# INTERFERENCE LEVEL ESTIMATION OF MULTI-REFLECTED WAVES IN BUILT-UP AREAS

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## 1. INTRODUCTION

Radio local distribution systems have been investigated to offer high-speed digital transmission services[1], [2]. For these systems, the frequencies above 10 GHz are used and in these cases the nodal station and the subscriber station should be connected by one line-of-sight.

In densely built-up areas, many buildings block out the line-of-sight propagation paths and cause reflected interference waves. Therefore, two important problems should be solved for radio zone design. One is propagation path visibility between the nodal station and surrounding subscribers. The other is reflected interference waves due to building walls. Path visibility and the number of reflected waves are obtained by the application of the visibility estimation method and a building distribution model[3]. Although the received power level of reflected waves is necessary to evaluate the interference, it has not been clearly determined.

This paper discusses the interference level of multi-reflected waves in built-up areas. The interference level distribution is derived from the building wall reflection coefficient and the free-space path loss

## 2. FORMULATION

The reflected wave propagation paths in a sectoral radio zone are considered as shown in Fig. 1. The solid line is the direct path from the nodal station to the subscriber station. The broken lines are reflection paths. The received power level z of multi-reflected waves relative to that of the direct wave can be calculated by

$$z=x\cdot y \quad , \tag{1}$$

where x is the reflection coefficient and y is the free-space path loss difference between the reflected and the direct path. The probability density function (pdf), $p_{1i}$, of z is given as

$$p_{1i}(z)=\int_0^\infty p_{ri}(t)\cdot p_{si}(z/t)/t\ dt \quad , \tag{2}$$

where $p_{ri}$ and $p_{si}$ are the pdf's of the reflection coefficient and the free-space path loss, respectively. Subscript i denotes the number of times of reflection.

## 3. REFLECTION COEFFICIENT OF BUILDING WALLS

### 3.1 MEASUREMENT OF REFLECTION COEFFICIENT

Measurements of reflection coefficient were carried out at the 26 GHz (25.25- 27.0 GHz) band which is used in the Japanese radio local distribution system. One-time and two-time specular reflections were measured for four typical office buildings.

Frequency dependence of reflection coefficients was measured using a frequency sweep oscillator. An example of the measured reflection coefficient is shown in Fig. 2; it shows that the reflection coefficient has a remarkable frequency dependence. Long and short pitches in frequencies are observed. These pitches are caused by short and long path differences in the building walls.

The phase of reflected waves varies because of surface unevenness due to frames and other structures. In addition, the reflected waves have various amplitudes, because building walls are made of various kinds of materials, such as concrete, metal panels, glass and ceramic tiles. Therefore, the measured reflected wave is composed of multiple reflection waves with different phases and amplitudes.

### 3.2 DISTRIBUTION OF REFLECTION COEFFICIENT

The statistical method is appropriate for evaluating the reflection coefficient characteristics shown in Fig. 2. Cumulative probability distribution, which is made by sampling the frequency response of reflection coefficient by 1 MHz, obtained from the reflection coefficient measurement is plotted in Fig. 3. It is found that one-time reflection can be approximated by Rayleigh distribution, as shown by the solid straight line. The pdf, $p_{r1}$, of the reflection coefficient x can be expressed as

$$p_{r1}(x)=(2x/\sigma^2)\cdot\exp(-x^2/\sigma^2) \ , \qquad (3)$$

where $\sigma=0.56$, which was determined from the average value of the reflection coefficient -7.5 dB. The pdf, $p_{r2}$, of the two-time reflection can be derived by the product of two independent one-time reflection coefficient distributions:

$$p_{r2}(x)=(4x/\sigma^4)\cdot K_0(2x/\sigma^2) \ . \qquad (4)$$

$K_o$ denotes the zero-order modified Bessel function of the second kind.

The calculated result of Eq. 4 is shown in Fig. 3. The calculation is compared with the measured results in the figure. Those of two-time reflection are slightly lower than calculated ones, because the most building walls are concrete, in cases of two-time reflection measurement. The reflection coefficient of more than two times can be numerically calculated in the same manner as the two-time reflection. The result of three-time reflection is also plotted in Fig. 3.

## 4. MULTI-REFLECTED WAVES IN BUILT-UP AREAS

### 4.1 CALCULATION OF REFLECTED WAVE PATH DIFFERENCE

Propagation path length distribution of reflected waves is calculated from the parameters which characterize the reflected wave path condition between the nodal station and the subscriber station [3] . They are the building density, building mean height and the height of nodal and subscriber stations. Figure 4 shows an example of the calculated distribution of path difference between the reflected and direct paths in a 90° sectoral radio zone. The building distribution parameters of the inner area of Tokyo were used as those of typical built-up areas. One-time and two-time reflection components are plotted. The distribution of path difference, $p_{di}$, can be approximated by the exponential function:

$$p_{di}(d)=\exp(-d/\beta_i)/\beta_i \ , \qquad (5)$$

where d is the path difference, and $\beta_i$ means the mean path difference with $\beta_1=1.12$ km and $\beta_2=1.70$ km. Three-time reflection characteristics are plotted assuming that the mean path difference increases in proportion to half-power of the reflection times. In another areas, the path difference distribution can be approximated by Eq. 5.

## 4.2 DISTRIBUTION OF FREE SPACE PATH LOSS

The distribution of free-space path loss of reflected waves is calculated from the distribution of the path difference. The path loss is calculated by the total reflection path length:

$$y=(r/(r+d))^2 , \tag{6}$$

where y is the difference between the free-space path loss of the reflected wave and that of the direct wave, and r is the distance between the nodal and subscriber stations. The reflection wall is assumed to be an infinite flat plane. The pdf of y is given by changing the random variable from d to y as

$$p_{si}(y)=(r/2\beta_i y\sqrt{y})\cdot \exp(r(1-\sqrt{y})/\beta_i) \ . \tag{7}$$

## 5. DISTRIBUTION OF INTERFERENCE LEVEL

The percentage of subscribers receiving reflected interference is calculated for the desired-to-undesired ratio D/U. Results are shown in Fig. 5 for three cases that take into account one-time reflection, both one- and two-time reflections and reflections up to three times. The probability of arrived reflected waves of one-, two- and three-time reflection are 28 %, 28 % and 14 % respectively. The upper and lower curves correspond to omnidirectional and pencil-beam subscriber antennas respectively. The lower curves are obtained from the radiation pattern of a pencil-beam antenna with a diameter of 0.3 meters, used in the 26-GHz band.

It is found that the interference will be underestimated if we take into consideration only one-time reflection. However, since the increase of percentage with the number of times of reflection tends to be saturated, more than three-time reflection is insignificant for interference.

Supposing that the required D/U is 20dB, 98.5 % of the subscribers can avoid the reflected wave interference.

## 6. CONCLUSION

The interference level of multi-reflected waves has been discussed, considering the distribution of the reflection coefficient and that of free-space path loss. The percentage of subscribers receiving interference has been determined for the value of D/U. This analysis is generally applicable to the design for point-to-multipoint communication systems such as radio local distribution systems, and mobile radio communications.

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## References

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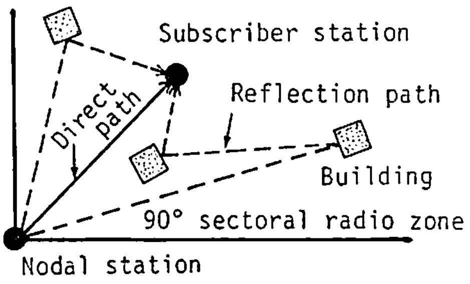
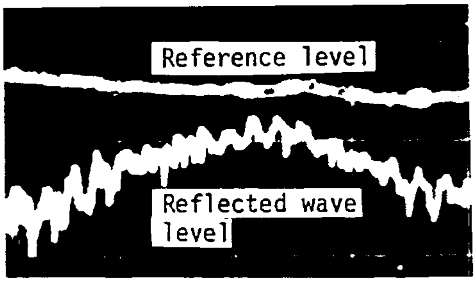


Fig. 1 Propagation path model.



Center frequency: 25.5 GHz
V: 10 dB/div. H: 50 MHz/div.

Fig. 2 An example of measured reflection coefficient.

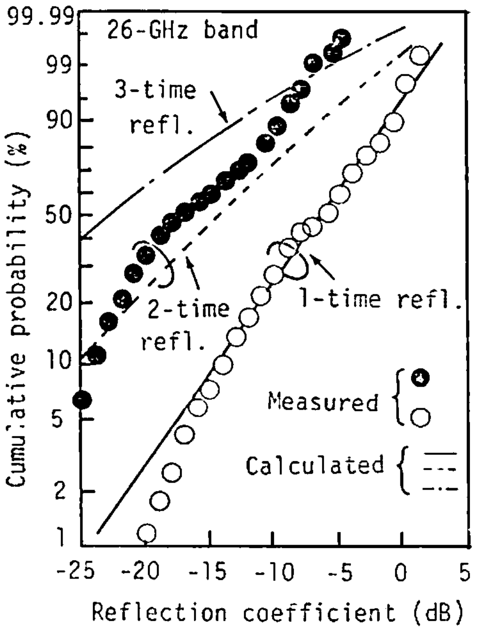
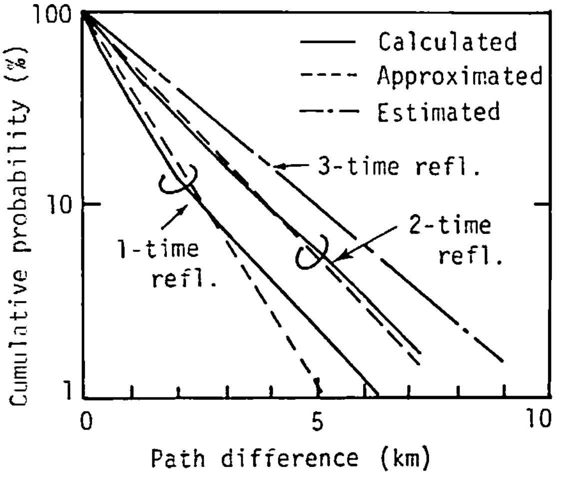


Fig. 3 Distribution of reflection coefficient of building walls.



Nodal station height: 100 m
Subscriber station height: 24 m
Building density: 282.7/km$^2$
Building mean height: 23.3 m

Fig. 4 Distribution of path difference.

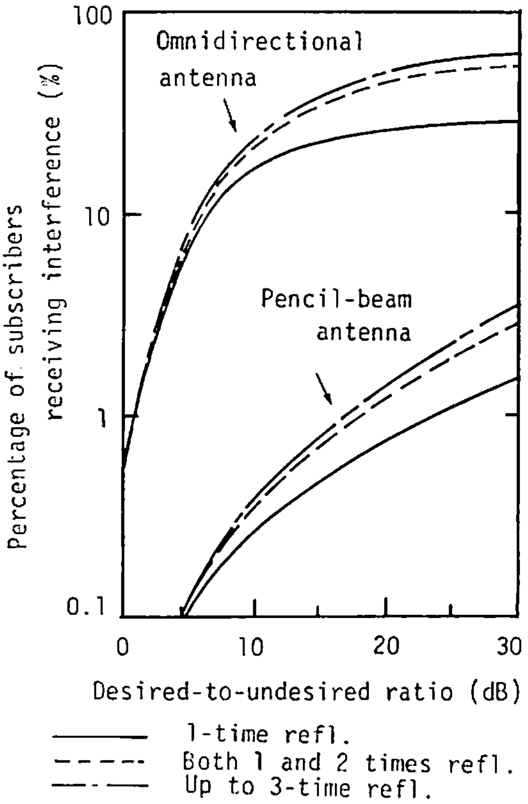


Fig. 5 Percentage of subscribers receiving the reflected interference.