Performance analysis of printed antenna on different novel substrates to enhance V2V communication in future

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Abstract: In recent years, advancement in wireless technologies, communication in automotive vehicles has witnessed a tremendous growth in the market. All the sophisticated wireless services offered depends on the type of antenna used in it. The researchers in antenna community are trying very hard to improve the performance of the systems by making smaller antenna devices; however they face both scientific and technical limits. Other alternative approach is to use of novel materials for patch and substrate to adhere higher performance and better functionality. In this paper rectangular patch antenna with stepped ground structure is proposed and its radiation characteristics are analyzed for different dielectric substrates like Si3N4, Al2O3, BN, Quartz and Silica. This study will facilitate researchers to get a clear idea on the patch and substrate material that can be used for V2V applications. The proposed CNT patch antenna on Si3N4 substrate resonates at 5.9 GHz is designed and simulated results show that the minimum return loss of -37 dB is achieved with maximum gain of 6.87. In Addition, the proposed antenna also achieves an omni-directional radiation pattern with maximum radiation efficiency of 89%.

Keywords: Microstrip patch, graphene, V2V Communication, Nano Materials, defected ground

1. Introduction

Now a days, most of the vehicles are developed with multiple antennas to facilitate wireless communication between moving vehicle with other vehicle or to the outside world. These devices are usually designed to help the drivers to improve their driving experience and increase travel safety. There is no wireless communication without an antenna, where it plays an important role in transmission and reception of signals in free-space. The latest communication technologies like GSM and LTE provides the interpersonal communication in the vehicles. In addition, Wireless fidelity (WiFi) allows people in the vehicle to connect Internet faster. Recently, researchers are fond of incorporating the artificial intelligence to vehicles and that would result in autonomous or unmanned vehicles in future. However, it is highly essential to the undergo communication between vehicles. In addition, using V2V communications, the real time traffic information are provided to drivers to ease traffic congestion. IEEE updated 802.11 standards for V2V communication with 5.9 GHz. In order to have a good reception in a vehicle, the antenna must be
able to receive the signals from any direction around the car. Hence the radiation pattern of the antenna is required to be omni directional. When compared to single antenna, antenna arrays shall also be considered to fulfill this requirement. The antenna must be easily integrated into the vehicle. The performance of the antenna is affected severely by its surroundings. Both the substrate materials and distances between the antenna and surrounding objects need to be considered during design. A box of 3 times of antenna size around the antenna is considered to obstruct the environment disturbances. The spurious noise generated from the engine disturbs transmission and reception of the signals in the vehicles. Therefore it is essential to maintain the distance between the antenna and engine to use the antenna for Vehicle-2- Vehicle communication at 5.9 GHz.

In recent years, vehicular communication has become a trending topic and it attracts the attention of people. Various antenna structures were proposed and developed for the V2V communication in literature. Authors [3-10] developed monopole antenna arrays and achieved omni directional radiation pattern. These miniaturized monopole antennas are easy to fix in vehicles and attained radiation pattern was most suited for vehicular applications. The four element antenna array with loading with short pins was designed for the frequency of 5.9 GHz [5].

The printed loop antenna proposed in [11-13] is used for taxis communication. The antenna was uniformly loaded with capacitance. Though, antennas proposed in literature are simple and easy to install, their gain is relatively low. Furthermore, manufacturing cost of some antennas are high and occupies large space and that increases the overall antenna size. The microstrip antenna is light weight, low profile, easy of manufacturing and integration. It also holds good concealing and hence it has wide-ranging applications in the field of automotive antennas [14-15]. A low profile rectangular microstrip antenna loaded with carbon nano tube patch with Si3N4 substrate is proposed to achieve high speed V2V communication. The proposed antenna achieves good impedance and radiation characteristics with etching stepped ground structures. It exhibits omni directional radiation pattern which is most suitable for V2V communication.

In general, any Microstrip patch antenna (MPA) has conducting patch on the substrate with perfect ground-plane at the bottom. The substrate is a dielectric material that separates the patch and ground-plane of an antenna [1]. In most of the previous work, researchers had copper patch as radiating element [1-2]. Now a days, in V2V communications, the antenna requires to be operate at high speed, cheaper, smaller in size with improved performance. In addition to copper, Graphene and Carbon Nanotubes can also be used as radiating element because of its significant electronic and material properties. Carbon Nanotube can be either semiconductor or metallic in nature. Both semiconductor and metallic CNTs are very popular in the field of high speed electronics. Graphene is one allotropes of carbon where in their atoms are bonded in the hexagonal form. Nowadays, most of the high speed communication devices are designed and fabricated using CNT and Graphene. The utilization of graphene is still underway where researchers are looking forward to eliminate nano -scale related problems associated with it. The performance of the antenna is analyzed for different substrates Si3N4, Al2O3, BN, Silica, Quartz using basic antenna parameters such as return loss, vswr, gain, directivity, efficiency and radiation pattern.
2. Antenna modeling

2.1 Design

The substrate dielectric constant, thickness of the substrate and operating frequency are three key parameters required for designing an antenna. The step by step design calculation are listed below:

Width of the Patch is calculated as

\[ W = \frac{c_0}{2f_r} \sqrt{\frac{2}{\varepsilon_r + 1}} \]  \hspace{1cm} (1)

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

\[ \frac{\Delta L}{h} = \frac{0.412 \left( \varepsilon_{reff} + 0.3 \right) \left( \frac{W}{h} + 0.264 \right)}{\left( \varepsilon_{reff} - 0.258 \right) \left( \frac{W}{h} + 0.8 \right)} \] \hspace{1cm} (3)

Where \( \Delta L \) is the function of effective dielectric constant \( \varepsilon_{reff} \), height of the substrate \( h \) and the width-to-height ratio \( (W/h) \).

The length of the patch is calculated by subtracting the length extended on both edges from effective length.

\[ L_{eff} = \frac{C}{2f_0 \sqrt{\varepsilon_{reff}}} \] \hspace{1cm} (4)

Length of the Patch

\[ L = L_{eff} - 2\Delta L \] \hspace{1cm} (5)

Figure 1. Structure of the proposed antenna
The dimensions of the proposed antenna are calculated using the above design equations. The layout of the proposed antenna and its parameters are provided in the Table 1 and Figure 1.

Table 1. Layout parameters of the proposed antenna

| Layout Parameter | Value (mm) |
|------------------|------------|
| Lp               | 12         |
| Wp               | 15         |
| Wf               | 3          |
| Lf               | 10         |
| Wg               | 2.5        |
| Wg1              | 1.5        |
| d                | 3          |

2.2 Analysis

The transmission line model is used to analysis of microstrip patch antenna. In this method, electric and magnetic currents are uniformly distributed over the two edges of the patch. The radiating patch acts as a resonator where it has transverse field that varies along the length of the radiator. Patch edges allow the electric fields to undergo fringing and these fields induce the antenna to radiate. Both the patch dimensions and substrate height has great influence on it. Due to fringing effect, wave incident on the patch travels in both the substrate and air, thus it is required to consider effective dielectric constant for analysis. The solutions are obtained based on the Maxwell’s Integral equations. Copper, Carbon Nano Tubes (CNT) and Graphene materials are considered as patch materials for simulation. The properties of the substrate materials are referred to in [3] where graphene has high electrical conductivity of $10^8$ compared to other materials. Similarly, dielectric properties of the substrate greatly influence the antenna performance. The simulation is carried out for different substrates like Si3N4, Al2O3, BN, Silica, Quartz.

3. Simulation results and discussion

The proposed antenna is designed and simulated using ADS (2016). Numerical computations are performed using direct dense solver that incorporates Methods of Moments techniques. The performance of the proposed antenna structure is analyzed for different combination of patch and substrate materials and the best suited material is obtained for V2V communications.

3.1 Impedance characteristics

The reflection characteristics of proposed antenna structure with different patch and substrate and patch materials are shown in Figure 2. The antenna shows either inductive or capacitive impedance in non-resonating mode. Therefore, wave travelling in the antenna gets cancel each other and radiation does not occurs. However, inductive and capacitive impedance gets cancel each other at resonant frequency and allows the waves to travel back and forth, which reinforce each other and radiate into free space. Figure 2 explains that the proposed antenna structure with CNT on different substrate, where it resonates at the frequency of 5.9 GHz for V2V communications. The return loss of the proposed antenna for different types of radiating elements on different substrates is shown in Table 2.
The voltage standing wave ratio (VSWR) measures the impedance mismatch between the antenna port and feed line connecting to it. The VSWR curves of proposed antenna structure with CNT on different substrates are plotted in Figure 3. The proposed antenna design attains minimum VSWR of 1.076 at the operating frequency of 2.45 GHz, which is well below the industrial standard.

### 3.2 Radiation characteristics

The strong and weak current distributions of the antenna are indicated in red and blue color. The ground plane of the antenna is etched to increase its electrical length. The stepped ground structure also alters the reverse current distribution which enhances the radiation pattern of the antenna.

The shape of radiation pattern is constant at far fields and hence radiation characteristics of the proposed antenna are evaluated in that region. E and H fields are perpendicular with each other and along with direction of propagation. Both E and H field strength decreases with increase in the distance. The antenna gain is always measured with respect to isotropic antenna. The gain characteristic of the final antenna structure is shown in Figure 4.
Figure 4. Gain of CNT based Patch antenna for different substrates

The radiation parameters for different substrates are highlighted in Table 3.

Table 3. Variations in radiation characteristics for different substrates

| Patch Materials | Parameters | Si3N4 | Al2O3 | BN | Silica | Quartz |
|-----------------|------------|-------|-------|----|--------|--------|
| Copper          | Gain       | 3.12  | 3.01  | 2.17 | 2.76   | 2.94   |
|                 | Directivity| 4.18  | 4.11  | 2.98 | 3.76   | 3.98   |
|                 | Efficiency | 76    | 74    | 72   | 72     | 73     |
| CNT             | Gain       | 6.87  | 6.42  | 5.21 | 5.42   | 5.89   |
|                 | Directivity| 7.67  | 7.53  | 6.98 | 7.08   | 7.10   |
|                 | Efficiency | 89    | 85    | 74   | 77     | 83     |
| Graphene        | Gain       | 5.68  | 5.14  | 4.62 | 4.04   | 4.91   |
|                 | Directivity| 6.94  | 6.47  | 6.32 | 5.73   | 6.45   |
|                 | Efficiency | 82    | 79    | 73   | 70     | 76     |

At resonant frequency, the radiation pattern of the proposed patch antenna is measured for particular angle. The radiation field pattern of E and H planes are examined at $\varphi = 0^0$ and $\theta = 90^0$ and its three dimensional perspective is shown in Figure 5.
When compared to other substrates, the CNT radiating patch on Si3N4 substrate provides good impedance and radiation characteristics, hence it is suitable to use for V2V communication.

4. Parameter study

The parametric study on antenna design layout is studied. The physical substrate thickness and ground length are varied to study the antenna performance.

4.1 Effect of Substrate thickness (h)

The effect of substrate thickness on return loss characteristics of the antenna is plotted in Figure 6. All printed antennas are constructed using substrate material which provides mechanical support to antenna and also it shows the variations in radiation characteristics. Hence, selection of appropriate substrate material is a key aspect in antenna design. Thick substrates with low dielectric constant increases the fringing fields for radiation, but substrate with high dielectric constant may also be used in special conditions. Hence, substrate thickness is varied and analyzed the antenna performance and desirable thickness is considered for further analysis.

4.2 Effect of Ground length (l_g)

The effect of ground length on return loss characteristics of the antenna is plotted in Figure 7. The ground length is varied from 2.5 mm to 4mm, where its length greatly affects the input impedance.
of the antenna and cause impedance mismatch between the port and antenna. Hence most of the input power to reflect back to port and thus have increased effect of return loss.

![Graph showing return loss characteristics](image)

**Figure 7. Return loss characteristics of CNT based Patch antenna for different ground heights**

5. Conclusion

In this paper, performance of the microstrip patch antenna was studied for different radiating and substrate materials. The stepped ground structure was used to optimize impedance and radiation characteristics. A method of Moments based ADS simulation was performed to model the antenna for resonant frequency of 5.9 GHz. The simulation was performed for various novel materials which have high performance impact over V2V communication. Si3N4 with carbon nanotube radiator realized the minimum return loss of -37dB with VSWR of 1.027 close to the ideal case. It also achieves the maximum gain of 6.87 dBi with stable radiation characteristics. When compared to other materials, it also attains the maximum radiation efficiency of 89%. Hence, it is concluded that CNT based patch on Si3N4 substrate can be a suitable choice for high speed V2V communication in future which could ease traffic congestion, prevent injuries, save human lives and improve the environment. The modern vehicles have around 20 antennas in and around the vehicle body to offer various communication services and hence SAR exposure has to be evaluated for proposed antenna in future. As vehicles are more susceptible to damage, the future directions also include to undergo stress analysis for proposed communication device.

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