933 MHz LOW POWER DOWNCONVERTER WITH 60 MHz I.F.

Introduction

This application note describes the performance of a 900 MHz low voltage (3 volt) downconverter intended for wireless applications like GSM, AMPS, TACS, CT1, CT1+ and NMT.
The main intention is to demonstrate the superior performance of the new Philips fourth generation RF wideband bipolar transistors used as an RF preamplifier and mixer. In addition, a buffer and oscillator circuit are also included in this design to make it convenient in assessing overall performance. The designs of the RF preamplifier and mixer were treated as more important while that of the oscillator and buffer were not the primary focus.

In determining the performance of a downconverter, several specs are important and the best trade-off between these will depend on the importance of these in the system. The system designer will decide which are the more important: signal handling (linearity), sensitivity (noise figure), supply power (efficiency). This application note includes the design for only one configuration for a cordless telephone (CT1+); however other downconverter designs can be derived from this basic design to satisfy the other system requirements.

Circuit Design Requirements

The converter block diagram (see fig. 1, next page) is the typical block diagram for a converter suitable in general for any of these systems. A particular system other than CT1+ may require something different, but the concepts are basically the same.

Preselect Filter Requirements

In the block diagram (fig. 1) between A and B and between C and D are the preselect filters, which are included in this design to improve image rejection; to reject out of band signals (such as coming from the transmitter); and to increase isolation from VCO to antenna (necessary for the LO radiation spec to be met). The most frequently used RF filters are made with high dielectric constant ceramic material with low loss tangent. They can be very small in size while maintaining low insertion loss,very important since the loss at the input adds directly to degrade the overall noise figure. The insertion loss of the SMD filters appeared to be around 2 dB.

The number of poles used in the filtering in this design is 4; two 2-pole filters with 1 in front of the RF preamplifier and 1 in the interstage between the RF preamplifier and the mixer. This give a better trade-off between noise and intermodulation. The input filter might in practice be part of a diplexer between transmitter and receiver.
The number of poles necessary to get sufficient image rejection depends, ofcourse, very much on the chosen intermediate frequency. The lower the IF, the more selective the filters need to be. SAW filters are also available for this purpose, which are in general more selective, but give a higher insertion loss.

933 MHz low power downconverter with 60 MHz I.F.

Application report

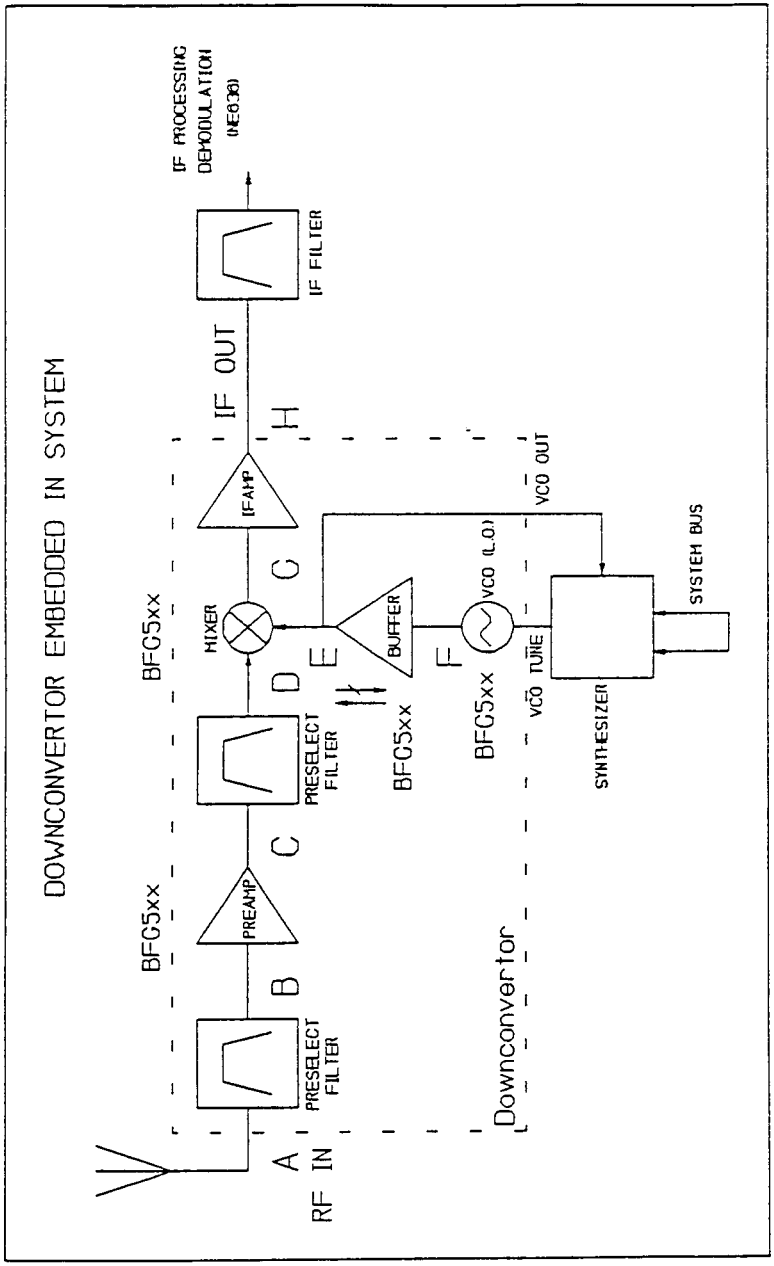


Fig 1. Block diagram receiver downconverter

RF Preamplifier requirements

The preamplifier (between B and C) is required to improve the downconverter noise figure as the mixer Noise Figure on its own is too high. The preamplifier also helps to improve isolation from VCO to antenna and adds some gain.

Mixer Requirements

Any of various mixer configurations could be considered. The mixer should provide a linear mixing conversion, i.e. provide an output level at the IF which is in proportion to the RF input signal level. In addition the choice is based on the most important requirements: the isolation required between the LO and the RF input (or points D and E); and the Noise Figure and linearity requirements. Linearity may be expressed by specifying IP_3 (third order intercept point) and/or F.R.S. (first repeated spot) specification; the latter being a measure of inband 2nd order distortion. The mixer should also give sufficient gain so that an additional IF-amplifier would not be required (between G and H).

VCO and Buffer Requirements

The VCO should provide a signal with high spectral purity (low phase noise) in order not to degrade receiver sensitivity when strong signals are present in adjacent channels. Requirements for the VCO include a predefined tuning slope and tuning range, and a reproducibility of the center frequency without the requirement for tuning or trimming in production. Also the output level should be sufficient to drive the mixer or buffer while operating at a low current. When the mixer isolation or VCO buffering is not sufficient (causing, either or both, too much leak through of the LO to the antenna and oscillator pulling), a buffer amplifier is necessary. VCO frequency-pulling can be improved considerably by using a well designed buffer amplifier.

MAIN SYSTEM CHARACTERISTICS

Fin= 931 MHz Fout=60 MHz (FLO=871 MHz tuned by means of Vtune)

CHARACTERISTIC	VALUE	REMARKS
CONVERSION POWER GAIN	typ. 20 dB	includes filter losses
NOISE FIGURE	typ. 6 dB	includes losses
IP3	typ. -10 dBm	at input
1 dB COMPRESSION	typ. -3 dBm	at output
LO RADIATION	< 100 pW	on RF input
FREQUENCY PULLING	< 50 kHz shift LO	RF input > 12 dBm
IMAGE REJECTION	typ. 78 dB	imagefreq=811 MHz
SUPPLY VOLTAGE	typ. 3.3 V	Vcc1=Vcc2
SUPPLY CURRENT	typ. 11 mA	mixer/pre= 4 mA LO/ buff = 7 mA
VCO CNR@100 kHz (phase noise)	typ -115 dBcHz	not optimised
REPRODUCABILITY	GAIN +/- 0.5 dB (*)	no alignments
BOARD SIZE	28x16x6 mm 15x23x2 mm	preamp+mix+filt. LO+buffer
PCB material	epoxy FR4 h=0.5 mm	Er=4.6
in/load impedance	50 Ohm	at meas. frequency

(*) with parts of +/- 5% tolerance (filter tolerances not included)
See also the graphs in the appendix.

Appendices:

Appendix A1: Board layout preamp + mixer
Appendix A2: " " VCO + buffer
Appendix A3: " " backside PCB (filters)
Appendix B : components list
Appendix C : measurements

Circuit Design

The circuit was built with the following sub-blocks:

1. RF Preamplifier and filters
2. Mixer, IF-Matching
3. VCO and Buffer amp

The circuit diagram is shown in fig. 2

RF preamplifier Design

The RF preamplifier is designed with the BFG505/x, which is gain optimized for low current in the range 1 to 5 mA. this transistor, in the SOT143 package style, has an F_T of 9 GHz, a maximum Gain of more than 16 dB at 900 MHz, and a minimum noise Figure of 1.2 dB at 900 MHz and 2 mA.
In order to fix the operating point, the choice must be made for the bias current setting to get a certain amount of minimum gain combined with an adequate low noise figure. Once the mixer Noise Figure has been determined (normally between 6 and 10 dB), the best trade-off between gain and noise figure for the preamplifier can also be determined. While, on the one hand, higher preamplifier gain will lower the overall intercept point due to higher mixer drive, more attention is given to a low noise figure for the RF preamplifier, with more attention to high intercept point given to the mixer design.

To simplify the design, due to extra gain available, the output matching of the preamplifier was done with a shunt resistor (R8), rather than using an LC-match. This lowers the gain somewhat but eliminates the use of a coil which takes more space on the board and/or is more costly than the resistor. The lower saturation point that results was not a problem, as the linearity is still sufficient. (In fact, the preamplifier bias current could still be reduced.)

The DC bias point stabilization is provided with a low cost PNP transistor, which eliminates the influence of h_{FE} on the bias current setting without using a capacitance bypassed resistor in the emitter lead. At this frequency capacitor bypassing tends towards instability so it is to be avoided. With the PNP transistor biasing method the circuit is unconditionally stable. The preselect filters are mounted on the bottom side of the PCB. When parts count is a critical factor the biasing method can be simplified, yield analysis to predict gain variation is necessary, however.

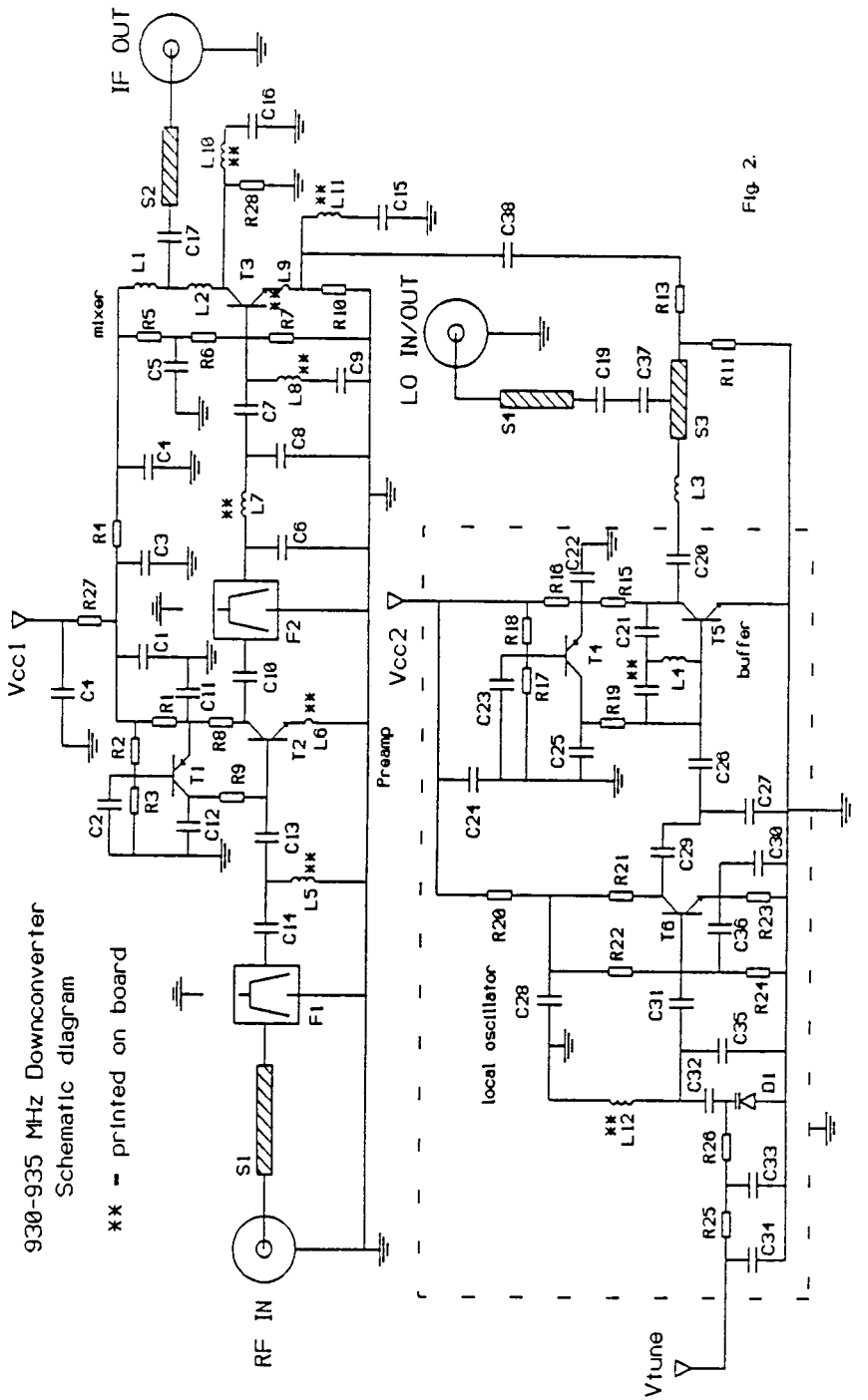


Fig 2.

Fig 2. schematic diagram receiver downconverter

Mixer Circuit

A single transistor solution, in this case the BFG520, was chosen for the mixer design with RF input connected to the base and LO to the emitter. This was done to simplify matching, but other configurations would also give comparable performance. Circuit optimization was done using large-signal CAD analysis based on SPICE modelling. Critical aspects are:

- matching RF port/LO port
- isolation
- instability
- linearity

Matching to the RF is done with a pi-section C6-L7-C8. The LO-port is not matched but by means of two resistors (R12, R11) a properly defined LO drive impedance is made. For intermediate frequency both base and emitter are capacitive loaded to give highest conversion gain. The value of the emitter decoupling capacitor (C15) should be chosen carefully (could make the circuit unstable, if the wrong value is chosen); resistive feedback is used for DC stabilization. The IF match (L1, L2, C16, C17) transforms the 50 Ohm load impedance into a high impedance. This high impedance at the collector results in a significant gain contribution since the output impedance of the transistor is almost a perfect current source at IF.

If the impedance has to be transformed down to a low load impedance (50 ohms) to the IF output or filter from the high collector impedance, more than one LC sections might be needed, otherwise the bandwith becomes too narrow and the sensitivity towards component spread high. Gain limitation can be caused by the component tolerance spread, if alignment has to be avoided. A transformation factor of about 30 can be reached with 5% tolerance value components and a double LC section. In this way the 50 Ohm load was transformed into 1.5 kOhm at the collector of the mixer transistor. A 50 Ohm match might be a somewhat unrealistic value for intermediate frequency filters but this theory holds also for other transformation factors. Typically, X-tal filters have a high impedance (1-2 kOhm) and this considerably reduces component count since the double LC-match is not necessary in this case.

Favourably the collector impedance should be low ohmic at RF frequencies. This is done by means of L10. A too inductive load here can lead towards instability. Therefore, the load formed by L10-C16 is not yet at series resonance at 900 MHz. This method also eliminates gain variations caused by the parasitic impedances of the SMD coils at 900 MHz. Observe the specifications of the mixer on the next page. The mixer design was optimized using CAD tools for a DC-current of 1.8 mA.

Measured characteristics of this mixer amp

CONVERSION POWER GAIN	12 dB	
IP3	-2 dBm	input, LO=-2 dBm
NOISE FIGURE	8 dB	LO=-2 dBm supressed image
DC-current	1.8 mA	
load imp. collector	1.5 kOhm	transf. factor =30
LO source impedance	50 Ohm	

Local Oscillator and buffer

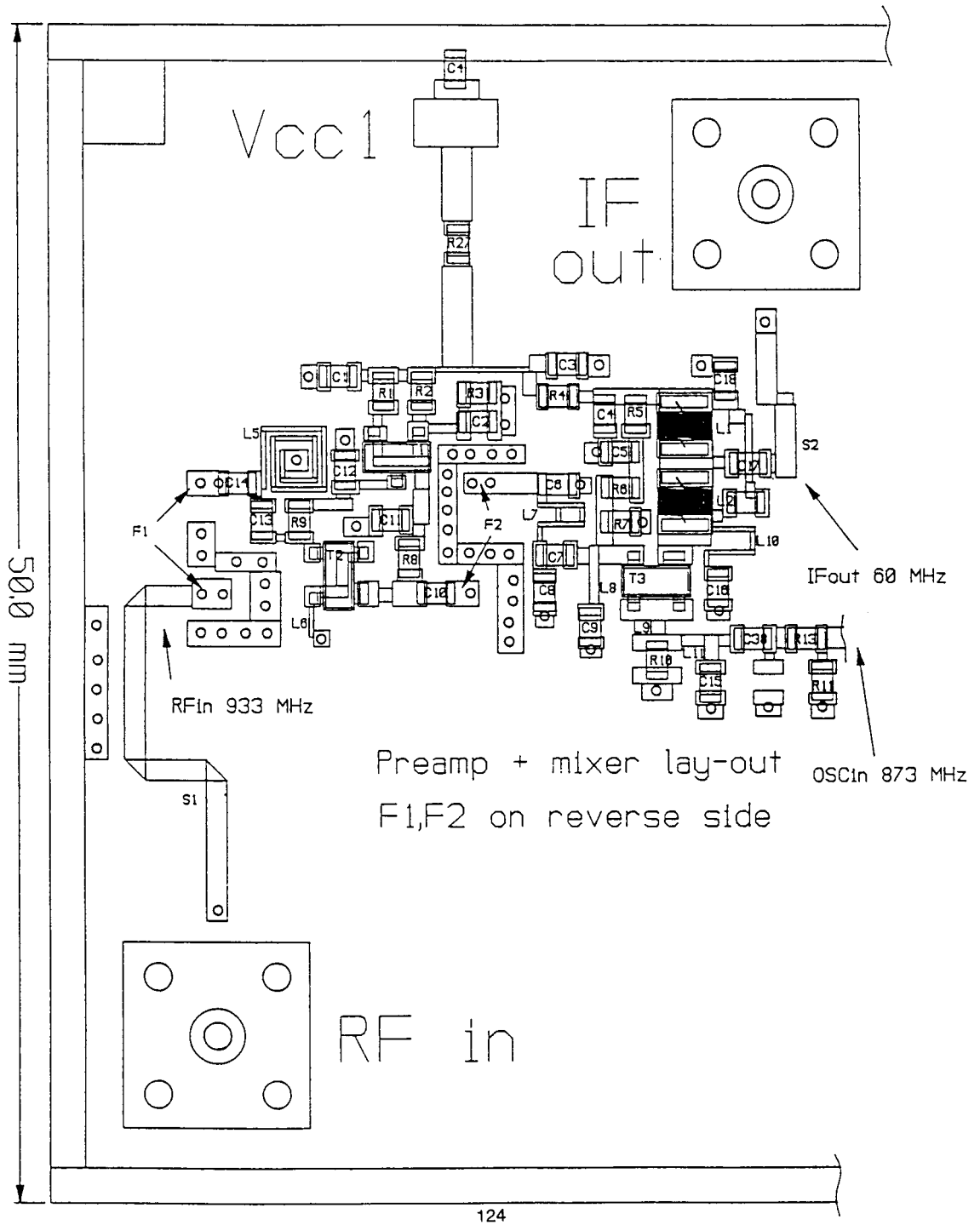
The bufferamp is designed to have 0 dB of gain, to act also as limiter and to have high isolation. The isolation is important to improve the frequency pulling and also to improve the intercept point of the downconverter. If the isolation of the buffer amp is too low this can cause modulation of the oscillator by the RF input spectrum, and the resulting FM-sidebands will be seen as linearity reduction. To increase the isolation of the buffer a neutralizing coil (L4) was added which tunes out the feedback capacitance of the RF transistor. This improves the buffer isolation by as much as 15 dB without making it unstable. Another solution that may work better is the use of a cascoded transistor stage as the buffer. A small coil (L3) is used for better match between buffer and mixer transistor. This coil can also be printed on board due to its low value (12 nH) but in the application a SMD coil was used.

The VCO design used is a straightforward common collector (colpitts) design. The BFG540/X transistor was used as the VCO as its low base resistance assures low phase noise (a result of low losses in the resonant circuit). Even with the small size printed coil on FR4 used as resonator a phase noise of -115 dBcHz at 100 kHz offset was obtained, which is satisfactory for most systems.

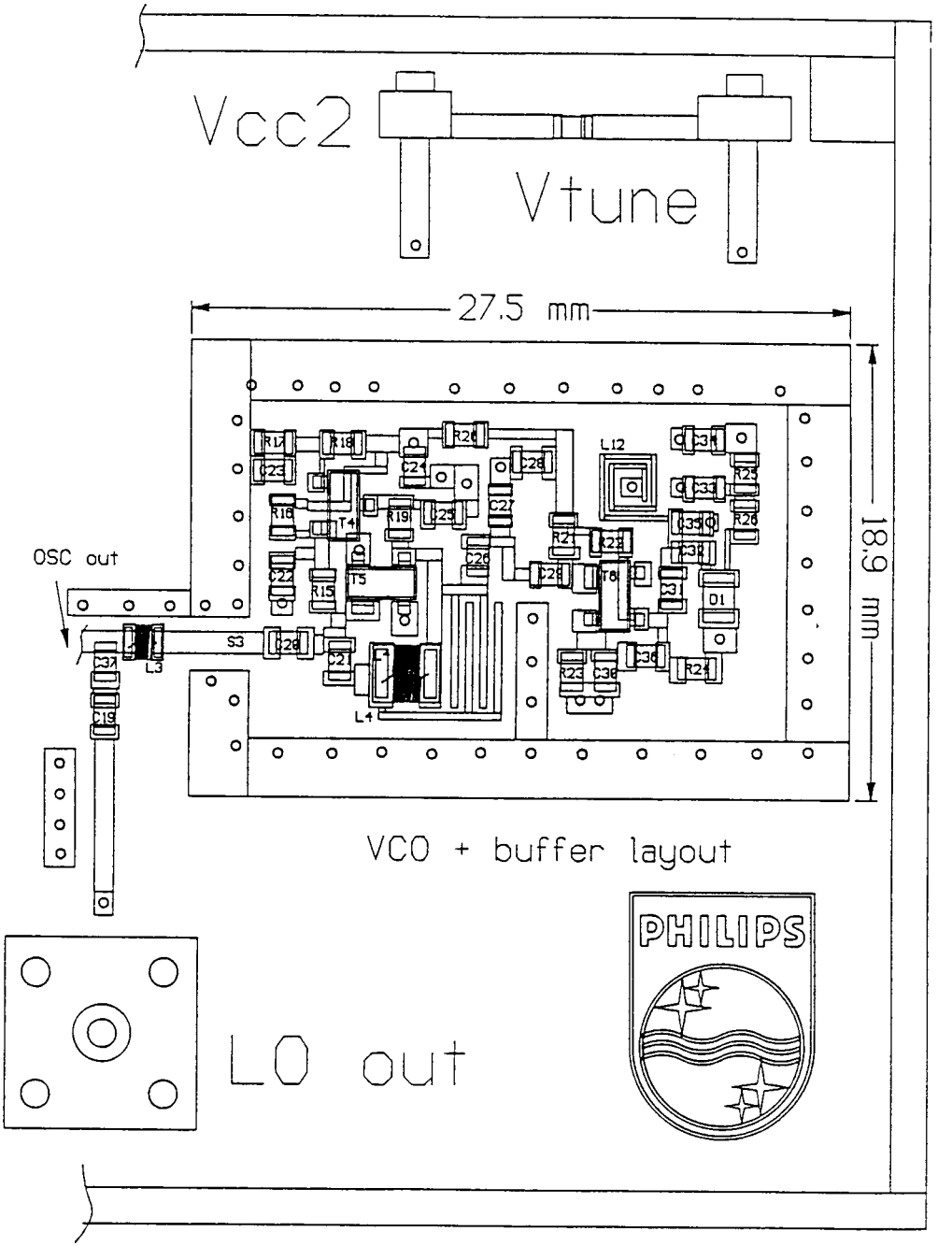
Testing Mixer/Preamplifier

In order to measure the performance of the mixer/preamp seperately, it is necessary to remove L3 and to change C36 into 33 pF (was 3p9). The LO output (normally intended for prescaler/synthesizer) can be used as the input. The oscillator should be turned off by means of removing the 10 Ohm resistor between Vcc1 and Vcc2. A supply of 3.3 Volt shoulinto 33pF (was 3p9). The LO-output (normally intended for prescaler/synthesizer)
can be used as input. The oscillator should be turned off by means of removing the 10 Ohm resistor between Vcc1 and Vcc2.
A supply of 3.3 Volt should be connected to Vcc1.
Results of measurements and board layout are in the appendices

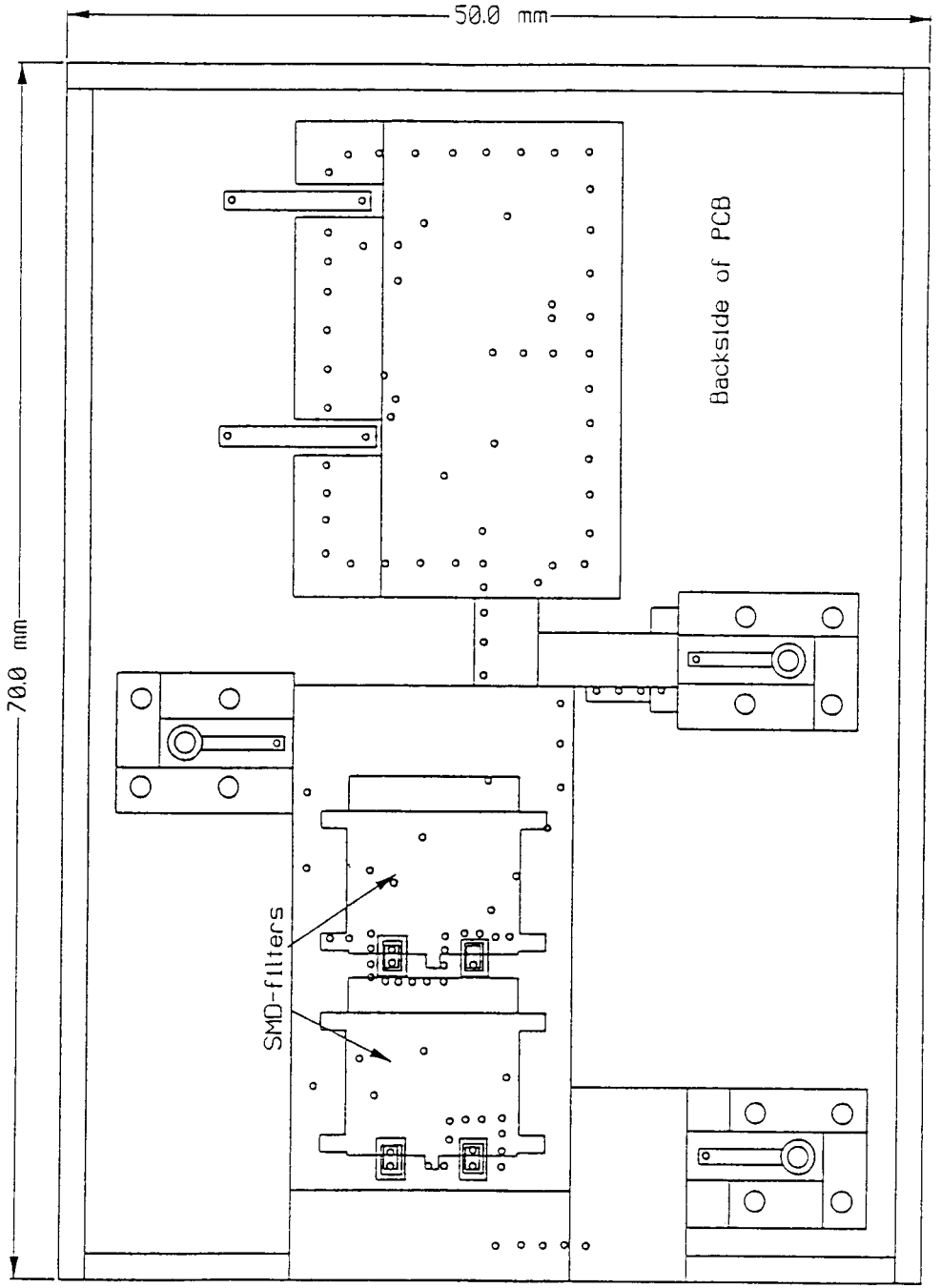
Appendix A1


Vcc1
IF
out
IFout 60 MHz
RFin 933 MHz
OSCin 873 MHz
RF in
F1
F2
S1
S2
50.0 mm
Preamp + mixer lay-out
F1,F2 on reverse side

Appendix A2


Vcc2
Vtune
27.5 mm
18.9 mm
OSC out
VCO + buffer layout
LO out
PHILIPS

Appendix A3



Appendix B

Capacitors

C1,C3,C4,C9,C11,C12,C15,
C18,C23,C24,C25,C33,C34.....10nF
C2,C5,C21,C26,C27,C28,C29.....1nF
C6.....1P6
C7.....150pF
C8.....5p6
C10,C19,C20.....33p
C13.....820pF
C14.....3pF
C16.....0p56
C17.....10pF
C22.....270pF
C30.....1p0
C31.....3p3
C32.....1p2
C35,C36.....to tune VCO freq.
C37.....3p9
C38.....27pF

Resistors

R1,R10.....220
R2,R26.....2k7
R3,R7,R17.....5k6
R4.....22
R5,R18,R19.....1k8
R6,R9,R24,R25.....8k2
R8.....330
R11.....68
R13.....12
R15.....390
R16.....120
R20.....22
R21.....180
R22.....8k2
R23.....470
R27.....18
R28.....8k2

Coils,filters

L1.....560 nH SMD 1008
L2.....2200 nH SMD 1008
L3.....12 nH SMD 0805
L4.....56 nH SMD 1008
F1,F2.....Siemens 2-pole SMD
(see app.)

Semiconductors

T1,T4.....BC807 (5DP)
T2,T5.....BFG505X (N39)
T3.....BFG520 (N36)
D1.....BB131
T6.....BFG540/X(N43)

Appendix c

Conv. Gain vs. IF frequency
Fixed RF Frequency- 933 MHz
gain (dB)
25
24
23
22
21
20
68 67 58 59 60 61 62 63 64
frequency
typical
Vcc=3.30 Volt (L.O. tuned)

NOISE FIGURE vs. LO frequency
Fixed IF Frequency- 60 MHz
N.F. (dB)
7
6.8
6.6
6.4
6.2
6
5.8
5.6
5.4
5.2
5
869 870 871 872 873 874 875 876 877 878 879
frequency
typical
Vcc=3.30 Volt HP8970B

Conv. Gain vs. RF frequency
Fixed Local Oscillator- 873 MHz
gain (dB)
25
20
15
10
5
0
920 925 930 935 940 945 950
frequency
typical
Vcc=3.30 Volt

Conv. Gain vs. input power
Fixed Local Oscillator- 873 MHz
gain (dB)
23
22
21
20
19
18
17
-40 -38 -36 -34 -32 -30 -28 -26 -24 -22 -20
RF power (dBm)
typical
Vcc=3.30 Volt