Malik Hasan Al-Taweel[1], Ayman Mohammed Ibrahim[2], Mohd Riduan Ahmad[1], Badrul Hisham Ahmad[1], Taha Raad Al-Shaikhli[3], Mustafa Murtdha Al-Saeedi[4].

(1) Universiti Teknikal Malaysia Melaka (UTeM), Malaysia, Malaysia, (2) Ministry of Trade/Development of private Sector, Iraq, (3) Al-Nisour University College, Iraq, (4) University of Technology, Iraq.
ORCID: 1. 0000-0003-3926-9536, 2. 0000-0002-5087-5185 3. 0000-0001-9474-7153, 4. 0000-0001-8014-2444, 5. 0000-0002-3913-9769, 6. 0000-0001-8912-8761.

doi:10.15199/48.2022.02.48

Design of radio receiver for lightning interferometry

***Abstract**. The design of wideband receiver for the application of lightning remote sensing in the VHF band is proposed. Recently, the VHF emissions has been detected from the lightning therefore, various studies motivated on designing sensing systems to detect and analyse the radiation signals from lightning. Previous studies were done by using commercial low noise amplifier and band pass filter which its expensive, low in accuracy and signal's magnitude. So, in order to detect the VHF emissions with better magnitude we required to design highly efficient low noise amplifier with paying attention to some specifications such as gain, noise figure, linearity of the LNA and the flatness of the band pass filter. The receiver designed for the lightning interferometer as lightning remote sensing therefore we used this technique in communication to apply in lightning. This article presents the design of high gain low noise amplifier supporting wide range of frequency from 10 MHz to 500 MHz and wide bandwidth band pass filter from 110 MHz to 400 MHz. The design is simulated by using Advance Design System (ADS) software simulator and then measured and fabricated by using FR-4 substrate. The measurement is highly satisfying to the simulation results at the (S21) gain around 20 dB at 255MHz Centre frequency and return loss (S11) around -31.204 dB at 255 MHz while the noise figure around 0.063. The designed system achieved excessive efficiency and used for lightning interferometer system.*

Streszczenie.** Zaproponowano projekt odbiornika szerokopasmowego do zastosowania teledetekcji wyładowań atmosferycznych w paśmie VHF. Ostatnio wykryto emisje VHF z piorunów, dlatego różne badania były motywowane do zaprojektowania systemów czujnikowych do wykrywania i analizowania sygnałów promieniowania z piorunów. Wcześniejsze badania zostały wykonane przy użyciu komercyjnego wzmacniacza niskoszumowego i filtra pasmowoprzepustowego, który jest drogi, ma niską dokładność i wielkość sygnału. Tak więc, aby lepiej wykrywać emisje VHF, musieliśmy zaprojektować wysoce wydajny wzmacniacz niskoszumowy, zwracając uwagę na pewne specyfikacje, takie jak wzmocnienie, współczynnik szumów, liniowość LNA i płaskość filtra pasmowego. Odbiornik zaprojektowany dla interferometru piorunowego jako teledetekcja wyładowań atmosferycznych, dlatego zastosowaliśmy tę technikę w komunikacji do zastosowania w piorunach. W artykule przedstawiono konstrukcję niskoszumowego wzmacniacza o wysokim wzmocnieniu, obsługującego szeroki zakres częstotliwości od 10 MHz do 500 MHz oraz filtr szerokopasmowy od 110 MHz do 400 MHz. Projekt jest symulowany przy użyciu symulatora oprogramowania Advance Design System (ADS), a następnie mierzony i wytwarzany przy użyciu podłoża FR-4. Pomiar jest wysoce satysfakcjonujący dla wyników symulacji przy wzmocnieniu (S21) około 20 dB przy 255 MHz częstotliwości środkowej i tłumieniu odbiciowym (S11) około -31,204 dB przy 255 MHz, podczas gdy współczynnik szumów około 0,063. Zaprojektowany system osiągnął nadmierną wydajność i został wykorzystany w systemie interferometru piorunowego.* (Projekt odbiornika radiowego do interferometrii piorunowej***)

Keywords: Radio receiver, Remote sensing, Lightning interferometry, VHF.
Słowa kluczowe: odbiornik radiowy szerokopasmowy, wyładowania, interferometria

Introduction

Lightning is the natural unexpected electrostatic electronic discharge that occurred commonly at some stage in a thunderstorm. This discharge takes place in the cloud that is charged electrically known as intracloud (IC) lightning or taking place between two clouds which is cloud to cloud (CC) lightning and between cloud and ground which is (CG) lightning.

Among the types of the lightning, (IC) is happening the most. Intensive studies has been done on (CG) lightning for its huge risk on the human's life and the nature [1]. The knowledge of the lightning is huge and, in some cases its specified, however, many statuses stay. cutting-edge studies regarding lightning physics are targeted on knowledge of lightning process, lightning initiation, positive and negative lightning, leader breakdown and run-away breakdown[2]. The study of the lightning initiation and its processes is the most important purpose has been done by examine the electromagnetic emission and its events during the lightning specially at Very high frequency.

The part of the VHF & RF spectrum is yet comparatively transparent in huge rainy environments [3].

So, there is still existing potential and susceptibility to lightning process observations at the mentioned frequencies. Based on the hypothetical investigation, [3][4] have described the electron avalanche, a fundamental procedure of the electrical discharge. It can be produced significant radiation in VHF RF bands. The Lightning interferometer system is an instrument that can determine the direction of the lightning flash produces radio points sources by correlating the incoming signals received by the antennas. In other words, Measuring the phase difference between VHF sources received by two or more of properly spaced antennas by determining the azimuth and elevation of the incident angle of VHF pulses. The early study on VHF emission from the lightning by using the interferometer technique has been done by [5] who reported observation study on the direction of the lightning using interferometric technique at 34 MHz using single baseline interferometer system. The system was useful for mapping the movement of the lightning. The pulses detected by Warwick were crude and his interferometer system was incapable of detect the location of the lightning and produce clear image because his narrow bandwidth. The previous studies and development of the interferometer system are having narrow bandwidth around 60 MHz, So the pulses of VHF signal are super imposed and almost overlapped causing difficulty in investigating and analyzing the signal so that will affect the sensitivity and accuracy of the interferometer system. In this paper, we are motivated to design the radio receiver system using this technique in telecommunication to apply it in lightning interferometer system at very high frequency (VHF) band. Furthermore, there is importance to observe the intracloud (IC) and cloud to ground (CG) lightning flashes to know which one interferes highly and severely to contribute on the high Bit Error Rate and burst error occurrences. The measurements of the bit error rate system and electric-field changing system was synchronized to deliver commonly time stamp info [6][7]. Detailed descriptions of design and simulation process, there are three techniques which are single stage, balanced, and the feedback for designing (LNA), the feedback technique is being used to attain wide bandwidth [8]. Measurement results show good according to the simulation results for the LNA-BPF system, achieved high gain and high output power.

Low Noise Amplifier (LNA)

The (LNA) is the essential part in the front-end receiver that's amplifying the very weak incoming signal captured by the receiver, with no pointedly reducing its signal to noise ratio. The (LNA) increase the signals power while reducing noise power. (LNA) is designed to minimize extra noise and provide stability without oscillation in the targeted frequency band. Engineers decrease noise through considering trade-offs which involve impedance matching, desiring the amplifier equipment as low noise components and taking low noise biasing circumstances [7]. LNA are established for the radio communication systems, medicinal instruments, electronic equipment. Although (LNA) are mostly dealing with weak power signals that are beyond the noise floor. LNA used for remote monitoring sensor at base station receiver with omni-directional range in VHF band for aviation academy [9].

Band-Pass filter (BPF)

The band pass filters (BPFs) is a device that allows the frequencies to be pass in a certain band of frequencies and (attenuates) reject the frequencies outside the targeted band. (BPFs) are widely employed in wireless communication system for the transmitting and receiving signals. the filter's essential task at the transmitter is that cut off the bandwidth for the output signal to be assigned for the transmitting and prevents the interference with other frequencies. At the receiver part, (BPFs) allows the signals to be passes in a picked range of frequency and cut off the frequency outside the wanted band. The (BPFs) optimize the signal to noise ratio as well as and sensitivity of a receiver [10] [11]. designed band pass filter with optimum bandwidth used for the mode and speed in the communication, increasing the signal's transmissions and reducing the jostle among signals [11].

Data and methodology

Instrumentation

The first step in designing the amplifier is selecting transistor according to the required specification. The attention should be paid to some aspects which is low power consumption, lower noise as possible and high gain. The low noise amplifier here is firstly simulated by using ADS software and selected the transistor from its library which has various transistors models that is applicable to designing LNA. The transistor selected here is diffusion Avago Technologies' sp_phl_BFG195_3_19900901 and stub matching is employed for its output and input matching. The type of transistor is created by InGaAs HEMT Avago Solutions (sp_phl_BFG195_3_19900901), achieved using Avago Technologies' GaAs Enhancement-mode pHEMT process which is operating from 10 MHz to 500 MHz frequency as shown in Fig. 1 below.

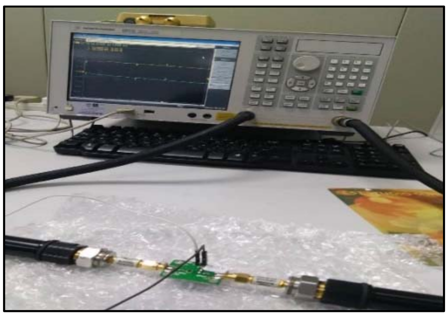

Fig. 1: Low Noise Amplifier at the laboratory measurement

Biasing Network

Biasing network purposely uses to deliver optimum Vds and Identity in line with the datasheet. In datasheet, the manufacturer provides examination of gain and sound figure with different value of bias point. Simply by selecting optimum DC opinion circuit should demonstrate steady thermal performance. Bias point of Vds = 2V while the Id = 12 mA been choosing to get optimum performance for the LNA. The biasing network was base on voltage divided circuit [12]. As showed in Fig. (2).

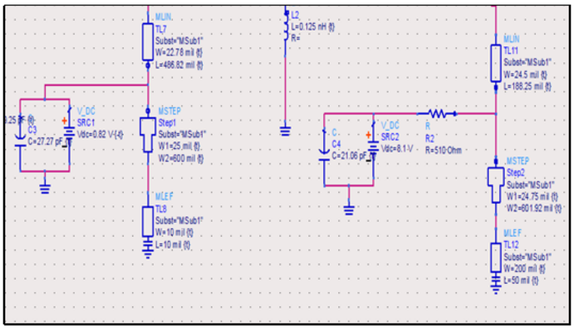

Fig. 2: Schematic design biasing circuit

Stability Condition

Single electric power transistor was used to design the low noise amplifier which it provides amplification for a specific frequency and desired linearity. For designing LNA, the stability of the amplifier must be concerted, because if the amplifier is unstable the signal will be oscillated. That's why the need of the amplifier to be wholehearted stable, which situation can be calculated by the use of K test or Δ, and the K must be more than 1. In this design the amplifier according to the noise figure graph is unconditional stable transistor. The method of unconditionally stables can be expressed in the following formula [8].

(1) $$(\Delta) = (S_{11}S_{22}) - (S_{21}S_{12})$$

(2) $$(K) = \left(\frac{1+|\Delta|^2-|S_{11}|^2-|S_{22}|^2}{2|S_{12}S_{21}|}\right) > 1$$

The aforementioned calculation indicates for the Rollet's Criteria of Unconditional stability, which is the main condition. Moreover the importance of K can be found by using the simulation [13].

Noise Figure

For the Low noise amplifier design, the critical part is around noise optimization. Mainly, the perfect technique to recognize the finest optimized noise number is via noise circle and gain circle which used to verify the input and output representation coefficient beyond the circuit. The transistor's noise figure can be calculated according to several parameters given by the maker such as f min, Rn and Yopt at the particular frequency by the following formula below [14].

(3) $$F = F_{min} + \frac{R_N}{G_S}\left|Y_S - Y_{opt}\right|^2$$

(4) $$N = \frac{\left|\Gamma_S-\Gamma_{opt}\right|^2}{1-|\Gamma_S|^2} = \frac{F-F_{min}}{4R_N/Z_0}\left|1+\Gamma_{opt}\right|^2$$

Band Pass Filter design

The band pass filter designed in 5th order that operating from 110 MHz to 400 MHz frequency, to avoid the interfering with the FM radio frequency in Malaysia which operating from 87.5 MHz to 108 MHz, ADS (Advance design System) software was used. Fig. 3 shows the schematic design of the filter.

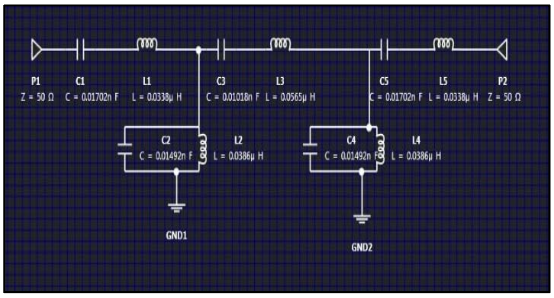

Fig. 3: the schematic design of band pass filter (BPF)

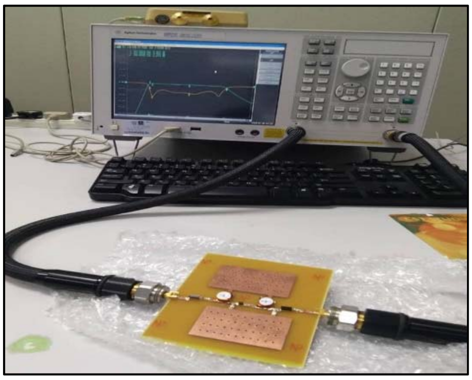

Fig. 4: Fabrication photo of the Band pass filter (BPF) at the labrotary measurement

Results and analysis

Low Noise Amplifier results

According to the designed style, the results are achieved the design specification that required in designing the LNA. Table 1 below shows the results for Low Noise Amplifier.

Table 1: the results of Low Noise Amplifier (LNA) values

Parameter name	Value
Frequency rang	10 MHz – 500 MHz
Canter frequency	255 MHz
Insertion loos S11	<-30 dB
Noise figure	< 1dB
gain S21	>20 dB
stability K	>1

The table above shows the LNA design results which is applicable to the design specification.

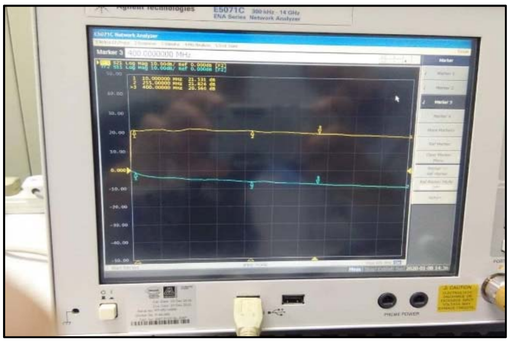

Figure 5: The S-parameter (S11) measurement result of (LNA)

The measured result of the LNA done by Vector Network Analyzer showed that the LNA gain (S21) is higher than 21 dB along the targeted band.

Band pass Filter results

The (BPF) was designed by using (ADS) software simulator with 5th order having very flat response to give more linearity as well as higher stability for (BPF) and make it at its best. Table 2 showed the S-parameters results of the band pass filter.

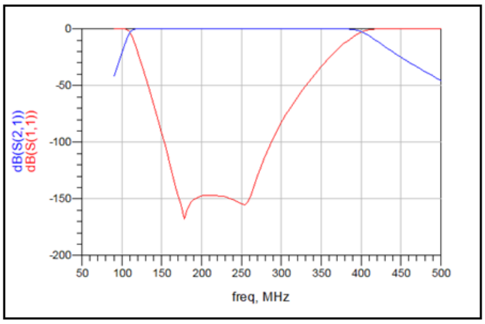

Figure 4: The ADS S-Parameter results of (BPF) value

Table 2: the results of design Band Pass Filter (BPF) value

Parameter	Value
Operating Frequency	110 MHz - 400 MHz
Centre frequency	255 MHz
Bandwidth	290 MHz
S (2,1)	-0.05 dB
S (1,1), Return loss	-150 dB

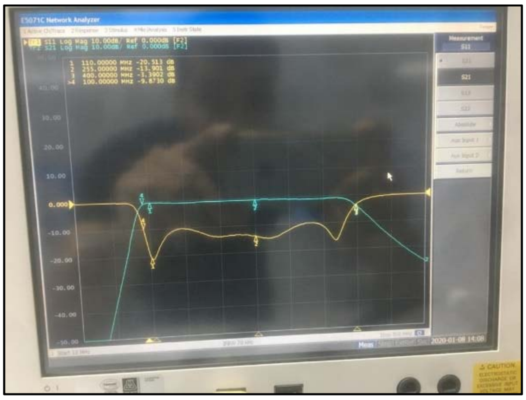

Fig. 6: Measured S-Parameters results of the Band pass filter (BPF) using Vector Network Analyzer (VNA) at the lab

The results of Combining (LNA-BPF)

The (LNA) will amplify the very weak signal captured by the receiver and at the same time the implementation of the band pass filter will reject and damping all the undesired signal outside the targeted band, figure 6 shows the S parameter result of combination the LNA with BPF.

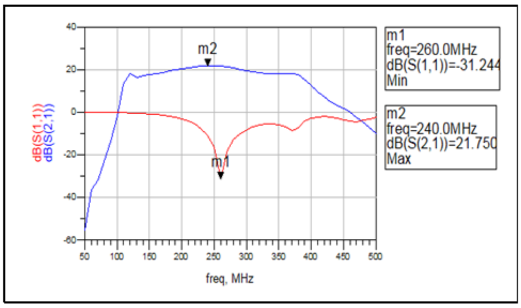

Fig. 5: The S-parameters results for the combining of Low Noise Amplifier with Band Pass Filter (LNA_BPF) value.

From the Fig. 6 above we can recognize the optimizing on the gain for S (2,1) parameters which shows the filtering on the band width range from 110 MHz to 400 MHz, as well as more smoothing for the gain signal response about 20 dB, with low noise figure (NF) as shows in figure 7 around 0.06.

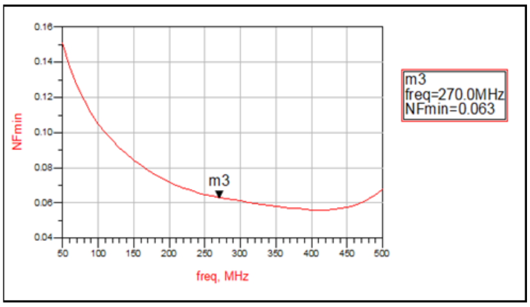

Fig. 6: The Noise Figure (NF) results for the combining of Low Noise Amplifier with Band Pass Filter (LNA-BPF)

Conclusion

The designing of the wideband radio receiver for the application of the lightning remote sensing was proposed. The simulated and fabricated result of the (LNA) with (BPF) show good performance and has met the design specification. The designed LNA is biased at Vds = 2V and Id = 12 mA. The results show that the comeback return loss achieved below -25 dB for the whole band. The highest gain is at 20 dB. Moreover, the noise figure is unbroken below 0.07 for entire LNA_BPF frequencies. The bandwidth achieves is wider compared with different style, whereas maintaining high gain and low noise figure for the LNA with very flat response of the Band Pass filter throughout the band, which will increase the accuracy of the receiver and capturing the signal with higher magnitude. The designed radio receiver is used for lightning detection and sensing system.

Authors: *Malik Hasan Al-Taweel, Email:malikaltaweel999@gmail.com, Ayman Mohammed Ibrahim, Email: ayman971972 @gmail.com, Mohd Riduan Ahmad, Email: riduan@utem.edu.my, Badrul Hisham Ahmad, Email: badrulhisham@utem.edu.my, Taha Raad Al-Shaikhli, Email: taha.alsheikhly@gmail.com, Mustafa Murtdha Al-Saeedi, Email: dithegoth@gmail.com.*

REFERENCES

[1] R. C. Moore, "An Introduction to LightningAn Introduction to Lightning , Vernon Cooray, Springer, 2015. $79.99 (386 pp.). ISBN 978-94-017-8937-0 Buy at Amazon ," *Phys. Today*, vol. 68, no. 6, pp. 54–56, 2015.
[2] M. R. Ahmad, "Lightning Interference in Multiple Antennas Wireless Communication Systems," *J. Light. Res.*, vol. 4, no. 1, pp. 155–165, 2012.
[3] V. Cooray and G. Cooray, "Electromagnetic radiation field of an electron avalanche," *Atmos. Res.*, vol. 117, pp. 18–27, 2012.
[4] A. M. Ibrahim, I. M. Ibrahim, and N. A. Shairi, "Compact MIMO antenna with high isolation for 5G smartphone applications," *J. Eng. Sci. Technol. Rev.*, vol. 12, no. 6, pp. 121–125, 2019.
[5] J. W. Warwick, C. O. Hayenga, and J. W. Brosnahan, "INTERFEROMETRIC DIRECTIONS OF LIGHTNING SOURCES AT 34 MHz.," *J Geophys Res*, vol. 84, no. C5, pp. 2457–2468, 1979.
[6] B. Ahmad, "A review on echo and phase inverted scanning in acoustic microscopy for failure analysis," *Przegląd Elektrotechniczny*, vol. 1, no. 3, pp. 11–16, 2021.
[7] T. R. Al-Shaikhli, B. H. Ahmed, M. R. Bin Ahmad, and M. Murtadha, "Integrated of low noise amplifier and notch filter for wireless communications," *Int. J. Appl. Eng. Res.*, vol. 12, no. 23, pp. 13690–13695, 2017.
[8] T. R. Al-Shaikhli, Z. Zakaria, B. H. Ahmad, M. R. Ahmad, M. Murtdha, and M. H. Al-Taweel, "Design of 1GHz low noise amplifier for microwave applications," *J. Adv. Res. Dyn. Control Syst.*, vol. 10, no. 7 Special Issue, pp. 647–651, 2018.
[9] F. Fatonah, M. Wildan, S. Purnomo, and A. M. Soleh, "Design of High Gain Low Noise Amplifier at Base Station Receiver VOR Equipment for Ground Check Monitoring as Learning Media in Civil Aviation Design of High Gain Low Noise Amplifier at Base Station Receiver VOR Equipment for Ground Check Monitoring as Learning Media in Civil Aviation Academy," no. October, 2020.
[10] D. C. Vaghela, A. K. Sisodia, and N. M. Prabhakar, "Design, Simulation and Development of Bandpass Filter at 2.5 GHz," *Int. J. Eng. Dev. Res.*, vol. 3, no. 2, pp. 1202–1209, 2015.
[11] R. Al-Amin, M. Omar, and F. Chowdhury, "Design and Simulation of Fifth Order Band-Pass Filter for S Band," *Iject*, vol. 7, no. 1, pp. 56–60, 2016,
[12] Z. Huang, C. Huang, C. Chen, and C. Hung, "CMOS Dual-Wideband Low-Noise Amplifier in Wideband Wireless Receiver TVu," *Ieee*, vol. 00, pp. 418–421, 2007.
[13] Y. C. Chen and C. N. Kuo, "A 6??10-GHz ultra-wideband tunable lna," *Proc. - IEEE Int. Symp. Circuits Syst.*, pp. 5099–5102, 2005.
[14] R. M. Weng, R. C. Kuo, and P. C. Lin, "An ultra-wideband LNA with notch filter," *2007 17th Int. Conf. Radioelektronika*, 2007.