Design Challenges of Low Noise Amplifier for Cognitive Radio

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Abstract— Cognitive Radio is a technology that increases the spectrum utilization by providing access to unlicensed users the spectrum unoccupied by the licensed users. Spectrum sensing and communication in Cognitive radios are performed in the range of tens of megahertz to 10GHz. As such, they pose tough architecture and circuit design problems. A low noise amplifier is generally the first stage of a transceiver and hence it is highly desirable that is introduces less noise while boosting the weak signals picked up by the antenna. This paper discusses the design challenges of low noise amplifier for cognitive radios.

Key words: Cognitive Radio, Low Noise Amplifier

I. INTRODUCTION

With the exploding popularity of all things wireless, the radio spectrum, which is finite, must accommodate cell phone calls and data traffic that is increasing at an unprecedented rate and hence it become a scarce commodity in many countries. According to Huawei, traffic on mobile broadband systems globally has grown so fast that current levels already exceed predictions made in 2010 for 2020.

A recent report published by the federal communication commission (FCC) in US has shown a surprising finding, which highlights a different cause of the shortage of frequency resource: “In many bands, spectrum access is a more significant problem than physical scarcity of spectrum, in large part due to legacy command-and-control regulation that limits the ability of potential spectrum users to obtain such access” [1]. Thus, the large part of the licensed spectrum is not utilized most of the time and space, and the frequency spectrum is actually abundant. According to Federal Communications Commission (FCC), 15% to 85% of the allocated spectrum is utilized with large temporal and geographical variations [1-2]. Thus, efficient utilization of the physical radio spectrum is a fundamental issue of wireless communications.

The conflict between the inefficient usage of spectrum and the rapid growth of wireless services calls for a more flexible and intelligent solution to manage such an important natural resource. Cognitive radio makes it possible to increase the spectrum utilization by providing access to unlicensed users the spectrum unoccupied by licensed users. The below figure 1 shows the concept of cognitive radio.

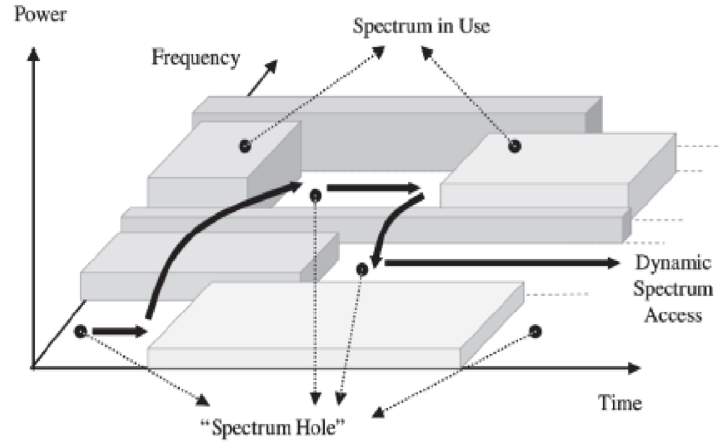


Fig. 1: Illustration of Cognitive Radio [2]

Different efforts have been made to design CR which focused on TV bands below 1GHz [3]-[4], due to release of the IEEE 802.22 Wireless region area network (WRAN) standard. This standard focuses on the implementation of a CR in the frequency band of 54MHz to 862MHz band. A cognitive radio do not target narrowband standards, it must operate at any frequency within the wideband. Consequently, the mixing spurs and the performance parameters, which characterize the linearity of the circuit due to the intermodulation effects, must satisfy more stringent bounds [4]. A CR receiver front-end must provide a relatively flat gain and a reasonable input return loss across the bandwidth of CR, putting a challenging demand on the radio and it’s Low Noise Amplifier (LNA).

II. LOW NOISE AMPLIFIER ISSUES

To design a cognitive radio transceivers there are many challenges [9], which can be classified into three broad domains namely: signal path design, carrier generation and spectrum sensing. While designing signal path two issues must be considered: (a) broadband characteristics, i.e., a relatively flat noise figure and gain and adequate input matching across two or three decades; (b) nonlinearity and local oscillator harmonics. The wideband requirement for future cognitive radio can be viewed as concatenation of the frequency of tens of megahertz to about 900 MHz (TV tuner frequency range), the cellular and wireless LAN frequency range (900MHz to few gigahertz) and the ultra-wideband frequency range (3GHz to 10GHz). The requirement of relatively flat gain and a reasonable input return loss across the bandwidth of CR, make it difficult to employ traditional RF circuit design techniques. Several techniques proposed so far to address the problem mentioned above [6] but the solutions are still inadequate for CRs. The broadband behavior of cognitive radio receivers is primarily determined by the front-end low noise amplifier. So, LNA is a most important component of CR receivers to work upon.

The parameters which are to be focused while designing low noise amplifier are: input matching, noise figure, gain, and bandwidth and voltage headroom.

It is not possible to improve each of the parameters mentioned above simultaneously, so we have make trade-offs between them. There are several techniques available which can be used to design LNA for these parameters. The choice of topology begins with the input matching requirement. The input matching of the LNA can assume one of the several forms: (a) a common-source stage with inductive degeneration, (b) a common-gate stage, (c) a gain stage with resistive feedback, (d) a combination of CS and CG stages.

Common-source (CS) stage with inductive degeneration provides very good input matching and moderate to low bandwidth. Thus, it cannot be used for broadband operation and is dismissed. The below figure 2 shows the common-gate stage amplifier.

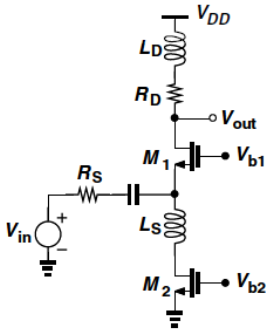


Fig. 2: Common-gate stage

Here, LS resonates with the capacitance in the input network, improving the return loss and LD with the capacitance at the output, extending bandwidth. CG stage provides large bandwidth and good input matching. CG provides high noise figure (NF≥1+γ, where γ denotes the excess noise coefficient of M1) and also suffers from other drawbacks also. First, unlike narrowband designs, in which M_2 and R_D can be replaced with a short circuit, this broadband topology faces severe headroom-gain-noise trade-offs. If body effect and channel-length modulation are neglected and the input is matched, the mid-band noise figure of the circuit is given by

$$NF=1+\gamma+\gamma g_{m2}R_S+4R_S/R_D \qquad (1)$$

This expression dictates that gm2 << gm1 (RS-1) and RD >> RS. That is, both the overdrive voltage of M_2 and the dc drop across R_D must remain much greater than the overdrive of M_1, requiring a high supply voltage.

The second drawback of the circuit stems from channel length modulation in deep-submicron devices. From the simplified mid-band equivalent circuit shown in figure 3, we have

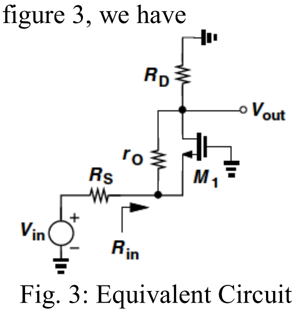


Fig. 3: Equivalent Circuit

$$R_{in} = \frac{R_1 + r_0}{1 + (g_m + g_{mb})r_0} \qquad (2)$$

And

$$\frac{V_{out}}{V_{in}} = \frac{1 + (g_m + g_{mb})r_0}{r_0 + (g_m + g_{mb})r_0 R_s + R_s + R_1} R_1 \qquad (3)$$

Setting R_{in} equal to R_S and using the result in (3), we obtain [7]

$$\frac{V_{out}}{V_{in}} = \frac{1 + (g_m + g_{mb})r_0}{2\,(1 + r_0/R_1)} \qquad (4)$$

Since r_O is on the order of R_D, the voltage gain of this stage is limited to roughly one-fourth of the transistor's intrinsic gain, hardly exceeding 3 (10dB). Thus, the noise of the following stage may contribute significantly to the receiver noise figure.

Let us now consider the CG/CS combination shown in figure 4. Here, the CS stage provides additional voltage gain and more importantly, forms a differential output along with the CG stage if $g_{m1} \approx g_{m3}$ and RD1 = RD2.

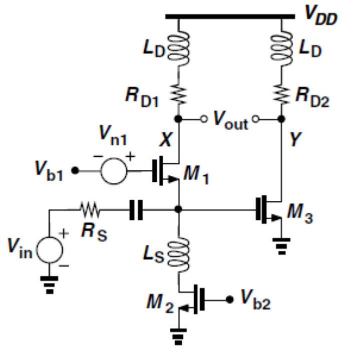


Fig. 4: CG/CS Stage

An interesting property of this circuit is that the noise ofM$_1$, V_{n1}, is canceled [8]. This can be seen by neglecting body effect and channel length modulation and writing

$$\frac{V_X}{V_{n1}} = -\frac{R_{D1}}{(g_m^{-1} + R_s)} \qquad (5)$$

And

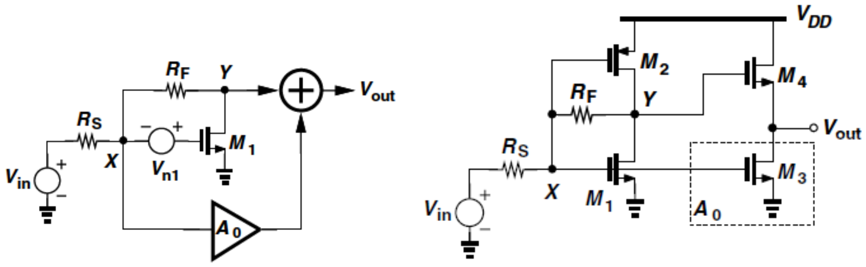
$$\frac{V_Y}{V_{n2}} = -\frac{R_{D1}}{(g_m^{-1} + R_s)} g_{m3} R_{D2} \qquad (6)$$

Thus, with $R_{D1} = R_{D2}$ and $gm3R_S = 1$, V_{n1} emerges only as a common-mode component at the output. However, the overall noise figure is only slightly lower than that of the simple CG stage:

$$NF = 1 + \gamma + \gamma g_{m2} R_S + 2\frac{R_S}{R_D} \qquad (7)$$

The topology of Fig. 4 still suffers from the drawbacks of the CG LNA shown in Fig. 3, facing serious headroom issues. Furthermore, the additional capacitance contributed by M_3 to the input degrades the S_{11}.

The concept of noise cancellation can be generalized as follows [8]. If a circuit contains two nodes at which the input signal appears with opposite polarities and the noise of a device with the same polarity, then the latter can be canceled. As illustrated in Fig. 5(a) [8], proper weighting and summation of the voltages at nodes X and Y retains the signal while removing the effect of Vn1. Figure 5(b) depicts an implementation of the idea [8]. Here, M_3 serves as the auxiliary amplifier and M_4 as the summer. Note that the noise of M2 is also canceled; if operating as a constant current source; M_2 would contribute substantial noise due to the limited headroom.



(a) (b)

Fig. 5: (a) Noise-canceling LNA, (b) Implementation of (a)

The cancellation technique described above also suppresses nonlinear components produced by the input device [8] even though they are correlated with the input signal. The linearity of the LNA is thus limited by that of the auxiliary amplifier.

III. CONCLUSION

In this paper the design challenges of low noise amplifier for Cognitive Radio is described. The required characteristics of the low noise amplifier are: input matching, noise figure, gain, and bandwidth and voltage headroom. Different topologies are discussed and each one of them has some drawbacks. So, a kind of technique required so that the required characteristics of LNA can be obtained for Cognitive Radios.

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