900 MHz LOW NOISE AMPLIFIER DEMOBOARD

Summary: The performance of wideband transistors, BFG505 (BFG520, BFR505, BFR520) is demonstrated in a 900 MHz Low Noise Amplifier in the frontend of a subscriber handset. (i.e. Cordless phone, cellular phone) The transistors, as evaluated in this application note, are available in the SOT23, SOT323 (SC70) and SOT143 (3 versions) packages.

General characteristics of demoboard with BFG505:

Supply	2.5-3.6 V, 2 mA	
Gain	typ. 11 dB	
Noise Figure	F<1.5 dB	includes losses
In/Out return loss	S11,S22<-10 dB	
PCB size	10 x 10 mm	active area
Components	BFG505 resistors capacitors coils	SOT143 Philips 0603/0805 Philips 0603 air wounded int. diam 1.5 mm wire 0.4 mm Cu
Stability	stable when terminated with 50 Ohm at all frequencies	

Introduction

Several AC-parameters are of importance when designing an RF low noise amplifier. The main goal is to improve system sensitivity. An optimally designed Low Noise Amp will be a trade off between noise and gain. Furthermore, when using 50 Ohm designed bandpass filters, a mismatch can result in extra losses. Obtaining 50 Ohm matching is also an important design aspect. Other AC-parameters include isolation to reduce Local Oscillator radiation and linearity. This contributes less to system performance, as it is determined mostly by the mixer. Other design requirements are a small size and very low power consumption.

Meeting all these requirements will always result in a design that is a trade off. Philips' fourth generation bipolar wideband transistors can meet the required specifications as they offer outstanding performance at 900 MHz.

Theory

A simplified formula valid for lower frequencies can learn us what match we should present to the input port of the bipolar transistor used in common emitter configuration to obtain minimum Noise Figure.
The optimal source impedance for minimum noise $R_s\{opt\}$ is given **by:**

$R_s\{opt\} = \sqrt{[\beta/s*(1/s+2*r_b)]}$ Ohm

while

$s= qI_c/kT$ and $\beta= H_{FE}(DC)$

This formula takes into account both shot noise and thermal **noise.**
One can see that a low bias current results in farely high impedances. (for the BFR505 X-tal at 2 mA follows: $R_s\{opt\}= 270$ Ohm) For higher frequencies the optimum source impedances must be more inductive to be able to tune out internal device parasitics.The power match which gives optimum gain occurs for: $R_s\{opt\}= \beta/s+ R_b$ (1.4 kOhm)
It is easily seen that for low currents both noise and gain match cannot be realised simultaneously.

The only way of obtaining noise and gain match simultaneously is applying a feedback. This can be done by a series emitter induction.
At 900 MHz, a few nH emitter induction can change the input impedance considerably and it will bring noise and gain match closer together at the cost of some gain (a few dB).
This makes a properly matched low noise design possible.
To show what trade-off can be reached figure 1 shows the results of Touchstone (R)[•] simulations based on the noise and gain parameters from the Touchstone Data diskette[••].
Return losses at both input and output were below -10 dB.

As far as stability is concerned, it is impossible to design the amplifier to be unconditionally stable for both input and output for all source and load impedances at all frequencies.
Some damping at frequencies outside the 900 MHz band could be necessary in some practical cases.
Negative feedback increases stability, postive feedback decreases stability.
Positive feedback can occur when the emitter is capacitively loaded. As far as possible, we should avoid this in an RF design.

[•] Touchstone is a registered trademark of Eesof
[••] Noise & s-parameter library surface mounted devices, available at your local Philips Sales office.

Practical circuit

The input and output match were realized with lumped elements since they give the smallest size at 900 MHz. (see fig. 2)
Decoupling capacitors forming short circuit at 900 MHz are 27 pF. Power supply decoupling is done with a 1 nF capacitor.
The coils could be replaced by PCB-track inductors or SMD inductors. Attention should be given to the value of the emitter induction which can be realized through a few mm track. A proper ground should be available. One should be carefull in choosing capacitance and inductance especially at the input since low Q elements give noise degradation.
The high impedance match at the input is not easy to realize and is most sensitive to parameter spread of the passive components. The PCB design was optimized for minimum noise.
Simulated component values for the different transistors can be found in figures 3-6. Results of measurements are shown in figures 7-9. Circuit layout can be seen in fig. 10. It was build on a 1 mm FR4 epoxy substrate.
Theoretical component values may slightly differ from practical values due to layout parasitics.

Biasing considerations.
At 3V supply, stable biasing can be difficult.
To reduce the effects of H_{FE} spread a decoupled emitter resistor is often necessary. This decouple capacitor increases the risk for instability. Another solution, requiring a low cost low frequency PNP transistor can be seen in fig.11.
This solution gives H_{FE} independent biasing in grounded emitter configuration.

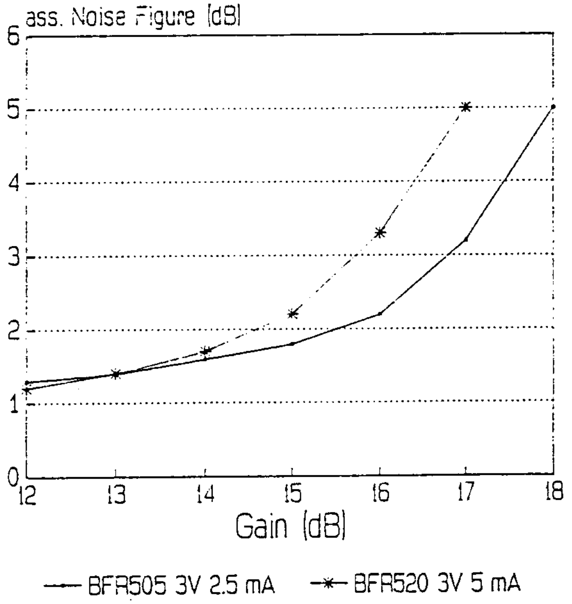

Fig. 1 Gain and associated Noise Figure

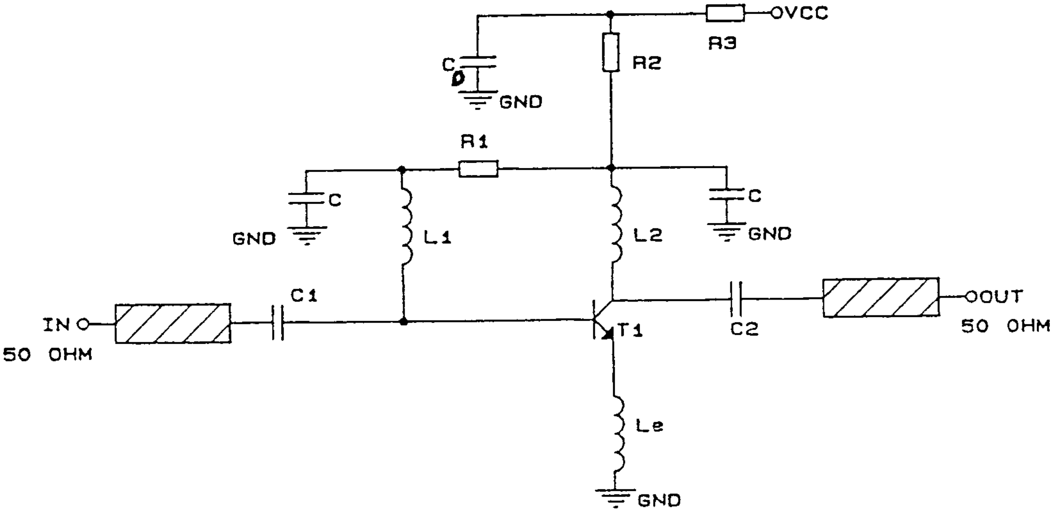

Fig 2. Schematic circuit diagram

Fig 3. BFG505 3V 2.5 mA values of components

C1 pF	2.3	2.5	2.8	2.9	2.9	2.4	1.7
L1 nH	14	12.5	11	9.5	8.4	7.1	7.0
Le nH	3.9	3.0	2.3	1.9	1.6	1.6	2.0
C2 pF	2.2	2.2	2.1	1.9	1.7	1.2	0.8
L2 nH	14	13.4	13.3	13.0	13.0	14.7	17.7
G dB	12	13	14	15	16	17	18
NF dB	1.4	1.5	1.7	1.9	2.3	3.3	5.1

Fig 4. BFR505 3V 2.5 mA values of components

C1 pF	2.4	3.1	3.1	3.0	1.5		
L1 nH	12.5	11.5	9.5	7.5	8.2		
Le nH	2.8	2.0	1.6	1.5	1.6		
C2 pF	2.9	2.5	2.2	1.7	1.1		
L2 pF	13	12.7	11.5	11.9	12.1		
G dB	11	12	13	14	15		
NF dB	1.4	1.6	1.9	2.6	4.4		

Fig 5. BFR520 3V 5 mA value of components

C1 pF	5.7	7.2	8.5	9.5	10		
L1 nH	10.4	8.5	7	5.3	4		
Le nH	0.7	0.3	0.1	0.05	0.0		
C2 pF	3.6	3.2	2.7	2.0	1.4		
L2 nH	10.5	9.5	9.0	9.5	11.5		
G dB	12	13	14	15	16		
NF dB	1.3	1.5	1.8	2.3	3.5		

Fig 6. BFG520 3V 5 mA values of components

C1 pF	5.2	10	27	33	33		
L1 nH	13.7	20	12	8	5.9		
Le nH	2.2	1.0	0.7	0.5	0.4		
C2 pF	3.2	3.7	3.3	2.9	2.1		
L2 nH	13.3	11.3	9.3	8.7	9.1		
G dB	12	14	15	16	17		
NF dB	1.2	1.3	1.6	2.1	2.8		

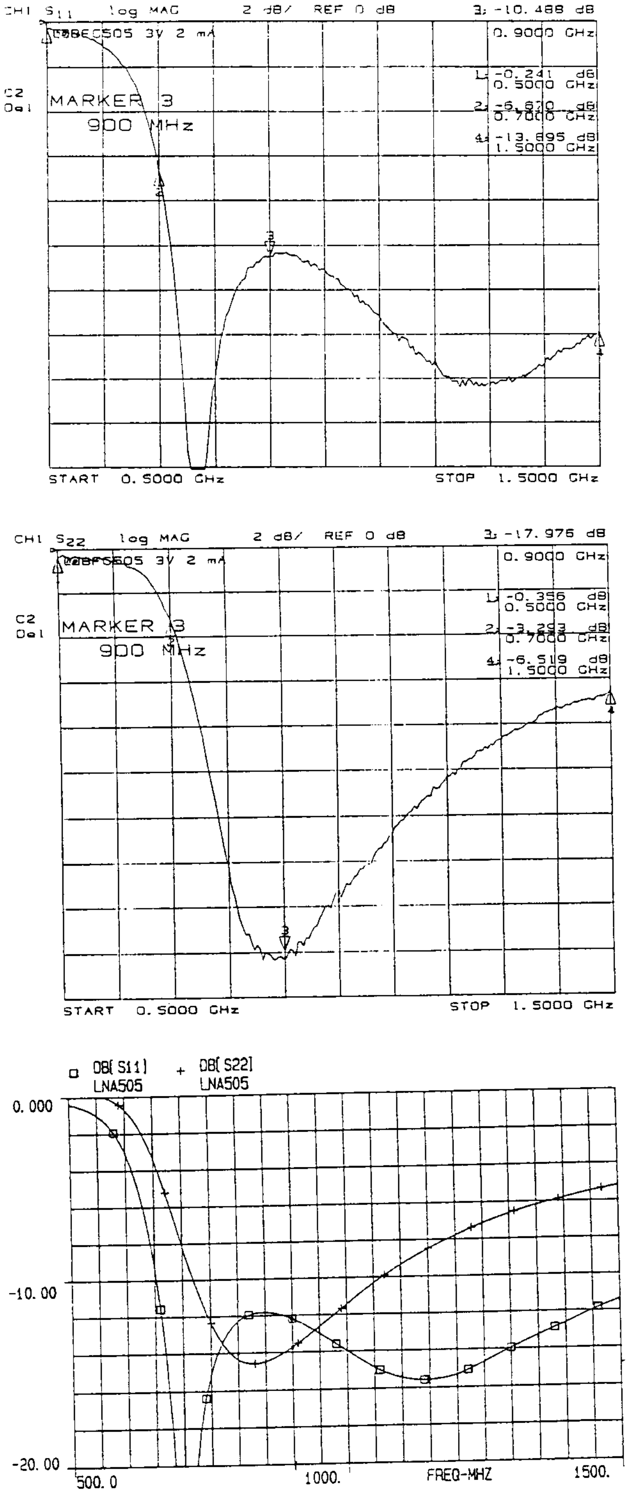

Fig 7. Measured and simulated in/out match.

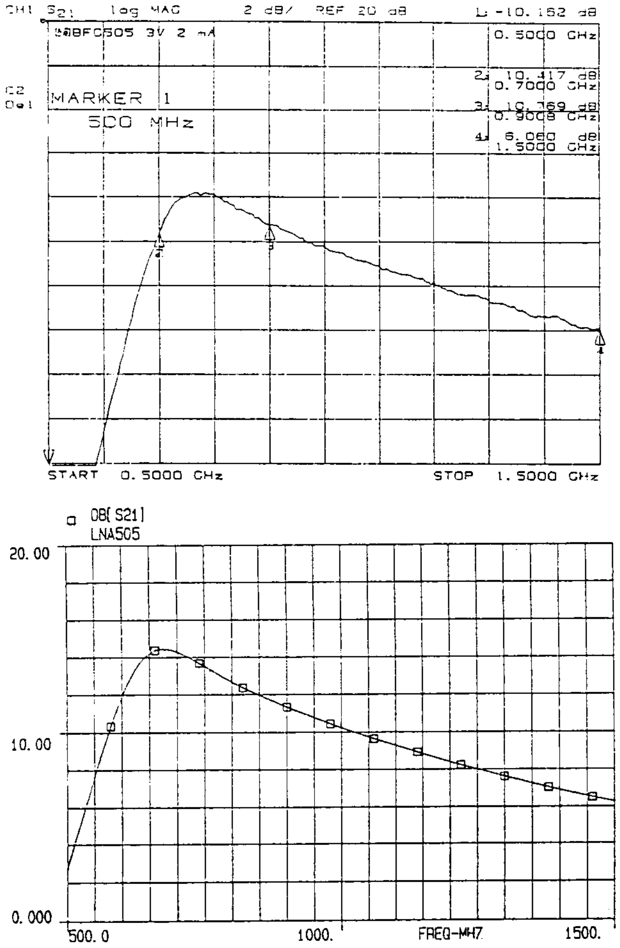

Fig.8 Measured and simulated gain.

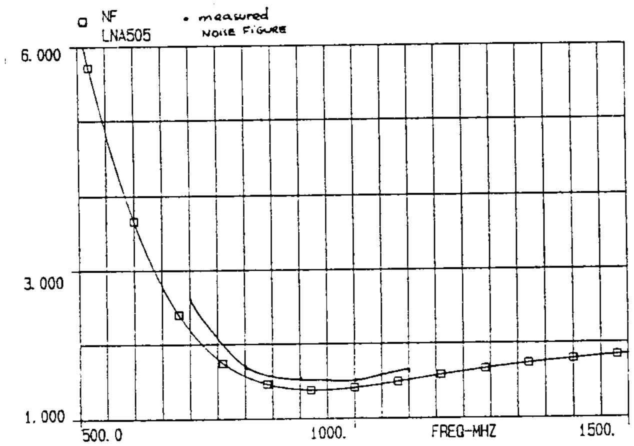

Fig.9 Measured and simulated Noise Figure

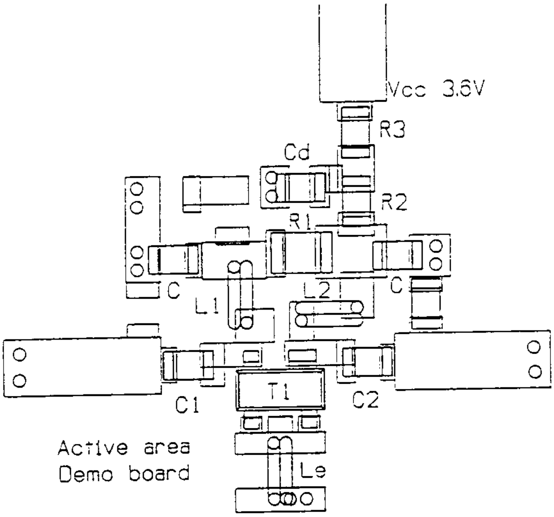

Fig. 10 Active Area Demoboard

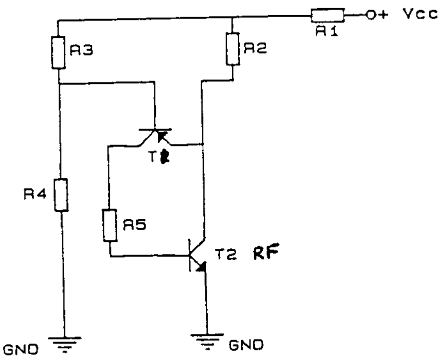

Fig. 11 schematic diagram biasing circuit

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