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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:

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

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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 lumpedcomponent.The QB-LNA was designed on FR4 microstrip substrate with εr= 4.4, thickness h=1.6 mm, and tan δ= 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 obtainreturn 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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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 frequenly used for MLNAdesign 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 εr= 4.4, h=1.6 mm, and tan δ = 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 LNAas shown in Figure 2.

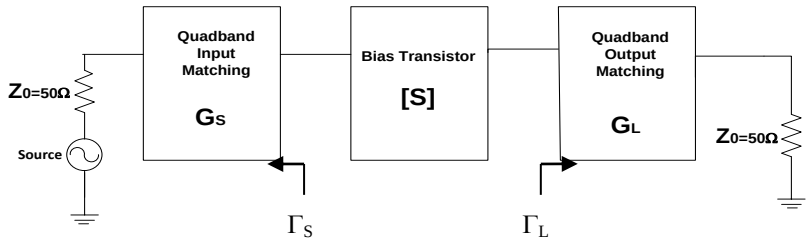


Figure 1. A subsystem of multiband LNA

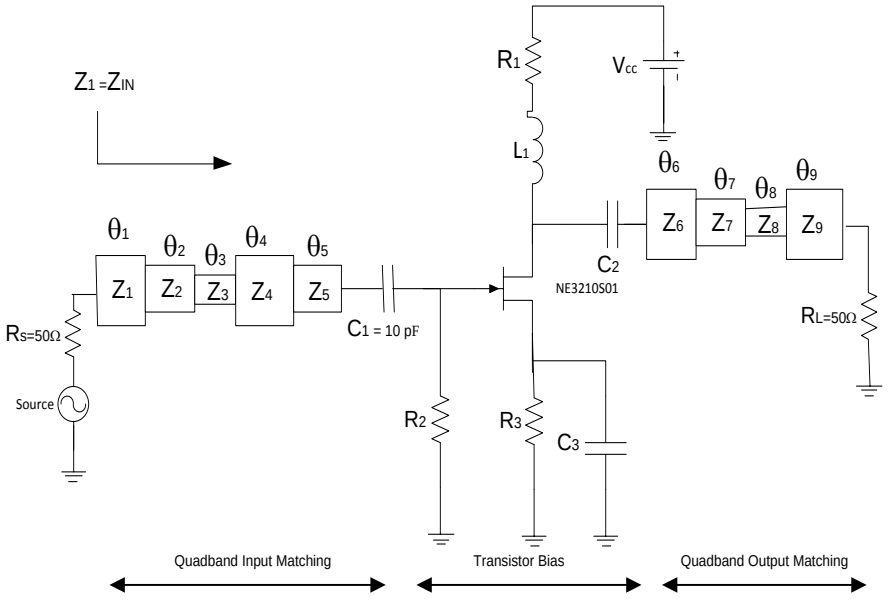


Figure 2. A multi-section impedance transformer (MIT) as IIM and OIM

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}).

$$Z_{IN} = j\omega L_s + j\omega L_g + \frac{1}{j\omega C_{gs}} + \frac{g_m}{C_{gs}} L_s$$
$$= j\omega\left(L_s + L_g\right) + \frac{1}{j\omega C_{gs}} + \frac{g_m}{C_{gs}} L_s \quad (1)$$

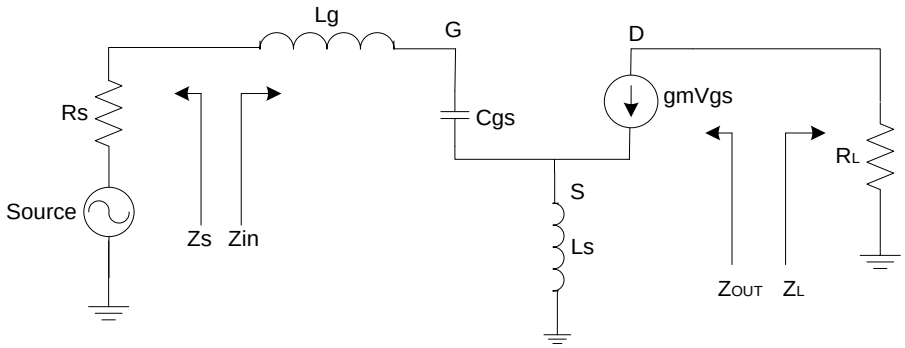


Figure 3. Small signal analysis of bias circuit

A relation of cutoff frequency and transconductance is given by:

$$\frac{g_m}{C_{gs}} L_s = \omega_T L_s \qquad \rightarrow \frac{g_m}{C_{gs}} = \omega_T \quad (2)$$

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

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

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

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

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

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

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

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

With $j\omega$ = sat resonant frequency (ω_0), the Equation (7) could be simplified;

$$S_{11} = \frac{s^2 + {\omega_o}^2}{s^2 + Bs + {\omega_o}^2} \quad (8)$$

With

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

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

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

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.

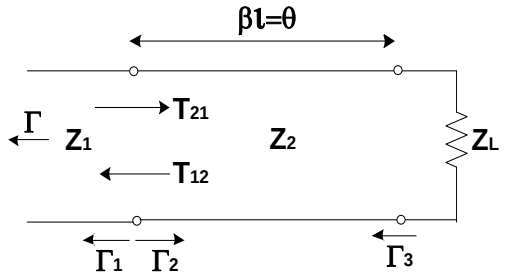


Figure 4. Single-section Impedance Transformer

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-bandimpedance 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 $i = 1, \dots M$, propagations constant (β), and electrical length (l_i).

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

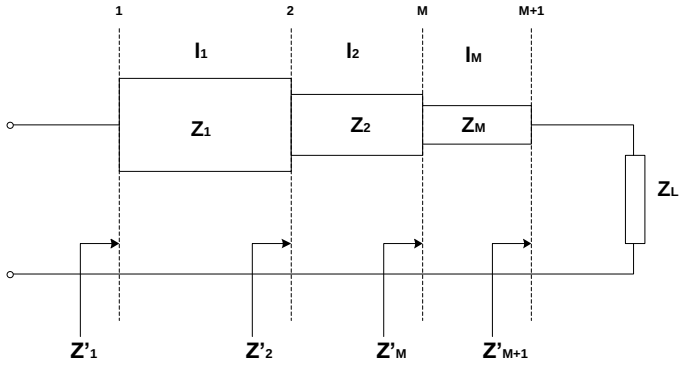


Figure 5. Multisection impedance transformer

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 maching condition, return loss is given by:

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

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 εr= 4.4, h=1.6 mm, and tan δ = 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 Ω, R_2 = 3 kΩ, R_3 = 51 Ω, C_3 = 30 pF, R_S = 50 Ω (as a input termination), and R_L = 50 Ω (as a output termination).

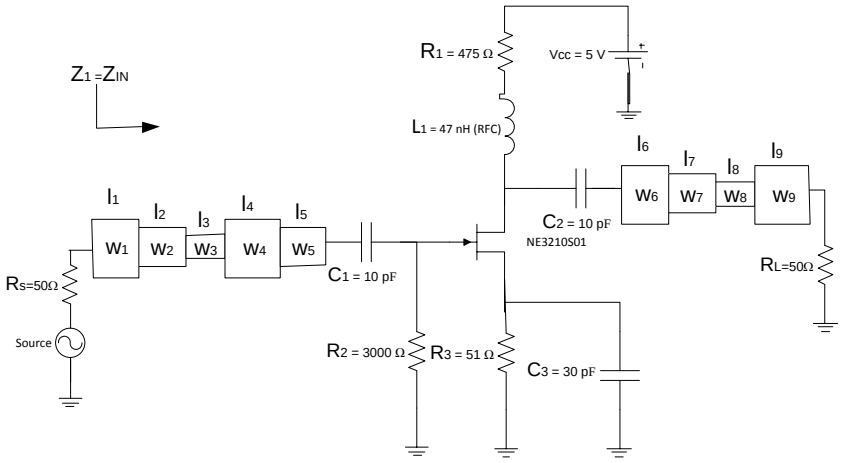
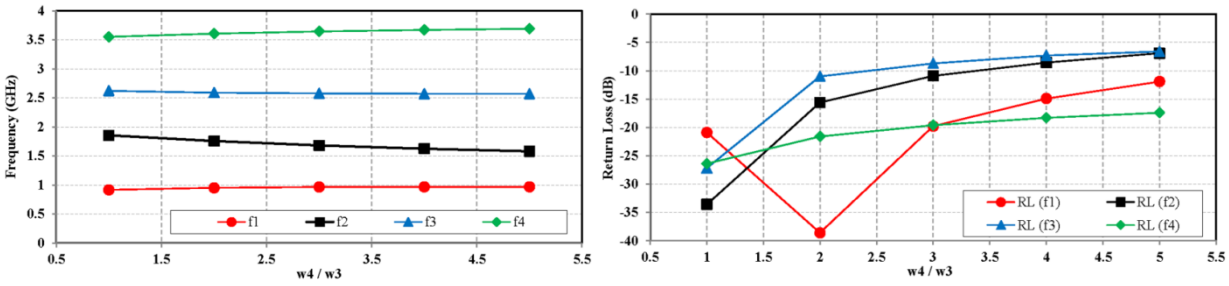
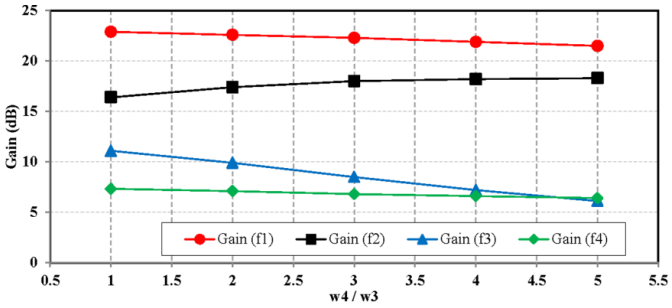


Figure 6. QB-LNA using multisection impedance transformer (MIT)



(a) (b)

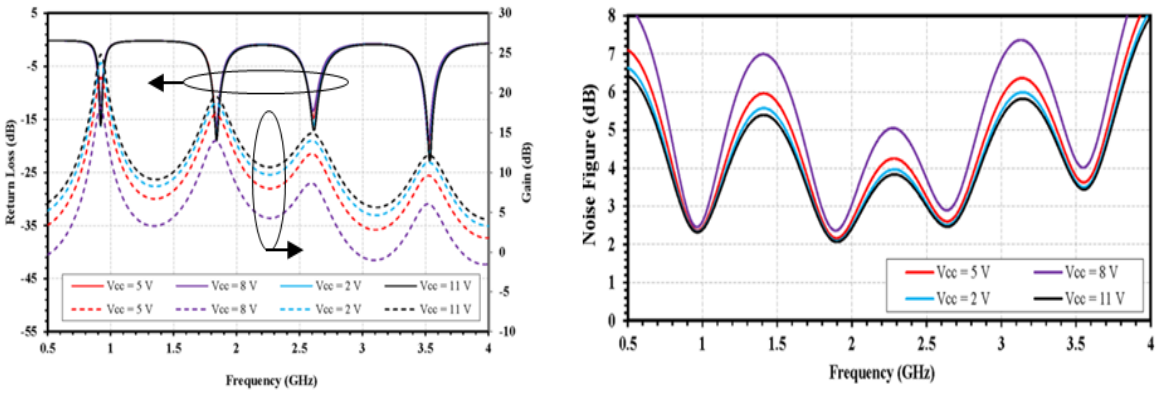


(c)

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 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.

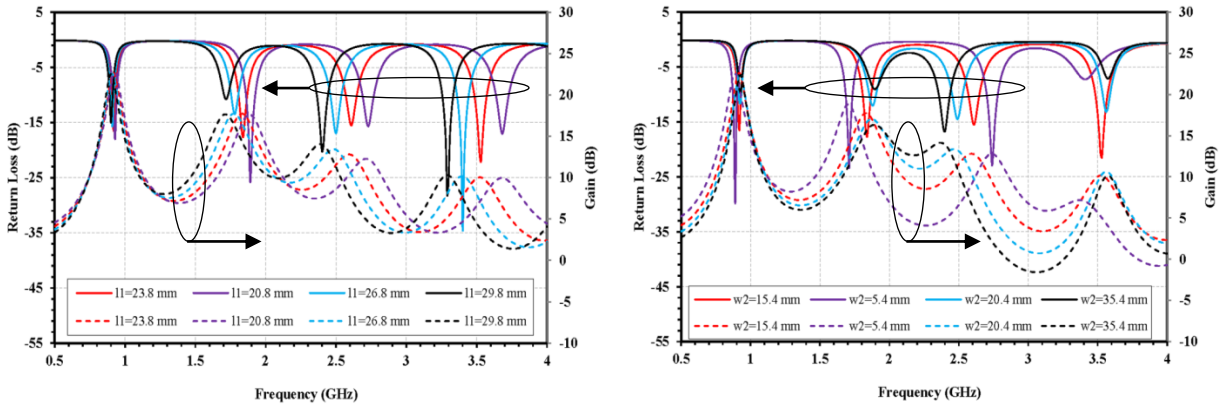
Figure 8(a) and 8(b) show the extracted return loss (S_{11}) and gain (S_{21}) with varied power supply (V_{CC}). It is useful for demonstrating the consistency performance of QB-LNA. The return loss (S_{11}) of frequency f_1, f_2, f_3, and f_4 remains constant. However, the value of gain (S_{21}) and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



(a) (b)

Figure 8. (a) The extracted of return loss (S_{11}) and gain (S_{21}), (b) Noise figurewith 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.



(a) (b)

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 εr= 4.4, thickness h=1.6 mm, and tan δ= 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.

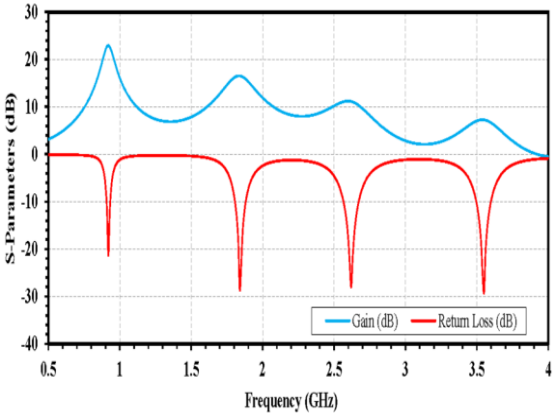


Figure 10. The performance of return loss (S_{11}) and gain (S_{21}) of QB-LNA

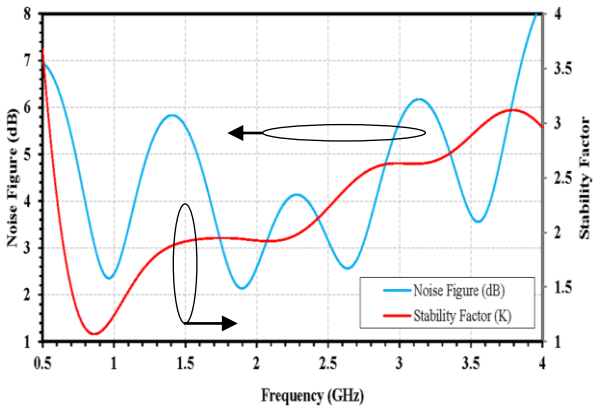


Figure 11. The performance of Noise figure (dB) and stability factor (K) of QB-LNA

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]

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

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

Parameter	Reference [17]		[18]		[19]		This work			
Method	Concurrent multiband		Concurrent multiband		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 εr= 4.4, thickness h=1.6 mm, and tan δ= 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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