3. CONCLUSION

The results for the two test cases indicate that the potential advantages of the utilization of wideband slot radiators are limited, while employing subarraying in the design of planar arrays is the most effective way of improving the bandwidth. This suggests that the main cause of performance degradation is the phase deviations in the elements excitations due to shifts in the standing-wave patterns. Only a small sample was considered, but additional numerical experiments on arrays of various sizes led to the conclusion that the advantages of wideband radiators are largely limited to increased input impedance bandwidth for arrays with a small number of slots in each branch. In all cases, the effects on the pattern performance of arrays were minimal. The most effective way of improving the bandwidth of linear arrays is to use centerfed branches, which may be viewed as a form of subarraying. While the implementation of subarrays in planar slot arrays inevitably results in an increased complexity of the beamforming networks, results indicate that it remains the only option when improved bandwidth is required, especially in the case of larger arrays.

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AN IMPROVED RAY-TRACING PROPAGATION MODEL FOR PREDICTING PATH LOSS ON SINGLE FLOORS

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ABSTRACT: An improved ray-tracing propagation prediction model for predicting path loss on single floors in indoor environments is developed. It utilizes the results of a two-dimensional (2-D) ray-tracing technique to deal with a three-dimensional (3-D) problem. This approach is more efficient than the usual 3-D ray-tracing model and more accurate than the usual 2-D ray-tracing model. Simulation results agree well with measurement. © 1999 John Wiley & Sons, Inc. Microwave Opt Technol Lett 22: 39–41, 1999.

Key words: ray-tracing; propagation model; path loss

1. INTRODUCTION

Indoor wireless communications such as personal communications (PCs) and wireless local area networks (W-LANs) are expanding today. The need for an efficient way to evaluate radio-wave propagation in buildings is also increasing. Recently, the ray-tracing technique has been used to predict radio-wave propagation in indoor environments. A 2-D ray-tracing model and a 3-D ray-tracing model are both widely used [1–4]. The 2-D model requires less computation time, but has lower accuracy, and the 3-D model has the opposite advantage and disadvantage.

There have been some investigations on indoor radio propagation modeling on single floors [5, 6]. In [5], the authors explored features of office buildings that influence propagation, and used a ray-tracing model. In [6], the authors used a direct-transmitted ray (DTR) model combined with a patched-wall model.

The objective of our work is to study the character of propagation on single floors, and to present an accurate and fast model. In our model, multireflection by the ceiling and the floor is included. It has the advantages of both the 3-D and 2-D models. The predicted path loss is compared with the measured one of 1.7 GHz radio propagation in a room of the teaching building on our campus.

2. MODEL DESCRIPTION

Indoor environments are composed of floors, ceilings, and walls vertical to the floor. On single floors, if taking the floor as the x-y plane and the direction vertical to the floor as the z-axis direction, we can find the following properties of propagation when using the ray-tracing technique (in this coordinate system, the transmitter and receiver are regarded as a point in the 3-D space, respectively).

- When the floor or the ceiling reflects a ray, the incident ray and the reflected ray have the same azimuth angle. Namely, the perpendicular projections of the two rays on the floor are in a line.
- 2. When a wall vertical to the floor reflects a ray, the fact that the angle of incidence is equal to the angle of reflection is also valid for their projections on the perpendicular projection plane, i.e., on the floor.
- The angle between the ray reflected by a wall and the z-axis is equal to that between the incident ray and the z-axis.
- The source rays having equal azimuth angle in a 3-D space have the same perpendicular projection on the floor.

In our model, we first project all walls, the transmitter, and the receiver (except for the ceiling and the floor) perpendicularly on the floor, use the 2-D ray-tracing model on the projection plane, and then apply the 3-D ray-tracing technique based on results of 2-D ray tracing to the propagation problem. This can be explained in Figure 1. Figure 1(a) is a simple indoor environment with a wall, a ceiling, and a floor. The height of the transmitter and the receiver are h_1 and h_2 above the floor, respectively. The height of the ceiling is habove the floor. In Figure 1(b), the wall, the transmitter, and the receiver are projected perpendicularly on the floor. By 2-D ray tracing on the projection plane, there are only two paths from the projection of the transmitter to the projection of the receiver. If no reflection by the ceiling and the floor is considered, there are only two actual paths in a 3-D space when using a 3-D ray-tracing model. One is the direct path from the transmitter to the receiver; the other includes reflection by the wall.

When multireflection by the ceiling and the floor is considered, the situation is different. In Figure 1(b), suppose that the unfolded length of one 2-D path is d, which can be obtained during 2-D ray tracing, and that the azimuth angle of projection of the corresponding 2-D source ray is ϕ . Taking the above-mentioned properties of propagation into account, we find that the source rays in a 3-D space with an elevation of θ given by (1) and an azimuth of ϕ may reach the receiver. These 3-D source rays are called useful 3-D source rays. The paths from the transmitter to the receiver of all of these useful 3-D source rays have the same perpendicular projection on the floor.

$$\theta = \frac{\pi}{2} + \alpha \arctan \frac{2nh + \alpha h_0}{d} \tag{1}$$

where $h_0 = h_1 + h_2$. The positive and negative signs are used when the total number of reflections by the ceiling and the floor is odd and even, respectively.

 $\alpha = \pm 1$: The positive and negative signs are used when the first reflection (not including reflections by walls) occurs on the floor and the ceiling, respectively.

 $n=0,1,2,\ldots,m$ ($n \neq 0$ when $\alpha=-1$): n is an index related to the considered order of reflection by the ceiling and the floor, and m is an index related to the maximum order of reflection by the ceiling and the floor. When m=0, two 3-D paths are included. One has no reflection by the ceiling or the floor, and another has only one reflection by the floor. When m=1, there are four 3-D paths included. The first one has one reflection by the ceiling. The second one has one reflection by the ceiling, and then one reflection

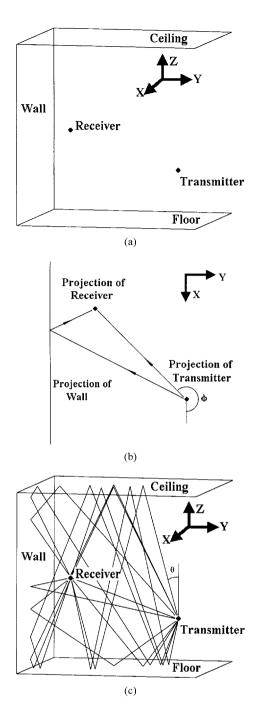


Figure 1 Principle of our model. (a) Simple room structure. (b) 2-D paths on projection plane. (c) Paths in 3-D space

by the floor. The third one has one reflection by the floor, and then one reflection by the ceiling, and the last one has one reflection by the floor, one reflection by the ceiling, and then one reflection by the floor again. All of these paths may include reflections by walls. There is a total of 2 + 4m paths included.

When there are many walls, the above principle also holds true.

During 2-D tracing on a projection plane, all 2-D paths from the projection of the transmitter to the projection of the receiver are recorded, and the unfolded length of each 2-D path is also calculated. After an integer m is given, 3-D ray tracing is performed for all useful 3-D source rays to each

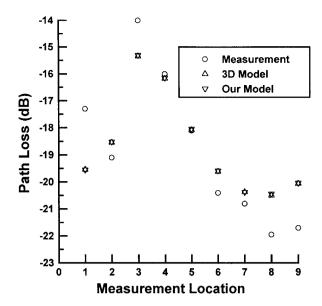


Figure 2 Path loss of prediction and measurement

2-D path. Because only part of all 3-D source rays is traced, much computation time can be saved. Based on Figure 1(b), Figure 1(c) shows paths in a 3-D space according to our model. If we choose m=1, there are six paths in a 3-D space corresponding to each 2-D path in Figure 1(b). Therefore, a total of 12 paths in a 3-D space is considered, as shown in Figure 1(c).

3. COMPARISON OF SIMULATION AND MEASUREMENT

To verify the model, the software using our model is developed to predict the path loss on single floors of modern buildings. The patched-wall model is also used. Measurements were done in a room. The room has a rectangular shape, with dimensions $5\times7.45\times2.7$ m³, and is divided into more than 20 patches. A CW signal at 1.7 GHz with a power range of 0–15 dBm is transmitted by a half-wavelength dipole antenna outside the room and at a height of 1.5 m above the floor. A half-wavelength dipole antenna with the same height receives the signal. The values of the path loss at nine locations within the room were measured.

Figure 2 shows the predicted and measured results for the path loss at each location of measurement. It indicates that predicted results of both our model and the usual 3-D model agree well with measurements. But the usual 3-D model takes about 100 times the computation time of our mode.

4. CONCLUSION

In this paper, we have proposed an improved propagation prediction model on single floors in indoor environments by using the results of 2-D ray tracing. The algorithm is easy to use, and has almost the same accuracy as the usual 3-D model, but takes less computing time than the usual 3-D model to obtain path loss.

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TRANSCONDUCTANCE EXTRACTION FOR PSEUDOMORPHIC MODULATION-DOPED FIELD-EFFECT TRANSISTOR (AIGAAS / InGAAS) FOR MICROWAVE AND MILLIMETER-WAVE APPLICATIONS

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ABSTRACT: An analytical model for two-dimensional electron gas (2-DEG) for a pseudomorphic $Al_zGa_{1-z}As$ / $In_yGa_{1-y}As$ modulation-doped field-effect transistor is developed. The 2-DEG density is calculated as a function of device dimensions and doping density. A simple analytical expression is established for the charge control. A high transconductance of 270 mS/mm is obtained, which is important in realizing the device for millimeter microwave applications. The results so obtained are compared with experimental data, and show excellent agreement. © 1999 John Wiley & Sons, Inc. Microwave Opt Technol Lett 22: 41–48, 1999.

Key words: pseudomorphic MODFET; sheet carrier concentration; transconductance

INTRODUCTION

Modulation-doped heterojunction semiconductor structures (MODFETs) have attracted a great deal of attention in terms of high-frequency applications. This is accomplished by the presence of a 2-DEG at the interface of two different bandgap materials. The separation of the electrons from the donors results in enhanced device performance over other field-effect transistors.

(AlGa)As/GaAs MODFETs have been demonstrated [1–3], but to eliminate deep level-related anomalies, In-GaAs/GaAs pseudomorphic MODFETs have recently been used [4–6]. The AlGaAs/InGaAs pseudomorphic MODFET has a greater conduction band discontinuity, allowing for greater carrier confinement and electron transfer (resulting in high carrier concentrations) without suffering from the effects associated with the high mole fraction of AlGaAs. The