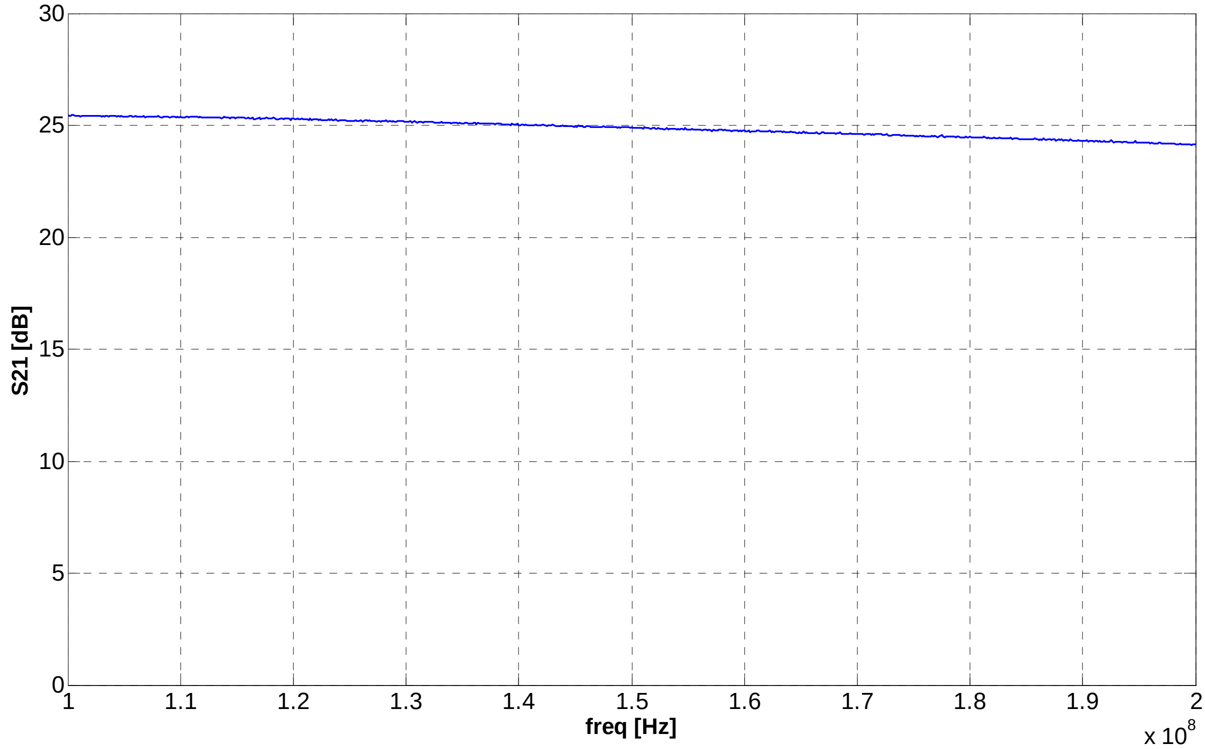

Fig. 14- S_{21} Parameter without filter

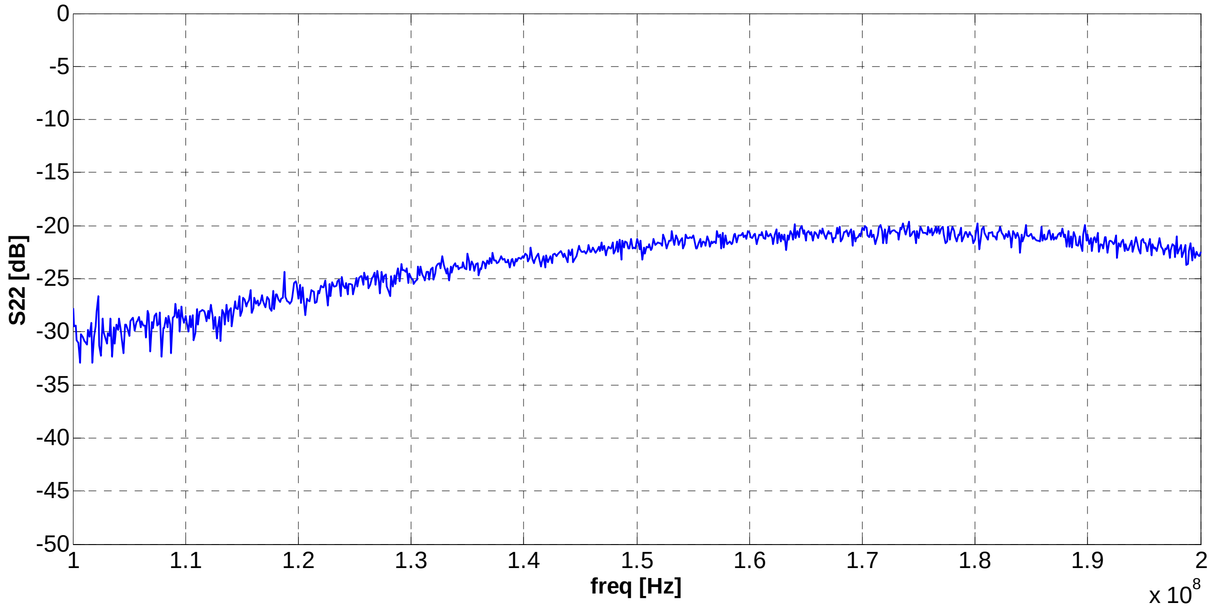

Fig. 15- S_{22} Parameter without filter

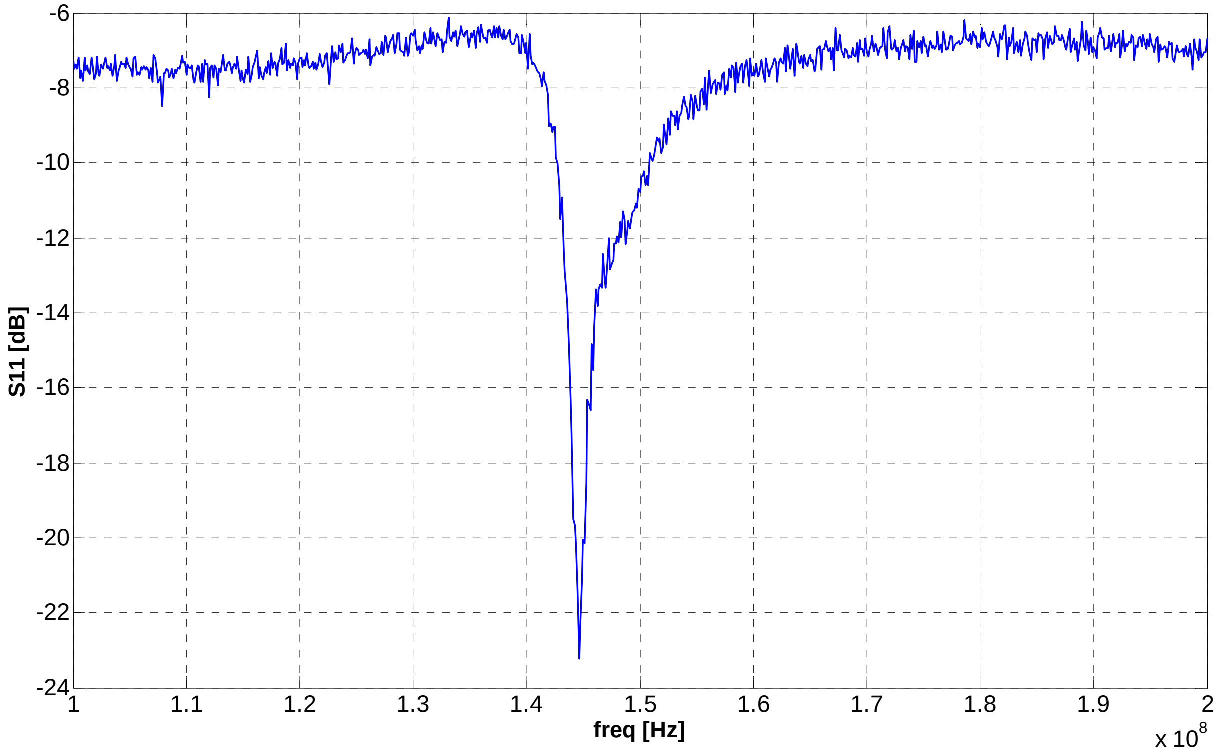

Fig. 16- S_{11} Parameter with TOKO filter on output

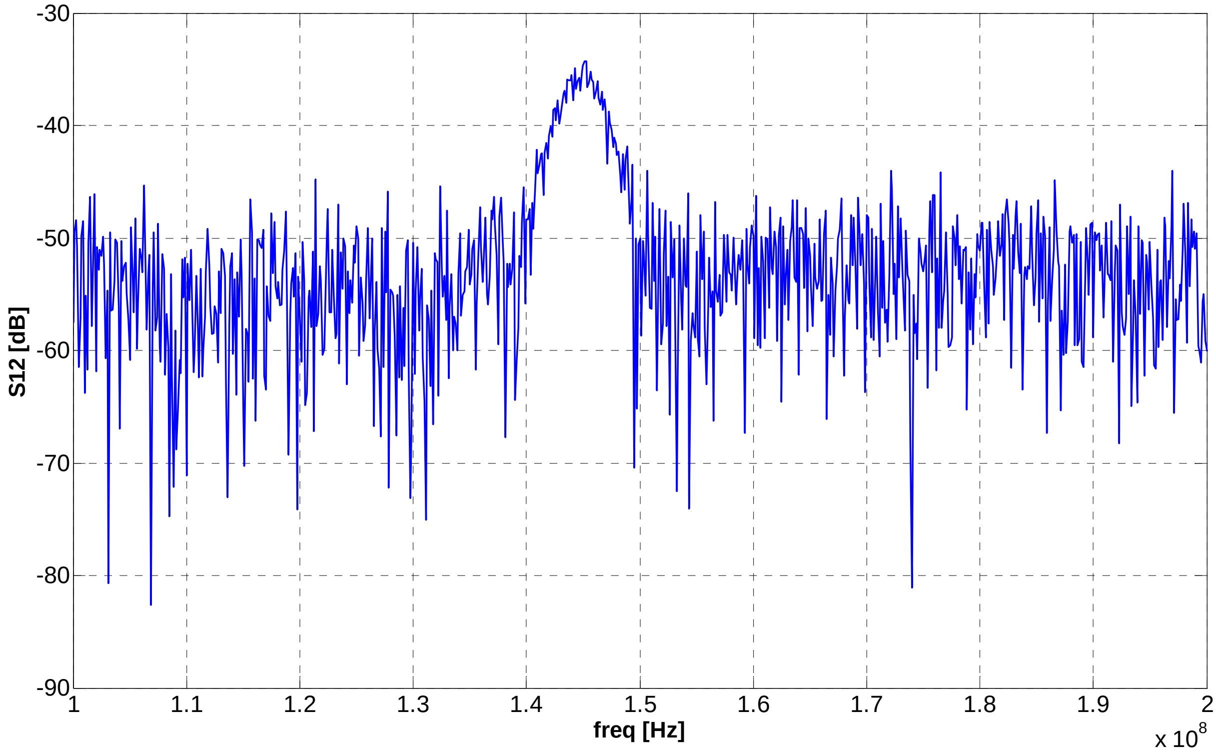

Fig. 17- S_{12} Parameter with TOKO filter on output

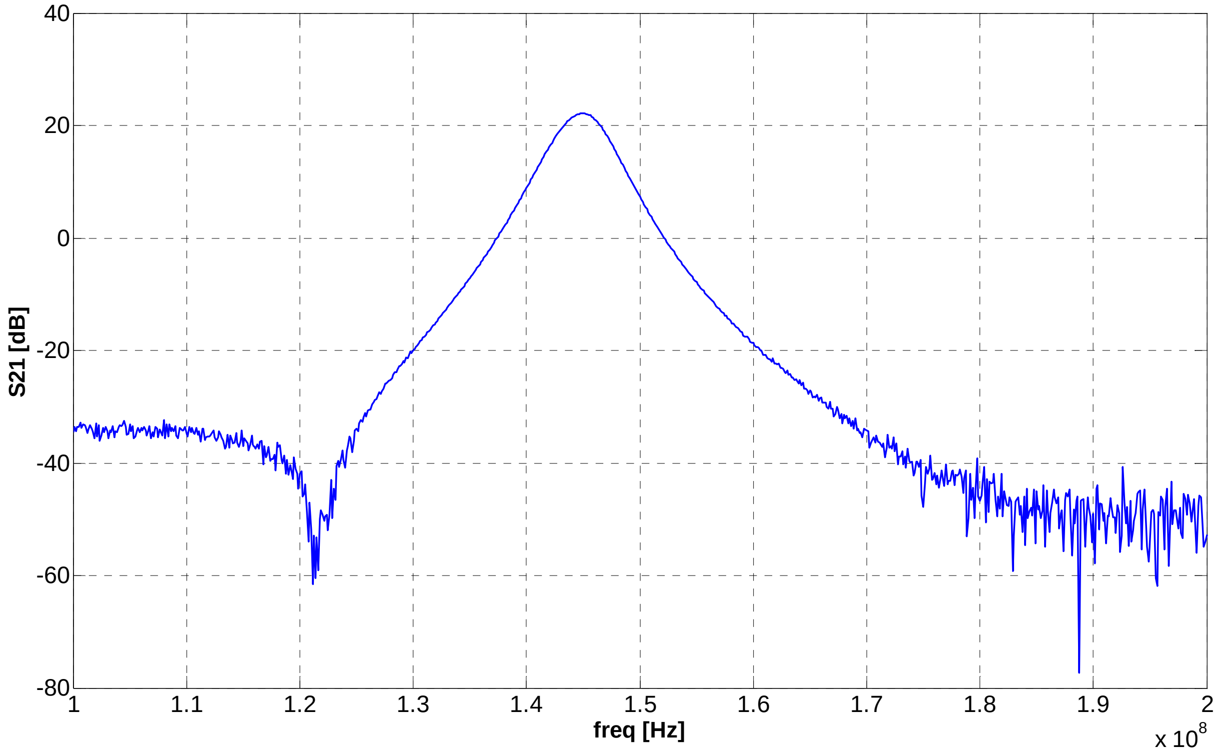

Fig. 18- S_{21} Parameter with TOKO filter on output

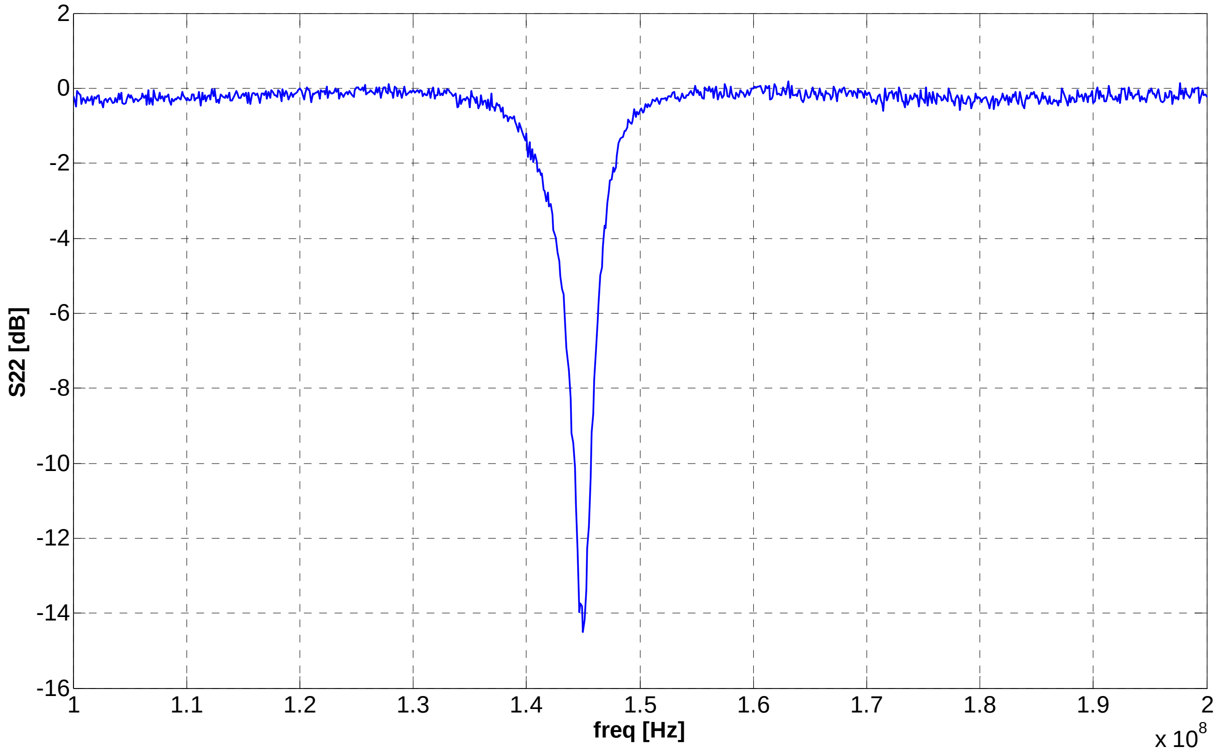

Fig. 19- S_{22} Parameter with TOKO filter on output

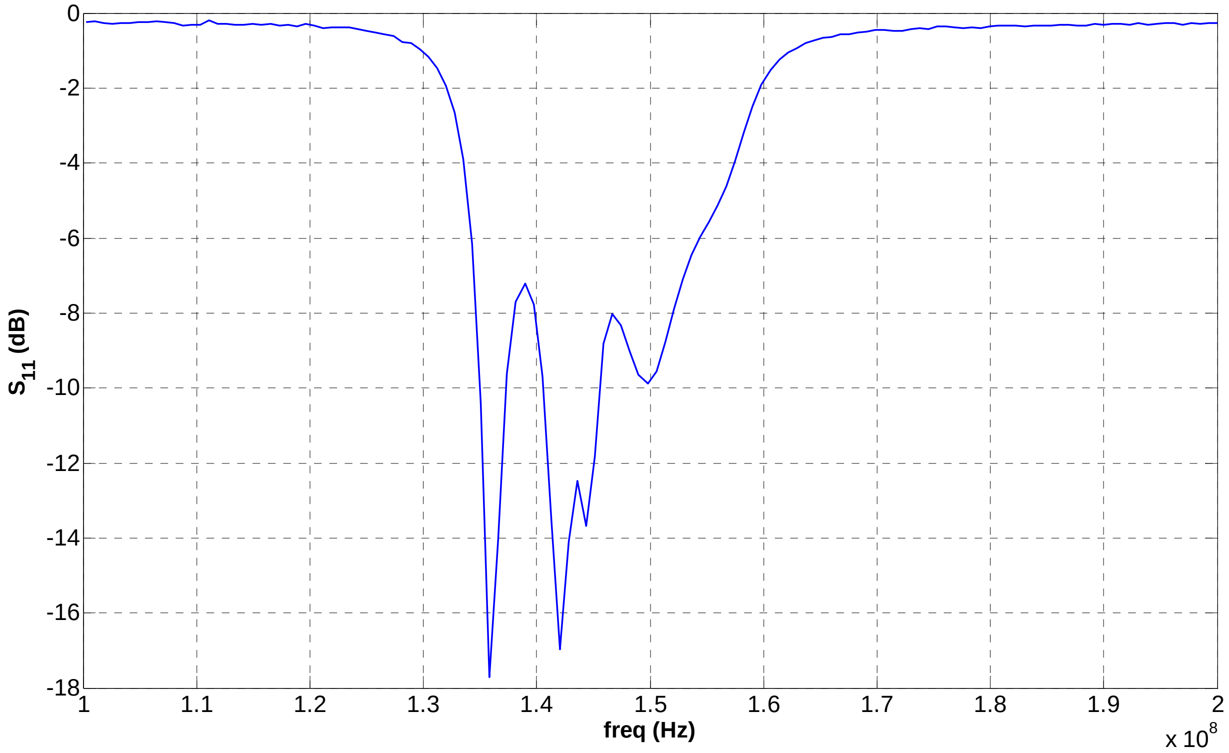

Fig. 20 - S_{11} Parameter with input and output filters

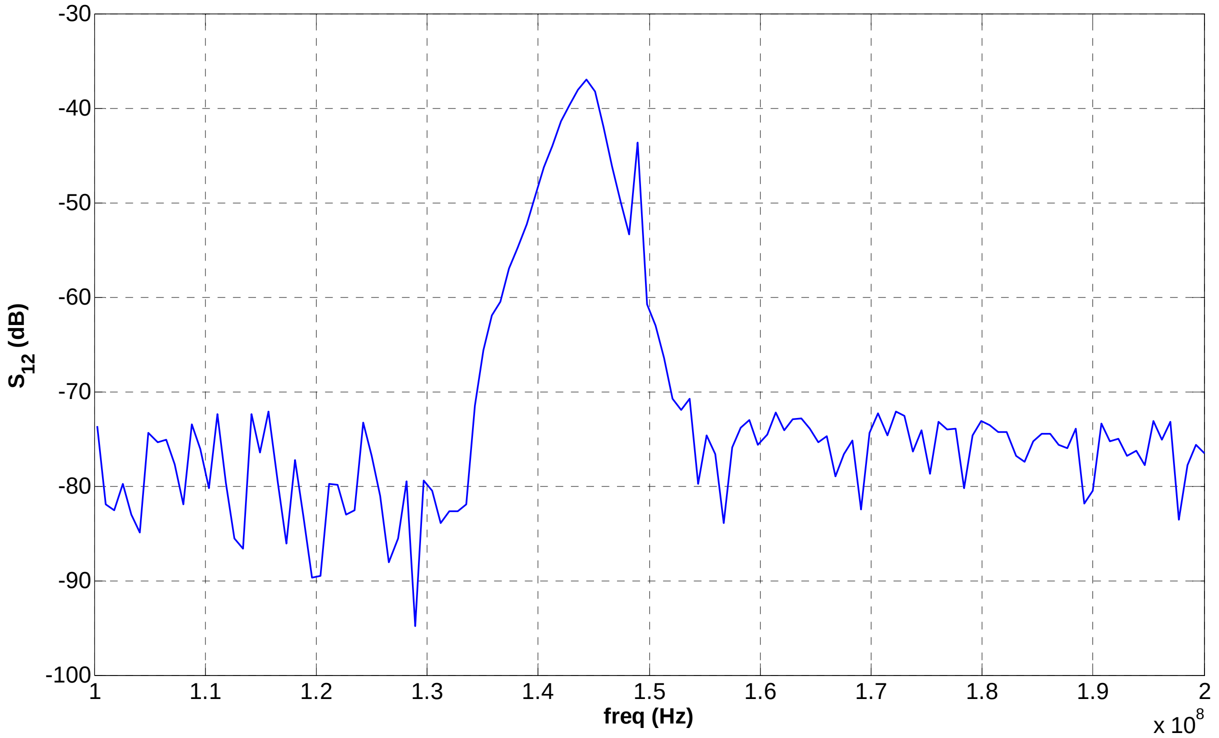

Fig. 21 - S_{12} Parameter with input and output filters

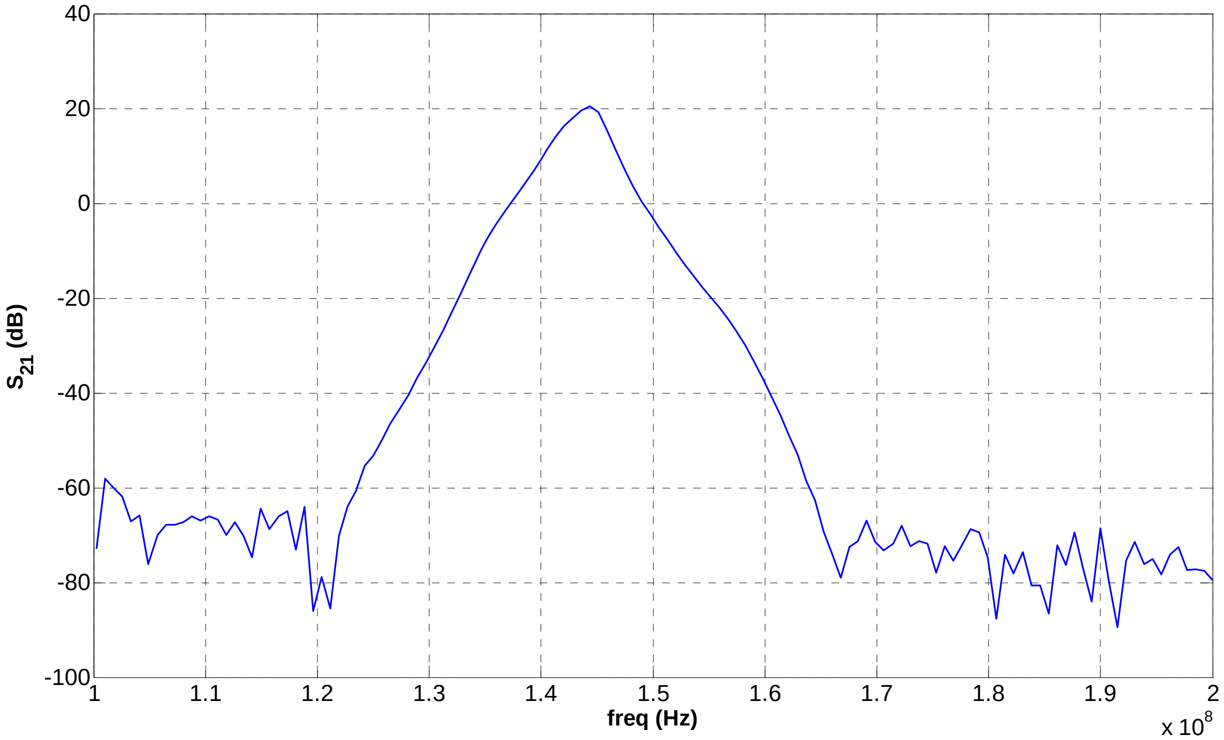

Fig. 22 - S_{21} Parameter with input and output filters

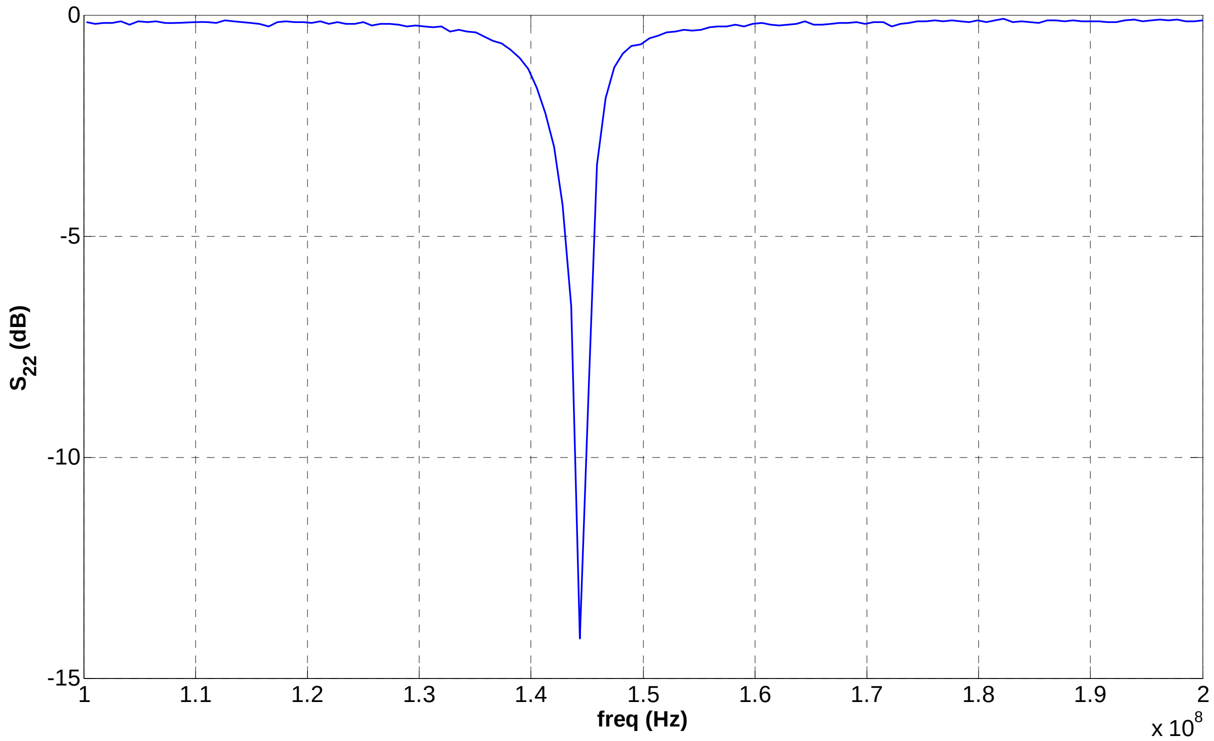

Fig. 23 - S_{22} Parameter with input and output filters

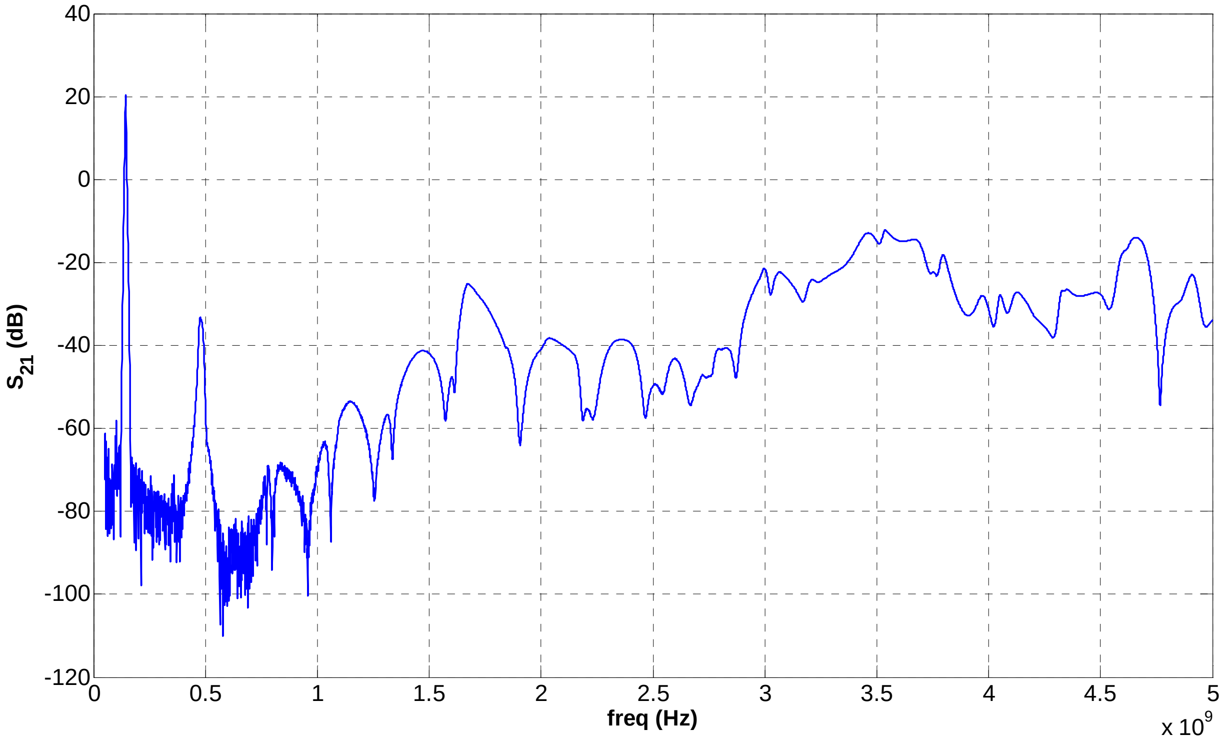

Fig. 24 - S_{21} Parameter with input and output filters for frequency range 0.05 – 5 GHz

4.2 Dynamic Range Measurement

4.2.1 Noise Figure

The noise figure was measured using an R&S spectrum analyzer FSP30 and also with an Agilent N8770B noise figure meter. The average noise figure without front end filter is 0.66 dB. See Fig. 25.

Fig. 25- Noise figure measurements

The average noise figure with both filters is 2 dB (6 pc were measured). For a less demanding RF environment, the front end filter may be replaced by a simple series resonant circuit, which reduces noise figure values to about 1 dB.

4.2.2 Intermodulation Measurement

We appreciated Franta – OK1CA`s help with this measurement. He has suitable equipment available for this measurement, an Agilent E4432B signal generator and a Hewlett Packard HP8593E spectrum analyzer. The *Input IP3* without front end filter is + 10.1dBm, with filter is +11.1 dBm. See Fig. 26.

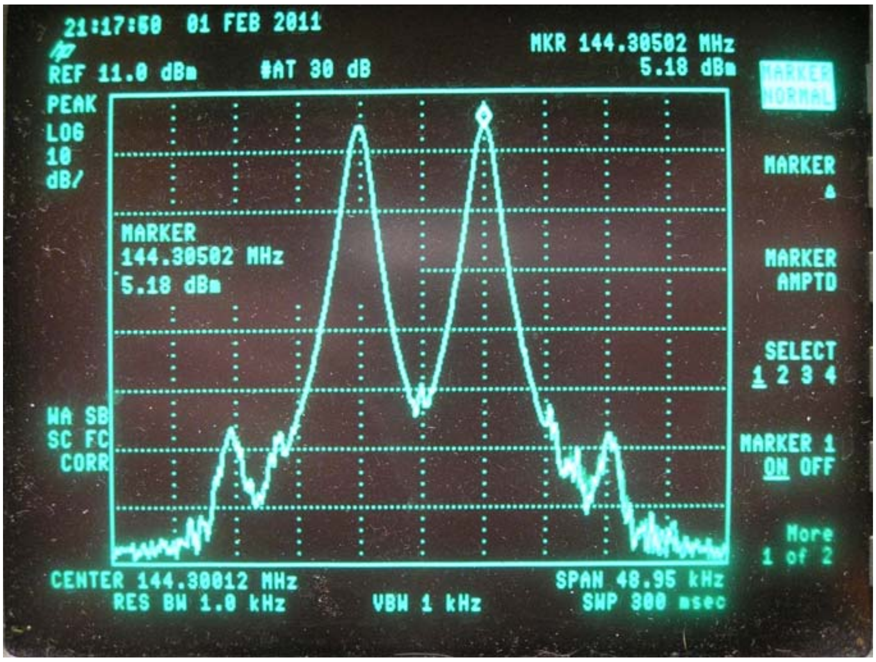

Fig.26 - Intermodulation Measurements

5. Conclusion

We have designed, analyzed, fabricated and measured a high dynamic range LNA for the 2 m band. The LNA's superior thermal stability, selectivity and linearity permit operation in high RF environments where, until now, it has been necessary to use large cavity filters at the front-ends of even of highly rated professional equipment. The good performance of this device permits applications in high dynamic range systems in conjunction with other elements of the receiving chain.

This LNA was used by the OM6A contest team during III. Subregional Contest 2011 and IARU Region 1 VHF Contest 2011 where 267 555 pts/ 725 QSO and 295 118 pts/ 760 QSO were respectively achieved.

Some RF parts, PC boards and pre-assembled LNA's are available from Peter- OK2ULQ,
E-mail: ok2ulq@seznam.cz

Acknowledgement

The authors wish to acknowledge the help of Frantisek Strihavka –OK1CA for performing the *IP3* measurements, Vladimir Masek – OK1DAK for technical consultation and Robert Valenta for his technical and language assistance.

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