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Surface roughness modeling for extremely high frequency applications

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Abstract. In this work, we show electromagnetic simulations of surface roughness in multiple conventional antennas applicable for 6G networks potentially operating in the W-band (75–110 GHz). Operations at such high frequencies require fine accuracy of surface processing that becomes to the order of the wavelength. We show simulations of the surface roughness of four devices, such as a horn antenna, a patch antenna, a rectangular waveguide, and a microstrip transmission line. Finally, we simulated S-parameters and conducted statistical analysis to define the requirements of surface processing.

Keywords: extremely high frequency, surface roughness, electromagnetic simulations

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Моделирование шероховатости поверхности для устройств, работающих на крайне высоких частотах

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Аннотация. В этой работе мы демонстрируем электродинамическое моделирование шероховатости поверхности для нескольких антенн, подходящих для применения в сетях шестого поколения, эксплуатирующих частоты порядка 75–110 ГГц. В качестве таких устройств были выбраны рупорная антенна, прямоугольный волновод, микрополосковая линия передачи и патч-антенна. После проведения электродинамического моделирования были получены графики S-параметров, на основании которых были определены требования к обработке поверхностей устройств.

Ключевые слова: крайне высокие частоты, шероховатость поверхности, электродинамическое моделирование

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Introduction

One potential application that uses extremely high frequencies, such as W-band (75–110 GHz), is the 6G wireless network [1, 2]. Several antennas could be used at such a high frequency, among them horn antennas and patch antennas. In addition, one could use rectangular waveguides, and microstrip lines, and many others. At such a high frequency, the manufacturing defect has an important role in antenna performance [3, 4]. Recently we have already performed an electromagnetic investigation of the surface roughness of some devices [5], whereas here we enlarge our work to the microstrip line and also investigate the convergence rate to validate our approach.

Materials and Methods

To simulate surface roughness, we performed numerical electromagnetic analysis using simulations in the CST Studio Suite. We separated all devices into two groups, such as additive devices and chemically etched devices, according to the manufacturing method (Fig. 1). In the first group (Fig. 1, *a*, *b*), we simulated a horn antenna and a rectangular waveguide with the WR-10 flange. In the second group, we simulate a patch antenna and a microstrip line (Fig. 1, *c*, *d*).

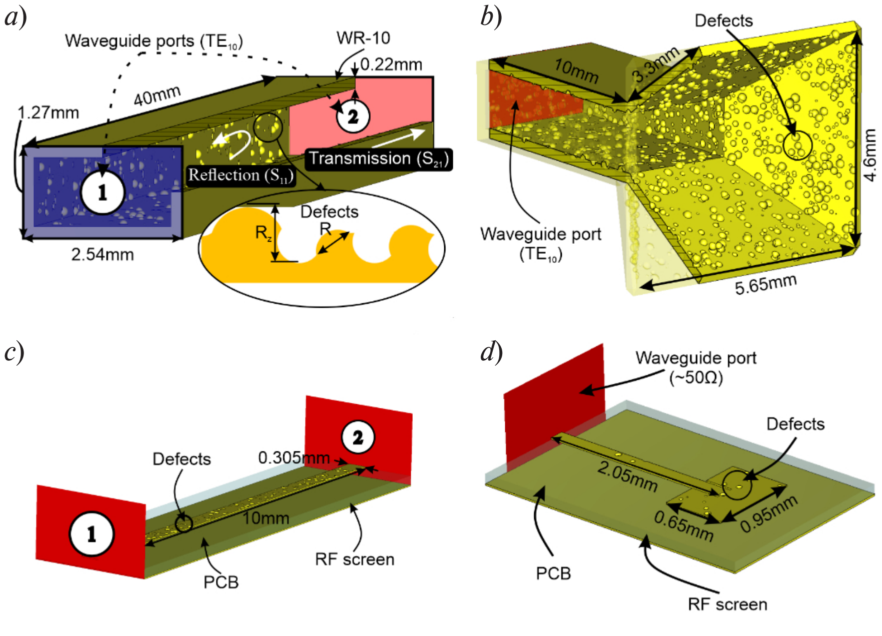

Fig. 1. Simulation setups and general view of structures with defects: waveguide (*a*), horn antenna (*b*), microstrip (*c*), patch antenna (*d*)

In the first group, we modeled the surface roughness as a set of bumps or hollows, whereas we modeled only hollows in the second group. These defects have a spherical shape with a radius of *R*. For each device, we performed a statistical analysis with 50 random series of simulations, and

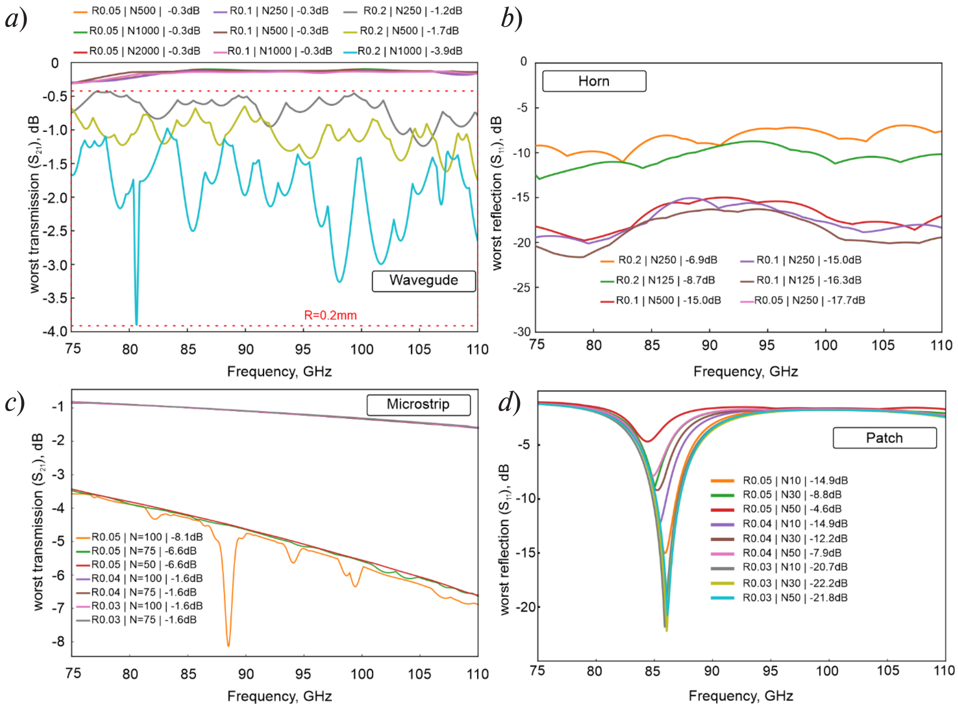

Fig. 2. Transmission coefficient of waveguide (*a*), worst reflection coefficient of horn antenna (*b*), worst transmission coefficient of microstrip (*c*), worst reflection coefficient of patch antenna (*d*). In plot legend tables, defect size *R* in first column is given in mm, *N* in second column is corresponding to total number of simulated spheres, third column depicts worst values across all frequency range

then the S-parameters were evaluated as the worst value at a picked frequency point, as shown in Fig. 2. For the waveguide, we assessed transmission coefficient S_{21} (Fig. 2, *a*, *c*), whereas for the horn and patch antennas, we assessed reflection coefficient S_{11} (Fig. 2, *b*, *d*). In each case, we assessed three levels of defect sizes and several defects' quantities, depending on the device. These sets of simulations are also shown in Fig. 2.

Finally, we performed statistical analysis on the waveguide to analyze the convergence rate. We observed that in the case of 200 random series, computation time increases drastically by a factor of 3, whereas the difference in terms of mean S-parameters becomes only 0.4% compared to the case of 50 random series. The convergence rate is shown in Fig. 3, *a*, and the mean S-parameters for two convergence scenarios are shown in Fig. 3, *b*.

Results and Discussion

In the case of the waveguide, the worst value of the transmission coefficient decreases to -3.9 dB (Fig. 2, *a*), whereas the cases R = 0.05 mm and R = 0.1 mm which S_{21} values do not exceed -0.3 dB, could be considered as acceptable, since this value is comparable to the ideal waveguide (0 dB), and its difference is about only 5%. This means that the acceptable surface roughness in the case of the waveguide corresponds to the wavelength/14 and the wavelength/28 respectively, at 110 GHz.

For the horn antenna, we observed that for R = 0.1 mm, the worst reflection coefficient S_{11} is nearly −15 dB (Fig. 2, *b*), which is also considered acceptable, because it is a typical value obtained on practice for horn antenna. In terms of wavelength, this surface roughness equals wavelength/14.

For the microstrip transmission line, we observed that for 0.03 mm defect size, the worst S_{11} is nearly −1.6 dB (Fig. 2, *c*), which is close to the ideal scenario corresponding to the case with a flat surface. In terms of the wavelength, these values are above the mean wavelength/90.

Finally, in the case of patch antennas, we can observe that the worst reflection coefficient S_{11} for 0.04 mm is approximately −15 dB (Fig. 2, *d*), which means wavelength/90.

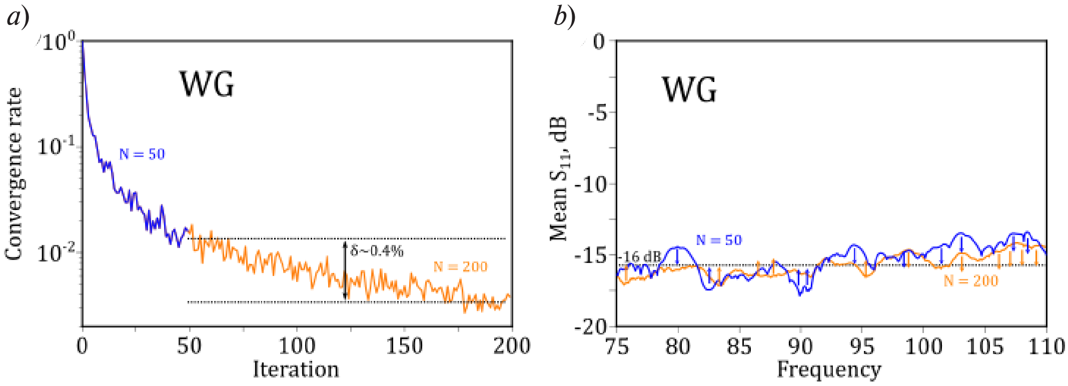

Fig. 3. Convergence rate of the waveguide (*a*),
mean S-parameters for two convergence scenarios (*b*)

For all cases mentioned above, we observed that with a small number of defects, but with a maximum size of defects, one observes acceptable performance of the devices under consideration.

Conclusion

In this work, we analyzed four structures: a waveguide, a horn, a microstrip, and a patch. We have shown that surface roughness $R = 0.1$ mm is acceptable for the waveguide and the horn, whereas in the case of the microstrip and the patch, one has to provide surface defects of 0.04 mm. After performing the set of electromagnetic simulations, we can conclude that in the case of the horn antenna and a patch antenna, the preferred surface quality should be at least wavelength/14, whereas in the case of the microstrip transmission line and the patch antenna, surface quality should be at least wavelength/90. Following these requirements, one has to select the proper manufacturing method or surface processing approach in order to maintain the quality of the surface.

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