Very High IP3 LNA for 144 MHz

1. Introduction

After careful inspection of different designs that could be used as the front end amplifier of my new 144/14 MHz transverter design I finally stopped at the Infineon's BF998 MOS FET tetrode. I have very good experience with the old BF981 so I started to test the BF998. This transistor is very cheap, easy to obtain and has very good characteristics. I ruled out various microwave power GAAS FETs as they are hard to get and are not among the cheapest.

Detailed analysis of the XVRT architecture gave the result that the front end amplifier linearity sets the linearity of the whole transverter (when you use +17 dBm mixers with 20 dBm of LO drive, the post mixer amplifier with IP3out > 36 dBm and neglect the IF stage - HF receiver)! OK, the commercial HF receiver linearity should not be neglected (IP3in < 15 dBm for the normal rigs and IP3in < 25 dBm for the best ones (30 dBm for the AOR-7030)) but one can homebrew high performance HF receiver with IP3in > 30 dBm. At that point the IP3out of the XVRT should be also at least at that level (+30 dBm). Taking into account that the commercial HF receivers have the NF of roughly 16 dB (when in high IP3 state, the homebrewed rig would have something like 13 dB of NF), adding the 0,5 dB of antenna-to-XVRT cable loss and setting the target system NF to about 2,2 dB one finds out that the gain of the XVRT should be at least 24 dB (with the NF of 1 dB). That means that the IP3in of the XVRT should be more than +6 dBm (= 30 dBm - 24 dB). And that is not so trivial because this figure must belong to the front end LNA ...

2. LNA with parallel configuration of n x BF998

After checking the BF998 in the same circuitry as the BF981 (see Fig. 1) I found that the results are quite the same, only the NF was something like 0,2 dB lower. The LNA from Fig. 1 has **26,5 dB** of gain, **0,8 dB** of NF, P1dB of **17 dBm** and IP3in of **0 dBm**. This is not bad but it should be better.

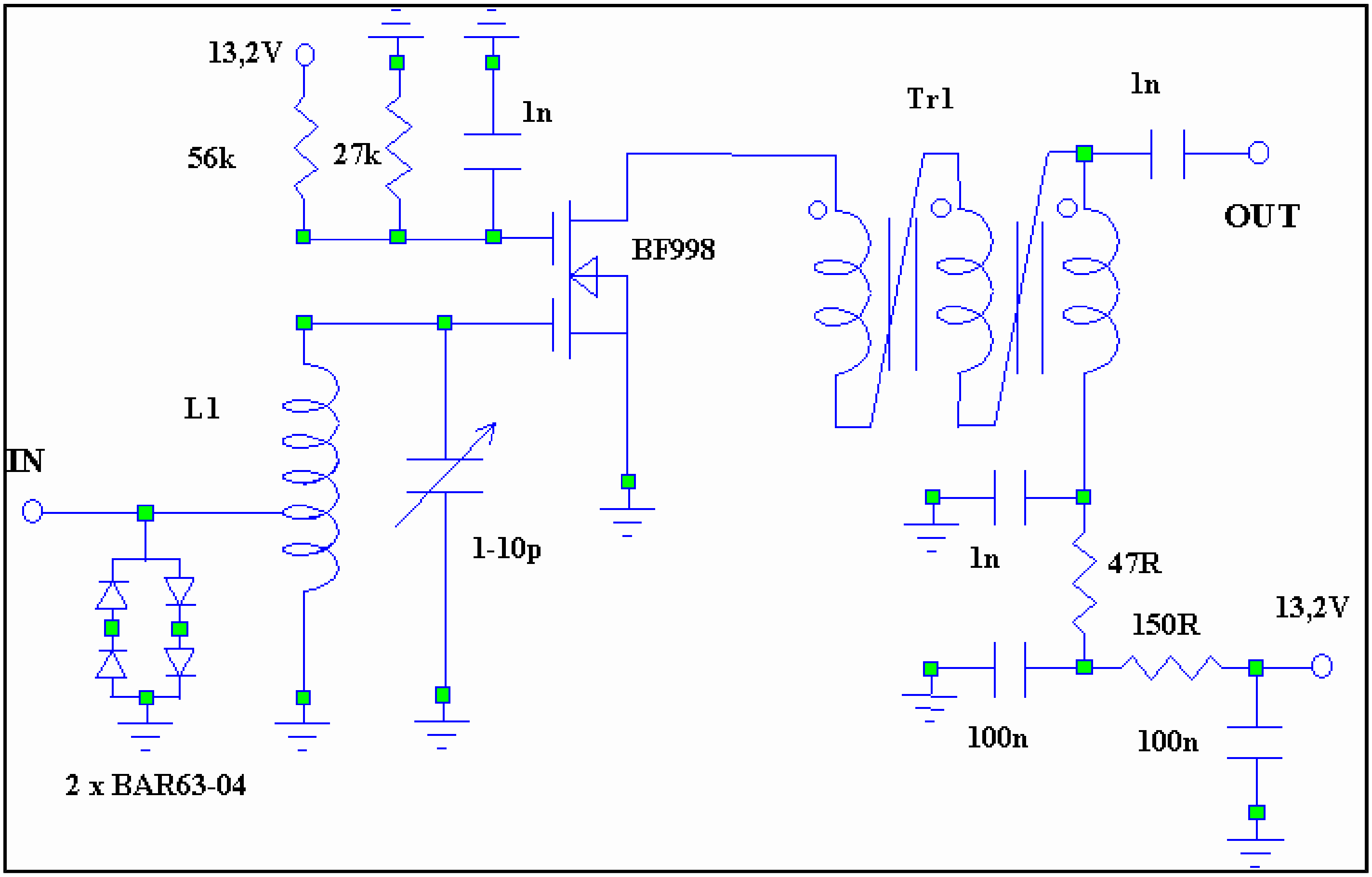

Fig. 1: standard configuration for the dual-gate MOSFET LNA and maximum output power matching. The FET operates at Idss as this is the best operating point for lowest noise (Idss is specified to be between 2 to 18 mA - I never got the 2 mA devices, the most common Idss was from 10 to 15 mA). Input coil L1 is wound on 5 mm diameter core with 1,0 mm AgCu wire; it has 6 turns with a total length of 11 mm. The coil should be mounted 2 mm above the ground and at least 10 mm from any metal wall. Trimmer capacitor should be of high quality. Diodes (Infineon BAR63-04) are for the protection of the MOSFET and have no influence on NF nor IP3 but are well proven (and of a value!) in a real life operation. The most critical part of the design is the transformer Tr1: it should be wound on the binocular core, size A7, material U17 (Epcos, former Siemens&Matshushita). Other materials of other manufacturers could be tried but special attention should be given to the obtained gain and P1dB. The transformer has two turns of trifiliar winding - it is even better to wound it as an autotransformer with 6 turns (=2x3) on the primary and tap at the 2-nd turn from the cold side (in practice you would wound 4 turns first, make a tap by twisting the wire and then proceed with last two turns). The wire lengths from Tr1 to the FET and capacitors should not be longer than 5 mm and should be run near the PCB ground or oscillations can occur.

After a lot of experimenting I found another interesting characteristic of FETs (well known in the audio amplifier scene as I found out latter) - when you parallel two identical FETs you get lower NF than with a single device! So if you piggy-back another BF998 to the original one (both should have the same Idss) you can get **0,6 dB** of NF, **26,5 dB** of gain and the same or worse (!?) IP3in! The IP3 problem was solved with proper output matching - the 3:1 transformer was changed to 2:1. In that way **+28,5 dBm** of output IP3 is obtained (P1dB is +19 dBm). The circuit is shown in the Fig. 2, generalized for **n** times **BF998** (the variable values are given in the Table 1).

Of course I tried to parallel four BF998 (who wouldn't) and the result is that the NF is still going down to **0,5**

dB, gain stays at **26,5 dB** (when tuned form minimum NF) and IP3out is **+34 dBm** (see Fig. 3)**.** To obtain this value of IP3 the Tr1 should be changed into 1,3:1 transformer. To get the 0,5 dB of NF the input should be tapped to the L1 at the middle (that is at the 3rd turn). At the first attempt I just piggy-backed four BF998's but some weak oscillations occured above 3,5 GHz not affecting the amplifier characteristics on the working frequency. Then I made new arrangement with two times 2xBF998 (piggy-backed) side-by-side; both pairs are connected together with short wires, and have separate G2 bias network (the circuit layout and G2 bias blocking is very critical). After that modification the oscillations disappeared but it should be noted that all the designs described here are only conditionaly stable. Overall component layout is **very** critical.

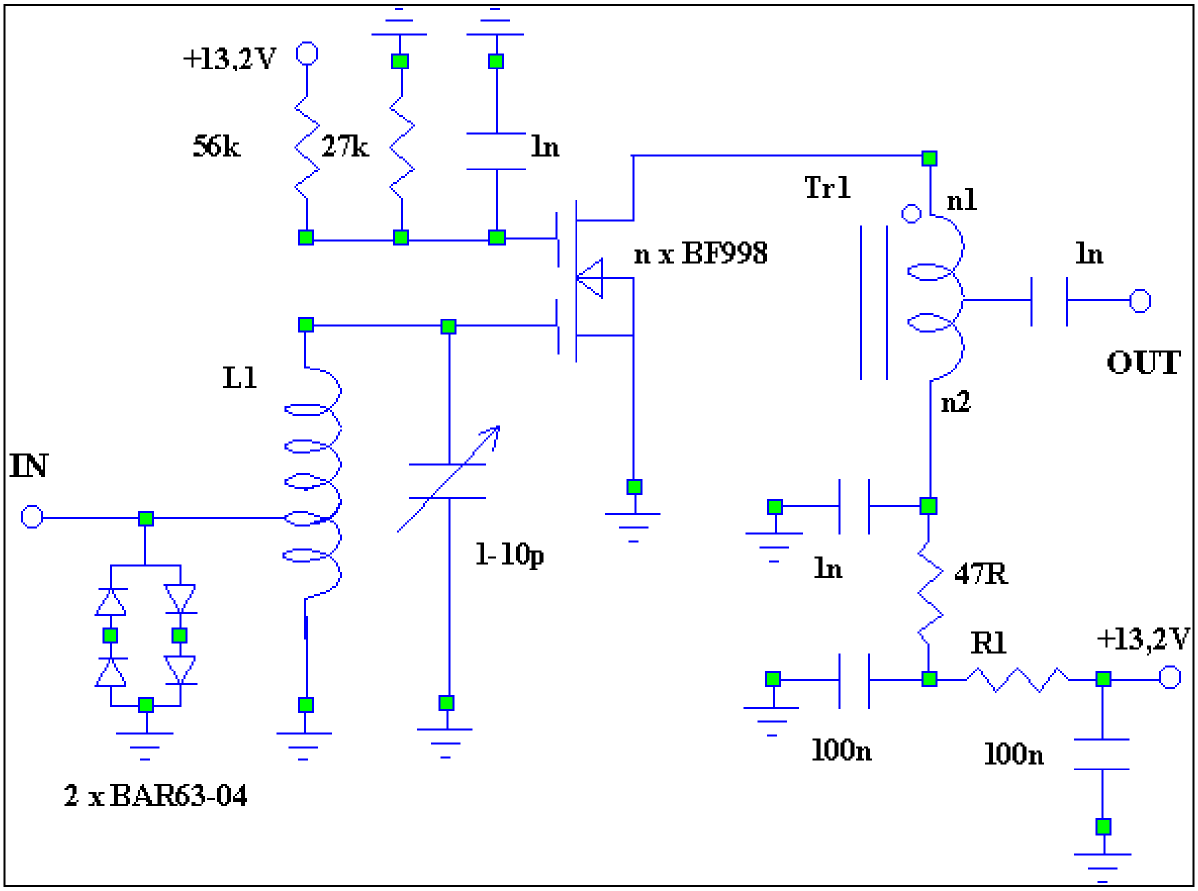

Fig. 2: generalized scheme for ***n x BF998*** *(it also covers the design shown in Fig. 1 with one BF998). The variable values are given in the Table 1. The input and output matching are different (see text). The core for the Tr1 should be of a larger size (material U17, size A4) when more than one BF998 is to be installed. The amplifiers can be approximately tuned for minimum NF without instruments with a little trick: they should be tuned for the maximum gain at 136 MHz (the minimum NF tuning point is quite broad).*

Table 1: variable values for the design shown in the Fig. 2.

	n1	n2	R1	NF [dB]	T [K]	G [dB]	IP3in [dBm]	P1db [dBm]
1 x BF998	4	2	150	0,8	61	26,5	0	17
2 x BF998	2	2	100	0,6	44	26,5	2	19
4 x BF998	1	3	10	0,5	36	26,5	7	23

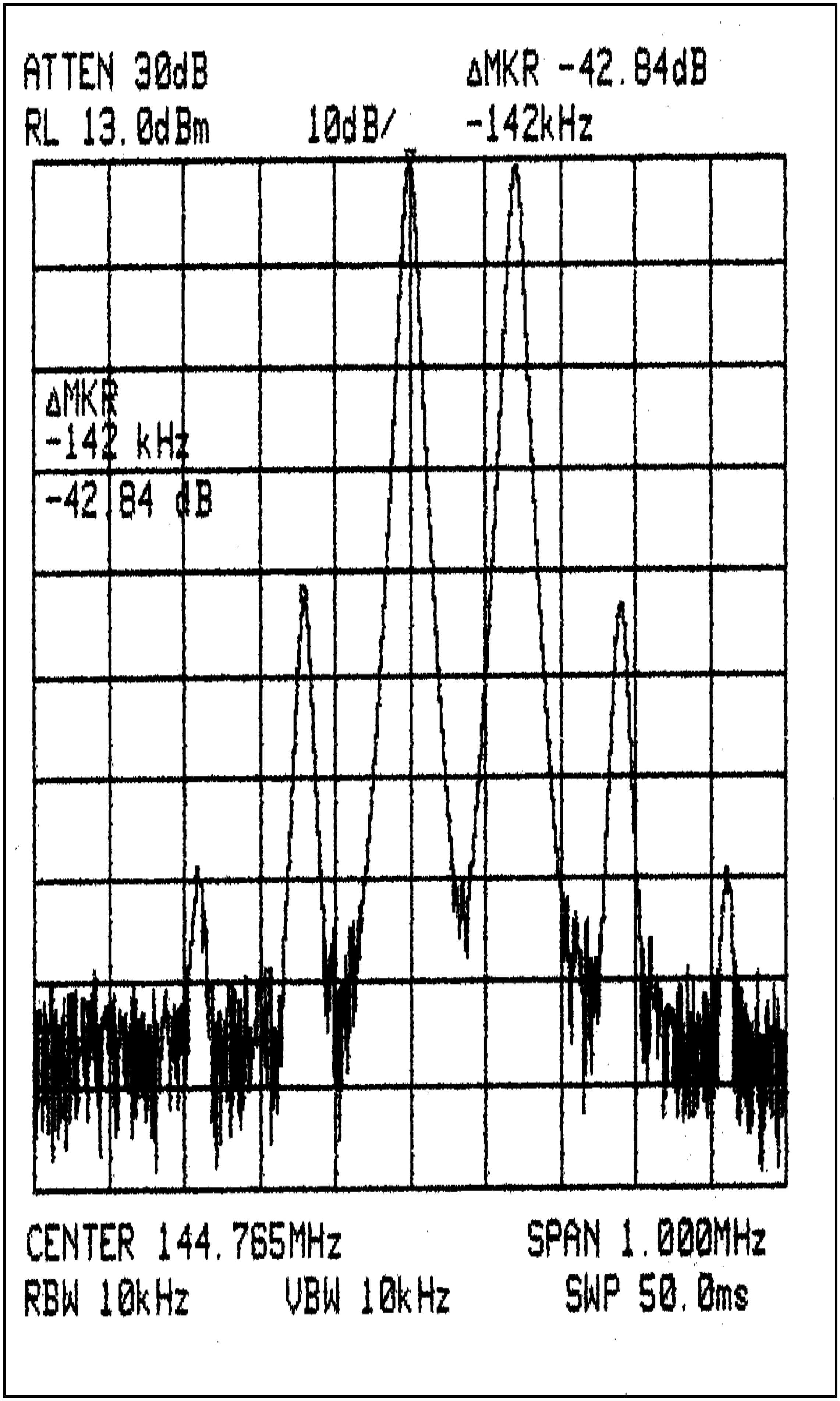
ATTEN 30dB
ΔMKR -42.84dB
RL 13.0dBm
10dB/
-142kHz
ΔMKR
-142 kHz
-42.84 dB
CENTER 144.765MHz
SPAN 1.000MHz
RBW 10kHz
VBW 10kHz
SWP 50.0ms

Fig. 3: IP3 measurement of the 4xBF998 amplifier - the IP3out is 13 dBm + 42,8/2 dB = 34 dBm.

3. Push-pull LNA with BF998

When you construct the push-pull amplifier from two single stage amplifiers you can get 3 dB higher IP3 as with the parallel configuration . So I thought that with two BF998 LNAs arranged in push-pull (see Fig. 4) one could get the +6 dBm IP3in (that was before I tried the parallel configuration). First experiment was great - IP3in was +6 dBm (P1dB of +23 dBm) but the NF could not be pushed lower than 1,3 dB! After redesign of the input coupling I finally got the **0,9-1,0 dB** of NF with solid IP3out of **32,5 dBm** and gain of **26,5 dB** (when tuned for minimum NF). The circuit is actually the push-pull arrangement of two circuits from Fig. 1.

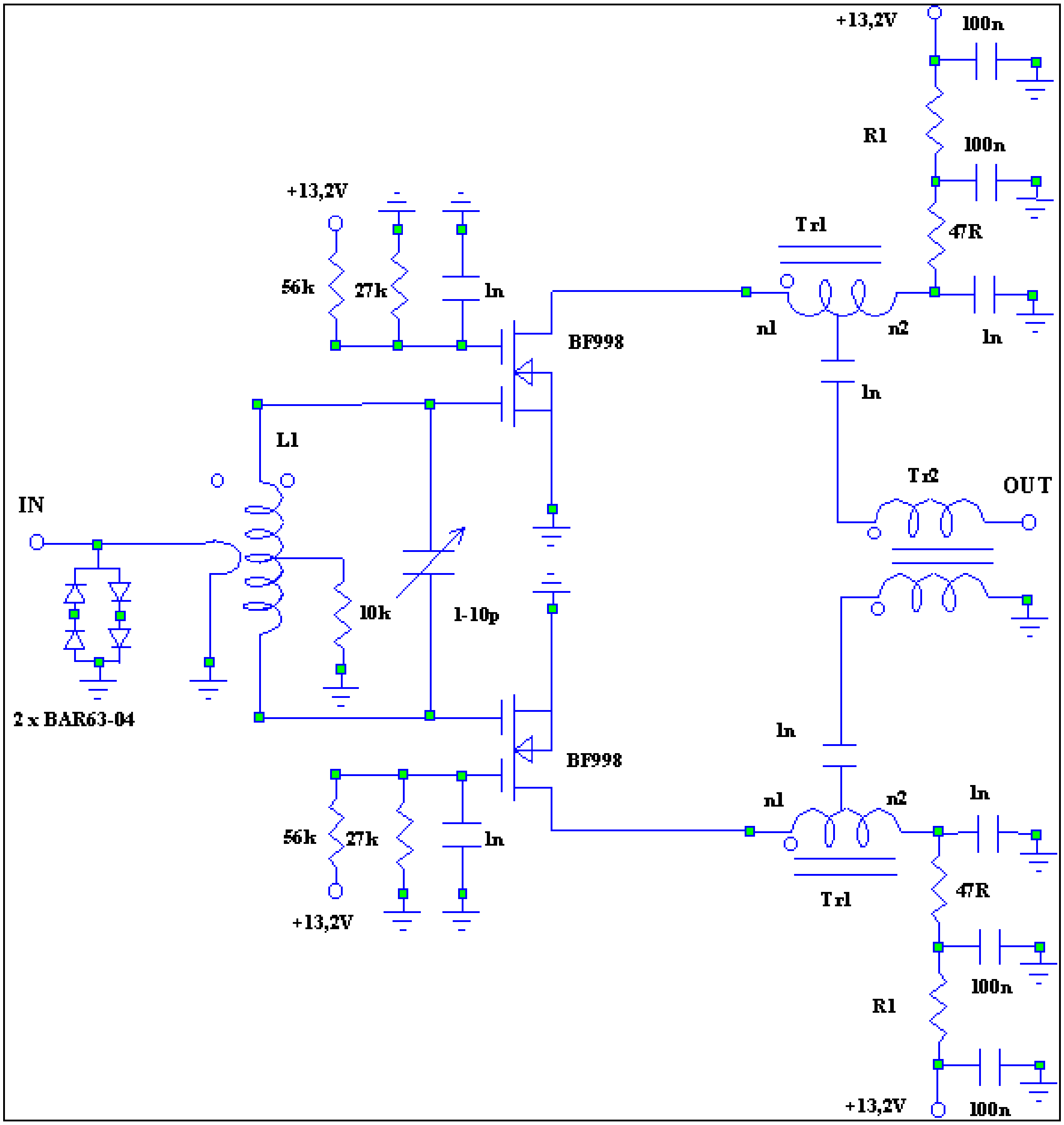

Fig. 4: push-pull configuration of two BF998. Input coil L1 is wound on 11 mm diameter core with 1,0 mm AgCu wire; it has 4 turns with a total length of 7 mm. The input coupling is done with a single turn coil

wound on the same diamater as L1 with enameled Cu wire so that the shorting of the L1 winding is prevented. The transformers Tr1 and Tr2 use the same core as described in Fig. 1 (size A7, material U17, Epcos). The output combining transformer Tr2 has 2 turn bifiliar winding.

Then I tried the push-pull configuration of four BF998. The intention was to get the IP3in of +9 dBm with some 0,8 dB of NF. After some experimeting I realized that I was not able to find the proper input match for the minimum NF although I got the +9 dBm of input IP3. The NF was allways above 1,3 dB what I found as unacceptable for my XVRT desgin. For other purposes the obtained NF could well be tolerable. Anyway, the circuit stays open for further optimization ...

NOTE:

Those amplifiers are not well suited for preamplifiers in front of receiver or xverter as they have much too much gain. In order to use them effectivelly (although I don't recommend using preamplifiers at all) one shoul add an attenuator at the output to lower the gain. In most occasions 6-10 dB of gain is enough for a preamplifier if it really has to be mounted. With an attenuator of 20 dB the overall NF will be degraded from 0,5/0,6/0,8 dB to 1,3/1,4/1,5 dB. With an attenuator of 16 dB the overall NF will be degraded from 0,5/0,6/0,8 dB to 0,8/0,9/1,1 dB. So I recommend installing of 16 dB post-LNA attenuator (values for PI attenuator are 68 ohm toward GND and 150 ohm in between).

For other high performance VHF&up preamplifiers I recommend visiting the Dragan's/YU1AW homepage at www.qsl.net/yu1aw/low_noise.htm.