PHILIPS

Philips Semiconductors

Application Note

Ultra Low Noise Amplifiers for 900 and 2000 MHz with High IP3

by Korné Vennema
Philips Semiconductors
Slatersville, RI

December 1996
#KV96-157

This application note describes four Low Noise Amplifier designs with the BFG410W and the BFG425W, two devices from Philips Semiconductors' fifth generation wideband technology. The amplifier designs include measurement results and pcb layouts. The following designs are included:

a) 900 Mhz LNA with BFG410W
b) 2 GHz LNA with BFG410W
c) 900 Mhz LNA with BFG425W
d) 2 Ghz LNA with BFG425W

Introduction

Today's wireless applications require Low Noise Amplifiers with a high third order intercept point (IP3) and a low noise figure (NF) at the same time. This is particularly interesting for 1900 MHz CDMA receiver front ends. This report describes four ultra low noise amplifiers for 900 MHz and 1900 MHz wireless applications, using Philips Semiconductors' fifth generation wideband technology. Philips' fifth generation die technology uses a double polysilicon process with a buried layer which results in transition frequencies (fT) higher than 20 GHz, gains in excess of 20 dB and Noise Figures as low as 1.2 dB. The amplifiers are designed for use at 2 Volt collector emitter voltage. A separate paragraph describes ways to improve IP3 in a LNA.

The fifth generation

Philips' fifth generation double poly silicon wideband technology (see figure 1) uses a steep emitter doped profile resulting in transition frequencies over 20 GHz, and with poly base contacts a low base resistance is obtained. Via the buried layer, the collector contact is brought out at the top of the die.

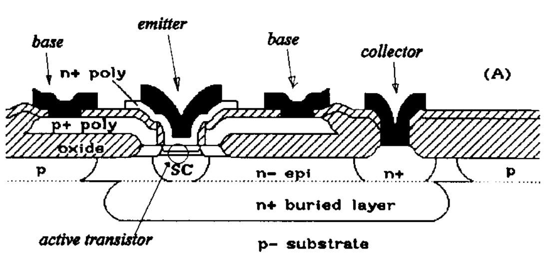

Figure 1: Double polysilicon buried transistor

The substrate is connected directly to the emitter package lead, resulting in improved thermal performance (see figure 2).

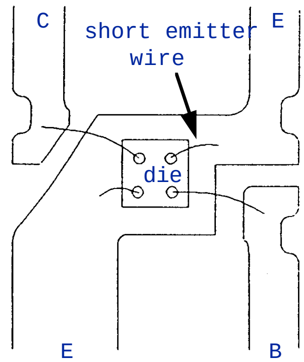

Figure 2: Short emitter bonding wires reduce emitter inductance, which results in high gain. Heat flows through two emitter leads which lowers thermal resistance. Overall: Improved RF and thermal performance

The types of the fifth generation

The table below shows the three new types that use the fifth generation die technology.

Type	I_E^ (mA)	f_T (GHz)	MSG (dB)	NF (dB)
			f=2GHz	f=2GHz
BFG403W	*3*	*17*	*22*	*1.5*
BFG410W	*10*	*22*	*23*	*1.3*
BFG425W	*25*	*24*	*21*	*1.3*

IP3, using bypassing to improve it

Third order intercept point is usually determined by using a two tone test, i.e. two equal carriers with a small offset in frequency. Due to transistor non-linearities, these two carriers generate distortion products, both in-band and out of band (see figure 3). The product f_2-f_1 is a low frequency product that is generated, which can modulate

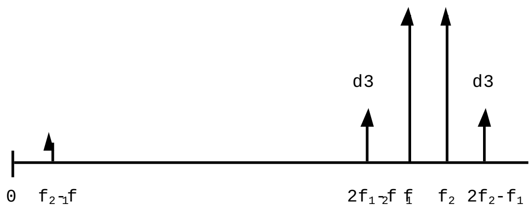

Figure 3: Two tone test and generated intermodulation distortion products. f_2-f_1 is the low frequency product

the base-emitter and collector-emitter voltages of a transistor used in an amplifier. This results in a fluctuating bias (base) voltage and supply (collector) voltage. For good linearity, a constant base and collector voltage are required. Lowering the collector voltage causes an amplifier to saturate earlier, thus decreasing linearity for a certain power level. The base voltage sets the quiescent current for the device, and thus the linearity (see also figure 4) . A fluctuating base voltage would change the linearity of the amplifier. Therefore it is important to apply proper bypassing at both collector and base.

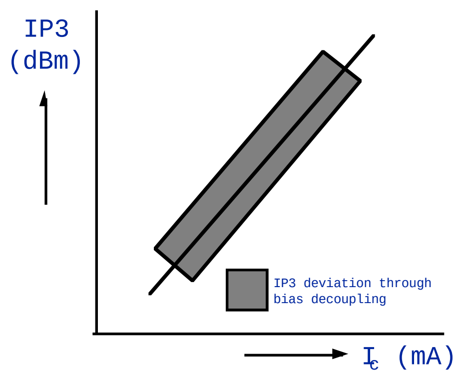

Figure 4: IP3 in a Low Noise Amplifier is related to the collector current and also collector emitter voltage. As a rule of thumb for bipolar technology: $IP3_{out}$=10 log (V_{ce} * I_c * 5E3) in dBm

Figure 5 shows the typical circuit diagram for a bipolar LNA. C is the bypassing capacitor for the working frequency, i.e. either 900 or 1900 MHz. Adding additional bypassing by means

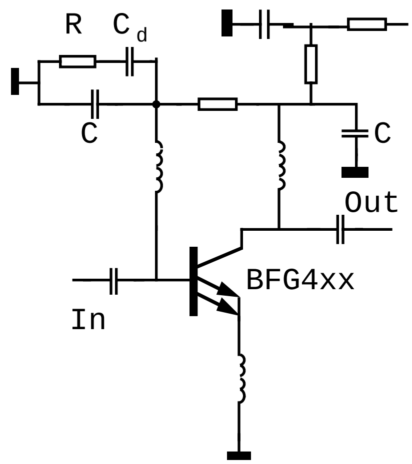

Figure 5: Typical circuit diagram for a LNA. C_d is the additional bypassing for low frequencies. R is added to prevent low frequency instabilities. C is a short for the working frequency (27 pF at 900 MHz and 5.6 pF at 1900 MHz)

of C_d improves the IP3 considerably. An improvement of 6 - 10 dB in IP3 can be expected. As a rule of thumb, the impedance of C_d should be smaller than 25 percent of the input impedance of the transistor at a particular carrier spacing. In case of a BFG520 (fourth generation wideband transistor) the following calculation is valid:

Z_{in} (25kHz) ≈ h_{fe} / g_m = 120 / (40 * 0.0065) ≈ 450 Ω
Cd < 0.25 * 450 ≈ 100 Ω
At 25 kHz, the capacitor value equals:
C_d = 1 / (2 * π* f * 100) ≈ 63 nF

63 nF is the minimum recommended value. It is obvious that a higher capacitor value does a better job. Space constraints often don't allow the use of electrolytic (or even better tantalum) capacitors. In most cases, a 100 nF or 220 nF capacitor is sufficient.
So far only base bypassing has been discussed. Similar effects can be

expected when collector bypassing is also applied; however, the effects are less dramatic.

a) 900 MHz LNA with BFG410W

This section describes a 900 MHz LNA with the BFG410W. The performance can be summarized as follows:

V_{ce}=2V, I_c=2mA, $V_{SUP}\approx$3.3V
freq. = 900MHz
$|S_{21}|^2$ = 14 dB
$|S_{12}|^2$ = -26 dB
NF = 1.4 dB
$VSWR_i$ = 1 : 1.9
$VSWR_o$ = 1 : 2.3
$IP3_{in}$ = -9 dBm (Δf=100 kHz)

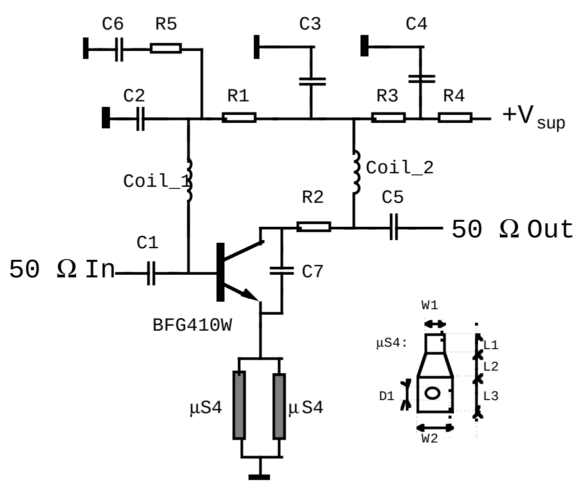

Figure 6: Schematic diagram 900 MHz LNA with BFG410W.

Input and output matching is realized with a LC combination. Additional emitter inductance on both emitter leads is used to improve the matching. All resistors and capacitors are 0603 or 0805 Philips SMD components. Coils are Coilcraft 0805. Board material is FR4.

Comp.:	Value:	Comment:
R1*	47 kΩ	Bias.
R2*	120 Ω	Better RF-stability (K>1).
R3*	22 Ω	RF-block.
R4*	560 Ω	Cancelling H_{FE}-spread.
R5**	100 Ω	To improve IP3-performance
C1*	2.2 pF	Input match.
C2*	27 pF	900MHz short.
C3*	27 pF	900MHz short.
C4*	1 nF	RF-short
C5*	1.5 pF	Output match.
C6**	100 nF	To improve IP3-performance
C7*	0.47 pF	Better RF-stability (K>1).
Coil_1	12 nH	Input match.
Coil_2	15 nH	Output match.
µs4	next table	µ-stripline + via
Board FR4: ε_r=4.6, h=0.5 mm, t=35 µm * 0603 Philips * * 0805 Philips Coils: 0805CS Coilcraft		

µS4 Emitter inductance (µ-stripline + via):

L1	2.0mm	µ-stripline Z_0~48Ω (PCB: ε_r ~4.6, H=0.5mm)
L2	1.0mm	
L3	1.0mm	
W1	0.5mm	Emitter inductance: µ-stripline
W2	1.0mm	
D1	0.4mm	via-hole

Table 1: 900 MHz LNA with BFG410W, List of components.

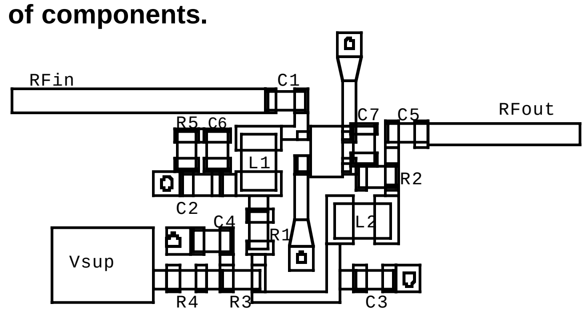

Figure 7: PCB-layout 900 MHz LNA with BFG410W.

b) 2 GHz LNA with BFG410W

This paragraph describes a 2 GHz LNA with the BFG410W. The performance can be summarized as follows:

V_{ce}=2V, I_c=2mA, V_{SUP}≈3.3V
freq. = 2 GHz
$|S_{21}|^2$ = 14.3 dB
$|S_{12}|^2$ = -30 dB
NF = 1.7 dB
$VSWR_i$ = 1 : 2.1
$VSWR_o$ = 1 : 2.1

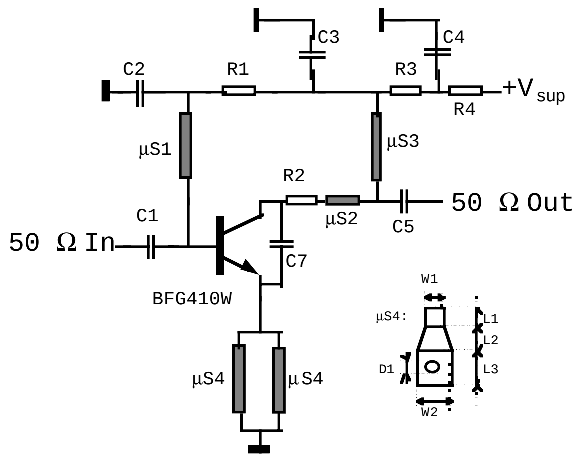

Figure 8: Schematic diagram 2 GHz LNA with BFG410W.

Input and output matching is realized with a microstrip-C combination. Additional emitter inductance on both emitter leads is used to improve the matching to 50 Ω. All resistors and capacitors are 0603 Philips SMD components. Coils are Coilcraft 0805. Board material is FR4.

Please note that this amplifier is not optimized for noise and IP3 (extra bypassing is missing)

Comp	Value:	Comment:

R1	47 KΩ	Bias.
R2	10 Ω	Better RF-stability (K>1).
R3	22 Ω	RF-block.
R4	560 Ω	Cancelling H_{FE}-spread.
C1	1 pF	Input match.
C2	5.6 pF	2GHz short.
C3	5.6 pF	2GHz short.
C4	1 nF	RF-short
C5	3.3 pF	Output match.
C7	0.47 pF	Better RF-stability (K>1).
µs1	W=0.25mm	µ-stripline Z_0~95Ω
µs2	W=0.25mm	µ-stripline Z_0~95Ω
µs3	W=0.25mm	µ-stripline Z_0~95Ω
µs4	(next table)	µ-stripline + via
Board FR4: ε_r=4.6, h=0.5 mm, t=35 µm All resistors and capacitors 0603 Philips		

µS4 Emitter inductance (µ-stripline + via):

L1	2.0mm	µ-stripline Z_0~48Ω
L2	1.0mm	
L3	1.0mm	
W1	0.5mm	Emitter inductance: µ-stripline
W2	1.0mm	
D1	0.4mm	via-hole

Table 2: 2 GHz LNA with BFG410W, List of components.

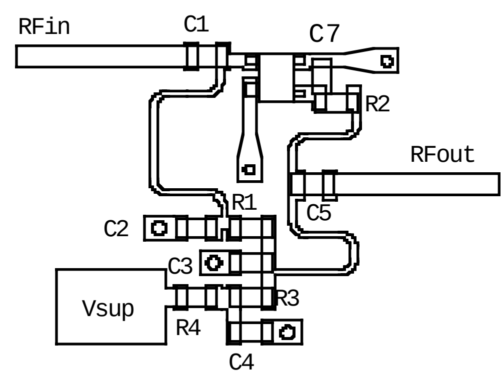

Figure 9: PCB-layout 2 GHz LNA with BFG410W.

c) 900 MHz LNA with BFG425W

This section describes a 900 MHz LNA with the BFG425W. The performance can be summarized as follows:

V_{ce}=2V, I_c=10mA, V_{SUP}≈3.7V
freq. = 900MHz
$|S_{21}|^2$ = 17.3 dB
NF = 1.7 dB
$VSWR_i$ = 1 : 2.5
$VSWR_o$ = 1 : 1.8
$IP3_{in}$ = +3 dBm (Δf=200 kHz)

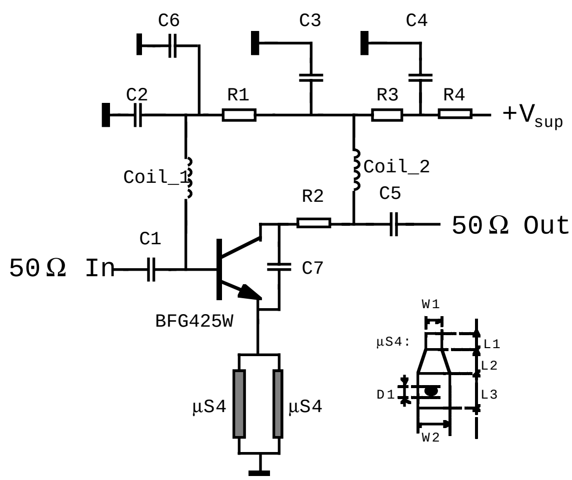

Figure 10: Schematic diagram 900 MHz LNA with BFG425W.

Comp	Value	Purpose, comment
R1*	8.2 kΩ	Bias (coll.-base)
R2*	10 Ω	better S22 and stability
R3*	22 Ω	RF blocking
R4*	150 Ω	cancelling hFE spread
C1*	8.2 pF	Input match (input to base)
C2*	27 pF	900 MHz short (L1 to ground)
C3*	27 pF	900 MHz short (L2 to ground)
C4**	100 nF	RF decoupling collector bias
C5*	22 pF	Output match
C6**	100 nF	To improve IP3
C7*	3.3 pF	Output match, stability
Coil_1	22 nH	Input match (base-bias)
Coil_2	12 nH	Output match (collector-bias)
µs4	next table	µ-stripline Emitter-inductance
Board FR4: ε_r=4.6, h=0.5 mm, t=35µm * = 0603 Philips ** = 0805 Philips Coils: 0805CS Coilcraft		

µS4 Emitter inductance of µ-stripline and via-hole

Name	Dimension	Description
L1	2.5mm	length µ-stripline; Z_0~48Ω
L2	1.0mm	length interconnect stripline and via-hole area
L3	1.0mm	length via-hole area
W1	0.5mm	width µ-stripline
W2	1.0mm	width via-hole area
D1	0.4mm	diameter of via-hole

Table 3: 900 MHz LNA with BFG425W, List of components.

Input and output matching is realized with a microstrip-C combination. Additional emitter inductance on both emitter leads is used to improve the matching to 50 Ω. All resistors and capacitors are 0603 or 0805 Philips SMD components. Coils are Coilcraft 0805. Board material is FR4.

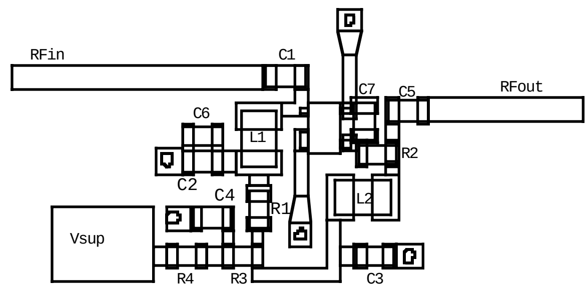

Figure 11: PCB-layout 900 MHz LNA with BFG425W.

d) 2 GHz LNA with BFG425W

This section describes a 2 GHz LNA with the BFG425W. The performance, for different collector currents can be summarized as follows:

I_C [mA]	$\|S_{21}\|^2$ [dB]	IP3_A [dBm]	IP3_B [dBm]	NF [dB]
V_{CE} ~ 2.5V	2GHz	input	input	2 GHz
2	14.4	-10.9	-2.3	1.5
3	15.9	-3.4	-0.4	1.7
5	16.3	-0.9	1.8	1.8
6	16.6	1.0	2.6	1.9
8	16.9	3.9	5.6	2.1
10	17.1	6.5	6.7	2.3

Table 4: Performance summary 2 GHz LNA with BFG425W

Input and Output VSWR is in all cases better than 1 : 2. IP3_A is the third order intercept *without* R5 and C6. IP3_B is the third order intercept *with* R5 and C6. It can be noticed that the IP3 improvement becomes less effective when the collector current increases.

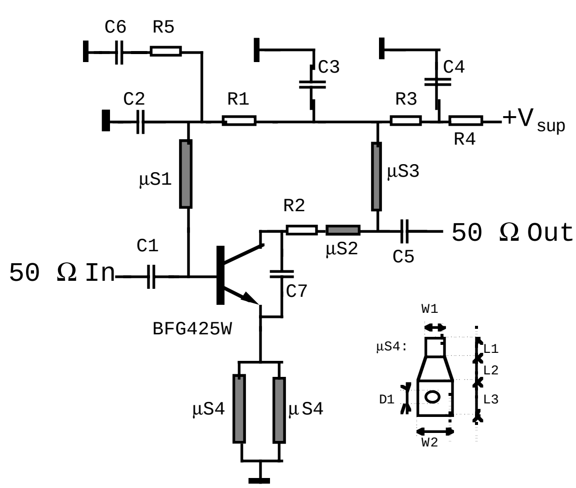

Figure 12: Schematic diagram 2 GHz LNA with BFG425W.

Comp	Value:	Comment:
R1*	15 KΩ	Bias.
R2*	0 Ω	Omitted.
R3*	22 Ω	RF-block.
R4*	82 Ω	Cancelling H_{FE}-spread.
R5**	100 Ω	To improve IP3-performance
C1*	4.7 pF	Input match.
C2*	5.6 pF	2GHz short.
C3*	5.6 pF	2GHz short.
C4*	1 nF	RF-short
C5*	2.7 pF	Output match.
C6**	100 nH	To improve IP3-performance
µs1	8.9 x 0.25mm	µ-stripline Z_0~95Ω
µs2	3.9 x 0.25mm	µ-stripline Z_0~95Ω
µs3	6.6 x 0.25mm	µ-stripline Z_0~95Ω
µs4	(next table)	µ-stripline + via
Board FR4: ε_r=4.6, h=0.5 mm, t=35 µm * 0603 Philips * * 0805 Philips		

µS4 Emitter induction (µ-stripline + via):

L1	1.0mm	µ-stripline Z_0~48Ω
L2	1.0mm	
L3	1.0mm	
W1	0.5mm	Emitter inductance µ-stripline
W2	1.0mm	
D1	0.4mm	via-hole

Table 5: 2 GHz LNA with BFG425W, List of components.

Input and output matching is realized with a microstrip-C combination. Additional emitter inductance on both emitter leads is used to improve the matching to 50 Ω. All resistors and capacitors are 0603 or 0805 Philips SMD components. Coils are Coilcraft 0805. Board material is FR4.

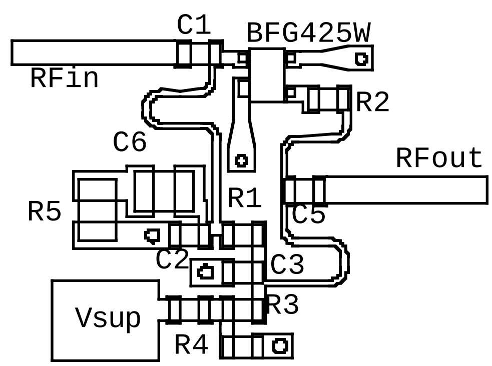

Figure 13: PCB-layout 2 GHz LNA with BFG425W.

CONCLUSION

High performance small size LNAs, with a low supply voltage and current can be made with the new Philips BFG400W series double polysilicon transistors. IP3 can be optimized with extra components, and/or by increasing I_C. Increasing voltage also improves the IP3 point.

The LNAs presented in this brief application note are not the most optimized designs, nor are shown all possible circuit configurations by any means . They only show some possible LNA-designs with the BFG400W series double polysilicon transistors.