Journal of Nuclear Energy Science & Power Generation Technology

Review Article

A SCITECHNOL JOURNAL

4G-LTE Front End Design with Reduced Transmission Leakage

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Received date: October 20, 2021; **Accepted date:** November 04, 2021; **Published date:** November 11, 2021

Abstract

In the wireless communication system, the obstacles in the atmosphere and also due to the inappropriate design components in the system degrade the signal. The signal undergoes loss, and restoration of the original signal at the receiver end is difficult. The transmission leakage must be minimized to get the maximum output. The prototype is produced using low dielectric FR-4 substrate and tested for both single and dual port devices using handheld vector network analyzer.

Keywords: Band notched antenna; LNA; ADS; HFSS; VNA and CSRR

Introduction

In Mehmet Tamer Ozgun et al. [1] the existing model the author has proposed to minimize the transmission leakage by introducing the notch filter after the mixer unit. Since the active notch filter is operating at IF frequencies, its noise, power, and area consumption penalty for the overall transceiver is negligible, and it does not require any complicated amplitude and phase calibration circuitry that is necessary for the cancelers which operate at RF frequencies. The system operates at the LTE band 20 which covers frequencies between 791-821 MHz. The transmission leakage is due to the signals present in air degrades the strength of the desired signal. At the receiver it becomes a great challenge to reconstruct the signal via wireless transmission. The devices in the receiver end have to be properly designed to meet the minimum leakage. The major disturbance is the IIP3 and IM2 interferences.

The impedance matching of the devices has to be done in order to have maximum power transfer and avoid damage to the device. The three front end devices have been taken into the consideration i.e. antenna, band pass filter and low noise amplifier. The LTE band 22 is chosen in order to cover 3.4–3.6 GHz frequency range, this band also covers mid 5G spectrum allocated range. The antenna used here is a notch band antenna which covers 3.1 GHz to 10 GHz frequency range and removes the WLAN frequency (5.5 GHz), for further smoothening the signal a coupled line band pass filter is used which covers between 3.4-3.6 GHz and in the LNA is designed for 3.4 GHz with minimum noise figure and moderate gain.

System Architecture

The system comprises of notch band antenna followed by band pass filter, low noise amplifier and vector network analyzer. The system for reducing the transmission leakage is shown in Figure 1.

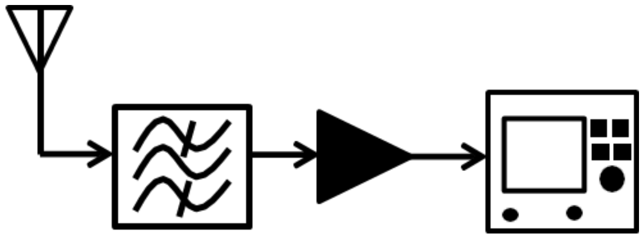

Figure 1: System block diagram.

Each module is tested individually on VNA and for the whole system performance the module has to be cascaded using male to male SMA connector and the s-parameters are analyzed. The VNA operating frequency is up to 9 GHz therefore the measurement can be carried over easily since the system operates at S-band i.e. 2-4 GHz. The system comprises of notch band antenna followed by band pass filter, low noise amplifier and vector network analyzer. Each module is tested individually on VNA and for the whole system performance the module has to be cascaded using male to male SMA connector and the s-parameters are analyzed. The VNA operating frequency is up to 9 GHz therefore the measurement can be carried over easily since the system operates at S-band i.e. 2-4 GHz. In real time the performance totally varies from that of the simulated result. The loss may occur because of the improper substrate selection, mismatching dielectric constant loss tangent to that of the parameters used in the design tool. The main factor is due to high cable loss.

Band notched antenna

The device which performs both the receiving and rejection of frequency band is said to be band notch antenna. Here the antenna notches at 5.5 GHz since the operating frequency band is from 3400 to 3600 MHz the WLAN signal suppresses the operating frequency. To overcome such issue the high frequency signal has to be removed for proper reconstruction the original signal. In Abdollahvand et al. [2], the authors used the circular patch antenna with CSRR structure to eliminate the WLAN transmitters.

Band pass filter

This filter is designed in such a way that it allows only 3400-3600 MHz band of signals to pass through the following receiving end modules. This helps in removing the unwanted harmonics. The coupled line filter is recommended at high frequencies [3-6]. The lumped components at high frequencies behave differently when it crosses its self-resonating frequency example; the capacitor behaves like inductor and vice versa.

Low noise amplifier

The signal from the transmitter would have undergone many obstacles and also the signal degrades at the receiver end due to improper design of the components. The amplifier is designed to increase the signal strength and low noise level as in Mehul et al. [7]. The main parameter is gain and noise figure, but the gain can't be high for low noise figure. There lies a tradeoff between the gain and noise figure, any one has to be adjusted. The bias and impedance matching network will result in better gain, noise figure and insertion loss.

Vector network analyzer

The analyzer used is from keysight technologies N9915A model which can measure up to 9GHz frequency. Before the measurements is carried out the ports has to be calibrated. The s-parameters of the DUT is viewed and also the data can be imported in excel format.

Simulation Software Used

Advanced design system

The software is used for RF, microwave and high speed digital applications. ADS pioneers the most innovative and powerful integrated circuit-3DEM-thermal simulation technologies used by leading companies in the wireless, high-speed networking, defense-aerospace, automotive and alternative energy industries. For 5G, IoT, multi-gigabit data link, radar, satellite and high speed switched mode power supply designs, keysight ADS provides an integrated simulation and verification environment to design high-performance hardware compliant with the latest wireless, high speed digital and military standards.

High frequency structure simulator

The HFSS uses Finite Element Method (FEM), efficiently handles complex material and geometries, volume based mesh and field solutions, fields are explicitly solved throughout entire volume and provide frequency and transient solutions.

Design of Band Notched Antenna and Coupled Line Band Pass Filter

Notch band antenna design

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{1/2}} \quad (1)$$

$$F = \frac{8.791 \ X \ 10^{9}}{f_r\sqrt{\varepsilon_r}} \quad (2)$$

$$f_r = \frac{1}{2\pi\sqrt{L_{net} \bullet C_{net}}} \quad (3)$$

$$C_{net} = (2l_1 - S/2)(\sqrt{\varepsilon_r}/CZ_0) + (\varepsilon_0 w_t / S) \quad (4)$$

$$L_{net} = (0.002)\left(8l_1 - S).(2.303\log_{10}\frac{4(8l_1 - S)}{W} - 2.853\right) \quad (5)$$

The above sets of equations are used to find the radius of the circular patch antenna and the Complementary Split Ring Resonators (CSRR). Here, “a” is the circular patch antenna radius, “F“ is the fringing field, $'f\square'$ is the CSRR resonant frequency, ‘Cnet’ and ‘Lnet’ are the net capacitance and inductance respectively as shown in Figure 2.

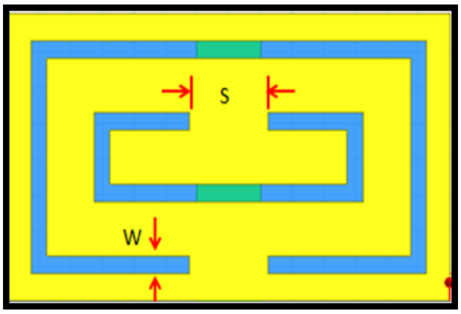

Figure 2: Complementary split ring resonator top view.

The split ring resonator is an artificially produced structure common to metametrials. Their purpose is to produce the desired magnetic susceptibility in various types of metamaterials up to 200 terahertz. The major advantage of the CSRR is high filtering capability which is useful for coupling suppression, compact size and easily fabricated. The negative permittivity is introduced by CSRR which results in band elimination due to opposing electric field. Several CSRR structures have been proposed only to reduce the amount of mutual coupling between array elements. The total size of the antenna is 22 mm × 26 mm and the defected ground structure is 7.3626 mm × 5.2808 mm, the position of the CSRR and the slit width decides the notch frequency and the bandwidth [8]. The antenna targets the WLAN frequency range 5.1-6 GHz and removes the band. Rectangular patch antenna is not used because of its poor return loss and bandwidth. The design of Circular Band Notch Antenna (CBNA) and Rectangular Band Notch Antenna (RBNA) are shown in Figure 3. The CSRR structure is inserted on the radiating patch along with slit on the partial ground plane, the simulated reflection coefficient of CBNA and RBNA is illustrated in Figure 4.

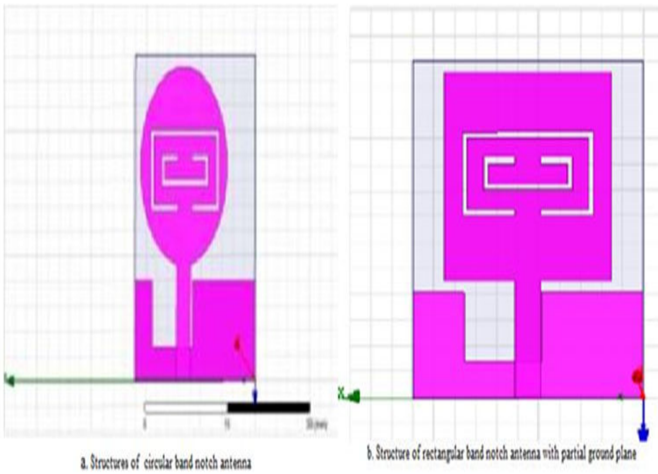

Figure 3: Structures of both circular and rectangular band notch antenna with partial ground plane.

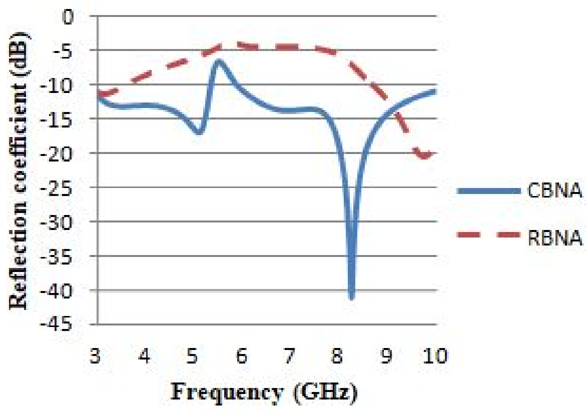

Figure 4: Comparison between simulated reflection coefficient S11 for CBNA and RBNA.

The standing wave ratio is a function of reflection coefficient, which describes the power reflected from antenna. The smaller the VSWR is, the better the antenna is matched to the transmission line and more power is delivered to the antenna. The VSWR at 5.5 GHz is high i.e. more than 2, which gives an idea about how the frequency is removed at the desired frequency. When VSWR is increasing then the reflected power will be more and leads to anti resonance. Figure 5 depicts the low power radiation at the desired WLAN band for Partial Ground Plane having no Slit (PGNS) and Partial Ground with Slit (PGS). The overall response obtained from PGS is better compared to that of PGNS structure.

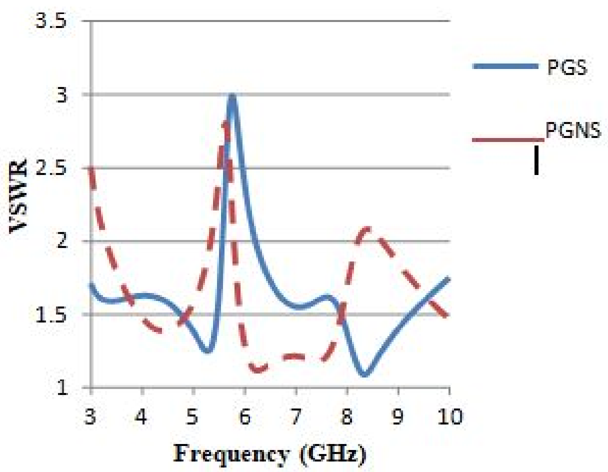

Figure 5: Simulated VSWR of PGS and PGNS as a function of frequency.

Figure 6 and Table 1 depict the simulated reflection coefficient of various ground planes. The Fully Grounded plane (FG) has shown a poor response, the PGS illustrates a better response over the wide band and the PGNS have poor response at lower end of the frequency band. The results are compared and analyzed using HFSS simulator [9].

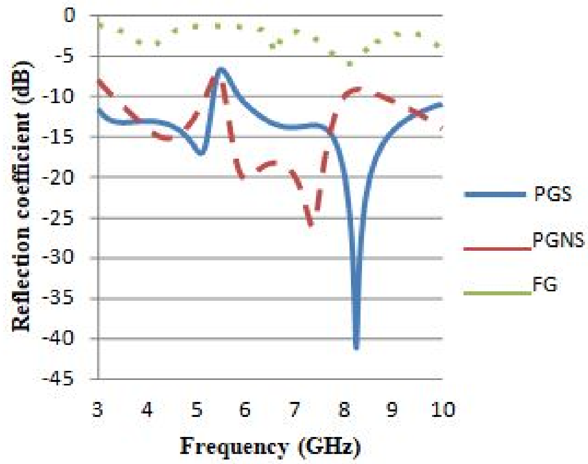

Figure 6: Comparison between simulated reflection coefficients S11 for various ground plane structure.

Configuration	Magnitude of Scatterin parameter		
	At 3.1 GHz	At 5.5 GHz	At 10 GHz
Partial ground with slit	-11.4044	-6.4814	-10.7874
Partial ground without slit	-7.8764	-7.6303	-13.9160
Fully grounded plane	-8.3046	-26.1529	-21.6436

Table 1: Analysis of antenna ground plane.

The top and bottom view of the antenna after fabrication using FR-4 substrate with s□=4.6, loss tangent=0.002 and substrate thickness=1.6 mm is shown in Figure 7. With low relative permittivity the fringing field and the power radiated is high [10].

The loss tangent is the angle between the resistance and reactance of a substrate. The antenna efficiency reduces with high loss tangent. A vector network analyzer (model number: N9915A) has been used for the measurements in a standard far-field testing environment. Figure 8 shows the measured S11 at lower end is poor and band elimination is obtained between 5.48 to 6 GHz as shown in Table 2.

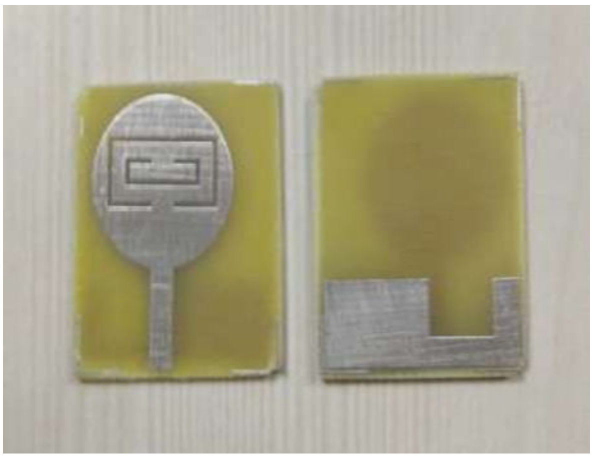

Figure 7: Photograph of the fabricated antenna.

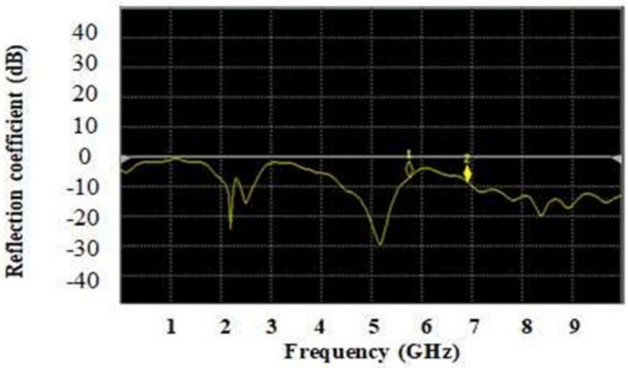

Figure 8: Measured reflection coefficient of CBNA.

For passband ripple □□□= 0.1 dB										
n	g1	g2	g3	g4	g5	g6	g7	g8	g9	g10
1	0.3052	1								
2	0.8431	0.622	1.3554							
3	1.0316	1.1474	1.0316	1						
4	1.1088	1.3062	1.7704	0.818	1.3554					
5	1.1468	1.3712	1.975	1.371	1.1468	1				
6	1.1681	1.404	2.0562	1.517	1.9029	0.8618	1.3554			
7	1.1812	1.4228	2.0967	1.573	2.0967	1.4228	1.1812	1		
8	1.1898	1.4346	2.1199	1.601	2.17	1.5641	1.9445	0.88	1.3554	
9	1.1957	1.4426	2.1346	1.617	2.2054	1.6167	2.1346	1.44	1.1957	1

Table 2: Element values for pass band ripple 0.1 dB.

Coupled line band pass filter design

$$FBW = \frac{f_2 - f_1}{f_c} = \frac{3.7e9 - 3.e9}{3.5e9} = 0.057 \quad (6)$$

$$n \geq \frac{\cosh^{-1}\sqrt{\frac{10^{0.1Las}-1}{10^{0.1Las}-1}}}{\cosh^{-1}\Omega_s} \quad (7)$$

$$L_{Ar} = -10\log(1-10^{0.1Lr})dB \quad (8)$$

$$\frac{J_0}{Y_0} = \frac{\sqrt{\pi.\text{FBW}}}{2.g1.g2} \quad (9)$$

$$\frac{J_{J,J+1}}{Y_0} = \frac{\pi.\text{FBW}}{2\sqrt{g_j.g_{j+1}}} \; j = 1 ton-1 \quad (10)$$

$$\frac{J_{J,+1}}{Y_0} = \frac{\sqrt{\pi.\text{FBW}}}{2.g_n.g_{n+1}} \quad (11)$$

Since the bandwidth is narrower, Chebyshev filter is recommended instead of butter worth filter. The return loss Lr is taken as -15 dB, LAr=0.1 dB therefore □ ≥ 5.44 let Ω□=2, LAs=40 dB. The element values for low pass prototype filter table based on the ripple value in Pozar et al. [11]. The order is 5 and its corresponding low pass prototype elements are noted, admittance interval for each filter stage is calculated using the above equation and this enable us to convert a filter circuit to an equivalent from [12].

The odd even impedances are used to find the width, length and space of the coupled line filter using linecalc in ADS software as shown in Table 3 and Table 4.

Filter stage	Admittance interval	Z0e	Z0o
1	0.388	76.9272	38.1272
2	0.138	57.8522	44.0522
3	0.105	55.80125	45.30125
4	0.105	76.9272	38.1272
5	0.138	57.8522	44.0522
6	0.388	55.80125	45.30125

Table 3: Even-odd impedance values.

Filter Stage	Width (mm)	Length (mm)	Space (mm)
1	2.00	11.50	0.3
2	2.86	10.99	1.1
3	2.84	11.05	1.3
4	2.84	11.05	1.3
5	2.86	10.99	1.1
6	2.00	11.50	0.3

Table 4: BPF coupled line dimensions for each stages.

The coupled line BPF is fabricated using FR4 substrate with εr=4.4, loss tangent=0.002 and substrate thickness h=1.6 mm. The physical dimension is 75.08 mm × 39 mm along with 50 Ω SMA connector as shown in Figures 9-11.

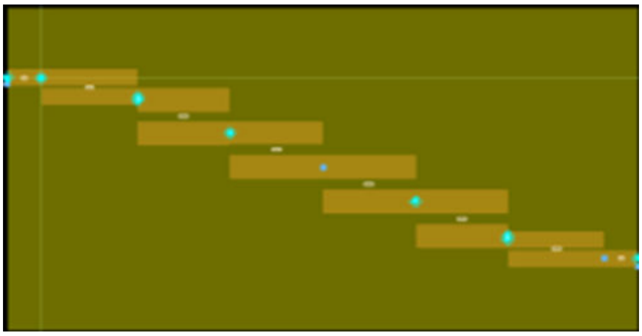

Figure 9: Layout of BPF with 75.08 mm × 39 mm ground plane.

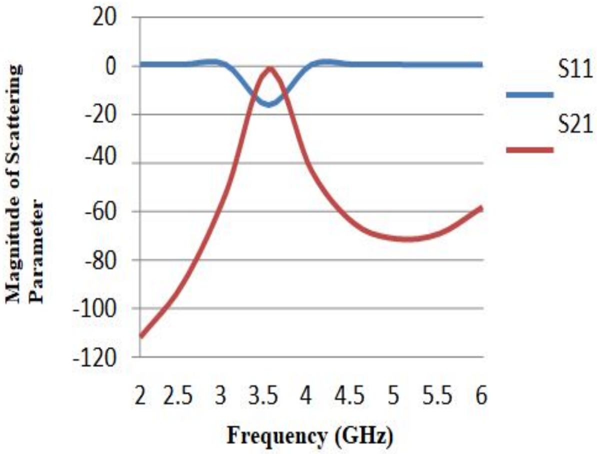

Figure 10: Simulated return loss and insertion loss of coupled line BPF.

Figure 11: Photograph of fabricated coupled line BPF.

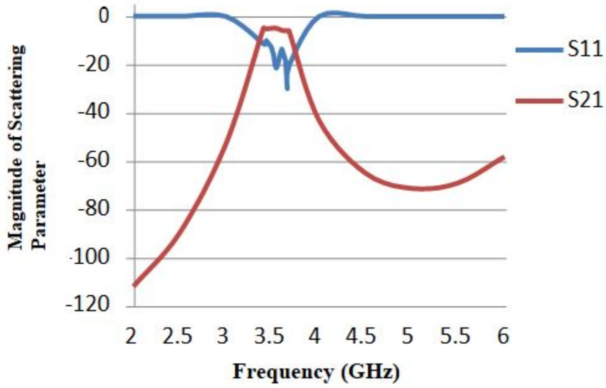

Figure 12: Measured return loss and insertion loss of coupled line BPF.

Figure 12 depicts a better return loss and a poor response from the insertion loss in the 4G-LTE band-22.

Conclusion

The band notched antenna and coupled line band pass filter is designed, simulated and fabricated using FR4 substrate. The antenna prototype shows a poor response at lower frequency range and the band pass filter prototype illustrates a poor insertion loss and better return loss at the desired 4G-LTE band. The transmission leakage can be further reduced by notch band antenna and the receiving signal is smoothen by band pass filter.

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