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Design and Analysis of Low Noise Active Integrated Antenna for Automotive Applications

Srigayathri.V* and M.S. Vasanthi**

Abstract: Automotive antenna requirements continue to push for smaller, more integrated solution while maintaining the high performance expected from modern infotainment and multimedia systems. Wireless cellular communication standards - GSM, LTE, 3G, 4G, Wi-Fi each of multiband frequency signals are received by active antenna systems with stubby, shark fin or windshield antennas placed in cars. As car infotainment units have become more complex, the need for number of active antenna system has grown. There is a need for sensitive circuitry like Low Noise Amplifier (LNA) to maintain stable power supply, protection and isolation from the environment, as well as the need for monitoring the antenna status. In this work, we analyze the requirements needed for designing a Low Noise Active Integrated Antenna (LNAIA), which can integrate antenna along with LNA. The designs will provide better performance and meets the requirements of the automotive industry. Through EDA simulations, results of the proposed designs is in accordance with multiband frequency operation for specified application.

Keywords: Low Noise Amplifier, Low Noise Active Integrated Antenna, Electronic Design Automation.

1. INTRODUCTION

Demand for the fast growing wireless communication application with robust trans-reception can be satisfied by RF front-end which offers a good value for both manufacturer and consumer with price and complexity. Hence the concept of Active Integrated Antenna (AIA) provides a new paradigm for designing modern microwave and millimeter wave communication with desirable features such as compactness, light weight, low cost, low profile, and minimum power consumption with multiple functionality. Antenna not only functions as a radiating element, it provides certain circuit function such as resonating, filtering which imparts as an integral part of the circuit design. A typical AIA consists of one or more active devices such as diodes (Gunn, IMPATT, Schottky, and Varactor) and/or transistors (BJT, FET, MESFET, HEMT, or HBT) integrated with planar antennas like printed dipoles, microstrip patches, bowties, or slot antennas. To realize different functionalities, AIAs can be made frequency tunable, injection locked, or mutually coupled. Choosing the adequate configuration, multiple communication and sensor applications can be realized.

Automotive Wireless Communication has expanded greatly. So it became obvious to implement Car Entertainment systems into the cars for comfort. It is well known that the antenna is the key element in determining communication system performance. High-end car has AM, FM, DAB, GPS navigation, Bluetooth and multiple radar systems. Next generation vehicles will add additional features like GSM, LTE, Wi-fi, WLAN for automated driver assistance. Instead of designing each antenna for particular application the single fabricated antenna will serve the purpose for multi-service at multi-band communication. Hence, these AIAs serves the purpose for multi-service antenna systems structures to be fitted in the vehicle. The miniature design of the antenna with active circuit becomes the trends in future years. Many research

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has been carried out in fabrication the antenna with active element to give a IC fabrication in providing maximum performance, flexibility and integration level for rapidly expanding the range of frequency bands to be operated in a single antenna in cars.

In this work, the active circuit element like low noise amplifier with active devices is designed which is made compatible to work with multiband frequency. Planar inverted F antenna microstrip antenna is designed with multi-resonating frequency capabilities. Performance of microstrip antenna and LNA will be analyzed individually with their parameters through simulation tool.

2. COMPREHENSIVE SYSTEM DESIGN

Schematics and layouts for active circuit element (LNA) and microstrip antenna will be designed using the EDA software tool. Integration of both the proposed designs will be the major challenge.

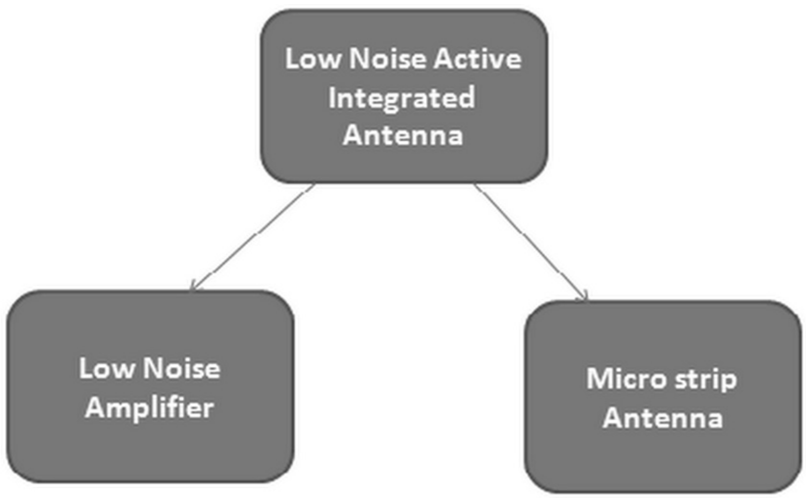

Figure 1: Comprehensive design overview

A. Design of Microstrip Planar Inverted F Antenna

Micro-strip antenna is widely used in the microwave frequency region because of its simplicity and compatibility with printed circuit technology. It consists of a planar radiating patch on one side which is been placed over ground plane. The two layers are separated by a electrically thin layer of dielectric substrate. The dielectric constant of the substrate is the one of the main parameter for designing antenna which should be low to enhance fringing fields which accounts for radiation. Most commonly used micro strip antennas are rectangular and circular patches. Microstrip antenna design becoming popular in automotive industry for high frequency applications which is easy to fabricate and implement. In this work, planar inverted F antenna is designed with multi-resonating capability which can operate at frequency standards of GSM/LTE/Bluetooth/Wi-fi operation. This antenna can be fed by a variety of methods: contacting methods and non-contacting methods In contacting method, the power is fed directly through coaxial feed line. In non-contacting method, coupling mechanism is done for the power transfer between coaxial feed line and radiating patch .As these antennas are of quarter wavelength ,size of antenna is reduced. This antenna is implemented in this design because it works can work at higher frequencies. It is simple and easy to modify these kind of antenna with preferably flat with minimum length which can be integrated and mounted in the vehicles for reception of the signals.

1. *Antenna Specification:* Antenna designed will have the radiating patch on one side of a dielectric substrate with ground on the other side.

Parameters	Specifications
Substrate	FR-4
Frequency of operation	GSM [890/950/1800(MHz)],LTE,WLAN, Bluetooth, Wi-Fi [2.4 GHz]
Heightof Substrate	12mm
Dielectric constant	4.4
Tangent loss	0.02

Figure 2: Design Specification for Antenna

2. *Calculations for Antenna design:*
   - Effective dielectric constant:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}$$

   - Actual length of the patch and substrate:

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \text{ obtained } L_{eff} = 61\text{ nm}$$

   - Extension Length:

$$\Delta L = \frac{0.412 \times h(\varepsilon_{reff} + 0.4)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)}$$

$$L = L_{eff} - 2\Delta L$$

   - Width of the Patch (W):

$$W = L_{eff} - 2L,$$

results, $W = 45$ mm

   - Height of the ground (H(g)):

$$H(g) = 2W + h,$$

results, $H(g) = 100$

3. *Antenna Configuration:* The three dimensional view of planar inverted F antenna proposed is designed with certain dimensions in Figure 3. The top plane radiating patch resonates at two impedance bands one with lower bands and other with higher bands. Therefore, these impedance bands covers the desired operating bands form GSM, UMTS, DCS, WLAN, LTE applications. The lower portion (ground plane) of the FR-4 substrate is made with dimension 45 × 100 milimeter square and upper portion with area 45 × 12 millimeter square .The antenna is divided into three main structures: main radiation structure, parasitic structure and impedance adjustment structure. At the upper right corner of radiator structure is 1mm away from the ground plane which is designed to resonate at lower impedance bands (911-1113 MHz). At the right edge corner of the substrate 9 mm extends leftwards by a length of 12 mm. Finally, the parasitic structure is excited to resonate at higher impedance band (1704-2512 MHz).Thus our

proposed design concludes that if the antenna is able to resonate at two impedance bands, the desired operation for multiband frequency because of its multi-resonating ability.

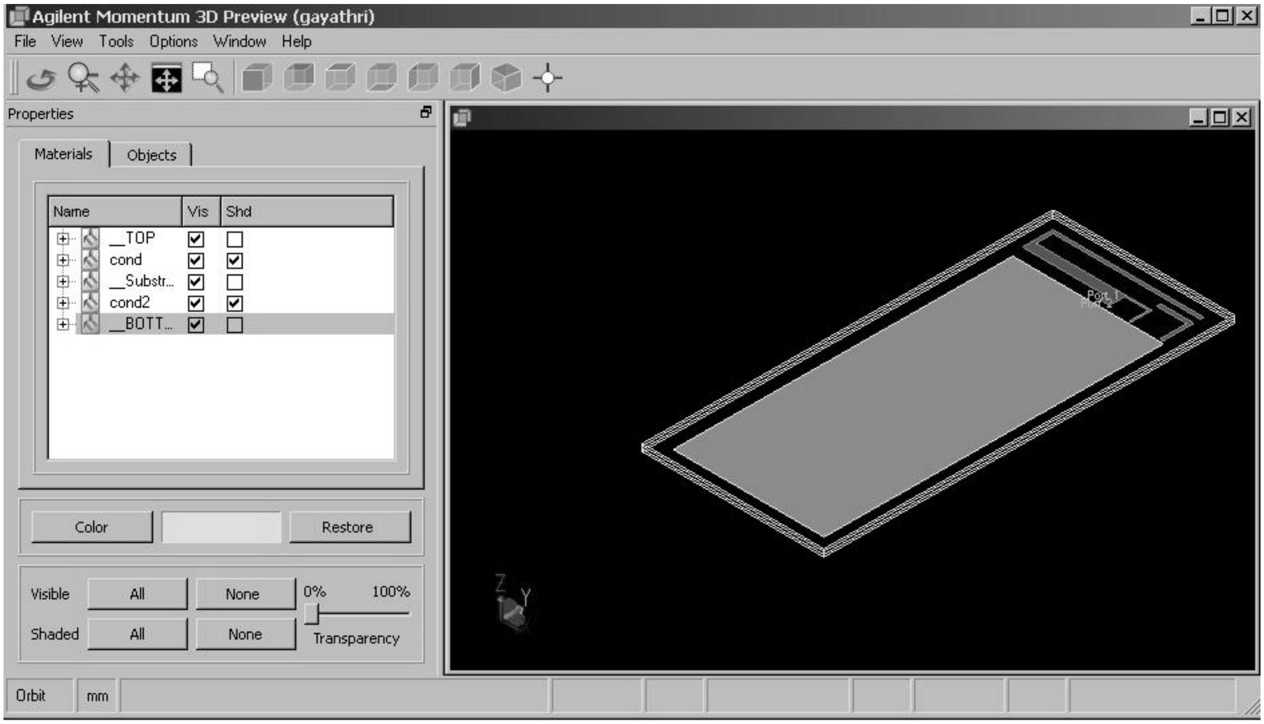

Figure 3: Three dimensional view of proposed antenna

The impedance for RF and Microwave sources are 50ohm.According to feed point, there should be efficient transfer of power from source to the receiver. For impedance matching, the input impedance must match with source impedance for efficient power transfer. If the line impedance at the transmission is 50 ohm then it is able to match with impedance of the substrate known as feed point. The type of feed point used must be suitable for array feed structure. The transmission line to antenna feed point is chosen such a way that it achieves proper radiation.

B. Design of Multiband LNA

In this work, the design procedure for low noise amplifier which is made to operate at multiband frequencies is carried out in following subsections:

1. *Choice of transistor:* The transistor used is HJ-FET NE32500 which utilizes the hetero junction between Si-doped (AlGaAs) and undoped (InGaAs) to create high electron mobility. This FET provides low noise and high gain.
2. *DC Bias Network*: DC Bias Network used in this design is self-bias; it needs single DC supply which has the ability to automatically adjust with any variations in the circuit. The method of self-bias is obtained by inserting the bias resistor directly between base and collector; the feedback voltage can be collected to the base to develop forward bias. The cascade stage of the transistor provides isolation between the input and output impedance matching. The circuit operates at voltage and current of 1.8V and 40 mA respectively.
3. *Topology:* Four parallel LC resonators are used since the operation is made widely to operate over four different frequencies by adding cascade transistor. The topology of the circuit designed is inductive source degenerative as it provides high gain, maintains high linearity and saves power consumption.

4. *Parameter Specifications:*

Parameters	Specifications
Substrate	FR-4
Frequency of operation	GSM [890/950/1800(MHz)],LTE,WLAN, Bluetooth, Wi-Fi [2.4 GHz]
Heightof Substrate	12mm
Dielectric constant	4.4
Tangent loss	0.02

Figure 4: Parameter Specifications of LNA

5. *Matching Networks:*

Input Matching Network: The matching network at the input is formed by inductive degeneration topology with LC components as resonators which are added in parallel. The input matching network of the circuit will be capacitive due to capacitive effect at the gate-source of the transistor. The capacitive reactance is removed by adding inductive feedback to the source. The input matching network of the LC resonators values are calculated based on the four center frequencies is shown in the Figure 5. The equivalent circuit diagram explains the input matching circuit. L_0C_0 are equivalent inductance and capacitance for series gate inductance L_4 and series coupling C_4 respectively with degenerated inductance L_s. The additional capacitance (Cex) is connected in parallel with gate to source capacitance (Cgs1).The value of L_0 and C_0 are written in the form:

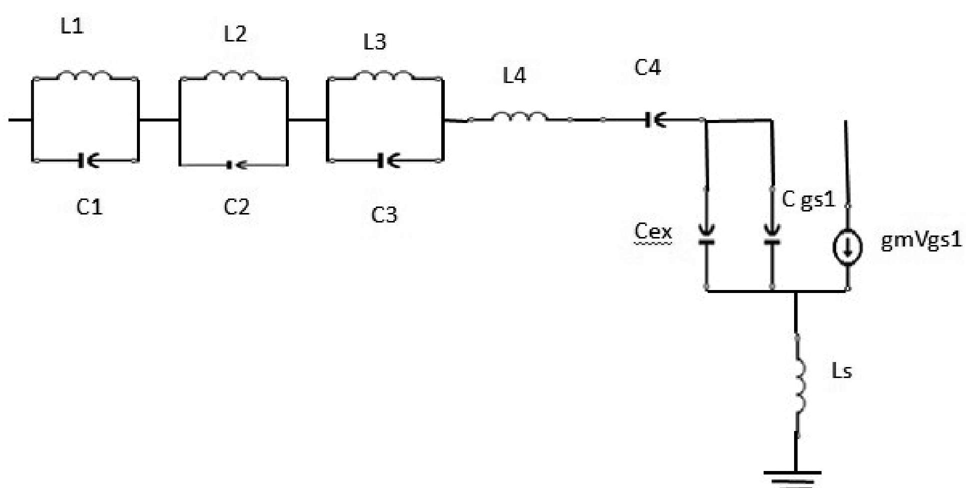

Figure 5: Equivalent Circuit for Input Impedance Matching

$$L_0 = L_4 + L_5$$

$$C_0 = \frac{1}{\frac{1}{C_4} + \frac{1}{C_{gs1} + C_{ex}}} = \frac{C_4(C_{gs1} + C_{ex})}{C_0 + C_{gs1} + C_{ex}}$$

The values component of L_1, C_1, L_2, C_2, L_3, C_3 to satisfy certain conditions:

- The resonating frequency of resonator L_1C_1 is selected at one frequency f_A between the band 800 MHz and 900 MHz

$$f_A = \frac{1}{\left(2\prod\sqrt{L_1C_1}\right)}$$

- The resonating frequency of resonator L_2C_2 is selected at one frequency say f_B between the band 900 MHz and 1.7 GHz.

$$f_B = \frac{1}{\left(2\prod\sqrt{L_2C_2}\right)}$$

- The resonating frequency of resonator L_3C_3 is selected at one frequency say f_C between the band 900 MHz and 1.7 GHz. For L_3C_3, the value greater than frequency f_C it becomes inductive with frequency 800 MHz, 900 MHz, 1.7 GHz, if lower than f_C then it is capacitive with frequency 2.4 GHz.

$$f_C = \frac{1}{\left(2\prod\sqrt{L_3C_3}\right)}$$

Output Matching Network: The impedance matching at the output end of the circuit design maximizes the maximum power transfer or minimizes the signal reflection at the load. Output matching network of LNA consists of RLC components which serve as a coupling circuit to the bias network. System design of the proposed LNA circuit is shown in Figure 6.

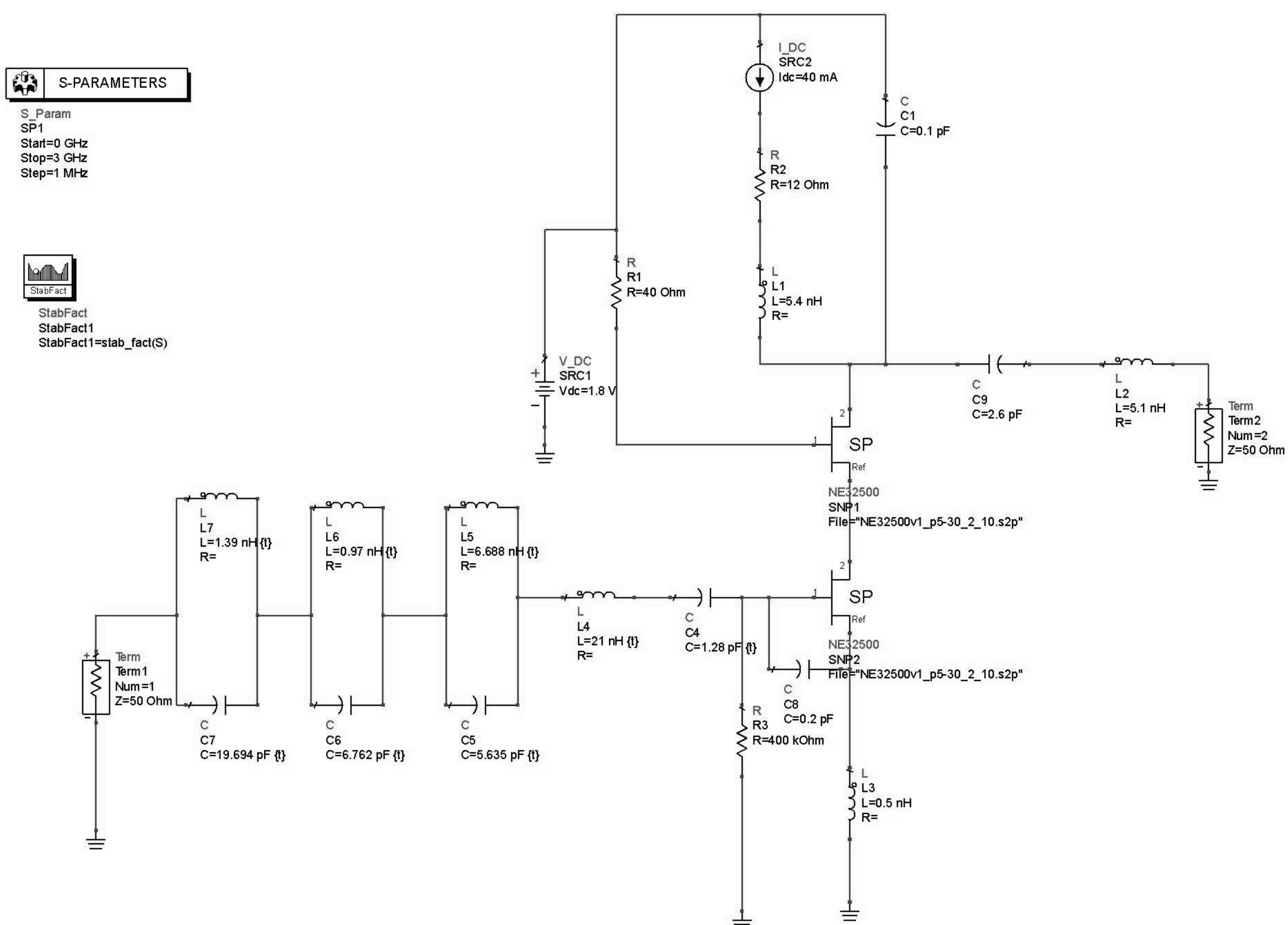

Figure 6: Proposed design of Multiband LNA

3. RESULTS AND DISCUSSIONS

A. Analysis of Antenna

The proposed planar inverted F antenna structure occupies a small area of 45 × 12 mm^2 from the observation it is found that VSWR < 3 with two impedance bands as mentioned earlier. The simulation output of the return loss (S_{11}) < –10 dB which is the desired result for resonating frequency bands shown in the Figure 7.

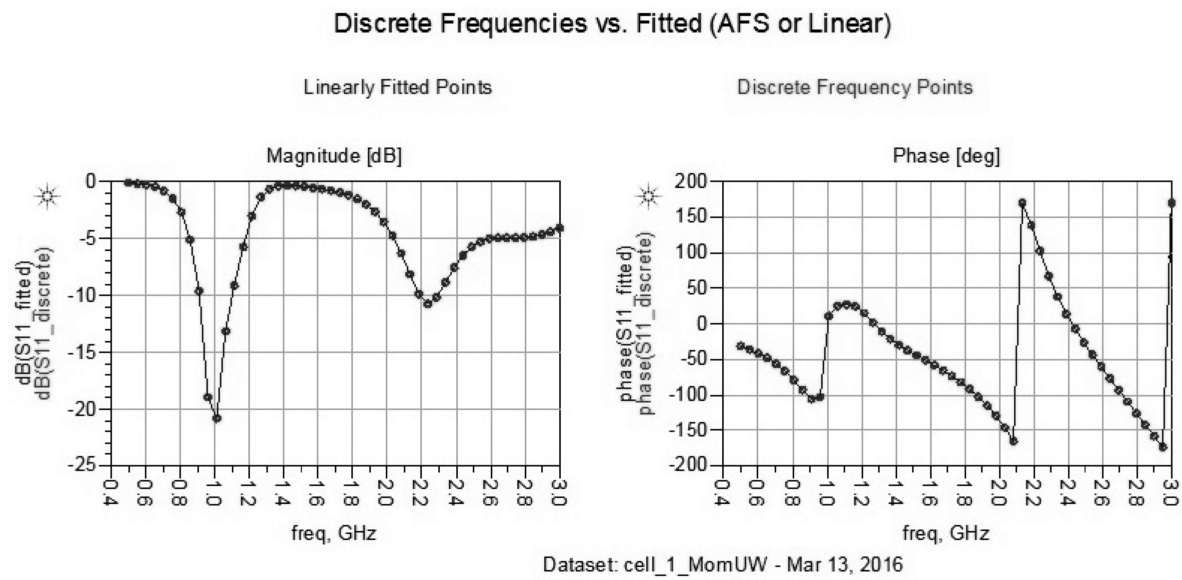

Figure 7: Simulated result

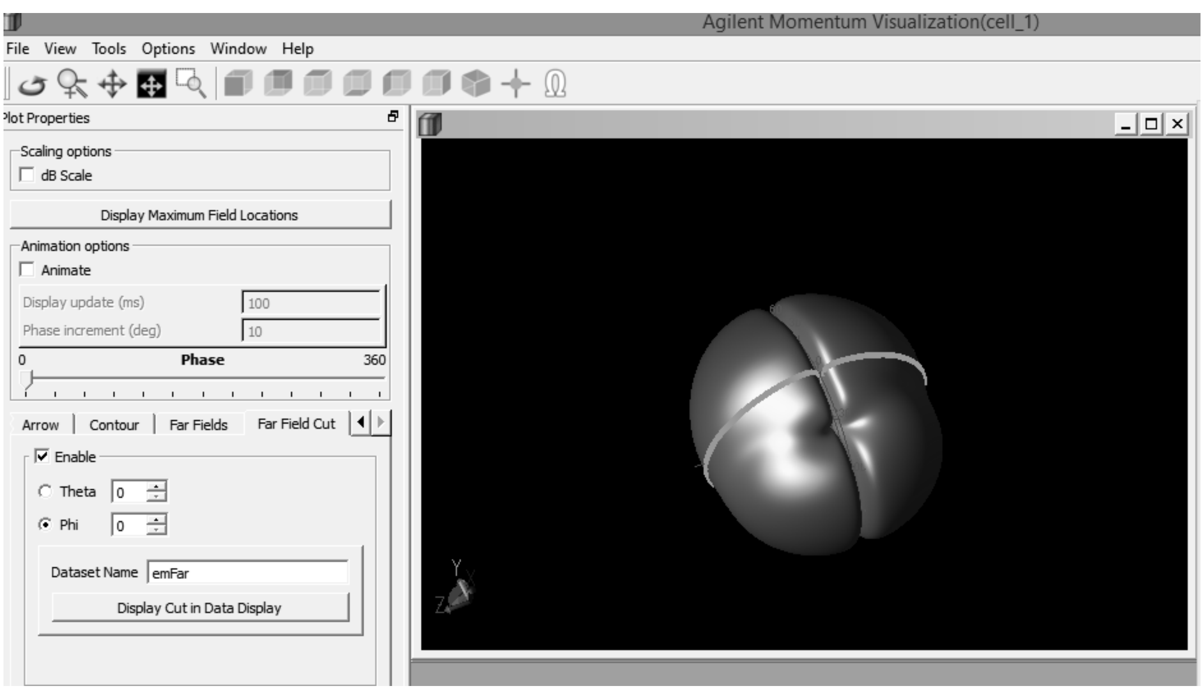

Figure 8: Radiation Pattern

The analysis of radiation pattern in Figure 8 observed through simulation where the orientation of electric field results in circular polarization. For general understanding, the particular nearest resonating frequency is represented with its parameters in Figure 9 which found to have good radiation characteristics with directivity 4.6 dBi .The peak antenna gain is found to have 3dBi making the antenna suitable for our application.

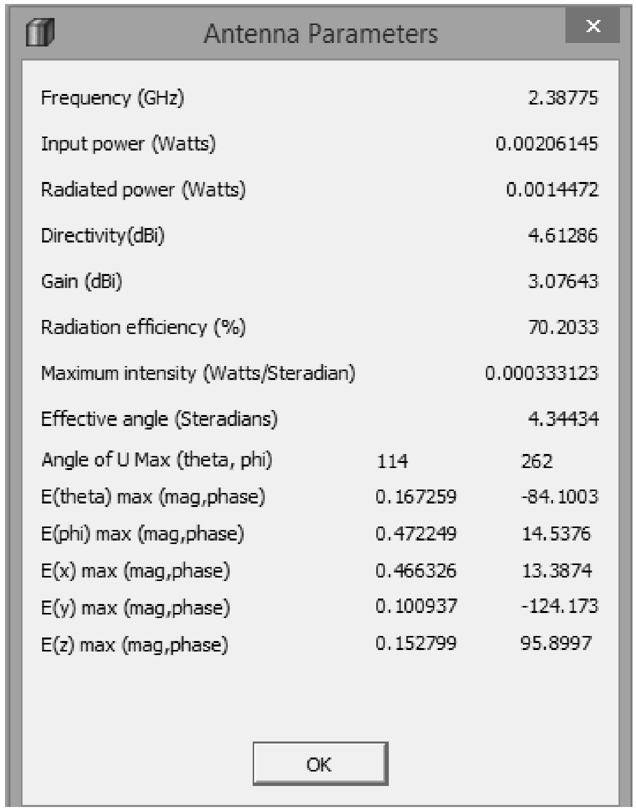

Figure 9: Antenna Parameters

B. Analysis of Multiband LNA

LNA has been designed to operate at quad band frequencies of 800 MHz, 900 MHz, 1.7 GHz, 2.4 GHz which indicates wireless cellular communication standards. The design parameters such as Gain, Return loss, Noise Figure and Stability of the circuit are analyzed. The circuit design of multiband LNA achieves $S_{21} > 10$ dB and $S_{11} < -10$ dB. Thus the results makes ideal for multiband operation for the system. The simulated results for Gain and Return loss are shown in the Figure 10 and Figure 11 respectively.

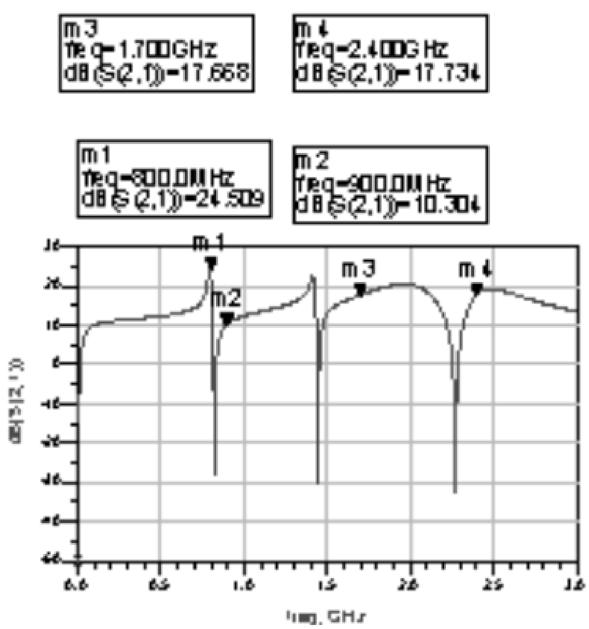

Figure 10: Simulation result for Gain

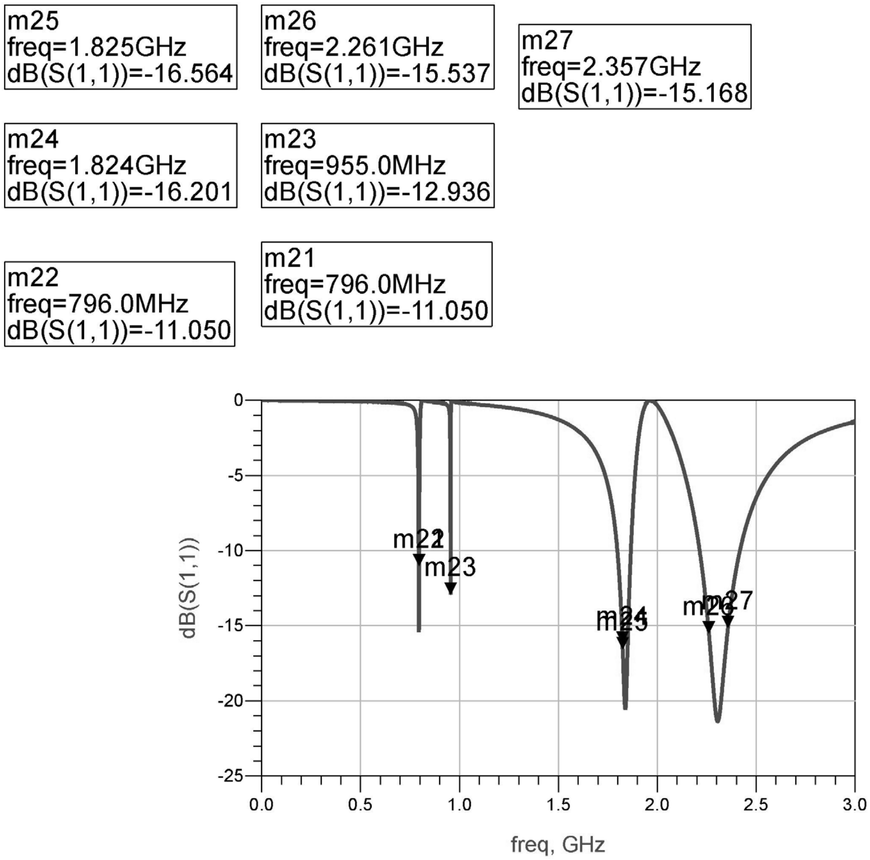

Figure 11: Simulation result for Input Return Loss

The simulation result for Noise Figure (NF) of multiband LNA circuit is shown in Figure 12. It appears that for four frequency band, the value for NF < 1 dB, they are 0.099 dB at 800 MHz, 0.109 dB at 900 MHz, 0.006 at 1.7 GHz and 0.011 dB at 2.4 GHz.

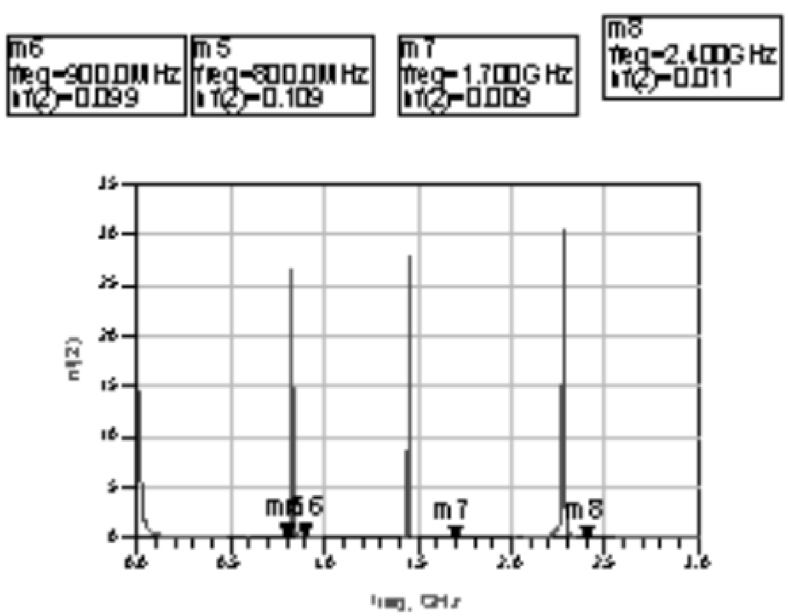

Figure 12: Simulation result for Noise Figure

In stability analysis, there is a term called Rollett's Stability Factor (K-factor).When K-factor is less than unity, the circuit is found to be conditionally stable for the combinations of source and load impedance.

Conditional stability provides stability at impedance terminations. The circuit will not become unstable and oscillate K-factor can be expressed from S Parameters.

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}||S_{21}|} \tag{10}$$

Where $\Delta = S_{11}S_{22} - S_{12}S_{21}$ and condition for conditional stability is $K < 1$, $|\Delta| < 1$. Simulation results for Stability is shown in the Figure 13. It shows the value of K < 1 at all the frequencies.

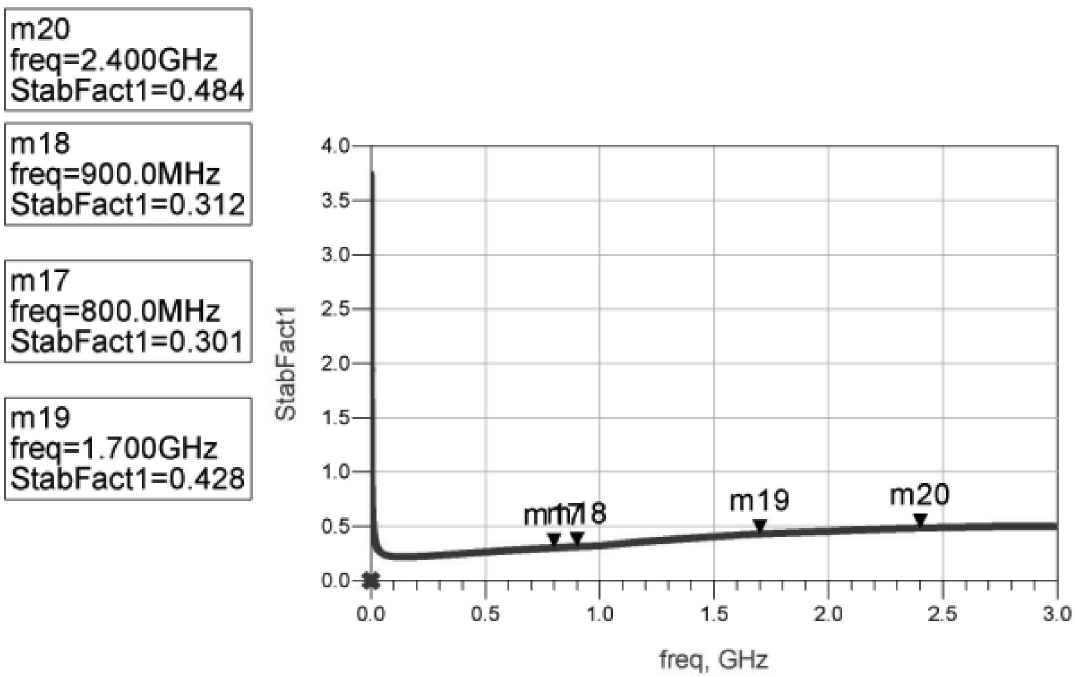

Figure 13: Simulation result for Stability

4. CONCLUSION

This research work has been carried out to analyze the requirements for designing LNAIA as integrated solution for automotive antennas to operate at multiband frequencies for wireless cellular communication standards as mentioned earlier. The analysis is based on the performance of the micro strip antenna (planar inverted F antenna) and active circuit element (LNA).It was inferred that, the planar micro strip antenna designed operates as multi-resonating antenna at the required operating bands of GSM, LTE, Wi-fi, WLAN operation. Correspondingly, the LNA circuit has been designed which operates at the same operating frequencies. The simulated results obtained from the designs have been analyzed with respect to their parameters in order to achieve desired multiband frequency operation. Integration of both the designs will meet the requirements of automotive industry which can be considered for the future work.

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