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Focus and Scope

International Journal of Electrical and Computer Engineering (IJECE), ISSN 2088-8708, e-ISSN 2722-2578 is the official publication of the Institute of Advanced Engineering and Science (IAES). The IJECE is open to submission from scholars and experts in the wide areas of electrical, electronics, instrumentation, control, telecommunication, and computer engineering from the global world. The journal publishes original research papers, review papers, and short communications in the field of electrical & power engineering, circuits & electronics, power electronics & drives, automation, instrumentation & control engineering, digital signal, image & video processing, telecommunication system & technology, computer science & information technology, internet of things, big data & cloud computing, and artificial intelligence & soft computing which covers, but not limited to, the following scope:

Electrical and Power Engineering: AC microgrids and DC microgrids; Advanced modelling of power system components; Co-simulation of power systems; DC and AC traction distribution systems for railways; Demand-side management; Deregulated power systems; Design and construction of the electrical parts; Design of modern energy management systems (EMS); Deterministic and reliability analysis of operational safety; Development modelling and analysis of environmental impact of electric power systems; Development, stability, availability, reliability and operational safety of electric power system subsystems; Dielectrics and insulation technology; Distributed energy resources (DER); Distributed energy storage systems; Distributed generation; Distribution management systems (DMS); Disturbances and transient phenomena in power systems; Economic analysis in electrical power engineering; Economic efficiency of electrical devices and systems; Efficient use of energy and energy conservation; Electric facilities automation; Electric power generation sources; Electric traction; Electric usage; Electrical and automation; Electrical apparatus connected to such systems; Electrical engineering materials; Electrical equipment, electrical capacitors, wires and cables; Electrical insulators; Electrical machinery; Electrical measurements; Electricity and electricity energy; Electrification and automation of agriculture; Electromagnetic compatibility; Electro-magnetic transients (EMT); Electro-mechanical transients; Electro-mechanics and electric transportation; Electrotechnology; Energy conversion and electric machines; Energy efficiency methods; Energy management; Energy storage technologies and system operation and planning; Environmental protection; Establishment of open market environment, risk management and electrical energy trading; Flexible alternating current transmission system (FACTS); Future power distributions systems in ships and aircrafts; Generation planning and control; Green facilities and industries; Harmonics and power quality; High voltage apparatuses; High voltage DC transmission and low voltage DC distribution networks; High voltage engineering; High voltage insulation technologies; Household electrification; Industrial electric power distribution and utilization systems; Industrial power systems; Information and communication infrastructure for future power systems; Instrumentation and novel sensor technology for advanced monitoring of power systems; Integration of consumer-side resource systems; Integration of unconventional sources into existing power systems; Interaction and integration of electricity with other energy vectors and sectors (heat, cooling, gas, hydrogen, or transport); Lighting and electroradiative technique; Lightning detection and protection; Mathematical modelling of power plants components and subsystems; Metering technologies; Methodologies and technologies for testing power system components, as well as complex protection and control schemes; Mixed AC-DC transmission networks, their interaction and technologies for their optimal operation; Nanogrids, microgrids, DC microgrids, autonomous, islanded and remote networks; New concepts of robust, secure, reliable, self-healing and resilient power systems; New power system technologies; New technologies and techniques for power transmission, distribution, protection, control and measurement; Off-line and real-time simulators, hybrid simulation (stability and EMT) of large-scale systems; Optimization methods applied to power systems; Power conversion equipment; Power economic; Power generation; Power industry; Power plants automation and control; Power quality; Power system analysis, economics, operation, planning, metering, control, protection and stability; Power system dynamic performance (system stability analysis and controls); Power transmission and distribution; Primary and secondary plant in modern EHV/HV/MV/LV substations; Prosumer resource systems; Protection of electrical devices and systems; Reactive power control; Reliability theory; Renewable energy technologies (wind, solar/photovoltaic, hydro, tidal, geothermal, biomass), clean fossil fuel technologies (e.g., carbon capture) and their integration in modern power systems; Semiconducting, superconducting, conductor, dielectric, insulating materials; Simulation of power systems transients and power electronics; Smart buildings, district and cities; Smart distribution networks; Standardisation and new energy policies in using novel technologies for future power systems; Substation automation and control; Supervisory control and data acquisition (SCADA); System integrity protection schemes (SIPS); Technologies and new solutions for ancillary services support in power systems; Technologies for real-time dynamic security assessment, situational awareness, prevention of power system blackouts and approaches for power system restoration; Technologies to enhance flexibility in future energy systems; Theoretical electrical engineering (physical basis of electrical engineering, electromagnetic field theory, the theory of electric and magnetic circuits); Theory of power systems control; Transformers and power reactors; Transient processes in power systems (slow, fast and very fast transients); Transmission and distribution; Utilization of electric power; Wide area monitoring, protection and control (WAMPAC) in power system; etc.

Circuits and Electronics: Amplifiers; Amplifying electronic signals; Analog, digital and mixed-mode circuits; Application-specific polymer optical fibres and devices; Application-specific silica optical fibres and devices; Bioelectronics; Biomechanics and rehabilitation engineering; Biomedical circuits, transducers and instrumentation; Building blocks and systems; Circuit models; Circuit theory and applications; Circuit theory and modelling; Circuits and electronics for data conversion and modulation; Circuits and systems; Circuits; Complementary metal-oxide-semiconductor (CMOS); Computer-Aided Design (CAD); Consumer electronics; Cryptographic circuits; Design and implementation of application specific integrated circuits (ASIC); Digital electronics; Digital filters; Electromagnetic theory; Electronic components, devices, and systems; Electronic instrumentation; Electronic materials; Electronic sensors; Electronic systems; Electronics for space exploration; Embedded and CMOS integrated circuit systems; Filters; Hardware/software codesign; High level synthesis; High levels design languages; Integrated circuits; Interface circuits; Laser and optical systems; Materials for state-of-the-art transistors, nanotechnology, electronic packaging, detectors, emitters, metallization, and superconductivity; Measurement and acquisition of physical quantities; Medical electronics; Memristors and Memristive circuits; Microcircuits; Microcontrollers; Microelectronic system; Microelectronics; Microprocessor; Mixed signal circuits; Molecular electronics; MOSFET; Nanostructures and nanotechnologies; Network analysis and synthesis; Neuromorphic circuits; Nonlinear circuits; Non-linear circuits; Optoelectronic devices; Organic and inorganic circuits and devices; Organic field-effect transistor; Oscillators; Phase-locked loop (PLL); Printed electronics; Programmable logic chips; Programmable logic devices; Prototype devices and measurement; RF circuits; Science and technology of electronic materials; Semiconductor devices, magnetic alloys, insulators, and optical and display materials; Silicon devices; Silicon thin-film cell; Solid state electronics; Superconductivity circuits; System-on-a-chip (SoC); Thin film electronics; Thin film technologies; Thin-film diode; Thin-film memory; Thin-film solar cell; Thin-film transistor; Transform to electrical signals; Transistor; Very large scale integration systems (VLSI); VLSI Design; Voltage-controlled oscillator (VCO); etc.

Power Electronics and Drives: Adjustable speed drives; Advanced power converter topologies; All types of converters, inverters, active filters, switched mode power and uninterruptible power supplies; Application of control methods to electrical systems; Applications of power semiconductor technology; Batteries and Fuses; Batteries and management systems (BMS); Contactless power supply; Control and conversion of electric power in electric machine drives; Current control for shunt active power filters using predictive control; Current control of AC/DC or AC/DC/AC converters using predictive control; Current control of three-phase inverters using predictive control; Current control of three-phase source rectifiers using predictive control; Current control; Distributed power supplies; Efficient predictive control strategies; Electric propulsion system; Electrical machines; Electro-mobility (E-mobility); Electronic ballasts and solid-state lighting; EMC and noise mitigation; Energy conversion and conditioning technologies in physics research and related applications; Energy conversion and conditioning technologies in the industry; Estimation and identification methods for power converters; EV's battery chargers: contact and contact-less, standards and regulations; Fault coordination and protection of DC grids; Hard and soft switching techniques; High performance drives; High-voltage direct current (HVDC); Industrial scale power conditioning; Measurements techniques, sensors, standard and advanced

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Automation, Instrumentation and Control Engineering: Adaptive controls; Advanced computing for measurement; Advanced control techniques; Advanced manufacturing systems; Applications of control theory in industry; Automated guided vehicles; Automatic process control; Automation and controls; Automation industrial applications; Autonomous and vehicle systems; Biomechatronics biosensors; Complex adaptive systems; Control and automation; Control and intelligent systems; Control networks; Control stochastic; Control system; Control theory and applications; Correction elements; Digital control; Distributed control; Dynamic simulation Man/Machine interface; Fault detection and isolation; Fieldbus technology and interfaces; Frequency response; Hybrid and switching control; Image-based control; Industrial automation; Instrumentation system elements; Linear and nonlinear control systems; Manufacturing systems and automation; Mathematical control theory; Measurement techniques; Mechatronics; Modelling and identification; Optimization and optimal control; PLC system; Predictive control; Process automation; Process control and instrumentation; Process controllers; Process optimization and scheduling; Recent developments in automation and control; Recent trends in control systems; Robotics and applications; Robotics and controls; Robust control; Sampled-data control systems and digital control; Sensors; Stirling engine electric power generation programme; Stochastic control and filtering; System identification and control; System models; System response; Systems and automation; Transducer principles; Transfer function; Underwater echo and source location; Virtual instrumentation and control; Wireless sensor network for real-time device control; etc.

Digital Signal, Image and Video Processing: Acoustic and vibration signal processing; Advanced circuit and system design and implementation for emerging multimedia services; Biomedical imaging and image processing; Biomedical signal processing; Biometrics; Communication signal processing; Compression; Data processing; Detection and estimation; Digital signal and data processing; Digital signal processing; Diverse functionalities and services (classification, compression, identification, protection, recognition, restoration and segmentation); Earth resources signal processing; Efficient media sharing schemes in distributed environments; Emotion detection; Environmental signal processing; Facial recognition systems; Fast and complexity-reducing mechanisms to support real-time systems; Feature extraction; Filtering; Forensic voice comparison; Genomic signal processing; Geophysical and astrophysical signal processing; Handwriting recognition; Image and video compression: scalability, interactivity, international; Image processing: statistical inverse problems, motion estimation; Image and video-based recognition algorithms using deep neural networks; Image processing; Industrial applications; Medical imaging equipment and techniques; Multi-dimensional signal processing; New applications; Emotion and mental state recognition from speech; Novel applications for emerging multimedia services; Optical signal processing; Pattern recognition; Radar signal processing; Remote sensing; Segmentation; Seismic signal processing; Signal processing systems; Signal processing technology; Signal, image, video processing algorithm for advanced machine learning; Signal theory; Sonar signal processing; Specific techniques (wavelets, mathematical morphology, Markov models); Spectral analysis; Speech and audio coding; Speech and speaker recognition; Speech based emotion recognition; Speech enhancement; Speech modelling and feature extraction; Speech processing, signal processing for audio; Statistical and multidimensional signal processing; Stochastic processes; Video processing; Visual and performance arts; etc.

Telecommunication System and Technology: Antenna and propagation; Cellular data service; Cellular, mobile and satellite-based systems; Coding and communication theory; Cognitive radio; Communication electronics and microwave; Communication network and systems; Communication systems and devices; Compression through intelligent communication; Configuring telecommunication systems with reliability and availability; Cooperative and cognitive wireless networks; Cost benefit analysis and economic impact of telecommunication systems; Design and analysis issues in metropolitan area networks; Design, modelling and optimisation of photonics devices; Diamond-based photonics devices; Distributed multimedia and hypermedia information space design, implementation and navigation; Distributed/cooperative media; DSL, ADSL, cable TV and their impact; Dynamics and capacity expansion of telecommunication systems; Electromagnetic; Error control coding; Fiber optic communication systems; Global navigation satellite systems; Green networking; High-speed switching architectures; Information network security, standards, and applications; Information processing in telecommunication systems; Information theory, coding and technology; Integrated service digital network (ISDN); Interactive communication media and content; Internet access and network communication; Internet/web-based systems and products; LDPC coding; Microwave Engineering; MIMO systems; Mobile communications, 5G, 6G; Mobile content distribution systems; Mobile satellite communications; Modal propagation in electromagnetic optical waveguides; Modulation and signal design; Modulation and signal processing for telecommunication; Multimedia based systems, their design configuration and impact; Multimedia network; Multimedia-centric VR/AR service and technology in networks; Multiuser information theory; Nanophotonics; Network architecture and interconnection; Network intelligence; Network planning, design and administration; Networking protocols; Optical communications; Optical networks; Optimization methods for communication systems; Orthogonal frequency-division multiplexing (OFDM); Performance analysis of local area networks; Performance evaluation of wide area and local networks; Photonic signal processing technologies; Photonic switching; Photonic systems; Physical layer security; Propagation models; Protocols and services; Quantum communications; Radar and sonar signal processing; Radio communication; Radio frequency; Robust communication of scalable multimedia content; Routing protocols; Satellite and drone communications; Satellite communication; Security, privacy and encryption in telecommunication systems; Sensor/ad hoc networks; Space-time coding; Spectrum usage and allocation; Standardization and regulatory issues; Stronger switching systems; Telecommunications and wireless technology; Telematics services and security network; Telephone switches; Terminals; Time division switching systems; Traffic engineering; Transmission system and signaling systems; Turbo coding; Urban or metropolitan area networks; User association in networks; Voice communications devices; Voice data integration schemes; Wide area networks; Wide local networks; Wideband-CDMA; Wi-Fi; Wire, wireless, ad hoc, and mobile networks; Wireless and mobile communications; Wireless communications; Wireless network coding; Wireless positioning systems; Wireless security; Wireless sensor network; Wireless systems; Wireless, mobile and satellite communications; etc.

Computer Science and Information Technology: Algorithms and bioinformatics; Algorithms and data structures; Algorithms and theory sequence; Analog computing; Anti-spam mail; Anti-virus issues; Approximate computing; Authentication or authorization issues; Bioinformatics; Blockchain; Business and technical communications; Business process; Case studies and experimental and theoretical evaluations; Cloud computing (runtime systems, parallel and distributed systems, virtualization, and software-hardware interactions); Cognitive systems; Computational complexity; Computational engineering, finance, and data science; Computational theory & mathematics, geometry, and linguistics; Computer architecture and engineering; Computer architecture; Computer components and interconnection networks; Computer graphics, visualization and computer-aided design; Computer network security; Computer networks and communications; Computer organizations and architectures (multicores, accelerators, application-specific, processing-in-memory, near-data processing, and datacenters); Computer science and game theory; Computer science applications; Computer security and cryptography; Computer security; Computer vision; Computer-human interaction; Concurrent, parallel and distributed systems; Cryptography and security; Data and knowledge level modelling; Data structures, algorithms, manipulation, retrieval, storage, transmission, communication and mining; Database systems, dependable, reliable and autonomic computing; Databases, digital libraries, discrete mathematics, distributed, parallel, and cluster computing; Data base management systems (DBMS); Dependable computing; Dependable, reliable and autonomic computing; Digital fabrication; Distributed and parallel systems & algorithms, embedded system and software; Distributed computing system; E-business applications; E-commerce; Edge computing; Ethics & professional practice; Firewall; Formal languages and automata theory; Functional programming; Game and software engineering; Game construction; Geographical information systems/global navigation satellite systems (GIS/GNSS); Graphics and human-computer interaction; Grid and scalable computing; High performance computing; Human-computer interaction; Human-machine interface; Implementation of computer languages; Information, coding theory and communications technology; Information management practices; Information retrieval; Information science; Information search engine; Information systems; Information theory, learning, logic in computer science, and mathematical software; Intelligent information & database systems; Internet service architectures; Internet trust and privacy; IT governance; IT infrastructure management; IT policy and business management, mobile and ubiquitous computing; IT project management; Knowledge based management system; Knowledge discovery in data; Management and information security; Mobile and ubiquitous computing; Mobile computing; Mobile processing; Mobile, wireless networks and mobile computing; Multiagent systems; Multimedia security; Multimedia systems and services; Network engineering; Networking and communications, parallel and distributed systems; Networking and internet architecture; Networking technology; Networks and distributed systems; Neuromorphic computing; New and important applications and trends; Next generation media; Next network generation; Numerical and symbolic computation; Object oriented systems analysis and design; Online multimedia; Operating systems, performance and programming languages; Parallel and distributed systems; Parallel computing; Performance, fault tolerance, reliability, security, and testability; Pervasive computing; Programming (programming methodology and paradigm); Programming languages; Quantum computing; Scientific computing; Scientific visualization; Security and cryptography; Security and information assurance; Server administration & maintenance; Software developments; Software engineering (software: lifecycle, management, engineering process, engineering tools and methods); Software engineering, web and internet computing; Software systems; Specification, design, prototyping, and testing methods and tools; Stochastic systems; Symbolic computation; Systems analysis; Theory of computation; User interface design and evaluation; Virtual and augmented reality; Web and internet computing; Web based information systems; Web development; Wireless security system; etc.

Artificial Intelligence and Soft Computing: Agent systems; AI algorithms; AI in modelling, simulation, scheduling and optimization; Ant algorithm; Ant colony optimization; Approximate reasoning (possibility theory, mathematical theory of evidence, fuzzy common knowledge); Artificial intelligence (theory, tools and applications); Artificial neural network (ANN); Automated reasoning, inference, and logic programming; Autonomous reasoning; Bayesian network; Bayesian statistics; Bioinformatics; Bio-inspired systems; Biologically inspired computing; Brain emotional learning; Business intelligence; Chaos theory; Chaotic systems; Cognitive science; Complex systems theory; Computational creativity; Computational theories of learning; Computer vision and speech understanding; Data and web mining; Data mining and machine learning tools; Decision support system; Deep learning; Derivative-free optimization algorithms;

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Concurrent Quad-band Low Noise Amplifier (QB-LNA) using Multisection Impedance Transformer

Teguh Firmansyah, Anggoro Suryo Pramudyo, Siswo Wardoyo, Romi Wiryadinata, Alimuddin

Department of Electrical Engineering, University of Sultan Ageng Tirtayasa, Indonesia

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ABSTRACT

A quad-band low noise amplifier (QB-LNA) based on multisection impedance transformer designed and evaluated in this research. As a novelty, a multisection impedance transformer was used to produce QB-LNA. A multisection impedance transformer is used as input and output impedance matching because it has higher stability, large Q factor, and low noise than lumped component. The QB-LNA was designed on FR4 microstrip substrate with $\epsilon_r=4.4$, thickness $h=1.6$ mm, and $\tan \delta=0.026$. The proposed QB-LNA was designed and analyzed by Advanced Design System (ADS). The simulation has shown that QB-LNA achieves gain (S_{21}) of 22.91 dB, 16.5 dB, 11.18 dB, and 7.25 dB at 0.92 GHz, 1.84 GHz, 2.61 GHz, and 3.54 GHz, respectively. The QB-LNA obtains return loss (S_{11}) of -21.28 dB, -31.87 dB, -28.08 dB, and -30.85 dB at 0.92 GHz, 1.84 GHz, 2.61 GHz, and 3.54 GHz, respectively. It also achieves a Noise figure (nf) of 2.35 dB, 2.13 dB, 2.56 dB, and 3.55 dB at 0.92 GHz, 1.84 GHz, 2.61 GHz, and 3.54 GHz, respectively. This research also has shown that the Figure of merit (FoM) of the proposed QB-LNA is higher than that of another multiband LNA.

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Corresponding Author:

Teguh Firmansyah,
Departement of Electrical Engineering,
University of Sultan Ageng Tirtayasa,
Jl. Jenderal Sudirman. Km. 3. Cilegon. Banten. 42435. Indonesia.
Email: teguhfirmansyah@untirta.ac.id

1. INTRODUCTION

High demand for various types of wireless communications, encourage the research and development of multiband transceiver [1]. The multiband transceiver accommodate multiple types of wireless technologies simultaneously, making it cheaper, more efficient, and compact [2]. A subsystem of multiband transceiver consists of a multiband antenna (MA) [3], [4], a multiband power amplifier (MPA) [5], [6], a multiband mixer (MM) [7], a multiband band-pass filter (MBPF) [8-10] and multiband low noise amplifier (MLNA) [11-13]. A low noise amplifier (LNA) is necessary to amplify a signal without increasing the noise and interference at several frequencies simultaneously [14].

There are several method frequently used for MLNA design such as; wideband matching [15], switch method [16], and concurrent multiband [17-19]. The wideband method can produce LNA with wide frequency operating. However, this method has drawbacks such as high interference signal, because the unneeded signal is also strengthened. Meanwhile, switch method has the advantage of low interference but a switch-LNA works optimally at a single frequency. In addition, the switch method also requires additional switch with a good performance. A concurrent method could produce LNA with low interference and good performance at multiple frequencies simultaneously. The employment of concurrent multiband can be done by using lumped components as input and output matching impedances, but it makes the design of MLNA be more complex.

As novelty, a concurrent quad-band low noise amplifier (QB-LNA) using multisection impedance transformer was proposed in this paper. A multisection impedance transformer (MIT) was used to produce a

multiband matching circuit. MIT has many advantages including low noise, high stability, simple, and easy in fabrication. The QB-LNA has frequencies 0.92 GHz, 1.84 GHz, 2.61 GHz, and 3.54 GHz, for GSM900, WCDMA1800, LTE2600, and LTE3500 application respectively. The QB-LNA was designed on FR4 microstrip substrate with $\epsilon_r = 4.4$, $h = 1.6$ mm, and $\tan \delta = 0.0265$. The QB-LNA was simulated by using Schematic Simulation Advanced System Design (ADS). This research also was shown that the Figure of merit (FoM) of the proposed QB-LNA is higher than that of another multiband LNA.

2. THE PROPOSED METHOD

A subsystem of QB-LNA consist of bias transistor, input impedance maching (IIM), and output impedance matching (OIM) [12], [14] as shown in Figure 1. The FET NE321S01 with a low power source of bias $V_{CC} = 5$ V was used. A multi-section impedance transformer (MIT) as IIM and OIM was proposed in this research to produce four-band LNAs shown in Figure 2.

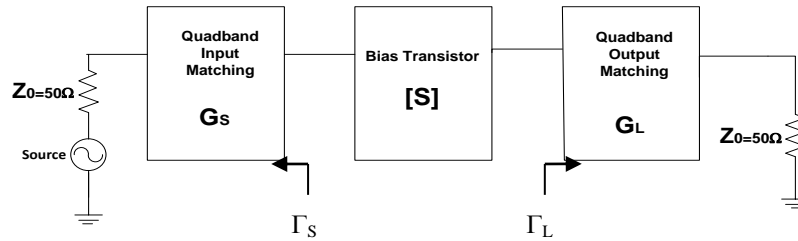


Figure 1. A subsystem of multiband LNA

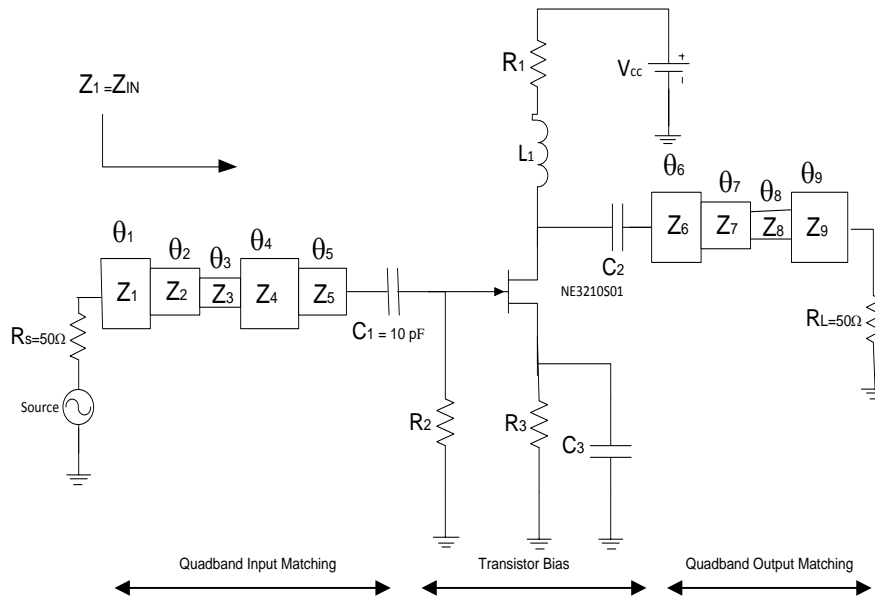


Figure 2. A multi-section impedance transformer (MIT) as IIM and OIM

with termination port (R_S and R_L), bias circuit resistance R_N ($N=1,2,3$), power supply (V_{CC}), coupling capacitor C_N ($N=1,2,3$), RF choke (L_1), the impedance of transmission line Z_N ($N=1,2,3,4,5,6,7,8,9$), electrical length θ_N ($N=1,2,3,4,5,6,7,8,9$), and input impedance Z_{IN} .

2.1. Small Signal and Resonant Conditions Analysis

Figure 3 shows a small signal analysis of transistor bias circuit. The input impedance Z_{IN} is given by Equation (1) with transconductance (g_m), source inductance (L_S), gate inductance (L_G), and gate-source capacitance (C_{GS}).

$$\begin{aligned}
 Z_{IN} &= j\omega L_s + j\omega L_g + \frac{1}{j\omega C_{gs}} + \frac{g_m}{C_{gs}} L_s \\
 &= j\omega(L_s + L_g) + \frac{1}{j\omega C_{gs}} + \frac{g_m}{C_{gs}} L_s
 \end{aligned} \tag{1}$$

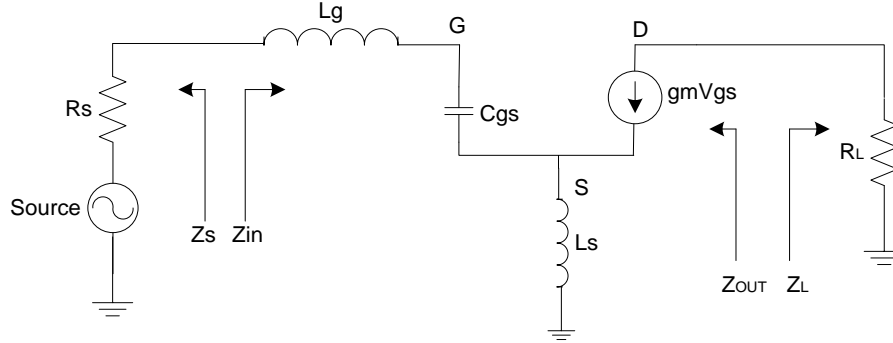


Figure 3. Small signal analysis of bias circuit

A relation of cutoff frequency and transconductance is given by:

$$\frac{g_m}{C_{gs}} L_s = \omega_T L_s \quad \rightarrow \quad \frac{g_m}{C_{gs}} = \omega_T \tag{2}$$

and Z_{IN} at cutoff frequency is given by:

$$Z_{IN} = j\omega(L_s + L_g) + \frac{1}{j\omega C_{gs}} + \omega_T L_s \tag{3}$$

At a resonant frequency, the Z_{IN} can be found as follows:

$$\text{Im}(Z_{IN}) = 0 \tag{4}$$

$$\text{Re}(Z_{IN}) = \frac{g_m}{C_{gs}} L_s \tag{5}$$

At matching condition, Z_{IN} and return loss are given by:

$$Z_{IN} = Z_S^* = R_S = \frac{g_m}{C_{gs}} L_s = \omega_T L_s \tag{6}$$

$$\begin{aligned}
 S_{11} &= \Gamma_{11} = \frac{Z_{IN} - R_S}{Z_{IN} + R_S} \\
 &= \frac{\left(j\omega(L_s + L_g) + \frac{1}{j\omega C_{gs}} + \frac{g_m}{C_{gs}} L_s \right) - \left(\frac{g_m}{C_{gs}} L_s \right)}{\left(j\omega(L_s + L_g) + \frac{1}{j\omega C_{gs}} + \frac{g_m}{C_{gs}} L_s \right) + \left(\frac{g_m}{C_{gs}} L_s \right)} \\
 &= \frac{j\omega(L_s + L_g) + \frac{1}{j\omega C_{gs}}}{j\omega(L_s + L_g) + \frac{1}{j\omega C_{gs}} + 2\frac{g_m}{C_{gs}} L_s} \\
 &= \frac{(j\omega)^2 + \frac{1}{C_{gs}(L_s + L_g)}}{(j\omega)^2 + 2\frac{j\omega}{(L_s + L_g)C_{gs}} + \frac{1}{C_{gs}(L_s + L_g)}}
 \end{aligned} \tag{7}$$

With $j\omega = \text{sat resonant frequency } (\omega_0)$, the Equation (7) could be simplified;

$$S_{11} = \frac{s^2 + \omega_0^2}{s^2 + Bs + \omega_0^2} \tag{8}$$

With

$$\omega_o^2 = \frac{1}{C_{gs}(L_s + L_g)}$$

$$B = 2 \frac{1}{(L_s + L_g) C_{gs}} \frac{g_m}{L_s}$$

A bandwidth of LNA could be found at S_{11} lower than -10 dB, the S_{11} is formulated by:

$$\begin{aligned} 20 \log |S_{11}| &\leq -10 \text{ dB} \\ \log |S_{11}| &\leq -0.5 \\ |S_{11}| &\leq 3.16 \end{aligned} \quad (9)$$

The upper and lower threshold is followed by:

$$\frac{-B + \sqrt{B^2 + \omega_o^2}}{6} \leq \omega \leq \frac{B + \sqrt{B^2 + \omega_o^2}}{6} \quad (10)$$

2.2. Single-section Impedance Transformer (SIT)

Figure 4 shows a single section impedance transformer.

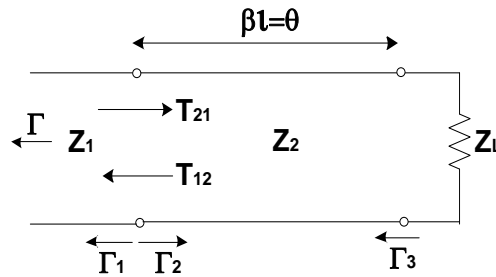


Figure 4. Single-section Impedance Transformer

The partial reflection coefficients Γ_N ($N=1,2,3$) and partial transmission coefficients T_N ($N=1,2$) are given by:

$$\Gamma_1 = \frac{Z_2 - Z_1}{Z_2 + Z_1} \quad (11)$$

$$\Gamma_2 = -\Gamma_1 \quad (12)$$

$$\Gamma_3 = \frac{Z_L - Z_2}{Z_L + Z_2} \quad (13)$$

$$T_{21} = 1 + \Gamma_1 = \frac{2Z_2}{Z_1 + Z_2} \quad (14)$$

$$T_{12} = 1 + \Gamma_2 = \frac{2Z_1}{Z_1 + Z_2} \quad (15)$$

A total reflection can be calculated as follows:

$$\Gamma = \Gamma_1 + T_{12} T_{21} T_3 e^{-2j\theta} \sum_{n=0}^{\infty} \Gamma_2^n \Gamma_3^n e^{-2j\theta} \quad (16)$$

A geometry series was used for simplifying Equation (16), then the total reflection can be found:

$$\Gamma = \Gamma_1 + \frac{T_{12} T_{21} T_3 e^{-2j\theta}}{1 - \Gamma_1 \Gamma_3 e^{-2j\theta}} \quad (17)$$

2.3. Multi-section Impedance Transformer (MIT)

To produce QB-LNA with quad-band impedance matching circuit at IMM and OIM, a multisection impedance transformer (MIT) was used, as shown in Figure 5. MIT has many advantages including low noise, high stability, simple, and easy in fabrication. The Z_{IN} is given by (18) with $i = 1, \dots, M$, propagation constant (β), and electrical length (l_i).

$$Z'_i = Z_i \frac{Z'_{i+1} + jZ_i \tan(\beta l_i)}{Z_i + Z'_{i+1} \tan(\beta l_i)} \quad (18)$$

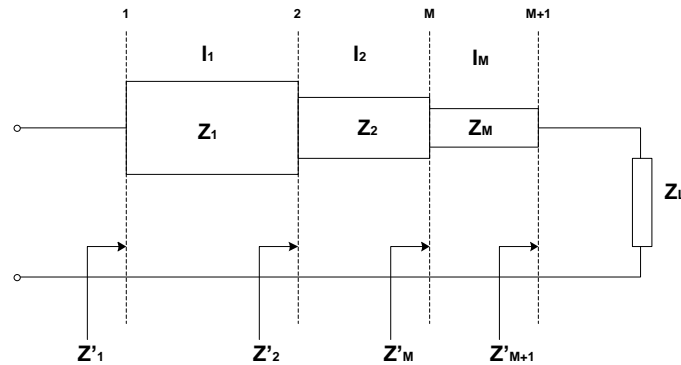


Figure 5. Multisection impedance transformer

with low frequency dispersion and $\theta(f) = \frac{f}{f_0} \theta_0$, input impedance (Z'_i) is given by:

$$Z'_i(f) = Z_i \frac{Z'_{i+1} + jZ_i \tan\left(\frac{f}{f_0} \theta_0\right)}{Z_i + Z'_{i+1} \tan\left(\frac{f}{f_0} \theta_0\right)} \quad (19)$$

At matching condition, return loss is given by:

$$\left\{ \begin{array}{l} \Gamma\left(\left(\frac{f}{f_0}\right), \theta_0, Z_L(f), Z_1 Z_2 \dots Z_M\right) \Big|_{f=f_1} = 0 \\ \Gamma\left(\left(\frac{f}{f_0}\right), \theta_0, Z_L(f), Z_1 Z_2 \dots Z_M\right) \Big|_{f=f_2} = 0 \\ \vdots \\ \Gamma\left(\left(\frac{f}{f_0}\right), \theta_0, Z_L(f), Z_1 Z_2 \dots Z_M\right) \Big|_{f=f_N} = 0 \end{array} \right. \quad (20)$$

3. DESIGN AND SIMULATION

To show the applicability of proposed concept of QB-LNA, a multisection impedance transformer (MIT) was used as shown in Figure 6. The QB-LNA has been designed with frequencies 0.92 GHz, 1.84 GHz, 2.61 GHz, and 3.54 GHz, for GSM900, WCDMA1800, LTE2600, and LTE3500 application respectively. The QB-LNA was designed on FR4 microstrip substrate with $\epsilon_r = 4.4$, $h = 1.6$ mm, and $\tan \delta = 0.0265$. The width and length of transmission line are $w_1 = 22.4$ mm, $w_2 = 15.4$ mm, $w_3 = 6.3$ mm, $w_4 = 1.6$ mm, $w_5 = 0.3$ mm, $w_6 = 2.0$ mm, $w_7 = 1.0$ mm, $w_8 = 3.0$ mm, $w_9 = 1.0$ mm and $l_1 = 23.8$ mm, $l_2 = 8.1$ mm, $l_3 = 12.56$ mm, $l_4 = 18$ mm, $l_5 = 21$ mm, $l_6 = 0.3$ mm, $l_7 = 0.5$ mm, $l_8 = 20$ mm, $l_9 = 20$ mm. The lumped components $V_{CC} = 5$ V, $L_1 = 47$ nH (as a RF Choke), $R_1 = 475 \Omega$, $R_2 = 3$ k Ω , $R_3 = 51 \Omega$, $C_3 = 30$ pF, $R_S = 50 \Omega$ (as an input termination), and $R_L = 50 \Omega$ (as an output termination).

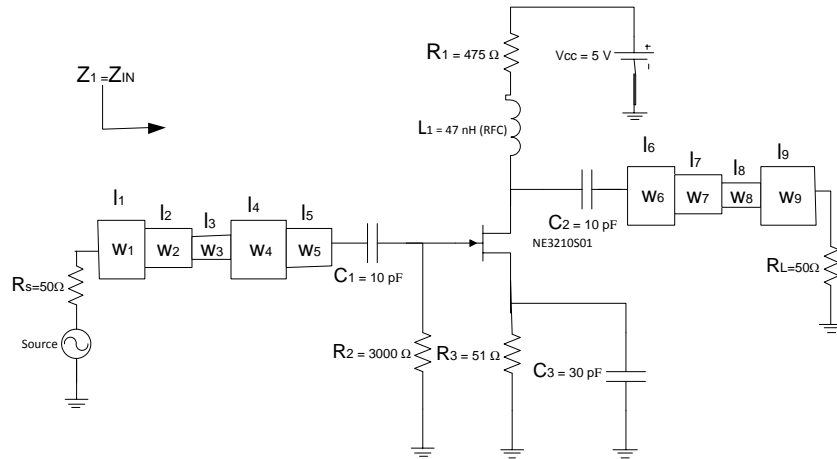


Figure 6. QB-LNA using multisection impedance transformer (MIT)

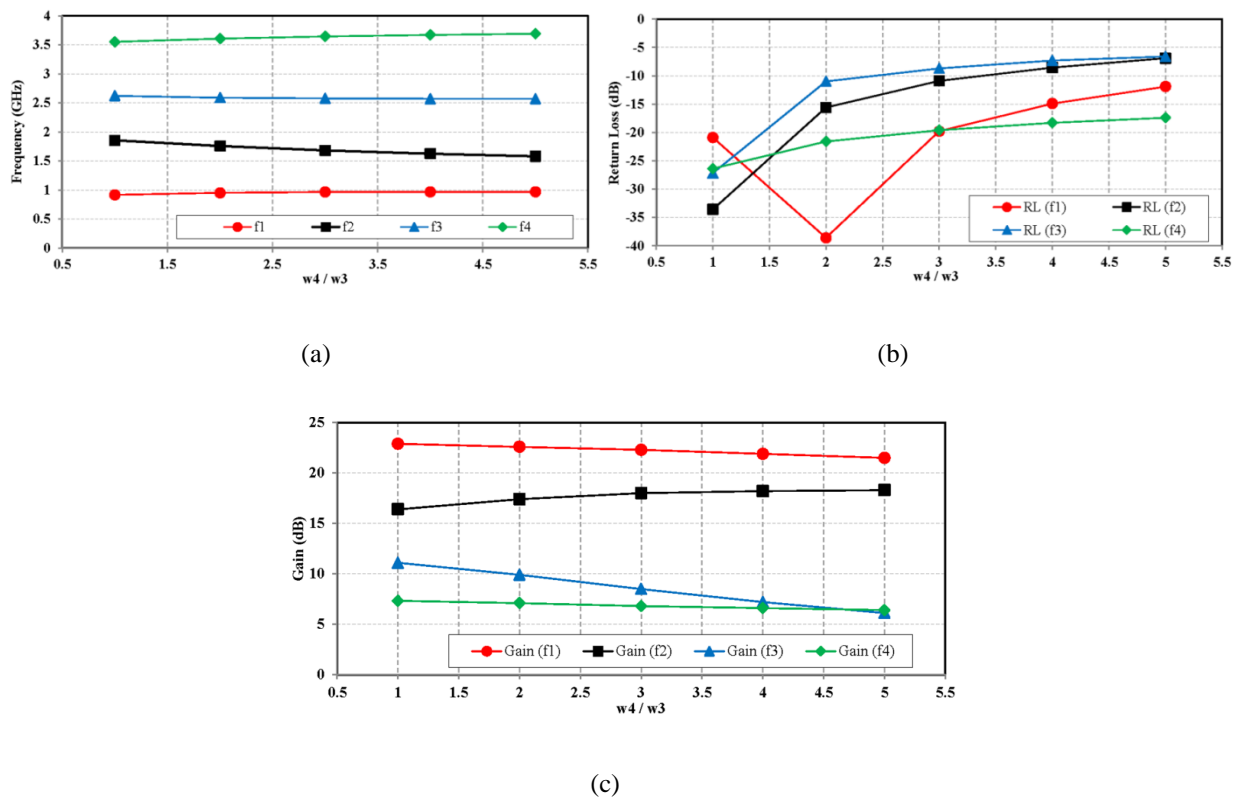


Figure 7. (a) The extracted center frequency with varied w_4/w_3 , (b) the extracted of return loss (S_{11}) with varied w_4/w_3 , (c) the extracted of gain (S_{21}) with varied w_4/w_3

The extracted center frequency with varied w_4/w_3 , a return loss (S_{11}) with varied w_4/w_3 , gain (S_{21}) with varied w_4/w_3 , are shown in Figure 7(a), 7(b), and 7(c), respectively. Figure 7(a) shows that the center frequency of f_1 , f_3 , and f_4 are still stable with varied w_4/w_3 . However, a return loss (S_{11}) of f_2 has decreased as shown in Figure 7(b). Figure 7(b) shows that the increase of w_4/w_3 would effect to the return loss (S_{11}). Figure 7(c) illustrated the extraction of gain (S_{21}) with varied w_4/w_3 . It shows that gain (S_{21}) of frequency f_1 , f_3 , and f_4 vary slightly, but a gain at frequency of f_3 falls dramatically. In general, the variation of w_4/w_3 only affects the performances of the second frequency (f_2), but it does slightly affect to performances of frequency f_1 , f_3 , and f_4 .

Figure 8(a) and 8(b) show the extracted return loss (S_{11}) and gain (S_{21}) with varied power supply (V_{CC}). It is useful for demonstrating the consistency performance of QB-LNA. The return loss (S_{11}) of frequency f_1 , f_2 , f_3 , and f_4 remains constant. However, the value of gain (S_{21}) and Noise figure (nf) shifted because a varied of power supply (V_{CC}).

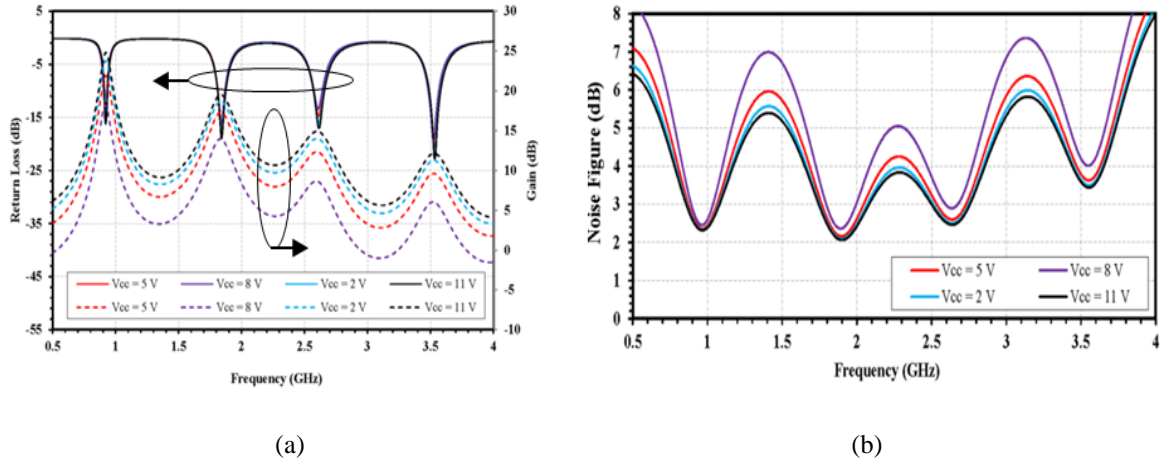


Figure 8. (a) The extracted of return loss (S_{11}) and gain (S_{21}), (b) Noise figure with varied V_{CC}

Figure 9 (a) shows the extracted return loss (S_{11}) and gain (S_{21}) with varied l_1 . The chart shows that a return loss (S_{11}) and gain (S_{21}) of f_1 has not changed. However, the center frequency of f_2 , f_3 , and f_4 are shifted by varied of l_1 . Figure 9(b) shows the extracted return loss (S_{11}) and gain (S_{21}) with varied w_2 . The results are similar, a return loss (S_{11}) of f_1 has not changed and the center frequency of f_2 , f_3 , and f_4 are shifted because variation of w_2 .

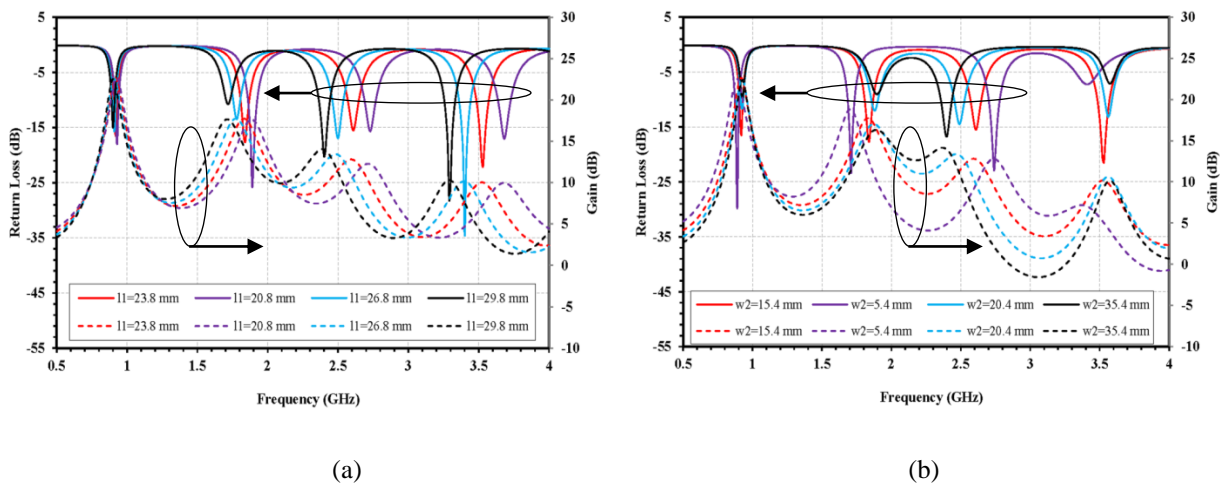


Figure 9. (a) The extracted return loss (S_{11}) and gain (S_{21}) with varied l_1 (b). The extracted return loss (S_{11}) and gain (S_{21}) with varied w_2

4. RESULTS AND ANALYSIS

The QB-LNA was designed on FR4 microstrip substrate with $\epsilon_r= 4.4$, thickness $h=1.6$ mm, and $\tan \delta= 0.026$. The proposed QB-LNA was designed and analyzed by Advanced System Design (ADS). Figure 10 shows the performance of return loss (S_{11}) and gain (S_{21}) of QB-LNA.

The simulation has shown that QB-LNA achieves gain (S_{21}) of 22.91 dB, 16.5 dB, 11.18 dB, and 7.25 dB at 0.92 GHz, 1.84 GHz, 2.61 GHz, and 3.54 GHz, respectively. The QB-LNA obtain return loss (S_{11})

of -21.28 dB, -31.87 dB, -28.08 dB, and -30.85 dB at 0.92 GHz, 1.84 GHz, 2.61 GHz, and 3.54 GHz, respectively. Figure 11 shows in the performance of Noise figure (dB) and stability factor (K) of QB-LNA. This QB-LNA achieves a Noise figure (nf) of 2.35 dB, 2.13 dB, 2.56 dB, and 3.55 dB at 0.92 GHz, 1.84 GHz, 2.61 GHz, and 3.54 GHz, respectively. Furthermore, the stability factor of all bands above 1.0 is also depicted in Figure 11.

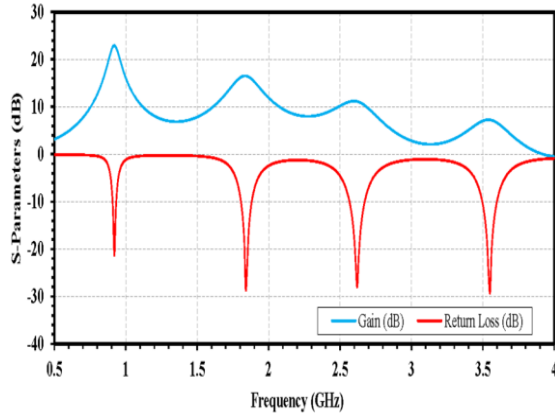


Figure 10. The performance of return loss (S_{11}) and gain (S_{21}) of QB-LNA

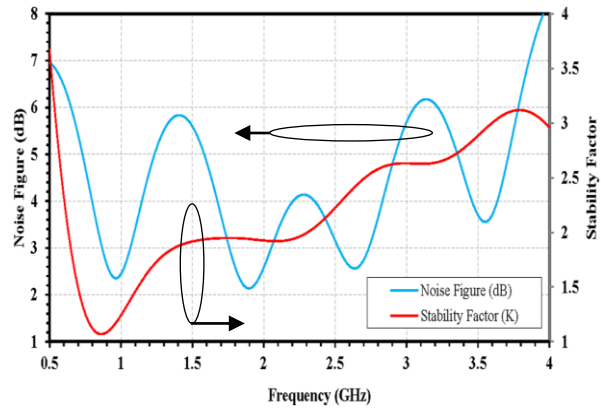


Figure 11. The performance of Noise figure (dB) and stability factor (K) of QB-LNA

This research has shown that the Figure of merit (FoM) of the proposed QB-LNA is higher than another multiband LNA, as shown in Table 1. A FoM is given by [20]

$$FoM [mW^{-1}] = \frac{Gain [abs]}{(NF-1)[abs].P_{DC}[mW]} \tag{21}$$

Table 1. The Figure of merit (FoM) of the proposed QB-LNA

Parameter	Reference				[19]		This work			
	[17]		[18]		Concurrent multiband		Concurrent multiband			
f_0 (GHz)	1,80	2,45	2,40	5,20	2,20	4,60	0,92	1,84	2,61	3,54
S_{21} (dB)	9,20	12,00	15,00	6,50	10,80	8,80	22,91	16,5	11,18	7,25
NF (dB)	5,70	6,40	2,50	2,40	3,53	2,52	2,35	2,13	2,56	3,55
P_{DC} (mW)	8,00		10		7,76		5,01			
Gain/ P_{DC} (dB/mW)	1,15	1,50	1,50	0,65	1,38	1,13	4,51	3,29	2,23	1,44
FoM (mW^{-1})	0,38	0,59	4,07	0,61	1,21	1,24	3,34	2,91	1,44	0,56

5. CONCLUSION

A multisection impedance transformer was used to produce QB-LNA. The QB-LNA has been designed with frequencies 0.92 GHz, 1.84 GHz, 2.61 GHz, and 3.54 GHz, for GSM900, WCDMA1800, LTE2600, and LTE3500 application respectively. The QB-LNA was designed on FR4 microstrip substrate with $\epsilon_r = 4.4$, thickness $h = 1.6$ mm, and $\tan \delta = 0.026$. The proposed QB-LNA was designed and analyzed by Advanced System Design (ADS). The simulation has shown that QB-LNA achieves gain (S_{21}) of 22.91 dB, 16.5 dB, 11.18 dB, and 7.25 dB at 0.92 GHz, 1.84 GHz, 2.61 GHz, and 3.54 GHz, respectively. The QB-LNA obtain return loss (S_{11}) of -21.28 dB, -31.87 dB, -28.08 dB, and -30.85 dB at 0.92 GHz, 1.84 GHz, 2.61 GHz, and 3.54 GHz, respectively. It also achieves a Noise figure (nf) of 2.35 dB, 2.13 dB, 2.56 dB, and 3.55 dB at 0.92 GHz, 1.84 GHz, 2.61 GHz, and 3.54 GHz, respectively. This research also has shown that the Figure of merit (FoM) of the proposed QB-LNA is higher than that of another multiband LNA.

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BIOGRAPHIES OF AUTHORS



Teguh Firmansyah was born in Subang, Indonesia. He received B.Eng (S.T) degree in electrical engineering and M.Eng (M.T) degree in telecommunication engineering from Department of Electrical Engineering Universitas Indonesia in 2010 and 2012, respectively. In 2012, he joined the Department of Electrical Engineering Universitas Sultan Ageng Tirtayasa as a researcher and lecturer. He has authored or coauthored over 20 papers published in refereed journals and conferences. He holds two patents for wideband antenna and multiband antenna. His research interests include microstrip antenna and microwave circuit for various applications.

Email : teguhfirmansyah@untirta.ac.id



Anggoro Suryo Pramudyo was born in 1984. He received BCS (S.Kom.) from Universitas Bina Darma in 2006 and MCS (M.Kom) from Universitas Gadjah Mada in 2006. He is interested in Artificial Intelligence included Computational Intelligence. Since 2010, he had become a lecturer and researcher at Departemen of Electrical Engineering Universitas Sultan Ageng Tirtayasa. Currently his researches are about intelligent designer for antenna.

Email : pramudyo@untirta.ac.id



Siswo Wardoyo received the Bachelor Engineering (S.T.) in Electric Engineering from Diponegoro University of Indonesia, in 2002. Master of Engineering (M.Eng) degree, received from Electrical Engineering Department, Gadjah Mada University in 2008. Currently, He lecturer at Electrical Engineering Department, University of Sultan Ageng Tirtayasa. His reseach interests are My research interest are in TVET, ANN, Image Processing, Computer Vision, and Control.

Email : siswo@untirta.ac.id



Romi Wiryadinata received the Bachelor Engineering (S.T.) in electrical engineering from Islamic University of Indonesia, in 2005. Master of Engineering (M.T.) degree, was received from Electrical Engineering Dept., Gadjah Mada University in 2007. He received Doctor (Dr.) degree from Electrical Engineering Dept., Gadjah Mada University in 2015. Currently, he is a lecturer at Electrical Engineering Dept., University of Sultan Ageng Tirtayasa. His research interests are in artificial neural network, sensor technology, guidance-control and navigation, and robotic.

Email : wiryadinata@untirta.ac.id



Alimuddin is Associate Prof. Dr. specialization Control, Computer, Power Stability System and Energy Conversion, Telecommunication, SMART ICT and Lecture and Researcher at the Department of Electrical Engineering on Faculty of Engineering, Sultan Ageng Tirtayasa University (UNTIRTA), Banten, Indonesia, Master Engineering Informatics and Magister Information Management Graduate Binus University (BINUS) Jakarta, Master electrical engineering, Graduate Mercubuana University (UMB) Jakarta, Master computer science graduate STIMIK Nusa Mandiri Jakarta, He received B.S.and Master Management from Indonesia Moeslem University and Master Engineering for Electrical Engineering from Hasanuddin University., Indonesia in 1999, 2002 and 2003 respectively. He graduated a Doctor (PhD) Degree at the Bio-Informatics and Control, Instrumentation Engineering, Conversion Energy Bogor Agricultural University,Indonesia and Research Collaboration University of Tsukuba, Japan, 2009, Program research in Grant in sponsored by Government of Indonesia (the Ministry of Education and the State Ministry of Indonesia)., He has more than 11 years of experience in teaching at several Universities. His research interests include Control System, Telecommunication, ICT, Model and Simulation, Artificial Intelligent and its application. optimization and information system, Power Stability System and Energy Conversion System, Information Technology and Computer, Distribution System, Power System Control and optimization, Transportation. He has published more than ten papers in national Journal. He has also presented more than twelve research articles in national and international conferences. He is currently with few projects sponsored by government of Indonesia (the Ministry of Education and the State Ministry).

Email : alimudy@yahoo.com