Dual-band CMOS low-noise amplifier without switches and with continuously adjustable gain

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A dual-band CMOS low-noise amplifier with inductor magnetic coupling and current steering is presented, which avoids the use of switches in the signal path, and has the possibility of controlling the voltage gain in the two bands, without disturbing the input impedance matching.

Introduction: Most wireless receivers use a narrowband low-noise amplifier (LNA), and the most typical LNA topology is the inductively degenerated topology, shown in Fig. 1a [1]. Dual-band LNAs are useful to combine different functions in the same receiver, such as GSM and GPS, a very demanding combination; much less demanding combinations are also possible, for example a heart rate frequency monitor with a wireless bicycle computer. Another recently reported application of dual-band LNAs is in UWB receivers [2]. A first approach to obtain a dual-band is to have two LNAs and use switches to select one of them, but this degrades the noise figure (NF), and only one band can be selected at a time. A second approach is to change the tuning of the input and output in Fig. 1a, by changing the value of either \( L \) or \( C \), as shown in Figs. 1b and c; in this case, there are again switches in the signal path [4]. A third approach, is to tune the input and output to different frequencies, by using complex multiband filters [5]. This Letter proposes a dual-band LNA, shown in Fig. 2, which is based on the topology of Fig. 1a and uses two magnetically coupled resonant networks.

New dual-band principle: In the proposed dual-band LNA (Fig. 2), \( L_1 \) and \( C_1 \) provide wideband impedance matching that embraces the two bands of operation [6]. The two coupled inductors, \( L_{11} \) and \( L_{22} \), and capacitors \( C_{11} \) and \( C_{22} \), originate two resonance frequencies [7], which, if they are far apart, originate two separate bands. In the proposed circuit there is a saving in die area with respect to other dual-band realisations, since there is only one input matching network and the two coupled inductors are superimposed (either totally or partially) using different metal layers. The circuit also has the advantage of having the two bands simultaneously and of eliminating switches in the signal path.

Magneically-coupled LC resonant circuits are an old subject [8, 9], and have been extensively used, for instance in double-tuned amplifiers. The difference here is that there are two cascode transistors, \( M_{\text{cascode}} \), which can be used to control the partition of the current between the two output branches, to change the relative gain in the two bands. This is useful, for example, if there is a strong signal in one band and a weak signal in the other: by reducing the gain in one band and increasing that in the other it is possible to place both signals well within the receiver's dynamic range. This form of gain adjustment can also be used to compensate for component variations and mismatches. The current through the input transistor \( M_1 \) is not affected, so the input impedance matching is not disturbed.

Since the proposed circuit is based on the cascode circuit of Fig. 1, the linearity in each band is the same as for the conventional circuit of Fig. 1, and the noise figure in one band is only slightly increased owing to the presence of the other band (this has been confirmed by simulation).

### Table 1: Circuit dimensioning

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( W_1 )/( L_{11} )</td>
<td>200 ( \mu )m/0.35 ( \mu )m</td>
</tr>
<tr>
<td>( W_2 )/( L_{12} )</td>
<td>30 ( \mu )m/0.35 ( \mu )m</td>
</tr>
<tr>
<td>( W_2 )/( L_{22} )</td>
<td>30 ( \mu )m/0.35 ( \mu )m</td>
</tr>
<tr>
<td>( L_1 )</td>
<td>8.8 nH</td>
</tr>
<tr>
<td>( L_2 )</td>
<td>7.8 nH</td>
</tr>
<tr>
<td>( C_1 )</td>
<td>1.1 ( \mu )F</td>
</tr>
<tr>
<td>( C_2 )</td>
<td>2.2 ( \mu )F</td>
</tr>
</tbody>
</table>

Fig. 1 Inductively degenerated cascode CMOS LNA, variable capacitor and variable inductor

- a Cascode CMOS LNA
- b Variable capacitor
- c Variable inductor

Fig. 2 Proposed dual-band LNA with inductor magnetic coupling (bias not represented)

Circuit analysis: The impedance \( Z_{\text{LOAD}} \) (Fig. 2) is given by:

\[
Z_{\text{LOAD}} = \frac{C_{12}(L_{11}L_{22} - M^2\alpha^2) + (C_{11}L_{11} + C_{22}L_{22})\alpha^2 + 1}{C_{11}C_{22}(L_{11}L_{22} - M^2\alpha^2) + (C_{11}L_{11} + C_{22}L_{22})\alpha^2 + 1}
\]

where \( \alpha \) is the ratio of the two output branch currents, \( i_1 \) and \( i_2 \), and \( M \) is the mutual inductance, \( M = k^2(L_{11}L_{22}) \), where \( k \) is the magnetic coupling coefficient. \( Z_{\text{LOAD}} \) has two complex pole pairs, independent of \( \alpha \), corresponding to the two bands of interest; their frequencies are approximately \( f_1 \approx \frac{1}{\sqrt{L_{11}C_{11}}} \) when \( k^2 \ll 1 \). \( Z_{\text{LOAD}} \) also has one zero at the origin and one complex zero pair, dependent on \( \alpha \), with a
frequency between that of the two pole pairs. The zero pair dependence on $\pi$ is used to adjust its position relatively to the poles, in order to change the gain in the two bands. The range of gain values in one band can be widened with respect to that of the other band by increasing the width of the corresponding cascode transistor.

**Simulation results:** The circuit in Fig. 2 was dimensioned to work at two different, widely used frequency bands: 900 MHz and 1.8 GHz. The dimensioning is given in Table 1 for the 0.35 $\mu$m CMOS technology of AMS, with 2.4 V supply and a supply current of 5.4 mA. The transformer was laid out with two superimposed coils in different metal layers. The transformer electrical model includes parasitic capacitances and resistances, extracted from the layout using the widely used tool ASITIC. BSIM3V3 transistor models have been used, which include all parasitics, except those due to the interconnections. Two cases are considered: $(W/L)_{M_{\text{asc}}} = 6(W/L)_{M_{\text{asc}}}$, with $V_{\text{BIAS}} = 2.4$ V and $V_{\text{BIAS}}$ variable from 1.2 to 2.4 V.

![Fig. 4 LNA voltage gain when $(W/L)_{M_{\text{asc}}} = 6(W/L)_{M_{\text{asc}}}$, with $V_{\text{BIAS}} = 2.4$ V and $V_{\text{BIAS}}$ variable from 1.2 to 2.4 V](image)

**Conclusions:** A dual-band CMOS LNA has been presented, which is based on the widely used inductively degenerated cascode stage, with an output network with two magnetically coupled LC resonators. The circuit does not require switches in the signal path and does not degrade the good noise performance of the single band version of the circuit. It also allows the possibility of varying the partition of the current between the two branches, providing the following further advantages over other dual-band LNA topologies: the gain can be controlled continuously (without switches), and without affecting the matching of the input impedance; and the die area is reduced, since the output coupled inductors are laid out superimposed on different metal layers.

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**References**