# Why need external LNA ?

Among all the cell-phone RF functions, due to the extremely weak signal, GPS is the RF function that uses eLNA (External Low noise amplifier) quite often [1].

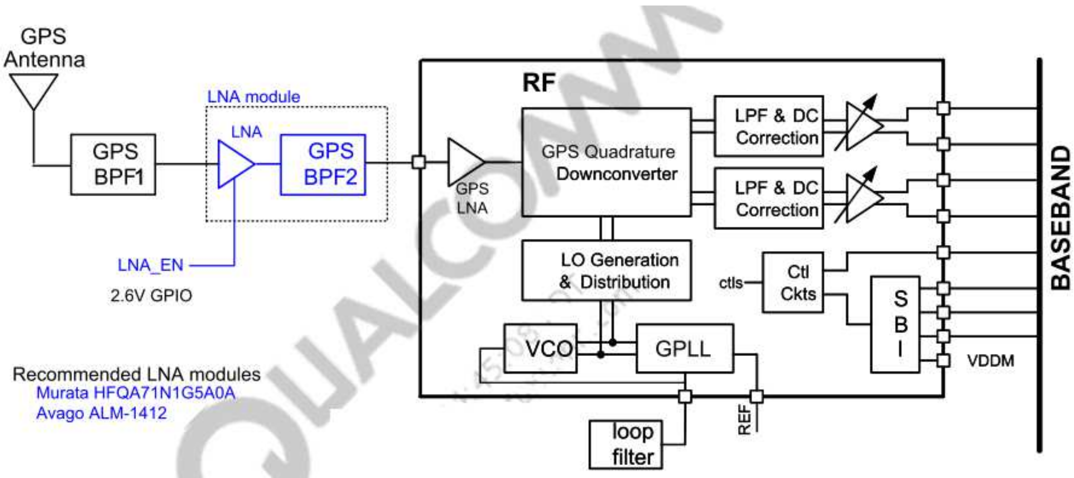
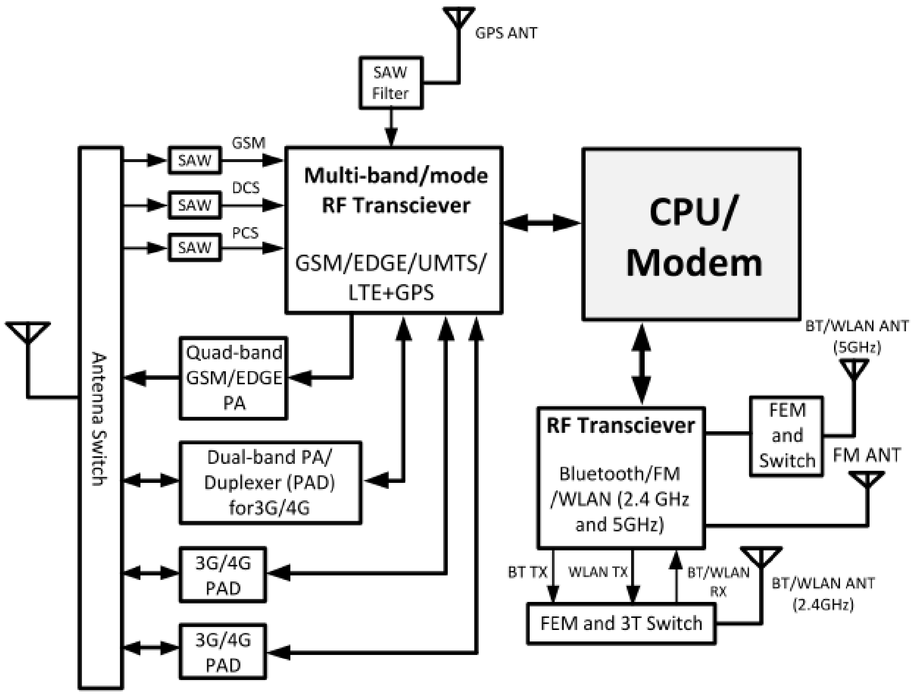


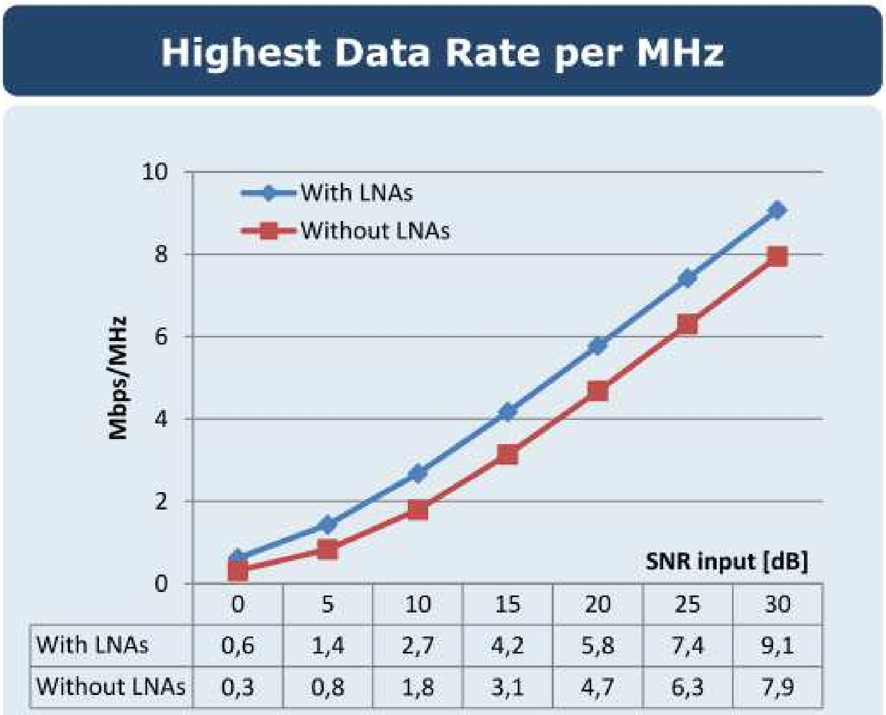

Fig1.

However, as the RF functions of cell-phone become more and more complex, and the bands are more and more [7],



there are a lot of passive components in the RF front end, just like switch, SAW Filter, Diplexer, etc. These passive components increase the receiver cascade noise figure, and then degrade the sensitivity [2]. Therefore, we need eLNA to improve sensitivity [3].

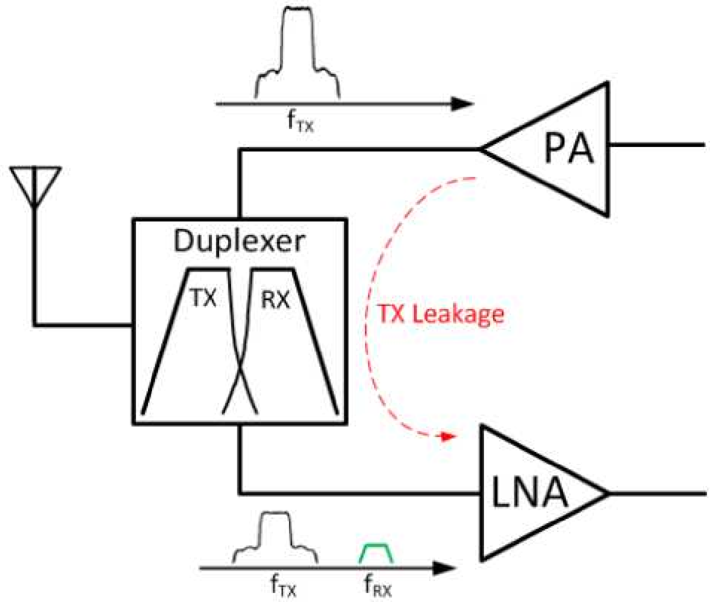
Besides, according to Shannon Theorem, we know that the more SNR, the more channel capacity. That is, with eLNA, we can also improve the data rate [4-6].



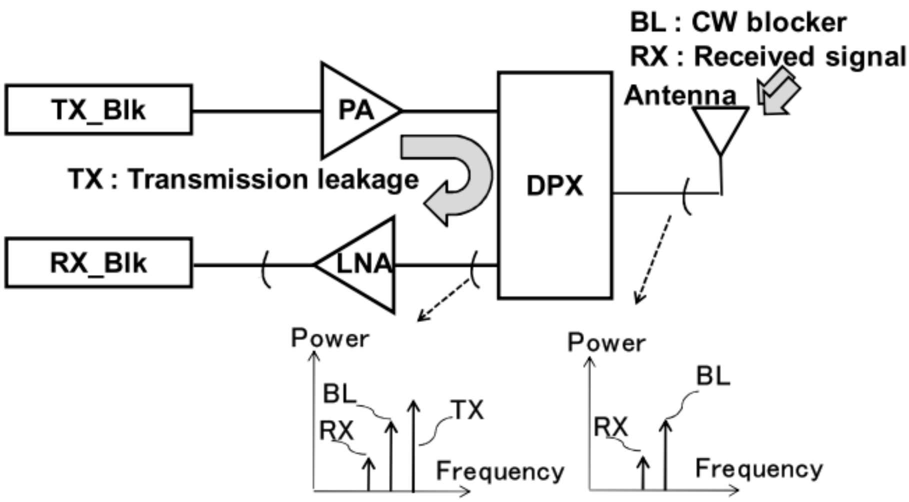

Therefore, eLNA can improve sensitivity and data rate simultaneously.

# Linearity and Sensitivity

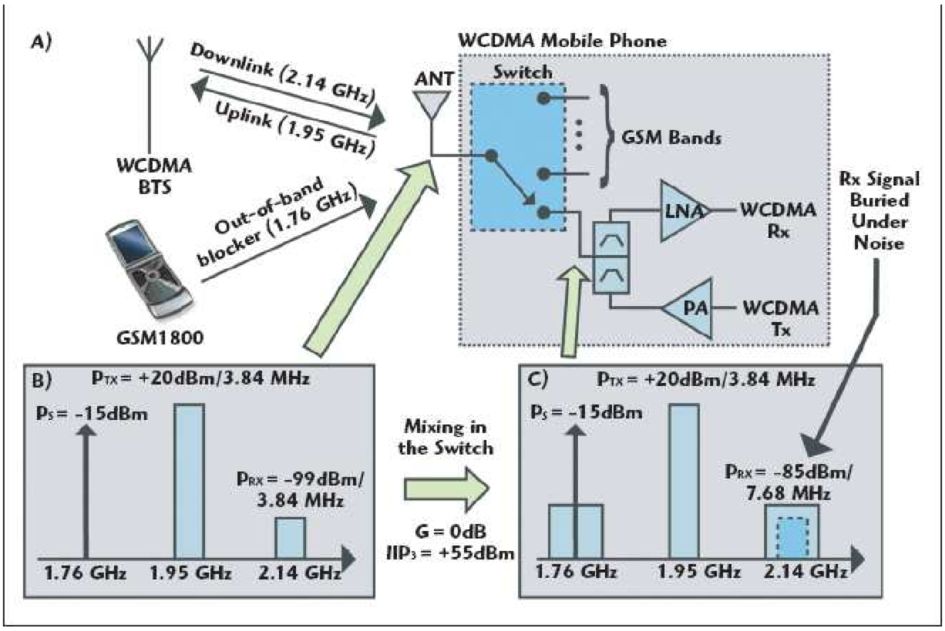
There is Tx leakage issue in WCDMA, CDMA, and FDD-LTE [7]:



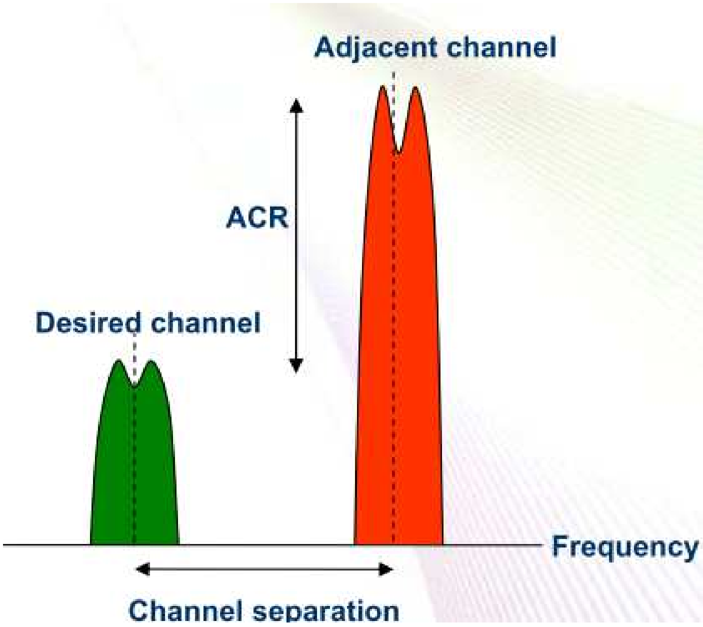

Therefore, there will be three signals in the receiver input : Blocker, Rx signal, and Tx signal [7]:



Because as long as two signals can produce IMD(Intermodulation).That is , if the IIP3 of receiver is not high enough, the strong Tx signal saturates receiver, which will be interfered by IMD easily. For example, Tx signal of WCDMA Band1 (1.95 GHz) and Tx signal of DCS 1800(1.76 GHZ) can produce IMD3, which will interfere Rx signal of WCDMA Band1(2*1.95 GHz – 1.76 GHz = 2.14 GHz ) [8].



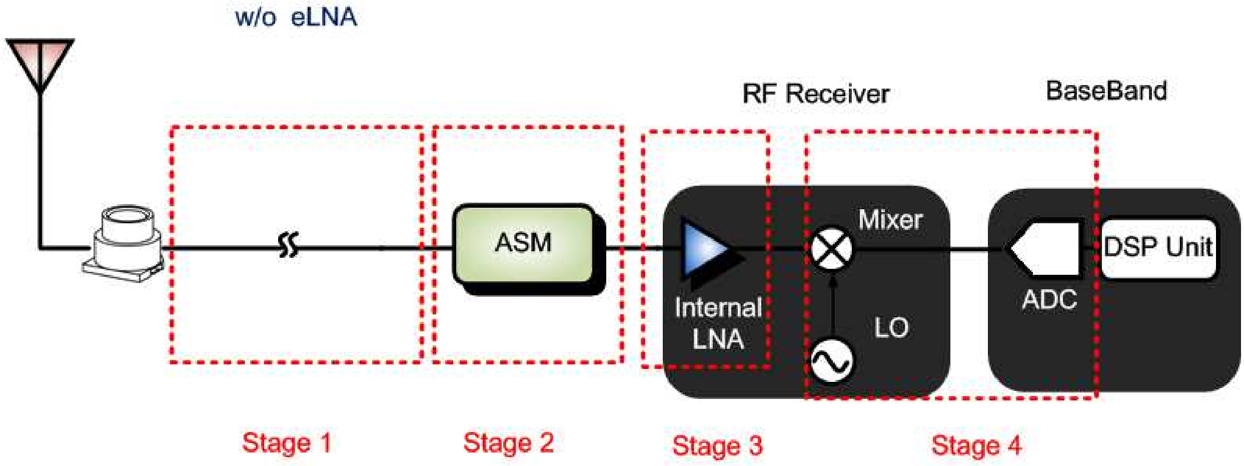
In addition, according to [9-11], the ACS (Adjacent Channel Selectivity) , or ACR (Adjacent Channel Rejection) depends on the IIP3 of receiver,




Therefore, we know that poor linearity will also lead to poor sensitivity and selectivity.

# For the eLNA gain, the more the better ?

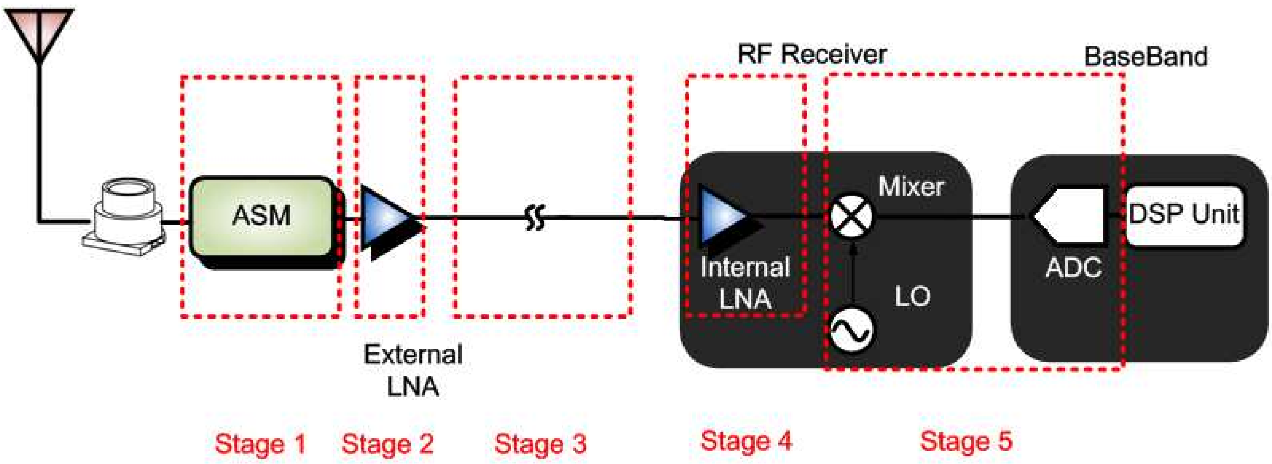
Without eLNA :




| | Trace | ASM | iLNA | Other |
|---|---|---|---|---|
| | Stage 1 | Stage 2 | Stage 3 | Stage 4 |
| Noise Factor | 2 | 1.26 | 1.22 | 2.51 |
| Gain (ratio) | 0.5 | 0.794 | 31.62 | 0.4 |
| Noise Figure (dB) | 3 | 1 | 0.85 | 4 |
| Gain (dB) | -3 | -1 | 15 | -4 |
| IIP3 | 10^10 | 10^8 | 3.162 | 0.028 |
| IIP3 (dBm) | 100 | 80 | 5 | -15.5 |

With eLNA :

w/ eLNA




| | ASM | eLNA | Trace | iLNA | Other |
|---|---|---|---|---|---|
| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 |
| Noise Factor | 1.26 | 1.22 | 2 | 1.22 | 2.51 |
| Gain (ratio) | 0.794 | 31.62 | 0.5 | 31.62 | 0.4 |
| Noise Figure (dB) | 1 | 0.85 | 3 | 0.85 | 4 |
| Gain (dB) | -1 | 15 | -3 | 15 | -4 |
| IIP3 | 10^8 | 3.162 | 10^10 | 3.162 | 0.028 |
| IIP3 (dBm) | 80 | 5 | 100 | 5 | -15.5 |

Let's compare the difference between w/o eLNA and w/ eLNA.

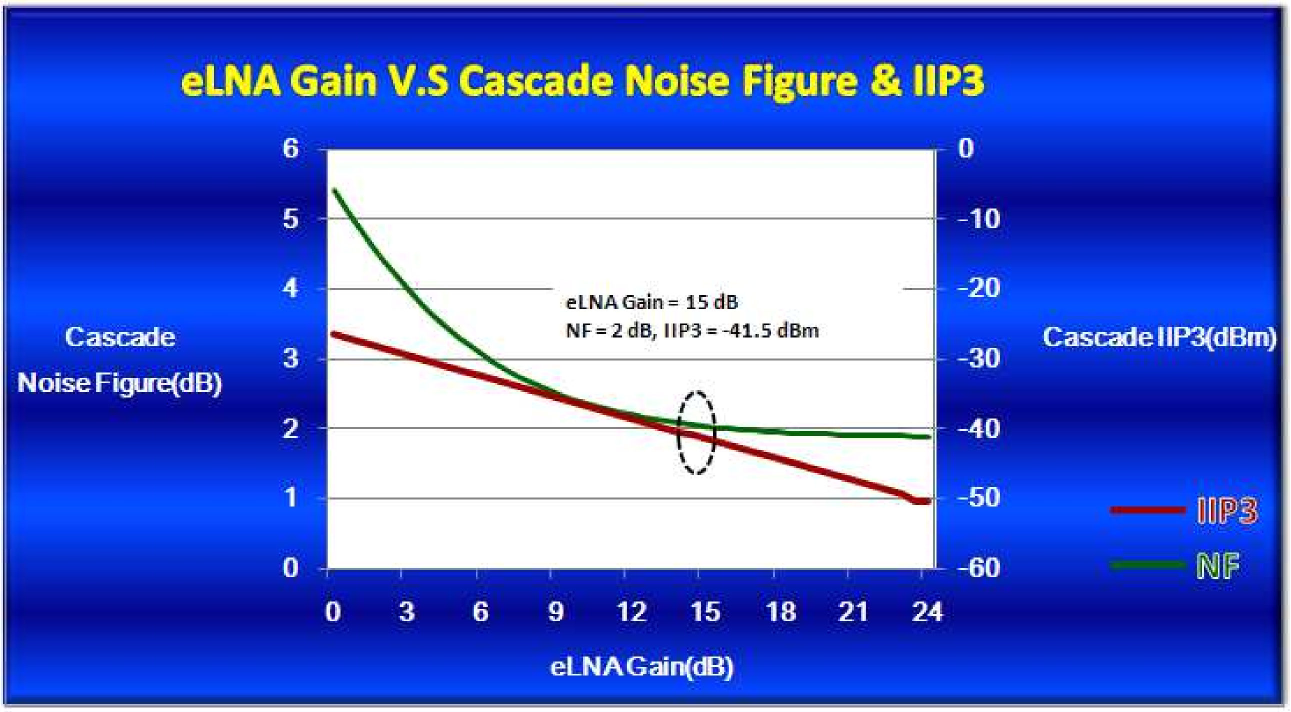
| | Without eLNA | With eLNA | Delta |
|---|---|---|---|
| NF (dB) | 5.04 | 2 | 3.04 |
| IIP3 (dBm) | -26.5 | -41.6 | -15.1 |

We observe that eLNA makes the cascade noise figure of receiver degrade, then improve the sensitivity, but the IIP3 also degrades. According to [3,12-13], we know that the IIP3 degration is due to eLNA gain.

According to cascade noise figure formula :

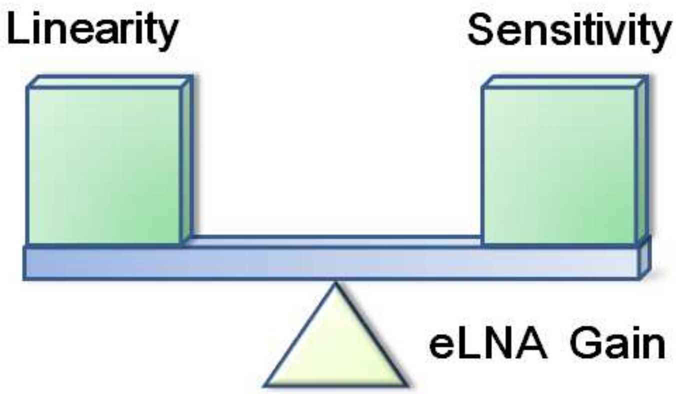
$$F_{total} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3} + \ldots$$

We know that the more eLNA gain, the less noise figure. However, let's plot the relationship between eLNA gain and noise figure, IIP3 :




We can observe that the ability of noise figure reduction from eLNA gain is limited. But, the IIP3 degration from eLNA gain is unlimited, Take the plot for example, when the eLNA gain is larger than 15 dB, the cascade noise figure is almost the same.

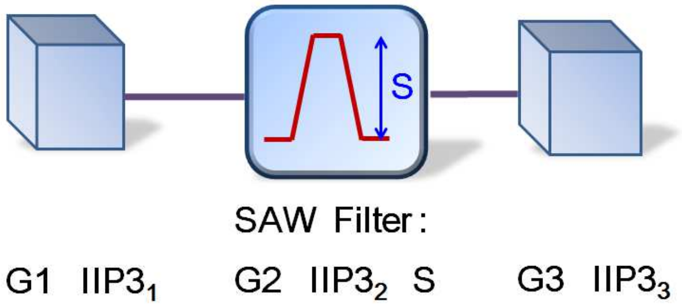
But, the IIP3 still degrades. And the IIP3 degration is inversely proportional to eLNA gain linearly. As the eLNA gain increases 1 dB, the cascade IIP3 also degrades 1 dB. From previous analysis, we already know that poor linearity will also lead to poor sensitivity. Therefore, the eLNA gain is the trade-off between linearity and sensitivity,




we should consider sensitivity and linearity simultaneously. The eLNA gain is neither the more the better nor the less the better. It should be the more exact the better.

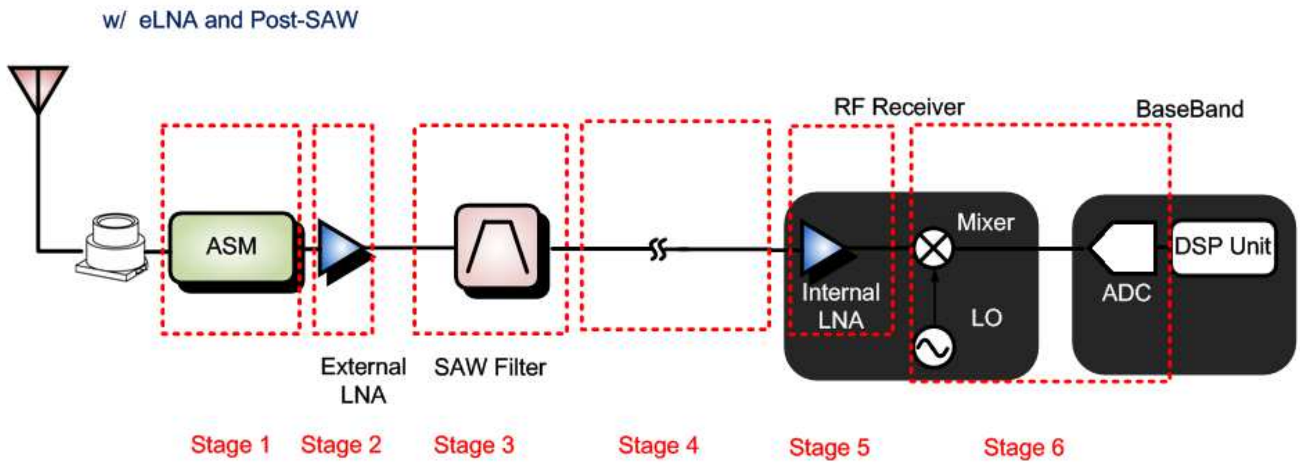
# SAW Filter and Linearity

We take the simple three stages circuits for example, if we add SAW filter, the IIP3 calculation is as following [14] :




$$Cascade\ IIP3 = \frac{1}{\frac{1}{IIP3_1} + \frac{G1}{IIP3_2} + \frac{G1G2}{IIP3_3 * S^{\frac{3}{2}}}}$$

Now, we add the SAW filter behind the eLNA, then calculate the cascade IIP3 :

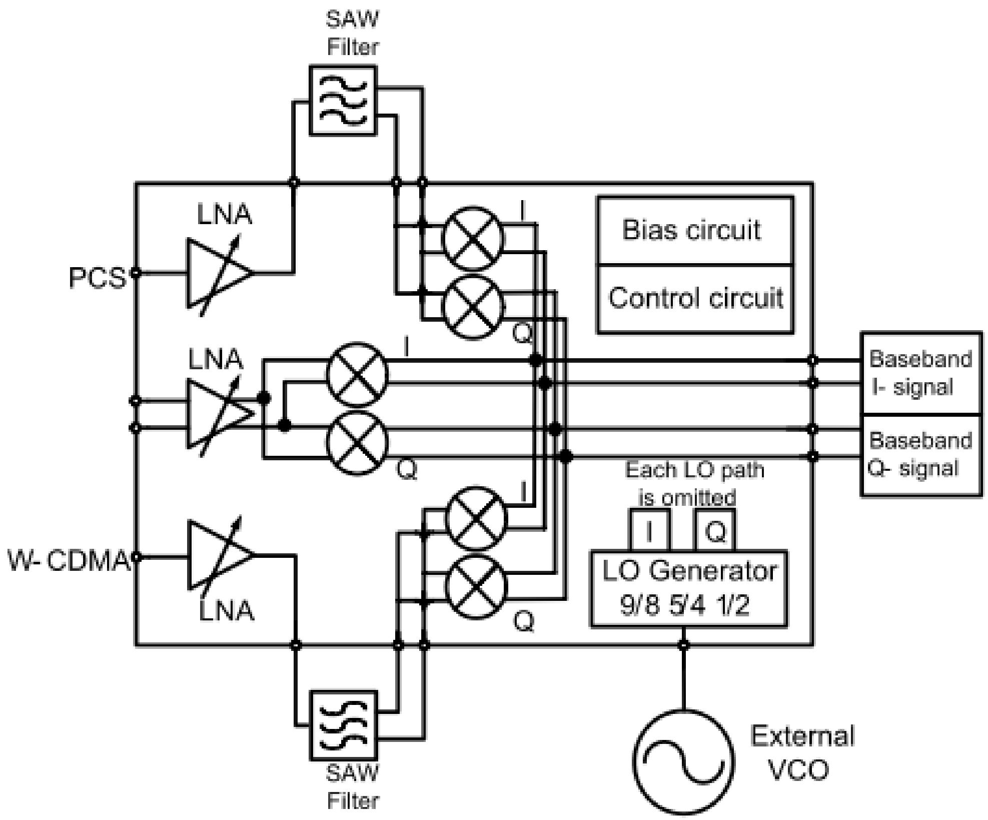


| | ASM | eLNA | SAW | Trace | iLNA | Other |
|---|---|---|---|---|---|---|
| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Stage 6 |
| IIP3 | 10^8 | 3.162 | 10^8 | 10^10 | 3.162 | 0.028 |
| Gain (ratio) | 0.794 | 31.62 | 0.63 | 0.5 | 31.62 | 0.4 |
| IIP3 (dBm) | 80 | 5 | 80 | 100 | 5 | -15.5 |
| Gain (dB) | -1 | 15 | -2 | -3 | 15 | -4 |
| Selectivity(ratio) | | | 10000 | | | |
| Selectivity(dB) | | | 40 | | | |

From the calculation, we know that the cascade IIP3 is 5.86 dBm. Besides, from previous cascade noise figure formula, we know that the eLNA pre-loss almost dominates the cascade noise figure. Because the SAW filter is behind the eLNA, the insertion loss of the SAW filter doesn't affect the cascade noise figure. Therefore, with eLNA, we compare the difference between with post-SAW and without post-SAW filter :

| | Without eLNA post-SAW filter | With eLNA post-SAW filter |
|---|---|---|
| NF (dB) | 5.04 | 5.04 |
| IIP3 (dBm) | -41.6 | 5.86 |

From the comparison, we know that the post-SAW can improve the receiver linearity, even better than the situation without eLNA (IIP3 = -26.5 dBm), but not degrade the sensitivity. Therefore, some receivers adopt the post-SAW design, the reason is also to consider the sensitivity and linearity simultaneously [15].



# Conclusion

Of course, the eLNA can improve the sensitivity, but also degrade the linearity. And poor linearity will also lead to poor sensitivity. Fortunately, we can use the post-SAW to consider the sensitivity and linearity simultaneously.

# Reference

[1] External GPS LNA Considerations, Qualcomm

[2] WTR1625L RF Transceiver and WFR1620 RF Receiver Design Guidelines/Training Slides, Qualcomm

[3] Improving Receiver Sensitivity with External LNA, Maxim

[4] Infineon's New LTE Low Noise Amplifiers Almost Double Smartphone Data Rates

[5] Single Band LTE LNA BGA7L1N6 Supporting Band-5 (869-894 MHz) Using 0201 Components, Infineon

[6] Guidelines for achieving best-in-class RX Diversity Performance in your Smartphone Applications

[7] A Highly Selective, Very Linear Low Noise Transconductance Amplifier Capable of Large-Signal Handling for Current-Mode Receivers Front-End

[8]Choosing the Right RF Switches for Smart Mobile Device Applications, Skyworks

[9] WTR4905 Wafer-level RF Transceiver Device Specification, Qualcomm

[10] RF RECEIVER REQUIREMENTS FOR 3G W-CDMA MOBILE EQUIPMENT

[11] RF Basics, RF for Non-RF Engineers, Texas Instruments

[12] Signal Chain Noise Figure Analysis, TEXAS INSTRUMENTS

[13] Understanding and Enhancing Sensitivity in Receivers for Wireless Applications, TEXAS INSTRUMENTS

[14] Use Selectivity to Improve Receiver Intercept Point, Maxim

[15] Circuits and Systems for Future Generations of Wireless Communications