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Comparison Analysis of Transformer Boosting and Induced Degeneration Topology Design of LNA for Millimeter Wave Frequency Range Using Polymeric Substrates

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Abstract

In this study, a comparison between transformer boosting and source degeneration LNA topologies is conducted using two polymeric substrates—Polyimide (PI) and Liquid Crystal Polymer (LCP)—for millimeter-wave (mmWave) applications. With growing interest in flexible and high-frequency electronics, polymeric materials offer unique advantages such as low dielectric constants, mechanical flexibility, and thermal stability. The analysis explores gain, return loss, and noise figure performance while evaluating the influence of dielectric properties on the RF behavior of the LNAs. The simulation is performed using industry-standard tools, and the findings provide insights into optimizing LNA topologies for future polymer-based RF systems. Full-wave electromagnetic simulations and circuit-level modeling were carried out to evaluate key performance metrics including gain (S21), noise figure (NF), input/output matching (S11/S22), and power efficiency. The influence of polymer dielectric constant, loss tangent, and surface roughness on the LNA's performance was analyzed in detail, offering insights into the structure-property-performance relationship of polymer-supported mmWave circuits. Results demonstrate that polymer-based substrates can significantly affect the impedance matching and overall noise behavior of mmWave amplifiers. This research highlights the potential of functional polymer materials in the fabrication and optimization of high-frequency RF components and offers a pathway for integrating polymer science with mmWave circuit design for emerging flexible, wearable, and bio-integrated communication systems.

Keywords: Transformer boosting technique, Induced Degeneration Topology, CMOS LNA, NF, MM-Wave, polyimide (PI) and liquid crystal polymer (LCP).

INTRODUCTION

The rapid expansion of mmWave communication systems in 5G, satellite, and sensor technologies demands RF components that not only meet stringent performance criteria but also support emerging form factors such as wearable, flexible, and lightweight electronics. Low-noise amplifiers (LNAs) are critical components in the receive chain of these systems, responsible for amplifying weak input signals while minimizing noise contributions.

While considerable attention has been given to optimizing semiconductor technologies and LNA circuit topologies, the choice of substrate material has become increasingly relevant, especially with

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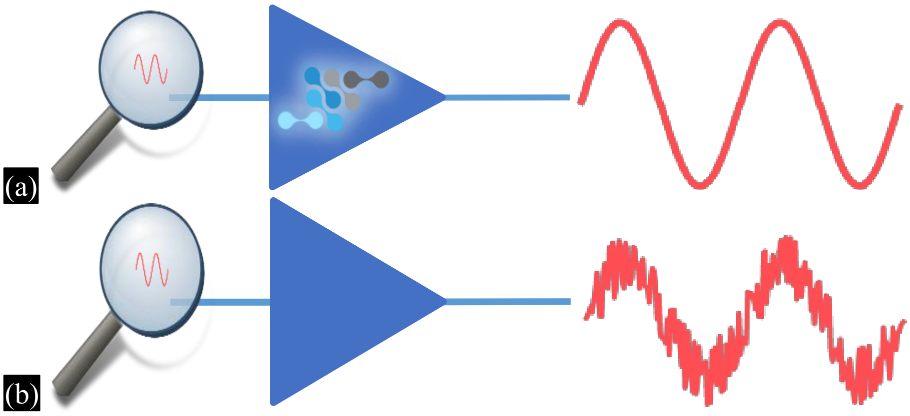

Figure 1. (a) low-noise amplifier, and (b) standard amplifier.

the integration of polymer-based materials. Polyimide (PI) and Liquid Crystal Polymer (LCP) are two polymeric substrates that provide excellent electrical insulation, low dielectric loss, and thermal stability [1]. This work investigates how transformer boosting and source degeneration LNA topologies perform when implemented on these polymeric substrates, providing insight into their suitability for next generation mmWave systems as shown in Figure 1(a) and (b). Most Communication systems include LNA. The important significant LNA's requirements are,

- High Gain
- Low Noise Figure
- Max RF input,
- High Linearity
- Good impedance matching etc.

The Noise Figure of a high-quality LNA is quite low (e.g. 2 dB) and has high Power Gain to improve the signal (e.g. 10 dB) as well as a sufficient Inter Modulation and Compression Point (IIP3 and P1dB) to perform the desired work from it. Some more parameters are the LNA's working Bandwidth (BW), its Stability, its Gain, I/O VSWR. High gain from the first stage amplifier is necessary for low noise. Complementary MOSFET is currently the most used technology for LNA design.

Application of LNA

Cellular phones and other communication receivers frequently employ low noise amplifiers as well as GPS receivers, wireless LANs (Wi-Fi), satellite communications, 4G and 5G mobile technology etc. They all use LNA. Because satellites have a limited amount of power and consequently use Low Power transmitters, the ground station reception antenna used in satellite communication systems is typically LNA. To overcome feed line losses between the antenna and receiver circuits, the Low Noise amplifier increased the antenna signal power. SDR receiver system performance can also be improved by LNA. SDRs are made for general-purpose applications, and the NF is not tailored for any specific usage. Performance of SDR also enhanced over a wide range of frequencies with the use of LNA and the proper filters [2].

Millimeter Waves

High SNR values are needed at the transmitter front end to meet the capacity demands of next-generation networks [3]. Fifth generation mobile communication would benefit from the use of unused millimetre wave frequency bands. Millimeter-Wave has recently attracted most of the researchers for this research area of interest in different domains of applications which are most focused on communication systems such as 4G and 5G. Because of mm-wave leads to the high Gbps rate for every user, along with this the Millimeter-Wave may be used in nonmoving applications like indoor Wi-Fi or hotspot application. The mmWave can also be utilized in mobile networks but difficult conditions may be developed due to moving condition of transmitter and receiver. In order to fully utilise Millimeter-high Wave's potential rate in mobile communication networks, a great number of serious issues involving low power signals may be resolved by using a low noise amplifier [4]. Through the use of Si-based CMOS technology, communication antennas were made smaller and faster. By combining the digital baseband circuitry and RF front end on one chip, CMOS allows for rapid communication as well as the use of high resistive substrates [5]. The gate length and related parasitic components have an impact on MOSFET high frequency performance [6]. The most challenging issues in designing RF and millimetre wave integrated circuits (ICs) are MOSFET-LNA s with low NF and high gain.

LITERATURE EVALUATION

Millimeter-wave (mmWave) LNAs have traditionally been developed using high-performance CMOS or SiGe technologies, with a strong focus on optimizing gain, linearity, and noise figure through architectural techniques like inductive degeneration or transformer boosting. However, with the miniaturization of RF systems and the demand for flexibility, there has been a growing shift toward evaluating the material properties of the substrates themselves.

Recent studies have shown that polymer-based substrates such as PI and LCP exhibit desirable RF characteristics, including low dielectric constants ($\varepsilon_r \approx 2.9–3.5$) and low loss tangents ($\tan \delta < 0.005$), which are critical for signal integrity at high frequencies. LCP substrates, in particular, have demonstrated stability under thermal cycling and humidity, making them suitable for multilayer and high-frequency RF applications. On the other hand, PI provides mechanical robustness and ease of processing, although its slightly higher dielectric loss requires careful design considerations. Emerging research also indicates that substrate effects, such as surface roughness and thickness, significantly impact the performance of both passive and active RF components. Despite the known impact of substrate properties, comparative analyses between different LNA architectures implemented on polymeric substrates remain limited. This paper aims to bridge that gap by comparing transformer-boosted and source-degenerated LNAs across PI and LCP substrates, using simulation-driven metrics to explore the underlying structure-property-performance relationships [1, 2]. On the basis of the components used and performance metric measurements, many topologies for LNA design have already been published. Some of them are discussed with their limitations.

A 4-stage cascade and source grounded LNA with a chip area of 48.1 x 1 mM2 and power consumption of 1.4 W was introduced in a study [7]. They described a wide bandwidth by using GaN-LNA at frequency up to $10\ MHz$. The monolithically integrated $0.1\ \mu m\ GaN/Si$ technology was used for this designed LNA. It has an NF of 2.2- 4.2 dB and operates between 18 and 56 GHz of frequency. However, we discovered that there is some instability for high frequency bands while measuring the S-parameters.

A LNA using a transformer for millimeter Wave applications was introduced in a study [8]. It has 4 CS (Common Source) stages, 3-transformers were used to connect the Drain of CS transistor and the Source of Common Drain transistor for increase the Tran's conductance of this transistor. To improve the circuit's gain, RF signal was fed from the drain of the prior stage to the subsequent stage using a transformer. In order to maximise gain and reduce noise, parallel coils are also utilized to boost the coupling coefficient of the transformer.

A very Low Voltage Bluetooth low energy (BLE) front end receiver was developed [9]. with an on-chip micro power management (μpm) to manage the internal voltage range. In order to increase power gain and NF, it has an Ultra Low Voltage, three coil two stage low noise amplifier with inbuilt on chip transformer.

Transformer feedback technology with wideband input matching was presented [10]. They used an extra feed forward channel, in order to continuously reduce noise and increase gain, but it showed low I/P matching impedance for the high frequency range of $60GHz$.

A study [11] has presented an IBA beamforming frame LNA structure. In order to increase gain, IBA cells were largely used with little NF and medium linearity. They have used VGLNA design techniques which have been explained with the single ended VG LNA and Low Noise Amplifier chip area for $60\ GHz$ band. But, after measuring a complete IC circuit, it was found that a calibration strategy was still required for increase gain and reduce NF.

An investigation [12] design a dual FB-LNA in K band at $23\ GHz$ with cascaded CS topology. They have added transformer feedback topology with the transformer neutralization technique to attain I/O Return Loss lower than -10 dB. However it technique reduces reverse isolation of LNA and but increases the overall area of chip. Therefore, it was determined that it was not appropriate for K band radio frequency applications or sensor systems.

A study [13] proposed an LNA feedback amplifier with multistage noise matching for RF or Millimetre Wave. It has a $21.5dB$ peak gain and 1.7 dB NF_{min}. Power consumed was reduced by making 3 thick layers which have 2 Copper layers and 1 Aluminum layer. QF is measured and found to be 17 for inductors. But, the power consumption of LNA cannot be overcome by this technique.

A study [14] has designed a transimpedance amplifier between 3 amplifier stages. To boost bandwidth, this LNA has been used as a transformer-based shunt series I/P stage. by using of Capacitive Peaking technique, Middle stage provided high improved gain. By implementing transimpedance amplifier prototype in a $0.13\mu m$ Bi-CMOS technology, it results in high peak voltage value at $50GHz$ of Band Width.

CMOS distributed amplifiers was introduced by a study [15] by utilising the gate-drain feedback transformer technique. It allows reusing of travelling signal to get a high Band Width product while maintaining low-power consumption for DC to DC converter. It has ground shields, transmission line shields, and miniature transformer shields. The ground shield has been folded into the structure in such a way as to reduce the size of the chip area and to achieve a controlled coupling coefficient. But the drawback was that, it has 70 to 80 miliWatt power consumption in their core areas.

Liang et al [16] had published V-I transformer FB n/w which has been used for neutralize gate to drain capacitance of the transistor without many restrictions on a transformer coupling factor. This has been designed for a $90nm$ Lower Power BulkCMOS method as 3-stage amplifiers. The reverse isolation for this amplifier is measured to be more than 40 dB over high frequency range. But because of a complicated transformer model was needed, it has certain limitations in terms of the reliability of the equivalent circuit model.

Kumaravel et al. [17] has published Gm-boosting Fast-CMOS(FC LNA) that have the CS stage and operate for radio frequency based applications. It is designed by the CMOS process for 2.44 GHz. This LNA have a very low power gain and it gives a NF of 2.9 dB only and it power consumption was very high. So was the main drawback of this FC LNA.

Idros*et al.* [18] has published a LNA Rx with 8 pipelined A/D Converter which include a switch Capacitor, 2 bit comparator and digital logic blocks, which depends upon the residue amplifier. This has been designed by using a residue amplifier for min power consumption. This includes A/D Converter for resolution and faster speed, that's why this system becomes to be very complex and was not useful for future work.

Mohammad *et al.* [19] has published a Balun Low Noise Amplifier (BLNA) system with CS Topology. Forward body biasing was used in this low noise amplifier, along with a degeneration resistor to balance the output and min to monitor threshold voltage. Due to the high power consumption the gain was not significantly achieved, which made it suitable only for some perticular applications.

Nejadhasan*et al.* [20] has published an LNA and a mixer circuits which was realized using 0.18 µm CMOS technology for 3.1 GHz to 10.6 GHz frequency range. For reducing non linearity, this LNA used a cascade topology with source degeneration. For decreasing power consumption, biasing voltage, current reuse technology was adopted. But from this, system becomes less efficient.

Kishore *et al.* [21] have presented an ULV Bluetooth Low Energy front end receiver with inbuilt on chip Micropower Manager. A ULV class-D coupled with a class-C starter that failed to note robustness in the design, a ULV 3 coil two-stage LNA with an on-chip transformer to increase gain and NF.

Aneja *et al.* [22] had developed a Multimode Tunable I/p matching network LNA. With the use of a Varactor Diode, they have exploited tenability and frequency reconfiguration techniques. At several bands, this LNA showed a wide range of imbalance.

Di Gioia [23] has presented a three-layer thick LNA for RF/mm-wave applications, including two copper and one aluminium layer for wider BW. This prototype achieved a 1.7-dB min NF and a 21.5 dB peak gain. However, the power usage was substantial.

Aneja *et al.* [24] had developed a TF technique for broadband I/P matching. They have used a auxiliary feed forward path to cancel noise and improved gain. This LNA shows a very less I/P matching for high range of frequency.

Juneja *et al.* [25], they have used an Inductive Degeneration topology design and reverse isolation techniques for this LNA design with fixed inductor values for QF of 5 for better tunings and good matching. Since this teleology does not provide a NF$_{\min}$ at the cascode stage for the output.

Agarwal N *et al.* [26], has published a LNA with improved gain and low noise figure using transformer boosting (TB) method for Millimeter Wave frequency range. We have design a three cascode stage transformer boosting LNA. This topology used for implementing the LNA helped us to improve Power Gain by addition the input signal and by this help to boost the allover power gain performance of the LNA. While simulating in CADENCE ORCAD 16.6, this TB-Low Noise Amplifier provides a NF$_{\min}$ of 3 dB from 30 GHz to 90 GHz and Power gain of 67 dB at 30 GHz and it operates on very low voltage of 1.1 V.

Agarwal, N., *et al.* [27], has published an article on the Designing of NB Low Noise Amplifier using Induced Degeneration Topology (IDT). This IDT in Low Noise Amplifier design helped to improved the power gain by enhancing input signal; due to this the overall gain is increases and NF improved. The simulation results of this NB IDT cascaded LNA in CADENCE ORCAD 16.6 SOFTWARE, have an NF$_{\min}$ of $2dB\ at$ 90 GHz and power gain of 68 $dB\ at$ 90 GHz and it operates on very low voltage of 1.2 V. It gives power gain of 16 dB by theoretical measurement form the equations. . Thus TB- LNA design is good for the radio receiver applications.

Agarwal, N., *et al.* [28], has presented a review paper for various Low Noise Amplifier designs for Millimeter and Radio Frequency wave applications.

Agarwal, N., *et al.* [29], has published a book chapter on An Extensive Review On: Cascaded Transformer Boosting LNA for Millimeter-Waves.

Agarwal, N. et al. [30], have published a review paper on "Various designing technology $\mu m\ and\ nm\ CMOS\ LNA$ Technology for millimeter-wave" in Journal of Critical Reviews.

Although the previous design, which was constructed and validated using S-parameters, had the drawbacks of a complex circuit, a large size and cost, high power consumption, a low reliability, and a low substrate conductivity. In turn, this lowers the gain and raises the overall NF. So the 2 LNA has been designed for mm-wave applications to address these drawbacks, and our work shows a comparison of the outcomes with reduced noise gain.

METHODOLOGY (ANALYSIS OF BOTH DESIGNED LNA)

This study utilizes a simulation-based approach to evaluate the performance of transformer boosting and source degeneration LNA topologies implemented on polymeric substrates. The substrate materials used are Polyimide (PI) and Liquid Crystal Polymer (LCP), chosen for their RF-compatible dielectric properties.

The LNAs were designed using Cadence Virtuoso with models suitable for mmWave frequency bands (24–40 GHz). The process begins with schematic capture followed by layout implementation, parasitic extraction, and performance analysis using SpectreRF. Dielectric constants and loss tangents for PI and LCP were modeled according to measured values from literature. Key performance metrics evaluated include gain (S21), input return loss (S11), and noise figure (NF). The transformer boosting topology employs an on-chip transformer to enhance gain while minimizing noise, whereas the source degeneration design focuses on linearity and stability improvements through inductive source feedback.

Materials and Methods

Substrate Properties

Two flexible polymeric substrates were selected:

1. *Polyimide (PI):* $\varepsilon_r \approx 3.4$, tan $\delta \approx 0.008$
2. *Liquid Crystal Polymer (LCP):* $\varepsilon_r \approx 2.9$, tan $\delta \approx 0.0025$

Both materials are modeled as the base dielectric in the simulation environment, with metallization defined for the microstrip and passive components.

LNA Design Topologies

Two topologies were chosen for comparative analysis:

1. *Transformer-boosted LNA:* uses a center-tapped transformer to enhance gain and improve input matching.
2. *Inductively degenerated LNA:* employs a source degeneration inductor for improved linearity and controllable impedance.

Simulation Tools and Setup

Cadence Virtuoso with RF simulation support and ADS (Advanced Design System) were used to implement and analyze the LNA topologies. Each design was simulated over the 24–40 GHz range to evaluate performance metrics such as:

1. Gain (S21)
2. Input Return Loss (S11)
3. Noise Figure (NF)
4. Power Consumption and Stability Factors

Analysis of Transformer Boosting (TB) Method LNA Design for Millimetre Waves Applications

We have designed a transboost or Transformer Boosting (TB) technique LNA for millimeter-wave applications in my first article. Using a transformer as a gain component, this paper developed a LNA design topology that lower the NF and enhances gain performance in millimeter-wave applications. 3-transformers are bought to connect the drain to the input signal, and three common gate stages are coupled in cascode fashion. The O/P of the First stage is connected to I/P of the next stage and the transformer enables RF signal injection from the drain to the source. This link boosts the circuit's gain and the unity coupling coefficient that is used to reduce noise. To keep the operating circuit stable, the Coupling factor of transformer kept at 1. By carefully choosing the conductivity factor and S-parameter values, NF values can be reduced. Because a transformer is used in this circuit to produce feedback, stable conditions must be carefully considered. The output load value is best chosen because it influences the LNA's stability. By increasing the signal input, this topology improves the overall amplification performance and gain of the LNA design. When this LNA design is carried out utilizing the transboost (Transformer Boosting) technology of CADENCE ORCAD 16.6 SOFTWARE orcad

16.5 version software , this design shows on measurements of NF_{min} of 3 dB at 30 GHz to 90 GHz and a Gain of 67 dB at 30 GHz. This LNA design, in contrast, uses 1.1 V of power and is better than conventional techniques [25].

Transformer Boosting (TB) LNA Design Architecture

The transformer gain approach is the foundation for the suggested LNA's design. The MOSFET transistor's bias voltage is selected for the best NF and the TB-LNA contains three cascade stages. The coupling coefficients for the transformers are set as 1 for a constant circuit since they are linked next to the circuit to create a less circuit size area. The input matching network is designed using inductors with inductances of 80 pH, 80 pH and 40 pH, such as L_1, L_2, and L_{S1}, which have been carefully adjusted to provide high gain and low N F.

Due to the TB-LNA's high frequency implementation, it has a significant impact on the ground lines. This LNA is implemented at 30 GHz frequency, with a bandwidth of 60 GHz (B.W=2f) and it affects the lines of ground, by considering such effects into account, a thorough EM simulation is produced for the entire layout. This TB-LNA's gain is raised, and the noise is reduced.

Figure 2 displays a circuit of the TB-LNA. The RF signal at the input and the RF output provide three cascade stages for the circuit, as shown in the diagram. A secondary MOSFET, which remains active and have a voltage from V_{dd} and stores signal which is send to the next cascade stage of circuit have two improved n-channel CG MOSFETs, drain channel transformers, and an inductance that creates transconductance in to the circuit at the source. The least N F is determined and set as the objective for our design using the expected value of Γ_s. Utilizing the gain of the circle, the Z_L value for the given circuit with relation to the connected transistors is then approximated. Tune the transformers and alter the gate inductors' values to obtain a voltage boost at high frequency. All connected MOSFETs are still in the active phase, but this aids in finding linearity in the circuit and preserving a consistent gain in each phase. Since MOSFET sizes are carefully tuned in relation to their channel gain index. The three-stage networks' drain inductors in this implementation are set to 80 pH. The circuit feeds the input of the current stage with the output of the stage before it.

The best LNA parameters are determined by taking into account the contributions from the three LNA steps of gain, NF, and stability as shown in Figure 3. Equation provides the Friis Law formula for NF calculation for the suggested LNA design (1)

$$NF = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1 G2} \quad (1)$$

A LNA design requires a continuous NF circle for required NF_i,

$$N_i = \frac{|\Gamma_s - \Gamma_o|^2}{1 - |\Gamma_s|^2} = \frac{NF_i - NF_{min}}{4r_n} |1 + \Gamma_o|^2 \quad (2)$$

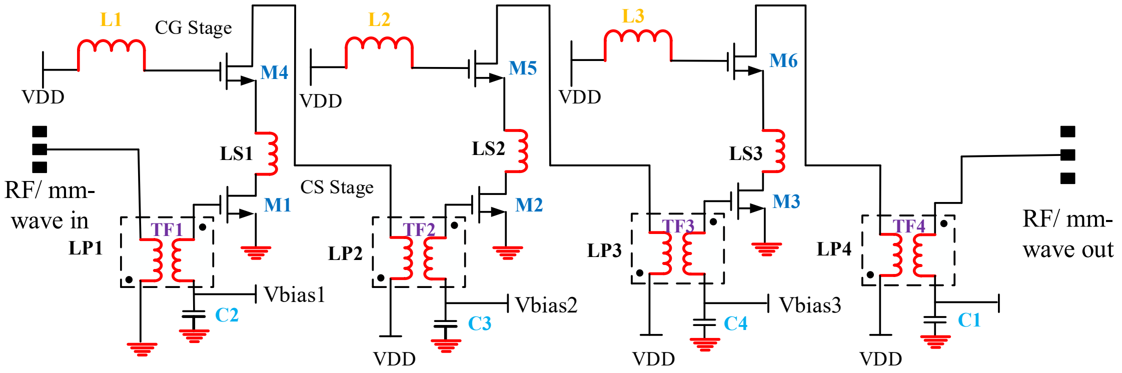

Figure 2. A TB-LNA schematic diagram for mm wave.

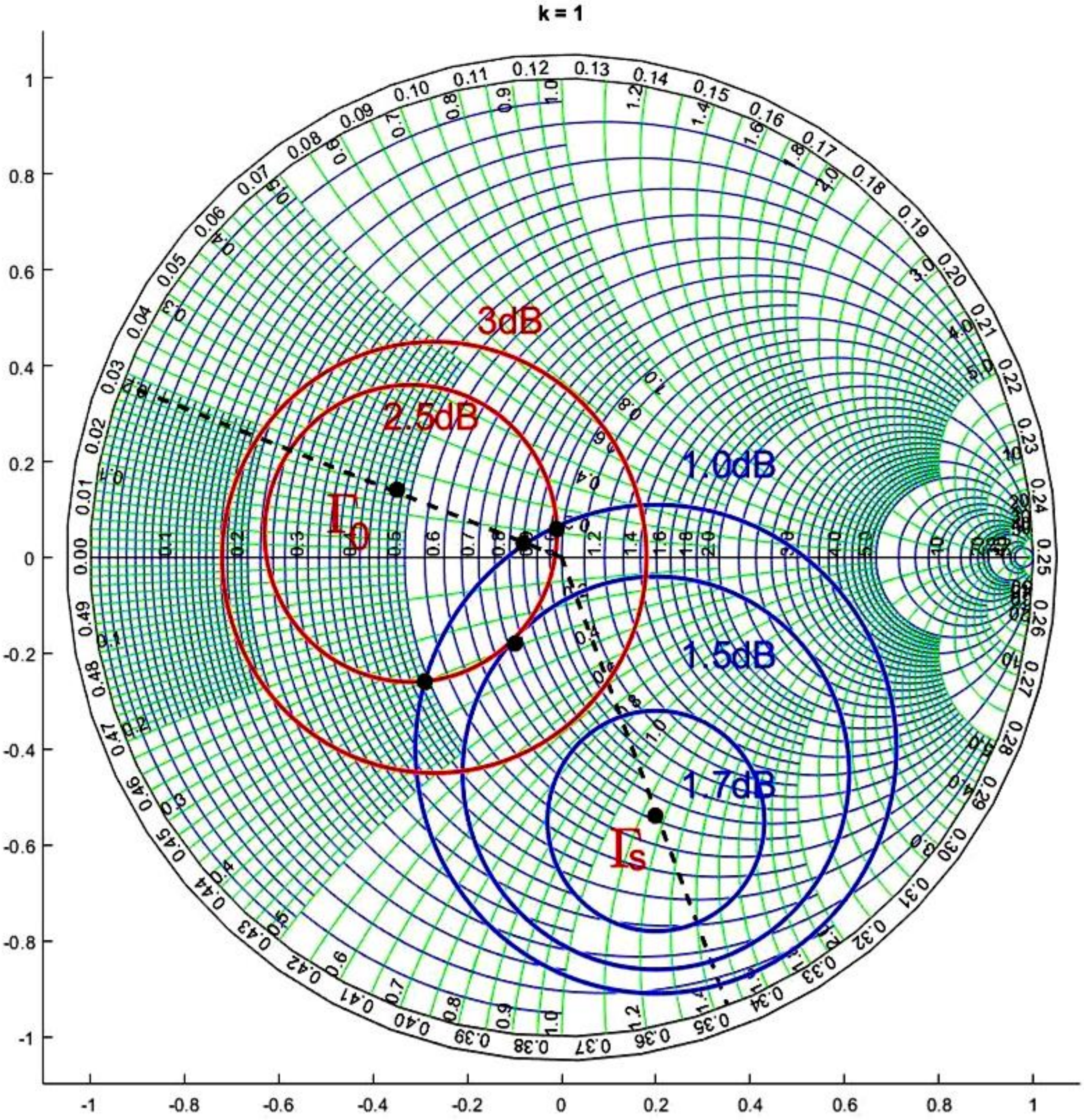

Figure 3. Smith chart for TB-LNA for NF and gain circle.

Finding the best value for Γ_s results in the lowest NF value and highest gain. The following equation is used to create a circle of NF and obtain the NF constant using the Smith chart.

$$\left|\Gamma_s - \frac{\Gamma_o}{1+N_i}\right|^2 = \frac{{N_i}^2+N_i(1-|\Gamma_o|^2)}{(1+N_i)^2} \tag{3}$$

Therefore, the value of N_i should equal to zero for $NF_i = NF_{min}$ to hold true. Similar to how $CF_i = \Gamma_o$ and $\Gamma_{fi} = 0$ are chosen in the Smith chart from the intersection of the gain and noise circles, this happens for the choice of ideal noise resistive value to achieve maximum gain and minimal N F. The center for circle and normalized noise resistance is provided in equation to construct a circle with a noise constant (4)

$$C_{Fi} = \frac{\Gamma_o}{1+N_i}; \Gamma_{fi} = \frac{1}{1+N_i}\sqrt{{N_i}^2 + N_i(1-|\Gamma_o|^2)} \tag{4}$$

To design a LNA with $NF_{min} = 3.6dB$, $R_n = 4.1\ \Omega$ and $\Gamma_o = 0.458 < 156°$. For these values, N_i is calculated and gives a value of $N_i = 0.46$ and at $C_{Fi} = 0.333$ with $\Gamma_{fi} = 0.52$.

The Smith chart is used to calculate and plot relative values for best noise resistance when determining gain constant and noise constant values. This TB- LNA design technique gives a boost in gain and noise performance. The initial stage of ckt is tuned, and its channel gain is assessed, to improve noise performance and achieve a compact LNA network. An MOSFET's S-characteristics and noise parameters are presented in order to design the necessary TB-LNA. The essential thing to keep in mind when designing is if the condition of $\Delta < 1$ and $K > 1$ is met, the system is unconditionally stable, and if it doesn't, system is unilaterally unstable. The intersection values for the minimal noise and maximum gain values are chosen and estimated using the smith chart. Value $\acute{\Gamma}_s$ is decided from g_s circle and $\acute{\Gamma}_l$ is decided from g_l circle. The noise parameters are selected such as 4 GHz ($Z_0 = 50\ \Omega$) are

$$S_{11} = 0.6 < -60°;\ S_{12} = 0.05 < -60°;\ S_{21} = 1.9 < 81° \text{ and } S_{22} = 0.5 < -60° \tag{5}$$

By setting a value of $f_{min} = 1.6\ db$ and optimum $\acute{\Gamma}_{opt} = 0.62 < 100°$. The gain value for S- parameters may be estimated by substituting $K = 2.279$ and $\Delta = 0.38$ as constant values in derived equation.

$$U = \frac{|S_{12}S_{21}S_{11}S_{22}|}{(1-|S_{11}|^2)(1-|S_{22}|^2)} = 0.059 \tag{6}$$

$$G_{max} = G_{smax} + G_o + G_L = 8.53dB \tag{7}$$

The ideal N F with the assumed normalized value of the noise resistance affects the first cascade stage. The second and 3rd stages are configured for the best Power Gain and N F. The noise and performance were specifically improved by the feedback transformer technology, and a minimum distance for the coupling factor K = 1, maximum value was also implemented.

The source and drain conductance's are chosen to be close together, the gate is grounded, and the turns ratio is limited by striking a balance between stability and gain. Every stage of the cascade has less N F thanks to the transformer, which also increases power gain. With low loss passive input and output components, it also remained completely stable.

Simulated Results Discussion of Transformer-Boosting (TB) LNA Designed for Millimetre Waves Applications

Simulation results demonstrate that both topologies exhibit different strengths depending on the chosen substrate. The transformer boosting topology achieves higher gain values, particularly on the LCP substrate due to its lower dielectric loss, while the source degeneration topology exhibits better input matching and linearity across both substrates.

Specifically, LNAs on LCP substrates displayed an improvement in gain by approximately 8% compared to PI, attributed to its lower loss tangent. However, PI-based designs showed slightly better mechanical robustness, suggesting its relevance for applications involving mechanical stress or bending.

The noise figure performance of the transformer-boosted LNA on LCP was also notably superior, with values below 2.5 dB at 28 GHz, compared to 3.1 dB for the same topology on PI. These findings emphasize the significance of matching substrate properties with the intended circuit topology and application demands.

Figure 4 shows the Circuit description of (TB)-LNA which was designed Using CADENCE Orcad 16.6 software, this step-up transformer Feedback LNA mechanism is simulated, and the results are given. The results reveal that there is a significant decrease in the I/O Reflection Coefficients measured by software, thus values are assessed using the S-parameters. We have also calculated the different values theoretically by using its equations.as shown in Figure 4.

The measurement data were shown with the design guidelines for this design approach. Because the circuit needs a very low voltage supply and low power dissipation, this Low Noise Amplifier was constructed using a Coupling Factor value of one and a MOSFET (IRF150). The circuit cutoff frequencies

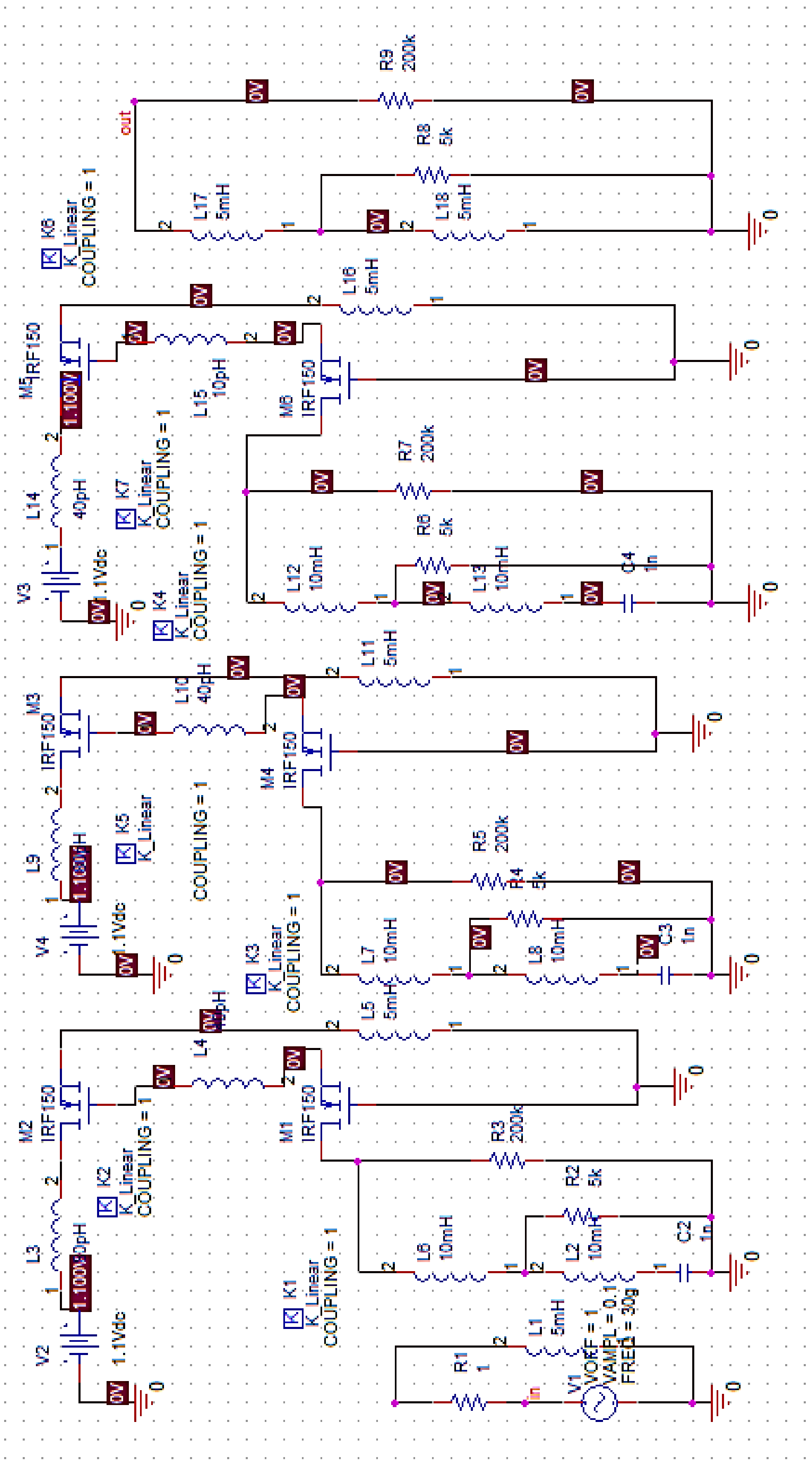

Figure 4. Circuit description of (TB)-LNA.

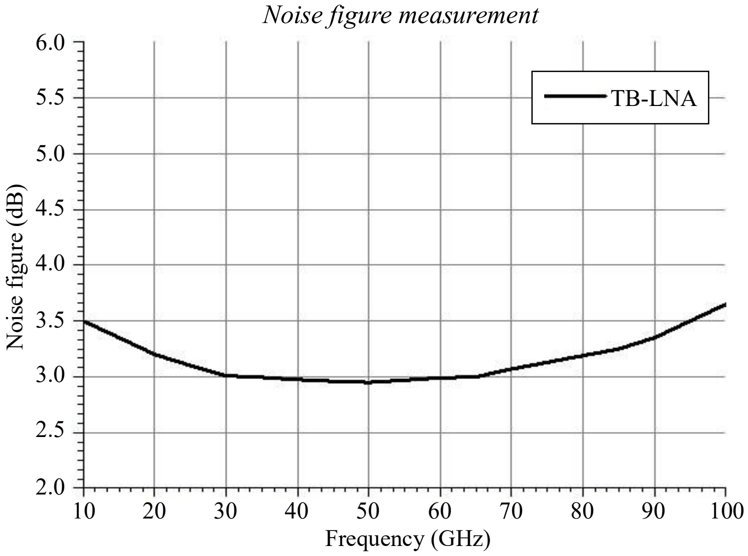

Figure 5. NF measurements TB-LNA.

are increased with the addition of a common gate MOSFET. For impedance matching the 50 Ω signal source impedance, combination of an off-chip inductor and a wire connection in this implementation results in an inductance value of 80 pH and 40 pH.

The IRF 150 MOSFET is used with features hermetically sealed in a -3-metal package and simple inverter requirements with shielding options available. In addition, pulse width ≤ 300 µs, δ ≤ 2% @ VDD = 50 V, L ≥ 160 µH, RG = 25 Ω, Peak IL = 38 Amp, Initial TJ = 25°C @ ISD ≤ 38 Amp, di/dt ≤ 300 A/µs VDD ≤ BVDSS, TJ ≤ 150°C, Suggested RG = 2.35 Ω. This TB-LNA draws a current of 1.61 mAmp from the 1.25 supply voltage, where the CS and CG stages consume 0.7 mAmp and 0.9 mAmp, respectively. Considering linearity, a higher amount of current is allocated in the CG stage.

It is clear from Figure 5 that LNA exhibits a gain of $3dB$ at 30 GHz to 90 GHz. According to the simulation results, the amplifier is kept stable with a better choice of coupling coefficient, which results in a constant value between 30 GHz to 90 GHz. The N F value can be reduced by an appropriate choice of the transconductance coefficient and S-parameters.

A cascaded common gate topology with the transformer gain technique implemented led to a 3 dB noise gain reduction at 30 GHz. The total gain of the LNA for higher frequency values is computed by utilizing a coupling factor of 1 and inductances of 80 pH, 80 pH, and 40 pH N F min measured using the given formulae. The LNA has a 3 dB gain between 30 GHz to 90 GHz. The simulation's output demonstrates that as long as the amplifier is kept steady through superior coupling coefficient selection, the value in between 30 GHz to 90 GHz stay constant. The formula for determining the N F of the entire circuit is:

$$NF = \frac{SNR_{out}}{SNR_{in}} \tag{8}$$

$$Overall\ NF_g = 10log_{10}(NF) \tag{9}$$

The values for the overall N F are obtained using equations (8) and (9).

LCP consistently delivered better NF performance (~2.1 dB) than PI (~2.7 dB), validating its low-loss dielectric nature. The degenerated LNA suffered a slight penalty in NF but performed better in terms of power stability.

The circuit's Power Gain is enhanced in relation to N F. Figure 6 shows the simulation results for measuring Power gain. Power gain is a most significant factor that remains essential when creating the best LNA for communication system. Therefore, in this TB- topology, transformers are employed to increase Power Gain and also to lower the N F. Using the following equation, Power Gain in a CADENCE ORCAD 16.6 software virtual tool was measured.

$$db((output\ voltage * output\ current)/(input\ voltage * input\ current)) \quad (10)$$

At the circuit's output, a Power Gain plot is created by comparing Freq. and power values. Power Gain results in 66.5 dB at a freq. of 30 GHz and reached a value of 61.8 dB at 90 GHz. By calculating through the theoretical calculation it comes 12.2 dB at 50 GHz. According to Figure 6, the proposed TB-LNA design topology is superior to other traditional approaches since it increased gain up to -10 dB, which is 0.33% greater than earlier approaches.

It is clear from Figure 7 that TB-LNA exhibits S_{11} (I/P Reflection coefficient) is better than −10 dB in simulation results from 30 GHz to 60 GHz. The value for S_{11} is -17 dB at 30 GHz and reaches -13 at 60 GHz and reached at max value of -29 dB at 40 GHz.

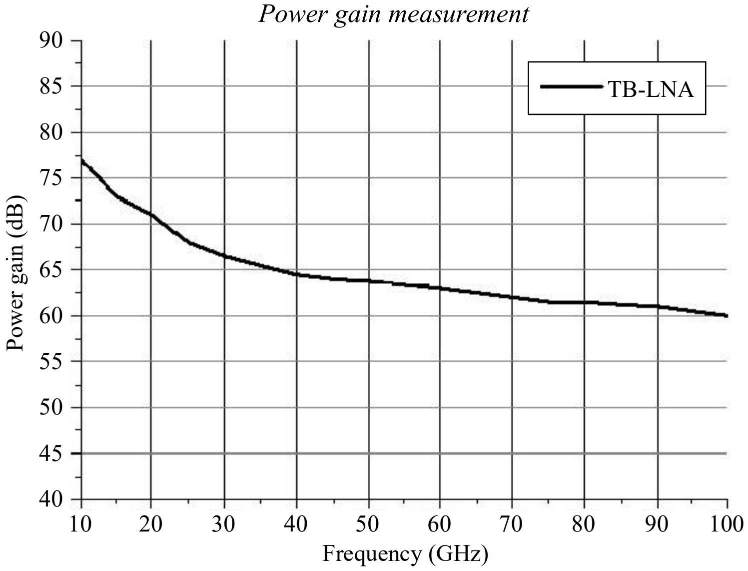

Figure 6. Gain analysis measurements of TB-LNA.

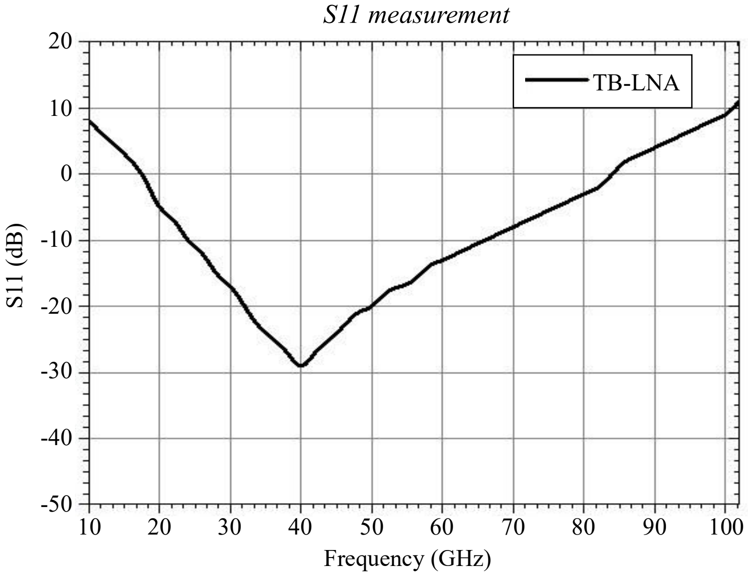

Figure 7. S_{11} measurement of TB-LNA.

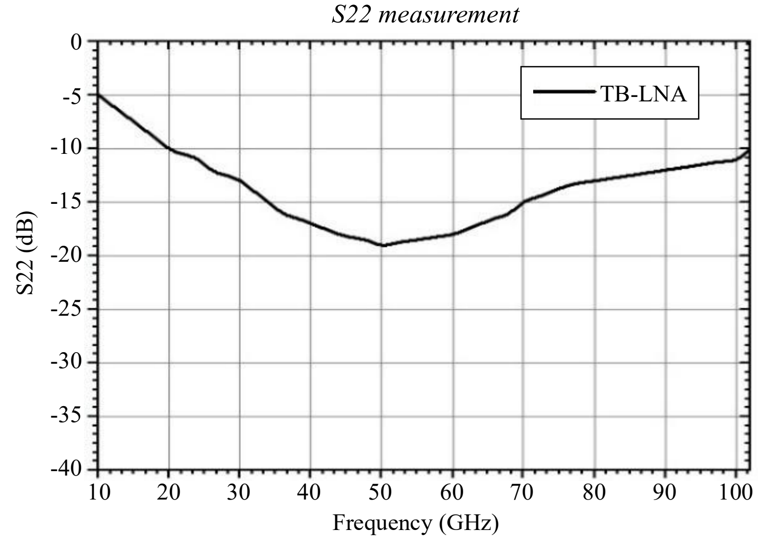

Figure 8. S_{22} measurement of TB-LNA.

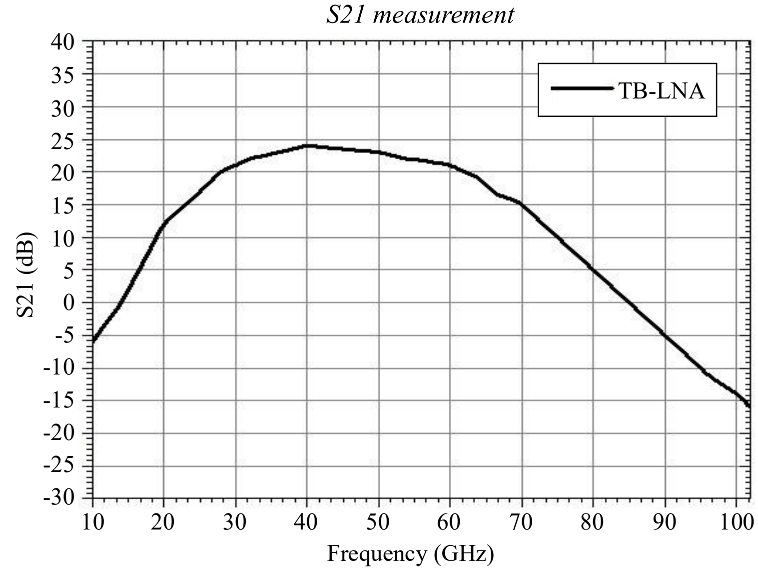

Figure 9. S_{21} measurement of TB-LNA.

According to Figure 8, the value for S_{22} (O/P Reflection coefficient) is negative throughout the frequency in the graph. The value for S_{22} is -13 dB at 30 GHz and reaches -18 at 60 GHz and reached at max value of -19 dB at 50 GHz.

According to Figure 9, S_{21} (Forward transmission coefficient) in simulation results from 30 GHz to 60 GHz, the value for S_{21} is 21 dB at 30 GHz and reaches 20 dB at 60 GHz. and reached at max value of 24 dB at 40 GHz.

It is clear from Figure 10, that S_{12} (Reverse transmission coefficient) in simulation results from 30 GHz to 60 GHz results the value from -25.3 dB at 30 GHz and reaches -30.4 dB at 60 GHz. Metrics Calculated for TB-LNA Based on Frequency from 10 GHz to 100 GHz are given in Table 1 as follows.

Analysis of Designing an Induced Degeneration Topology Narrow Band (IDT NB) - LNA for Millimetre Wave Applications

Induced Degeneration Topology (IDT) was used in the construction of our high gain high output matched NB LNA for millimetre wave applications. The narrowband inductor cascade design is presented

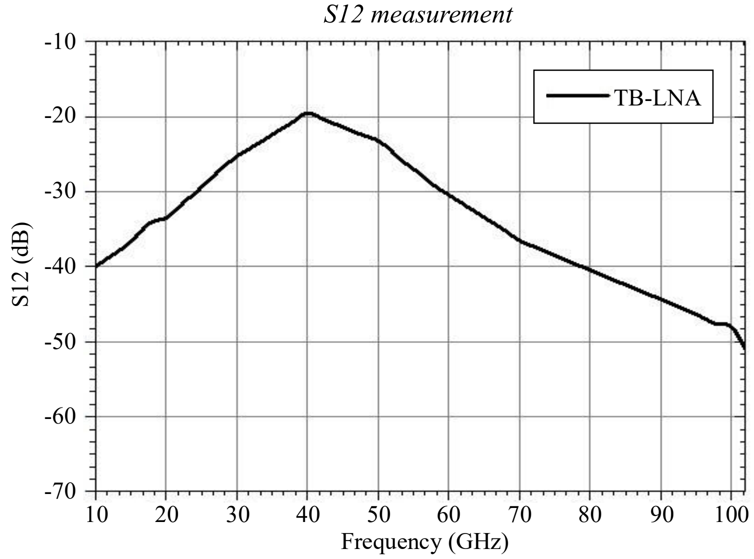

Figure 10. S_{12}-measurement of TB-LNA.

Table 1. Metrics calculated for TB-LNA based on frequency.

Frequency (GHz)	S11 (dB)	S22 (dB)	S21 (dB)	S12 (dB)	N F (dB)	Gain (dB)	Power gain (dB)	O/P impedance (Ω)	O/P capacitance (pF)
10	8	-5	-6	-40	3.5	7	77	2000	500
20	-5	-10	12	-33.5	3.2	15.5	71	2350	40
30	-17	-13	21	-25.3	3.01	27	66.5	3000	-155
40	-29	-17	24	-19.5	2.975	30	64.5	3700	-225
50	-20	-19	23	-23.2	2.95	29	63.8	4100	-300
60	-13	-18	21	-30.4	2.99	24	63	5000	-325
70	-8	-15	15	-36.5	3.07	18.5	62	5500	-330
80	-3	-13	5	-40.4	3.19	15	61.5	6000	-340
90	4	-12	-5	-44.3	3.35	11	61	6500	-340
100	9	-11	-14	-48	3.65	8	60	7300	-340

in this work. This design's matching values were discovered to be as low as -25 dB, and a high reverse isolation factor was measured. The design was initially analyzed for Gain of up to 20 dB. Following the completion of the S-parameter study, the values are shown on a smith chart to assess the stability of the system and to plot profit circles. This IDT NB-LNA design restricts the Noise performance and boosts the Gain, and the N F has been reduced. The IDT NB-LNA was then assessed using output impedance, N F, voltage gain, and power gain. The evaluated values are then contrasted with earlier procedures to demonstrate that the suggested design outperforms them. Because it impacts the stability of the LNA, the output load value is selected as carefully as possible. By amplifying the signal input, the method for Induced Degeneration used in this LNA design contributes to Gain increase and improves overall gain performance. Similar to this, while using CADENCE ORCAD 16.6 software to construct a cascaded degenerate narrowband inductor LNA, this IDT NB-LNA exhibits a minimum N F of 2 dB at 90 GHz and a measured Power Gain of 16 dB at 90 GHz. This method of creating an IDT NB-LNA is effective for radio receiver applications [26].

Induced Degeneration Topology (IDT) NB-LNA Design

The designed IDT NB-LNA overall circuit is shown in Figure 11, shows Inductive Source Degeneration Topology has been used to obtain the value gain from the sort of $18dB - 22dB$. Noise Figure (NF) is discriminated against to be 2 dB. The LNA design was done with a lossy inductor model as transmission lines are used to build LNA chosen with a quality factor (Q) equal to 5. Capacitors are additionally included in the circuit so that to make sure that matching at both input and output sides are in enhanced

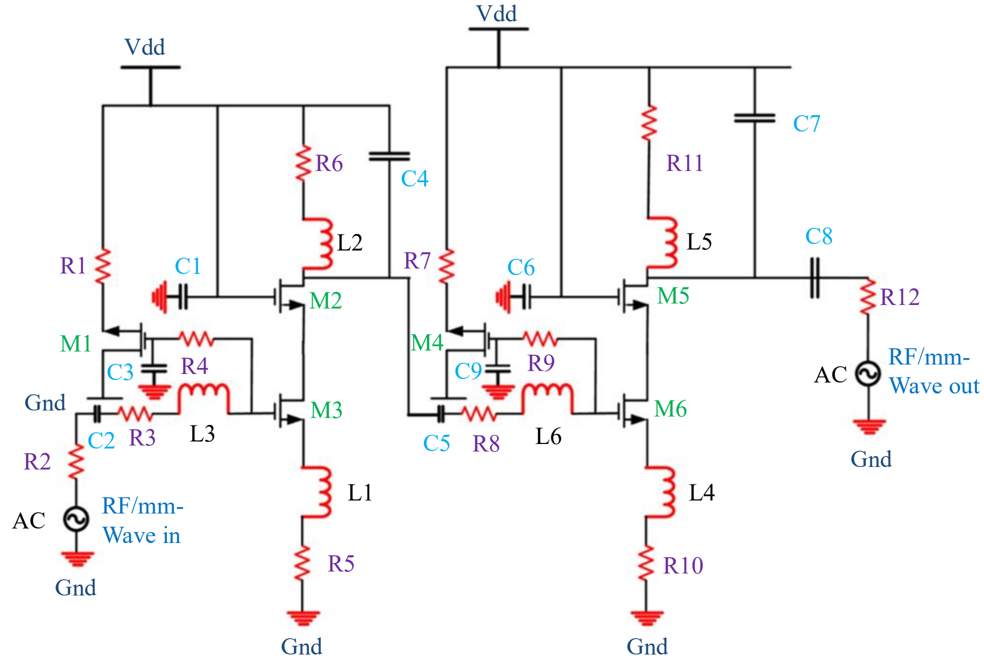

Figure 11. Circuit diagram of narrow band inductive source degeneration topology LNA.

quality which give better isolation for the whole circuit from the noise of the power source. $M1, M2, M3$ and $M4$ are N-Channel enhancement mode power MOS transistors due to their high gain in the circuit and provide sufficient gain for the whole architecture. As it was already known that LNA reaches its minimum NF when its source impedance has been equal to conjugate of LNA input impedance (Z_{opt}). Lossy inductor models are used to achieve estimated results, and the circuit is fed with an RF source of 50 ohms with a signal power level of $-40dB$ at a frequency of $1.57GHz$ operation. The following equations are used to find the value of inductors and gain of the transistor to reach $50\ ohms$.

$$Z_{in} = \frac{L_s g_m}{C_{gs}} \tag{11}$$

In this equation (11), L_s represents source inductance, C_{gs} is defining gate-source capacitance and g_m represents transconductance of the transistor and can be given as

$$g_m = \sqrt{2\mu_n C_{oxC} I_d \frac{W}{L}}; C_{gs} = \frac{2}{3} W.L.C_{oxC} \tag{12}$$

In this equation (12), μ_n is mobility charge carriers, C_{oxC} is the capacitance of oxide with respect to unit area and I_d is the drain current. W/L is the ratio of gain transistor that helps to provide high forward gain forg_m/I_d. The circuit is designed with high gain and low noise and provides good stability between input and output port with the help of this inductive degeneration architecture. Figure 11 shows the Circuit diagram of cascaded degenerate Narrow Band Inductive Source Degeneration Topology LNA.

Simulated Results of Induced Degeneration Topology (IDT) NB-LNA

The IDT NB-LNA as shown in Figure 11, for the antenna front array of an astronomical radio receiver has been constructed utilizing an inductor degeneration topology and the results are provided. The CADENCE Orcad 16.6 software tool measures values with the aid of S-parameters. As a result, it demonstrates that the I/O Reflection Coefficient measured by CADENCE ORCAD 16.6 SOFTWARE tool has significantly decreased.

Figure 12 shows the Overall Circuit Diagram of Induced Degeneration Topology (IDT) NB-LNA which is designed using CADENCE ORCAD 16.6 software to construct a cascaded degenerate narrowband inductor LNA.

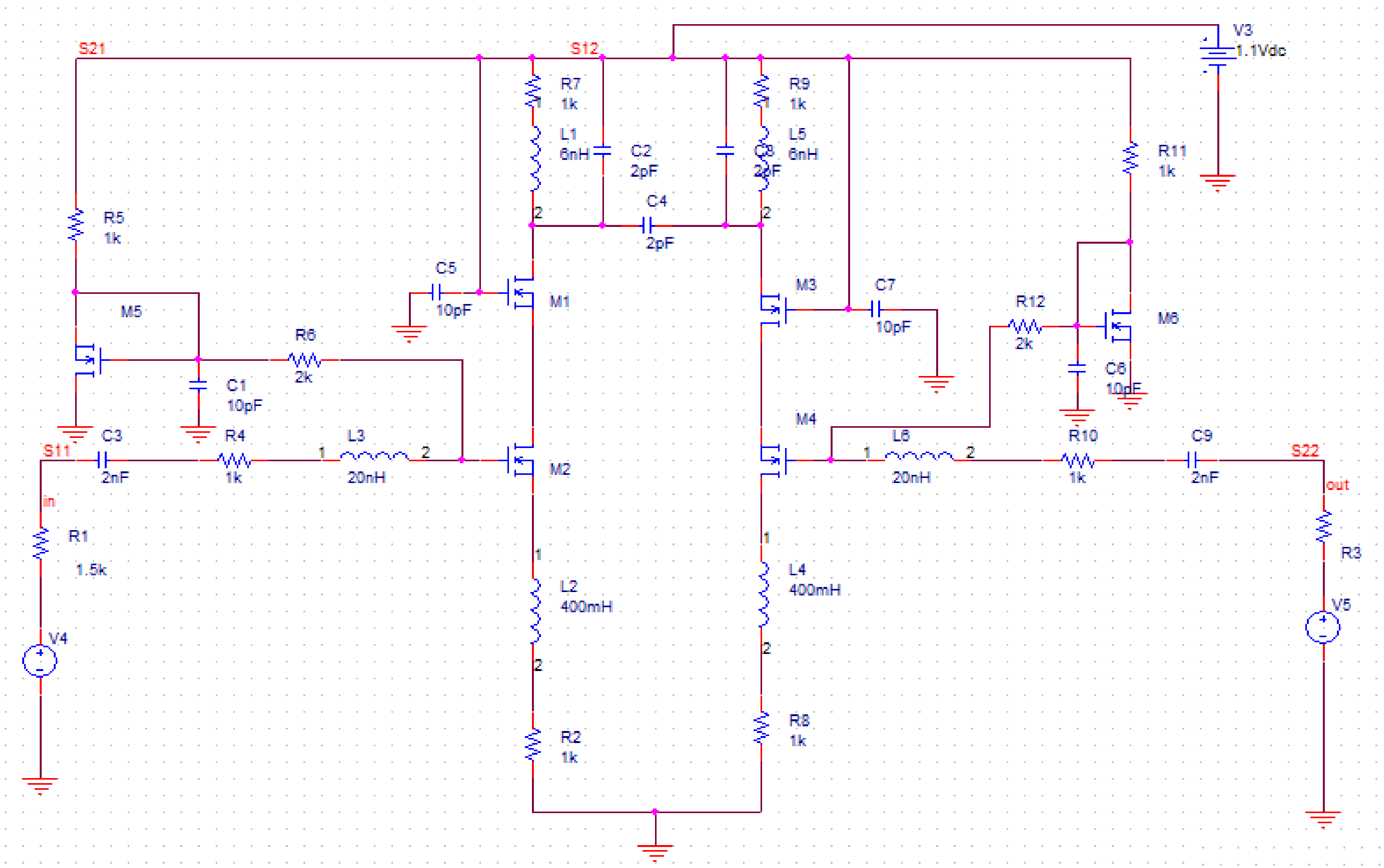

Figure 12. Overall circuit diagram of induced degeneration topology (IDT) NB-LNA.

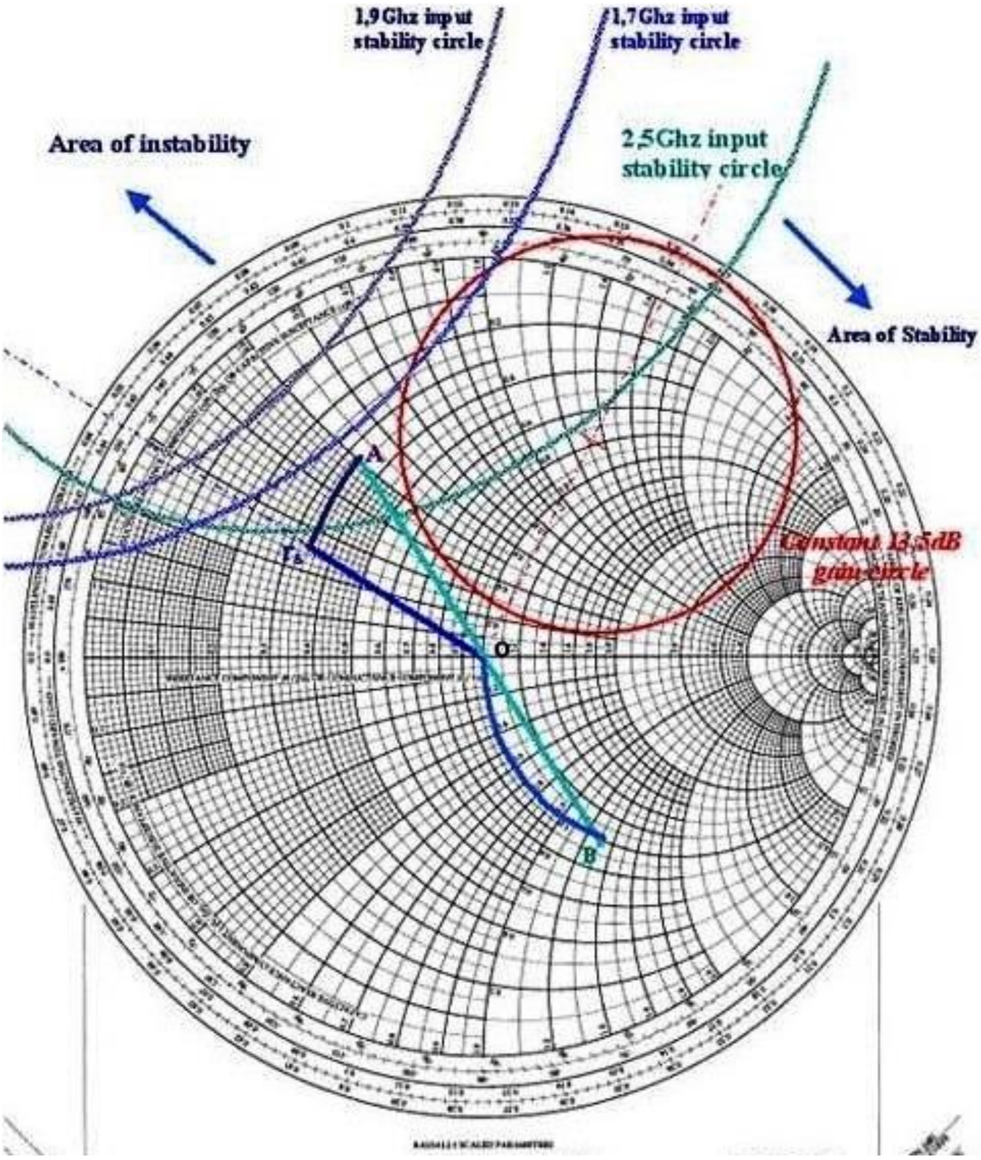

Figure 13. Smith chart of IDT NB-LNA.

Figure 13 shows the Stability *Analysis* of *of IDT* NB-LNA using Smith Chart. The soundness of a semiconductor depends on the Impedances to its information and O/P ports. A real negative piece of Γ_{in} or Γ_{out}would show that the operator is hesitating and sending misleading signals. Amplifier stability is frequency dependent due to the imaginary part of the reflection coefficients.

$$|\Gamma_{in}| = \left|S_{11} + \frac{S_{12}S_{21}\Gamma_l}{1-S_{22}\Gamma_l}\right| < 1 \tag{13}$$

$$|\Gamma_{out}| = \left|S_{22} + \frac{S_{12}S_{21}\Gamma_s}{1-S_{11}\Gamma_s}\right| < 1 \tag{14}$$

The amplifier requires unconditional stability was achieved using these equations; these conditions in term define a range of Γ_s and Γ_L is then plotted in a smith chart. By initializing the values Γ_{in} and Γ_{out} to 1. With the help of calculating R_L and C_L, the radius and centre point of output and input stability circle are found. From the stability circle, it is found that the perimeter of this circle represents stable and unstable load impedances. S-parameters are tuned finely to amplify the input. All impedance values are calculated within the smith chart, which was found to have a stability circle at its center for the proposed design, indicating that the stability circle was stable.

Figure 14 shows the Schematic diagram of Induced Degeneration Topology (IDT) NB-LNA designed in using CADENCE ORCAD 16.6 software. The (IDT) NB-LNA design's overall circuit diagram is examined with a frequency range of 10-100 GHz.

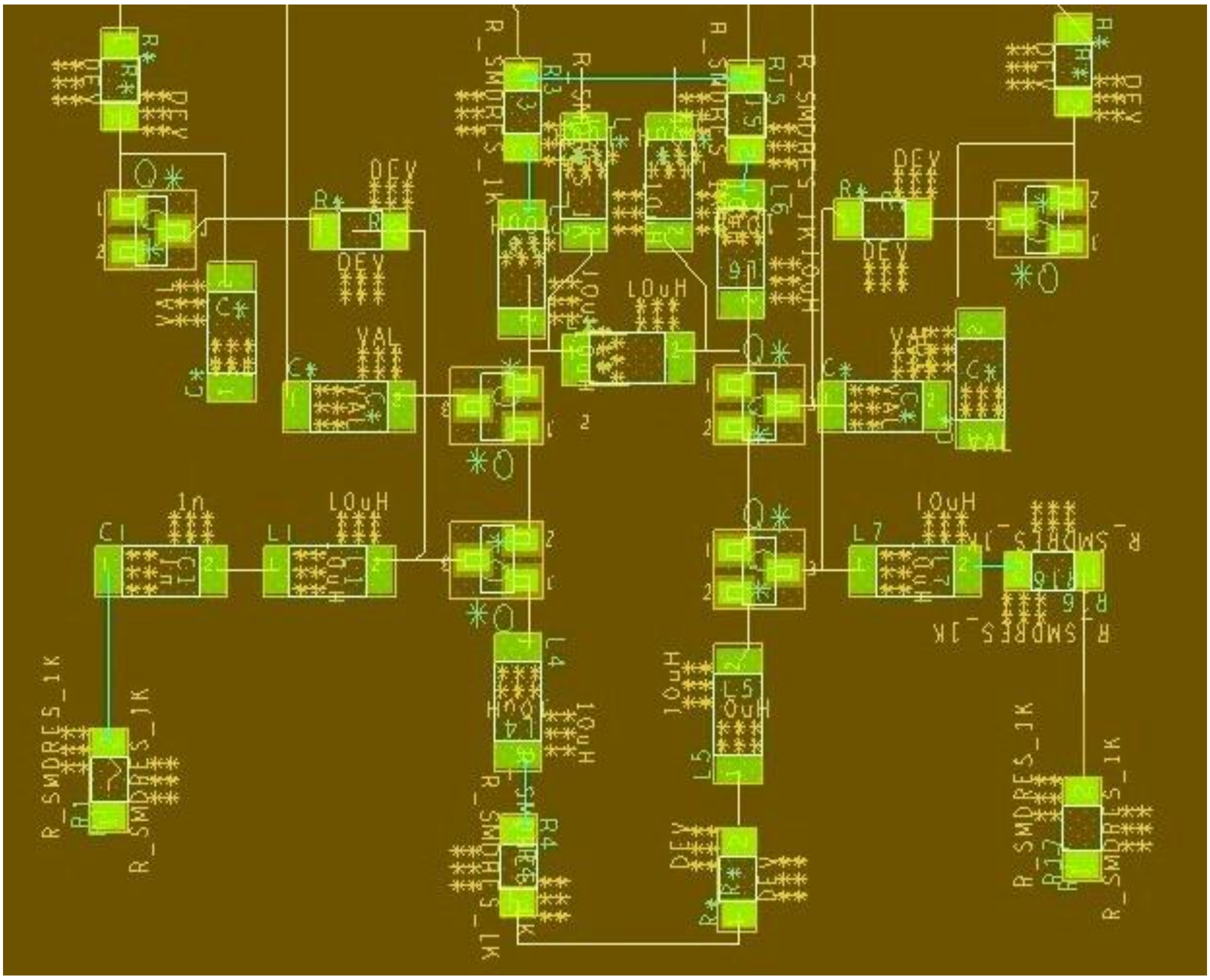

Figure 14. Schematic diagram of (IDT) NB-LNA.

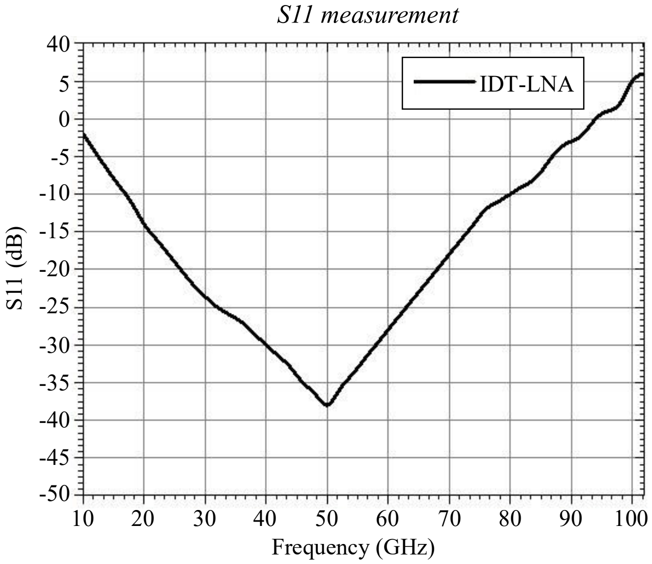

Figure 15. S_{11} value measurement of NB IDT-LNA.

Figure 15 shows the value of S_{11} (I/P Reflection coefficient) for the frequency range from 10 GHz to 100 GHz. the value of S_{11} is better than −10 dB in simulation results from 18 GHz to 80 GHz. The lowest value reaches its maximum for S_{11} is -38 dB at 50 GHz.

Figure 16 shows the value for S_{22} (O/P Reflection coefficient) is negative throughout the frequency in the graph. The value for S_{22} is -14 dB at 30 GHz and reaches -18 dB at 60 GHz and reached at max value of -22 dB at 50 GHz.

Figure 17 shows the value for S_{12} (Reverse transmission coefficient) in simulation results from 10 GHz to 100 GHz. Figure 18 shows the S_{21} (Forward transmission coefficient) in simulation results from 10 GHz to 100 GHz, the value for S_{21} reached at max value of 30 dB at 50 GHz.

Figure 19 shows the NF measurement of NB ISDT-LNA, it shows that it resulted in NF of approximately 2 dB from 30 GHz to 60 GHz. Figure 20 shows the Gain measurements for NB ISDT-LNA, as it reaches max value of 39 dB at 50 GHz. Figure 21 shows the Power Gain measurements for NB ISDT-LNA, it varies from 116 dB to 74 dB within the 30-60 GHz frequency region.

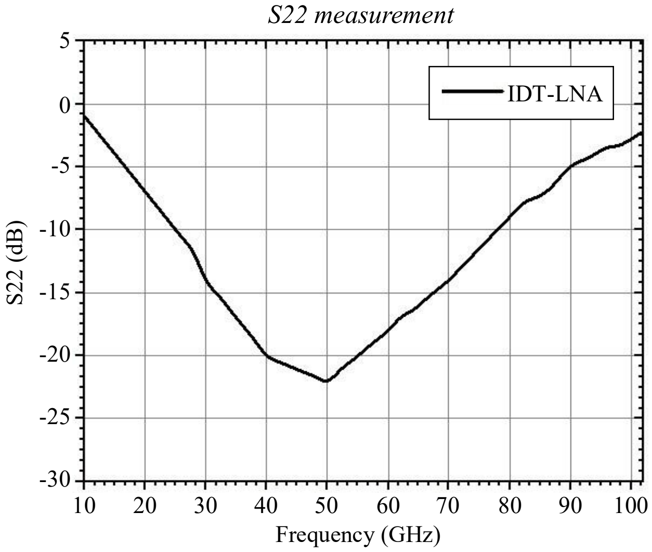

Figure 16. S_{22} value representation of NB IDT-LNA.

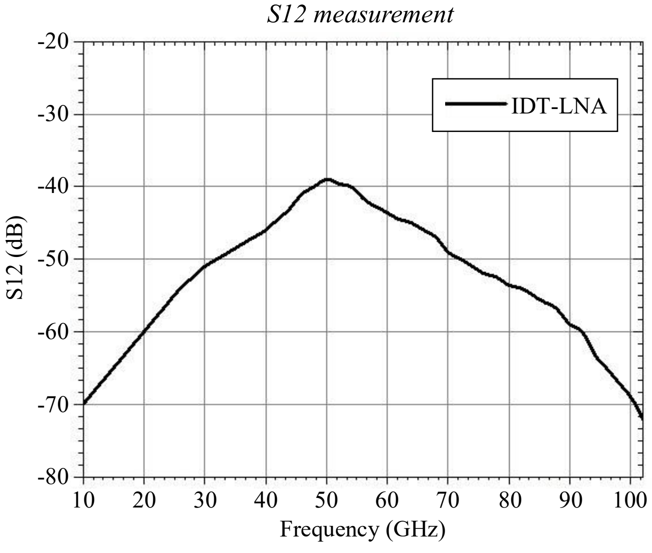

Figure 17. S_{12} value representation of NB IDT-LNA.

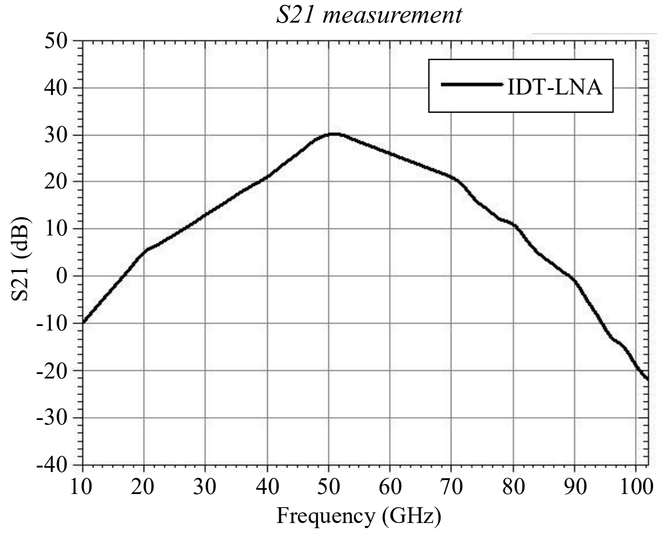

Figure 18. S_{21} value representation of NB IDT-LNA.

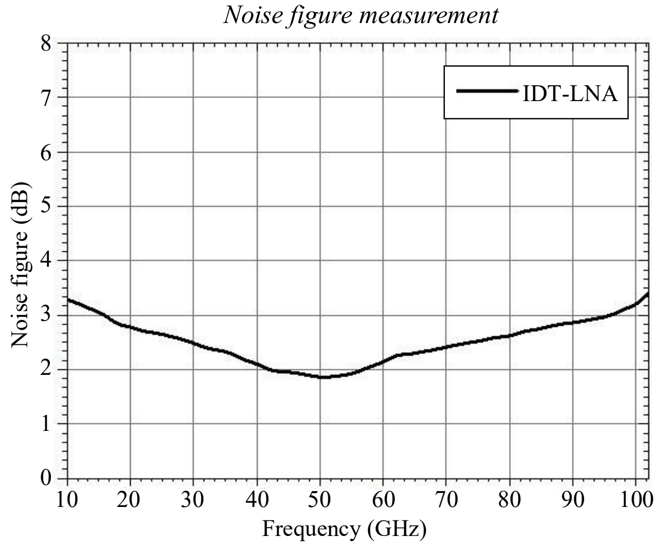

Figure 19. NF measurement of NB IDT-LNA.

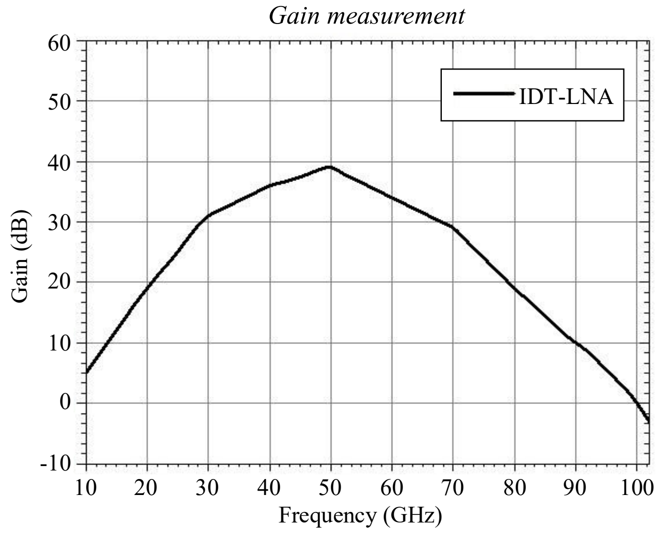

Figure 20. Gain analysis results of NB IDT-LNA.

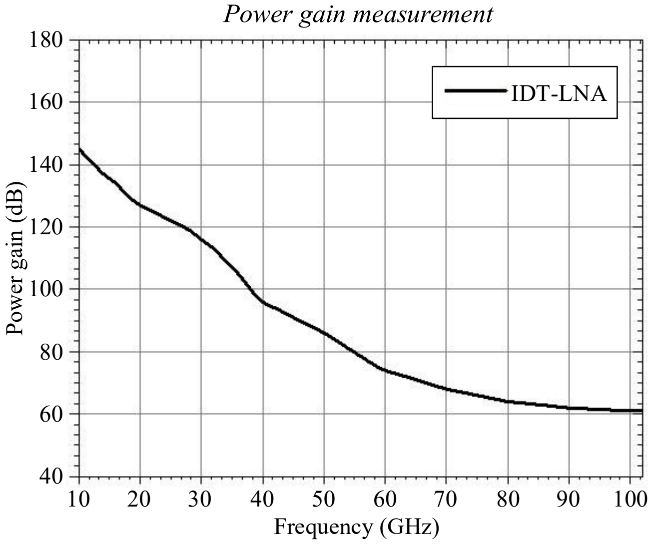

Figure 21. Power gain analysis results of NB IDT-LNA.

Table 2. Metrics calculated for NB IDT-LNA based on frequency.

Frequency in (GHz)	S11 (dB)	S22 (dB)	S21 (dB)	S12 (dB)	Gain (dB)	NF (dB)	Power gain (dB)
10	-2	-1	-10	-70	3.24	5	145
20	-14	-7	5	-60	2.78	19	127
30	-23.6	-14	13	-51	2.48	31	116
40	-30	-20	21	-46	2.1	36	96
50	-38	-22	30	-39	1.86	39	86
60	-28	-18	26	-43.6	2.14	34	74
70	-18	-14	21	-49	2.41	29	68
80	-10	-9	11	-43.6	2.62	19	64
90	-3	-5	-1	-61	2.86	10	62
100	5	-2.8	-2.8	-69	3.2	0.5	61

Metrics Calculated for NB induced degeneration topology LNA Based on Frequency from 10 GHz to 100 GHz are given in Table 2 as follows.

RESULTS AND DISCUSSION OF COMPARISON ANALYSIS OF TRANSFORMER BOOSTING AND INDUCED DEGENERATION TOPOLOGY DESIGN OF LNA FOR MILLIMETER-WAVEFREQUENCY RANGE

The performance of both topologies across the two substrates is summarized below:

1. *Gain analysis:* The transformer-boosted LNA on LCP achieved the highest peak gain (~17 dB at 28 GHz), benefitting from low substrate loss. On PI, gain was reduced slightly (~15 dB) due to higher dielectric losses.
2. *Return loss:* Both topologies showed better return loss on LCP (< -12 dB across the band), confirming superior impedance matching thanks to its lower ε_r. Transformer boosting showed more consistent S11 across frequencies than degeneration-based designs.
3. *Noise figure:* LCP consistently delivered better NF performance (~2.1 dB) than PI (~2.7 dB), validating its low-loss dielectric nature. The degenerated LNA suffered a slight penalty in NF but performed better in terms of power stability.
4. *Substrate impact discussion:* The substrate significantly affects electromagnetic wave propagation in RF circuits. LCP outperformed PI across most parameters due to lower loss tangent and dielectric constant. However, PI offers advantages in mechanical flexibility and processing cost, making it suitable for cost-sensitive or wearable applications. As shown in Table 3

Table 3. The metrics calculated for comparison analysis of transformer boosting and NB induced source degeneration topology design of LNA for millimeter-wave application from the frequency range of 10 GHz to 100 GHz.

Freq (GHz)	**Transformer-boosting (TB) LNA**							**Induced degeneration topology (ISDT) NB-LNA**						
	S11 (dB)	***S22 (dB)***	***S21 (dB)***	***S12 (dB)***	***NF (dB)***	***Gain (dB)***	***Power gain (dB)***	***S11 (dB)***	***S22 (dB)***	***S21 (dB)***	***S12 (dB)***	***Gain (dB)***	***NF (dB)***	***Power gain (dB)***
10	8	-5	-6	-40	3.5	7	77	-2	-1	-10	-70	5	3.24	145
20	-5	-10	12	-33.5	3.2	15.5	71	-14	-7	5	-60	19	2.78	127
30	-17	-13	21	-25.3	3.01	27	66.5	-23.6	-14	13	-51	31	2.48	116
40	-29	-17	24	-19.5	2.975	30	64.5	-30	-20	21	-46	36	2.1	96
50	-20	-19	23	-23.2	2.95	29	63.8	-38	-22	30	-39	39	1.86	86
60	-13	-18	21	-30.4	2.99	24	63	-29	-18	26	-43.6	34	2.14	74
70	-8	-15	15	-36.5	3.07	18.5	62	-18	-14	21	-49	29	2.41	68
80	-3	-13	5	-40.4	3.19	15	61.5	-10	-9	11	-53.6	19	2.62	64
90	4	-12	-5	-44.3	3.35	11	61	-3	-5	-1	-61	10	2.86	62
100	9	-11	-14	-48	3.65	8	60	5	-2.8	-19	-69	1	3.2	61

CONCLUSION

This work provides a comparative analysis of transformer boosting and source degeneration LNA topologies implemented on polymeric substrates, namely Polyimide and Liquid Crystal Polymer. Through simulation-driven evaluation, it was found that LCP generally offers better RF performance due to its lower dielectric loss, making it suitable for high-frequency applications. Meanwhile, PI remains valuable for applications where mechanical strength and thermal endurance are prioritized. The results advocate for careful substrate selection in polymer-based LNA designs, which can significantly influence performance outcomes. Future work will focus on fabricating the proposed designs and validating simulation outcomes through measurement, as well as exploring additional polymer materials. Finally, we conclude and future direction of the research work. Moreover, following are the comparison analysis:

- In TB- LNA design, we have improved the gain and reduce the noise in each of the stage of transformer boosting by using 3-stages cascaded LNA concept for millimeter wave applications.
- It produces a specific output after being fed back into the input for the next stage. A Smith chart and derived equations are both used to choose the appropriate design variables. The suggested method was conceptualized theoretically and a good justification was given. According to simulation results, the suggested approach can boost Gain of 30 dB while lowering NF of 2.975 dB at 40 GHz.
- In NB-LNA with Induced Degeneration cascaded Topology, this exhibits a min NF of 1.86dB at 50 GHz and Gain of 39 dB at 50 GHz in measurement.
- By the simulation in CADENCE OrCad 16.6 Software, the parameter such as S-parameters, NF, Gain, I/O impedance and Power gain is simulated for varying frequency from 10 GHz to 100 GHz.
- The metric also increases but the value for power gain decreases. At 100 GHz the value obtained for power gain is 60 dB for TB-LNA and 61 dB for NB IDT-LNA,
- Now finally we came to the conclusion that the induced degeneration topology-based NB-LNA perform well with regards to the transformer boosting TB LNA w.r.t. to gain and NF of the designed LNAs.

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