Analysis of indoor exclusion zone in nuclear power plant environments

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***Abstract*—This article investigates the indoor exclusion zones (EZs) according to room dimensions and compares them with the free space EZs. Fluctuations in the received power level with respect to the distance for various paths are investigated.**

Keywords*—*exclusion zone; nuclear power plants; indoor propagation

I. Introduction

Wireless technologies become attractive to nuclear power plants (NPPs) since wireless control and monitoring systems can provide easy connectivity to personnel, wireless data networks, and sensing systems while significantly reducing the wiring costs. Although the wireless devices are efficient when operating in NPPs, the corresponding electromagnetic interference (EMI) problems should be investigated. The exclusion zone (EZ) is one of the important EMI regulations when installing instrumentation and control (I&C) equipment.

Electric field strengths for various cases were measured, and their field levels were compared [1]. However, the research did not consider the indoor environment, and therefore the multiple reflection effects were excluded. In this work, we analyze the field radiation properties from wireless devices in an NPP room environment. Fluctuations in the received power level with respect to the distance for various paths are investigated. In order to avoid high received power levels due to multiple reflections in an indoor environment, it is necessary to use lower transmit power than in the case of free space.

II. Minimum Distance in Free Space

The minimum distance d of EZ from the free space propagation model is obtained as $d = \sqrt{30 P_t G_t} / E$ [m], where P_t and G_t are radiated power and antenna gain of the emitter, respectively, and E is allowable radiated electric field strength of the receiving antenna at the point of installation [2]. The EZ is defined as the allowed minimum distance d from a transmitter position. In other words, the safety-related I&C equipment should be located more than the distance d from the emitter to prevent potential EMI problems. As the P_t or G_t increases, the distance d also does. This indicates that allowable installation range of the I&C equipment in a room is reduced when P_t or G_t increases. The distance d from the definition of the EZ is only valid when the emitter is in free space but is not appropriate for indoor environments that depend on room dimensions or cabinet arrangement. We investigate radiation properties according to the indoor geometry including walls and large cabinets.

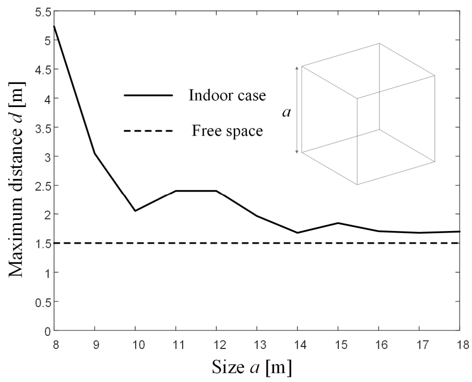

Fig. 1. Minimum distance d as a function of cubic dimension a.

III. Indoor Exclusion Zone in a Concrete Room

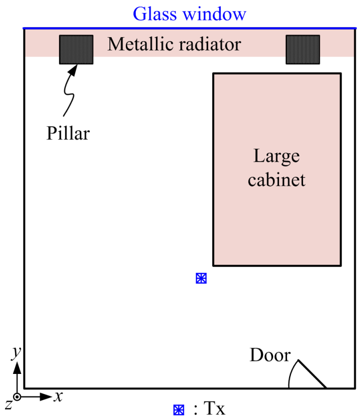

Fig. 2. Configuration of indoor geometry.

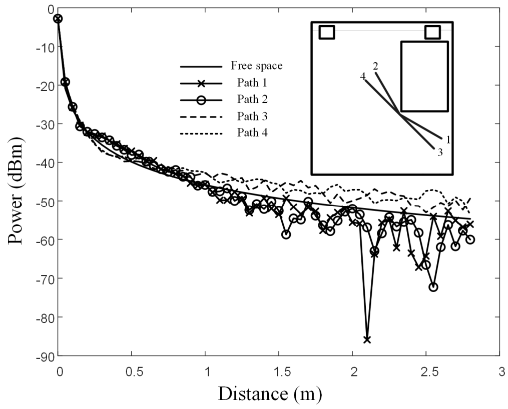

Fig. 3. Received power levels for different paths in NPP room environment.

Fig. 1 shows the minimum distance d depending on room dimensions. Inset shows an arbitrary cubic concrete room with the side length of a by assuming a thickness of the concrete wall of 0.2 m. We set G_t = 0.792 dBi and P_t = 1.0 W for a transmitter at the center of the room. When E = 4 V/m, the minimum distance d for the free space is obtained as 1.5 m, which is indicated as the dashed line in Fig. 1. The solid line shows the minimum distance d as a function of the side length a. The d for a small room is generally greater than that for a large room since a narrow room space makes more multiple reflections, resulting in stronger field strengths. As the room dimension increases, the d converges to 1.5 m, which means that the indoor EZ for large room dimension approaches the EZ in the free space case.

IV. Three Dimensional Indoor Geometry

Fig. 2 shows a proposed hexahedral indoor geometry, which imitates the I&C equipment room in NPPs to observe electromagnetic scattering characteristics. The transmitters are mounted at the lower left corner of the large cabinet and are indicated by blue markers. The transmitter emits a signal at 2.4 GHz, which is considered to be a measuring equipment using WirelessHART communications. In this work, z-directionally polarized dipole antenna is applied. The transmitter is located at one wavelength away from the cabinet. The wall dimensions in x and y axes are 8.3 m and 8.92 m, respectively, and the height of the room is 2.74 m.

V. Received Power Levels in a Room Environment

Received power levels in accordance with various directions are investigated from the room environment in Fig. 2. Fig. 3 shows the received power levels versus the distance from the transmitter for four different paths as well as the free space case. The inset shows the simplified room environment of Fig. 2 and four different paths. Two of them are the strongest paths, and the other two are the weakest paths. The solid line indicates the received power for the free space case (The room environment is not included.), which is independent on the directions. The received power levels for four different paths are plotted. Below the distance d of 0.8 m, the difference between received power levels by the four paths and the solid line is not significant, however, at the distance d more than 0.8 m, the difference in level becomes larger. The received power levels for paths 3 and 4 are stronger than the free space case, while the levels for paths 1 and 2 are weaker. The fluctuations and the power level differences among paths are due to the phase differences of multiple reflected rays. From these results, it can be seen that the transmitted power levels P_t should be 7 ~ 8 dB lower than the free space case to avoid potential EMI problems.

VI. Conclusion

We have investigated the indoor EZs with respect to the room dimensions and compared them with the free space EZs. The radiation properties were affected by NPP indoor geometry and propagation directions. From this research, we can extensively investigate indoor EZs even in complicated indoor environments.

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