INVESTIGATION OF VEHICLE BODY RADIATION PATTERN AS AN ANTENNA TRANSMISSION SYSTEM

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ABSTRACT

Wireless communication is in high demand in today’s society. The mobility of communication is not limited to the people walking along the streets but also for those who are driving. Therefore, communication inside the vehicles has become more and more important. The problem faced today by the common antenna technology is the strength of its receiving signal. In order to have an effective transmit and receive signals, the car body itself can be turned into an antenna. The main aim in this research is to study and simulate the radio wave distribution along the body of a car. Apart from that, the research also studies the radiation pattern of the waves transmitted or received. Finally, the health issue is also studied and aims to meet the standard SAR requirements. The simulation software used in this study is FEMM (Finite Element Mesh Method) CAD software. FEMM is a finite element method to analyze the electromagnetic radiation generated from the body of a car. The electromagnetic radiation for Mini Cooper and Camaro sport are different in terms of current density, field strength and wave distribution. Apart from that, the mesh size is also different from each other. From the simulation, the electromagnetic field distribution show that the field strength is highly concentrated from within the vehicle due to the antenna source is placed there. Besides that, the H-field strength shows different parts of the car exhibits different types of characteristics when it comes to field intensity distribution. It is seen that Mini Cooper has higher field strength in relation to the material conductivity. Mini Cooper small in size, has lower surface area compared to the Camaro sport car. The small size has a lower resistance but higher conductivity compared to the Camaro sports car. Simulation was also done on different types of frequencies and different types of material properties.

ABSTRAK

Komunikasi tanpa wayar adalah permintaan yang tinggi dalam masyarakat hari ini. Kemudahan komunikasi tidak terhad hanya kepada golongan berjalan kaki di sepanjang jalan raya, tetapi ia juga penting bagi mereka yang memandu. Oleh itu, komunikasi di dalam kenderaan telah menjadi penting dari semasa ke semasa. Masalah yang dihadapi kini oleh technology antena ialah kekuatan antena untuk menerima isyarat. Peningkatan pada antena boleh dilakukan dan dilaksanakan di dalam kenderaan. Untuk mempunyai pemancar dan penerima isyarat yang berkesan, badan kereta itu sendiri boleh dijadikan sebagai antena. Tujuan utama kajian ini adalah untuk mengkaji dan mensimulasikan pengagihan gelombang radio di sepanjang badan kereta. Selain itu, kajian ini juga mengkaji corak sinaran gelombang yang dihantar atau yang diterima. Akhir sekali, isu kesihatan juga dikaji dan bertujuan untuk memenuhi keperluan SAR standard. Perisian simulasi yang digunakan dalam kajian ini adalah FEMM (Unsur Terhingga Mesh Kaedah) perisian CAD. FEMM adalah kaedah unsur terhingga untuk menganalisis sinaran elektromagnet yang dihasilkan dari badan kereta. Radiasi elektromagnet untuk Mini Cooper dan Camaro adalah berbeza dari segi ketumpatan arus, kekuatan medan dan pengedaran gelombang. Selain itu, saiz jejaring ini juga berbeza antara satu sama lain. Daripada simulasi, sinaran electromagnet menunjukkan bahawa kekuatan menerima isyarat adalah di kawasan dalam kereta. Ini disebabkan punca arus adalah dari dalam kereta. Selain itu, kekuatan sinaran elecktromagnet adalah berbeza di setiap bahagian kereta. Simulasi juga dijalankan dalam pelbagai frekuensi dan bahan kereta.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Wireless communication for mobility nowadays are getting quite important for businessmen, presenters, students and all other kinds of white collar employees. The mobility of communication is not limited to the people walking along the streets but also for those who are driving. Many drivers are always engaged with their hand phones. They make and receive calls while driving. Therefore, communication inside the vehicles has become more and more important. The constant quality of signal provided by the network service providers, the quality of communication along the road should be continuously maintained.

In order to have a good quality of signals received and transmitted, it does not only depend on the mobile station power but also the body of vehicles and its materials which plays an important role on the effects of transmission and reception of the radio signals. According to the paper "Effects of Car Body on Radiation Pattern of Car Antenna Mounted on Side Mirror for Inter-Vehicle Communications", the antenna is a main factor which guided the radiation of radio waves (Suguru Imai, Kenji Taguchi and Takashi, 2014). The antenna mounted can guide the radio waves transmitted and received in one direction as well as in all the direction (omnidirectional). Therefore larger antenna which matched to transmit and receive power, the transmission becomes more efficient with little loss on noise.

The improvement on the antenna can be done and implemented in the vehicle. In order to have an effective transmit and receive signals, the car body itself can be turned into an antenna. The main aim of this research is to study and simulate the radio wave distribution along the body of a car. From the simulation results, one will know the condition of the communication when the body of the car is turn into an antenna. Finally, the health issue is studied and aims to meet the standard SAR requirements. The simulation software used in this study is FEMM (Finite Element Mesh Method) CAD software.

1.2 Problem Statement

The problem faced today by the common antenna technology is the strength of its receiving signal. Although there is a huge rising need on the intelligent technology within vehicles, however their communication segment is still unexplored yet. Many concept cars from different prominent car dealers have come out with various new systems making their vehicle look more sophisticated, yet the communication section is still unanswered. This could be due to the reason that it could not be officiated due to the traffic rules which do not allow drivers to make calls while driving is in progress.

The direct link between vehicle and the communication tower is the antenna. This antenna is our only way to receive and transmit calls within vehicles. However there is a limitation for such a miniature structure. Antenna size has been its biggest setback. The area of surface is too small that any dented mark or broken antenna will cause a lot of noise interference and loss in signal.

It is quite irritating when there is static noise at the background of our calls or while listening to the radio. Our first perception would be is the antenna raised to its maximum height? Is the antenna plug connected to the radio? If so, is it firmly seated in the connector? Is the antenna properly grounded? Has the antenna been knocked off or has a permanent dent on it? Many questions arise in our mind in trying to understand the problem faced. But it’s not always the antenna that could be the problem. There are times when it has reached its limitation. Due to its size, whether it being long or broad, there is a maximum limitation to the amount of signal strength it can receive or transmit. Certain locations like inner states or hilly areas, there are high chances there is no communication tower to help to boost up the antenna strength. Bad weather conditions can also cause a lot of interference into the signal.

The current antenna mounted on the vehicles and cell phones still lack in its quality of service. In certain areas and weather conditions, the signal is weak and hence wireless communication breakdown tends to happen. With the help of vehicle's body as an antenna, the radiation becomes stronger which makes reception of waves energy becomes apparent and with little losses.

1.3 Research Objectives

i. To study the gain and directivity of the waves.
ii. To simulate the radiation pattern when the car body is turned into an antenna.
iii. To analysis the radiation pattern whether it meets with the SAR requirements.

1.4 Significance of This Study

The findings from this research may be able to provide useful information and guidelines on how to effectively increase the signal strength using the car body as an antenna. This could be the starting platform of a new era in communication within vehicles. Many car manufacturers will find this research convenient as it gives a stepping stone to achieving what seems to be an impossible and a hassle task.

Although the communication within vehicles is still a new segment and unexplored, yet this could be an interesting technology embedded into a car if it is successfully tested. With the rising on demand of new intelligent technologies being introduced into luxury cars, this could yet be an interesting section to explore.

1.5 Outline of Thesis

Chapter one presents the introduction of this thesis which covers a brief introduction on research background, problem statement, research objectives and the significance of this study.

Chapter two discussed on literature review which covers topics on antenna, radiation pattern, theory on electromagnetic waves distribution, energy radiated in complex form, the basic properties of antennas, S-parameters and review on previous papers or projects done by other researchers.

Chapter three elaborates about the methodology of this thesis. The softwares used in this study are Matlab and FEMM CAD. This chapter also covers topics on electromagnetic analysis in Finite Element Methods as it is the core of FEMM software understanding.

Chapter four presents the results achieved through simulations done by FEMM and also discussion on the achieved results. Among the results that managed to be simulated are electromagnetic field distribution, electromagnetic field radiation, field intensity, current density, 2D ration pattern, H-field strength of different parts of car and also the SAR computation.

Chapter five concludes the thesis with a summary on the results achieved and some recommendation for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents the literature study on the body of the car acts as a transmitter and receiver. The topics covered in this chapter are: antenna, radiation pattern, electromagnetic distribution on the surface of the body, radiation pattern, far field and near field concept. The chapter also reviews other relevant project. It is important to do that to find out the research gap and perhaps improvement that can be applied.

2.2 Antenna

Antenna is one of the key points in this study. Although the key idea is to study its radiation pattern exhibit by the antenna, understanding its structure and construction is an essential part of this research. An antenna consists of an arrangement of metallic conductors which are electrically connected to the receiver or transmitter [1]. In our research, the body of the car consist an arrangement of metallic conductors. This metallic conductor allows an oscillating current of electrons to run through it creating an oscillating magnetic and electric field around the elements. These time-varying fields will radiate away from the metallic conductors into space as a moving transverse electromagnetic field wave.

Antennas can be specially designed to transmit and receive radio wave signals at all horizontal direction or from a particular direction [2]. The difference between an omnidirectional antenna and a directional antenna is omnidirectional antenna covers a wider scale of area to transmit and receive radio wave signals compare to the directional antenna. However a directional antenna has much more stronger beam to capture the signal or even transmit the signal to a particular direction compare to an omnidirectional antenna.

2.3 Radiation Pattern

Radiation pattern is a graphical depiction of the relative field strength transmitted from or received by the antenna [3]. Antenna radiation patterns are taken at one frequency, one polarization, and one plane cut. The patterns are usually presented in polar or rectilinear form with a dB strength scale. Patterns are normalized to the maximum graph value, 0 dB, and directivity is given for the antenna. This means that if the side lobe level from the radiation pattern were down -13 dB, and the directivity of the antenna was 4 dB, then the side lobe gain would be -9 dB.

The antenna radiation pattern is a measure of its power or radiation distribution with respect to a particular type of coordinates. We generally consider spherical coordinates as the ideal antenna supposed to radiate in a spherically symmetrical pattern. However antenna in practice is not omni-directional but have a radiation maximum along one particular direction.

2.4 Theory on Electromagnetic Waves Distribution

In order to understand the waves distributed along the surface of an object before transmission, it is important to review some properties of the waves. Consider Maxwell's equation which states that:

$$\nabla \times H = J + \varepsilon \frac{\partial E}{\partial t} \qquad (2.1)$$

The electric power P = VI = (Ed)(JA), where V is a voltage driving current I through a conductor, J is the current density, A is the area of cross section of the conductor through which the current flows, E is the electric field intensity associated with V (given by E = V/d, where d is the distance between the plates across which V is applied) [4].

The power per unit volume or power density is given by [5]:

$$P = \frac{VI}{Volume} = \frac{VI}{Ad} = EJ \quad \text{Watts/m}^2 \qquad (2.2)$$

In vector notation, 2.1 becomes [6]:

$$P = E \bullet J \qquad (2.3)$$

Performing the vector operation of "E" on equation 2.2:

$$E \bullet \nabla \times H = E \bullet J + E \bullet \varepsilon \frac{\partial E}{\partial t} \qquad (2.4)$$

Notice that the first term on the RHS of equation 2.4 is E•J, which represents power density. Therefore, equation 2.3 represents a power density relation. Rearrangement of equation 2.4 yields:

$$E \bullet J = E \bullet \nabla \times H - E \bullet \varepsilon \frac{\partial E}{\partial t} \quad (2.5)$$

Now, consider the first term on the RHS of equation 2.5. This can be seen to be the first term on the RHS of the vector identity.

$$\nabla \bullet E \times H = H \bullet \nabla \times E - E \bullet \nabla \times H \quad (2.6)$$

From equation 2.6, the following equation is obtain [7]:

$$E \bullet \nabla \times H = H \bullet \nabla \times E - \nabla \bullet E \times H \quad (2.7)$$

But, combining both the Maxwell equations, the following equation is obtain [8]:

$$\nabla \times E = -\mu \frac{\partial H}{\partial t} \quad (2.8)$$

Substituting this in equation 2.8:

$$E \bullet \nabla \times H = -\nabla \bullet E \times H + H \bullet \left(-\mu \frac{\partial H}{\partial t} \right) = -\nabla \bullet E \times H - H \bullet \mu \frac{\partial H}{\partial t} \quad (2.9)$$

Substituting the relevant expression from equation 2.8 into 2.9:

$$E \bullet J = -\nabla \bullet E \times H - H \bullet \mu \frac{\partial H}{\partial t} - E \bullet \varepsilon \frac{\partial E}{\partial t} \quad (2.10)$$

Integrate equation 2.10 over the volume v to obtain the entire power contained in it in watts. Thus, we find that:

$$\iiint_v E \bullet J dv = -\iiint_v \nabla \bullet E \times H dv - \iiint_v H \bullet \mu \frac{\partial H}{\partial t} dv - \iiint_v E \bullet \varepsilon \frac{\partial E}{\partial t} dv \quad (2.11)$$

Now, consider the first term on the RHS. This can be simplified using Gauss's theorem as follows:

$$\iiint_v \nabla \bullet E \times H dv = \iiint_A E \times H \bullet da \tag{2.12}$$

where A is the surface area of volume v. The cross product E×H represents power density or power per unit area. This is because, E = V/d and H = I/d, so that EH = VI/d^2. Thus, the product E×H integrated over the area A represents the total power contained in the area A. Now, fields E and H represent travelling waves. Therefore, the cross product of these two travelling vectors must represent a power flow, the direction of which depends on the directions of E and H. If E and H are waves travelling in the forward direction, then E×H represents power flowing out of volume v into the space surrounding it. But, if E and H are reverse travelling waves, then E × H represents power flowing into volume v from the space surrounding it. Thus, from observation of the cross product vector [9]:

$$E \times H = P \tag{2.13}$$

represents power flows, with the positive sign of the vector representing outward flow and the negative sign representing inward flow of power. The vector P is called the 'Poynting's Vector'.

Based on these arguments, we find that $-\iint_A E \times H \bullet da$ represents power flowing into our volume v from its surrounding surface. Now consider the second term $H \bullet \mu \frac{\partial H}{\partial t}$ in equation 2.10. This can be written as [10]:

$$H \bullet \mu \frac{\partial H}{\partial t} = \mu \frac{\partial (H \bullet H)}{\partial t} = \mu\left(H \bullet \frac{\partial H}{\partial t} + H \bullet \frac{\partial H}{\partial t} \right)$$

$$= \frac{1}{2}\mu\left(2H \bullet \frac{\partial H}{\partial t} \right) = \frac{\mu}{2}\frac{\partial (H^2)}{\partial t} = \frac{\partial}{\partial t}\left(\frac{\mu H^2}{2} \right) \tag{2.14}$$

From the term $\mu H^2/2$ represents the power stored in a magnetic field. Since $\partial/\partial t$ of any quantity gives the time rate of change of that quantity, $\frac{\partial}{\partial t}\left(\frac{\mu H^2}{2}\right)$ represents the time rate of change of power stored in a magnetic field. Now, consider the term $-\iiint_v H \bullet \mu \frac{\partial H}{\partial t} dv$ again. This can be written as follows [11]:

$$-\iiint_v H \bullet \mu \frac{\partial H}{\partial t} dv = -\iiint_v \frac{\partial}{\partial t}\left(\frac{\mu H^2}{2}\right) dv = -\frac{\partial}{\partial t}\left[\iiint_v \left(\frac{\mu H^2}{2}\right) dv\right] \tag{2.15}$$

Based on the arguments given in equation 2.15, this term represent the rate of decrease of power stored in a magnetic field (with the negative sign indicating a decrease in the stored power). Lets consider the third term $-\iiint_v E \bullet \varepsilon \frac{\partial E}{\partial t} dv$ on the RHS of equation 2.14. Following the same principles as given previously, this terms represents the rate of decrease of power stored in electrostatic field, and is simplified as [12]:

$$-\iiint_v E \bullet \varepsilon \frac{\partial E}{\partial t} dv = -\iiint_v \frac{\partial}{\partial t}\left(\frac{\varepsilon E^2}{2}\right) dv = -\frac{\partial}{\partial t}\left[\iiint_v \left(\frac{\varepsilon E^2}{2}\right) dv\right] \tag{2.16}$$

Summarizing the statements given above, the term is as follows:

- $\iiint_v E \bullet J dv$ represents the power dissipated in the conductors (or resistors) kept inside a surface of volume v.
- $-\frac{\partial}{\partial t}\left[\iiint_v \left(\frac{\mu H^2}{2}\right) dv\right]$ represents the time rate of decrease of the energy stored in inductors (or magnetostatic field) kept in v.

- $-\frac{\partial}{\partial t}\left[\iiint_v \left(\frac{\varepsilon E^2}{2}\right) dv\right]$ represents the time rate of decrease of the energy stored in capacitors (or electrostatic field) kept in v.
- $-\iint_A E \times H \bullet da$ represents the energy flowing into the v from the surface surrounding it.

Therefore sum the above statements in equation form is as follows:

$$\iiint_v E \bullet J dv = -\frac{\partial}{\partial t}\left[\iiint_v \left(\frac{\mu H^2}{2}\right) dv\right] - \frac{\partial}{\partial t}\left[\iiint_v \left(\frac{\varepsilon E^2}{2}\right) dv\right] - \iint_A E \times H \bullet da \qquad (2.17)$$

which is a statement of the Poynting's theorem to show the electromagnetic waves distribution with the direction in mathematic form. The word statement of this theorem is:

The energy dissipated (in the conductors and resistor) within a volume v is equal to the sum of the rate at which the energies stored in the electric and magnetic fields kept inside it is decreasing as well as the energy flowing into it from its surrounding surfaces.

The above statement is not surprising and is very much in conformity with the law of conservation of energy. This theorem can be explained by quoting the following example. Consider a radio receiver tuned to a specific radio station (see Figure 2.1). The antenna of the receiver accepts energy from the electromagnetic (EM) waves confronted by it. This energy is represented as the third term on the RHS of equation 2.17.

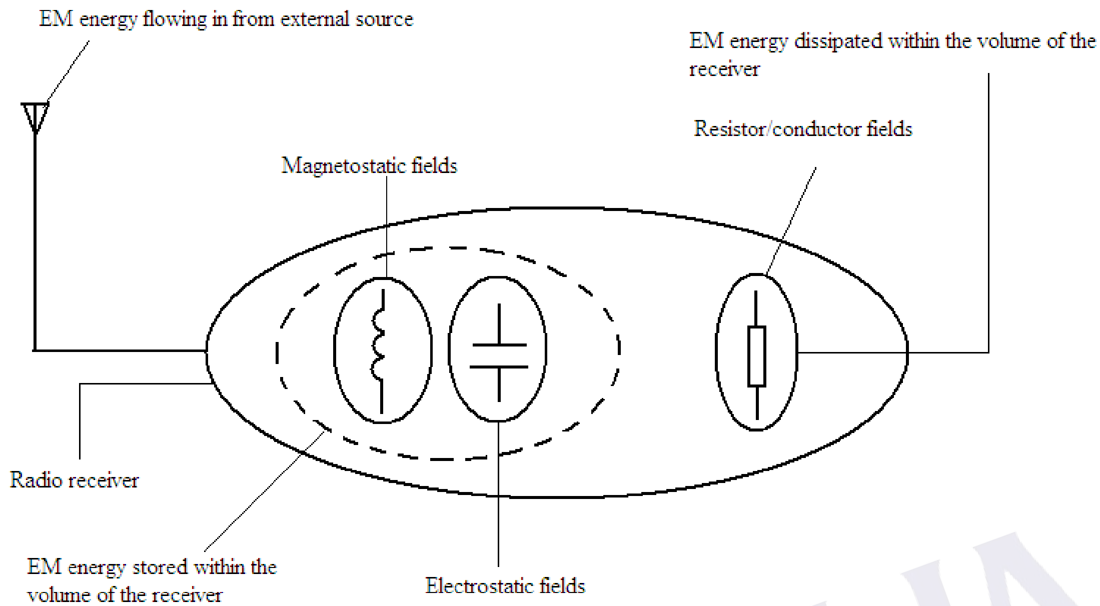

Figure 2.1: The meaning of radiated energy from a body acts as an antenna. [13]

The energy accepted by the antenna is then delivered to various circuit elements such as resistors, inductors and capacitors forming the receiver circuit. Of these, capacitors and inductors, which stored energy in the electrostatic and magnetic fields, respectively, will deliver energy to resistors in the circuits, which in turn dissipate it. On such resistor is the loud speaker of the receiver which reproduces the signal transmitted. This signal reproduction requires energy in the loudspeaker. Thus, the energy dissipated in the resistors is found inside the receiver (which is now our volume v) is delivered by the EM energy flowing in from the external sources into the receiver through the antenna, and the energies stored in the capacitors and inductors inside the receiver circuit.

2.5 Energy Radiated in Complex Form

The power in the electric circuit is given by the expression [13]:

$$P = VI\cos\theta \tag{2.18}$$

where V is the RMS value of voltage, I is the RMS value of current and cosθ is the phase angle between V and I. In terms of peak values, equation 2.18 becomes:

$$P = \frac{V_{max}}{\sqrt{2}}\frac{I_{max}}{\sqrt{2}}\cos\theta = \frac{V_{max}I_{max}}{2}\cos\theta \tag{2.19}$$

Representing V_{max} by V and I_{max} by I, and calling them as average values instead of RMS values, the average power is:

$$P = \frac{1}{2}VI\cos\theta \tag{2.20}$$

Equation 2.20 may also be written as:

$$P = \mathrm{Re}\left(\frac{1}{2}VIe^{j\theta}\right) = \frac{1}{2}\mathrm{Re}\left[VI(\cos\theta + j\sin\theta)\right] = \frac{1}{2}VI\cos\theta \tag{2.21}$$

Finally, the average power is represent as follows:

$$P = \mathrm{Re}\left(\frac{1}{2}VI^*\right) = \frac{1}{2}\mathrm{Re}\left[Ve^{j\theta_1}Ie^{-j\theta_2}\right] = \frac{1}{2}\mathrm{Re}\left[VIe^{j\theta}\right] \tag{2.22}$$

where we have $\theta = \theta_1 - \theta_2$ and $I^*(= Ie^{-j\theta 2})$ is the complex conjugate of $V (= Ve^{j\theta 1})$. The real part of the complex Poynting vector is:

$$P_{Re} = \frac{1}{2}\text{Re}[E \times H^*] \tag{2.23}$$

which represents the actual power dissipated in a resistor or conductor. The imaginary part representing the reactive power is written as:

$$P_{Ig} = \frac{1}{2}\text{Im}[E \times H^*] \tag{2.24}$$

We now use this for driving the complex Poynting theorem. For this, consider the vector form of Maxwell equation as:

$$\nabla \times H = J_g + \sigma E + j\omega\varepsilon E \tag{2.25}$$

where J_g is a new term introduced to represent non-ohmic currents such as the current from a specific and/or convection currents generated within the volume. Now, taking dot products of the type E•J* as before:

$$E \bullet \nabla \times H^* = E \times J_g^* + E \bullet \sigma E^* + E^* \bullet j\omega\varepsilon E \tag{2.26}$$

Consider the first term on the LHS of equation 2.26. This can be seen to be the first term on the LHS of the vector identity:

$$\nabla \bullet E \times H^* = H \bullet \nabla \times E^* - E \bullet \nabla \times H^* \tag{2.27}$$

Substituting equation 2.26 into equation 2.27:

$$H \bullet \nabla \times E^* - \nabla \bullet E \times H^* = E \bullet J_g^* + E \bullet \sigma E^* + E \bullet j\omega\varepsilon E^* \tag{2.28}$$

Using Maxwell equation again, we have:

$$-H\bullet j\omega\mu H^* - \nabla\bullet E\times H^* = E\bullet J_g^* + E\bullet\sigma E^* + E\bullet j\omega\varepsilon E^* \qquad (2.29)$$

Rearranging equation 2.29:

$$E\bullet J_g^* = -j\omega\mu HH^* - \nabla\bullet E\times H^* - \sigma E\bullet E^* - j\omega\varepsilon E\bullet E^* \qquad (2.30)$$

Integrating over volume v,

$$\iiint_v E\bullet J_g{}^*dv = -\iiint_v j\omega\mu HH^*dv - \iiint_v \nabla\bullet E\times H^*dv - \iiint_v \sigma E\bullet E^*dv - \iiint_v j\omega\varepsilon E\bullet E^*dv$$

Using Gauss's theorem on the second term on RHS, and rearranging:

$$\iiint_v E\bullet J_g{}^*dv = -j\omega\left(\iiint_v \mu HH^* + \varepsilon E\bullet E^*\right)dv - \iiint_v \sigma E\bullet E^*dv - \iiint_v E\times H^*\bullet da \qquad (2.31)$$

Equation 8.3.0 can be separated into its real and imaginary parts to give the dissipated power and the stored power, respectively. Thus:

$$\frac{1}{2}\mathrm{Re}\left(\iiint_v E\bullet J_g{}^*dv\right) + \frac{1}{2}\mathrm{Re}\left(\iiint_v \sigma E\bullet E^*dv\right) = -\frac{1}{2}\mathrm{Re}\left(\iint_A E\times H^*\bullet da\right) \qquad (2.32)$$

Using equation 2.31 and 2.32:

$$\frac{1}{2}\mathrm{Re}\left(\iiint_v E\bullet J_g{}^*dv\right) + \frac{1}{2}\mathrm{Re}\left(\iint_A P\bullet da\right) = \frac{1}{2}\mathrm{Re}\left(\iiint_v \sigma E\bullet E^*dv\right) \qquad (2.33)$$

Similarly, using equation 2.32 in equation 2.33, the imaginary part is obtain:

$$\frac{1}{2}\mathrm{Im}\left(\iiint_v E\bullet J_g{}^*dv\right) + 2\omega\left(\iiint_v \mu HH^* + \varepsilon E\bullet E^*\right)dv = -\frac{1}{2}\mathrm{Im}\left(\iint_A P\bullet da\right) \qquad (2.34)$$

The interpretations of these parts of the complex Energy radiations are as follow:

- Equation 2.33 deals with the general and dissipated powers. For example, the term $\frac{1}{2}\mathrm{Re}\left(\iiint_V E \bullet J_g^* dv\right)$ represents the real part of the power generated within the volume and $-\frac{1}{2}\mathrm{Re}\left(\iint_A P \bullet da\right)$ represents the real part of the power flowing into the volume from external sources. The term $\frac{1}{2}\mathrm{Re}\left(\iiint_V \sigma E \bullet E * dv\right)$ represents the total power dissipated within the volume.
- The imaginary terms given in equation 2.34 represents the stored powers that are unable to do work. For example, the terms $\frac{1}{2}\mathrm{Im}\left(\iiint_V E \bullet J_g^* dv\right)$ and $\frac{1}{2}\mathrm{Im}\left(\iint_A P \bullet da\right)$ represents, respectively, the reactive part of the power generated within the volume and the power flowing into the volume from external sources and the term $2\omega\left(\iiint_V \mu HH * + \varepsilon E \bullet E *\right) dv$ represents the power stored in the magnetic and electric fields within the volume.

2.6 Basic Properties of Antennas [14]

A radio antenna may be defined as the structure associated with the region of transition between a guided wave and a free space wave or vice versa. Antenna converts electrons to photons or vice versa.

Regardless of antenna type, they all involve the same basic principle that radiation is produced by accelerated charge. The basic equation of radiation is proportional to the charges carried. Thus time changing current radiates and accelerated charge radiates. For steady state harmonic variation, we usually focus on current. For transients or pulses, we focus on charge. The radiation is perpendicular to the acceleration and the radiated power is proportional to the square of $\dot{I}L$.

From the circuit point of view, the antenna appears to the transmission lines as a resistance R_r called the radiation resistance. It is not related to any resistance in the antenna itself but is a resistance coupled from space to the antenna terminals.

In the transmitting case, the radiated power is absorbed by objects at a distance: trees, buildings, the ground, the sky and other antennas. In the receiving case, passive radiation from distant objects or active radiation from other antennas raises the apparent temperature of R_r. For lossless antennas this temperature has nothing to do with the physical temperature of the antenna itself but is related to the temperature of distant objects that the antenna is "looking at", as shown in Figure 2.2.

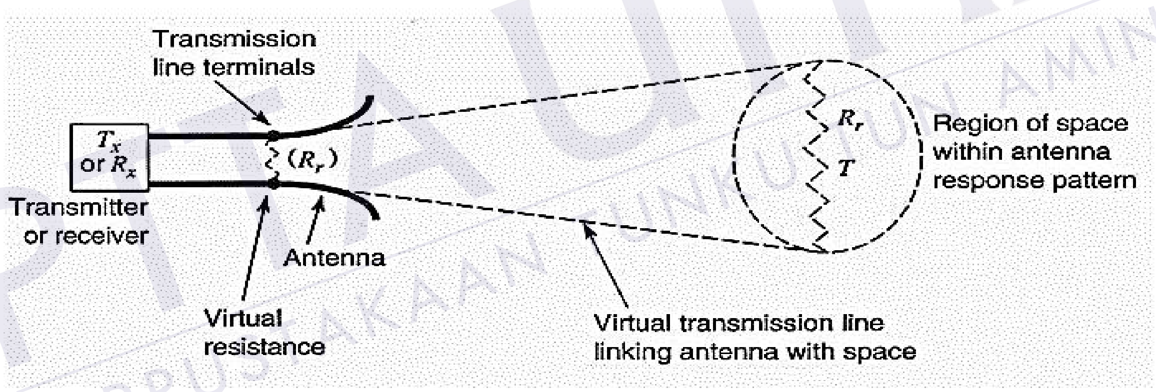

Figure 2.2: Schematic representation region of space linked with transmission line. [14]

Both the radiation resistance R_r and its temperature T mentioned in Figure 2.2 are simple scalar quantities. The radiation pattern on the other hand are three dimensional quantities involving the variation of field or power as a function of the spherical coordinates θ and ϕ. Figure 2.3 shows a three dimensional field pattern with pattern radius (from origin to pattern boundary at the dot) proportional to the field intensity in the direction θ and ϕ. The pattern has its main lobe (maximum radiation) in the z direction ($\theta = 0$) with minor lobe (side and back) in other directions.

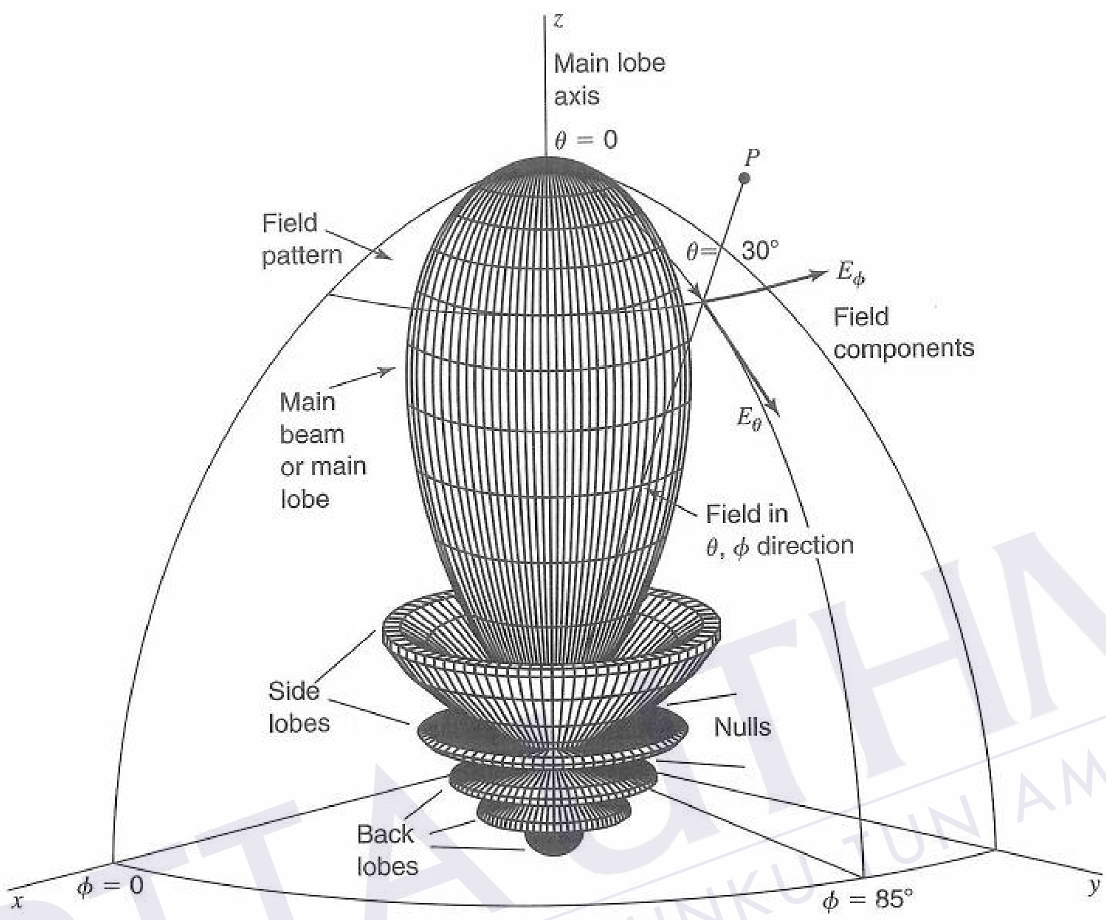

Figure 2.3: Three dimensional field pattern. [14]

In order to completely specify the radiation pattern with respect to field intensity and polarization, it requires three patterns:

- ☑ The θ component of the electric field as a function of the angles θ and ϕ or $E_\theta(\theta,\phi)$(V/m).
- ☑ The ϕ component of the electric field as a function of the angles θ and ϕ or $E_\phi(\theta,\phi)$
- ☑ The phases of these fields as a function of the angles θ and ϕ or $\delta_\theta(\theta, \phi)$ or $\delta_\phi(\theta, \phi)$(rad or deg).

Any field pattern can be presented in three dimensional spherical coordinates as in Figure 2.3 or plane cuts through the main lobe axis. Two such cuts at right angles called the principle plane patterns (as in the xz and yz plane in Figure 2.4) may be required but if the pattern is symmetrical around the z axis one cut is sufficient.

Figure 2.4(a) and (b) is principle plane field and power patterns in polar coordinates. The same pattern is presented in Figure 2.4(c) in rectangular coordinates on a logarithmic or decibel scale which gives the minor lobe levels in more detail.

The angular plot beamwidth at the half power level or half power beamwidth (HPBW) (or -3dB beamwidth) and the beamwidth between first nulls (FNBW) as shown in Figure 2.4 are important pattern parameters.

Dividing a field component by its maximum value we obtain a normalized or relative field pattern which is a dimensionless number with maximum value of unity. Thus the normalized field pattern for the electric field is a ratio of E field to the Emax.

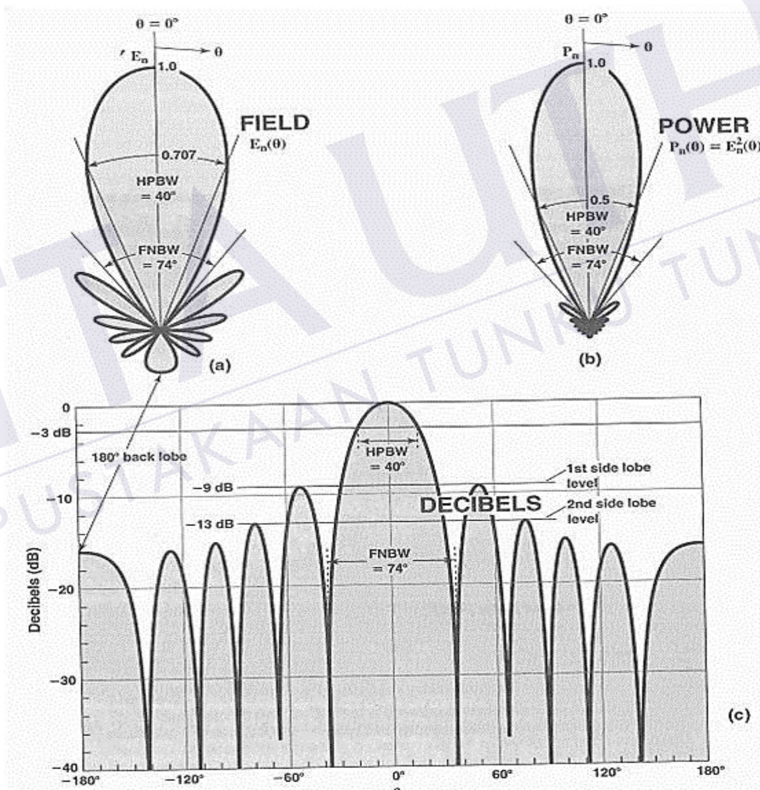

Figure 2.4(a): Two dimensional field, (b): Two dimensional power
(c): Decibels plots of the 3D antenna pattern. [14]

At distances that are large compared to the size of the antenna and large compared to the wavelength, the space of the field pattern is independent of distance. Usually the patterns of the interest are for this far field condition.

Pattern may also be expressed in terms of the power per unit area or poynting vector S(θ,ϕ). Normalizing this power with respect to its maximum value yields a normalized power pattern as a function of angle which is a dimensionless number with a maximum value of unity. The normalized power can be defined as the power divided by the maximum power.

2.7 S-Parameters

S parameters are important to determine the impedance matching and maximum power flows to the antenna. There are four types of S parameters [15]:

a) S_{11} - Input reflection coefficient
b) S_{12} - Reverse transmission coefficient
c) S_{21} - Forward transmission coefficient
d) S_{22} - Output transmission coefficient

For antenna measurement, S_{11} and S_{22} will be concerned. S_{11} is the best choice to be concerned because it measure how much the signal reflected back from the antenna to input coefficient. The concept of S-parameters can be seen in the following diagram:

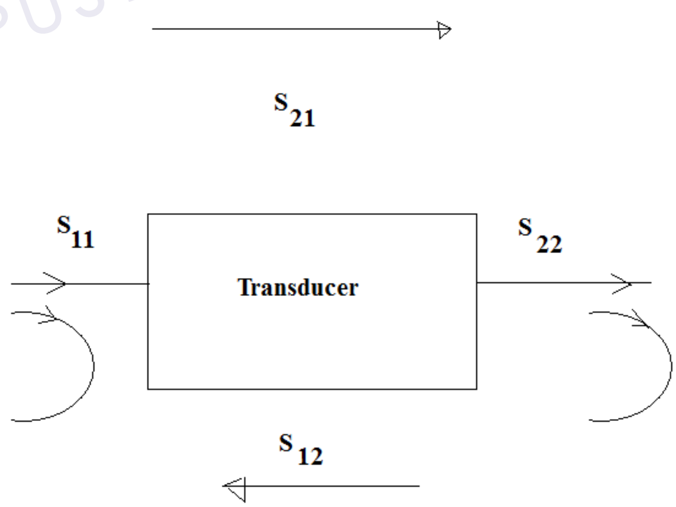

Figure 2.5: S parameters concept. [15]

The arrow indicates the flows of the power to the transducer. It depends on the transducer, if the impedance is matched, the maximum power transfer will occur. If the impedance of the transducer is different with the transmission line, the signal will be reflected back. This explains the two types of arrows at S11 and S22, one arrow moving forward representing the impedance being matched and the other arrow representing the impedance not being match and is reflected back.

2.8 Reviews on the Related Project

This section reviews some papers which published in the Internet and journals. This section will show a brief explanation on the results obtained by other researchers.

Referring to the paper Optical Wireless for Intra-vehicle Communications: A Channel Viability Analysis by (Matthew D. Higgins, Roger J. Green, and Mark S. Leeson, 2012), a study of optical wireless communication impact on the vehicle object is performed [19]. From the research, the model developed is shown as follows:

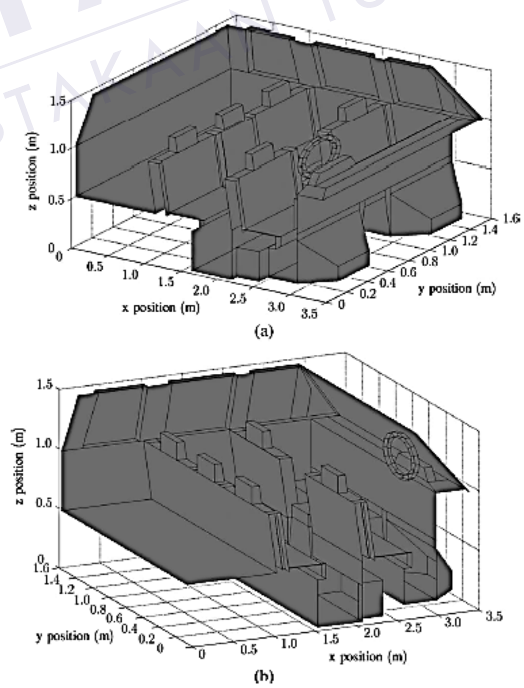

Figure 2.6: Passenger seats model [19].

Using the finite element software, the object in Figure 2.6 is divided in small element. From each element, it can be seen the detail of light absorbed and reflected. Taking the integration or using finite element methods, the sum of elements will show the total light absorbed and reflected.

Another paper, Effects of Car Body on Radiation Pattern of Car Antenna Mounted on Side Mirror for Inter-Vehicle Communications by (Suguru Imai, Kenji Taguchi, Tatsuya Kashiwa, Takeshi Kawamura, 2014), discussed that the waves distribution along the car body is random but most of the waves are strong as they accumulates at the source. Figure 2.7 shows the simulation results for the research outcomes [20]. This simulation results shows that the current distribution is less distributed at the rooftop, front and back of the car as the source of the current is from the side mirror.

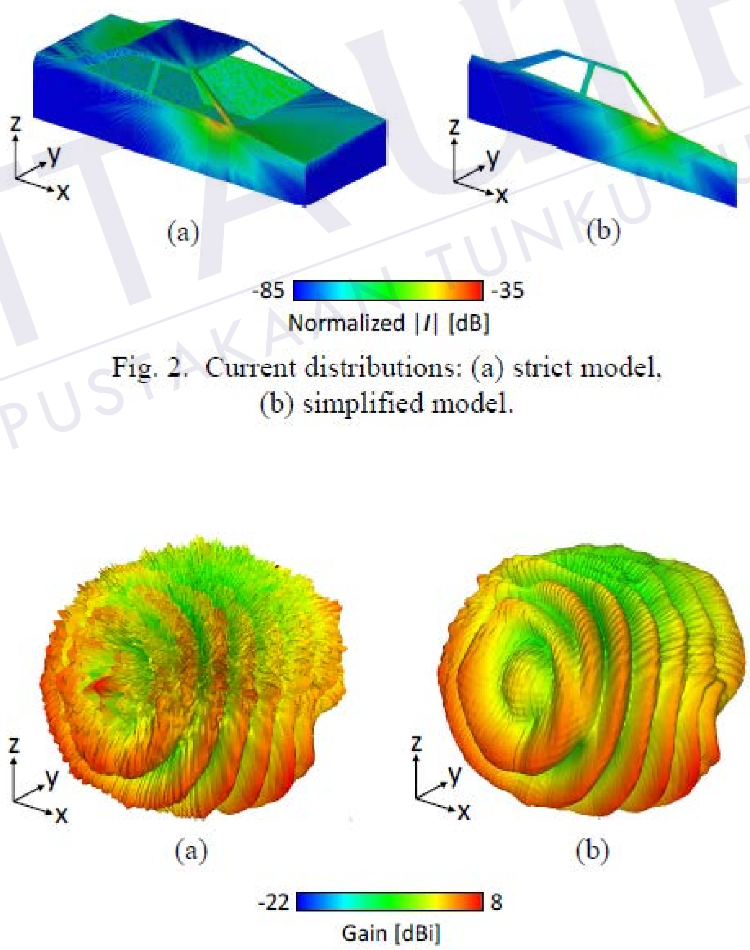

Figure 2.7: Simulation results for the wave distribution along the body of the car [20].

Based on the paper Radiation Pattern of Patch Antenna with Slits by (V.Karthikeyan and V.J.Vijayalakshmi, 2014) a study on the introduction of flat panel patch with slits at its corners as a rectangular micro strip antenna which is a kind of broadcasting transmitter by means of a small outline, is mounted on a smooth plane[21]. Figure 2.8 and 2.9 shows the simulation results for the research outcome: The basic patch covered now is linearly polarized since the electric field only varies in the one direction. This polarization can be either vertical or horizontal depending on the orientation of the patch.

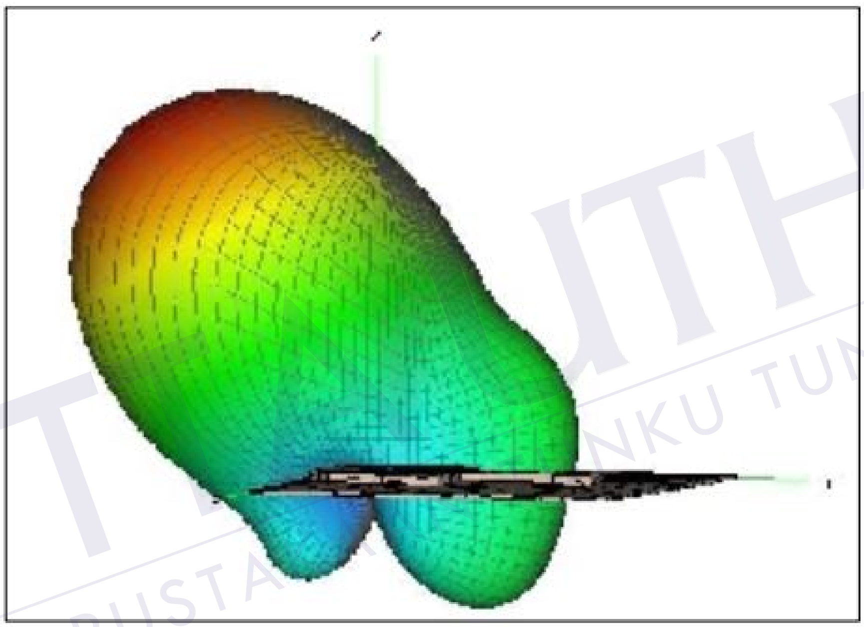

Figure 2.8: Radiation pattern of the Micro-strip Patch Antenna. [18]

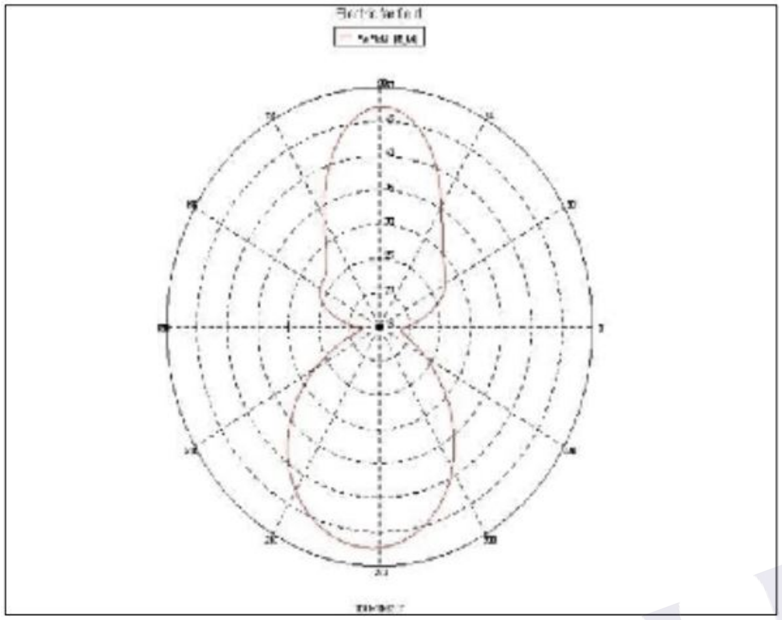

Figure 2.9: Electric far field for Micro-strip Patch Antenna [18].

Using the CADFEKO software, the findings on the electric far field, radiation pattern, gain and directivity was able to be obtained.

2.9 Summary

Based on the study of literature review, an understanding on how the wave distribution as well as its direction and propagation are achieved. The Poynting Vector is used to represent the directional energy flux density of an electromagnetic field. It is the rate of energy transferred from a region of space equals to the rate of work done on a charge distribution plus the energy flux leaving the region. It can be defined as S = E x H where E is the electric field and H is the magnetic field.

Based on the paper by Matthew D.Higgins on the Optical Wireless for Intra-vehicle Communications: A Channel Viability Analysis; it shows that a different angle of elements shows a different amount of light being absorbed and reflected. This means that at different locations, different types of bandwidth and signal strength are achieved.

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