Integration of an External Low-noise Amplifier, Improving the Sensitivity of the Receiver

ATA5743 Integrating an External LNA

Application Note

Introduction

The UHF receiver ATA5743 has a sensitivity of –110 dBm for ASK (1 kBaud data rate) and –104 dBm for FSK (1 kBaud data rate; frequency deviation ±16 kHz). For some applications a higher sensitivity is needed. An external low-noise amplifier (LNA) can be applied, improving the system sensitivity. The ATA5743 is designed to simplify the use of an external LNA, since a special output pin (IC_ACTIVE) exists which switches between power supply (VS) and ground (GND) simultaneous to the polling mode of the receiver. If the receiver is in sleep mode, the pin switches to GND; if the receive is in active mode, IC_ACTIVE switches to VS.

The purpose of this application note is to show the integration of an LNA with ATA5743 using discrete components, as well as the bottle neck caused by and the physical aspect due to adding the LNA. This application note is not a special discussion of LNA circuits. Therefore, a very simple LNA circuit is used here.

1. General Theory

Sensitivity of a receiver system is defined as the minimal signal level which can be properly received and demodulated by the receiver achieving the required bit error rate. This value can be expressed generally as

$$\text{Sens} = NF + n_0 + \frac{S}{N} \qquad \text{(equation 1)}$$

where
Sens = Sensitivity
NF = Noise figure
S/N = Required signal to noise ratio
n_0 = Thermal noise of the system

4922A–RKE–06/06

The thermal noise of the system can be calculated as follows

$$n_{0(dBm)} = 10\log\left(\frac{kTB}{10^{-3}}\right) \qquad \text{(equation 2)}$$

where
k (Boltzmann's constant) = 1.38E-23
T = Temperature in Kelvin
B = IF bandwidth of the system

For a 1Hz bandwidth, the thermal noise comes to –174 dBm/Hz.

A noise figure plays a role in the sensitivity performance, so the Friis formula calculating the total noise factor of a cascaded system has to be mentioned.

$$F_{Tot} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 \times G_2} + ... + \frac{F_n - 1}{G_1 \times G_2 ... G_{n-1}} \qquad \text{(equation 3)}$$

Note: F is defined as the relationship between the input's signal to noise ratio and the output's signal to noise ratio.

$$F = \frac{S_i / N_i}{S_o / N_o} \qquad \text{(equation 4)}$$

where
S_i = Signal power at input
N_i = Noise power at input
S_o = Signal power at output
N_o = Noise power at output

The noise figure (NF) represents the noise factor in decibels.

$$NF = 10\log F \qquad \text{(equation 5)}$$

If a SAW filter is implemented in the receiver system, then, as shown by the Friis formula, the LNA has to be added in front of the SAW filter in order to optimize the effect of the noise figure degradation caused by the SAW's behavior. Please bear in mind the SAW filter does not have a gain and makes a contribution to the noise figure of the system due to the attenuation.

Dynamic range is an important performance characteristic of a receiver system. The dynamic range sets the maximum and minimum limits of the signal level which can be properly processed by the receiver system. The minimum limit is defined by the sensitivity level, whereas the maximum limit will be determined by the receiver's capability of processing the high signal level linearity. A drawback of adding an LNA with a high gain as a pre-stage of a receiver is the degradation of the linearity. This effect can be seen in equation 6, which describes the total linearity of a cascaded system in the form of the third input intercept point (IIP3).

$$\frac{1}{IIP_{3\_tot}} = \frac{1}{IIP_{3\_1}} + \frac{G_1}{IIP_{3\_2}} + \ldots + \frac{G_1 \times G_2 \ldots G_{n-1}}{IIP_{3\_n}} \qquad \text{(equation 6)}$$

2. Example Demonstrating the Impact of Adding an LNA in Front of a Receiver

This section shows the impact of adding an LNA in front of a receiver system via calculations and with some figures. For this purpose some values are assumed, as follows.

Receiver

- IF bandwidth = 300 kHz (assumption: the IF bandwidth is equal to the system bandwidth)
- Sensitivity of the receiver = –104 dBm
- Noise figure of the receiver = 7 dB (noise factor F = 5.01)
- IIP3 of the receiver = –28 dBm (1.585 mW)

LNA

- Noise figure is about 3 dB (noise factor FLNA = 2)
- Gain is about 19 dB (GLNA = 79.43)
- IIP3 is –17.6 dBm

The thermal noise of the receiver system can be calculated with equation 2 to –119.2 dBm (≈ 119 dBm). Thus, the signal to noise ratio can be calculated using equation 1 to be

$$\frac{S}{N} = -Sens + n_0 + NF = 104 - 119 + 7 = 8\ dB$$

After adding an LNA before the receiver, the cascaded noise figure of the system can be determined using equation 3

$$F_{Tot} = F_{LNA} + \frac{F-1}{G_{LNA}}$$

F_{Tot} is 2.05, whereas the total noise figure is 3.11 dB. The cascaded sensitivity from equation 1 results in –108.1 dBm, which points to an improvement of 3.89 dB.

For the total linearity of the system, equation 4 can be applied, as follows

$$\frac{1}{IIP_{3\_tot}} = \frac{1}{IIP_{3\_1}} + \frac{G_1}{IIP_{3\_2}}$$

The IIP3 of the system after adding the LNA will be –47 dBm. This shows a reduction of the linearity of about 19 dB, which is comparable to the additional gain of the LNA.

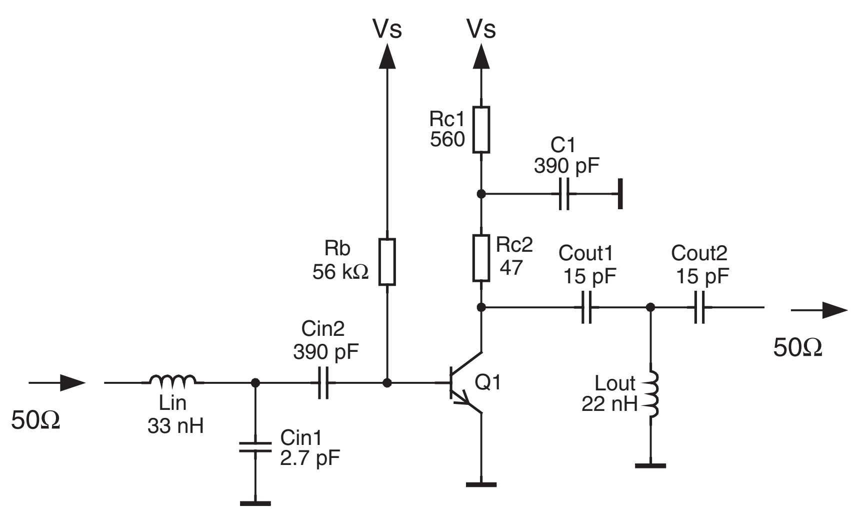
In this example, the improvement of the sensitivity by about 4 dB (3.89 dB) will cause a loss of the linearity of about 19 dB, which points at the reduction of the dynamic range.

3. Addition of an LNA to ATA5743

Atmel's ATA5743 (T5743) receiver consists of an internally programmable polling-mode functionality, which enables the receiver to handle sleep and active mode. This reduces the operating current consumption. In order to simplify the application of an external LNA with these receivers, the pin IC_ACTIVE was designed. With this pin, an external LNA can be activated simultaneously with the receiver's active mode, a simple way of guaranteeing zero current consumption of the LNA while the receiver is going to sleep mode.

Figure 3-1 shows the schematic of an external LNA implemented using discrete elements optimized for 315-MHz operating frequency. In the design, the transistor BFP420 is used. For this purpose, the LNA is designed to have 50Ω input and output matching at 315-MHz operating frequency. This enables a quick measurement of the impact of the LNA in the sensitivity performance using the 50Ω-matched demo board for ATA5743.

Figure 3-1. Schematic of the External LNA



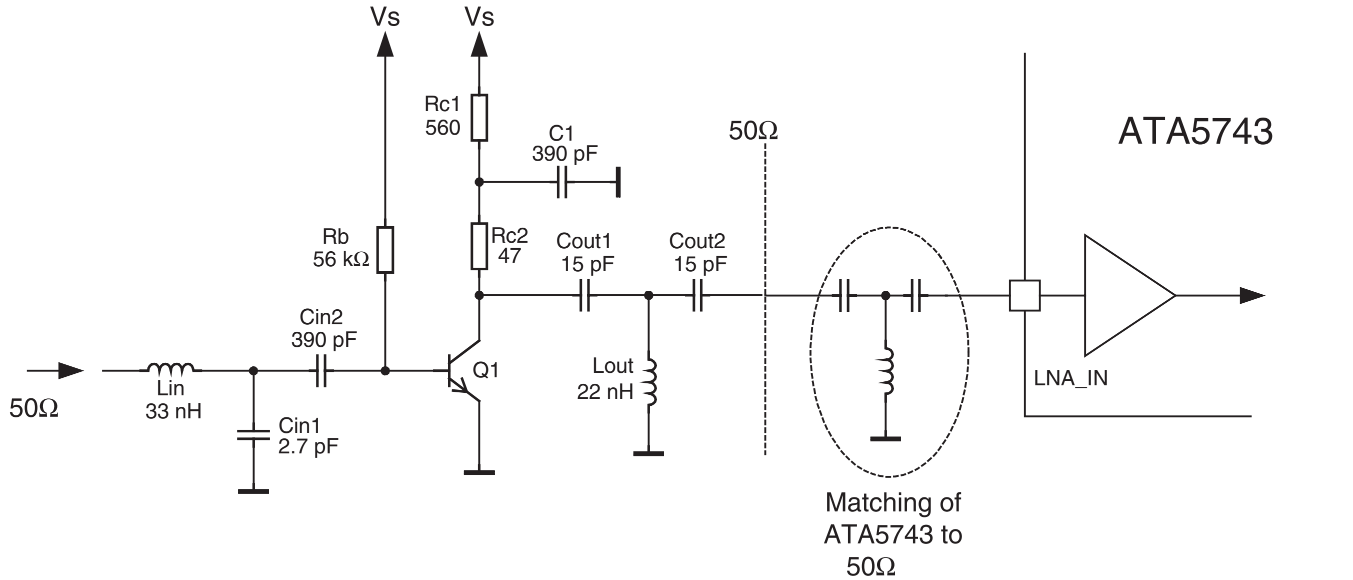
Note: The blocking procedure for the power supply is not shown in Figure 3-1.

The measured performance of the LNA is outlined below.

- Current consumption = 5 mA (Power supply VS = 5 V)
- Noise figure = 3.2 dB
- IIP3 = –17.6 dBm
- Gain = 19 dB

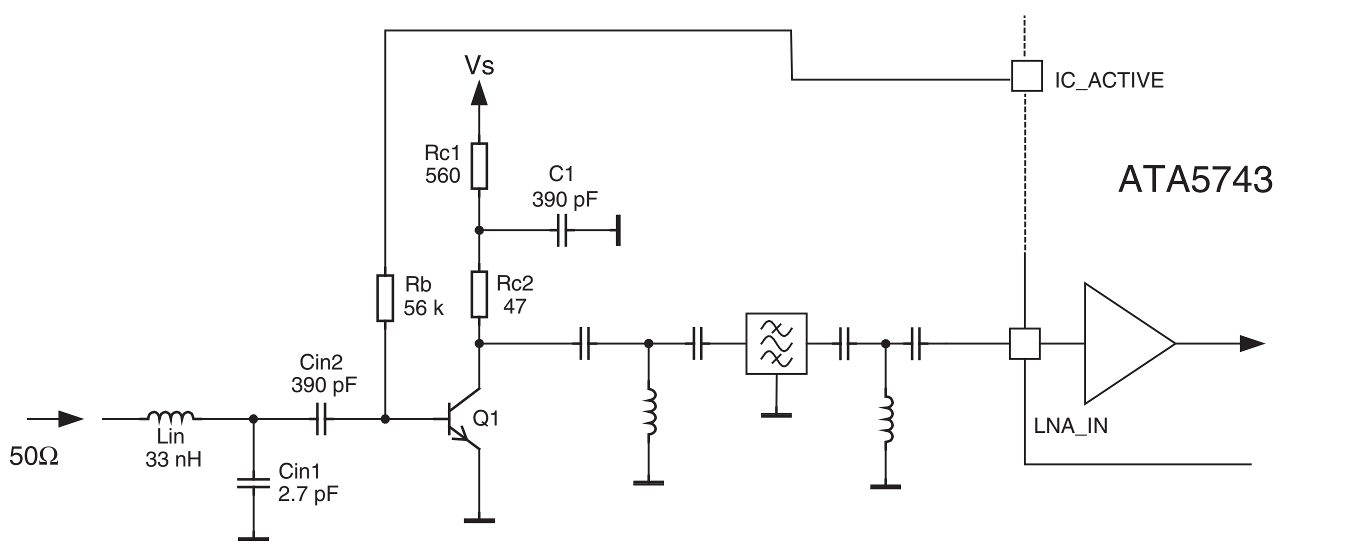
The values measured above allow the improvement due to adding an external LNA to be predicted, as well as the reduction of the dynamic performance of the system. Equations 1 and 3 show an improvement of 3.64 dB can be reached in the system sensitivity, whereas the linearity of the system decreased to –45.01 dBm. The sensitivity measurement using the ATA5743 demo board (50Ω matching) results in a sensitivity improvement of 3.5 dB. The system assembly for the measurement is shown in Figure 3-2 on page 5.

Figure 3-2. Schematic of the Receiver System with the External LNA for the Measurement



For a general application using the ATA5743, a SAW filter is applied in front of the receiver. Therefore, the influence of the LNA on the application with SAW filter was also measured. For this measurement, the ATA5743 demo board with SAW filter matched to 50Ω is used. The measured sensitivity is about –111 dBm. The sensitivity's improvement on the LNA application with SAW is definitely higher than the application without SAW. In this case, the influence of the structure to the noise contribution on the image frequency has to be taken into account. Figure 3-3 shows the application of an LNA with SAW filter using pin IC_ACTIVE to bias the LNA. More information about pin IC_ACTIVE can be read in the ATA5743 datasheet.

Figure 3-3. Schematic for the LNA Application With SAW Filter and the Pin IC_ACTIVE as Controlling Pin



4. Summary

- In order to improve the linearity of the LNA, an inductor can be inserted on the transistor's emitter.
- There is a lot of good information and excellent papers about LNAs, giving the designer a lot of potential in the implementation, depending on and specific to the application itself.
- As shown in Section 2. on page 3, the improvement of the sensitivity will cause a loss in the dynamic range of the system. This compromise between the sensitivity and the linearity, which is also related to the current consumption and bill of materials, will appear every time in designs of this kind and require for a compromise to be made.
- In order to achieve proper blocking performance in the application of the LNA as a pre-stage amplifier of a receiver, both a small band antenna and RF filter stage will be needed in addition to the high linearity performance of the LNA itself.

Atmel Corporation

2325 Orchard Parkway
San Jose, CA 95131, USA
Tel: 1(408) 441-0311
Fax: 1(408) 487-2600

Regional Headquarters

Europe
Atmel Sarl
Route des Arsenaux 41
Case Postale 80
CH-1705 Fribourg
Switzerland
Tel: (41) 26-426-5555
Fax: (41) 26-426-5500

Asia
Room 1219
Chinachem Golden Plaza
77 Mody Road Tsimshatsui
East Kowloon
Hong Kong
Tel: (852) 2721-9778
Fax: (852) 2722-1369

Japan
9F, Tonetsu Shinkawa Bldg.
1-24-8 Shinkawa
Chuo-ku, Tokyo 104-0033
Japan
Tel: (81) 3-3523-3551
Fax: (81) 3-3523-7581

Atmel Operations

Memory
2325 Orchard Parkway
San Jose, CA 95131, USA
Tel: 1(408) 441-0311
Fax: 1(408) 436-4314

Microcontrollers
2325 Orchard Parkway
San Jose, CA 95131, USA
Tel: 1(408) 441-0311
Fax: 1(408) 436-4314

La Chantrerie
BP 70602
44306 Nantes Cedex 3, France
Tel: (33) 2-40-18-18-18
Fax: (33) 2-40-18-19-60

ASIC/ASSP/Smart Cards
Zone Industrielle
13106 Rousset Cedex, France
Tel: (33) 4-42-53-60-00
Fax: (33) 4-42-53-60-01

1150 East Cheyenne Mtn. Blvd.
Colorado Springs, CO 80906, USA
Tel: 1(719) 576-3300
Fax: 1(719) 540-1759

Scottish Enterprise Technology Park
Maxwell Building
East Kilbride G75 0QR, Scotland
Tel: (44) 1355-803-000
Fax: (44) 1355-242-743

RF/Automotive
Theresienstrasse 2
Postfach 3535
74025 Heilbronn, Germany
Tel: (49) 71-31-67-0
Fax: (49) 71-31-67-2340

1150 East Cheyenne Mtn. Blvd.
Colorado Springs, CO 80906, USA
Tel: 1(719) 576-3300
Fax: 1(719) 540-1759

Biometrics/Imaging/Hi-Rel MPU/
High-Speed Converters/RF Datacom
Avenue de Rochepleine
BP 123
38521 Saint-Egreve Cedex, France
Tel: (33) 4-76-58-30-00
Fax: (33) 4-76-58-34-80

Literature Requests
www.atmel.com/literature

4922A–RKE–06/06