# Wideband Low Noise Amplifier for Long Term Evolution Systems

Jelena Mišić, Vera Marković

*Abstract* – This paper introduces wideband low noise amplifier design for Long Term Evolution systems. The three-stage, cascade wideband low noise amplifier structure will be presented. The low noise amplifier (LNA) is design for uplink channels for LTE systems. The LNA is designed for LTE receiver front-end which operates in 700-1300 MHz frequency range, covering almost entire LTE uplink frequency band. Wide bandwidth performances are presented. The LNA provides gain above 30 dB and its noise figure is 1.2-1.7 dB. An input and output reflection coefficients are lower than -30dB over the whole frequency range

*Keywords* — long term evolution, low noise amplifier, wideband amplifier

## I. Introduction

In recent years, mobile communications systems have become the main type of communications in the world. There is a global need to communicate with anyone, at anytime and from anywhere, and only wireless mobile communications systems make that possible. Due to that the demands for new and improved services and commodities become higher.

The mobile communications systems are moving rapidly through a series of generations, starting (in early eighties of the twentieth century) from the first generation, which main characteristic is usage of analogue techniques for transmission. During the early nineties, the rapid increase in use of internet started at the same time as 2G digital systems came widespread used. The 2.5 generation was the first one that enabled the mobile Internet access, followed by 3G with further improvements in broadband data transmission. Both 2.5G and 3G mobile systems process/switch voice and data through two separate domains: circuit-switched (CS) for voice and packet-switched (PS) for data. Although 3G systems support TCP/IP traffic, they are not fully IP oriented. Considering the need for high speed internet services support in mobile communications system a new technology was necessary. This led next stage in mobile networks development, which are fully IP oriented [1].

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The Long Term Evolution System (LTE) defined by the *3rd Generation Partnership Project* (3GPP) in Release 8 provides users much faster data speeds than 3G is able to. Many consider that LTE should be labelled as 3.9G, and according to them the first “true 4G” is LTE Advanced, defined in Release 10. LTE and LTE advanced systems have a lot of advantages for both end users and mobile operators. End users could have better performances and higher number of services on their mobile devices, while mobile operators could improve their networks in order to provide wide bandwidth service with lower latency and higher level of mobility.

According to high LTE requirements, the interest in designing appropriate LTE devices has increased. Especially, the receiver part has come in the centre of attention and in recent years, a lot of LTE front-end have been designed.

There are a variety of amplifier topologies used in those receiver front-end blocks. A 2.3 GHz narrowband low noise amplifier is presented in [2]. It is designed for WiMax but it can be implemented in any system which works at mentioned frequency. Proposed LNA has very simple structure, it implements single stage common-gate topology and his features are: 15 dB gain and noise figure 1.1 dB. In [3] a LTE wideband low noise amplifier is presented with 38 dB gain and 4.5 dB noise figure. Both narrowband and wideband amplifiers employ source degeneration as noise cancelation technique. The same noise cancelation technique is used in [4] where a low power CMOS receiver front-end for LTE system is presented. Presented receiver has folded cascade topology and consists of wideband common-source low noise amplifier and mixer. The illustrated front-end operates from 2545-2700 MHz, which covers 7 frequency bands. This front-end achieves 8.89 dB gain and 8.25 dB noise figure.

Nowadays, the most used topology for low noise amplifiers is cascade topology for the reason of high gain and low noise figure [5], [6]. In [5] the cascade low noise amplifier with optimal noise figure, high gain and good input and output matching is designed. In the implemented cascade structure two inductors are used. The input inductor is used for input matching and noise reduction, and the output inductor is used for output matching and acceptable OIP3. In [6] two-stage low noise amplifier is presented. It consists of common-gate stage and common-source stage. Common-gate stage is employed as the input stage, and the common-source stage is employed as the output stage. The input stage provides low noise figure and good input matching, while the output stage provides high frequency gain and output power matching. By combining these two stages good wideband (0.4-10 GHz) features are achieved, power gain is around 12 dB, and noise figure is between 4.4-6.5 dB.

The design of a 0.7-2.7 GHz LTE low noise amplifier is given in [7], with 17.3 dB gain and 2 dB noise figure obtained. However, noise figure and gain are directly dependent, so it can be expected that with the increase of gain the noise figure will increase too, and vice versa.

In this paper, a LTE low noise amplifier with improved noise cancelation technique will be presented.

This paper is organized in five sections. In Section 2 the theoretical background of LTE is provided. In Section 3 the LTE receiver fundamentals are presented. In Section 4 LNA design and its performances are illustrated, and Section 5 contains summarized results and future research trends and developments.

## II. LTE Architecture

As already noted, the need for high speed internet and new services was the primary demand of new technology for mobile communications systems. However, that was not the only demand of the 4G system technology, there was also a need for more spectrum resources. Therefore, a wider spectrum and better spectrum efficiency have been necessary to achieve the requirements placed in front of the 4G systems.

With more spectrum coming into use there is a need to operate in huge number of different frequency bands, which can be different size and sometimes fragmented in spectrum. So, it was needed high spectrum flexibility with the possibility for a varying channel bandwidth.

The overall aim of providing a new radio-access technology is switching on packet-switched data only. In parallel to the development of new radio-access technology it was necessary to develop new network architecture, including both the radio access network and the core network.

The network architecture of LTE [8] is comprised of following three main components (Fig.1.):

- the user equipment (UE) - usually called end user,
- the Evolved Terrestrial Radio Access Network (E-UTRAN), and
- The Evolved Packet Core (EPC).

The E-UTRAN provides the radio communications between the end user and the Evolved Packet Core. The E-UTRAN consists of just one type component, the evolved base stations, called eNodeB or eNB (evolved NodeB). Each eNB is a base station that controls mobile users in one or more cells.

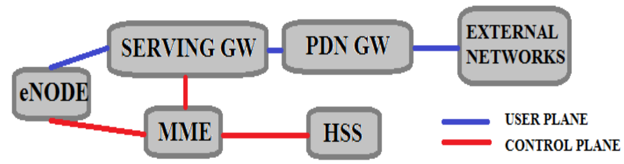



Fig. 1. The architecture of LTE network

The EPC was introduced by 3GPP in Release 8. The main idea was to develop a flat architecture and to separate the user data and the signaling. Thanks to that data split, the operators can dimension and adapt their network easily.

The key components of EPC are:

- Mobility Management Entity *(MME)* which manages session states and tracks a user across the network,
- Serving Gateway (S-gateway) which routes data packets through the access network,
- Packet Data Node Gateway (PGW) which acts as the interface between the LTE network and other packet data networks; manages quality of service (QoS), and provides deep packet inspection (DPI) and Policy and Charging Rules Function (PCRF).

The architecture of the EPC is organised in a way that the user equipment (UE) is connected to the EPC over Universal Terrestrial Radio Access Network (E-UTRAN) which is LTE access network. The EPC is connected to the external networks, which can include the IP Multimedia Core Network Subsystem (IMS).

The LTE radio access, E-UTRA is based on multiple access technique called Orthogonal Frequency Division Multiple Access (OFDMA) in the downlink, while the uplink uses Single Carrier Frequency Division Multiple Access (SC - FDMA). The basic idea of the OFDMA is that the total data stream is divided into a number of streams that are transmitted in parallel, using specific orthogonal frequency subcarriers. OFDM technique is extremely resistant to frequency selective fading, which was the biggest problem with wideband channels. Each of the sub-channels in LTE system is 15 kHz width and it is modulated with one of the conventional modulation: QPSK, 16QAM or 64QAM. The OFDM provides some additional benefits: provides access to frequency domain, flexible transmission bandwidth (1.4MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz), broadband/multicast transmission, and the possibility for carrier aggregation (introduced in Release 10), etc.

In the carrier aggregation solution, multiple LTE carriers can be transmitted in parallel to/from the same terminal. Thereby, wider bandwidth and correspondingly higher data rates are provided. Up to five components with

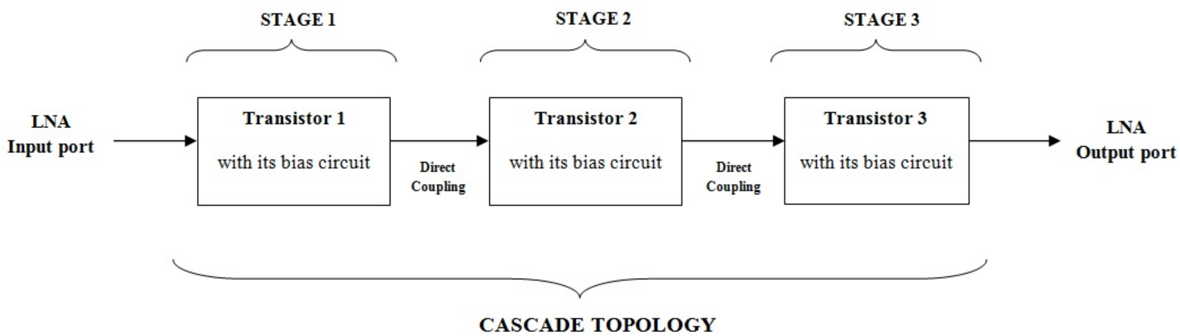



Fig. 2. Cascade topology

bandwidths up to 20 MHz can be aggregated, so overall transmission bandwidth can be up to 100 MHz. Aggregated component carriers do not need to be contiguous in the spectrum. With respect to the frequency location of the aggregated carriers, three different cases can be indentified:

1. intra-band, aggregation with frequency contiguous component carriers,
2. intra-band, aggregation with frequency non-contiguous component carriers, and
3. inter-band, aggregation with frequency non-contiguous carriers.

The possibility to aggregate non-contiguous component carriers allows operators to operate with a fragmented spectrum. Thereby mobile operators can provide high data rate services even though they do not possess a single wideband spectrum allocation.

## III. The LTE Receiver

Accordingly to the previously mentioned LTE performances, there are several basic requirements for LTE receiver [9]:

- high gain and low noise figure at the same time, but this two requirements often exclude each other, and some trade-offs should be managed.
- sufficient level of sensitivity, which represents the lowest level of the received signal which can be detected. Sensitivity level must be lower than expected level of the signal, otherwise the signal will not be detected.
- good selectivity, which is defined as the receiver ability to extract the desired signal in the presence of other signals that interfere with it. Due to increasing number of wireless service spectrum is becoming completely filled. Therefore, it is important that the receiver has the appropriate selectivity in order to fulfil certain frequency signal reception.
- good linearity, dynamic range, etc.

Low noise amplifiers are key components in the receiver of any communications system. Regarding to the very low level of receiving signal low noise amplifier should enhance the level of incident signal without introducing significant noise and distortion. As it well-known, the most important part in total noise factor of a receiver system is a noise factor of its first stage. Due to that low noise amplifier, as a first stage in receiver, must have a very low noise factor.

In the literature, various designs of the LNA can be found [2]-[7]. The main differences between them are LNA topology and active component in LNA.

## IV. LNA design

The goals in LNA design are to maximise its gain and minimise its noise figure with sufficient linearity and impedance matching. It should be highlighted that it is impossible to design low noise amplifier with peak performances for all criteria, because some of them exclude each other, so some trade-offs must be made.

In order to meet the key demands for LTE receiver characteristics, a LNA is designed starting of the following: LNA performances that should be met are the noise figure less than 2 dB, and gain above 20 dB through the whole range which is of interest. Also, good input and output impedance matching should be achieved, the parameters $S_{11}$ and $S_{22}$ must be lower than 30 dB.

The features of low noise amplifier are limited by properties of its active device. Due to that, the selection of active device with correspond parameters, is crucial step for reaching the target LNA specifications. Many active components can be suitable for LNA, as for instance the Bipolar Junction Transistor (BJT), the Heterojunction Bipolar Transistor (HBT), the Metal Epitaxial Semiconductor Field Effect Transistor (MESFET), the High Electron Mobility Transistor (HEMT), etc. Although the MESFETs technology became widely spread, the BJT still present the transistor of choice for many amplifiers because of their greater linearity and ease of manufacture.

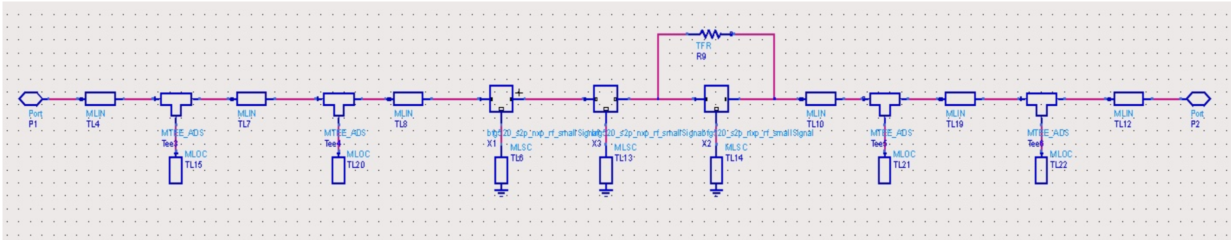
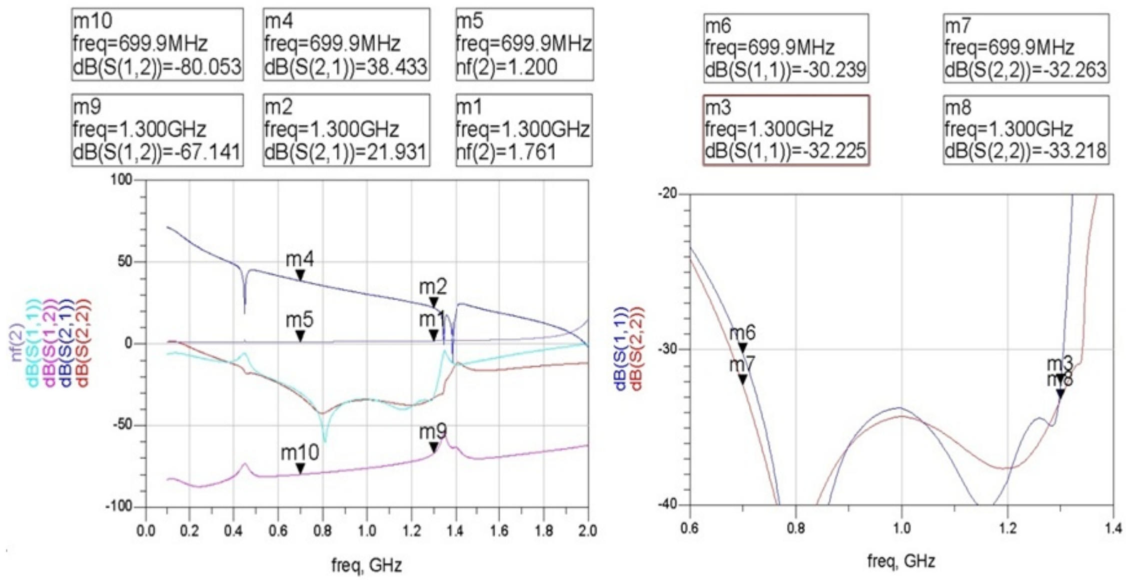


Fig 3. The low noise amplifier circuit




(a) (b)

Fig 4. (a) *S* parameters and noise figure over the frequency range 0-2 GHz
(b) parameters $S_{11}$ and $S_{22}$ over the frequency range 0.6-1.4 GHz

Due to the large voltage gain, very low cost and high robustness of the BJTs, it was decided to design the LNA with BJT transistors. Also, the BJT transistor is very easy to bias. The NXP bfg520 BJT transistor [10] is chosen to be used in this LNA design.

The design of the amplifier is performed within a software environment Advanced Design System (ADS) from Agilent Technologies Company.

Generally, there are a large number of different possible LNA topologies involving single-transistor topology, cascode-based topology, and different types of two (or more)-stage topology, called cascade topology. However, the topology which performances meet the best the performances of LNA needed for a particular application, should be chosen as the most suitable.

If amplification of single stage is not enough for a particular application, cascode or cascade topologies can be implemented. The cascode structure consists of certain number of active components. It could be realised as simple cascode or cascode with some variations. The cascade topology with more than one transistor is often used to achieve an overall higher gain. It could be simple cascade topology or cascade topology with some implementation, like a noise-cancelation cascade topology.

Due to cascade topology high gain, it was decided to use this type of amplifier topology in design, Fig. 2. Three amplifiers are cascaded together, whereby the common-emitter cascade arrangement is chosen because it is quite easy for realisation and implementation and high gain level that can be achieved. There are a variety of cascade amplifier coupling. Due to simple circuit arrangement and quite inexpensive characteristic direct coupling is implemented in design. With direct coupling, the output of one transistor is connected directly to the input of the next transistor.

In order to make amplifier more stable, the negative feedback is used. The feedback is implemented by a thin film resistor (TFR) component. TFR represents a resistor designed using a thin film conductor with a resistance of 50 Ohm/square. The conductor width and length were chosen to achieve the most suitable resistance for our device. TFR component width and length were also included in simulation and optimization process. However, negative feedback reduces gain, but the three amplifier stages provide enough gain and relatively large amounts of feedback may be used without sacrificing gain.

The emitter degeneration technique is used in this design as a noise cancelation technique. This technique implies element insertion between the emitter and ground. Usually, some lumped component is employed in this noise cancelation technique. Due to fact that microstrip lines are very commonly used and widespread, it was decided in this work to realise source degeneration employing microstrip lines. Three microstrip lines of certain dimensions, one per transistor, were placed between transistor emitters and ground.

In order to reduce losses in amplifier circuit appropriate impedance matching is necessary at both ports. The matching networks are realised by microstrip lines with certain dimensions. The microstrip substrate is Rogers TMM 10i Laminates [11]. The most appropriate lengths and widths of microstrip lines were determined in the process of optimization in ADS. During the optimization lengths and widths of lines were changed while the parameters of the substrate were held constant. Also, during the optimization process bias positions of transitors had not be changed, only dimensions of microstrip elements were optimized. The proposed amplifier circuit is presented in Fig.3.

Some simulation results for the designed LNA after optimization, obtained using the same software environment ADS, are presented in Fig.4.

The Fig. 4 shows the results of $S$ parameter analysis of the designed amplifier. In Fig. 4 all $S$ parameters and noise figure are displayed at 700-1300 MHz frequency band.

The graph in Fig. 4(a) shows the values of the $S$ parameters and the noise figure level in the range 0-2 GHz. As it can be noticed form graph in Fig. 4(a), the $S_{11}$ and $S_{22}$ lines are very close and in order to have a better view on their values, they are displayed separately on the graph in Fig. 4 (b) in narrower frequency range, 600 MHz - 1400 MHz. That frequency band is still wider than frequency band of interest. On both graphs markers are positioned on the boundaries of frequency range in order to give a better overview of the parameter values on the cut-off frequencies (700 MHz and 1300 MHz).

As it is displayed in Fig. 4, excellent results are achieved. All $S$ parameters meet essential criteria over the specified frequency range and it can be concluded that satisfactory performances are obtained. Parameter $S_{21}$ is above 21 dB over the whole frequency range which is of interest. Moreover, it is greater than 30 dB in 700-1000 MHz frequency band. Impedance matching is also good at both ports, $S_{11}$ and $S_{22}$ have value lower than -30dB. The amplifier isolation is also great, the parameter $S_{12}$ value is lower than -50 dB. The average noise figure of LNA is around 1.5 dB which is excellent for one three-stage wideband amplifier. Also, it was shown that source degeneration technique can be implemented by microstrip lines instead of lumped elements.

## V. CONCLUSION

A three-stage wideband LNA intended for the LTE system has been proposed. The common-emitter topology is implemented in each stage of amplifier. The emitter degeneration technique with microstrip lines is employed as noise-cancelling technique. Although, each of transistors has noise figure around 1 dB, a great overall noise figure is achieved. An ultra-high gain is managed, even though emitter degeneration technique is implemented. Also, wideband input and output impedance matching are provided. It can be concluded that proposed amplifier is completely appropriate for the current LTE requirements.

The LTE system expects further improvements. Accordingly, all devices intended to LTE systems must enhance their performances. In the light of that trend, further research will be directed to developing low noise amplifiers and other devices of the LTE receiver front-end with improved performances including better linearity, simplicity, low cost and higher energy efficiency.

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