行政院國家科學委員會專題研究計畫成果報告
無線通訊通道特性之模擬、量測與分析—子計畫一：
無線通道特性之量測與數據分析(Ⅲ)
Measurements and Data Analysis for Radio Channel Characteristics

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一、 中文摘要 （關鍵詞：無線通訊、通道量測、通道特性）

本子計劃的主要目的在建立無線通訊通道特性的量測系統，並對量測數據做通道特性的統計分析。本年度的主要工作項目為探討在多路徑環境下電波穿透樹林的寬頻量測方法與結果分析。使用一般的功率量測方法，直接波無法單獨被取出，因此量測結果不能代表電波的穿透損失。使用寬頻量測;直接穿透波可以單獨被取出。欲決定樹林的衰減常數及有效介電常數，可以找尋均勻的樹林，並使用寬頻量測來獲得此等參數。我們可以在數個距離位置量測直接穿透波的穿透損失及所行走的電長度，再由迴歸線的斜率來求出衰減常數及等效介電常數。量測結果顯示，衰減常數約在 1dB/m 至 2dB/m 之間，而樹林的等效介電常數則很接近 1。

二、英文摘要 （Keywords: Wireless Communications, Channel Measurements, Channel Characteristics）

The purpose of this project is to establish measurement system for measuring radio channel characteristics, and to statistically analyze channel properties from simulated and experimental data. The main task of this year is to develop wideband measurement method for waves penetrating through trees in multipath environment.

With the power measurement method the direct penetrating path cannot be singly isolated and the results obtained cannot reflect the true penetration loss. With wideband measurements, the direct penetrating wave can be singled out. To determine the attenuation constant and the effective dielectric constant, we can carry out the measurement in environments with uniform tree clusters and employ wideband measurement method to derive the desired parameters. We can first measure the penetration loss and the electrical length of the direct penetration path at different penetration lengths, and then derive the attenuation constant and the effective dielectric constant from the slopes of the regression lines. In our measurements, the attenuation constants range from 1dB/m to 2dB/m. We have found that the effective dielectric constant is very close to 1 no matter how dense the leaves are. This can be explained by the fact that leaves or branches only occupy a small portion of the tree volume and most volume is occupied by air.

I Introduction

An ordinary way to measure the attenuation constant of wave penetrating through trees is to measure the amount of attenuation at single frequency for different penetration depths. This method can work well if there is no other significant reflection or scattering from other object. In the presence of multipath, the field measured is the superposition of all path components. When the magnitude of the wave directly penetration thought trees is comparable to or smaller than those of other path components, the results obtained will be incorrect.

The electrical length of the wave penetration through trees will be different from the real penetration length by a factor of the effective dielectric constant $\in_{eff}$ of trees. One may think that the effective dielectric constant will be much different from that of air because of leaves and branches that contain ingredient of water. However, this is not true as we will show later in the report.

It is known that wideband measurements can separate multipath[1,2,3]. Therefore the attenuation properties of the direct penetration wave can be obtained by isolating the desired path from others even though the measurements are taken in a multipath environments. In this report we will compare penetration attenuations obtained by narrowband measurements and wideband measurements. We will propose measurement methods to determine the attenuation constant and effective dielectric constants of the whole cluster of trees.

Ⅱ. Description of the Problem

Consider a wave penetrating through trees with a traveling distance of ℓ. The field received can be expressed by

$$E = E_o e^{-\gamma\ell} \qquad (1)$$

where E_o is the field before entering the trees, $\gamma = \alpha + j\beta$, α is the attenuation constant and β is the propagation constant. The attenuation constant depends on several factors such as the types of tree, the shapes of leaves, the density of leaves and the percentage of water in leaves and branches etc. The propagation constant will be proportional to the effective dielectric constant of the whole tree cluster. If α and β can be accurately obtained, then the behavior of wave penetrating through trees can be predicted.

To measure the wave attenuation, a popular method is to compare magnitudes of the field received before and after penetration through trees. If the measurement is done in an open environment or if there is no other significant multipath, the above method will work well. Otherwise, the power measured may contain contributions from other paths and the measurement results will be incorrect. Therefore, in the presence of multipath, we should isolate the direct penetration path from other contributors and only count the contribution of the desired one.

It is well known that multipath components can be differentiated by wideband measurements [1,2,3]. Therefore, the direct penetrating wave can be isolated and the measurement can be done even in the presence of multipath. Once the direct penetrating wave has been extracted, the determination of α and $\in_{eff}$ becomes very simple. We need only to measure the amount of attenuation and the electrical length at different penetration distances and then plot them versus distance. The slopes will give α and $\in_{eff}$.

Ⅲ. Channel Environments and Measurement Methods

(A) Coherent Measurements by a Network Analyzer System

To analyze the attenuation property of wave penetrating through trees, we choose a street island in the campus of National Taiwan University as the measurement environment. Several different types of trees, such as cypress trees, banyan trees, and azalea trees are planted in this street island. The simplified layout is shown in Fig.1. the transmitting antenna is placed at the position marked by Tx, and the receiving antenna is placed around the island as shown in Fig.1. Both the transmitting antenna and the receiving antenna are vertical $\lambda/2$ dipoles and both have a height of 2m. The transmitting antenna is connected to port 1 of the network analyzer and the receiving antenna is connected to port 2 through a low noise amplifier. First, these two antennas are separated by 1m and their complex frequency responses are measured and recorded. The frequency range is swepted from 2.2GHz to 2.6GHz and 401 frequency points are sampled. At each receiving location, frequency responses are measured and are divided by the frequency response measured at the reference distance to obtain frequency responses of the relative propagation loss. We then take the Fourier transform of the frequency response of the relative propagation loss to obtain the delay profile, where the abscissa represents the excessive delay time and the ordinate represents the propagation loss relative to that at the reference distance (1m).

To examine the attenuation of wave penetrating through trees, we measure the delay profile at each position. From each delay profile we calculate the difference of the dashed line and the first peak. The difference represents the attenuation of wave penetrating through trees. We then plot the penetrating loss versus the separation between the transmitting antenna and receiving antenna. The result is shown in Fig.2. It is seen that the attenuation loss is almost exponentially increased with separation. However, due to the nonuniform distribution of tree clutters, at some positions the attentions are smaller although the separation is greater. After a separation of 28m, we cannot differentiate the first peak from the background level due to serious penetration attenuation and the first peak approaches a constant value. For comparison, Fig.2. also shows the mean attenuation obtained by the power measurement method. It is seen that after a separation of 19m, the mean attenuation approaches to a constant value. This is because after that separation, the main contributions to the total field are mainly from multipaths rather than from the direct penetrating path. The attenuation versus distance at the center frequency f = 2.4GHz is also shown in Fig.2. One can easily see the abrupt changes for adjacent positions and this is and evidence of power fading.

From the above examples we can make the following conclusions. To study the attenuation property of wave penetrating through trees in a multipath environment, we should use the wideband measurement technique to differentiate the direct penetrating wave. The power measurement method, either measured at a aingle frequency of over a frequency band, in general will not give the correct results.

(B) Measurement of Attenuation constant and Effective Dielectric Constant

In the environment of Fig.1, trees are not uniformly distributed. The relation between the attenuation (in dB) and the distance is therefore not linear. In order to obtain the attenuation constant and the effective dielectric constant of trees, we should choose an environment where the distribution of trees is as uniform as possible.

On the NTU campus we found a place having a uniform cluster of banyan trees. To reduce the multipath effect, we use two directive antennas, both are vertically polarized log-periodic antennas. Both antennas are at a height of 2m and are connected to the network analyzer. We select three straight lines as shown in Fig.3. Along each line, for every 1m in separation, we measure frequency responses at three points, one on the line, one on the right and one on the left. Following the same procedure as described we obtain the delay profile of each position and form which we can obtain the penetration loss of the direct penetrating wave. For each separation we take the average loss of the three points and plot the average loss versus the distance. The results of the three routes are shown in Fig.4. The regression line of each route and its slope are also shown in the figures. Because the densities of leaves and branches of these three routes are different and the receiving antenna may be blocked by branches or trunks, the slopes of these three regression lines have different values. It is noted that the slope represents the attenuation constant of trees along that route.

To determine the effective dielectric constant, we can measure the delay time or electrical length of the direct penetrating wave. In the delay profile the abscissa represents the delay time. Therefore, the position of the first peak represents the delay time of the direct penetrating wave. The electrical length is equal to the light speed times the delay time. The division of the electrical length by the real penetration length gives the square root of the effective dielectric constant. For each position we measure the penetration distance and the electrical length of the first peak in the delay profile. We then plot the electrical length versus the real distance and the results for the three routes are shown in Fig.5. The slopes of the regression lines are also shown in the figure. It is surprisingly found that all slopes are very chose to 1.

In the measurement of real distance, there could be and error of ± 15cm. The range resolution with a bandwidth of 2GHz is about 15cm. Therefore the accuracy of the electrical length and the real distance can be within ± 15cm. When the distance is as long as 10m, the distance error is only in ± 1%. Therefore the errors of slopes obtained in Fig.9 are within 3%, and the effective dielectric constant is still very close to 1.

Ⅲ. Conclusion

In this report we propose measurement methods for waves penetrating through trees in mulitpath environments. With wideband measurements, the direct penetrating wave can be single out. To determine the attenuation constant and the effective dielectric constant, we can choose environments with uniform tree clusters and employ wideband measurement method to derive the desired parameters. We can measure the penetration loss and the electrical length of the direct penetrating path at different penetration lengths, and then derive the attenuation constant and the effective dielectric constant from the slopes of the regression lines. The attenuation constant depends on the types of trees, densities of leaves and branches, and percentages of water ingredients, etc. In our measurements, the attenuation constant is very close to 1 no matter how dense the leaves are. This can be explained by the fact that eaves or branches only occupy a small portion of the tree volume and most volume is occupied by air.

References

[1] T. S. Rappaport, Wireless Communications, Principles and Practice, Prentice Hall PTR, 1996.

[2] H. J. Li, R. Y. Lin, C. C. Chen, T. Y. Liu and Z. Y. Lane, 'Determination of Propagation mechanisms using wideband measurement techniques, ' Progress In Electromagnetics Research, PIER 20, P.P. 281-297, 1998.

[3] H. J. Li, R. Y. Lane, and J. W. Hsieh, 'Discussion on the spatial and spectral power fading for wireless communication channels,' Proceedings of the National Science Council, Part A: Physical Science and Engineering, Vol.22, No.2, PP.272-278, 1998.

[4] E. P. Donaldson, M. Fattouche, and R. W. Donaldson, 'Characterization of in-building UHF wireless radio communication channels using spectral energy measurements,' IEEE Trans. On Antennas and Propagation, Vol. 44, No. 1, PP. 80 -86, 1996.

Figure caption.

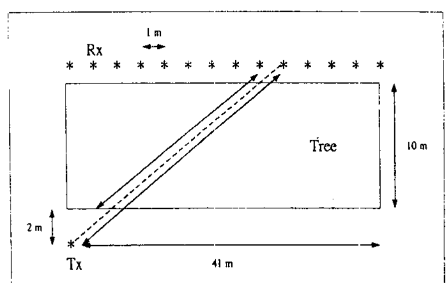

Fig.1.Simplified layout of the street island.

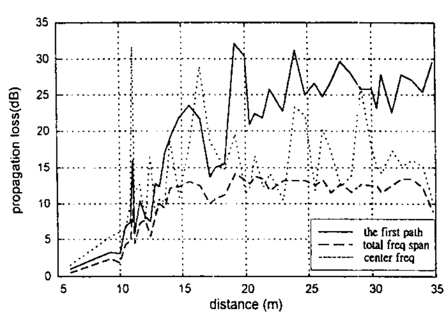

Fig.2. Plots of the mean propagation loss and standard deviation of (a) Route 1, (b) Route 2, and (c) Route 3.

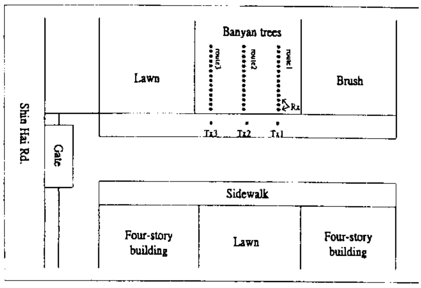

Fig.3.Layout of the measure environment.

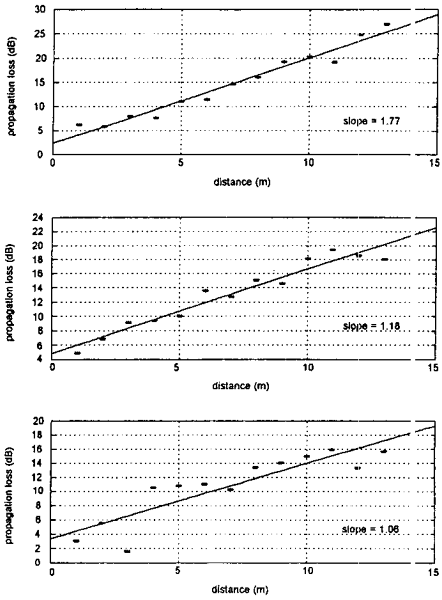

Fig.4. Plots of average penetration loss versus distance for (a) route 1 (b) route 2 and (c) route 3.

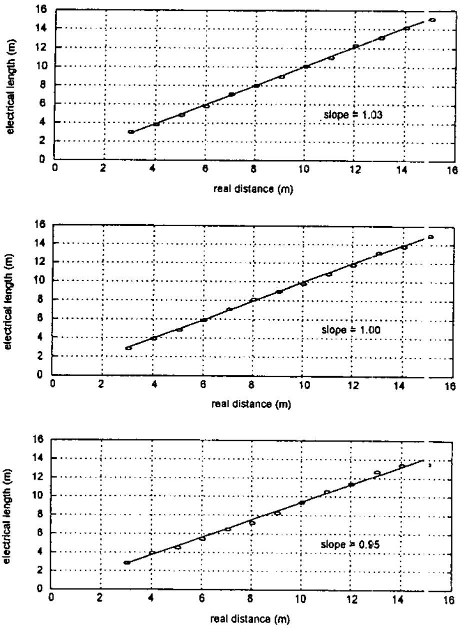

Fig.5. Plots of electrical length versus real distance for (a) route 1, (b) route 2 and (c) route 3.