

A high image rejection SiGe low noise amplifier using passive notch filter

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Abstract: A new design is presented that combines a low-noise amplifier (LNA) with a new passive base-collector notch filter based on Jazz 0.18 μ m SiGe technology. Extra capacitor is introduced in notch filter, eliminating the operating-frequency input mismatch in formal base-collector notch filters. Results show that LNA obtains a 4 dB S_{21} enhancement of 14.1 dB and a 7 dB increase S_{11} of -15 dB at 20.5 GHz, image rejection ratio is 33.5 dB. IIP_3 is 3.43 dBm at the operating frequency for a power consumption of 18 mW from a 3 V power supply.

Keywords: LNA, notch filter, SiGe, IRR

Classification: Integrated circuits

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1 Introduction

In superheterodyne architecture, suppression of image-frequency signals is

one of the most fundamental performances [1], thus notch filters are required to provide an image-rejection-ratio (IRR) to least more than 30 dB in order to filter out the undesired image signal [2]. [3] introduces active notch filter to compensate parasitic resistance of on-chip inductor to achieve a large Q notch filter. This is, however, not preferred because negative impedance means more power consumption. [4, 5] introduce a notch-filter between base and collector in LNA which shows great IRR. However, S_{11} in these LNAs are unsatisfying, that is, about -8 dB. This is shown in Table I which compares main performances of [4, 5] and this paper at similar frequency. Suffixes ‘im’ and ‘op’ indicate the image signal and operating frequency signal. Good IRR can ensure a good image rejection, but poor input match at operating frequency may degrade the useful signal injection performance [8, 9]. Attentions should be made that [3] adopts an extra capacitor to tune the operating frequency without affecting the image frequency, this is, theoretically, can also be utilized in passive filters. In order to optimize the input match as well as save power [10], a new passive IR filter is introduced.

Table I. Performances of image-rejection LNAs

Ref.	F _{op} (GHz)	F _{im} (GHz)	S _{11,op} (dB)	S _{21,op} (dB)	F _{im} /F _{om}	NF(dB)	IIP3(dBm)
[4]	27.2	21.6	-8	14	0.79	8.9	-14
[5]	24	18.5	-9	16.5	0.77	5.9	-9.5
This work	20.5	15	-15.9	14.1	0.73	4.8	3.43

2 Proposed notch filter design

The whole LNA architecture is shown in Fig. 1 with notch filter enclosed in the line box. By using resistive feedback and input π network [6, 7], wideband LNA is designed. The input 50Ω is formed by the resistive feedback. Cascode topology is used to increase isolation between input and output which can enhance the performance of S_{11} and Noise Figure

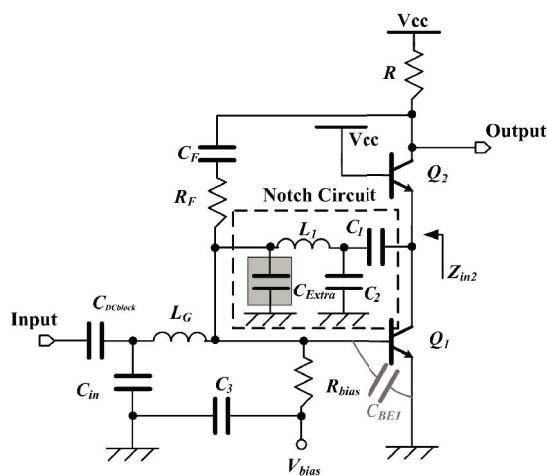


Fig. 1. LNA architecture

(NF) [11]. Capacitor C_{Extra} is added in the notch filter for two reasons: 1) To fulfill the input π network. 2) To optimize the operating frequency.

Fig. 2 shows the small signal of notch filter and matching network looking from the Z_{in2} direction. $C_{C,Q1}$ and C_{BE2} are the collector capacitor of Q_1 and base-emitter capacitor of Q_2 correspondingly. Even [4, 5] also adopt the same base-collector notch filter configuration only with the difference of not adding C_{Extra} , derivations of image and operating frequency are roughly set as $1/\sqrt{L_1 \cdot (C_1 + C_2)}$ and $1/\sqrt{L_1 \cdot C_2}$, this is actually inaccurate in these cases. The inaccuracy mainly comes from the fact that base of input transistor is not directly connected to an ac ground whereas to the right terminal of input match network (shown in Fig. 2), so new analysis is needed include the impact of source resistance R_S and match network.

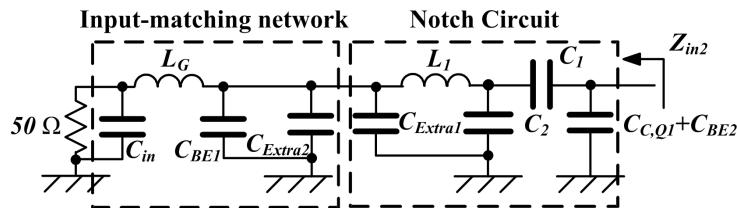


Fig. 2. Small signal architecture of notch filter and matching network

In Fig. 2, C_{Extra} is divided into two parts: C_{Extra1} and C_{Extra2} . C_{Extra1} is included in matching together with C_{BE1} to form π network, this can decrease the required value of C_{BE1} , thus enhancing the linearity of LNA. Even though this will drop the gain a little, but with the consideration of linearity and the quasi-exponential characteristic of C_{BE} along with base-emitter voltage, adding C_{Extra1} is a good compromise. The other part C_{Extra2} is included in the notch circuit. To understand this component's function, expression of Z_{in2} is given as

$$Z_{in2} = B \cdot \frac{s^2 L_1 + s \left(R_S \parallel \frac{1}{s C_{Extra2}} \right) + \frac{1}{C_1 + C_2}}{s^2 L_1 C_1 \cdot C_2 (1 + D) + s \left(R_S \parallel \frac{1}{s C_{Extra2}} \right) C_1 \cdot C_2 \cdot E + C_1 \cdot C_2 + C_1 + C_{C,Q1} + C_{BE2}} \quad (1)$$

$$B = \frac{(C_1 + C_2)}{s} \quad (2)$$

$$D = \frac{(C_{C,Q1} + C_{BE2}) \cdot (C_1 + C_2)}{C_1 C_2} \quad (3)$$

$$E = \frac{(C_1 + C_{C,Q1} + C_{BE2})}{C_1 + C_2 + C_{C,Q1} + C_{BE2}} \cdot \frac{(C_1 + C_2) \cdot (C_{C,Q1} + C_{BE2})}{C_1 C_2} \quad (4)$$

Symbols B , D and E in (1) are shown in (2)-(4). Unlike [4], because first order expressions exist on numerator and denominator in (1), poles and zeros are conjugate which are not easily to solve. However, it is shown that with the existence of C_{Extra2} , weight of first order expression decreases as frequency goes up. For example, the amplitude of R_S in parallel with C_{Extra2} is 50Ω , but at 20 GHz, this value is only 20Ω . After the shrink of these expressions, and based on (1) and some simplifications, the image and

operating frequency can be expressed as

$$f_{im} \approx \frac{1}{2\pi} \cdot \sqrt{\frac{1}{L_1 \cdot (C_1 + C_2)}} \quad (5)$$

$$f_{op} \approx \frac{1}{2\pi} \sqrt{\frac{C_1 + C_{C,Q1} + C_{BE2}}{L_1 \cdot C_1 \cdot C_2 \cdot (1 + D)}} \quad (6)$$

f_{im} is the image frequency and f_{op} is the gain peak frequency. From (5) and (6), the zero is same as [2, 3, 4, 5] and the pole is determined by notch components. It is interesting to find that C_{Extra} is not located in (6); this is because this capacitor is used to attenuate the impact of source resistance, making the base terminal of Q_1 act like an ac ground at desired frequency.

3 Results and discussion

The schematic of a prototype image-rejection LNA circuit is designed and realized in Jazz 0.18- μ m SiGe BiCMOS technology. All inductors are on-chip elements, and as a result of the input matching and operating frequency optimization, the notch circuit is designed to have L_1 of 0.46 nH, a C_{Extra} of 300 fF, a C_2 of 200 fF and a C_1 of 50 fF. L_1 is 0.46 nH and C_{in} is 50 fF. Resistors of R_F and R are 500 Ω and 300 Ω . Power consumption is 18 mW at 3 V voltage supply. Simulation results are shown in Fig. 3 which consists of S_{11} and S_{21} with and without C_{Extra} . Because image frequency has the same expression, S_{11} and S_{21} are almost unchanged in two conditions at f_{im} , but enhancements is lead to by the addition of C_{Extra2} at f_{op} , indicated in (6). From Fig. 3, the optimization point A is drawn down to B by the addition of C_{Extra} , leading to an increase of S_{21} as well. S_{11} is increased to -15 dB from -8 dB. Operating S_{21} was 14.1 dB and image rejection gain was -19.51 dB which means the IRR was 33.50 dB. Figure 4 gives the noise performance with and without C_{Extra} . As can be seen, noises of two conditions are same at image frequency, and because gain is increased at operating frequency shown in Fig. 3, noise is optimized. Large signal characteristic is shown in Fig. 5 at 20 GHz, it is found that linearity is enhanced with C_{Extra} , this is mainly because C_{Extra} contributes capacitance of π network, and nonlinear characteristics of C_{BE1} and

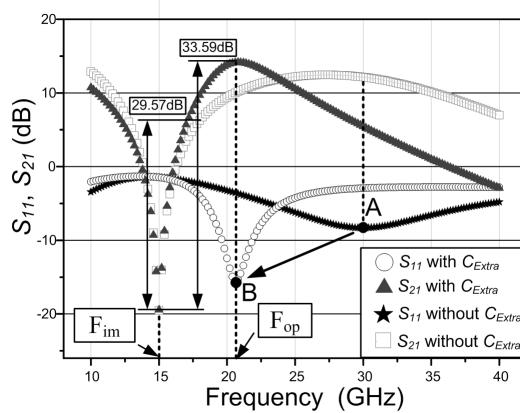


Fig. 3. Simulated S_{11} and S_{21} frequency-dependence with and without extra capacitor C_{Extra}

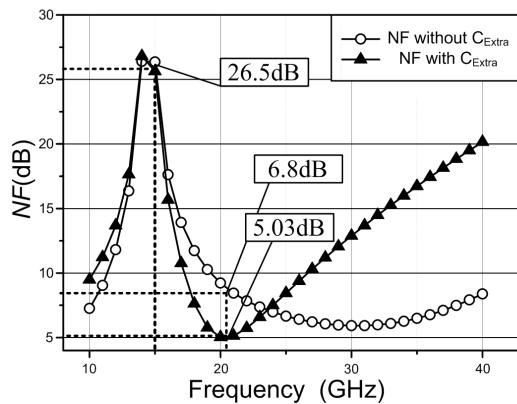


Fig. 4. NF of proposed LNA with and without C_{Extra}

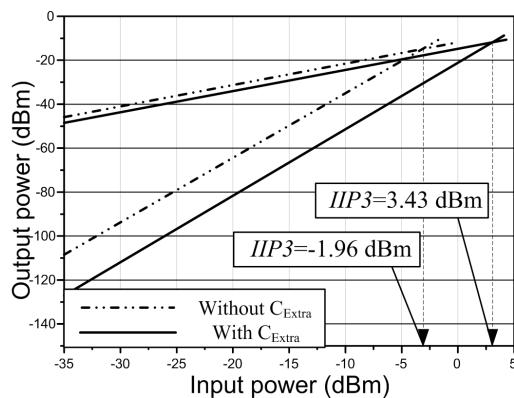


Fig. 5. Large signal characteristics of LNA with and without notch filter

transconductance of Q_1 are decreased as the base-emitter voltage drops down a bit.

4 Conclusions

A new LNA base-collector notch filter has been presented. The proposed image-rejection filter employs a third-order notch filter and extra capacitor is added to optimize the circuit performances. Compared to the formal researches, this new topology can ensure a good input match and linearity at operating frequency.

Acknowledgments

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