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Research Article

Low noise amplifier design for hidden wireless lan applications using band pass filter with geometric mean prototype element values

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ABSTRACT

Detection and perception problems may occur when the amplitude level of some signals that need to be received and detected is weak. Information that is requested to be kept confidential or not shared with other units is always available in the environment as wireless electromagnetic (EM) waves. Detection can only be made with the appropriate method. Thermal radiation emitted by objects that are intended to be hidden under clothing can also be given as an example. The signal level of these EM waves is very low. In this case, low noise amplifier (LNA) circuits are used to increase such values to a measurable level by network analyzer. In this study, a design with 17.19 dB gain for WLAN applications is made using BL011 LNA chip gathered from BeRex company with a 3rd order band pass filter (BPF) at 2.4 GHz center frequency, it has 200 MHz band width (BW) and 50 ohm characteristic impedance. An innovation has been introduced to design BPF as using the geometric mean prototype element values (PEV) by the help of geometric mean of 4 known techniques: Butterworth, Chebyshev (0.5 dB ripple), Bessel and Gauss (to 12 dB) normalized table values. According to the researches, the BPF circuit created by the geometric averaging method with the BL011 LNA chip has never been used to detect hidden EM signals in the WLAN band. Finally, the proposed BPF circuit is 2 in total, one at the input and one at the output; LNA circuit designed by using BL011 module and impedance matching circuit, a total of 3 consecutively connected and combined systems are formed. The proposed full system has the merits of compactness, good input reflection coefficient and good S21, gain characteristic.

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INTRODUCTION

LNA is an amplifier circuit and it tries to reveal the real signals by adding extra little noise to the main circuit. It can be used alone or cascade connection can be made. Other circuit elements that are often used together are mixer, detector, power amplifier (PA), filters and antennas. These systems can be used in applications such as RADAR, SONAR, LIDAR, satellite communication as well as to obtain and amplify EM signals during the transmission of

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digital information in the air, which is mostly confidential or hidden [1-4].

In this project, BL011 LNA chip that may operate from 5 MHz to 4 GHz frequency ranges and BPF with 2.4 GHz center frequency are used. A new proposal is presented as PEV and 4 types of the existing PEVs were selected. The geometric average was taken to start the design of BPF. Since it is the goal to amplify the hidden or weak signals in WLAN applications. It is considered sufficient to strengthen the frequencies between 2300-2500 MHz. The gain is obtained 17.19 dB when using a single LNA and it is amplified to 51.8 dB by means of cascading connection. The designs were made on the AWR program tool.

Bharathy G. T. et al. performed the LNA, which they obtained 15.86 dB gain, at 2.4 GHz using the ADS tool [5]. Yilmaz İ. E. et al. designed an LNA with 1.014 dB noise figure (NF) and 19.85 dB gain at 2.4 GHz for RADAR applications [6]. Divya A. L. et al purposed noise reduction and high gain LNA for receivers [7]. Receiver application were presented by Burak A. et al. at 28 GHz using 0.13 µm SiGe BiCMOS technology [8]. CMOS technique was used by Patel A. V. et al. up to 4 GHz and it has greater than 30 dB gain with design of three cascaded system [9]. Another CMOS LNA circuit with 90 nm structure was purposed by Bhuiyan M. A. S. et al. for internet of things (IoT), it has 164.2 MHz band width and 19 dB gain for 2.4 GHz [10]. Gholinia M. et al. were proposed a model of Si-IGBT power module for energy storage [11].

On the other hand, without using circuits such as LNA or BPF, it is possible to detect hidden cameras, which emits low signals and works as WLAN, only by phone and software as detecting hidden wireless camera (DeWiCam) [12]. Wang W. et al. were succeeded at uncovering hidden wireless threat by the help of interference method [13].

If we talk about the band-pass filter literature; Demirel M. produced a dual-band band-pass filter with the help of a meander resonator using varactor and capacitance [14], Hu Q. et al. designed compact S band band-pass filter with ultrawide band-stop filters using crossed resonator, coupled microstrip lines, and defect ground structures [15], Bao-Qin L. et al. suggested a two-dimensional periodic structure frequency selective surface with polarization rotation property to design a band-pass filter [16], A faster artificial neural network model for designing a microstrip low-pass and band-pass filters developed by Hathat A. [17].

As it can be seen, LNA or BPF designs are sometimes made with transistors and sometimes with chips. Also, in some cases, FSS or software-based neural networks or applications may be used in literature. In this study; BL011 chip and matching circuit for LNA, novel-newly proposed prototype geometric averaging method for BPF and cascade connections are used to end up the system.

MATERIALS AND METHODS

The design consists of 2 stages, BPF and LNA. While a different technique is applied for BPF, BL011 chip is used over AWR tool for LNA.

Band Pass Filter

For the BPF prototype element values characteristic, 4 techniques (Butterworth, 0.5 dB ripple sort of Chebyshev, Bessel and 12 dB sort of Gauss) of the other characteristic values are selected and their geometric mean is taken. It is shown in Table 1 for different orders (3 to 8). If one examines the design results, the answer to the question of whether it is possible to switch from low pass filter (LPF) to BPF by means of this PEV found by this method will be positive.

The LPF lumped element LC values can be found by Equation 1. Afterwards, the new LC values for purposed BPF are calculated for even and odd elements. There will be 3 capacitances and 3 inductances in the last circuit. In this design, odd elements are connected parallel even elements are connected series. Later on, a 3rd order BPF whose first element is parallel capacitance is designed. The circuit is shown in Figure 1. Inductance and capacitance values of passive elements can also be seen on Figure 1. Band width of this circuit is measured as 246 MHz (2.279-2.525 GHz) with the AWR tool as seen on Figure 2.

$$L = \frac{Z \times g}{\omega}, C = \frac{g}{Z \times \omega} \quad (1)$$

Table 1. Normalize geometric mean PEV

Order	Geometric Mean of Butterworth, Chebyshev (0.5 dB ripple), Bessel and Gauss (to 12 dB)							
	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8
3	0.61	1.14	1.67					
4	0.51	0.96	1.45	1.34				
5	0.46	0.87	1.33	1.22	1.52			
6	0.42	0.80	1.25	1.16	1.42	1.23		
7	0.38	0.73	1.17	1.11	1.38	1.16	1.41	
8	0.36	0.69	1.11	1.07	1.35	1.14	1.34	1.15

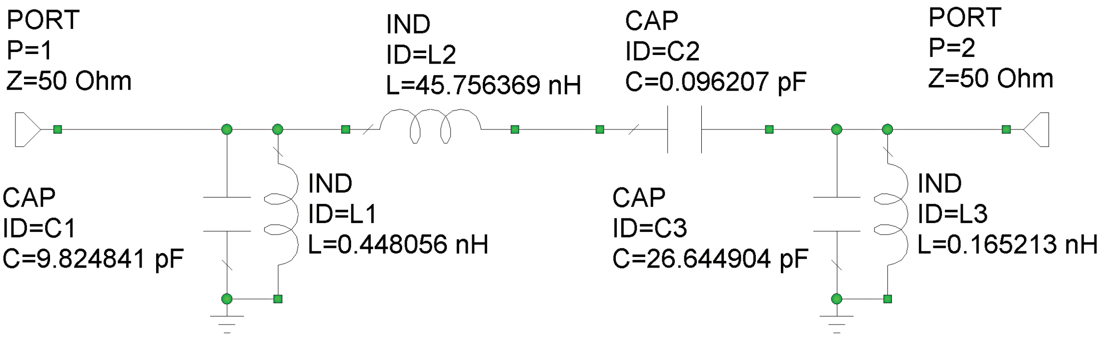

Figure 1. Purposed BPF circuit with element values.

The Bessel and Gaussian characteristic outweighed and the graph (gain) of the suggested method resembled them as Figure 2 with f_c frequencies. In Table 2, the LC lumped elements values for 4 types are given.

S_{21} graphs of circuits created with other methods are shown in Figure 3–5, respectively. Firstly, the S_{21} graph of only Chebyshev values is given in Figure 3. Secondly, the S_{21} graph of only Gauss values is given in Figure 4. At third, purposed circuit is given in the same graph with Chebyshev (0.5 dB ripple), Butterworth, Bessel, Gauss (to 12 dB) in Figure 5. A close-up view of the pass band region of Figure 5 is given in Figure 6. In this graph, it can be seen that the proposed method is similar to the Bessel and Gaussian method, but the pass band area is wider, like the

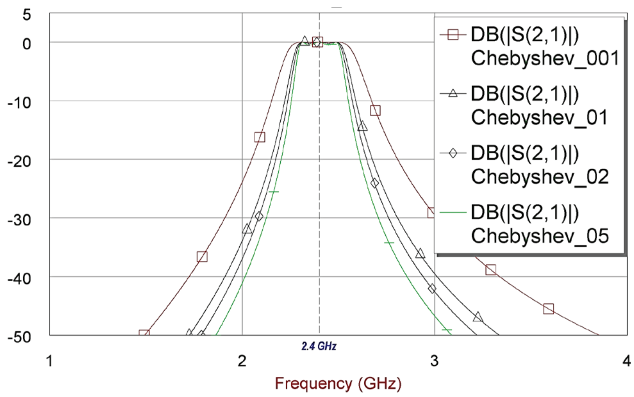

Figure 3. S_{21} graph of the Chebyshev methods.

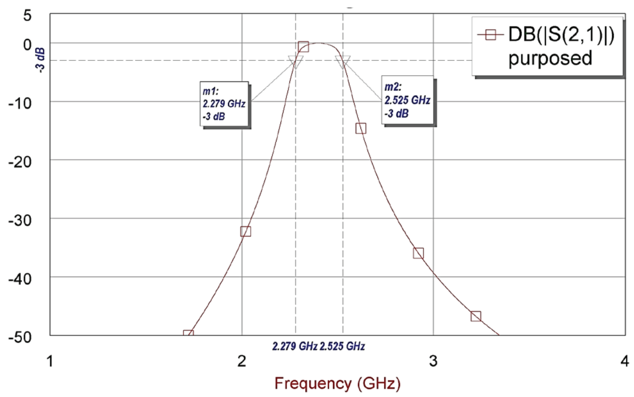

Figure 2. S_{21} graph of the suggested method.

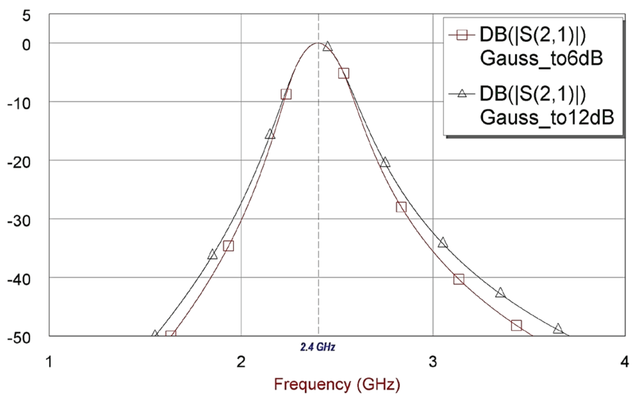

Figure 4. S_{21} graph of the Gauss methods.

Table 2. LC lumped elements values for 4 techniques

	C_1 [pF]	L_1 [nH]	C_2 [pF]	L_2 [nH]	C_3 [pF]	L_3 [nH]
Chebyshev (0.5 dB)	25.418	0.173	0.100	43.658	25.418	0.173
Butterworth	15.923	0.276	0.055	79.617	15.923	0.276
Bessel	5.372	0.819	0.113	38.634	35.085	0.125
Gauss (to 12 dB)	4.285	1.027	0.134	32.651	35.493	0.124

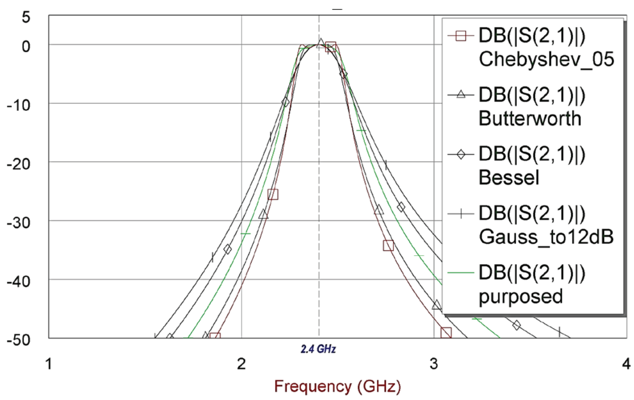

Figure 5. S_{21} graph of 5 different methods.

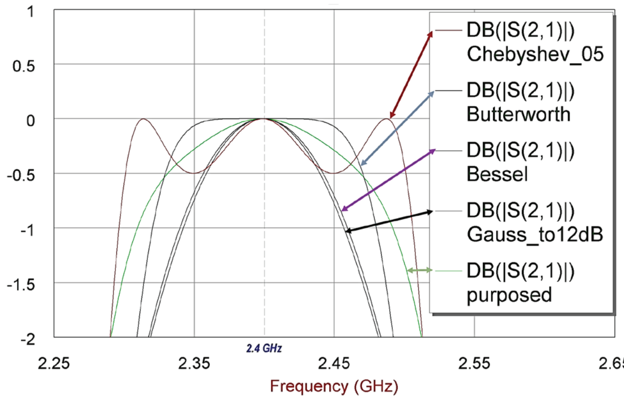

Figure 6. A close-up S_{21} graph of 5 different methods, (pass band region of Figure 5).

Butterworth and Chebyshev method, unlike Chebyshev, there is no ripple in the pass band region.

The difference of the purposed version from the Bessel and Gauss types is that it is wider like the Butterworth type. But the pass band part is not as wide as the Butterworth type. As in the Chebyshev type, there is no fluctuation in purposed type.

Low Noise Amplifier

For the LNA, BL011 module from BeRex company is used. The same chip might be seen in the "Parts By Vendor" section of the AWR tool. Information for the amplifier, called 5-4000 *GHz* Wideband LNA, is taken from the datasheet [18] and given in Table 3. An application circuit has been bettered in accordance with the datasheet specifications, but the C_1 element value of the application circuit has been changed. With this change, the gain is achieved to 17.19 *dB* and the S_{11} value is obtained as -32.96 *dB*. Also, the minimum point of S_{11} and the maximum point of S_{21} are aligned. Since the LNA design is intended to be operated at 2.4 *GHz* for WLAN applications. Measurements are taken by using it with purposed BPF as given in Figure 7.

Moreover, purposed BPF has been inverted and added to the output part of the LNA application circuit. Thus, fluctuations and distortions in the S_{22} parameter of the LNA are prevented. Therefore, -5.452 *dB* is obtanined from the LNA as S_{22} parameter.

The final circuit created using one LNA is given in Figure 7 (the purposed BPFs are shown as sub-circuits at the input and output in this figure) and all of the S parameters of this circuit are given in Figure 8. After this step,

Table 3. Information of the LNA chip

Name	Value	Unit
Gain	15.5	dB
S_{11}	-19.5	dB
S_{22}	-15.5	dB
P1dB	20	dBm
NF	1.3	dB
BW	5-4000	MHz
Vc	5	V
Ic	75	mA
Rth	43	°C/W

Material: GaAs E-pHEMT process

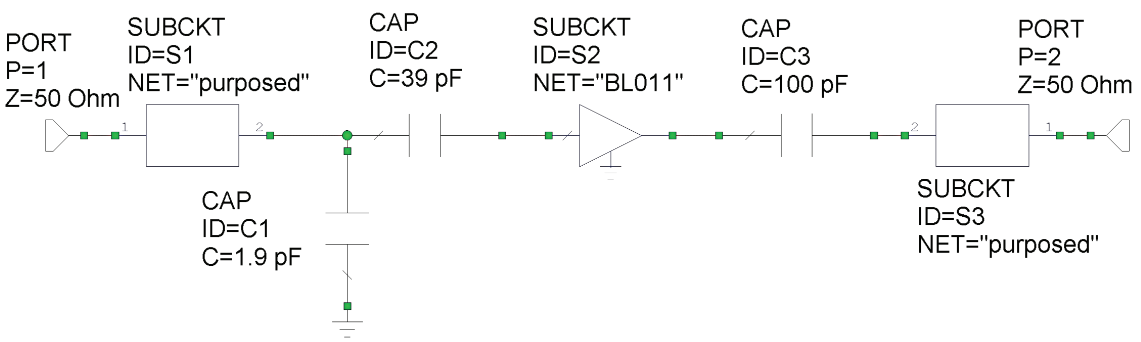

Figure 7. LNA application circuit with purposed BPFs.

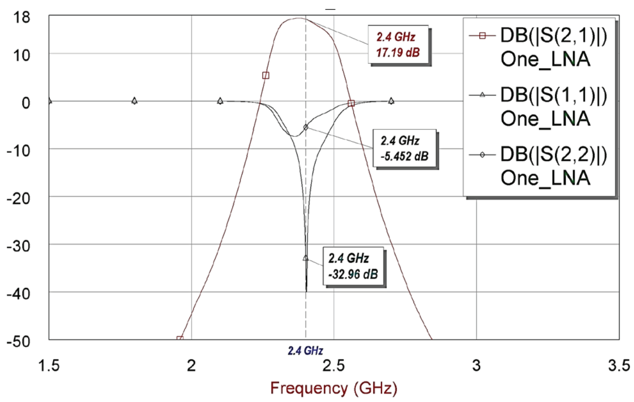

Figure 8. S parameters of one LNA.

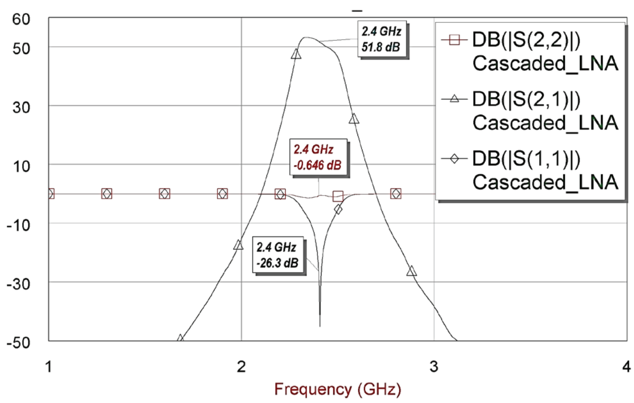

Figure 10. S parameters of cascaded system.

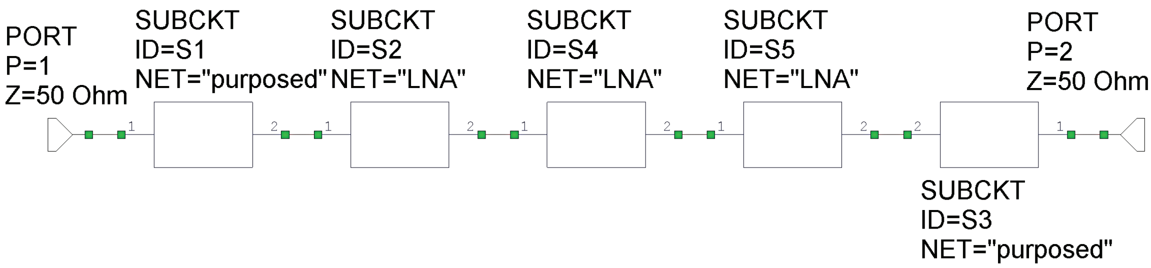

Figure 9. The circuit of three cascaded LNA application circuits with purposed BPFs.

three LNAs are planned to be connected in cascade as given in Figure 9 (here both BPFs and LNAs are demonstrated as sub-circuits). There are BPF circuits at the input and at the output section; there are also 3 cascaded LNA in the middle of the circuit. In this way, we will be able to increase the gain.

In Figure 10, the graph of S parameters of the cascaded system is presented. All of the S parameters values increased. In other words, while S_{21} was rising, S_{11} and S_{22} approached 0. The desired method is selected according to the intended use of the circuit. In some applications, while it is desired to increase the gain, at the same time, it is desired that the values of back reflection from the input and back reflection from the output should be at negative levels. It is sufficient to use the recommended circuit with one LNA for this project which is trying to detect hidden electromagnetic signals in wireless LAN applications. Cost is also important in this regard.

RESULTS AND DISCUSSION

The new prototype element values created by taking the geometric mean of 4 techniques works. It functions as a filter made by using resonator circuits for the transition from LPF to purposed BPF. The band width of BPF, which is planned as 200 MHz during the design, is determined as 246 MHz in the measurements made. It is still able to perform the desired tasks because of operating in WLAN frequency band, 2.4 GHz. It is determined that the intended method is close to Bessel and Gauss methods. There are no fluctuations in the pass band section like Chebyshev. Its width is like Butterworth. If other prototype element values of the Chebyshev or Gauss methods were used while taking geometric mean, a different result could be obtained. As a result, a bandpass filter that can operate passively and filter the desired frequencies is obtained.

The LNA gives 17.19 dB gain result and it is quite enough for amplifying the hidden signals in the WLAN environment. Optimum results are also obtained for S_{11} and S_{22} by changing the values of some circuit elements mentioned in the LNA section. Throughput of the final LNA circuit is proof that datasheet features are provided.

The LNAs and BPFs are harmoniously connected (3 LNAs and 2 BPFs) according to the measurements and the final circuit can operate at 2.4 GHz for wireless apps. It can amplify signals that are hidden or obvious in space. Thus, the data that is desired to be concealed can be found. However, finding the data and transferring it to the computer by strengthening is not the final solution. One may also need to decode.

The last system created can also help in recognizing hidden objects that are intended to be hidden under clothing. Since every object is greater than 0 Kelvin, it radiates and these radiations are at different levels. It can be determined what the object is (gun, knife) according to the radiation it emits. Because of being this emitted radiation is very low, it may need to be amplified with LNA systems.

Although a cascaded system is made, it has been seen that the system made with a single LNA is sufficient and better about cost.

CONCLUSION

As a result, an LNA-BPF system that can be used for perceptional project, which is one of the applications that has become popular in wireless communication systems in recent years, has been presented. The main purpose is to amplify and make low signals visible; unknown-hidden signals can be read and decoded/deciphered by a decoder after amplified.

The final proposed system operates in the IEEE S band, the standard UHF band, at 2.4 *GHz*, has a bandwidth of 176 *GHz* and has a gain of 17.19 *dB*. The cascaded system has 51.8 dB gain. If a larger amplifying is desired, the cascade system is used. In this regard, cost calculation and the status of S_{22}, S_{11} parameters should be checked. Consequently, a new LNA circuit that can operate in the S band and BPF designed with a different method were introduced and the whole integrated circuit was created.

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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