Received: May '22
Revised:
Accepted: Jun '22

AN EVALUATION OF DEVELOPMENT THE HIGH-PERFORMANCE WIDEBAND LNA USING THE IEEE BAND SYSTEMS

Gayatri Kansotia
Research Scholar, University of Technology, Jaipur

ABSTRACT

In this research, a low-noise amplifier (LNA) circuit is demonstrated that has a bandwidth of 2 decades, from 15.5 MHz to 1.55 GHz. Its wide frequency coverage (HF to UHF) necessitates the use of multiple bands, including the ISM bands (27.12 MHz, 40.7 MHz, 434.79 MHz, and 928 MHz), the GSM850 and GSM900 bands, and the IEEE 802.22 WRAN bands (54 MHz - 862 MHz). The proposed circuit is both compact and versatile; it can be used as a balun (single-ended input - differential output) because of the absence of an inductor in its construction. The LNA will save a substantial amount of money as a result of this. The use of an extra amplifier allowed for the design to achieve both high gain and IIP3 with low Noise Figure (NF). Dispersion cancellation was used to enhance linearity, and noise cancellation was used to boost NF. The amplifier used a CMOS technology with a size of 130 nm and a PDK from the Silterra foundry to be built in a tiny core region of 77 m by 54 m. The input power reflection coefficient was less than -11.4 dB, the input third order intercept point was equal to -0.4 dBm (@ 750 MHz), and the power consumption was 10.4 mW under a 1.2 V supply in simulations that included post-layout parasitic, bondwire, ESD protection, and PAD input parasitic (across the entire band). The gain, noise figure (NF), and sensitivity to temperature changes (S11) of this balun LNA are remarkably stable between 0 and 85 degrees Celsius, and the worst-case gain imbalance between the outputs is only 1.2 dB.

Keywords: Wideband LNA, IEEE band System, Co-Optimization, Co-Design, Design, Performance.

1. INTRODUCTION

Communication technology is moving closer to a significant accomplishment. We are compelled to make rapid advancements in communication technology by the shaky expansion of remote business, global web access, and the consistently growing need in swift information exchange. In this transition to a new era of communication frameworks, remote communication acquires a key role. PDAs, pagers, wireless local area networks (WLAN), portable global positioning systems (GPS), and short-range information communication devices utilizing Bluetooth and ultra wideband (UWB) innovations are for the most part examples of practical remote communication devices. Nowadays, RF designers are required to develop new approaches that enable the structure of such items due to the insatiable company want for low-effort, multi-standard small gadgets. Any RF recipient's front-end low-clamor enhancer is a crucial component (LNA). The LNA should provide substantial growth while minimizing the turmoil associated with the framework because it is the main dynamic building barrier in the beneficiary front end. The got flag is often filtered, boosted by an LNA, and blended with a local oscillator to mean the base-band (LO). After being demodulated, the flag is connected to an ADC, which digitizes the simple flag, to complete the circuit. The advanced flag preparation unit handles the computerized flag after that (DSP). As can be seen, the LNA has completed the first stage of flag upgrading. In this way, the execution of LNA can significantly change the general collector's affectability and commotion parameters.

1.1. LNA (Low Noise Amplifier)

A low-noise amplifier (LNA) can boost a weak signal without distorting the original signal-to-noise ratio. An amplifier will boost the signal power and the noise power at its input, but it will also introduce some new noise. In order to cut down on this unwanted background noise, LNAs are manufactured. Additional noise can be minimised by designers using low-noise components, operating points, and circuit topologies. Minimizing noise is a design goal that must be weighed against others, such as power gain and impedance matching. Low-noise amplifiers are used in radio communication systems, medical equipment, and electronic test equipment. In some cases, a standard LNA can deliver a power increase of 100 times while only halving the signal-to-noise ratio (at 3 dB

NF) (20 dB). Although LNAs are designed to amplify extremely low-level signals (those that are just above the noise), they must also account for the possibility of bigger signals that cause intermodulation distortion.

LNA Parameters

The following is a list of the main LNA parametric measurements:

- Bandwidth,
- Gain,
- Noise Figure,
- Stability,
- Return Loss/VSWR,
- Linearity,
- Power Consumption, and others

The goals of LNA design include reducing its noise figure and providing moderate to high gain with sufficient linearity across the targeted frequency. The Return Loss and Voltage Wave Standing Ratio (VSWR) of the LNA design, which determines how well the LNA circuit is matched to 50 industrial standards to the source and load respectively. If the LNA design is not unconditionally stable (Rollet Factor $K > 1$ and auxiliary factor B1 or $\beta > 0$), it will oscillate instead of amplifying signals as it should. For portable devices, the LNA design should offer good performance with little power consumption.

There has recently been a major push to develop remote devices with multiple applications (telephone, computer gaming comfort, guide, digital camera, internet browser, and so forth.) integrated onto a single chip. For each of these applications, there are a variety of metrics available. The numerous standards include GPS, IEEE802.11a/b/g and HiperLAN2 for LAN access, Bluetooth for short-range communication, and the Global System for Mobile Communications (GSM) and Universal Mobile Telecommunications System (UMTS) for cellular connection. Such a collector's RF front-end must support a wide range of varied bearer frequencies. Wideband recipient front-end execution is desired to achieve this goal. To meet this requirement, numerous constructions have been proposed. Utilizing a parallel blend of a few tuned narrowband LNAs is one technique. Although simple, this method is power-hungry and wasteful of space. Therefore, it isn't very logical for simple flexible frameworks. Simultaneous LNA and adjustable LNA are two further LNA models that can be used for multi-standard flag gathering. While the final structure strategy is complicated if a wideband tuning-extend is desired, the preceding procedure is adequate when the recurrence groups of desired principles are all around separated. Planning a single wideband LNA that covers the entire intrigue band is an alternative method that is the focus of this analysis.

1.1.1. Wideband LNAs

The various applications depend on wideband LNAs. Little data will be transferred for the baseband signals, but wideband is necessary at the collector side due to the strictness of the linearity estimates. With the least conceivable NF, a mild growth and addition levelness are required. Considerations regarding power, range, and cost are raised when one wideband LNA is substituted for three or four restricted band LNAs. High-data transmission LNAs often provide additions with high Gain (15–20dB) and levelness up to +/–2dB.

1.1.1.1. Global Advantages

Numerous RF and microwave organizations are currently depleting neighborhood RF and microwave components for the expansion of distant systems, including AWR, ADS Agilent, DRDO, Icon Design and Automation, National Instruments, Mini Circuits, Astra Microwave, Power wave, and many more.

1.1.1.2. Benefits to the Nation

According to publicly available data, a number of Indian associations, associations, institutes, and companies are finishing up a basic investigation and improvement in this microwave field for both commercial and noncommercial uses. Even though some pieces are made in India, the execution is improved as a fundamental step. This makes this form of analysis particularly important for the advancement of our country's communication field through research.

1.1.1.3. Band and S Band

The IEEE L Band is specified for frequencies in the radio spectrum between 1-2 GHz, while the IEEE S band is defined for frequencies in the radio spectrum between 2-4 GHz, crossing as far as UHF and SHF at 3.0 GHz. A portion of the L-band (1452-1492 MHz) has been combined in Europe by the Electronic Communications Committee (ECC) of the European Conference of Postal and Telecommunications Administrations (CEPT), allowing various nations to receive the same range for earthbound helpful/settled communication frameworks supplemental downlink. Table 1 lists the key applications for the IEEE L and S bands along with their frequency and type.

Table 1: Uses of IEEE L and S band

F	Item	Application
1177.25 MHz (L5)	Satellite Navigation	Carrier of GPS, GNS
1455-1498 MHz	Services of Mobile	LTE Advanced
850-950 MHz 1850-1950 MHz 1550 and 1680 MHz	Telecommunications	LLC Phones, Satellite Phones
1120 MHz 1130 MHz	Surveillance of Aircraft	Information of Traffic and Avoidance
1250 to 1350 MHz 1275 to 1280 MHz	Amateur Radio	AMSAT

1.2. C-band

TV signals, Internet traffic, data, correspondence, voice communication, and flight are all communicated through satellite using the IEEE C band technology. Indian groups are permitted to use satellite communication systems with a bandwidth of 3.6 to 4.8 GHz. Similar recurrence extend bunches utilized to provide satellite organizations are what broadband comes to be like Wi-Fi and Wi-max. For satellite downlink organizations, it is necessary to use the frequencies in the C band during the time when 3G and 4G mobile frameworks are legal. The C band satellite, broadband, and flexible organizations for mobile administrations are quite important. For each of them to be effective, the approaches to cope with finding the appropriate repetition extend.

1.2.1. Importance of IEEE C-band

The use of the C-band in satellite communications systems is becoming increasingly widespread. Because of its quality inside seeing large downpour, it is particularly essential for several developing countries, particularly in India, South and Central America, southern Asia, and tropical Africa. Additionally, several developed nations make substantial use of C-band earth stations. Since the many businesses were started in earlier years, 3 frequencies have been allocated for satellite downlinks.

Remote applications are surely growing in today's world of remote communication frameworks. The getting frameworks play a crucial role. The benefactors must therefore be strong, upright, and resilient to the indications of various recurrence bands with the requirements of the least amount of commotion figure with perfect solidity growth under lower recurrence misery. The Semiconductor Component LNA is a crucial radio component that serves as the primary front-end receiving section in remote applications that demand cutting edge performance, such as defense, remote detecting, differentiating, and radio space science. According to various calculations, the success of a collector circuit design is determined by the beneficiary's affectability, the recipient's selectivity, and the propensity to received message flag errors. With a focus on the first and most important dynamic device that comes after the receiving wire, RF (Radio Frequency) and microwave circuit configuration engineers are aiming to improve efforts to simplify radio recipient's front-end structure performance. The prerequisite for managing many remote applications, such as radio and TV transmission, cell connectivity, and land escape routes. For instance, the European Galileo framework and the U.S. Global Positioning System (GPS) are frequently utilized to select the accurate global situating of devices, automobiles, airships, ships, etc.

2. LITERATURE REVIEW

different norms there are three possible uses for LNA. (a) Using separate narrowband LNAs for each communication standard; this approach is easy to implement and has produced excellent results, but it necessitates a great deal of silicon area and consumes a great deal of power. Band-switching and multiband LNA was used by B. G. Perumana, J. H. C. Zhan, S. S. Taylor, B. R. Carlton, and J. Laskar (2008). Although multiband LNAs can reduce power consumption, their larger size is a result of the higher-value tuning inductors required for operation. The third option, proposed by A. Liscidini, M. Brandolini, D. Sanzogni, and R. Castello, is to use a single wideband LNA to support all standards simultaneously (2006). Wideband LNA offers a lesser power gain compared to the first and second methods, but it is less expensive and takes up less room. H. P. Koringa and Dr. V. A. Shah (2016). Wideband LNA supports a wide variety of standards. V. A. Shah, M.D. (2016). Wideband LNAs offer constant gain, input impedance matching, noise figure (NF), and input isolation (IIP3) over their entire operational bandwidth. Vasanthi, M. S., and Vasanthi, S. (2016) created an active feedback circuit with a common drain amplifier in the feedback stage and a common source amplifier in the input stage. In this circuit, the input impedance is determined by the transconductance of the common drain stage, while the transconductance of the common source amplifier contributes to the gain and NF of the entire LNA. Using active feedback, the input impedance and NF can be adjusted independently of the design. The main issue with this design is the increased power consumption caused by the additional feedback step.

In 2016, Fernandes, M. D., et al. introduced a balun-based low noise amplifier (LNA) design with dramatically reduced NF and power consumption by the use of a feedback biassing circuit architecture. Wideband low-noise amplifiers (LNAs) and a common noise-cancelling approach were used in the construction of this circuit. By using a transistor in place of the CG stage's traditional current source, they were able to set up a feedback loop within that stage. Gecan, D., et al. (2016) implemented linearity adjustment of a 10 W GaN HEMT PA using a dynamic gate biassing strategy to smooth an exchange period of the PA, as measured by the fast information power. Incorporating an element biassing circuit onto the chip has been shown to increase execution strength and consistency, as well as reducing biassing point variance, by Zhang, Ma, Yu, and Li [46]. The on-wafer measurements include the measurement of noise and very small signals. In contrast to the polarisation considerations taken into account by Active Frequency Selective Surface, Ghosh and Srivastava's [48] symmetric design biassing method renders the structure polarization-uncaring (AFSS). Harzheim, Heuermann, and M. Marso (2016) showed a versatile biassing method controlled by a product schedule for brush generators based on step recovery diodes. The goal was to retain information power variation while providing the best feasible consonant yield power for a given arrangement and a range of information frequencies. Priyansha et al. (2016) suggested a broad band LNA that couples to different matching networks on the input and output of a 3.2 GHz RF receiver. The input and output matching circuit was constructed using micro strip lines. It disentangles the "T" and "L" type matching networks' impacts. To compare the performance of several LNA matching circuits in the stable zone, T-L type matching is superior to LL matching, L-T matching, and T-T type matching. S. Klnç et al (2014), Outcomes from the virtual and physical prototyping of the circuit used to evaluate the wideband matching network design are presented. Several UEs were connected in series to form the circuit, and a micro strip MLEF was used to simulate a Richards capacitor. The driving point impedance or admittance function of the designed circuit was calculated using the Real Frequency Direct Computational Method (RFDCT). Impedances of micro strip unit-elements, open circuits, and short stubs can be computed with the use of the "high precision Richards synthesis package's" output characteristic. In order to reduce potential issues during assembly, the Kuroda identity was used to transform short-stubs into open-stubs. A thorough evaluation will incorporate what-if planning, a play-through, and estimates.

Matching network insertion losses (S12) were demonstrated by Carlos H. P. Lorenz et al. (2015) utilising a short circuited stub and a micro strip L-matching approach, both of which were selected because of their broad use in a number of dispersed MPH studies. It has been demonstrated that, with proper matching network architecture and material, the ideal Schottky diode zero-bias resistance may be achieved, hence increasing the efficiency with which the circuit transforms microwave energy into direct current. With the help of bypass circuits in both the input and output networks, Chung-Ping Lin et al. (2015) developed a novel matching technique that can be used to construct a tri-band active filter. Any working frequency can be disrupted by a properly shunted bypass circuit. Input and output matching networks are developed with micro strip lines utilising this tri-band approach.

METHODOLOGY

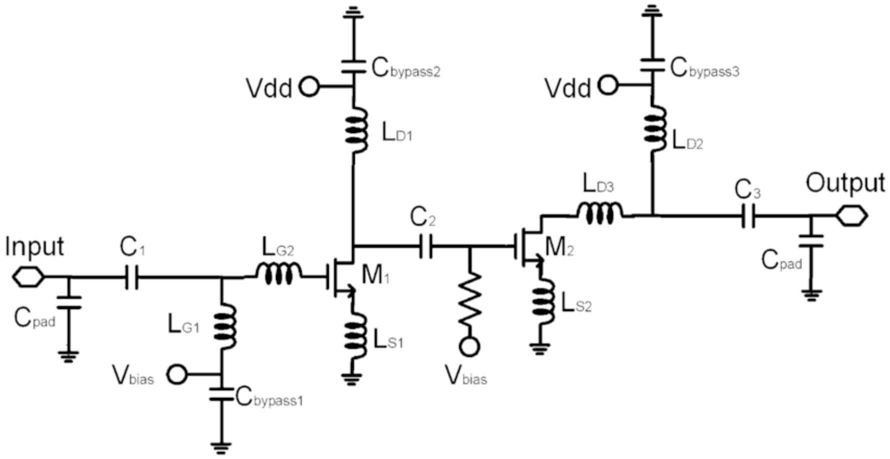

Figure 1: Conceptual topology for an LNA circuit

Fig. 1 depicts the suggested LNA circuit topology. The self-biased main amplifier of this design is composed of the transistors M_1–M_2 and the resistor RF. Transistor M_3 serves as a second load and a diode. The primary amplifier's IIP3 can be changed to a greater extent thanks to M_3. In order to minimize interference with the main amplifier's gain ($gm_3 << (gm_1+gm_2)$), the M_3 bias current is set to be 2%–3% of the current of M_1. The parasitic capacitances and transistor parasitic AC series resistance were ignored in all tiny signal analyses (rds). Input impedance is determined by:

$$R_{IN} = \frac{1 + g_{m_3} R_F}{g_{m_1} + g_{m_2} + g_{m_3}} \approx \frac{1}{g_{m_1} + g_{m_2}} \qquad (1)$$

The bias stability of the main amplifier is controlled by the RF feedback resistor. For the first auxiliary amplifier, we link M1's gate to that of M_4. gm_1 and gm_2 control the bias of the main amplifier. In a cascaded auxiliary amplifier, the output of the first stage determines the bias of the second stage.

M_4, M_5, M_6, and R_{OUT} form the auxiliary amplifier, which uses two common-source (CS) amplifiers in cascade. A diode-connected NMOS load (M_5) is used in the first CS amplifier to provide a low and linear gain at the expense of additional flicker noise from M_5.

$$A_{VAUX1} = -\frac{g_{m_4}}{g_{m_5}}.$$

is the formula for the small signal gain of the first stage. A resistive load is used in the second CS amplifier. Since the goal was to operate at low frequencies, around 50 MHz, an active load was not used to keep the output from being too noisy and flickering.

This stage's differential output sums to, where $A_{VAUX2} = -gm_6 ROUT$ is the tiny signal gain.

$$A_{V_{TOTAL}} = -\frac{R_F}{2R_S} - \frac{g_{m_4} g_{m_6} R_{OUT}}{g_{m_5}}$$

Identical voltage gains were planned for the amplifier's primary and secondary outputs, and for the auxiliary amplifier's first and second stages. An overall maximum gain of 16 was achieved by designing an LNA with 9 V/V voltage gains at each of its four branches (24 dB). The voltage gain of each stage in the auxiliary amplifier is roughly 3 V/V. Keep in mind that improvements above 3 would reduce IIP3 and increase current consumption. Due to the prevalence of the word 1/ gm5 on its load, the gain of the first stage is necessarily low. Due to linearity loss, the second stage cannot have a particularly high gain. The goal here is to maximize the LNA's differential gain without considerably damaging the IIP3 or N_F by using two tiny boosts to build up the auxiliary amplifier's gain to its maximum.

The gain of the auxiliary amplifier's two stages was deliberately kept low to minimize distortion in the final signal. It was important that the first stage have little distortion (high linearity) when used with a diode-connected load. And since the distortion of the feedback main amplifier is proportional to the RF level, a high R_F setting at the main amplifier is out of the question as well. Increasing the RF can reduce the N_F, whereas decreasing the R_F can reduce the distortion. By utilizing the additional design space provided by the M_3 size and the auxiliary amplifier, we can obtain the best possible result.

3.1. Design tradeoffs

It is up to the designer to implement the LNA topology specified here. The amplifier's overall performance can be tweaked by adjusting the amplifier blocks represented by the dashed rectangles in Fig. 1. After a first, basic design is made, many paths toward optimization can be pursued to learn more about the topology options available. Below, you'll see a screenshot of the one used in this study, along with a short summary of the correction methods employed. Therefore, the designer is aided in locating the topological sweet spot.

Gain at the positive output is increased by increasing the RF until the NF and IIP3 are both close to 0 dBm; the S11 is maintained by increasing gm1,2; the IIP3 is maintained by increasing the W of M3; and the gain at the negative output is balanced without increasing the NF by increasing gm6 by a small amount. In our design, if the R_F is set too high, the input impedance starts to mismatch (because the RIN is being influenced by the R_F), and the power required to run the circuit rises accordingly. The LNA's auxiliary branch's R_{OUT} should be rather low so as to produce minimal thermal noise. After implementing all of these improvements, the final transistor sizes are displayed in Table 1. In the following section, the outcomes of the electrical simulations are shown.

Table 1: Sizing of Device

MOSFETs	SIZING		
	W(µm)	**L (µm)**	**g_m (mS)**
M_1	132	0.18	29.2
M_2	137	0.42	12
M_3	7.9	0.26	1.9
M_4	265	0.18	50
M_5	95.3	0.6	24
M_6	95.2	0.13	26

4. RESULTS

Cadence Virtuoso Specter was utilised to mimic the LNA's parasitic extraction utilising the Silterra Malaysia 130 nm CMOS technology PDK. This step followed the removal of parasitic organisms. ESD protection (30 m x 2 m diodes in simulation), external decoupling capacitors (CACIN = 500 pF and CACOUT = 10 pF), and estimated bond wire inductances (LBOND = 2 nH) are all featured on the simulation test-bench shown in Figure 2. Also considered was a load with parameters of RL = 1.5k and CL = 100k fC. An assumption was made that this load typified the input impedance of a differential wideband mixer. When running the simulations, we accounted for the performance-degrading impacts of package-level parasites like LBOND and CP AD on the LNA. It is possible that the results may be enhanced without the LNA if it was designed to act as an internal block of an application circuit, such as in an RF front-end. Both the input and each of the outputs have double diodes installed for ESD protection. Figures 3 display its simulated findings. Gain, NF, and S11 are all perfectly flat from 15.5 MHz to 1.55 GHz. Figure 3 demonstrates that over the full frequency range, the topology attained a voltage gain of more than 20.8 dB and a noise figure of between 2.7 and 3.7 decibels. The input impedance mismatch parameter S11 was found to need to be less than -11 dB. At 750MHz, smack in the middle of the spectrum, the IIP3 is -0.4 dBm.

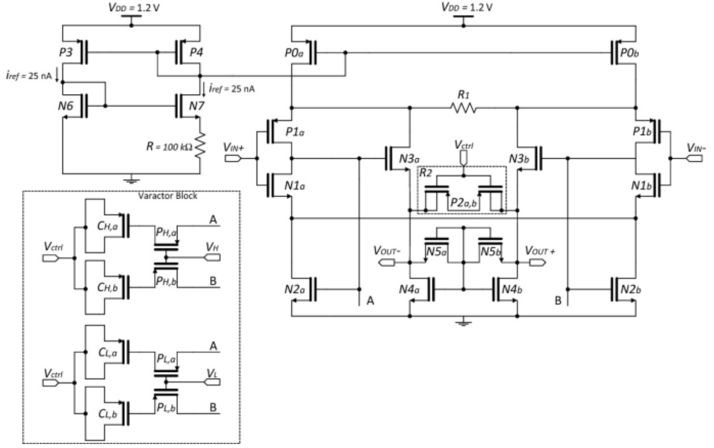

Figure 2: Test-bench for extracted layout simulations

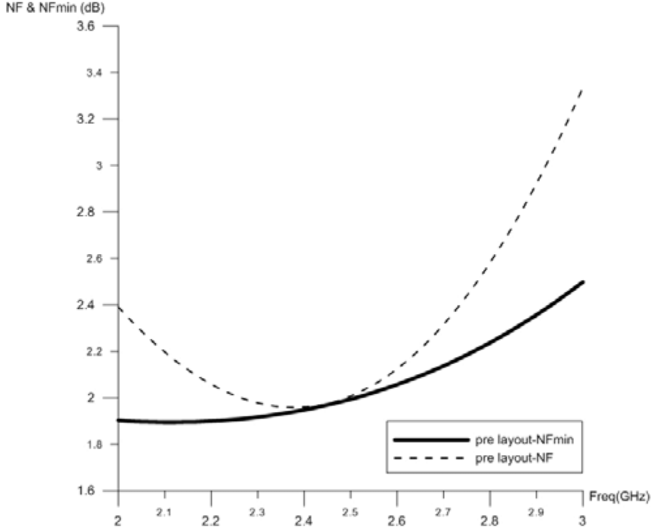

Figure 3: Post-layout voltage gain, NF and S11 simulation results for the proposed LNA

Table 2: Wideband LNA comparisons. *Power gain values.

BW(GHz)	Gain (dB)	NF (dB)	S_{11} (dB)	IIP2 (dBm)	IIP3 (dBm)	Power (mW)	Area (mm^2)	Tech (nm)	BALUN
1.7-8.3	8.9-12.3*	3.9-6	<-8	7.8-25	12.5-14.3	2.65 (core)	0.56	140	NO
0.075-0.29	15.2*	3.8	-	39	2.9	12.22	0.05	140	NO
0.6-1	11-19	2.9-4	<-10	-	1-15	13.2	0.004	175	NO
0.05-1.4	17.2*	2.6-3.3	<-10	-	0	15.3	0.026	190	NO
0.19-0.8	38.2*	1.8	-	-	-15	19	-	60	YES
0.04-5	14*	1.6-2.8	<-10	-	-7.26	17	0.06	140	YES
0.05-15	19.22	2.3-5.4	<-10	15-18.2	-11.5-(-7.2)	24	-	60	YES
0.17-1	19-25.3	<3.5	<-10	>20	0-4.2	23	0.009	65	NO
0.0155-1.6	**20.8-24.9**	**2.7-3.7**	**<-11**	**9@750 MHz**	**-0.4@750MHz**	**10**	**0.0042**	**130**	**YES**

IIP3 > 3.3 dBm, S11 -16, and NF 3.6 dB, spanning a narrower range of input frequencies

5. CONCLUSION

A wideband LNA topology for balun use without inductors was introduced, including HF ISM, IEEE 802.22, and amateur and military radio bands. Noise and linearity are reduced. The proposed auxiliary amplifier gives the designer more design options. The 130 nm topology covers 15.5 MHz to 1.55 GHz. Inductances, ESD protection, and PAD capacitances were simulated post-layout. IIP3 = -0.4 dBm @750MHz, NF = 2.7-3.7 dB from 0.0155 GHz to 1.6 GHz. This topology can work between 0°C and 85°C, according to simulations.

REFERENCES

1. A. Ximenes and J. Swart. A wideband noise canceling low-noise amplifier for 50mhz x2013;5ghz wireless receivers in cmos technology. In New Circuits and Systems Conference (NEWCAS), 2011 IEEE 9th International, pages 197–200, June 2011.
2. A. Youssef, A. Ismail, and J. Haslett. A sub - 2 db noise figure wideband lna in 65 nm cmos for mobile tv applications. In Silicon Monolithic Integrated Circuits in RF Systems (SiRF), 2010 Topical Meeting on, pages 164–167, Jan 2010
3. B. Razavi, "RF Microelectronics", Prentics-Hall, Upper Saddle River, 1997.
4. B. Razavi. Cognitive radio design challenges and techniques. Solid-State Circuits, IEEE Journal of, 45(8):1542–1553, Aug 2010.
5. B. Razavi. RF Microeletronics. Prentice Hall, Upper Sadle River, NJ-US, second edition, 2011.

6. C. H. P. Lorenz, S. Hemour and K. Wu, "Modeling and influence of matching network insertion losses on ambient microwave power harvester," 2015 IEEE MTT-S International Conference Non Numerical Electromagnetic and Multiphysics Modeling and Optimization (NEMO), Ottawa, ON, 2015, pp. 1-3. doi: 10.1109/NEMO.2015.7415051.
7. C. P. Lin, B. M.Chen and Z. M. Tsai, "A multiple-band matching network using bypass circuits concept applying on active filter," 2015 Asia-Pacific Microwave Conference (APMC), Nanjing, 2015, pp. 1-3. doi: 10.1109/APMC.2015.7413372.
8. Camarchia, V., Teppati, V., Corbellini, S., & Pirola, M. (2007). Microwave Measurements Part II Non-linear Measurements. IEEE Instrumentation & Measurement Magazine, vol. 10, no. 3, 34-39.
9. D. Feng, B .Shi, “Comprehensive Analysis and Optimization of CMOS LNA Noise Performance”, IEEE. ASP.DAC., pp. 1204-1207, 2005.
10. F. Bruccoleri, E. A. M. Klumperink, and B. Nauta, “Noise Canceling in Wideband CMOS LNAs,” in Proc.2002 IEEE ISSCC and Distribution Conf., Vol. 1, pp. 406–407, Feb. 2002.
11. M. Barros, J. Guilherme, and N. Horta, “Analog Circuits Optimization Based on Evolutionary Computation Techniques,” The VLSI Journal, Vol. 43, pp. 136–155, 2010.
12. M. Moezzi and M. Bakhtiar. Wideband lna using active inductor with multiple feed-forward noise reduction paths. Microwave Theory and Techniques, IEEE Transactions on, 60(4):1069–1078, April 2012.
13. M. Sumathi, S. Malarvizhi, “Design and performance analysis of 5GHz CMOS RF front end circuits for IEEE 802.11 application”, European Journal of Scientific Research, Vol. 54, No. 3, pp. 418-426, 2011.
14. M. Taherzadeh, R. Lotfi, H. Zare and O. Shoaei, “Design optimization of analog integrated circuits using simulation-based genetic algorithm”, Proc. IEEE International Symposium on signals and circuits.1: 73-76, July 2003.
15. P. V. V Koteswara Rao, Ch. Vishnu Vardhan Reddy, K. Tejaswini, B. V. V. Ravindra Babu, and K, Jagadeesh Babu, “A Wideband H Shape Dielectric Resonator Antenna for Wireless MIMO Systems,” The International Journal of Engineering and Innovative Technology (IJEIT), March 2012, ISSN: 2277-3754
16. Priyansha, K. R. Samatha and S. Sivasundarapandian, "A novel input output impedance matching network for LNA," 2016 International Conference on Communication and Signal Processing (ICCSP), Melmaruvathur, Tamilnadu, India, 2016, pp. 2089-2093. Doi 10.1109/ICCSP.2016.7754546
17. R. A. Vural, O. Der, T. Yildirim, “Investigation of Particle Swarm Optimization for Switching Characterization of Inverter Design,” The Journal of science Direct, 2010.
18. S. Kılınç, R. Köprü and B. S. Yarman, "Design and realization of wideband matching networks in Richards domain," 2014 IEEE Benjamin Franklin Symposium on Microwave and Antenna Sub-systems for Radar, Telecommunications, and Biomedical Applications (BenMAS), Philadelphia, PA, 2014, pp. 1-3. doi: 10.1109/BenMAS.2014.7529476.
19. Schreurs, D. (2010). Applications of vector non-linear microwave measurements, IET Microwaves, Antennas & Propagation, vol. 4, no. 4 doi: 10.1049/iet-map.2009.0479, 421-425.
20. Y. Pang, G. X. Shen, “Improving Excitation and Inversion Accuracy by Optimized RF Pulse Using Genetic Algorithm,” The Journal of Magnetic Resonance, Vol. 186, pp. 86–93, 2007.