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LNA for Biomedical Applications

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Abstract: *LNA, which stands for low noise amplifier, as the name suggests, is used for amplifying weak and very low power signals. LNA is an important part of transceiver system. It is the fundamental building block of communication systems. LNA is used in industrial, scientific and medical bands (ISM). Radios, cellular telephones, GPS receiver, and satellite communication, etc. employ LNA. In this paper, we have discussed about various topologies of LNA and their mode of implementation in biomedical applications. Biomedical applications involve the use of LNA in neural applications, biosensors, ECG applications, etc. Comparison of the different topologies in terms of power consumption, chip area and mode of implementation has been done.*

Keywords- LNA, Biomedical applications, Neural applications, ECG, Biosensors, etc.

I. Introduction

LNA is an amplifier that amplifies a very low power signal without degrading its signal to noise ratio (SNR). An amplifier amplifies both the signal and the noise, which is present at its input but the low noise amplifier, amplifies the signal present at its input but adds very little noise to the signal. The purpose of LNA is to get larger gain with very low noise figure. Also, we desire low power consumption, small chip area, low cost and good input and output matching for the LNA used in RF communication. For example, an outdoor antenna is connected to the receiver end with the help of transmission line called as feed line. During the transmission, it causes a loss of around 3dB which can be compensated by placing LNA close to the receiver end, which provides sufficient gain to reduce the losses.

II. LNA for Biomedical Applications

In biomedical applications, we encounter very weak signals. For the amplification of very weak signals, especially in biomedical applications, LNA is used. In [1], LNA with cascade inductor with degeneration topology has been used, which provides higher gain and low noise figure. LNA in biomedical applications requires extremely low power consumption as well as small size. LNAs designed using inductor loaded topology, are found to be less favourable for biomedical implants as they are bigger in size. Therefore in [2], LNA was designed using g_m boost technique having input impedance of 600Ω. And the current obtained was below 500µA for ultra–low power design. This was implemented on 130nm IBM technology and simulated. The LNA implemented using common gate (CG) topology attained less sensitivity and drastically reduced power consumption and resistance. The federal commission introduced medical radio communication for providing secure, un-scattered health monitoring in homes and hospitals. The operating range for this application is 401-406 MHz. This is done to provide continuous communication for both implantable and wearable medical devices. The RF front –end was designed using balun LNA topology in UMC 0.18µm CMOS technology. This was configured by stacking power phase splitter on top of inductively degenerated common source topology. It attained a gain of 19dB and consumed 280µA current from 1V supply.

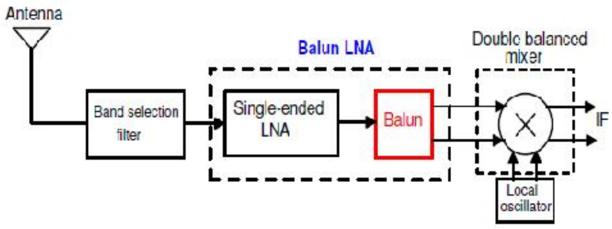

Fig.1: Receiver with balun LNA (reproduced from [2])

In [3], a wireless transceiver system was implemented using LNA for developing of network

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system which functions as a link budget for low power design. The low power system designed so will reduce a lot of power consumption but occupies larger area and results in installation problem, therefore transceiver system so designed was installed at 60GHz frequency. WSN is configured in indoor environment separated by a 10m distance. Signal bandwidth so obtained depends upon sample rate and resolution. WSN operates by sending biomedical signal from sensor node; and the signal are merged by MCU and are further converted by ADC and transmitted through 2.4 GHz band to the collecting point tuned at 60GHz.

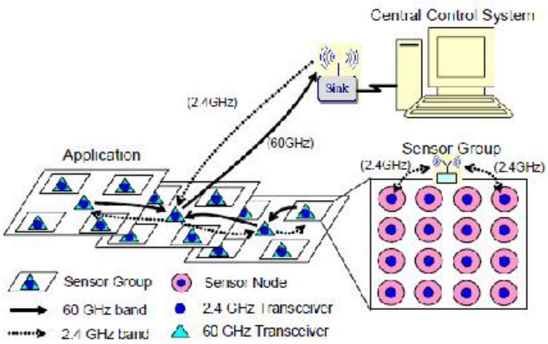

Fig.2: Hierarchical architecture of WSN system (reproduced from [3])

Use of LNA in Neural Applications

Neural signals in biomedical applications deal with the study of and understanding of brain function and its therapeutic and prosthetic applications. Neural interfacing consists of large number of channels for the study of neurons for specific brain microcircuits. It entirely deals with important parameters like power consumption, noise performance and CMRR. The Na^+/K^+ are powered by the ATP molecules which are the main energy molecules in animal cells. Whenever ionic channel becomes activated electrically, biochemically or through other mechanism, depolarization caused is generally the result of voltage sensitivity, causing the channel containing Na^+ to open first which causes the influx of positive charges across the cell, causing the potential to increase rapidly. However, balance is obtained when after a while K^+ channel is opened, which causes the influx of ions across the cell membrane.

In [4], the most common topology used for implementing low-noise amplifier are OTAs which are implemented using two stage op-amp and current mirror OTA. The folded cascade combination when compared to differential mode has larger swing margin and phase margin. Chae.M.et.al [7] implemented a self biased OTA which attained a gain of 40.5dB, NEF of 4.5 and a power consumption of 12.5µw. In [5], for low power application in biomedical domain, the wireless medical telemetry requires a portable device which can operate at a low supply voltage using a battery or with the help of energy source. Super –regenerative RF receiver is designed keeping this configuration in mind. In a non-coherent front end RF receiver, the LNA and energy detector are crucial designing elements of the module. For ON-OFF keying, RF envelope detector requires a high precise local oscillator for which receiver is required to have phase locked loop but this configuration increases power consumption. However, for demodulating at the receiver, RF input signal is sent to mixer which converts it to a baseband signal. A Gilbert Cell has been used in this work; such circuit offers high conversion gain and port to port isolation; therefore it is implemented using bipolar or CMOS simulation process.

LNA designed using current-reuse technique consumes more power so cascode topology is used but since it is inefficient at low supply voltage, so folded topology is used. For low supply voltage and low power consumption, a current reused two stage common source topology is proposed for RF front end amplifiers.

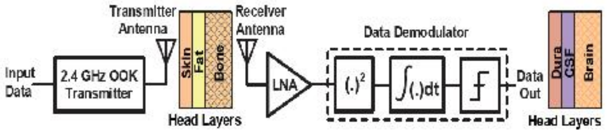

Fig. 3:: Conceptual block diagram of wireless link including transmitter, LNA , head tissue layer ,OOK data detector (reproduced from [5])

The above is a low voltage, low power 2.4 GHz CMOS OOK receiver; that includes modified current reuse two common source LNA topology to provide enhanced gain and noise figure. After simulation, the digits '0' and '1' are obtained at a time instant of 10ns. This means receiver successfully recovers OOK data at 100Mbps.

The two noises which dominates at lower frequency are thermal and flicker noise; therefore in [6] EKV model is used for biasing current and for reducing flicker noise. PMOS input transistors are used with

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large gate area and they are operated in weak inversion mode. Using such technique, the power consumed by the circuit is found to be 15.17µW. Measurement of very weak neural signal ranging between 0.5-5mV and frequency from 100Hz to 7 KHz is necessary for clinical and neuro-prosthetic applications; and also for neuroscience research. PMOS acts here as input for minimizing flicker noise.

The Input noise power density is given by

$$E_n^2 = \frac{8kT\gamma}{g_{m1}} + 8kT\gamma\left(\frac{g_{m5}}{g_{m1}}\right)^2 + \frac{2K_p^{1/f}}{C_{ox}W_1L_1f} + \frac{2K_n^{1/f}}{C_{ox}W_5L_5f}\left(\frac{g_{m5}}{g_{m1}}\right)^2$$

We can approximate:

$$g_{m1} \gg g_{m5,}$$

And thus,

$$\left(\frac{W}{L}\right)_1 \gg \left(\frac{W}{L}\right)_5$$

which gives noise power density as:

$$E_n^2 = \frac{8kT\gamma}{g_{m1}} + \frac{2K_p^{1/f}}{C_{ox}W_1L_1f}$$

The noise efficiency factor is obtained by:

$$NEF = Vrms\sqrt{\frac{2I_{tot}}{\pi U_T 4kT.\,BW}}$$

where Vrms is the input noise voltage and I_{tot} is the total current And BW is the amplifier bandwidth.

On comparison, we observe that the neural amplifier implemented using OOK modulation scheme results in low power consumption of 7mW.

Use of LNA in Biosensors Applications

Biosensors are analytical devices that detect the analyte (chemical species) and combines a biological component with physicochemical detector. The sensitive biological elements consists of tissue, microorganism, cell receptors, etc). These are made to interact with analyte under study. The transducer or the detection elements consists of optical, piezoelectric and electrochemical sensors that transform the signals after interaction with analyte, to another form, which can be measured and analysed. The increasing demands for the biological information in medical diagnostics, healthcare, etc has resulted in tremendous interest in biological sensors.

In [13], m-health (mobile computing , medical sensors and communication technologies) is considered wherein an increasing number of biosensors are worn and implanted in an individual for monitoring and diagonisis of diseases. The interconnection of biosensors inside the single human body produces a system called as a body area sensor network (BASN). The BASN performs two functions: (i)The passive function of transmitting the data for processing; (ii)To avail data to the biosensors, which are present at the same node inside the human body and communicate through a secure channel. The BASN identifies the individual based on biometric or identifying individual on pyshcological and behavioural characterstics. In [18], several systems focus on providing physical aspect of a person at the expense of emotional aspects. However,the negative emotions can lead to social and mental health problem. To cope with the negative emotions, a system has been designed that focuses on emotional aspects. The system has been designed using an AR (augmented reality), using cognitive behavioral therapy, providing 3-D virtual world. The system can interact with the help of kinect which interacts freely with the virtual world. Sensors measure biological signals like EEG and ECG to detect and analyse the emotions of the user.

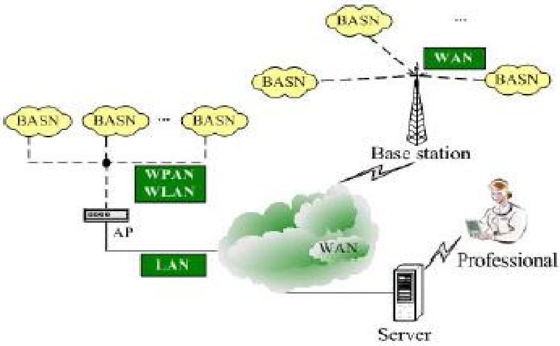

Fig.4: A BASN combined health model [reproduced from 16]

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In [14], the WBSN plays an important role in health care monitoring system. In this, each wireless sensor network receives the packets from the other sensor node and selects the adjacent sensor node for the trnasmitting of data, depending upon the header containing the address of the adjacent node. The WBSN is further seperated in communication and control path for biomedical applications. A communication cycle which is constructed also synchronises the whole WBSN system. The control system works by adding control signals which add the controllability and scheduling to the architecture.

Table 1:LNA in Biosensor Applications

S.No.	[14]	[15]	[16]
Implementation	TSMC 0.18 µm	0.5µm CMOS	0.7µm CMOS
Chip size	-	2.5mm^2	4.5mm^2
Power consumption	1440µW	-	-
Supply (V)	1.8	2.7-5.5	2.5-5.5
Current (µA)	800	130µA	75µA

Use of LNA in ECG Applications

Since we know that the biomedical signals are very weak signals, the measurement of ECG signals involves the accuracy and reproducibility. The ECG signals are generally recorded during ambulatory or strenous conditions. The resultant signals get affected by noise, for which signal processing is applied. The ECG signals are sometimes recorded for longer duration of time. For e.g. in case of cardiac problems like irregular heart rhytm, data recording is huge and requires extra space, therefore extra space is required. Therefore, it needs to be compressed both at the receiver and transmitter end, for transmission through public telephonic network. Another example is contraction of muscles that results in overlaping of ECG and muscle noise, therefore filtering becomes difficult.

After receving of ECG signals, signal processing is done for quantifying heart rhytm and heartbeat morphological properties. In [8], the authors report the use of sensor systems combined with wireless protocol for data communication with capacitive ECG sensing and processing. The system uses a ANT protocol and a low data rate wireless module to reduce power consumption and chip area. The entire design is integrated in a cotton T-shirt, together having a signal processing and two layer standard printed circuit board design technology. The entire system is found to have small size and thus, occupies low area and has low power consumption. The ECG signal acquired is amplified, filtered , digitized and transmitted to the differential amplifier. The amplifier diffrentiates the signal and sends it to ADC block. Unwanted frequency is removed by low, high and notch filters used at 60GHz frequency and it improves the SNR. The processed signal is then digitised into small packets and wirelessly transmitted to the main module. In [9], bio signals are acquired using nyquist rate analog –to-digital conversion without exploiting the bio signals characterstics. A fully integrated low power CS compressed signal at analog front end acts as a ECG sensor). Key biosignals have a small bandwidth and dynamic range (40-70dB). The basic circuit consists of analog front end with signal conditioning and a Nyquist analog to digital converter. The encoder receives a conditioned biosignal from LNA and compression of N input samples results in M output samples which are digitised and transmitted. The ADC and RF are made to operate at nyquist rate and since a compression factor N/M is greater then 1, the signal is downconverted into the output y(t).

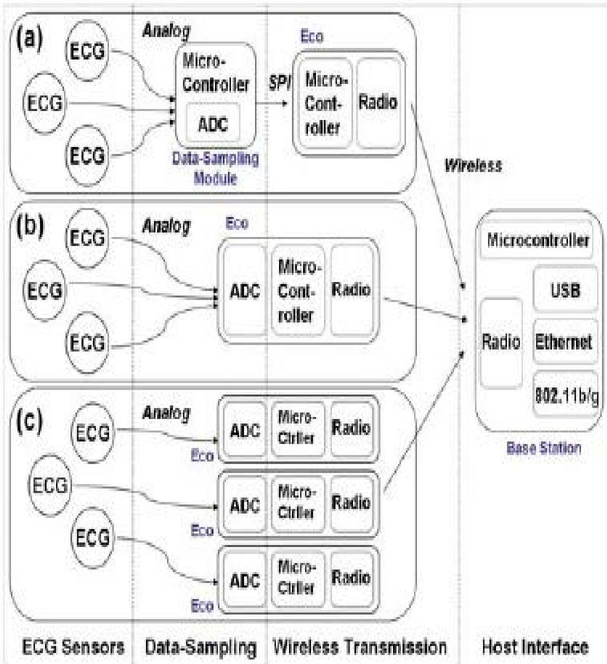

Fig.5: System architecture of ECG monitoring system [reproduced from 13]

Table 2: LNA in ECG Applications

S.No.	[11]	[12]	[13]	[9]
Technology	Using SAC and QRS detection	Capacitive sensing	Ultra low power	Nyquist rate
Implementation	On body	On cloth	Wire-less	0.13µm CMOS
Power Consumption	9.6µW	30µW	1mW	1.8µW
Area	5.74 mm^2	-	57 mm^2	6 mm^2

III. Conclusion and Future Scope

Biomedical engineering involves the knowledge of medicine and biology for health care applications. In this paper, use of LNA for biomedical applications like neural applications, biosensors and ECG is discussed. The other applications of biomedical engineering include EEG, EKG, PPG, echo normal(for chest pain), etc. which are yet to be discussed.

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