A High Selectivity Tunable LNA with High Q Series Resonance for an SDR Receiver

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Abstract

This paper proposes a high selectivity low noise amplifier (LNA) for a software-defined radio (SDR) receiver. This LNA is achieved by series resonance with a high quality factor using a microstrip line and external inductor. This series resonance provides a band-pass filtering characteristic and high voltage gain.

Keywords : High selectivity LNA, Series resonance, Band-pass filtering, Voltage gain, High quality factor

1. Introduction

Use of wireless communication services has being increasing across the world. Wideband software-defined radio (SDR) receivers are considered an attractive solution for achieving multi-service in a single device [1],[2]. For wideband SDR receivers, strong out-of-band interference signals rejection is required to prevent aliasing signals [2]. External RF surface acoustic wave(SAW) filters help achieve this strong interference signals rejection specification, but these external components tend to make the RF system bulky and expensive. Recently, inter-stage SAW-less receivers have been researched and suggested due to their low cost and small form-factor [1],[3]-[6].

However, inter-stage SAW-less receiver architecture has a serious weakness: strong out-of-band interferers make it difficult for the receiver to detect in-band signals [7]. To reduce these strong unwanted signals, a tunable LC filter technique has been proposed [4]. This technique can improve the harmonic rejection (HR) and the noise figure (NF). However, more attenuation is required to prevent distortion.

In this paper, we suggest a high quality factor(Q) series resonance technique to achieve high voltage gain and a high attenuation characteristic for the SDR receiver. This technique provides a band-pass filtering characteristic and high voltage gain.

2. A series resonance with LNA input capacitance

An RF pre-filtering is desired to block strong out-of-band interferers, which make it difficult to detect the desired signal. To attenuate these unwanted signals, a series LC resonance was employed in [4]. The technique has high Q—twice as high as the Q in case of a conventional impedance matching—and it helps in-band signal voltage amplification and out-of-band signals attenuation. However, due to source impedance, which is usually 50Ω, LC series resonance provides insufficient attenuation. To achieve a higher attenuation performance, we need to improve Q when series resonance occurs. In this paper, a new, high Q series resonance technique is proposed to improve Q. This improved Q is achieved using source impedance transformation. The source impedance transformation can be easily achieved by exploiting the microstrip line.

The proposed LNA input design and the equivalent circuit are shown in Figure 1 and Figure 2, respectively. The source impedance R_S (Antenna, Filter, or Switch) is transformed to Z_S' by the microstrip line with characteristic impedance Z_0 and length of l. The impedance Z_S' can be derived as

$$\mathbf{Z_S' = Z_0 \frac{R_S + jZ_0 \tan \beta l}{Z_0 + jR_S \tan \beta l} = R_S' + jX,} \quad (1)$$

where R_S' is the real part of Z_S' and X is the reactive part of Z_S'.

If the microstrip line is lossless, the voltage source value V_S redefined to $V_S^{'}$. The equivalent voltage source $V_S^{'}$ is written as

$$\mathbf{V_s'} = \mathbf{V_s}\sqrt{\frac{\mathbf{R_s'}}{\mathbf{R_s}}}. \tag{2}$$

When series resonance occurs, the voltage at gate-source capacitor (V_{GS}) is calculated as

$$\mathbf{V_{gs}} = \mathbf{V_s'} * \mathbf{Q} = \mathbf{V_s'}\sqrt{\frac{\mathbf{L}}{\mathbf{C}}} * \frac{\mathbf{1}}{\mathbf{R_s'}+\mathbf{R_{eq}}} = \mathbf{V_s}\sqrt{\frac{\mathbf{R_s'L}}{\mathbf{R_sC}}} * \frac{\mathbf{1}}{\mathbf{R_s'}+\mathbf{R_{eq}}} = \mathbf{V_s}\sqrt{\frac{\mathbf{L}}{\mathbf{R_sC}}} * \frac{\sqrt{\mathbf{R_s'}}}{\mathbf{R_s'}+\mathbf{R_{eq}}}, \tag{3}$$

where R_{eq} is the equivalent LNA input resistance.

The gate-source voltage V_{GS} can be increased as the $R_S^{'}$ approaches R_{eq}, which is usually lower than 50Ω. We can get the proper impedance $R_S^{'}$ by choosing the microstrip line characteristic impedance Z_0 and the length *l*. The source impedance transformation provides not only high voltage gain, but also high out-of-band signals attenuation.

The frequency tuning is easily achieved by switching S1 and S2. Because it is not necessary to consider the impedance matching at the center frequency, the center frequency tuning is attained.

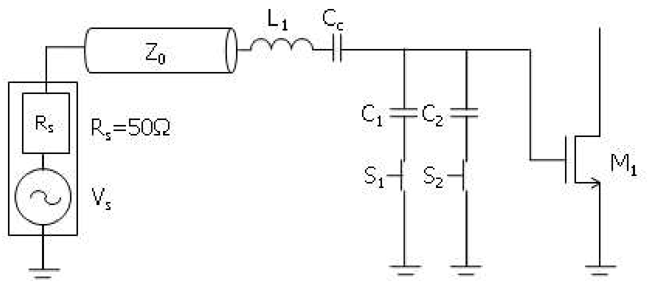


Figure 1: Proposed high Q series resonance technique

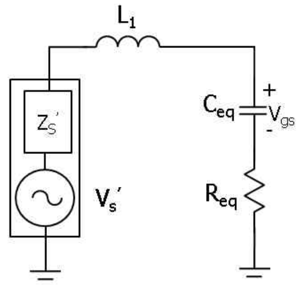
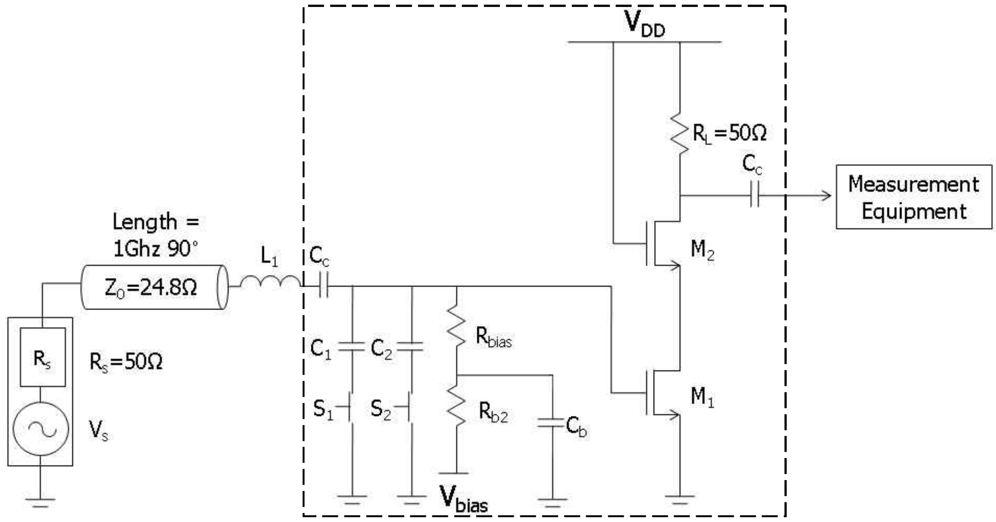


Figure 2: The equivalent circuit

3. Circuit design

The implemented circuit is shown in Figure 3. The source impedance R_S (50Ω) is transformed to $R_S^{'}$ + jX. The reactance value X, L1, and equivalent input capacitance are resonant with each other. The circuit is designed to series resonance occurred around 1GHz with the 24.8Ω microstrip line. This microstrip line transforms the source impedance to lower impedance. The transformed source impedance's real values are 15.5Ω, 14.4Ω, 12.8Ω, 12.1Ω corresponding to 0.64GHz, 0.7GHz, 0.82GHz, 1.07GHz, respectively. The equivalent gate-source impedance is changed using switch control. The load impedance consists of the simple 50Ω resistance to wideband matching, with measurement equipment, such as a spectrum analyzer, to prove the proposed technique's effect.



off-chip on-chip

Figure 3: Implemented circuit schematic

4. Result

The LNA simulated gain is plotted in Figure 4. The conventional in the graph means the LNA with the 50Ω impedance matched and the proposed means the LNA with the proposed high Q series resonance technique. The difference between the conventional LNA and the proposed LNA is the input matching part only, but the other conditions have been kept same. S00 means that switches S1 and S2 are both off; S01 means that switch S1 is off and S2 is on; S10 means that switch S1 is on and S2 is off; and S11 means that switches S1 and S2 are both on.

The simulation result shows that the gain of the proposed LNA is 12.7dB to 18.3dB at each mode, while the gain of the conventional LNA is 6.6dB. The simulated NF of the proposed circuit is 1.2–2.2dB at each mode center frequency. The supply voltage is 1.2V and the DC current is 7.19mA. This proves that the proposed technique offers high gain and high filtering performance.

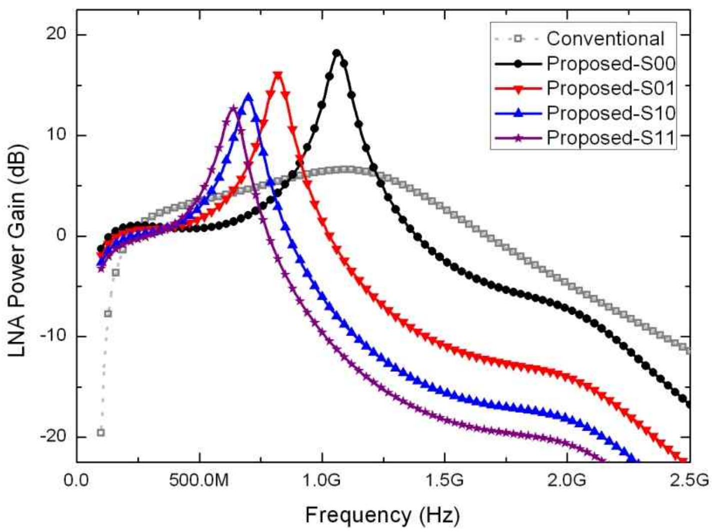


Figure 4. Simulated gain of LNA with the impedance matching (square) technique and proposed high Q series resonance technique (circle, down triangle, up triangle, star)

5. Conclusion

A high Q LNA input series resonance technique and an LNA with the proposed technique are presented. The proposed technique provides high voltage gain and sharp filter performance. This effect has been shown by the gain simulation of the LNA with the proposed technique. This LNA also can easily tune the center frequency simply by turning the switches on and off. This will be helpful for SDR receivers.

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