

Development and Application of FM Multipath Distortion Rate Measurement System Using a Fading Emulator Based on Two-Stage Method

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ABSTRACT

The suitability of FM radio receivers for automobiles has conventionally been rated by evaluating reception characteristics for broadcast waves in repeated driving tests in specific test environments. The evaluation of sound quality has relied on the auditory judgment due to difficulties to conduct quantitative evaluations by experiments. Thus the method had issues in terms of the reproducibility and objectivity of the evaluations.

To address these issues, a two-stage method generating a virtual radio wave environment on a PC was developed. The research further defined the multipath distortion rate, M_{Dr} , as an index for the sound quality evaluation of FM receivers, and the findings concerning the suitability of the evaluation of FM terminals for automobiles were reported at the 2015 SAE World Congress.

However, extended periods of measurement were necessary because the upper limit for delay time, τ_{Max} , cannot be determine in advance for the measurement of M_{Dr} using the Two-Stage Method.

This research clarified the characteristics of the multipath distortion rate, M_{Dr} , in relation to the modulation frequency (f_m) and the delay time (τ) of the FM broadcast wave, and preliminarily determined τ_{Max} , the upper limit for delay time necessary for the Two-Stage Method.

The research also indicated the possibility of applying the Two-Stage Method to Intelligent Transport Systems (ITS) to evaluate reception in the case of vehicle-to-vehicle communication on PC. By comparison with conventional proving trials, the Two-Stage Method makes it possible to generate radio wave environment characteristics as desired, and represents a useful evaluation tool displaying good reproducibility.

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INTRODUCTION

The suitability of FM radio receivers (termed "FM terminals" below) for automotive applications has conventionally been evaluated by testing the reception characteristics of broadcast waves while conducting repeated driving tests in special test environments. However, because it is challenging to perform quantitative evaluations in tests using actual broadcast waves, the evaluation of reception characteristics during vehicle operation has relied on the evaluation of sound quality based on the auditory judgment of a limited range of test subjects. As a result, these tests present issues in terms of the reproducibility and objectivity of the evaluations.

In order to address these issues, the research discussed in this paper developed a two-stage fading emulator that generates a virtual radio wave environment on a PC (termed the "Two-Stage Method" below). The research further defined the multipath distortion rate, M_{Dr} , as an indicator for evaluation of the sound quality of FM terminals, producing reports concerning the evaluation of the automotive applicability of FM terminals [1, 2, 3].

The major technological issue for the Two-Stage Method was the reproduction of a radio wave environment corresponding to an actual reception environment on a PC. Because of this, it was important to

understand the characteristics of the radio wave environment using FM broadcast waves; a Multiple Signal Classification (MUSIC) method using virtual array antennas was therefore developed [2], making it possible for the first time to estimate the number, L , arrival direction, θ , and delay time, τ , of incoming waves and other characteristics of the radio wave environment using FM broadcast waves in an actual reception environment. Reports were published concerning this development [4, 5].

However, because the upper limit for delay time, τ_{Max} , for the measurement of M_{Dr} using the Two-Stage Method cannot be determined in advance, extended periods of time were necessary for measurement of the parameter. In order to use the method practically, it was therefore necessary to determine an indicator for τ_{Max} in advance.

In addition, it was clear that the prediction of the maximum delay time was similarly important in the estimation of radio wave environment characteristics using the MUSIC method in actual reception environments.

The authors therefore determined the upper limit for delay time, τ_{Max} , which is essential for the Two-Stage Method, in advance by elucidating the characteristics of the multipath distortion rate, M_{Dr} , in relation to the modulation frequency of FM broadcast waves, f_m , and τ . A basic overview of this procedure was published in reference [6].

Specifically, it was possible to generate a simulation model of the radio wave environment characteristics in the Two-Stage Method, and measure the characteristics of M_{Dr} in relation to f_m and τ .

The results of these measurements demonstrated that it was possible to quantitatively evaluate M_{Dr} using the Two-Stage Method in a wide range of locations, including urban areas, suburban areas, and mountainous areas, and in radio wave environments that were challenging to estimate.

The characteristics of actual radio wave environments were also estimated using the MUSIC method. The results of these estimates were reproduced in the Two-Stage Method, and measurements of M_{Dr} in relation to the automotive applicability of FM terminals were conducted. The location for these estimations was Bakersfield, CA in the U.S.

The research discussed in this paper considered the determination of the upper limit for delay time, τ_{Max} , essential for the abovementioned Two-Stage Method, in greater detail. Estimations of radio wave environment characteristics were also conducted using the MUSIC method in an urban environment in Tokyo [7]. The results of these estimations demonstrated that radio wave environment characteristics including the number and direction of incoming waves and the magnitude of the MUSIC spectrum varied significantly due to the effect of surrounding buildings when the measurement position was moved.

This indicates the benefit of conducting evaluations of reception using the Two-Stage Method, given that it is possible to estimate radio wave environment characteristics and reproduce them in the Two-Stage Method even in areas in which the reproduction of radio wave environment characteristics is challenging.

In environments in which it is difficult to conduct tests for the estimation of radio wave characteristics, it is possible to estimate characteristics by means of numerical calculations using the ray-tracing method and 3D maps [7].

Given this, it is possible to conduct an evaluation of reception using the Two-Stage Method by reproducing the estimation results obtained using the MUSIC method or the ray-tracing method in the Two-Stage Method.

The application of the Two-Stage Method considered in this research to future Intelligent Transport Systems (ITS) will make it possible to evaluate reception in the case of vehicle-to-vehicle communication on PC.

By comparison with conventional proving trials, the Two-Stage Method makes it possible to generate radio wave environment characteristics as desired, and represents a useful evaluation tool displaying good reproducibility.

TWO-STAGE METHOD FADING EMULATOR

An over-the-air (OTA) method in which probe antennas are positioned in a circle around the terminal to be measured in order to form a fading environment is effective in the evaluation of mobile terminals in virtual radio wave environments [8]. Figure 1 shows the configuration of this fading emulator-type evaluation method.

This configuration makes it possible to freely control characteristics of the radio wave environment including the number, arrival direction, delay time and desired signal to undesired signal ratio (DUR) of incoming waves, in addition to the Doppler frequency in relation to speed of motion.

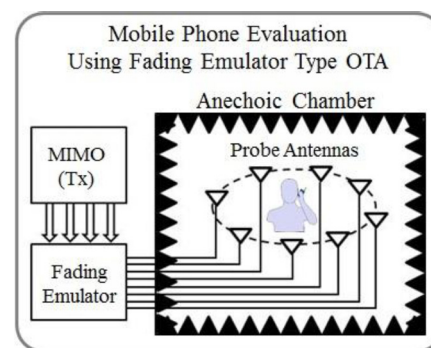


Figure 1. Fading emulator-type evaluation method

However, it has been challenging to realize the use of this OTA method in vehicles as a method of evaluating the suitability of FM terminals for automotive applications due to the following issues:

The wavelength of an FM broadcast wave is approximately 4 m, and the size of the vehicle fitted with the FM antenna and the FM terminal is approximately 5 m. It is generally indicated that when the terminal is smaller than the wavelength of the radio waves, it is necessary for the distance between the terminal to be measured and the probe

antennas to be 10 wavelengths (termed “far-field”). Because the vehicle is longer than the wavelength of the FM broadcast waves, a distance of more than 10 wavelengths is required, necessitating an enormous OTA environment.

Because a fading emulator is necessary for each probe antenna, the evaluation system becomes complex and high-cost.

In order to address these issues, the research under discussion used the configuration of the developed Two-Stage Method [9], and allocated the function of the control section for the fading emulator signal to antenna branch control [10], making it possible to realize a method of evaluation of FM terminals [1, 2] on a PC.

Figure 2 shows a flow chart of the Two-Stage Method.

In the 1st stage, the characteristics of the onboard antenna, which change with the type of antenna, the shape of the vehicle and the mounting position of the antenna, are measured in a large anechoic chamber and the directivity characteristic of the antenna is sent to the fading emulator employed in the 2nd stage. In the 2nd stage, the fading emulator generates a virtual radio wave environment on a PC based on the results of estimation using the MUSIC method. The directivity of the onboard antenna measured in Stage 1 and the virtual radio wave environment generated in Stage 2 are combined with a signal sent by the base station emulator, and the resulting synthesized reception signal is sent to the FM terminal. It is therefore possible to evaluate reception characteristics during vehicle operation including multipath distortion in any arbitrary radio wave environment.

1. Tx connection matrix: A function that realizes the spatial decorrelation characteristics for the transmission signal sent from FM broadcast stations (For example, it acts as a converter for the number of probe antennas in relation to the number of transmitting antennas when transmission diversity is executed by a FM broadcasting station).
2. Delay generator: A function that imparts a delay time and an amplitude level to each probe antenna when each incoming wave has different delay time and amplitude level.
3. Doppler shifter: A function that imparts vehicle speed (Doppler frequency) information to each probe antenna.
4. Rx connection matrix: A function that imparts the directivity pattern characteristics measured in the 1st stage as well as the cross-polarization characteristics in the actual environment to each probe antenna.

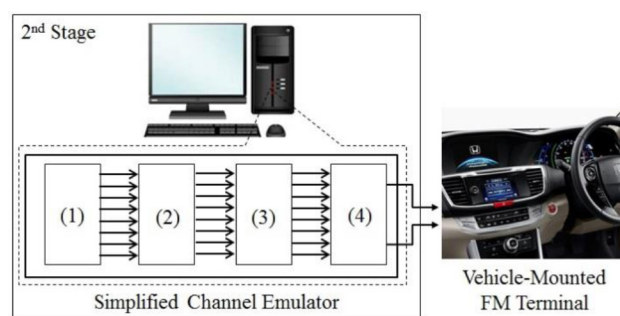
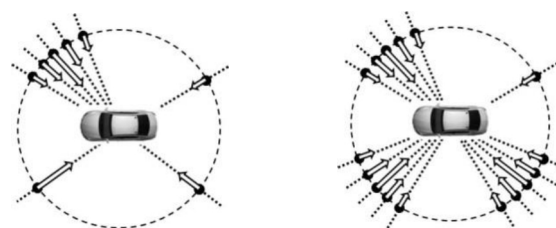


Figure 3. Evaluation of vehicle-mounted FM terminal using Two-Stage method

In the research discussed in this paper, a software configuration was employed for the fading emulator. Changing the number and characteristics of the probe antennas made it possible to create a virtual radio wave environment conforming to an actual radio wave environment. Figure 4 shows incoming wave models for a number of probe antennas, L , of 8 and 16. Because a greater number of probe antennas make it possible to create a more complex clustering model and a radio wave environment corresponding to the region of strong electrical field generated close to the broadcasting station, the use of more antennas offers the advantage of creating an incoming wave model that is closer to an actual radio wave environment.



a. Probe antenna number $L=8$

b. Probe antenna number $L=16$

Figure 2. Flow chart of Two-Stage method

The fading emulator developed in the research will be considered next. Figure 3 shows a schematic diagram of the configuration of the fading emulator. The fading emulator comprises four functions, labeled (1)-(4). These functions are discussed below.

MULTIPATH DISTORTION OF FM RECEPTION

When reflected waves are produced as a result of the nonlinear modulation of analogue FM broadcasts and exist together with the direct waves, the modulation signal passes through a multipath environment that differs from the propagation path of a direct wave alone. This results in distortion of the receiver output, producing an uncomfortable noise. This is multipath distortion, and it is a major cause of deterioration in the sound quality of radio receivers.

The multipath distortion component at this time is determined by multipath environment conditions including the DUR, the delay time of the reflected wave relative to the direct wave, and the phase difference between the direct wave and the reflected wave, in addition to factors including the modulation frequency and degree of modulation of the FM broadcast wave [1, 2, 3, 11].

Therefore, noticeable distortion will occur if FM broadcast waves of very similar magnitude are received along two or more paths.

This distortion due to irregularity of phase can be approximated by Eq. (1) [1, 2, 3, 11, 12].

$$M_D = \sqrt{2} \alpha \sin(f_m \tau / 2) \text{ dB} \quad (1)$$

M_D : Multipath distortion

$\alpha = 1/\text{DUR}$

f_m : Modulation frequency

τ : Delay time of reflected wave relative to direct wave

The following conclusions can be drawn from Equation (1).

1. When reflected waves arrive relative to direct waves, changing the directivity of the receiver antenna changes α in Equation (1), making it possible to reduce the degree of multipath distortion.
2. The degree of multipath distortion varies depending on the modulation frequency and delay time.

Definition of Multipath Distortion Ratio

Conventionally, the signal to noise and distortion ratio (SINAD) is employed to evaluate the reception of FM broadcast waves.

With regard to the degree of multipath distortion, Reference [11] conducts numerical analyses of the relationship between delay time and the maximum distortion rate and between the modulation frequency and the maximum distortion rate for both monaural and stereo broadcasts using FFT.

The research discussed in this paper defined the multipath distortion rate, M_{Dr} , based on the following equation, as an indicator for the evaluation of sound quality in multipath environments during vehicle operation [1, 2, 3].

$$M_{Dr} = k/2500 \times 100\% \quad (2)$$

This equation shows the ratio of the number of multipath distortion components, k , exceeding the threshold value that provides a criterion for judgment of sound quality in a sample of 2,500 audio signals extracted at $T_{\min} = 5$ s. The multipath distortion rate, M_{Dr} , for $k=2,500$ would therefore be 100%.

EVALUATION OF FM TERMINAL USING TWO-STAGE METHOD

Two-wave virtual radio wave environment characteristics produced by a direct wave and a reflected wave were generated using the Two-Stage Method, and the magnitude of M_{Dr} in relation to the modulation frequency, f_m , and delay time, τ , of the FM broadcast waves were analyzed. The results of this analysis made it possible to determine the maximum delay time necessary for the Two-Stage Method, $\tau_{\max}$, in advance.

Next, the characteristics of a radio wave environment at the point of reception were estimated using actual FM broadcast waves via the MUSIC method using a virtual array antenna. The results of this estimation were reproduced in the Two-Stage Method, and the method was employed to measure M_{Dr} when the directivity of the antenna and the FM terminal type (non-diversity/diversity) were varied in an actual reception radio wave environment. These results demonstrated the effectiveness and novelty of the Two-Stage Method.

Analysis of Multipath Distortion Ratio using Virtual Radio Wave Environment

This section discusses the analysis of the magnitude of the multipath distortion rate, M_{Dr} , in relation to the modulation frequency, f_m , and the delay time, τ , shown in Equation (1), using the Two-Stage Method. A method of determining $\tau_{\max}$, the upper limit for delay time necessary when using the Two-Stage Method based on the magnitude of M_{Dr} was proposed [6]. This method was expected to have the following effects:

1. Significant reduction of time for analysis of M_{Dr} using Two-Stage Method.
2. In $\tau_{\max}$, provision of indicator for maximum delay time in estimation of arrival waves using MUSIC method.

This indicator would increase the flexibility of allocation of the number of virtual frequency arrays, M_p , and, in combination with the correlative suppression method, would increase the accuracy of estimation of delay time using the MUSIC method.

Determination of Upper Limit for Delay Time, $\tau_{\max}$, using Two Incoming Wave Model

Figure 5 shows the proposed method of determining $\tau_{\max}$, the upper limit for the delay time necessary for analyzing M_{Dr} using the Two-Stage Method.

Two incoming waves, a direct wave and a reflected wave, were employed as the virtual radio wave environment.