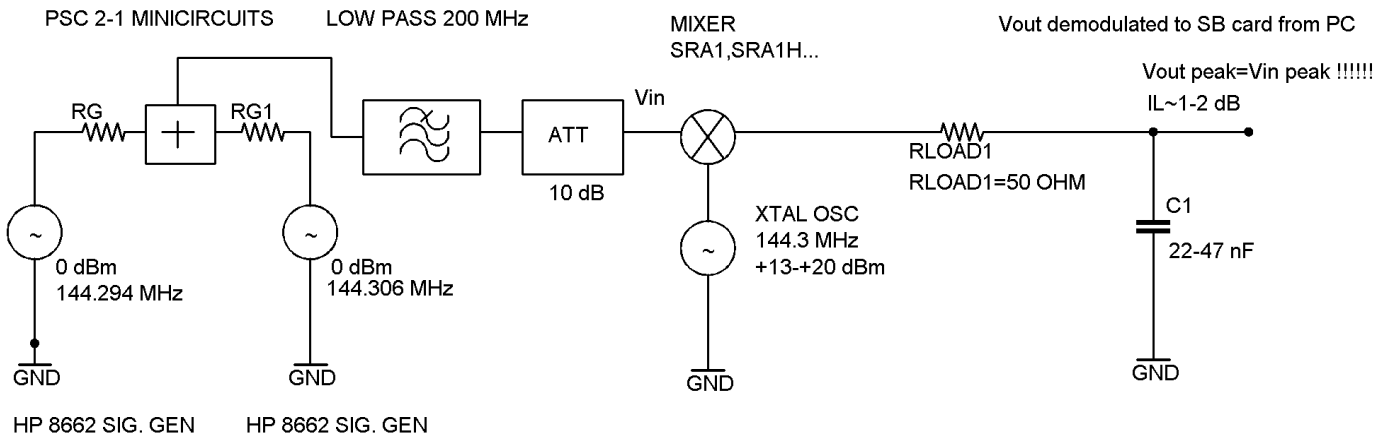# *HF, 6 m, 2 m and 0.7m SDR (Software Defined Radio) Receivers AR1 and AR2 Series -Make it Simple as Possible with Outstanding Performances, part1*

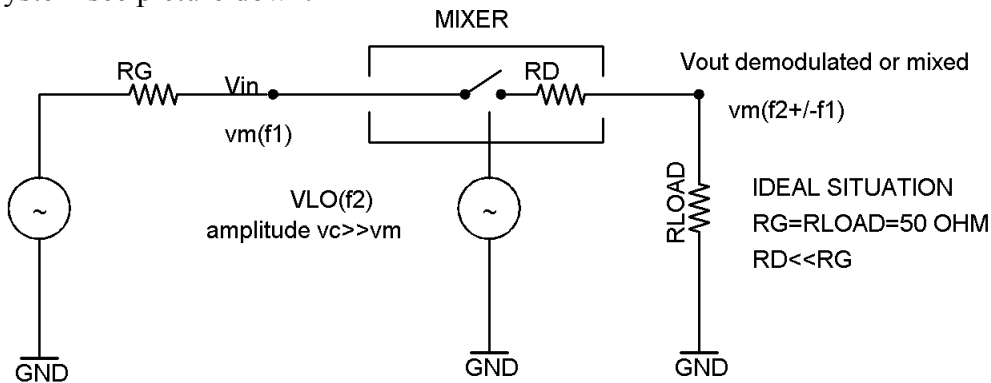Dipl.ing Tasić Siniša-Tasa YU1LM/QRP

A lot of ham like to try SDR technique at higher VHF and UHF bands 6m ,2 m or 0.7 m. In this moment it is not easy task to make simple SDR receiver for the VHF and UHF HAM bands except if we use some HF SDR receiver (like mine DR1, DR2, DR2….) as first or second IF in classic design with intermediate frequency. I made some experiments in 2004 and tryed to make DC (direct conversion) receiver for high frequencies. I deigned new type of S/H (sample and hold) receiver which is working, even at 23 cm, with very good or better to say fantastic performances with several very cheep components. I will publish this design soon. I was experimenting with an old phasing method for DC receivers before that. I revised it and here are some mine results of my try to enable new bands for SDR at simple and easy way. These designs are in connections with results of mine DC designs for professional use.

First receiver is AR1 which is simple as possible with only one branch without image rejection. It is a design similar to mine previously published receivers DR1 and DR1A. VHF and UHF HAM bands which hare very small portion of the central frequency and because of that they are ideal for the phasing method in receiver design. AR2 receiver is receiver with image rejection and design is similar to a lot of mine designs staring from the DR2, DR2A….. The phase shifting is happening at LO (local oscillator) branch at the receiving frequency. Both receivers are without RF pre-amplification, it isn't to big disadvantage as I expected. Receivers still have a very good sensitivity even without RF amplification. Also receivers are without LO. I will make some proposal in part 2 but every builder can decide how to make LO for the receivers fixed or variable LO. It isn't possible design oscillator which will work at 50 MHz and 432 MHz at the same time. Lets start from the some theoretical facts without too much mathematics. Resistive broadband termination is very important for diode mixer especially IF port in mixing process. A lot of articles have been written with this subject and it is key for achieving max IMD performances from used mixer. It is very hard to obtain IMD2 and IMD3 numbers declared from manufacturers in practically realized circuits. But for the demodulation we have similar situation with one little relaxing thing that we can very easy achieving RF termination. I didn't make power termination at demodulator port for demodulated signal as I do leading all relevant articles. I made only voltage match. My test gave results which are very interesting and I didn't find similar realization in other designs. Down is a picture how I measured demodulator IMD3 performances with SB card. I obtain at PC screen IP3 from 24-26 dBm for SRA1H mixer MiniCircuits what is very good results for unmatched port not so far from max IP3 30-32 which had been declared from manufacturer.
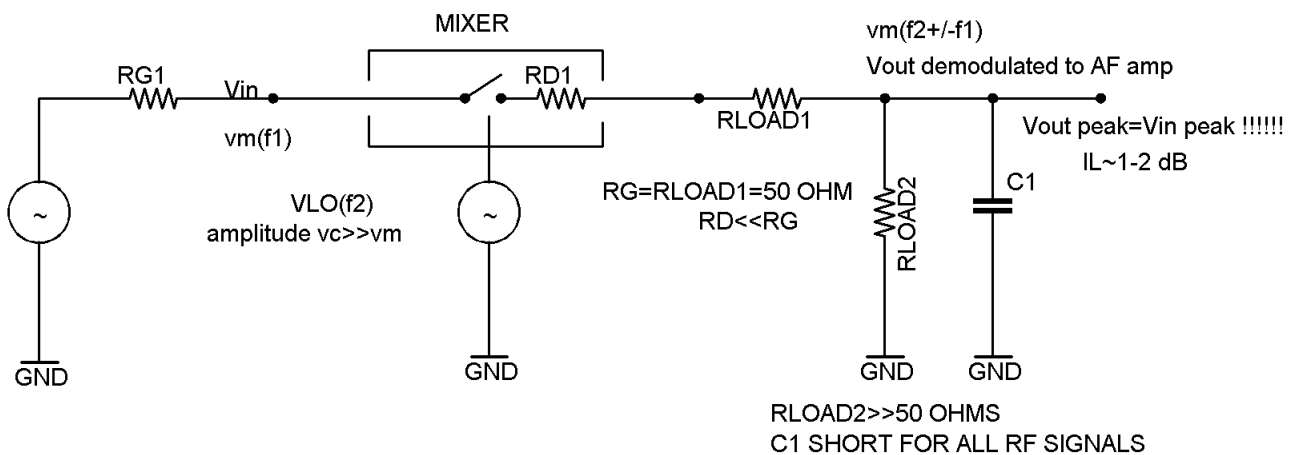
MIXER
SRA1,SRA1H...

Vout demodulated to SB card from PC

Vout peak=Vin peak !!!!!!
IL~1-2 dB

RG   RG1

Vin

ATT

10 dB

RLOAD1
RLOAD1=50 OHM

C1
22-47 nF

0 dBm
144.294 MHz

0 dBm
144.306 MHz

XTAL OSC
144.3 MHz
+13-+20 dBm

GND   GND

GND

GND

HP 8662 SIG. GEN   HP 8662 SIG. GEN

DEMODULATOR USED IN HF/VHF/UHF SDR RECEIVERS AR....SERIAS YU1LM IMD3 MEASUREMENTS

If we simplified receiver with passive detector min IL (insertion loss) is 3 dB in terminate system see picture down.

MIXER

RG   Vin

RD

Vout demodulated or mixed

vm(f2+/-f1)

vm(f1)

VLO(f2)
amplitude vc>>vm

RLOAD

IDEAL SITUATION
RG=RLOAD=50 OHM
RD<<RG

GND

GND   GND

MIXER EXTREMELY SIMPLIFIED

MIXER

vm(f2+/-f1)
Vout demodulated to AF amp

RG1   Vin

RD1

RLOAD1

Vout peak=Vin peak !!!!!!
IL~1-2 dB

vm(f1)

VLO(f2)
amplitude vc>>vm

RG=RLOAD1=50 OHM
RD<<RG

RLOAD2

C1

GND

GND

GND   GND

RLOAD2>>50 OHMS
C1 SHORT FOR ALL RF SIGNALS

DEMODULATOR USED IN HF/VHF/UHF SDR RECEIVERS AR....SERIAS YU1LM EXTREMELY SIMPLIFIED

The mixer and diode as mixing elements are presented as resistor, half energy go to receiver in ideal terminate system. In double balanced mixer we have two branches and we have common connection in which one IF port is grounded that mean half of useful energy goes to the ground this lead to additional losses which are common for the most double balanced mixers 4-6 dB. One way to overcome this situation, which was not used often in past in published and realized designs for diodes mixer, it is using balanced post mixer amplifiers. This means that we also must have a termination at both input ports very important to obtain good dynamic performances IP3, DR...from used diode mixers. I designed low noise balanced

AF amplifiers with bipolar transistors and JFET few times in past. Now to simplify realization I am using ultra low noise OP AMP (better OP AMP like "state of the art" Analog Device AD797 or LT1115 from Linear Technology), it is much easy to achieve better results in overall NF (noise figure)), instead pre amplifier with bipolar transistors (it is possible better NF in some schematics even 0.3- 0.4 nV/SQR (Hz) or NF 0.5 dB). Using some easy obtainable low noise OP Amps like OP027, NE5534… will ruin overall receiver NF for few dB, 3-10 dB. This OP AMP specification is spoiling NF and results is related with chosen type OP AMP connection and chosen component values. At picture down show how OP AMP can be analyzed in noise calculation for case inverting OP AMP and non inverting connections and how these performances are for cases 2 most used low noise OP AMP AD797 and cheaper NE5532 used in most mine design for HF bands. The data had been taken from data sheets from Analog Devices and Philips OP AMP manufacturers.
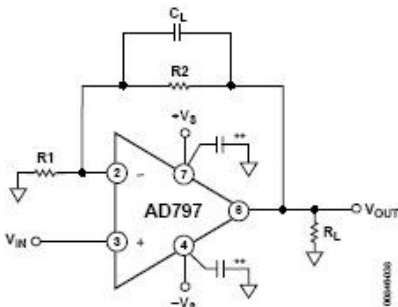

Figure 38. Low Noise Preamplifier
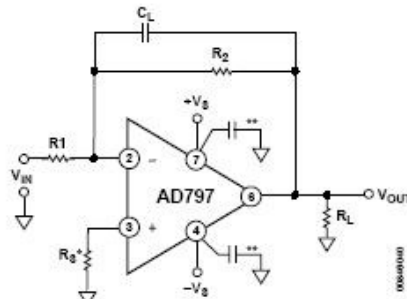**Use Power Supply Bypassing Shown in Figure 35

THE INVERTING CONFIGURATION

The inverting configuration (Figure 40) presents a low input impedance, R1, to the source. For this reason, the goals of both low noise and input buffering are at odds with one another. Nonetheless, the excellent dynamics of the AD797 makes it the preferred choice in many inverting applications, and with careful selection of feedback resistors, the noise penalties are minimal. Some examples are presented in Table 4 and Figure 40.

*SEE TEXT
Figure 40. Inverting Amplifier Connection
**Use Power Supply Bypassing Shown in Figure 35

Table 4. Values for Follower with Gain Circuit

Gain	R1	R2	C_L	Noise (Excluding rs)
2	1 kΩ	1 kΩ	≈20 pF	3.0 nV/√Hz
2	300 Ω	300 Ω	≈10 pF	1.8 nV/√Hz
10	33.2 Ω	300 Ω	≈5 pF	1.2 nV/√Hz
20	16.5 Ω	316 Ω		1.0 nV/√Hz
>35	10 Ω	(G − 1) × 10 Ω		0.98 nV/√Hz

The I-to-V converter is a special case of the follower configuration. When the AD797 is used in an I-to-V converter, for example as a DAC buffer, the circuit of Figure 39 should be used. The value of C_L depends on the DAC and again, if C_L is greater than 33 pF, a 100 Ω series resistor is required. A bypassed balancing resistor (R_S and C_S) can be included to minimize dc errors.

Table 5. Values for Inverting Circuit

Gain	R1	R2	C_L	Noise (Excluding rs)
−1	1 kΩ	1 kΩ	≈20 pF	3.0 nV/√Hz
−1	300 Ω	300 Ω	≈10 pF	1.8 nV/√Hz
−10	150 Ω	1500 Ω	≈5 pF	1.8 nV/√Hz

TOTAL EQUIVALENT INPUT NOISE VOLTAGE
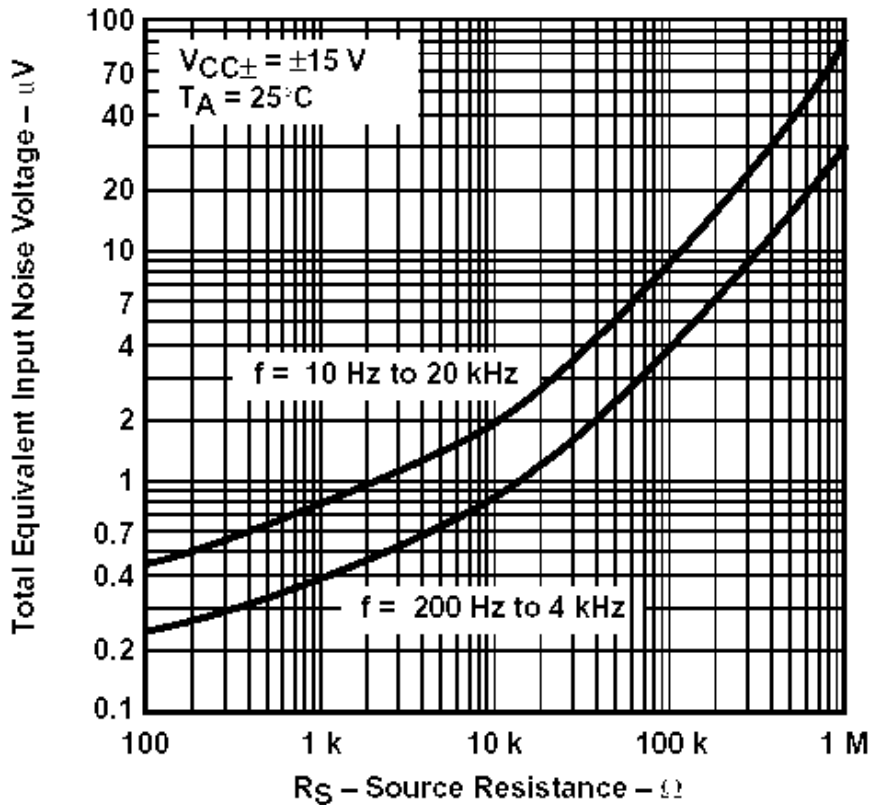## vs
SOURCE RESISTANCE

NE5534

Figure 9

If we are looking in these diagrams most readers will not understand what they and what numbers mean exactly, except that noise numbers have to be smaller as possible. Let we start with very simple mathematics and ordinary case with resistor as noise source as help in better noise problem understanding.

$$En = SQRT(4kTRB) \dots\dots\dots\dots\dots\dots\dots(1)$$

En=RMS noise voltage in [V]
K= Boltzmann constant 1.38 10 EXP-23 [J/K]
T =room temperature in [K]
R= resistance [Ohms]
B=is the noise bandwidth [Hz]

For the 50 Ohms resistor we are obtaining that it is En=140 nV for B= 24 kHz. Why B=24 kHz because it can easily be measured with audio programs. The bandwidth reduction for listening will increase MDS but this parameter depend from many things SB card quality setting in signal processing OP AMP performances and used configuration. We can also substitute OP with resistor and equivalent resistor noise source and ideal noiseless OP AMP. Very low voltage loss in mixer enables me to make SDR receiver with very good sensitivity even without RF pre amplification.
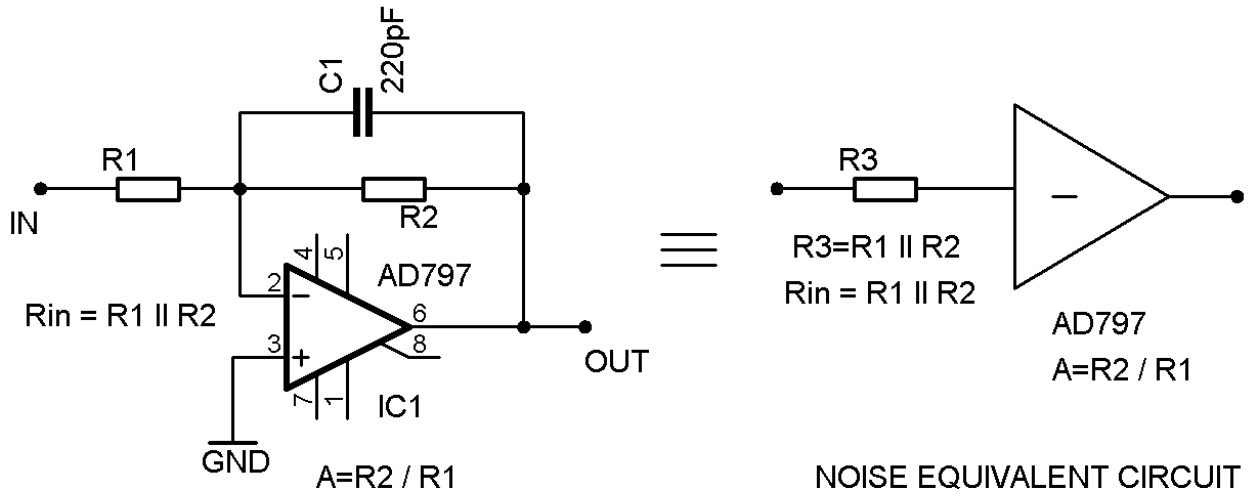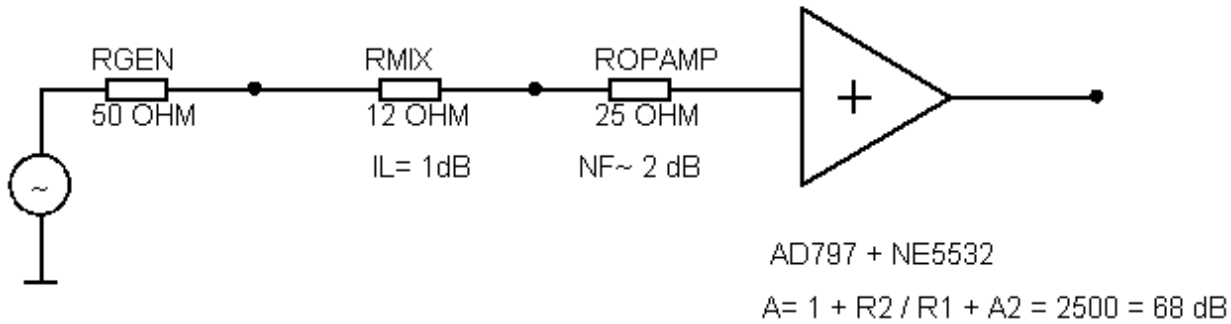
INVERTING OP AMP CIRCUIT
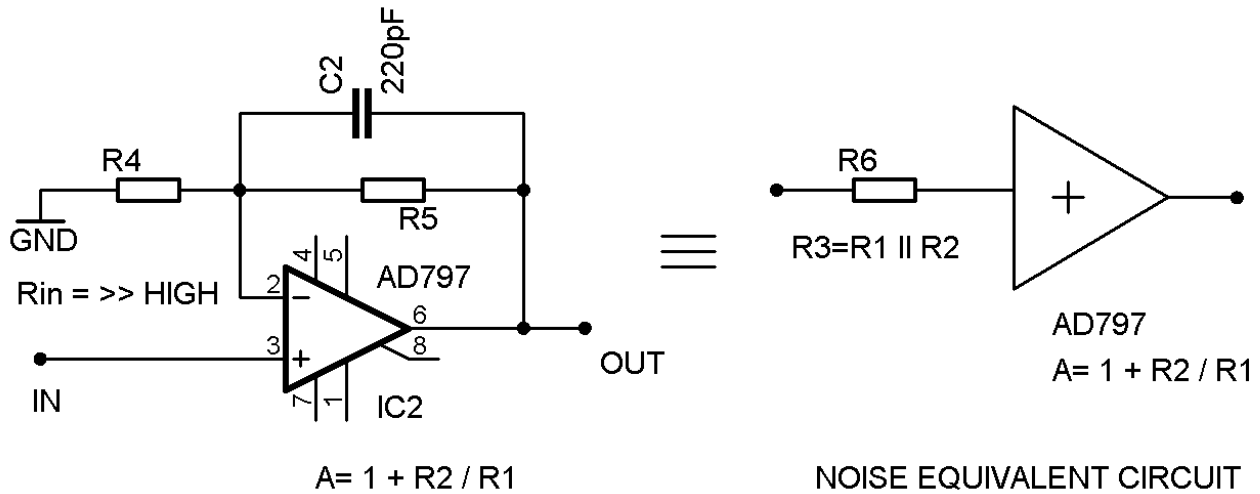
NONINVERTING OP AMP CIRCUIT

If we assume that OP AMP for example in non inverting configuration has equivalent noise from En = 1 nV / SQR (Hz) we can calculate (from formula 1) that AD797 we can replace with 25 Ohm resistor and ideal noiseless amplifier. Also we can add one 12 Ohms resistor for mixer losses in this configuration and than we can calculate equivalent noise at input noiseless amplifier. The equivalent noise is at input of ideal lossless amplifier we will calculate according formula (2) 25 Ohms from mixer and OP AMP will give equivalent noise of 140 nV according to formula (1).

$$Eeq = SQRT((EnxEn + EdiodexEdiode+ E\ opamp\ x\ Eopamp)) \ldots\ldots\ldots\ldots(2)$$

$$Eeq= SQRT((140\ nVx140\ nV + 121\ nV\ x121\ nV))=\ 185\ nV$$

ANTENNA   MIXER (DEMODULATOR)   POSTMIXER AMPLIFIER   SOUND CARD

RGEN   RMIX   ROPAMP
50 OHM   12 OHM   25 OHM

                        IL= 1dB   NF~ 2 dB

                                                              AD797 + NE5532

                                                              A= 1 + R2 / R1 + A2 = 2500 = 68 dB

The maximum gain in receiver is 68 dB or 2500 times this will give 2500 x 185 nV= 0.46 mV noise for +/- 24 kHz bandwidth at the output of receiver. If we read carefully articles from Gerald AC5OG part 4 ,we can read that even sound card best quality have limitation in capability to receive max signal of 10-12 V peak-peak at input. The maximum number of possible useful bits from sound card is not determined with SB quantization levels. It is not possible to achieve max number of bits, we are loosing LSB bits always. The producer had been announced in 24 bit SB card specification max S/N of 102 dB. This data mean that instead 24 x 6.02 +1.75 = 146.23 dB we have to lost 7 LSB bit and that we have 16.7 equivalent bit resolution for signal processing. According to Gerald AC5OG article's calculations we can determine minimum quantum level at level -75 dBm (for 24 bit SB Audigy NX2). From this data we can determine also noise figure NF for SB card in B=24000 Hz.

NF sound card [dB] =quantum level -174 dBm-10 log B [Hz] = 55 dB

From other side system noise is

-174 + 10 log (B [Hz]) [dBm] =0.45 nV/SQRT (Hz)

Or for bandwidth B=24000 Hz receiving system has noise at input
-130 dBm= 70 nV

From the other side MDS for SB used card is – 174 dBm – 55 = -119 dBm referenced to the input port. For the 2 meters band terrestrial noise is 2 dB in quite environment.
Signal from 0.46 mV referenced to input and with gain from 68 dB is giving receiver MDS = -54 dBm - 68 dB = -122 dBm or RX NF from -122 + 130 = 8 dB This values will seem to all readers high too much but for normal bandwidth 500 Hz equivalent natural noise is :
- 174 + 10 log (500Hz) = - 147 dbm or with NF =8 dB or MDS (S/N=3 dB) is - 136 dBm or 36 nV. Practically results are next, I can easy hear in head phones at receiver output signal from 80-100 nV or -129 -127 dBm at input. For the increasing receiver sensitivity to -138-141 dBm I am using preamplifier with Agilent HP GaAs transistor ATF 54143 NF broad band circuits amplifier mine design from 50 -430 MHz measured NF was better than 0.7 dB including input circuits . The final result was NF for whole 2m receiving system was better than 1 dB. The result is determined with many parameters starting from used hardware and SB quality also with setting inside SDR programs. I have admit also that for receiver without image rejection we have problem with DSB noise and because of that we have some deviation from exactly calculated number but this deviation is in range of 2dB maximum (theoretically max influence is 3 dB for receiver wit very bad NF). The receiver NF is good enough for all terrestrial communication and even for satellite communication. I didn't try this system to real 2 m signals because I am orthodox HF HAM and I measured all results with instruments and signal generators as signal sources.
        Now I will leave theoretical consideration and explain how to make receivers series:
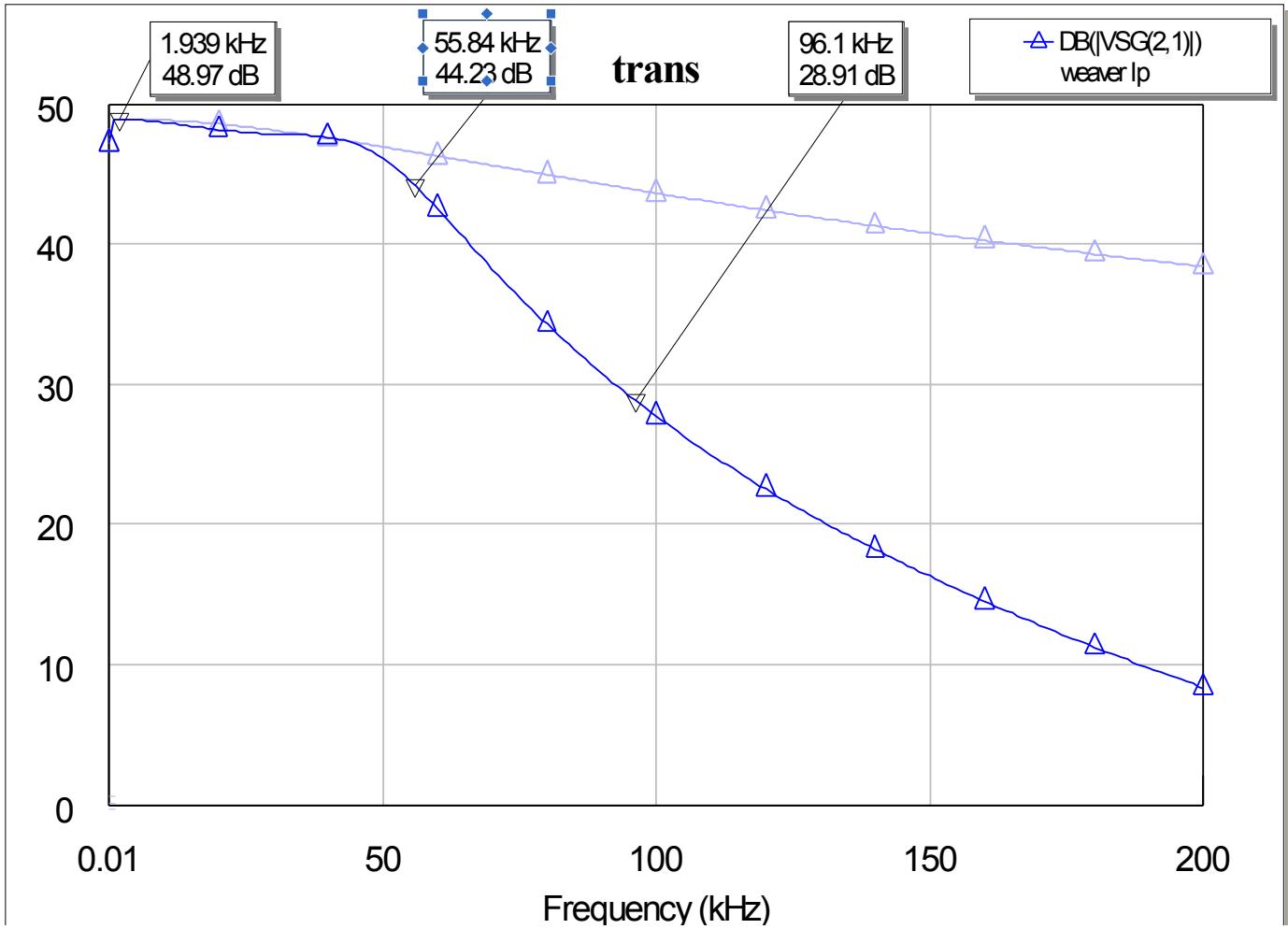
1. AR1 (simple as possible) HF/VHF/UHF SDR receiver without image rejection with encapsulated mixer such as SRA1, SRA1H, and HPF505….2. The **AR1-1** RX is the same RX as AR1 but with homebrew mixer. I gave one possible solution for AR1-1 without any ferrite for frequencies from 50-250 MHz,

3. AR1B HF/VHF/UHF SDR receiver without image rejection with encapsulated mixer such as SRA1, SRA1H, HPF505,… (Please take care that are all diode ports free not connected to can like in SBL…series). AR1B receiver has balanced instrumental audio amplifier realized with ultra low noise OP AMP AD797 or LT1115.

4. AR1C is the same RX as AR1B receiver but with ordinary low noise OP AMP such as NE5532…… This realization has the worst NF from all proposed RXs here.

All receivers can be realized in 2 versions with additional LC low pass filter or without it. Choice is on the RX builder side. RC low pass filter is the same as I am using in mine HF SDR RX designs and at diagrams we can see difference. I have to notice also that this RC low pass frequency amplitude characteristic is selectivity around sampling frequency, selectivity without LC components. It is quite natural that amplitude frequency response is not flat without additional LC filter.
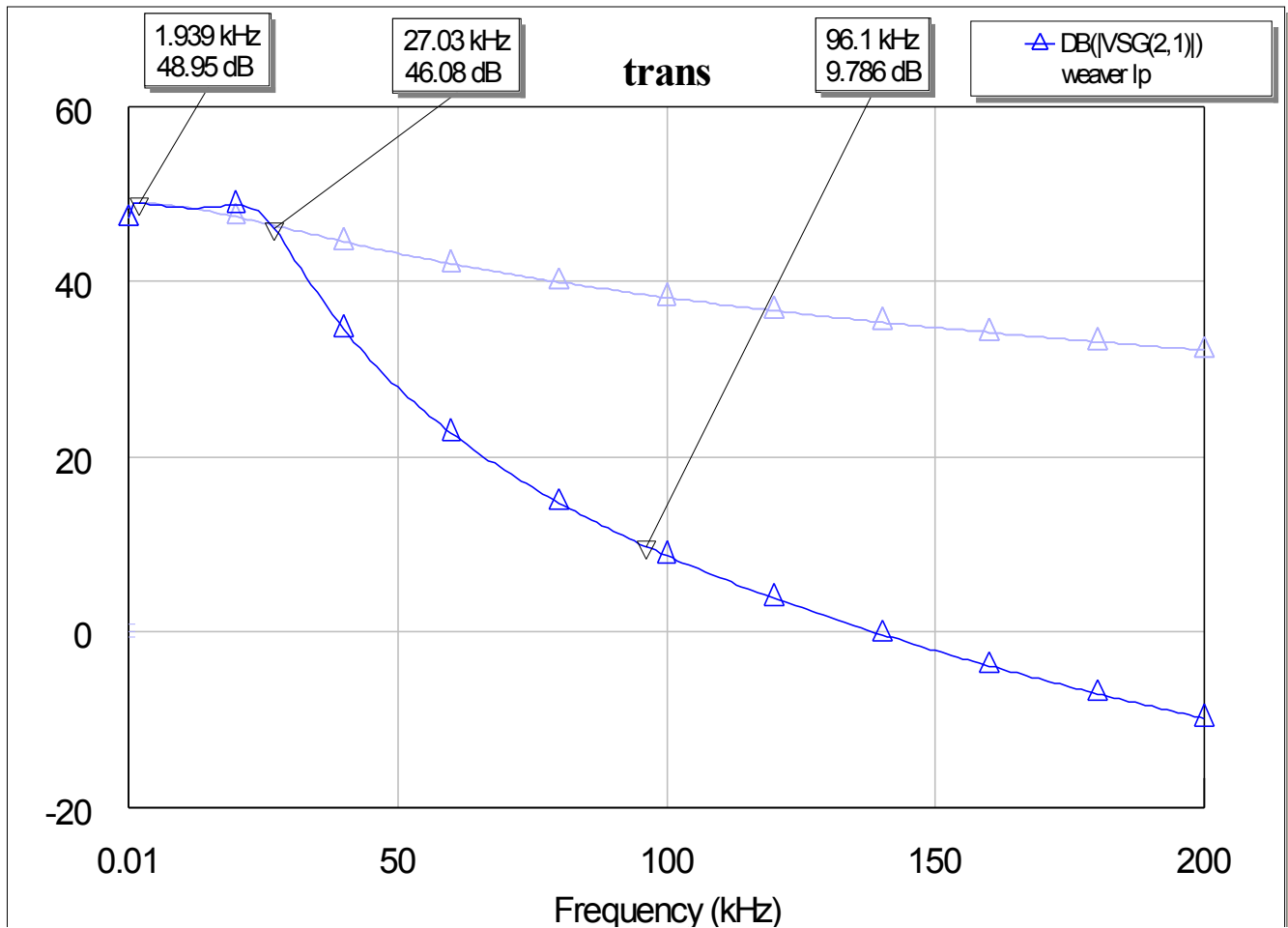
CXX=47 nF (faded line) or with RLC filter CXX=47 nF, LXX=1 mH, CYY = 82 nF

Version 2 if we increase bandwidth new elements are now for RC version CXX=22 NF (faded line) and RLC version is CXX= 22 nF, LXX = 470 nF, CYY = 47 nF

trans

| 1.939 kHz | 55.84 kHz | 96.1 kHz | DB(|VSG(2,1)|) |
| 48.97 dB | 44.23 dB | 28.91 dB | weaver lp |

1. AR1 and AR1-1 SDR receivers in version without LXX it had been replaced with jumper and CYY was omitted.
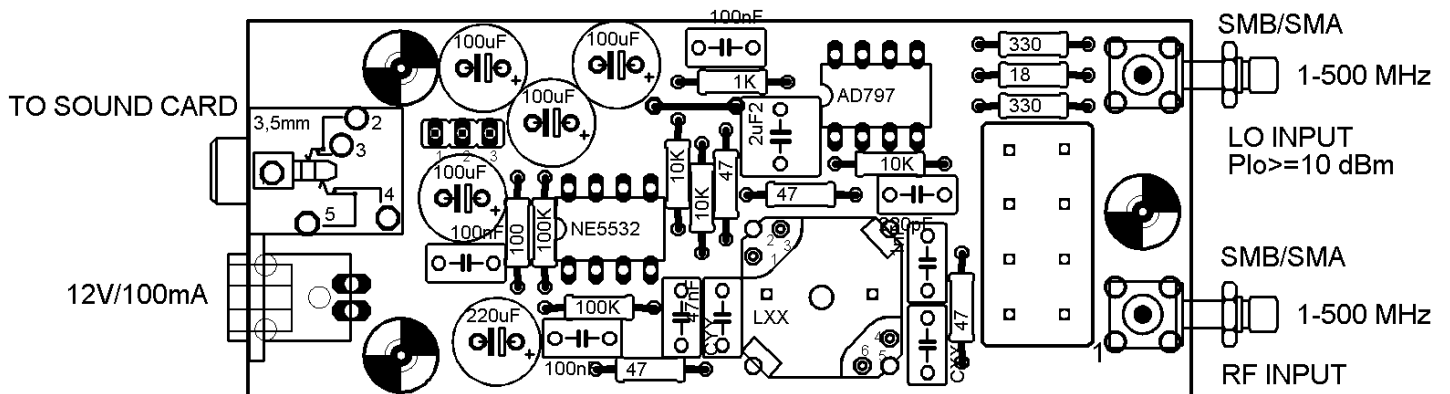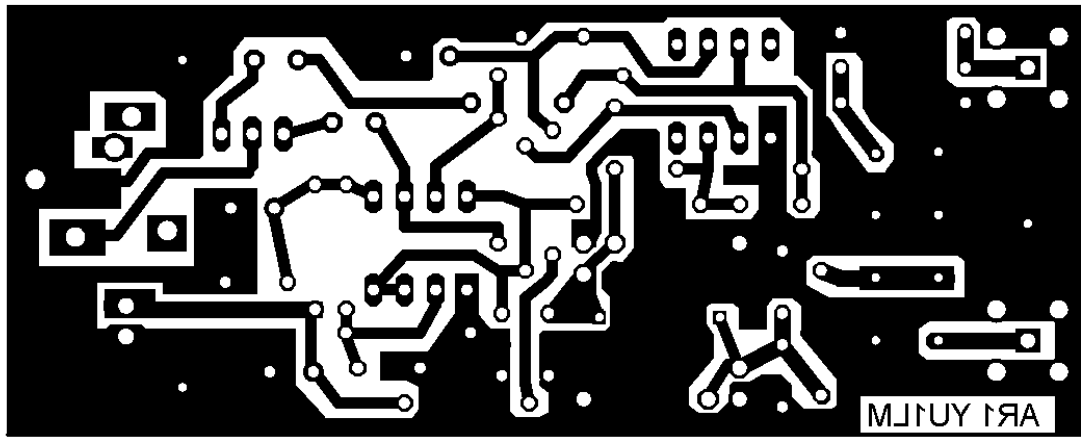
Single side PCB for AR1 dimension 88 x 35 mm

AR1 YU1LM

HF/VHF/UHF SDR Receiver AR1

1MHz-500 MHz   YU1LM/QRP

HF/VHF/UHF SDR Receiver AR1

1MHz-500 MHz   YU1LM/QRP

Flo 1MHz-500 MHz (see text)
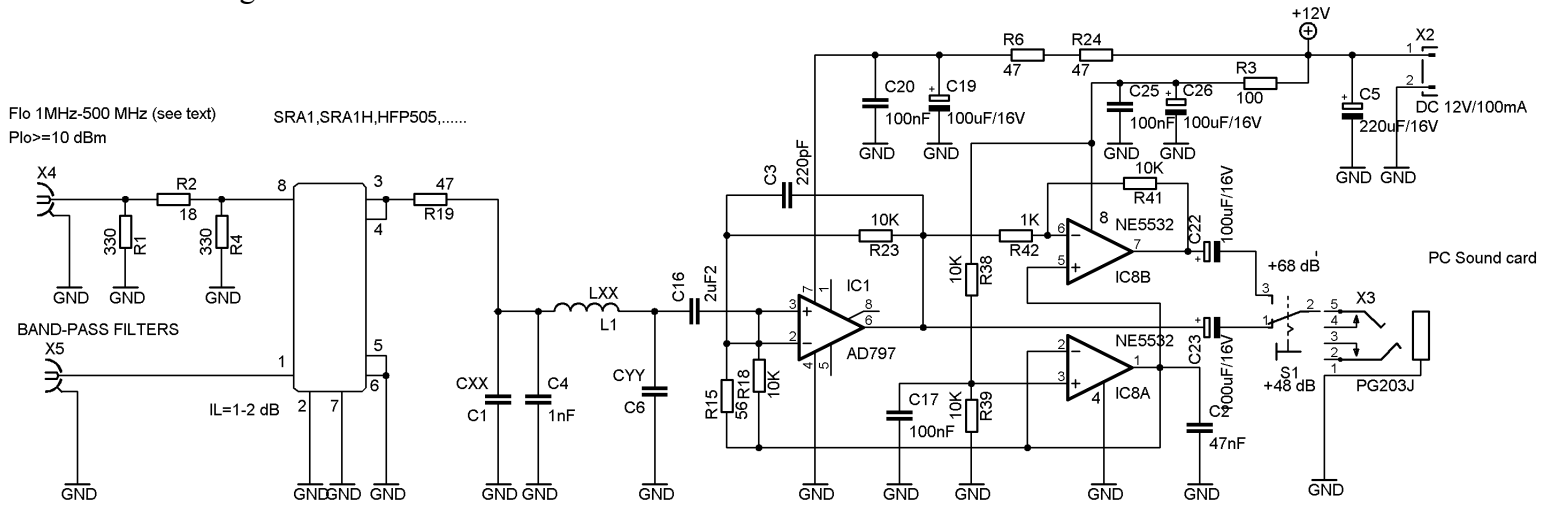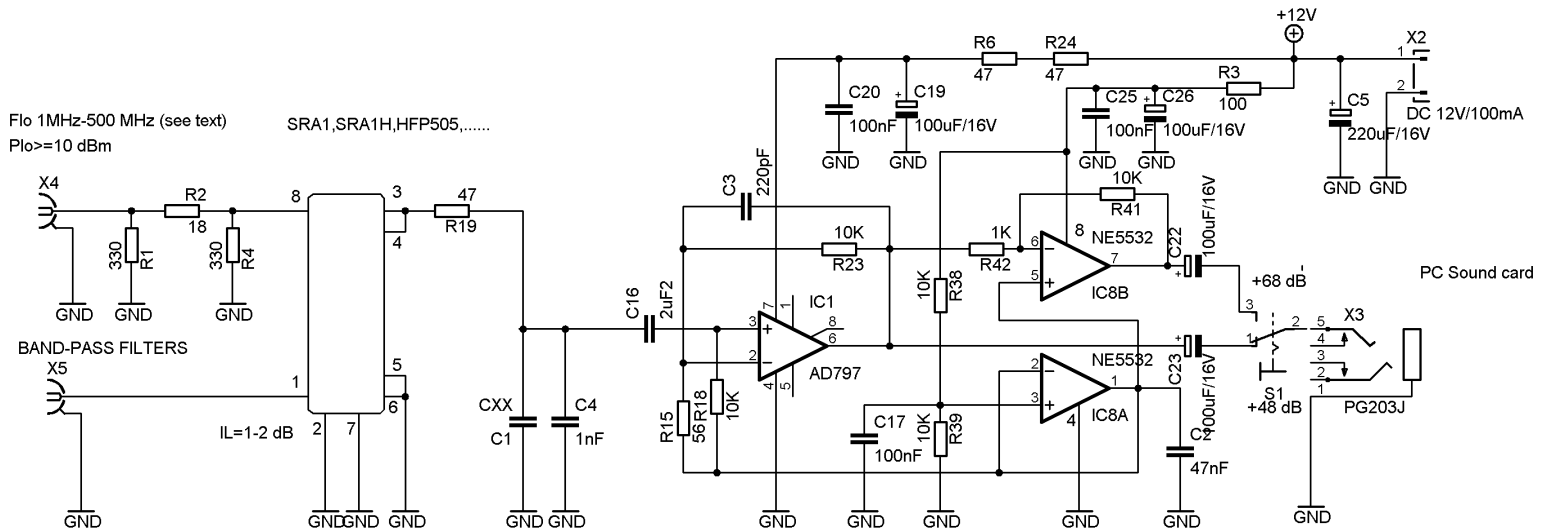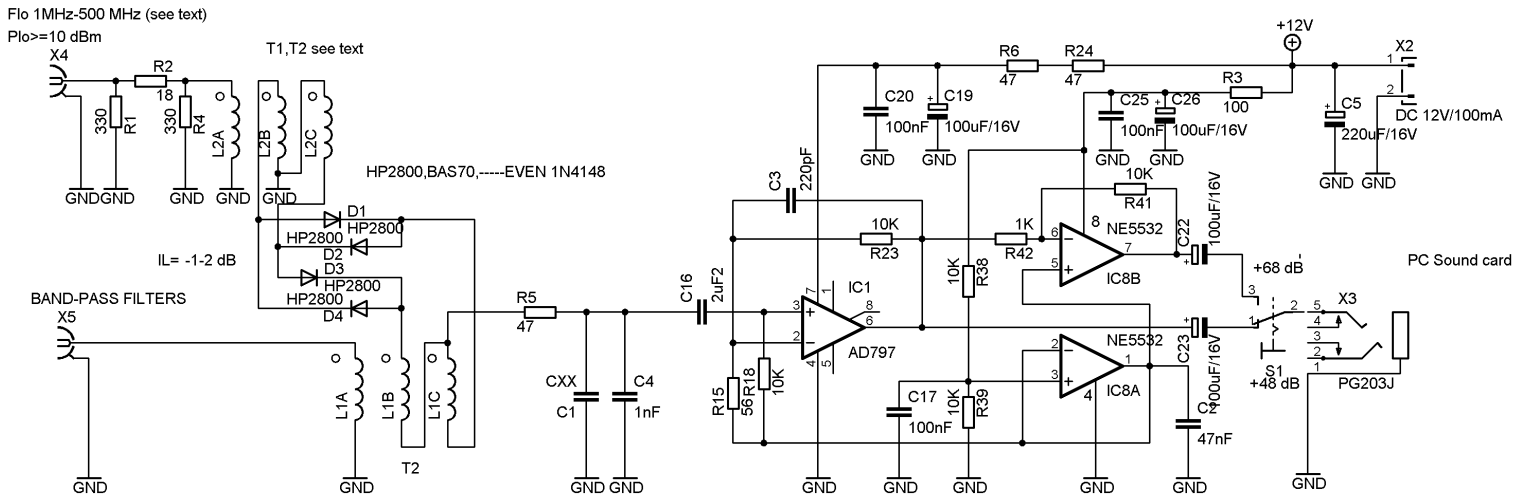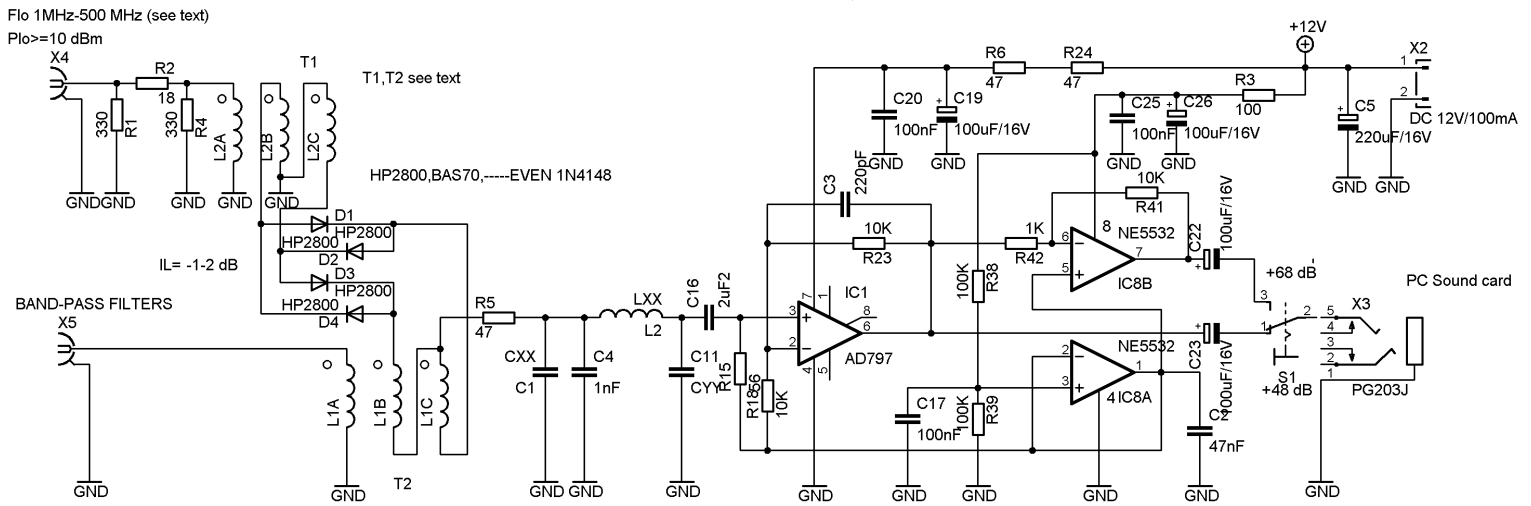Plo>=10 dBm
X4

R2 18
R1 330
R4 330
L2A
L2B
L2C
T1,T2 see text
GND GND GND GND GND

HP2800,BAS70,-----EVEN 1N4148
IL= -1-2 dB
D1 HP2800
D2 HP2800
D3
D4 HP2800

BAND-PASS FILTERS
X5
L1A L1B L1C
GND GND GND
T2

R5 47
CXX C1
C4 1nF
C16 2uF2

R15 56 R18 10K

C3 220pF
R23 10K
IC1 AD797

R38 10K
R42 1K
R41 10K
IC8B NE5532 8 7

C20 100nF
C19 100uF/16V
GND GND

R6 47 R24 47
R3 100
+12V
X2 1
2
C5 220uF/16V
DC 12V/100mA
GND GND

C25 100nF
C26 100uF/16V
GND GND

C22 100uF/16V
+68 dB

IC8A NE5532
C17 100nF
R39 10K

C23 100uF/16V
C24 47nF
+48 dB
S1
X3 PG203J
PC Sound card
GND GND GND GND GND GND

HF/VHF/UHF SDR Receiver AR1-1
1MHz-500 MHz   YU1LM/QRP

Flo 1MHz-500 MHz (see text)
Plo>=10 dBm
X4

R2 18
R1 330
R4 330
L2A
L2B
L2C
T1
T1,T2 see text
GND GND GND GND GND

HP2800,BAS70,-----EVEN 1N4148
IL= -1-2 dB
D1 HP2800
D2
D3
D4 HP2800

BAND-PASS FILTERS
X5
L1A L1B L1C
GND
T2

R5 47
CXX C1
C4 1nF
LXX L2
C16 2uF2
C11 CYY
R15 56 R18 10K

C3 220pF
R23 10K
IC1 AD797

R38 100K
R42 1K
R41 10K
IC8B NE5532 8 7

C20 100nF
C19 100uF/16V
GND GND

R6 47 R24 47
R3 100
+12V
X2 1
2
C5 220uF/16V
DC 12V/100mA
GND GND

C25 100nF
C26 100uF/16V
GND GND

C22 100uF/16V
+68 dB

IC8A NE5532 4
C17 100nF
R39 100K

C23 100uF/16V
C24 47nF
+48 dB
S1
X3 PG203J
PC Sound card
GND GND GND GND GND GND

HF/VHF/UHF SDR Receiver AR1-1
50MHz-500 MHz   YU1LM/QRP

AR1-1 YU1LM
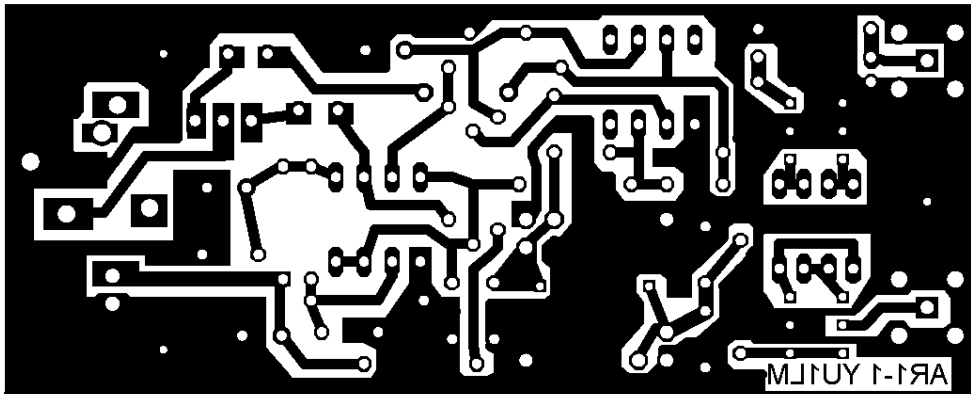
Single side PCB for AR1-1 dimension 88 x 35 mm

TO SOUND CARD

3,5mm

12V/100mA

100nF
1K
AD797
NE5532
100uF 100uF 100uF 100uF 100uF 100nF
2uF2
10K 10K 47 47
100K 100 100K
220uF 100K
100nF 47 100nF 47
LXX
330
18
330
10K
220pF
47

SMB/SMA
1-500 MHz
LO INPUT
Plo>=10 dBm

SMB/SMA
1-500 MHz
RF INPUT
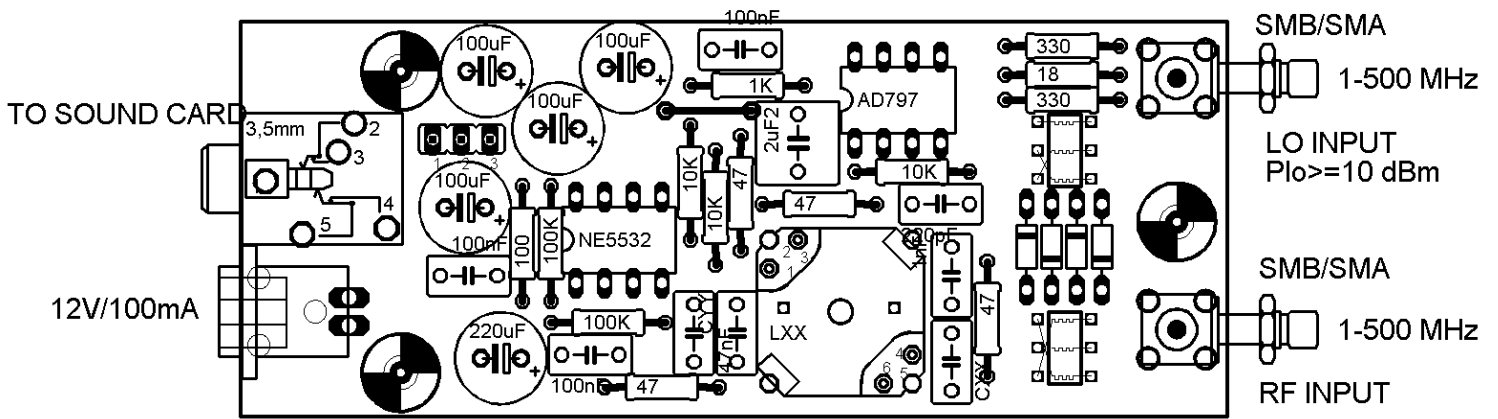
It is possible to make transformers T1, T2 for AR1-! without any ferrite see down how I do this. Of course it is possible use ferrite and than wound adequate numbers turns but it is very important ferrite quality if we want to achieve broadband characteristics. These PVC plastic toroids are working very well between 50-250 MHz. For lower frequencies it is necessary to increase turns number for higher it is necessary to decrease turns number. Increasing turn number will decrease bandwidth from upper side or vice versa.

8-10 mm

5 mm

CUT FROM OLD PENCIL'S PLASTIC TUBE

TWISTED 3 ISOLATED COPPER WIRE 0.2-0.3 mm

A   A
B   B
C   C
10mm
3 NODES
120 mm

8-10 TURNS WOUND AROUND TOROID
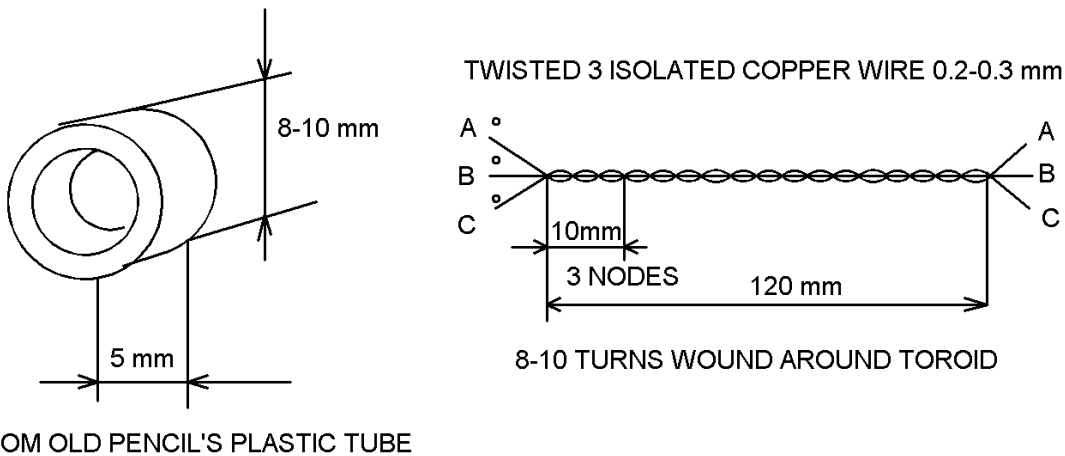
HOW TO MAKE PLASTIC T1,T2 TOROID TRANSFORMERS FOR AR1 AND AR1-1 FREQUENCY RANGE 50-250 MHz

Flo 1MHz-500 MHz (see text)
Plo>=10 dBm

SRA1,SRA1H,HFP505,......

+6V

+12V
X2

C20 C19
100nF 100uF/16V

C7 C6
100nF 100uF/16V

R24
100
R3
100

X4

R2
18
R1
330
R4
330
-3dB

8 3 47
R19
CXX
C2
C3
1nF
GND GND
LXX
L1
C12
CYY
GND

C15
2uF2
10K
R17

IC2
AD797
10K
R25
100
R15
GND
10K
R23

C9
220pF
10K
R39
10K
R37

C25
100nF
C26
100uF/16V

R34
1K
C5
220uF/16V
GND GND

+6V

BAND-PASS FILTERS
X5

1 5 R20
6   47
CXX
C1
C4
1nF
GND GND
LXX
L2
C11
CYY
GND
R18
10K
+6V

C16
2uF2

IC1
AD797

C8
220pF
R40
10K

R38 IC8A
10K
NE5532
GND

R41
10K
1K
R42
NE5532
IC8B
+68 dB

100uF/16V
C22

C23
100uF/16V

C17
100nF

S1
+48 dB

1K
R30
C29
100nF
C28
100uF/16V
GND GND

+6V
X3 PC Sound card

PG203J

GND

R25=R23
R39=R38=R37=R40
GAIN A=2 x (R25/R15)

DC 12V/100mA

HF/VHF/UHF SDR Receiver AR1B
1MHz-500 MHz YU1LM/QRP

HF/VHF/UHF SDR Receiver AR1B-1
1MHz-500 MHz YU1LM/QRP

Flo 1MHz-500 MHz (see text)
Plo>=10 dBm

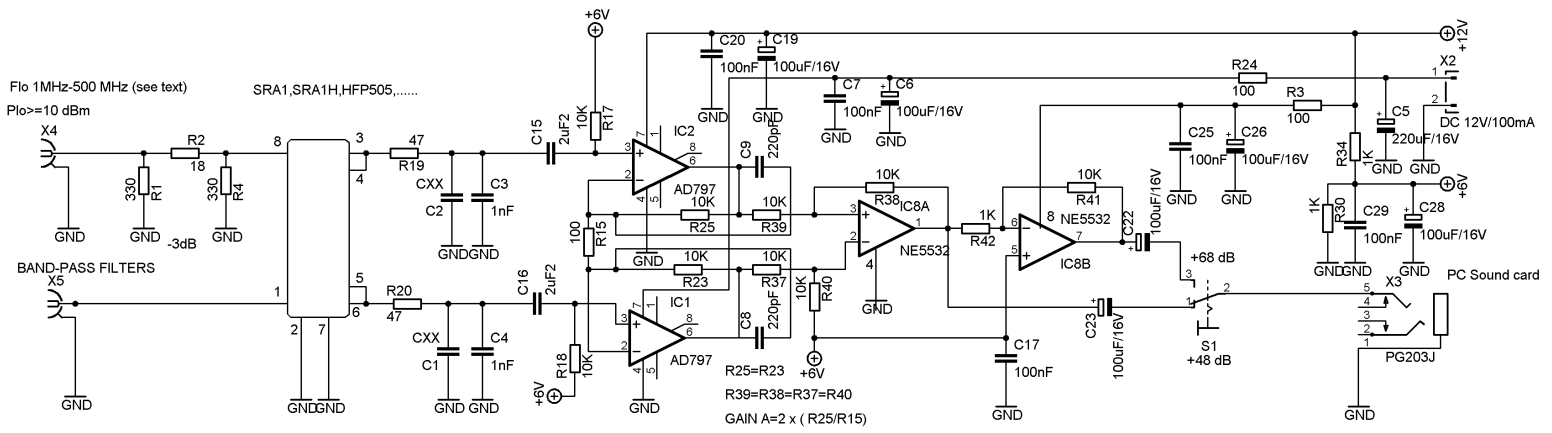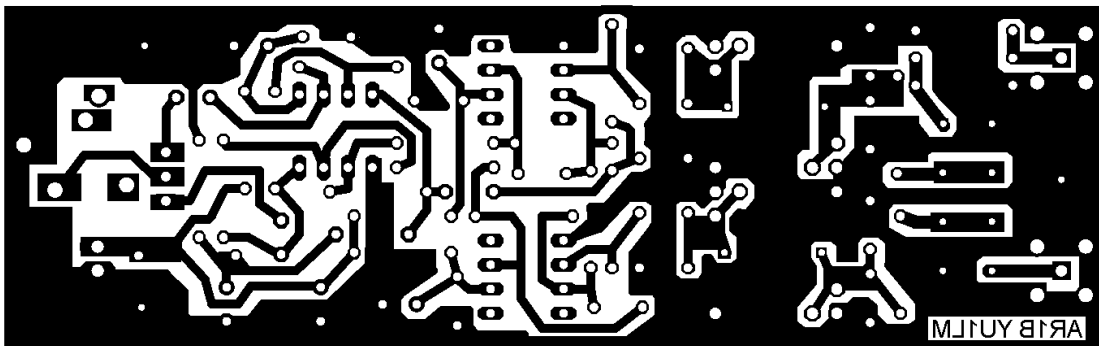SRA1,SRA1H,HFP505,......

BAND-PASS FILTERS

+6V
+12V
DC 12V/100mA
PC Sound card

GAIN A=2 x (R25/R15)
R25=R23
R39=R38=R37=R40

+68 dB
+48 dB
S1

AD797
NE5532
IC8A
IC8B
IC1
IC2

TO SOUND CARD 3,5mm
12V/100mA

SMB/SMA 1-500 MHz
LO INPUT Plo>=10 dBm
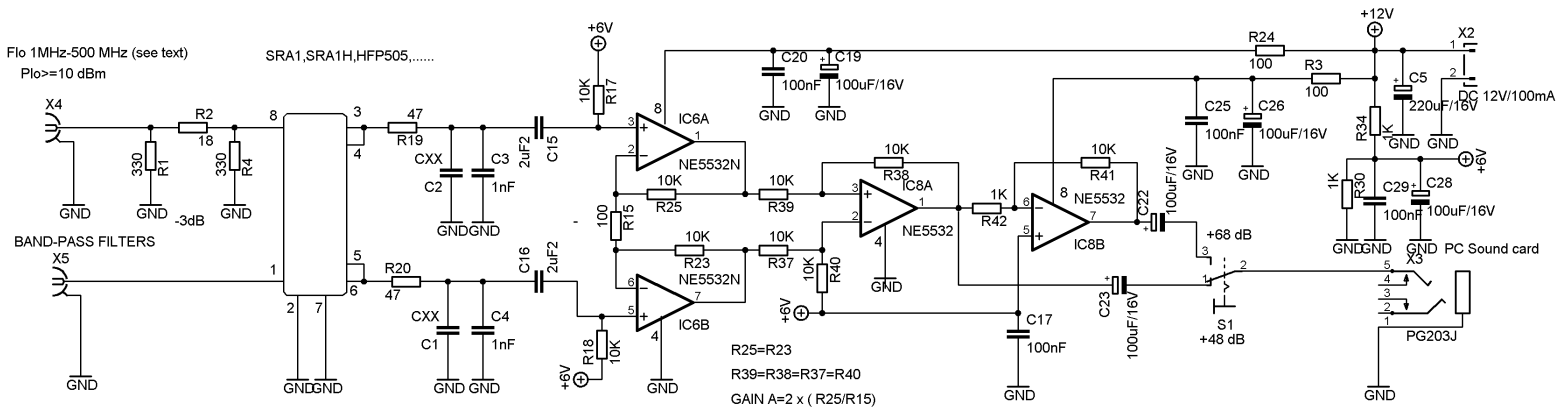SMB/SMA 1-500 MHz
RF INPUT

SRA1,SRA1H,HPF505,...
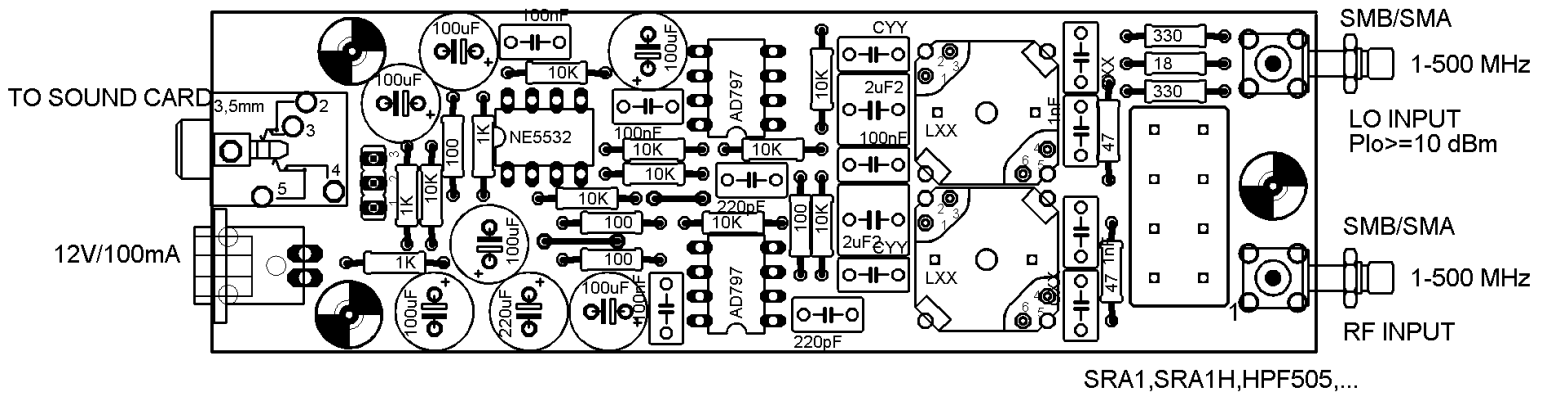
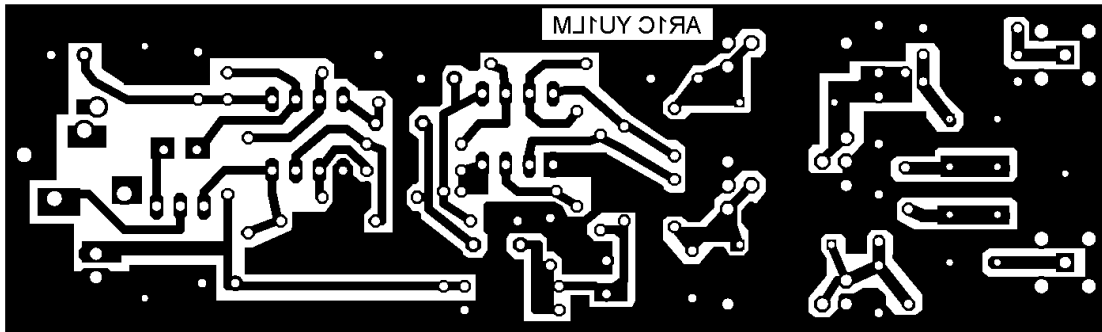DR1B SDR receiver, single side PCB dimensions 115 x 36 mm
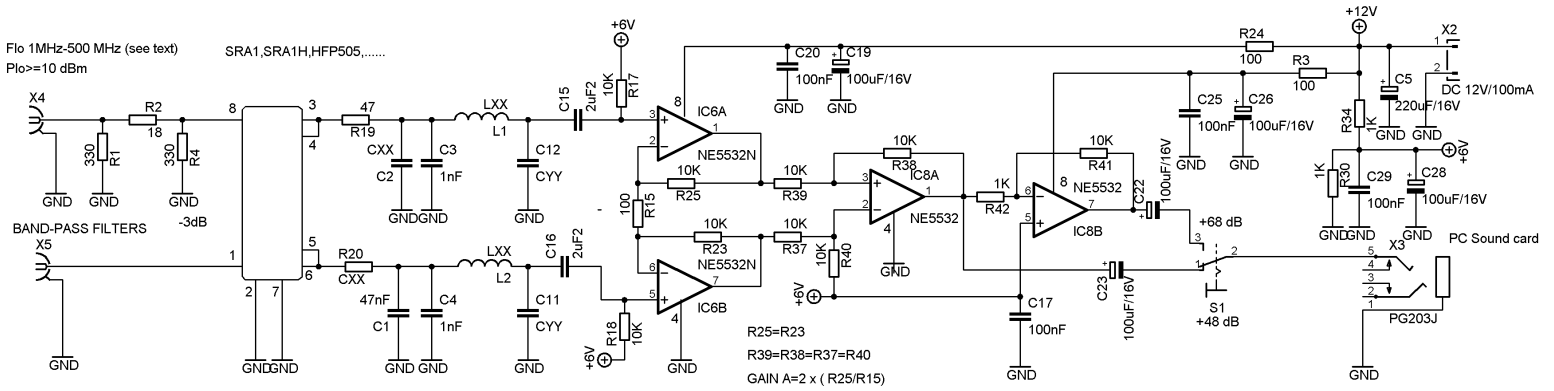
HF/VHF/UHF SDR Receiver AR1C
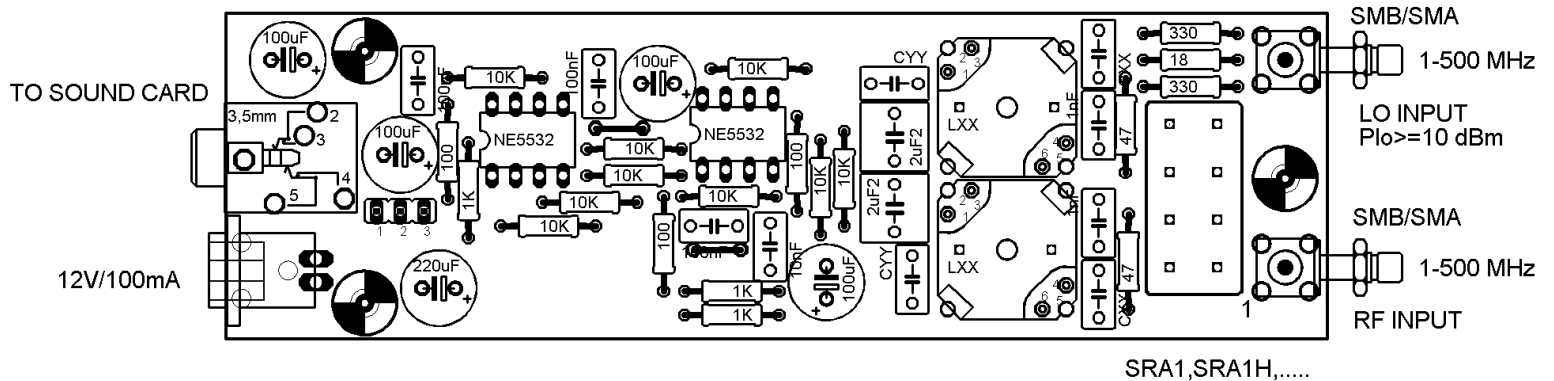### 1MHz-500 MHz YU1LM/QRP

HF/VHF/UHF SDR Receiver AR1C-1
1MHz-500 MHz YU1LM/QRP

AR1C SDR receiver, single side PCB dimensions 118 x 36 mm

There is no adjustment for these AR1…receivers and all have to work instantly. There are some other performances for all receivers with SRA1H like:

1. 1dB compression point is at input level -25 dBm or 59 +78 dB!!!! (all receivers without RF pre amplification)
2. IIP3 is -10 dBm for SRA1H

In part I will describe AR2 series it is combination AR1.. sreies and Wilkinson power splitter at RF input and quadrature splitter at LO input between 2 RX. I will also describe some possible LO for RX. We can divide LO at possible 4 solutions:

1. Fixed XTAL oscillator (5,7th overtone)(separate article –Universal HF/VHF oscillator)
2. Very good DDS LO with AD9951
3. Mixed circuit between DDS LO with AD 9850(51) and REF oscillator for DDS 120 -125 MHz
4. PLL LO

I wish you successful AR1….RX realization and I am apologizing for the some possible mistakes. I made great effort to make SDR projects and share them with all who are interesting for. Send me your comments positive or negative anyway, results or photos of your realization please.

GL in SDR homebrew and VY 73/72 Tasa YU1LM/QRP
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4. *Skidan@mail.ints.net T03DSP UR3IQO http://users.ints.net/skidan/T03DSP*
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7. *http://www.njqrp.org/mbrproj/9850dds.html*

www.analog.com/en/prod/0,,770_843_AD9850,00.html

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http://www.k6ese.com/DDS_Project.htm

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http://www.qsl.net/om3cph/dds/rx.html

http://www.seboldt.net/k0jd/othervfo.html

http://perso.wanadoo.fr/f6itv/p2063001.htm

http://koti.netplaza.fi/~jonverro/ad9854.htm

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   5.   *RF Design 6/1995*

9. Ultra Low Noise, High Performance, Zero IF Quadrature, Product Detector and Preamplifier-Dan Tayloe N7VE

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Software LINK for SDR radio receiving and transmitting

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2. *www.ciaoradio.com*

3. **www.m0kgk.co.uk/sdr**

4. *www.g8jcf.dyndns.org* **Peter G8JCF**

5. http://www.nitehawk.com/sm5bsz *Leif LINARD*

6. http://www.flex-radio.com *SDR1000 Gerald AC5OG*

7. **dl6iak.ba-karlsruhe.de**