A PSEUDO-CONCURRENT 0.18μm MULTI-BAND CMOS LNA

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***Abstract* — A novel multi-band LNA, which can switch between standards GSM800MHz/GSM1.8GHz or GSM800MHz/WCDMA2.1GHz, is presented. The LNA provides 22.4dB gain at 800MHz and 14.1 dB at 1.8GHz. The device selects between GSM1.8GHz/WCDMA2.1GHz by means of a simple PMOS switch. The LNA is fabricated in 0.18μm technology using only CMOS transistors. Post-Layout simulation results indicate a Noise Figure below 1.6dB in all bands while drawing 8.5mA from a 1.8V power supply. To save die area, the input matching circuit is partially off-chip.**

I. INTRODUCTION

Low Noise Amplifier (LNA) performance sets a lower limit on the Noise Figure of the entire Receiver. Receiver designs will have to support multi-standard reception in the near future. Recent LNA designs have explored techniques for multi-band reception without a substantial increase in power consumption/chip area [5].

In this work, a programmable concurrent LNA for 3 bands, GSM0.8GHz, GSM1.8GHz and WCDMA2.1GHz is proposed. The GSM0.8GHz band is received simultaneously with one of the two other bands. The frequency selection is done by a simple PMOS switch, which changes the capacitance of an output LC filter and modifies the location of the system zero. A test chip has been fabricated in a high-performance 0.18μm RF process, with inductors having Q ≈10-15 and CMOS transistors with very high f_T.

II. MULTI-MODE LNA DESIGN APPROACHES

There are a number of approaches for the design of multi-mode LNAs: Switched mode LNA [1], [2], parallel mode LNA [3], wideband LNA [4] and concurrent LNA [5].

The approach taken in [5] is the method of choice for designing concurrent LNAs, as it reduces the power consumption by using only one driver for all bands. It also saves chi area by reducing the number of on-chip LC components. Inherently wideband trans-conductance of the device makes it possible to design a LNA with optimum noise figure (NF) over a wide frequency range. Filtering is needed to provide frequency selective gain at the output. This is provided by using a Multi Band-Pass filter at the load, due to which the LNA is able to amplify signals in two or more different bands. By appropriate pole/zero placement of the filter, it is possible to obtain

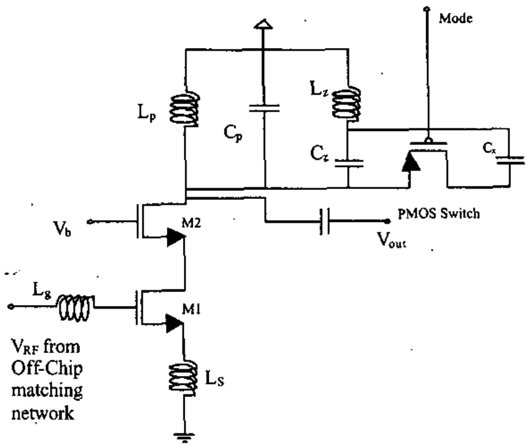

Fig. 1. Pseudo-3 band Concurrent LNA (biasing not shown)

enough gain, reverse isolation and low NF in all modes of operations. Fig. 1 shows the block diagram of the proposed LNA.

III. LNA DESIGN AND SPECIFICATIONS

Since GSM1.8GHz and WCDMA2.1GHz have relatively close frequencies, a high Q filter is required in the LNA to separate the signals. A suitable compromise was done to simplify the system to a concurrent 2-band receive with GSM0.8GHz being received along with either 1.8GHz or 2.1GHz bands. The two modes of operation have been named GSM and WCDMA, depending on which band is being received (along with 0.8GHz). The mode selection is done by switching an extra capacitance to the LC tank; thereby modifying the location of Transfer Function zero.

Cascode architecture as shown in Fig. 1, has been used to increase forward gain while decreasing the reverse gain and providing near minimum noise figure. Inductive source degeneration is used for input matching. This also increases the stability of the LNA through negative feedback at the expense of lower gain.

A. Input Impedance

The input impedance match shown in Fig. 3 has been used to provide concurrent match. The circuit has 5 degrees of freedom (1 for each component) and can

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theoretically provide a match at 4 different frequencies. The input impedance is:

$$Z_{in}=\frac{b_3s^3+b_1s}{a_4s^4+a_2s^2+1}+(L_{g3}+L_s)s+\frac{1}{C_{gs}s}+R_{min}+\frac{g_mL_s}{C_{gs}} \quad (1)$$

Where $b_3=L_{g1}L_{g2}C_{g1}, b_1=L_{g2}+L_{g1}, a_4=L_{g2}L_{g1}C_{g1}C_{g2}$
$a_2=C_{g2}(L_{g2}+L_{g1})+L_{g1}C_{g1}$

It can be shown [6] that noise figure will be minimized when the sum of the impedances of L_s, C_{gs} and the network shown in figure (3), Z_g, are minimized.

If $R_{min}\approx 0$, then a real match of Z_{in} (to 50Ω) may be obtained by choosing L_s such that:

$$L_s=\frac{R_{in}C_{gs}}{g_m}\approx\frac{R_{in}}{\omega_T} \quad (2)$$

As technology improves, f_T increases; this leads to a reduction in inductor L_s size, making the system more suited to on-chip integration.

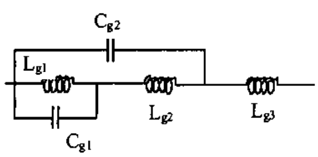

Fig. 2. Network used for input matching.

Substituting $s=j\omega$ and equating the imaginary part of equation (1) to zero results in a 4[th] order equation, from which the values of L, C can be found (since f is known). Inductor L_s is calculated from (2). This matching network can be simplified when the bands are close to each other. The matching network Q is limited by the low Q of on-chip inductors that is typically less than 10. The design has been simplified further by using only C_{g1}, L_{g1} and L_{g2} to provide a wideband match over 1.8 to 2.2GHz. To save die area, L_{g2} is on-chip while C_{g1} and L_{g3} are off-chip.

B. Amplifier Transfer Function and Gain

A Multi Band pass filter is used at the output for gain peaking at 2 frequency bands. This filter has a zero between LC tank poles [6]. The zero between two poles forms a notch shape at a specific frequency dividing the pass band into two different bands. This idea can be generalized to a system with more than two frequency bands.

Assuming Z_{gs} as C_{gs} impedance, Z_L as the load impedance, Z_s as L_s impedance, Z_g as gate impedance and Z_f as feedback impedance between input and output of amplifier, pole/zeros of the CS amplifier are:

$$z_1=\frac{g_mZ_f+Z_L+Z_LZ_sC_{gs}}{Z_LZ_sg_m} \quad (3)$$

$$p_{1,2}=\frac{g_mZ_LZ_s(2Z_g+Z_f)\pm\sqrt{K^2-4Z_fZ_s(Z_g-Z_f)g_m}}{-2Z_fZ_sg_m(Z_g-Z_f)} \quad (4)$$

Where

$$K=Z_f+Z_f^2+g_mZ_fZ_g+2Z_L+Z_sZ_fC_{gs}-2Z_LZ_sC_{gs}+Z_fZ_L$$

By proper choice of the values of $Z_g, Z_f, Z_s, C_{gs}, g_m, Z_L,$ poles will be in LHP (Left Half Plane) and the amplifier will be stable. Higher Z_f values have stabilizing effect on amplifier. Fig. (3) shows variations in magnitudes of Zero & Pole as Z_l, Z_g, g_m, C_{gs} vary.

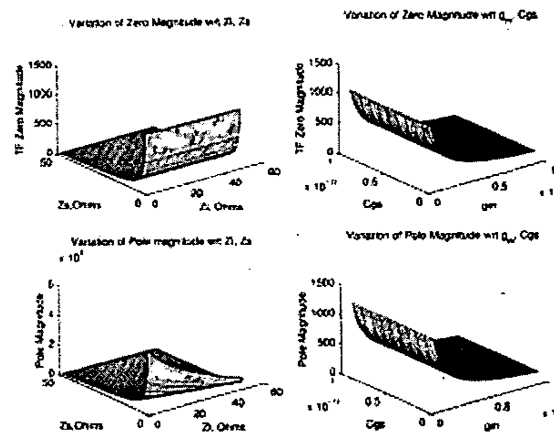

Fig. 3. 3D plots of variation of pole/Zero magnitude

C. Switch Effects

To change the frequency band between GSM1.8GHz and WCDMA 2.1GHz, a simple wide PMOS switch has been used to change the location of zero at load. When the switch is turned off, the LNA operates in WCDMA mode. The PMOS switch has a minor effect on NF, and this is borne out by simulation.

The major effect of PMOS switch is the shift in center frequency. This is due to the switch parasitic resistance and capacitance that is considered in Table 1.

D. *Noise Figure*

For a CS amplifier, the noise figure is:

$$F=1+|1+Y_s(Z_g+(\omega Z_{gs})^{-1}+\omega L_s)|^2\cdot\frac{1}{g_m^2\,|(\omega Z_{gs})^{-1}|^2}\cdot\frac{\overline{i_{nd}^2}}{\overline{i_s^2}} \quad (5)$$

Where i_{nd} is the noise associated with drain of MOSFET and Y_s is the admittance of input source voltage

The full formula for Noise Figure has been derived in [6] and will not be repeated here.

<table>
<tr><td></td><td colspan="2">MODE</td></tr>
<tr><td></td><td>WCDMA</td><td>GSM</td></tr>
<tr><td>1. Input Impedance</td><td colspan="2">$Z_{in} = \frac{g_m C_{gs}}{L_s} + \frac{L_{g2}.s}{L_{g2}.C_{g2}.s^2 + 1} + (L_s + L_{g3}).s + \frac{1}{C_{gs}.s}$, For both Modes</td></tr>
<tr><td>2. Output Impedance</td><td>$Z_{out} \approx Z_{Load1} = Z_p \parallel \left(Z_1 + \frac{1}{C_z.s} \right)$

Where
$Z_p = C_p \parallel (L_p.s + R_p),$
$Z_1 = L_Z s + R_Z$
$R_z = \frac{L_z.\omega}{Q_{Lz}}, R_p = \frac{L_p.\omega}{Q_{Lp}}$
$Z_g = \left((L_{g1}.s + R_{g1}) \parallel \frac{1}{C_{g1}.s} \right) + (L_{g2}.s + R_{g2})$
$Z_s = sL_s + R_s$

(Z_g, Z_s are used in Gain formula below)</td><td>$Z_{out} \approx Z_{Load2} = Z_c' \parallel \left[(R_{sw} \parallel Z_B) + (Z_A \parallel Z_p') \right]$
where
$Z_p' = (L_p.s + R_p) \parallel \frac{1}{C_p.s} \parallel \frac{1}{C_{gssw}.s}$
$Z_1 = L_z.s + R_z$
$Z_c' = \frac{1 + C_x.Z_1.s^2 + C_z.Z_1.s^2}{C_x.s} \parallel \frac{1}{C_{gdsw}.s}$
$Z_A = \frac{1 + C_x.Z_1.s^2 + C_z.Z_1.s^2}{C_z.s}$
$Z_B = \frac{1 + C_x.Z_1.s^2 + C_z.Z_1.s^2}{C_x.C_z.Z_1.s^3}$
$R_{sw} = \frac{1}{\mu_n C_{ox} \left(\frac{W}{L_{eff}} \right) (V_{gs} - V_t)}, C_{gssw} \approx C_{gdsw} \approx \frac{1}{2} W L_{eff} C_{ox}$</td></tr>
<tr><td>3. Gain</td><td>$\approx \frac{-g_{m1} g_{m2} Z_{Load1}}{(g_{m2} + C_{gs2}.s)(C_{gs1}(Z_g + Z_s).s^2 + g_{m1} Z_s.s + 1)}$</td><td>$\approx \frac{-g_{m1} g_{m2} Z_{Load2}}{(g_{m2} + C_{gs2}.s)(C_{gs1}(Z_g + Z_s).s^2 + g_{m1} Z_s.s + 1)}$</td></tr>
</table>

Table 1: Summary of Multi-Band LNA Parameters

IV. SIMULATION RESULTS

Post-Layout Simulation results of S_{21}, S_{12} and NF of the LNA have been shown in figures (4) and (5). The shift in centre frequency and second pass band is clearly visible in Fig 4. S11 is less than −25dB over the entire bands from 1.8 GHz to 2.2 GHz.

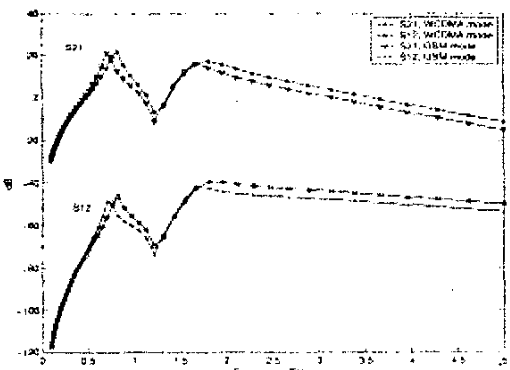

Fig.4. S_{21} and S_{12} in both GSM and WCDMA mode.

In both modes, a gain notch of -9dB provides isolation between bands. The NF is marginally higher in GSM mode because the switch operates "in - circuit".

Fig. 6 shows sensitivity of S_{21} to Temperature. There is a -3dB drop in performance as T varies from -30°C to 150°C. The LNA simulated performance is summarized in Table 2.

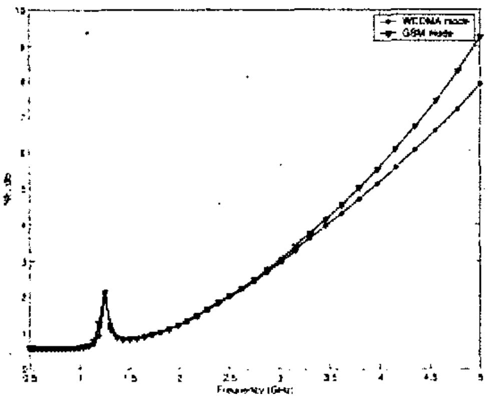

Fig.5. NF (dB10) in both GSM and WCDMA mode

Fig. 7 shows sensitivity of S_{21}, S_{12}, and NF to process variations as a function of frequency. The reference is taken from the typical process simulation, which is plotted as the 0dB line. At worst, S_{21} is degraded by-6dB and S_{12} by +9dB at 1.2GHz. Performance degradation, indicated by a drop in S_{21} and rise in S_{12}/NF, is much more severe at

1.2GHz ("out-of-band") than at 800MHz/1.8GHz (" in-band").

Mode	WCDMA		GSM	
Frequency	0.8GHz	2.1GHz	0.8GHz	1.8GHz
S_{21} (dB)	22.4	14.1	16.2	14.5
S_{12} (dB)	-45.0	-40.6	-53.0	-42.3
NF (dB10)	0.6	1.4	0.6	1.0
IIP3 (dBm)	-5.3	-3.1	-5.5	-3.8
Devices	0.18μm CMOS Transistors			
DC Power	8.5mA from 1.8 V supply			

Table 2: Simulated LNA performance

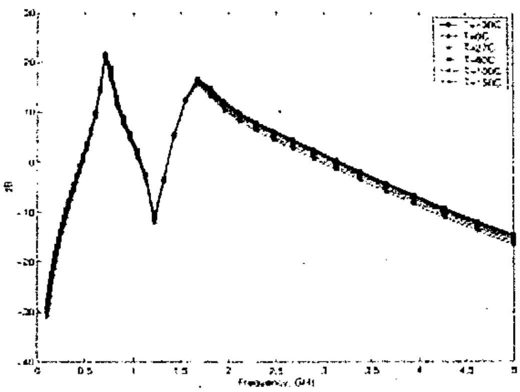

Fig. 6. Sensitivity of S_{21} to Temperature

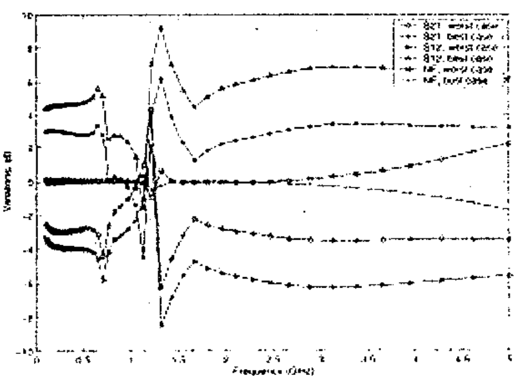

Fig. 7. Process Parameter Variations w.r.t. Typical and as a function of frequency. 0dB represents typical

V. LAYOUT

The design has been implemented in 0.18μm technology. The LNA layout presented two conflicting requirements: keeping the wire-lengths as short as possible while maintaining adequate separation between inductors and devices to prevent induced currents. Fig. 8 shows the view of the layout, imported from Cadence Virtuoso-XL. 4 spiral inductors are clearly visible, and MOS devices are in the center. Grounded metal strips provide adequate isolation between devices. The die occupies a size of 1.3mm X 1.4mm, inclusive of pads.

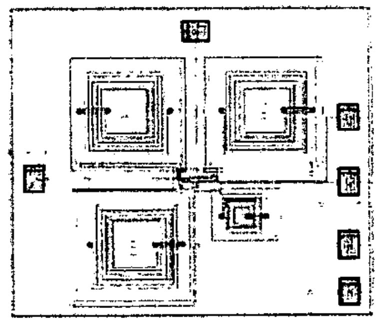

Fig.8. LNA layout cell view from Cadence Virtouso-XL

VI. CONCLUSIONS

This work presents the first pseudo 3-band GSM/WCDMA LNA, with 2-band concurrency with the lowest reported NF of less than 1.6 dB. Gains above 14dB have been achieved in both frequency bands. With improvements in technology, it may be possible to design true multi band concurrent LNAs with excellent performance. Minimizing power consumption and designing tunable multi-band LNAs with more selective load filter using active inductors and varactors, are future goals.

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