Effect of Surface Roughness on Antenna Array for Automotive Radar Applications

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***Abstract*— Recently, applications that use millimeter (mm) wave frequencies (30-300 GHz) have increased significantly to facilitate very high data rates and wide operational bandwidth. However, designing circuits and antennas at mm wave frequencies pose a challenge of its own. One such factor is surface roughness, which affects the conductivity of the metals used in the design and leads to degradation of performance. Surface roughness can be controlled using advanced and precise manufacturing techniques; however, they can be expensive. So, it is important to study the effect of surface roughness while designing mm wave circuits and antennas to avoid expensive modifications later in the design stages. In this paper, we consider one such application of automotive cruise control (ACC) radar that operates at 76.5 GHz and study how various values of surface roughness affect different performance parameters of the design.**

Keywords*— Surface roughness, Antenna, Automotive cruise control (ACC) radar, Antenna array, millimeter wave, MoM (Method of Moments), Green's Function, Feko.

I. Introduction

In the past two decades, applications that require high speed communications or data transfer have increased significantly. There are certain applications that require high precision and for some it is crucial that data is parsed at very high speeds to make quick decisions. These applications include high frequency imaging, remote sensing, telecommunications, automotive sensors or radars, security screening, through wall imaging, and many more. The need for such high data rates in the above-mentioned applications led to the use of mm wave frequency bands.

Although switching to mm wave frequencies do provide the required high data rates, designing antennas and circuits is a challenge. Among others, a factor that contributes to the degradation of the device performance at such high frequencies is surface roughness. Wavelength at mm wave frequencies can now fall in a comparable range to the value of surface roughness. This affects the electrical properties of the conductor as it alters the effective conductivity of the metal. It has been reported that surface roughness increases the signal loss and dispersion as mentioned in [1]-[7] due to reduced conductivity.

In this paper, performance of the automotive cruise control (ACC) radar antenna that operates at 76.5 GHz is studied to show how various values of surface roughness affect different performance parameters of the design. ACC radar systems require a compact antenna usually with very high gain and low Side Lobe Levels (SLL) for long range operations and to avoid false detections, respectively. In this paper, comparisons are made by evaluating key antenna performance parameters by considering Perfect Electric Conductor (PEC), and copper with various values of surface roughness. All the simulation results presented in this study are obtained using Altair Feko [8].

II. Antenna Design

We consider a microstrip array that consists of six single columns. Each column has ten individual radiating patch elements that are connected with a strip line feed as shown in Fig. 1. The substrate used has relative permittivity of 2.35 and dielectric loss tangent of 0.004. Planar multilayer Green's Function option in Feko is used for analysis of the antenna. The dimensions of individual patch elements are optimized to achieve good matching with 50-ohm reference impedance and required side-lobe-level. The conducting patch elements are initially set to PEC as a base line. Later, the simulations were conducted with copper of 35µm thickness with and without surface roughness values.

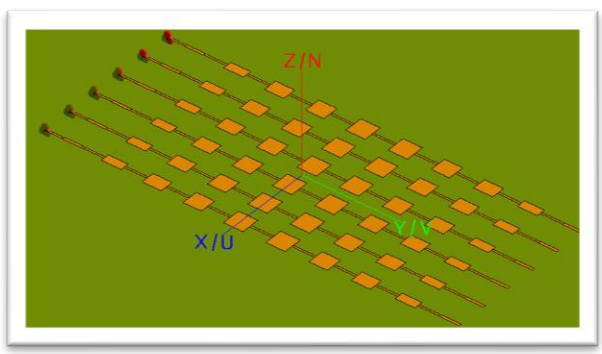


Fig. 1. Microstrip Patch antenna array with 6 columns.

III. Simulations and Results

A. Antenna Array with PEC

All the radar array columns are well matched with a reflection coefficient below -15dB, as shown in Fig. 2. The return loss for four internal columns overlaps with each other represented by S11, S22, S44, S55. The return losses of two columns at the end of both sides of the radar are represented by S33 and S66 in Fig. 2. Since antenna patches are set to PEC, the efficiency of the array is 100% ignoring the dielectric losses in the substrate. The 3D gain plot shown in Fig. 3 (a) and the two principal plane cuts of the radiation pattern are shown in Fig. 3 (b). The SLL in the XZ plane and YZ plane is around 34 dB and

20.43 dB, respectively, as shown in Fig. 3 (b). The maximum gain achieved in XZ plane is around 21 dB, whereas the YZ plane is around 22 dB because of the beam tilt.

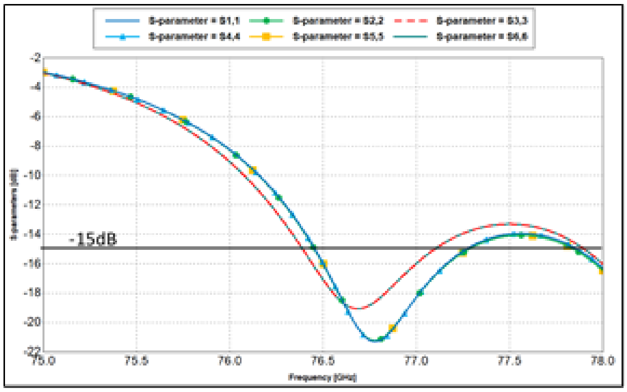
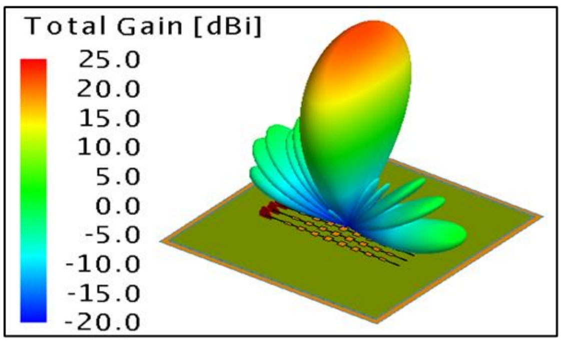
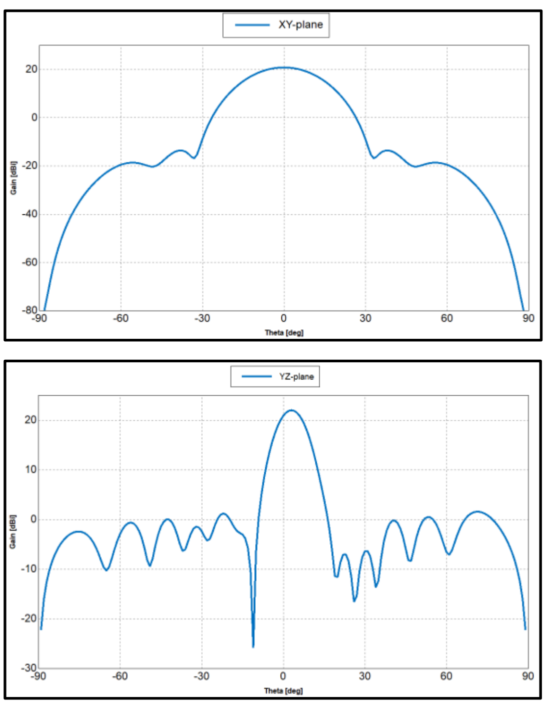


Fig. 2. Return loss of individual array columns in the radar.



(a)



(b)

Fig. 3. (a) 3D Farfield results *(Gain);* (b) XY and YZ cut planes.

B. *Antenna Array with Copper*

In this section we will discuss the use of copper with finite conductivity (5.813 E+07 S/m), thickness (35 µm) as well as surface roughness in place of PEC. Again, as a base line, efficiency of the array antenna with zero surface roughness is computed as given in the first row of the Table I.

A detailed study of effect of surface roughness on the antenna array performance is carried out, varying the RMS value of surface roughness using the corresponding ISO grade numbers [9]. Table I shows the gain, efficiency, and losses due to varying surface roughness. It is observed that the efficiency reduces as the value of surface roughness is increased. But after a point, the efficiency remains constant. The same is observed for conductor losses. The gain also shows a similar trend. This could be related to surface roughness in relation to the skin depth.

TABLE I. EFFECT OF SURFACE ROUGHNESS ON ANTENNA ARRAY PERFORMANCE

Sr. No	Surface Roughness (RMS in µm)	Losses (mW)	Efficiency	Gain	
				XZ Plane	YZ Plane
1	0	8.89	64.11	18.64	19.98
2	0.0559	9.09	63.20	18.56	19.92
3	0.1118	10.59	56.07	17.95	19.35
4	0.2235	11.98	48.72	17.21	18.6
5	0.447	12.55	45.37	16.83	18.31
6	0.8941	12.75	44.15	16.69	18.18
7	1.7602	12.81	43.75	16.64	18.13
8	3.4925	12.83	43.61	16.62	18.12
9	6.985	12.84	43.56	16.61	18.11
10	13.97	12.84	43.54	16.61	18.1
11	27.94	12.84	43.54	16.61	18.1

IV. CONCLUSIONS

In this paper, effect of surface roughness on antenna array performance for ACC radar for automotive applications is studied. As could be seen by the data presented in the previous section, surface roughness can significantly reduce the efficiency and hence the gain of the array. ACC radar design need to take this into account. For critical applications that need precise values of these parameters, designers should evaluate the effect of surface roughness before prototyping the design to estimate the degradation. Such a study can also aid in selecting the appropriate manufacturing grade based on applications to ensure balance between cost and accuracy of the designed product.

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