AN EXTENSIVE REVIEW ON: LOW NOISE AMPLIFIER FOR MILLIMETER AND RADIO FREQUENCY WAVES

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Graphical abstract
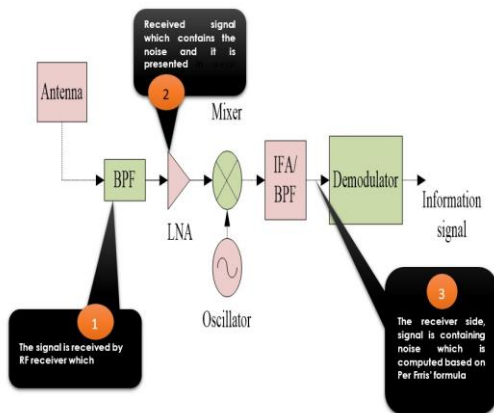
Abstract

In today's world, radio receiver system is a prevailing wireless technology in that the major part is Low Noise Amplifier (LNA) which widely used to improve weak signals in many applications with millimeter and radio frequency waves such as optical communication, multimode transceivers and measurement instrumentations. The real drawbacks of LNA is that it fails to maintain specific properties in critical conditions like as minimum power consumption, provide low noise figure, input matching and linearity. Additionally, promoted by various application demands, design methods and control methods must require to improve performance of LNA. The performance of LNA can be improved by adding extra components in basic circuit by proper arrangement for millimeter and radio frequency waves. The review paper provides information about design methodology, optimization techniques and control techniques. The different design of LNA is reviewed and analyzed such as 3-stage near-mm Wave LNA, 5-stage near-mm Wave LNA, common-gate amplifier, shunt-feedback amplifier, Resistor-terminated common-source amplifier, Traditional inductor-less amplifiers, cascode connection and double common source. This review paper also provides the information about design circuit diagram. The performance improvement of LNA can be achieved with the help of different techniques and our review based on optimization and control techniques with parameter tuning. Finally, the direction for the future study is presented based on review analysis of LNA.

Keywords: LNA, gain, optimization, control techniques, design analysis

1.0 INTRODUCTION

Recently, LNA design has become an inspiring environment, especially for low power applications. A low noise amplifier (LNA) is capable of amplifying the very weak signals receives from the antenna with adding extra noise [1]. LNAs have different advantages, such as low voltage standing ratio (VSWR), minimizing noise figure, high power gain, good stability, and proper impedance matching. LNA can be found in a variety of applications which include Industrial, Scientific, and Medical (ISM) band radios, transponders, mobile phones, GPS reception, and radio wireless local area networks [2]. An LNA is introduced initiated in the RF receiver. Especially in communication systems, it is considered as a basic building block.

In receiver area of the device, the LNA is an important one because it is serves as an amplifier for electronically amplifying the received signals and it is already placed in front of the receiver [3]. In addition, the important process of the LNA is to increase the low level signal. This amplification process can be analyzed without addition of noise to attain the mandatory signal to noise ratio from the lowest signal level [4]. Similarly, highest signal level condition, the receiver receives the signal and provides amplification first. The basic circuit design of Radio frequency (RF) receiver with LNA is illustrated in Figure 1.
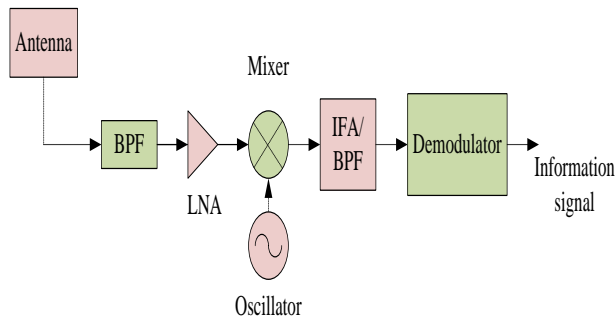

Figure 1 Basic Building Block of RF-LNA [1]

From the Figure 1, at initial condition the signal is received by RF receiver which sends the signal to band pass filter (BPF). The signal is received with the consideration of antenna system after that which forward to LNA. The LNA get the received signal which contains the noise and it is presented in weak condition [5]. The initial condition of receiver contains few different stages which analysis with formula to compute noise figure (NF). The LNA is a main important electronics device to reduce the noise from received signal by amplifying the signal through increase of gain in signal under subsequent stages [6]. Though, LNA is created itself which inserted into the receiver side signal. Therefore, it is required for an LNA to increase the reference signal power by adding as distortion and low noise as possible, getting required information from received signal by the use of LNA in subsequent stages [7].

2.0 REVIEW BASED ON MM-WAVE AND RADIO FREQUENCY WAVES

The LNA can be used for many different applications, including medical, wireless communication systems. The main usage of LNA is the reduction of noise and increasing the low-power signals into high-power signals. In particular, with a lot of radio frequency wave and millimeter-wave (mmWave) applications in the present telecommunication devices due to this wideband circuits have been given much consideration due to their robust versatility and applicability [8]. To meet the applications with mm Wave and radio frequency waves in the issues of noise

behavior and low power signals which should be reduced with the help of LNAThis entry was posted on July 8, 2010. It is able to increase the low power signals into high power signals with reduction of noise [9]. The different design must be developed related on applications in the two different waves of mm Wave and radio frequency waves. The existing design of LNA amplifier has been analyzed specially in mm Wave and radio frequency waves with different applications. Some of the research papers related to mm Wave and radio frequency waves are reviewed in following sections.

2.1 Design of LNA Amplifier for mm Wave

Millimeter wave (mm Wave) has recently attracted large research interest in different domain applications especially in communication systems. Since communication systems with mm Wave, large available bandwidth can potentially lead to rates of multiple Gbps (gigabit per second) per user [10]. The mm Wave can be utilized in stationary conditions like as backhaul or indoor hotspots which most challenging task to utilize mm Wave in mobile networks. Difficult condition can be created due to moving condition of receiver and transmitter nodes [11], channels (i.e., structure is complicated) and also coordination between multiple nodes (i.e. complicated) [12].

LNA works on low power signals in mobile network. The mm Wave can be used in massive multiple input multiple output (MIMO) in communication arrangements [13] for increasing data rate based on availability of wide bandwidth in addition of more no of antennas in small array space. [14] Author designed LNA which enable the best power transfer in receiver signals of antenna. The RF signals are generated with the consideration of photo-detector related to required load impedance within range of frequency; the designed LNA is illustrated in Figure 2.
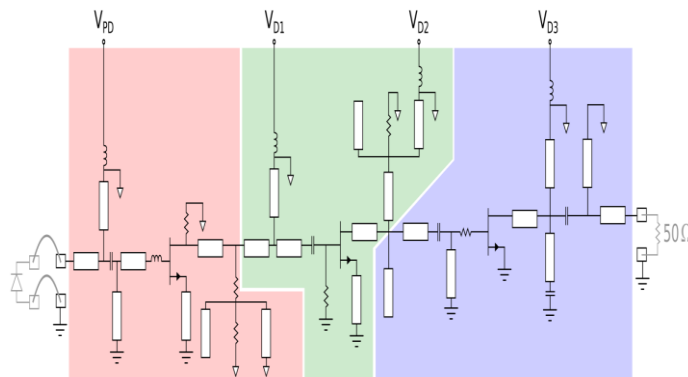

Figure 2 Structure of 3 stages mm Wave LNA [13]

The LNA complete design of the LNA is contains of three amplification stages which can be biasing independently. The LNA can be used to amplify the

signals in photo-detector. Various methods are developed to give amplification in the output side of photo-detector which is attained with the use of LNA. The three stages LNA have ability towards deliver better optimal power transmission as of the received side signal generated in photo-detector related on load impedance in frequency range [15]. The LNA design with narrowband should allow for a best trade-off among increasing of gain level and decreasing noise level in received side it works under larger frequency also. When add wire bond inductance on LNA which produce increasing advantages for increasing gain level and decreasing noise level. In the narrowband structure, the LNA operates in best performance which acts as friendly movement by increasing gain compared with conventional amplifiers [16]. The 88.5–110 GHz CMOS based LNA can be designed to meet mm Wave imaging applications [17]. The developed amplifier consists of five different stages in the cascode topology with T-output matching and L-type input matching. From five stage of design, the peak signals were distributing the peak gains at initial four stages with two various frequency points. Related on distributing peak gains, LNA attains flat gain response over a wide bandwidth. The LNA performance measurements results provide amplifier features a minimum noise figure is 7.72 dB, 21.5 GHz - 3dB and maximum peak gain 104GHz - 16.7dB. Additionally, LNA has taken a compact core place of 0.05 mm^2 and taken 48.6mW. The pictorial design of LNA amplifier related to mm Wave imaging applications is presented in Figure 3.
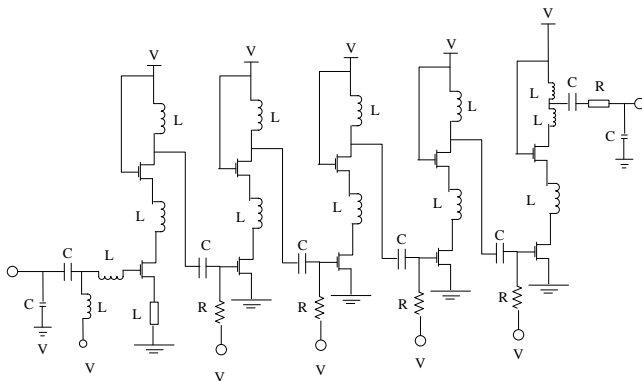
Figure 3 Overall schematic of the 5-stage -mm Wave LNA [17]

The above five stages mm Wave LNA is mainly used to amplify the low signals into high signals with high gain specially in imaging applications.LNA is mainly connected in receiver side, for high performance mm-Wave imaging receivers which can be mostly important to attain a low resolvable temperature gain. However, with the utilization of the LNA design in RF, high gain and wide bandwidth can be achieved related to small variations. Atiyeh Karimlou *et al.* [18] have designed inductor less Sub-mW differential Common-Gate Low Noise Amplifier (CGLNA) for ZigBeestandard.The design circuit have the

advantages of dual capacitive cross coupling (DCCC) and shunt feedback for reducing power consumption in addition the bandwidth extension capacitors to assits 2.4 GHz ISM band. Different inductor less amplifiers can be designed that provide input impedance matching and voltage gain without any inductors such as common gate amplifier (RCS), shunt feedback amplifier (SFB) and resistor terminated common source (R-CS) amplifier. Based on the conventional methods, different LNA can be designed to meet required voltage gain in mmWave applications which designed in single or combination.
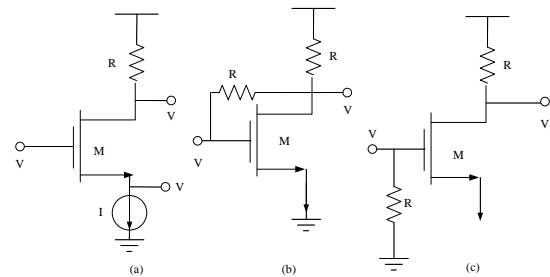
Figure 4 Traditional inductor-less amplifiers: (a) common-gate amplifier, (b) shunt-feedback amplifier and (c) Resistor-terminated common-source amplifier [19]

LNA can be a essential building block in the receiver for increaing gain, must qualify best impedance matching and reduced noise figure related to freqency band. To achieve better performance in mmWave applications, best LNA design sholud essential. The LNA should be design to meet mmWave applications some of the designs are discussed in this section. The radio frequency wave applications with LNA releted analysis presented in below section

2.2 Design of LNA Amplifier for Radio Frequency

The radio frequency wave LNA, which is essential to attain best performance from low signals [19]. For example, wireless LANs, Wi-Fi, cell phones and radios astronomy were cover frequency wave which presented in 2.4 GHz. In the receiver side, LNA block can be one of the most important block in all devices. Because, the signal come from an antenna are moderately, weak such as little micro voltage (µV) and nano voltage (nV) range of the signal. This nano and micro signals should be amplified which attained with the utilization of LNA to increase signal strength. To maintain input-output matching network, the special LNA design is required. The authors [20] have designed LNA to achieve high gain in addition low noise figure which presented in Figure 5.
The LNA design can be developed based on cascode connection. The circuit diagram consists of four different stages such as input impedance matching stage, common source stage (CS), common gate stage (CG) and the output impedance matching stage. Initial stage of designed LNA is input impedance network consists of inductors, capacitors

and resistances. The designed LNA can achieve important properties such as less consumption power, effortless input output matching, high gain and less noise figure. The author [21] have designed CMOS based LNA to meet specific properties in radio frequency wave receiver side. The developed LNA was designed with double common source structure that design solve narrowband problem and attain wide band input matching in band of 3-12 GHz which presented in Figure 6.
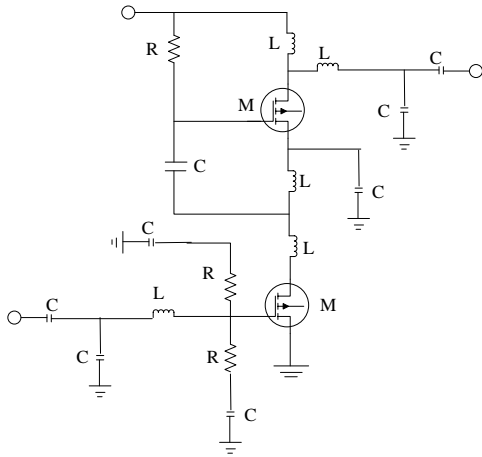

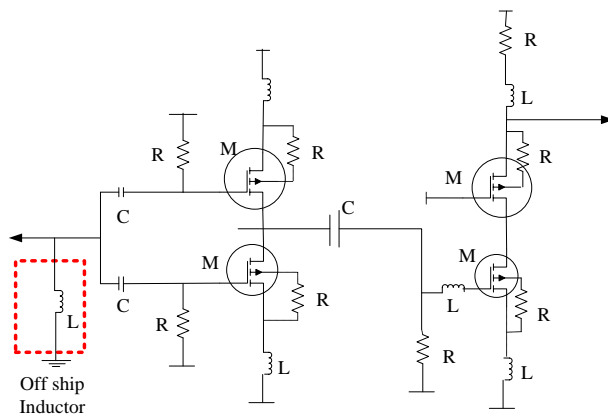**Figure 5** Circuit structure of the developed LNA Circuit [20]

Figure 6 Circuit diagram of the LNA Circuit with double common source [21]

The common source design is a narrow band structure here the double common source structure is utilized in input and two frequency points. These parameters were created to cover whole frequency band with resonating parasitic inductors and capacitances which located in the source terminals. To reduce noise figure of the receiver, the series resistors are introduced in the circuit which connected to the source bulk substrate resistance. The second stage of the circuit is utilized to attain low power structure and high gain. The authors [22] have designed T-type matching based LNA design to meet requirements especially in radio frequency waves. Sometimes, T-type matching circuit with passive components are used in the input matching circuit

which attained matching input but required gain cannot achieved and power consumption also high. Farshad Eshghabadi *et al.* [23] have designed radio frequency CMOS based LNA. This design aims to attain high gain through first pass silicon fabrication success to reduce cost in addition time overriding progress. Saeed Ghaneei Aarani *et al.* [24] have designed ultra wide band (UWB) LNA which used to increment in noise figure in addition gain improvement using 0.18um radio frequency CMOS technology. This structure was designed with two cross coupled capacitors (CCC) in addition new gain flattening method with cascode common gate design. The LNA design should require control techniques to meet better performances of high gain, low noise figure and less consumption power.

3.0 CONTROL TECHNIQUES OF LNA

LNA design has been increased in multi band transceiver to meet different applications with better performance. The LNA should have specific characteristics of low noise figure, high gain, and supply best input matching with low ingestion of power. There are various LNA design presented to attain more linear that working related on IM3 cancelation utilizing piecewise linear, feed-forward, feedback, low impedance termination in addition pre-post distortion methods. The different control techniques are essential to meet all requirements with better and high gain attainments. The control techniques are reviewed and listed below.

3.1   Optimization based Control Techniques

With the improvement of applications in various domains, such as information sharing, industrial settings, healthcare, and agriculture, Generally, these presentations mostly involve difficulties with a front-end circuit that contains an LNA to deliver the signals with high gain and low power consumption. The LNA must work continuously to provide proper signals in specific applications. To ensure the performance of the LNA, control techniques are included in the design operation of the LNA, which is attained with the help of an optimization algorithm. Manish Kumar *et al.* [25] have designed an LNA for wide band applications using the particle swarm optimization (PSO) technique. This article provides the design investigation of low voltage and low power enhancement in LNA intended for wide band presentations. Based on design experiments with LV and LP, a biasing metric was developed for analogue circuits with radio frequency. The designed LNA contains two different phases, such as the current reuse topology and the mutually coupled CS phase. The first phase was a grouping of the top NMOS transistors and PMOS transistors with consideration of sequence inductive peaking in the feedback circle. From the LNA design,

passive component parameters can be optimised with the help of the PSO technique.

Chabungbam Lison Singh *et al.* [26] have introduced Particle Swarm Optimization with an Aging Leader and challengers (ALCPSO)-based control strategy in LNA. It was mainly used to CMOS analog amplifier with low noise intended for automate sizing. The sizing was achieved in LNA with the help of optimization algorithm. Charles baylis *et al.* [27] has developed Pareto optimization to improve design parameters in LNA. Here, fundamental solution methods for the source reflection coefficient supplying the high gain under a constraint of noise figure and also low gain under a constraint of noise figure. The developed method was working related to small signal S parameters and noise parameters of the device. Yi-Tsen Ku *et al.* [31] have developed gain boosted and noise optimization technique in special design CMOS wide band low voltage LNA. The designed LNA have gain boosted technique with negative feedback condition for increasing high frequency gain towards wide bandwidth and attain high gain. Additionally, it has been utilized mirror bias technique to attain complete output swing. Because of this technique, this operating current cannot change due to supply voltage variation.

Ram Kumar *et al.* [32] have introduced multi firefly algorithm to optimize the parameters of 5.5 GHz LNA. The firefly algorithm was utilized to improve the specific values of LNA like as output and input matching, gain noise figure in addition linearity by satisfying complete constraints. Here, five parameters were considered to optimize which taken as multi objective function. Weighed sum technique was utilized to change multi objective function to single objective function. The design LNA has the inductive source degeneration topology with cascode structure. Kosuke Katayama *et al.* [30] have presented Bias-Optimization Technique for reducing the number of measurements in LNA. This technique was utilized to reconstructing a completed model of LNA amplifier by reducing number of measurements solutions. Here, design an eight stage D-band LNA with the utilization 65 nm CMOS method. This method was mainly used to increase gain of amplifier. Ram Kumar *et al.* [32] have presented firefly algorithm to optimize LNA design parameters. The main parameter of LNA was optimized such as gain and noise figure. Here, two main objective functions were concentrated such as maximizing gain and minimizing NF. These two parameters were considered as the single objective function. To handle the constraints of LNA, the penalty factor method was initialized. Additional parameters also considered in this case such as stability, linearity and power consumption. The designed LNA have different structure such as cascode connection with inductive source degeneration topology. The LNA was designed for 5.5 GHz frequency. Chun-Chieh Chen *et al.* [28] have presented gain and product optimization technique for increasing gain in LNA. The design was presented cascode LNA, common gate and dual bandwidth that decreasing value of capacitance in equivalent with the consideration the resonator loads. The optimization algorithm was utilized to select best bandwidth in addition gain product of LNA. Finally, the input impedance and noise factor of the designed LNA was examined.

Angelos Papadimitriou *et al.* [33] have developed genetic computation to optimal parameters of radio frequency with LNA. This article was introducing a methodology for multi objective with optimization using an analytical model of LNA in MOS transistor related with genetic computation. The best performance was derived by a figure of merit (FoM) which considers both RF performance and power efficiency of LNA. Here, short channel model was utilized to analysis the FoM model which presents MOS inversion level present in the moderate inversion. R. Tamilchelvan *et al.* [34] have introduced nonlinear technique to improve performance of wideband microwave amplifier design adopting negative image synthesis. The different microwave properties and RF properties of the amplifier were analysis and investigated. The developed method was amalgamated nonlinear model of the transistor in LNA which considered as input. Additionally, negative image synthesis intended for impedance matching systems at the output intended for input phase of the amplifier. The designed LNA parameters of inductor, capacitor and chip resistor were selected with the help of nonlinear technique. From this analysis, optimization methods were used to enhance the performance of LNA design in receiver side for increasing gain and reducing power consumption so on. To attain best performance of LNA, various control techniques are available which reviewed in below section.

3.2 Different Control Techniques

Generally, an electrical system can be combined with various components. Due to changes in current and voltage, noise is generated in circuits. Very low signals are amplified with the help of LNA. The noise of the system can be reduced and gain can be increased with LNA. Mostly LNA is used in receiver side.

The LNA's design is based on the S parameter in the transistor component. The LNA should have different properties such as good dynamic range, good linearity, good sensitivity is desirable, third order intercept point, amplifier stability. with the selection of the proper transistor, and proper biasing conditions, bandwidth, gain, and noise figure can be improved. Different control techniques are available to increase gain, bandwidth, and reduce noise in LNA designs. The various control techniques of LNA are reviewed in this section.

Abolfazl Zokaei *et al.* [35] have designed 65nm linear broad band differential LNA with the help of post distortion method. The post distortion method was utilized to a wide band differential common gate LNA which used with noise cancelation technique. The main objective of the technique was noise channel cancellation of the CG input transistor under various

output nodes by increasing gain of input signal. From the input transistor, noise channel can be passes by two various paths with equal polarity which removed at the differential output modes. Mohsen Hayati*et al.* [36] has presented current reused technique for noise cancelling in UWB-LNA. In the UWB LNA amplifier, a combination of current reused and noise cancelling technique for reducing noise, power consumption and increasing gain, linearity. With the utilization of resistive feedback methods in addition of inductive source degeneration, the best input impedance matching was attained.

Yu-Teng Chang *et al.* [37] have introduced current reused methods intended for stable matching in addition maintains linearity in CMOS based variable gain low noise amplifier (VGLNA). The developed VRLNA designs have three amplifier phases' in addition three digital gain control bits. Initial stage was a common source amplifier. Second in addition of third stage were reused techniques. To protect control gain in addition dc power, current reuse method in addition connect the digital switch among lower and upper transistors. Because of constant dc current, the reused stage of input impedance was stable. The output impedance was stabilized with connection of ac grounding capacitor at source terminal of the upper transistor under gain switching. Yo-Sheng Lin *et al.* [38] have presented $\lambda/2$-spiral-inductor-basedpositive feedback technique in low power and wideband LNA. The developed technique was used at the input common source stage for increasing gain value. Additionally, T-match method was used to attain output impedance matching, input impedance matching and noise figure.

Kai Jing *et al.* [39] have presented asymmetric π filter and shunt-peaking technique for increasing gain and input with output matching in LNA. Shunt feedback method was used to improve wide operating point as well as form using noise reduction methods. Jianquan Hu *et al.* [40] have presented Multiple Bandwidth Extension Techniques in broadband LNA. With the utilization of multiple bandwidth extension methods, consisting double series peaking techniques, shunt and feedback methods, the designed LNA attains a calculated average gain of 26.5 dB from one to 40 GHz with reduced amount of noise figure.

Dalia Elsheakh *et al.* [41] have introduced Differential Noise Canceling method in UWB LNA. The developed system contains of a CMOS differential LNA and off chip micro strip antenna with the consideration of differential noise canceling (DNC) method. Here, design antenna was printed on a low cost FR$ substrate and trapezoidal dipole shaped with balun in addition dimensions 10×10×0.8 mm³. To improve antenna impedance matching, balun circuit can be integrated with the antenna in ground condition. To remove noise from LNA, differential block was initialized. Shita Guo *et al.* [42] have presented Boosting Technique to increase gain in LNA and noise reduction to decrease noise in LNA. A transformer

feedback boosting method was developed in single ended cascode design towards reduce noise and increase gain. The developed method was theoretically calculated and complete analysis was presented. To increase gain and reduce noise of LNA, the presented method was used and analyzed. Guangy in Feng *et al.* [43] have presented Bandwidth Extension Technique to improve gain and decreasing noise from three stage cascode LNA. The three stages cascode LNA was designed related to negative drain source transformer and pole converging technique.

4.0 PERFORMANCE ANALYSIS

LNA design performance can be improved with the help of control techniques by increasing gain and reducing noise. Optimization algorithms were utilized to increase gain and reducing noise by select optimal parameters in LNA design. The different optimization based control technique in LNA amplifier is listed in Table 1.

Table 1 LNA control techniques with optimization

S. No.	Author	Year	Technique	Design
1	Manish Kumar [25]	2019	Particle Swarm Optimization	Low power, low voltage LNA
2	Chabungbam Lison Singh [26]	2017	Particle Swarm Optimization with an Aging Leader	low-noise CMOS
3	Charles Baylis [27]	2015	Pareto optimization	low-noise amplifier
4	Chun-Chieh Chen [28]	2016	Product Optimization Technique	Dual-Wideband CMOS LNA
5	Deepak Joshi [29]	2017	Hybrid Particle Swarm Optimization with Levy Flight	2.4 GHz CMOS LNA
6	Kosuke Katayama [30]	2016	Bias-Optimization Technique	14.4-dB CMOS D-band LNA
7	Yi-Tsen Ku [31]	2018	Gain Boosted and Noise Optimized Techniques	CMOS wide-band low-voltage LNA
8	Ram Kumar [32]	2016	firefly algorithm	5.5-GHz CMOS LNA
9	Angelos Papadimitriou [33]	2017	Genetic Computation	RF- LNA
10	R. Tamilchelvan [34]	2018	Nonlinear Technique	Wideband Microwave Amplifier

Table 2 LNA control techniques with parameters

S. No	Author	B.W	Gain	NF	IIP3	FoM	Power (nW)	Tech	Size(mm2)
1	A. Saberkari [44]	3.1-10.6	12.1	4.56	-12.5	1.83	13.6	180nm	-
2	G. Gramegna [45]	2.8-7.5	9	3.6	-10.5	-	3.8	180nm	0.77
3	K.V. Reddy [46]	1-10.3	16	4.1	11	-	10.9	180nm	0.2
4	A. Sahafi [47]	2.35-9.37	10.3	3.68	-4	-	9.97	130nm	0.39
5	S. Arshad [48]	3.2-10.64	17	2.5	-	-	16.5	180nm	0.56
6	A. Taibi [49]	3-10	16	3.7	-	-	16.2	65nm	0.12
7	M. Sun [50]	3-12	13.5	4.3	-7	4.33	8.5	130nm	0.85
8	Benqing Guo [51]	0.1-2	13	2.9	10.6	-	21.3	CMOS 0.18μm	0.63
9	Mahdi Parvizi [52]	0.1-2.2	17.5	4.9	-11.5	17.9	0.4	CMOS 0.13μm	0.0052
10	Taeyoung Chung [53]	0.1-1.6	12.3	2.1	5.5	-	20.08	CMOS 65 nm	0.014
11	Hankyu Lee [54]	0.1-2.5	13	1.7	0	14.6	13	CMOS 65 nm	0.008
12	Lanqi Liu [55]	0.01-1.7	18	2.8	1.13	-	-	CMOS 0.18μm	0.092

5.0 FINDINGS

In order to reduce noise and increasing gain in electrical and electronic devices by LNA are the most appreciated technology in the wireless communication networks. Hence, importance of increasing gains in low signals of devices in wireless devices. The low signals are changed into high signals for increasing gain by LNA with proper controlling technique and optimization algorithm. The optimal design parameters of the LNA are selected with the help of optimization algorithm. Additionally, the controller techniques are used to adjust the design parameters in LNA design for reducing noise cancel and increasing gain also. So many research works have been proposed for the proper controller in LNA, some of the reviews are presented in previous sections. From the review we are suggesting that the optimization or control techniques are highly essential to increasing gain and reducing noise from the circuit. The future control techniques or optimization algorithms in LNA will be used to improve the performance of circuits. The design parameters of LNA will be adjusted and optimized with the help of control techniques. In future, different novel techniques will be introduced to improve the performance of LNA by adjusting design parameters.

The various control techniques are used to increase gain and reducing noise from LNA design which constraints are presented in Table 2. The specific parameters of bandwidth, noise figure, power, technology and sizes were analyzed.

6.0 CONCLUSION

In this paper, LNA design and control techniques were reviewed to improving gain and reducing noise in different applications with millimeter and radio frequency waves. The LNA is a most important part in radio receiver system in wireless devices with millimeter and radio frequency waves. The review is progressed based on different techniques to improve gain and reducing noise in LNA. The different design of LNA is reviewed such as 3-stage near-mm Wave low noise amplifier, 5-stage near-mm Wave LNA, common-gate amplifier, shunt-feedback amplifier, Resistor-terminated common-source amplifier, and traditional inductor less amplifiers, cascode connection and double common source. The notable optimization and control techniques with parameters were analyzed and reviewed in this paper. The comparative analysis of control techniques and optimization techniques were analyzed and tabulated. The future direction also provided in this paper for increasing gain and reducing noise in LNA with proper controlling and optimization techniques. In the future, cascaded feedback techniques need to be initialized for improving performance of the LNA in system to meet different applications especially in wireless communication system.

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