A Pseudo-Concurrent Multiband LNA Using Double Tuned Transformers

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Abstract— ***A new method for band selection in multi-band low noise amplifiers (LNA) is introduced. Based on a double tuned transformer, two concurrent bands can be achieved where one of them can be displaced continuously in an adaptive manner using a control signal. No switches have been used in this method. Based on the proposed method, a pseudo concurrent multi-band LNA has been designed. The first band is located at 0.9 GHz while the second band can be adjusted from 1.57 GHz up to 2.4 GHz depending on the application.***

Keywords— Low Noise Amplifier, Multiband, Pseudo concurrent, Band Selection.

I. INTRODUCTION

For multiband reception in an RF receiver we conceptually need to use several narrow-band receivers in parallel named as parallel receivers where their main problems are high power consumption and large area occupation [1]. Wide-band receivers, on the other hand, are more prone to sensitivity degradation due to blocker signals especially when the receiver linearity is not sufficient [2]. Concurrent multi-band receivers are capable to receive multiple bands simultaneously by just one driver circuit [3]. In these receivers, no switch is employed. In dual band concurrent receivers, input impedance matching network and output load network are usually accomplished using a compound of a parallel LC circuit and a series LC circuit as shown in Fig.1 [1-3, 6]. By this approach, two distinct resonance frequencies are achieved corresponding to desirable band locations. Pseudo concurrent receivers provide the potential to change the band locations and reduce the total number of concurrent bands. Band selection mostly carried out using some switches to alter a resonance circuit and thus changing the reception channel [4, 5]. As a result, each programmable band has just two modes of operation depending on whether the switch is on or off. However, MOS switches add noise and reduce quality factors of resonance circuits employed in due to their parasitic elements and usually require large chip area.

In this paper, a new method for band selection in multiband LNAs has been presented where the location of bands can be changed continuously in a pseudo concurrent mode. Section II discusses a new resonance circuit followed by implementation of the proposed LNA in section III. Simulation results are given in Section IV. Section V concludes the paper.

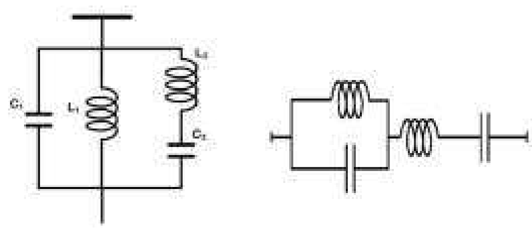

Fig. 1. Conventional LC resonant circuits used in dual band concurrent receivers

II. BAND SELECTION CIRCUIT

Proposed resonance circuit for band selection is shown in Fig.2. The primary and secondary windings of the transformer are tuned by capacitors C1 and C2. Assuming no losses, input impedance of this circuit is given by:

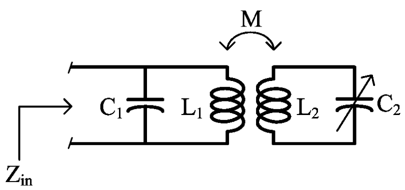

Fig. 2. Double tuned transformer as band selection circuit

$$|Z_{in}| = \frac{\omega^3 C_2 L_1 L_2 (1-k^2) - \omega L_1}{\omega^4 C_1 C_2 L_1 L_2 (1-k^2) - \omega^2 (C_1 L_1 + C_2 L_2) + 1} \quad (1)$$

where k is the coupling factor. Using the assumptions that L1 = L2 and C2 << C1, beside zeros in ω=0 and ω=∞, |Zin| shows the following zero and poles:

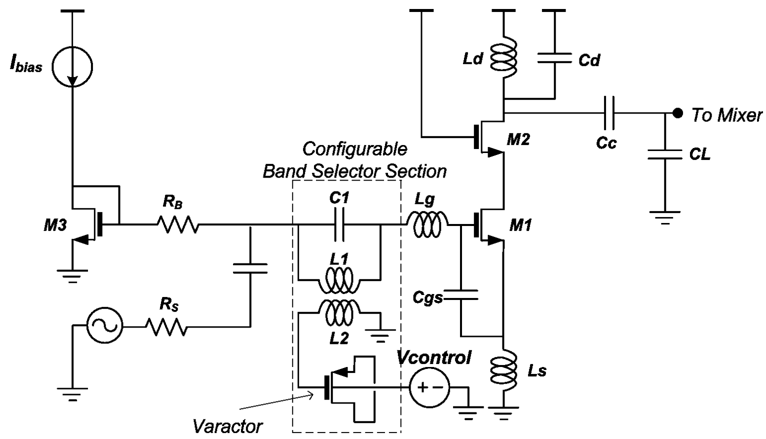

Fig. 4. The schematic of the proposed pseudo concurrent .LNA based on double tuned transformer as a part of input matching circuit

$$\omega_Z^2 = \frac{1}{C_2L(1-k^2)}$$
$$\omega_{P,1}^2 \approx \frac{2-k^2}{2C_1L(1-k^2)} \qquad (2)$$
$$\omega_{P,2}^2 \approx \frac{1+2k^2C_2/C_1}{C_2L(1-k^2)}$$

where ω_Z is the frequency of zero and $\omega_{P,1}$ and $\omega_{P,2}$ are frequency of the first and second poles respectively. Existence of two poles implies that the circuit in Fig. 1 can be utilized for signal reception over two specific channels placed around pole locations. According to (2), the value of $\omega_{P,1}$ depends on C1 while $\omega_{P,2}$ and ω_Z greatly vary with C2. Thus, C1 determines location of the first band and C2 decides place of the second band. A plot of Zin for L1 = L2 = 5 nH, k=0.5 and C1=1 pF is shown in Fig. 3. A 50 fF change in C2 causes about 800 MHz displacement in second band. It should be noted that the impedance value at second band can be increased if L2 is chosen higher than L1.

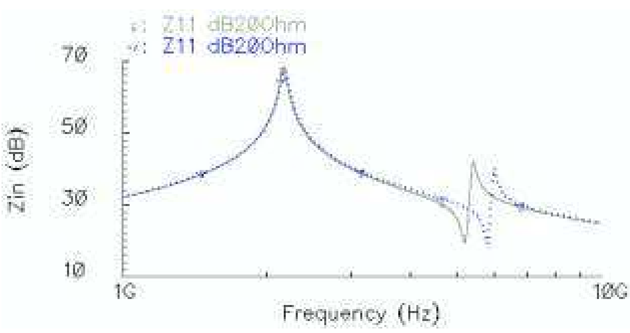

Fig. 3. Input driving impedance of double tuned transformer. Solid line is for C2= 0.25 pF and dotted line is for C2=0.2 pF

III. PSEUDO CONCURRENT ADAPTIVE LNA

As a simple implementation, Fig. 4 shows the LNA circuit with source degenerated cascode architecture in which the presented band selection circuit is employed as a part of input matching circuit. In this circuit, C2 is replaced with M0 which plays the rule of a MOS varactor. By applying a control voltage, $V_{Control}$, to the bulk of the M0, the second reception band can be moved continuously toward desired location. Note that if using a wideband matching circuit at input, the double tuned transformer can be used as the output tuned circuit (at drain of M2).

In order to inspect the matching condition at the input, the input impedance is calculated as:

$$Z_{in} = S(Lg+Ls) + \frac{1}{SCgs} + \frac{g_m}{Cgs}Ls + \frac{S^3L_1L_2C_2 + SL_1 - S^3M^2C_2}{S^2C_2L_2 + S^2C_1L_1 + S^4C_1L_1C_2L_2 - S^4M^2C_1C_2 + 1} \qquad (3)$$

where gm and Cgs are transconductance and the gate capacitance of M1, respectively. To achieve input impedance matching at desired bands, the value of Lg and Ls should be determined well. Since input impedance should be adjusted at 50Ω, by substituting s=jω and equating the imaginary part and real part of equation (3) to zero and 50Ω, respectively, we have:

$$\mathrm{Re}[z_{in}] = \frac{g_m}{Cgs}Ls = 50\Omega$$

$$\mathrm{Im}[z_{in}] = \omega(Lg+Ls) - \frac{1}{\omega Cgs} + \frac{\omega^3(K^2C_2L_1L_2 - C_2L_1L_2) + \omega L_1}{\omega^4(C_1C_2L_1L_2 - K^2C_1C_2L_1L_2) + \omega^2(C_1L_1 + C_2L_2) + 1} = 0 \qquad (4)$$

By the assumption that C1>> (C2, Cgs), the imaginary part of Zin has following zeros:

$$\omega_1^2 \approx \frac{1}{Cgs(Lg+Ls)}$$
$$\omega_2^2 \approx \frac{1}{C_2 L_2 (1-K^2)} \quad (5)$$

According to (5), the value of ω1 is independent of C2 while ω2 varies with C2. Consequently the circuit is matched at the input at two concurrent band. While the location of one band is always fixed, the other band position can be displaced continuously by changing C2.

TABLE I. Circuit Parameters of the proposed LNA

parameter	value
M1	8*86um/0.18um
M2	2*86um/0.18um
M3	34.1um/0.18um
M4	5*18um/0.18um
L1, L2	10nH
C1	2pF
Lg	12nH
Ls	0.5nH
Ld	5nH
Vdd	1.8 V

IV. Simulation Results

Proposed LNA has been designed in a 0.18 μm RF CMOS technology. The circuit parameters are summarized in Table I. In the presented scheme, 0.9 GHz for GSM is intended as the fixed band while 1.57 GHz for GPS and 2.4 GHz for WLAN/Bluetooth are considered as the second variable adaptive band. Figs. 5, 6 and 7 show the S21, S11 and NF plots of the LNA for two different control voltages. For a $V_{Control}$=1.5 V, corresponding to about 1.5 pF varactor capacitance, the first and second band at 0.9 GHz and 1.57 GHz show a gain (S21) of 10.1 dB and 8 dB, a reflection (S11) of –18 dB and – 17 dB, and a noise figure (NF) of 2.4 dB and 3.7 dB respectively. By a $V_{Control}$=0 V that yields a 0.55 pF varactor capacitance, the second band moves to 2.4 GHz. The S21, S11 and NF at first band are approximately 10 dB, –10 dB and 2.2 dB respectively, and at second band they are about 6 dB, –22 dB and 4.1 dB respectively. To ensure circuit functionality against process corners, corner analyzes has been done for S21 and S11 and the results are given in Figs. 8 and 9 respectively.

The values of circuit elements in the matching circuit as well as the transistors' dimensions are provided in Table 1.

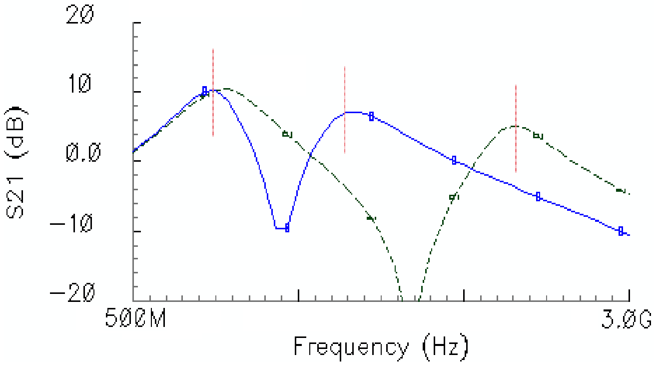

Fig. 5. S21 of the proposed LNA. Solid (blue) lines are for $V_{Control}$=1.5 V and dashed (green) lines are for $V_{Control}$=0 V. Dotted (red) lines indicate the location of the bands at 0.9 GHz, 1.57 GHz and 2.4 GHz.)

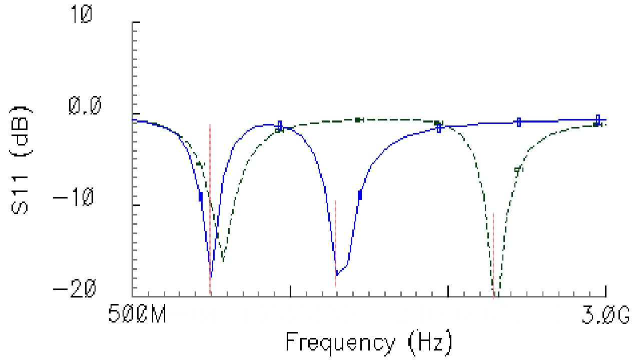

Fig. 6. S_{11} response of the proposed LNA. Solid (blue) lines are for $V_{Control}$=1.5 V and dashed (green) lines are for $V_{Control}$=0 V. Dotted (red) lines indicate the location of the bands at 0.9 GHz, 1.57 GHz and 2.4 GHz.)

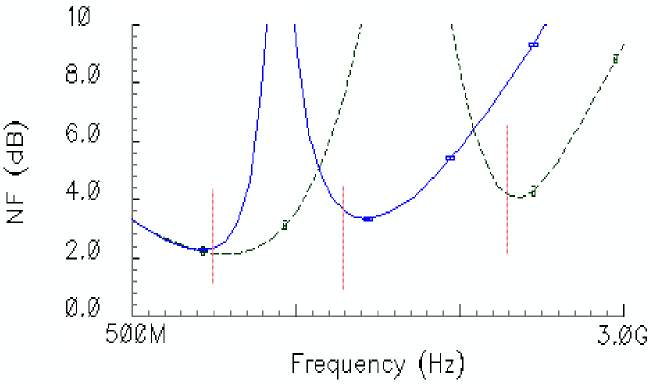

Fig. 7. Noise figure of the proposed LNA. Solid (blue) lines are for $V_{Control}$=1.5 V and dashed (green) lines are for $V_{Control}$=0 V.

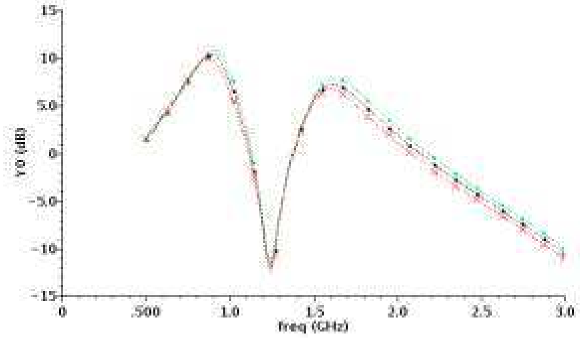

Fig. 8. Corner analyze for S21

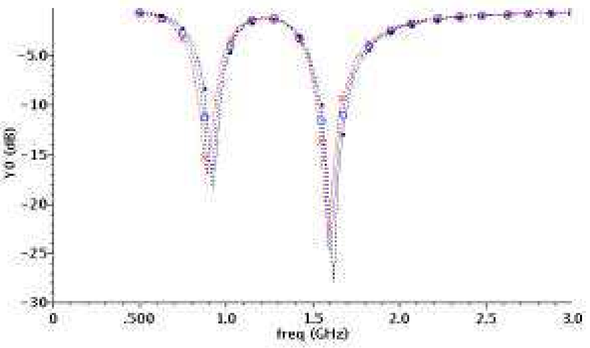

Fig. 9. Corner analyze for S11

The overal characteristics of the proposed pseodu concurrent LNA along comparison with previously published works is given in Table II.

V. CONCLUSION

Continues band shifting using double tuned transformers in pseudo concurrent LNAs is discussed. A LNA based on the introduced method is reported which is able to receive two bands simultaneously. While the location of one band is always constant, the second band can be moved and shifted to a new frequency location in a pseudo concurrent mode. Moving the bands is done using a control voltage and by a variable capacitor and no switches are used in the presented scheme.

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Table II. Overal characteristics of the proposed multi-band LNA and comparison with previously published works

Parameter	*[1]*	*[2]*	*[3]*	*[4]*	*[6]*	*This work*
S21(dB)	*11.79*	*18.6*	*14*	*14.1*	*12.2*	*14.47*
S11(dB)	*-10.37*	*-16.2*	*-25*	*N.A*	*-8.5*	*-18.7*
NF(dB)	*3.89*	*1.95*	*2.3*	*1.4*	*0.53*	*2.3*
Process (μm)	*0.18*	*0.13*	*0.35*	*0.18*	*0.15 GaAs*	*0.18*
Vdd(V)	*1.4*	*1.2*	*2.5*	*1.8*	*4*	*1.8*
No. of Bands	*2*	*2*	*2*	*4*	*2*	*4*
Type	*Concurrent*	*Concurrent*	*Concurrent*	*Pseudo concurrent*	*Concurrent*	*Pseudo concurrent*
Power (mW)	*13.5*	*12*	*10*	*15.3*	*40*	*5.976*