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Microwave Principles in the Modelling of Radar Antennas for Automotive Applications

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Abstract- In this paper we devise a general model in determining several salient parameters that have an effect on the 24 GHz radar antenna. This method is also applicable to several antenna design areas such as the satellite communication in the Ku band and C-band but our focus is mainly on the 24 GHz and 77GHz radar.

Keywords: antenna radiation patterns; radio frequency; radar.

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I. Introduction

Radars have been developed for several applications and frequency ranges. High frequency radars such as the 24Ghz and 77Ghz radars are mostly used in the ground vehicle applications, radars in the Ku and Ka band are known to be used mainly for satellite applications while marine radars, usually in the X, S and Ku bands are mainly used in research (which includes weather monitoring) and navigation in marine environment.

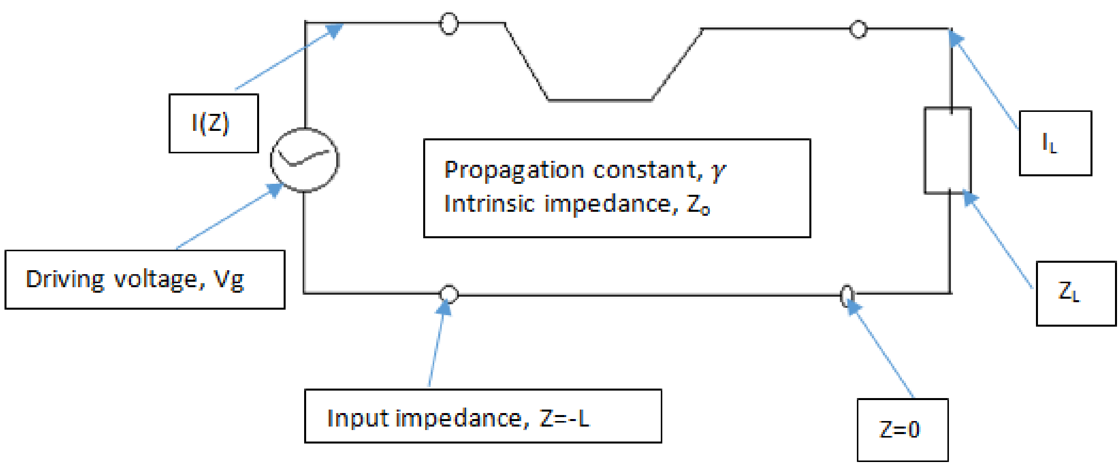
In this research, our focus is mainly on high frequency radars in the 24 GHz and the 77 GHz region. These radars are mainly used in these applications because of their detecting range, low cost of circuit components and light weight (recent advances in solid-state semi-conductors) and the amount of driving power required. The radars used in these applications are generally known to consist of the following components: Power amplifier, band pass filter, control and frequency detection unit, Analog-to-digital converter, mixer, low pass filter, a floating point computation unit and an antenna unit.

These radars mostly concerned with traffic safety parameters and the protection of vulnerable road users due to their ability to detect pedestrian in the dangerous scenarios of the vehicle.

The performance of such radar units are affected by the following parameters: gain of the antennas used, the signal-to-noise ratio of the detected low frequency (LF) radar return signal, the polarisation of the antenna, the floating point algorithms, bandwidth, the side-lobe and the main-beam width lobe of the beam forming unit.

II. Circuit Model of Antenna

The electronic engineer views the antenna as part of the electronic system, in which case it is just another circuit element with the properties of conductivity, resistance or admittance and can take on complex values due to the presence of reactive elements.



III. Proposed General Model

The propagation constant relates the different Field patterns or modes (usually denoted as the TM_{mn} where either m or n can be zero) Hence the propagation constant is denoted as:

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$\gamma = \sqrt{-(k^2) + \frac{m\pi}{a} + \frac{n\pi}{b}}$ Where a and b are the dimensions of the waveguide $k = \omega\sqrt{\varepsilon\mu}$ [1]

The attenuation of this nature and the circuit model provides us a way of determining what happens even when there is no current in the circuit. It is possible to deduce from our circuit model the possibility of obtaining non-trivial solutions assuming the circuit model has wave reflections (in which case, the VSWR parameter becomes prominent) inherent in them which of course results to zero due to non-excitation.

Therefore this leads to the reinforcement of the generally accepted principle and a further iteration that there is no solution at all frequencies but solutions are obtained at a particular frequency specification (we obtain the cut-off frequency for the existence of a certain TM, TEM or TE mode).

At microwave frequencies we may need our resonator to work with other types of resonators because at high frequency, the losses become important in the transmission line.

Waveguides are an instance of our circuit model with regards to the transmission line theory. Though the same concept of application the transmission line differs from the waveguides in the following respect:

1. While the transmission lines support only transverse electromagnetic (i.e TEM) wave, the waveguides are able to support several operating modes based on specifications.
2. Waveguides are employed in specialized frequency ranges for specialized applications while transmission lines are usually inefficient at microwave frequencies usually due to skin effect. Metallic enclosures are a classic example as frequently used in most antenna applications.

IV. Discussion of Model Parameters

Considering the basic circuit model the important parameters are the voltage standing wave ratio, the reflection coefficient and the input impedance.

The input impedance [1] of the circuit model in I can be written as:

$$Z_{in} = z(-l) = \frac{V(z=-l)}{I(z=-l)} ohms$$

The input impedance also provides Behavioral modelling of the circuit: open circuit and short circuit (z=∞) at various lengths (wavelengths) of the transmission line.

The reflection coefficient [1] of the circuit model in I can be written as:

$$\Gamma(z) = \frac{V_o^- e^{+\gamma z}}{V_o^+ e^{-\gamma z}}$$

Here we measure how the electromagnetic wave has been reflected by an impedance inconsistent with the desired frequency. The voltage standing wave ratio [1] of the circuit model in I can be written as:

$$VSWR = \frac{|1+\Gamma|}{|1-\Gamma|}$$

It is function of the reflection coefficient which describes the power reflected from the antenna. The VSWR has a profound effect on the antenna power and the bandwidth with a minimum of 1 indicating no reflection by the antenna.

For directional antennas such as the pin antenna, the flag antenna and the circular antenna, the direction of emission corresponds to the direction where maximum power is received. The excitation of antennas such as the Ferrite rod antennas, cylindrical antenna, segmented dipole, center-fed dipole and the yagi-uda antennas rely very much on the discussed parameters for maximum power gain.

A good automotive radar antenna should possess the following qualities:

1. A reasonable wide scan angle (excellent scan rate and faster update time, antenna with a 360 degree field view are prominent candidates) and easy integration into vehicle.
2. Small size and affordable to the consumer after integration.
3. Good antenna performance in terms of radiation patterns main beams and side lobes and excitation voltages.

The gain of the antenna is also an important parameter in determining the size of the antenna whilst the wavelength is crucial in the determining the frequency and the range of coverage. In the case of the automotive radar, the range in which an obstacle can be detected is also of great importance.The gain of the antenna [1] can be represented by the following equation:

$$G = \frac{4\pi}{\lambda^2} A_{eff}$$

The impedance of the antenna [1] is determined by applying the following formula:

$$P_r = H^2 Z_o \quad in \quad \frac{watts}{meter^2}$$

Where H is the rms magnetic field intensity and Z_o is the intrinsic impedance (being calculated) of the medium.

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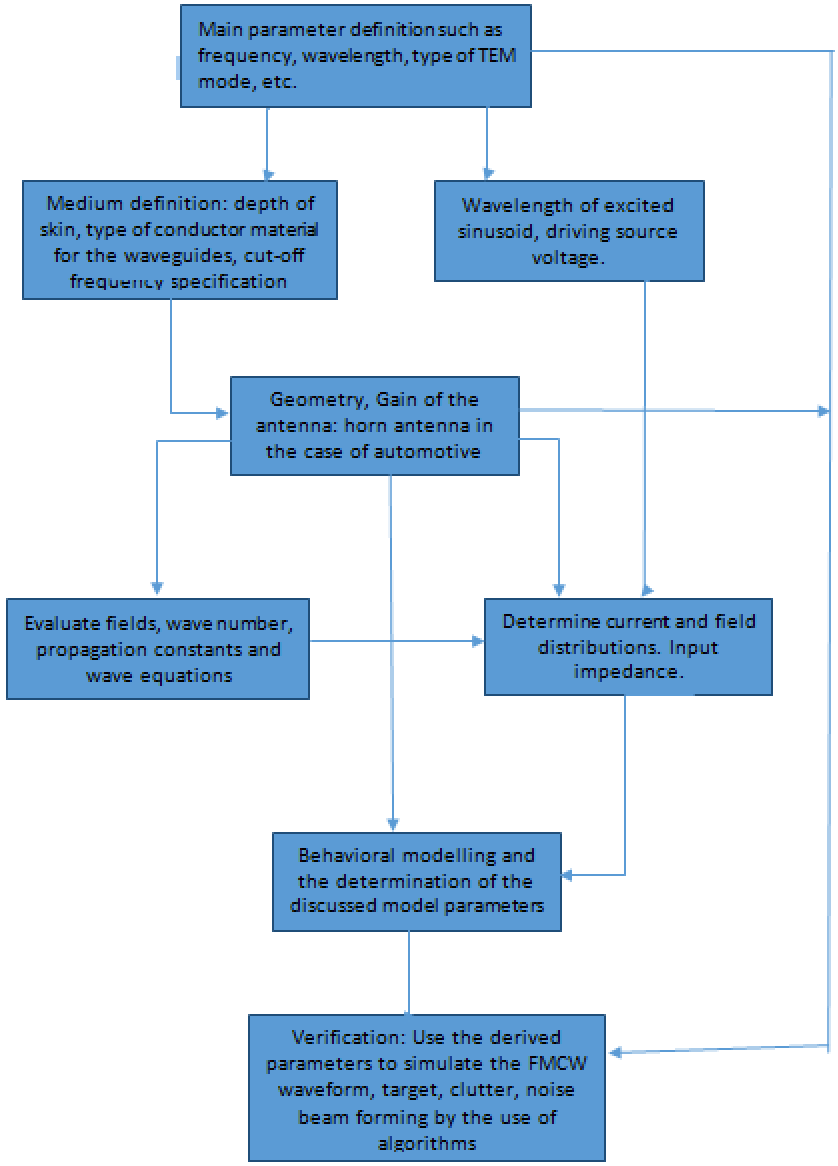
IV. Analytical Model for Antenna Evaluation



[2] does an impressive work by the use of the analytical model in simulating the Forward Moving Collision Warning system (FMCW) for a 77 GHz radar system by the using MATLAB phase array tool box. The system parameters enabled behavioural modelling in line with our discussed model parameters by the use of the MATLAB software. A complete system simulation of the radio frequency (RF) elements of the antenna is done and the verification step is also achieved.

V. Conclusion

In this paper, we put together some general salient parameters that affect antennas generally with our focus on the automotive radar antennas. This method have a profound effect on the design parametersneeded for simulation (and antenna design). It has effect on the beam forming unit and the polarisation of the antenna. We provide an analytical framework model for the computation and determination of some of the discussed parameters and more. The discussed parameters also play a major role in the excitation (driving power) of the antenna.

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