

## 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 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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## 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.

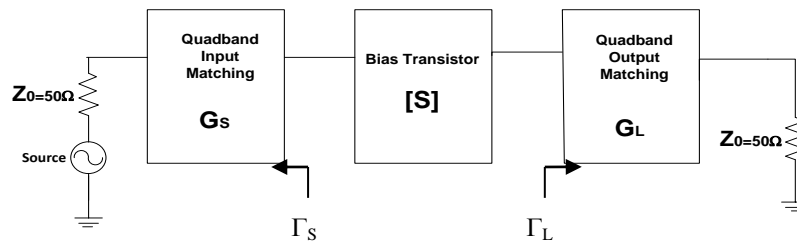


Figure 1. A subsystem of multiband LNA

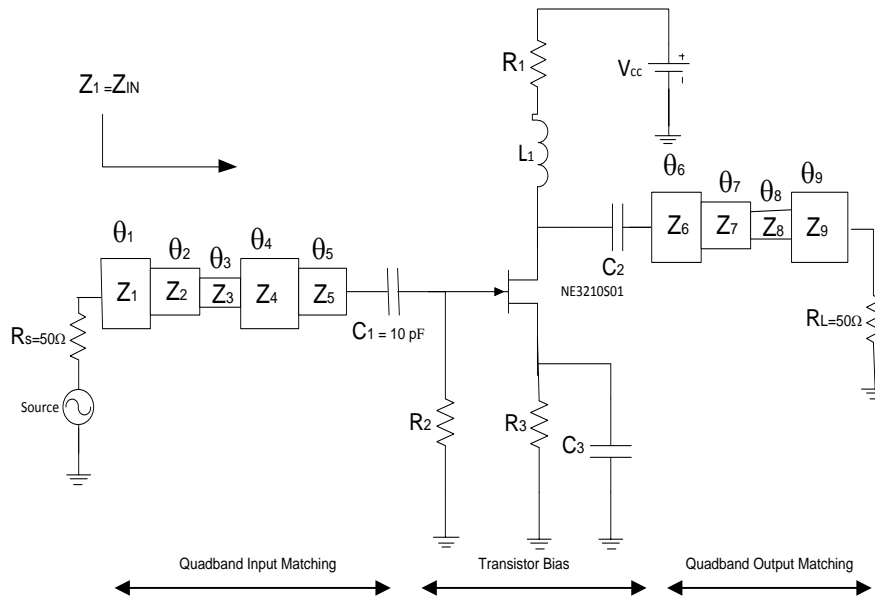


Figure 2. A multi-section impedance transformer (MIT) as IIM and OIM

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  $\theta_N$  ( $N=1,2,3,4,5,6,7,8,9$ ), 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 ( $C_{GS}$ ).

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

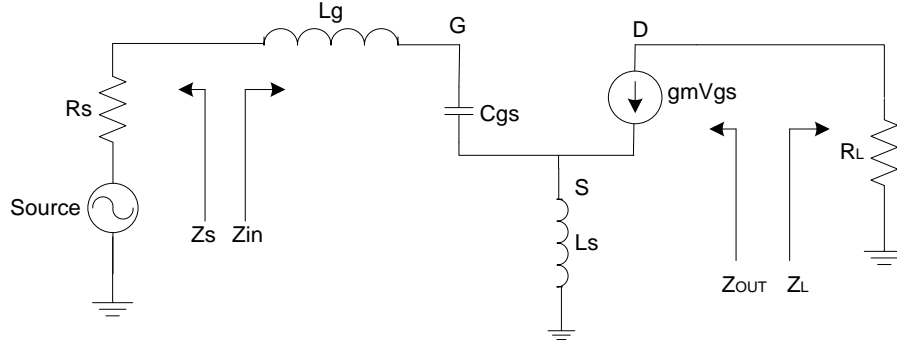


Figure 3. Small signal analysis of bias circuit

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:

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

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

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

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

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

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.

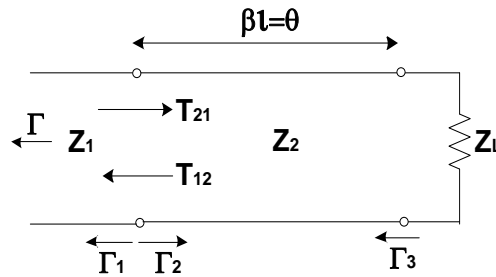


Figure 4. Single-section Impedance Transformer

The partial reflection coefficients  $\Gamma_N$  ( $N=1,2,3$ ) 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 ( $\beta$ ), and electrical length ( $l_i$ ).

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

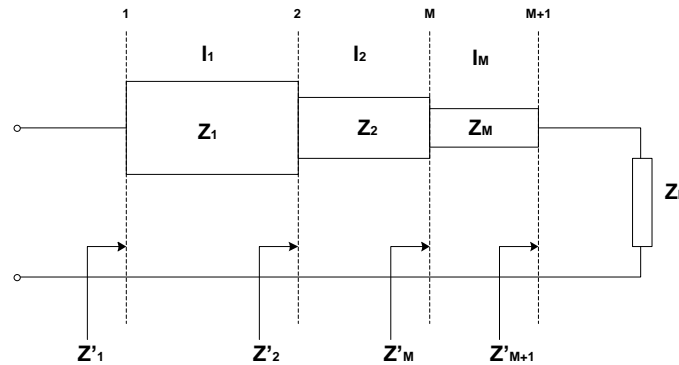


Figure 5. Multisection impedance transformer

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 $\Omega$ ,  $R_3 = 51 \Omega$ ,  $C_3 = 30$  pF,  $R_S = 50 \Omega$  (as an input termination), and  $R_L = 50 \Omega$  (as an output termination).

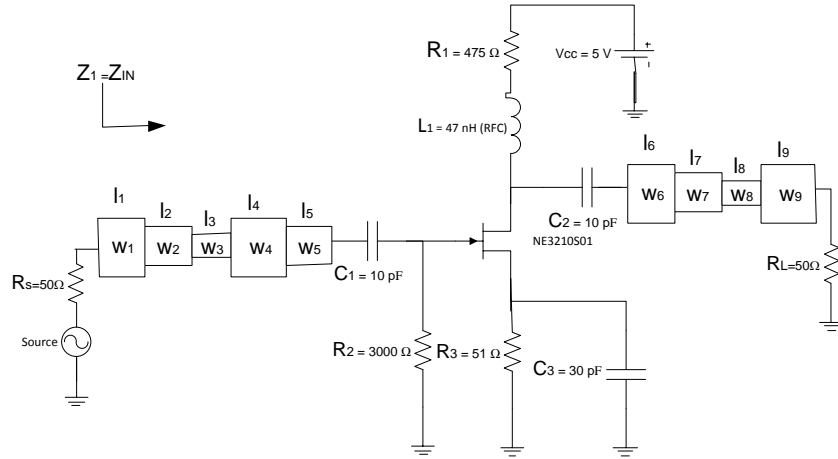


Figure 6. QB-LNA using multisection impedance transformer (MIT)

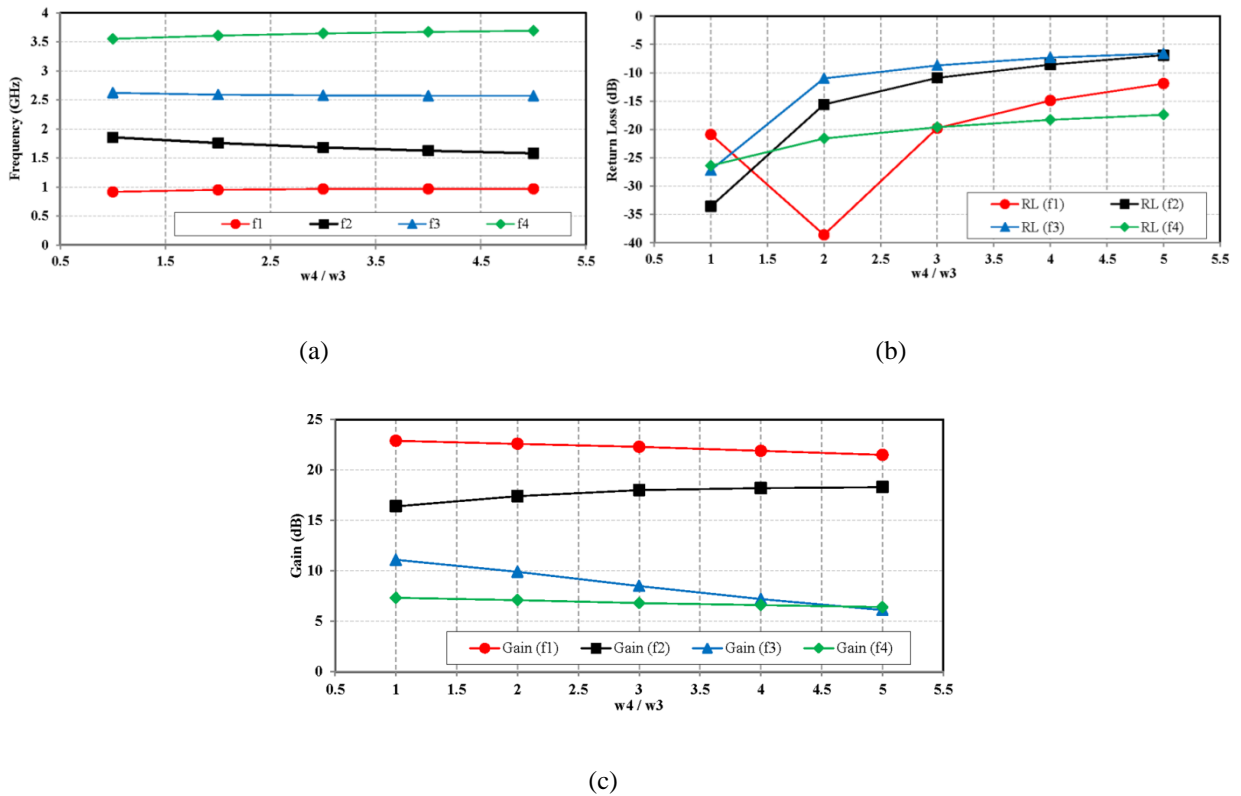


Figure 7. (a) The extracted center frequency with varied  $w_4/w_3$ , (b) the extracted of return loss ( $S_{11}$ ) with varied  $w_4/w_3$ , (c) the extracted of gain ( $S_{21}$ ) with varied  $w_4/w_3$

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 ( $V_{CC}$ ).

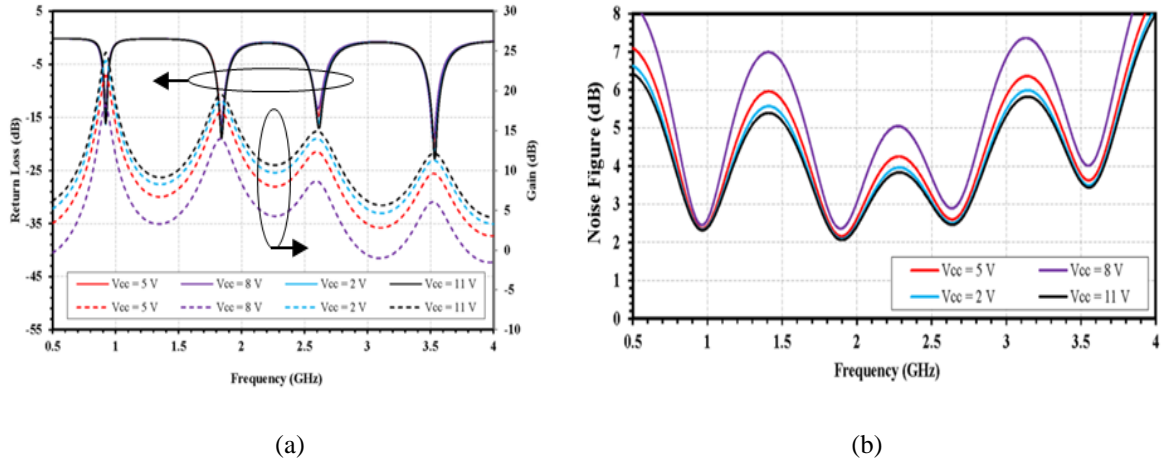


Figure 8. (a) The extracted of return loss ( $S_{11}$ ) and gain ( $S_{21}$ ), (b) Noise figure with varied  $V_{CC}$

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  $w_2$ .

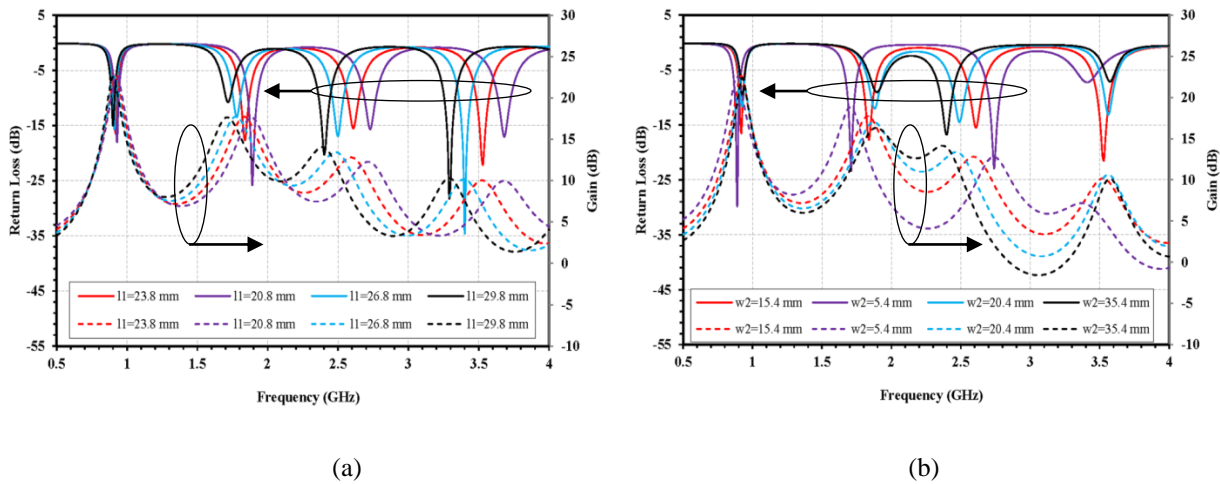


Figure 9. (a) The extracted return loss ( $S_{11}$ ) and gain ( $S_{21}$ ) with varied  $l_1$ (b). The extracted return loss ( $S_{11}$ ) and gain ( $S_{21}$ ) with varied  $w_2$

#### 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.

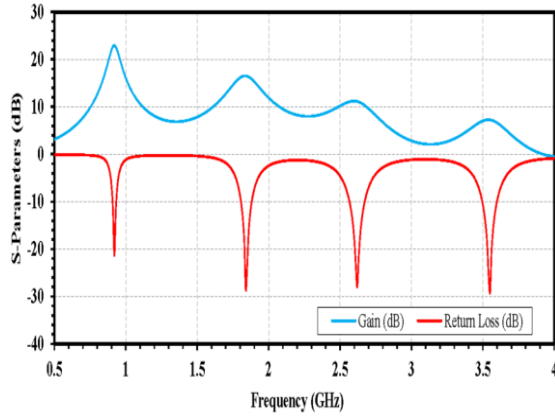


Figure 10. The performance of return loss ( $S_{11}$ ) and gain ( $S_{21}$ ) of QB-LNA

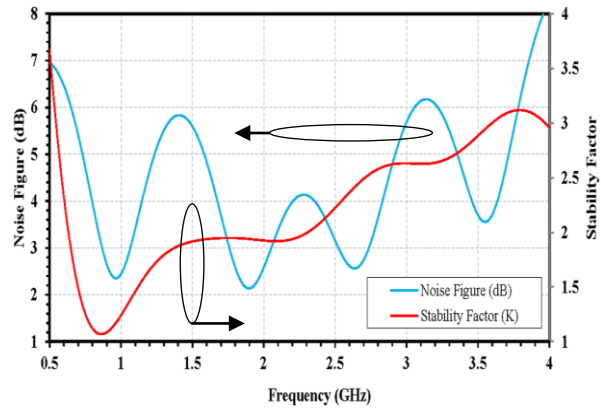


Figure 11. The performance of Noise figure (dB) and stability factor (K) of QB-LNA

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            |       | Reference            |      | Reference            |      | This work            |      |       |      |
|------------------------|----------------------|-------|----------------------|------|----------------------|------|----------------------|------|-------|------|
|                        | [17]                 |       | [18]                 |      | [19]                 |      | Concurrent multiband |      |       |      |
| 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  $\epsilon_r = 4.4$ , 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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