

Development of Tool for Evaluation of Automotive Conformity of FM Receivers Using Two-Stage Method

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ABSTRACT

The suitability of FM radio receivers for automotive applications has conventionally been evaluated by evaluating the reception characteristics of broadcast waves while conducting repeated driving tests in a special test environment. Because the evaluation of sound quality while driving relies upon the auditory judgment of a limited range of test subjects, these tests present issues in terms of the reproducibility and objectivity of the evaluations.

In order to resolve these issues, a method of evaluating the suitability of FM receivers for automotive applications through the creation of a virtual radio wave environment on a PC was developed (this has been termed the "Two-Stage method").

In the research described in this paper, the Two-Stage method was used to analyze the effect of multipath distortion on FM receivers when driving through arbitrary radio wave propagation environments. In order to quantify the effect of multipath distortion, the multipath distortion rate was defined as an index of sound quality evaluation while the vehicle is in motion.

Employing the multiple signal classification (MUSIC) method made it possible to estimate the characteristics of the arbitrary radio wave propagation environment such as number, arrival direction, and delay time of incoming waves for the first time.

By generating the results of these estimations in the Two-Stage method, it was possible for the first time to compare the suitability for vehicle fitting of FM diversity receivers and non-diversity receivers, and to compare suitability for vehicle fitting based on differences in the directivity of vehicle-mounted FM antennas.

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INTRODUCTION

The suitability of FM receivers for automotive applications has conventionally been evaluated by evaluating the reception characteristics of broadcast waves while conducting repeated driving tests in a special test environment. The evaluation of sound quality while driving is based on the auditory judgment of a limited range of test subjects. Because these evaluations are affected by changes in the radio wave environment surrounding the vehicle due to traffic conditions and other factors, these tests present issues in terms of the reproducibility and objectivity of the evaluations.

In order to resolve these issues, a Two-Stage method was developed that makes it possible to evaluate the suitability of FM receivers for vehicle fitting by creating a virtual radio wave environment on a PC [1]. The major technological challenge in the Two-Stage method is gaining a grasp of the characteristics of actual FM propagation environments. A test-based method of estimating incoming waves

that is able to accurately estimate propagation environment characteristics including the number, arrival direction, and delay time of incoming waves in an actual FM propagation environment is therefore essential.

The MUSIC method using an array antenna [2, 3] is one method of estimating incoming waves. This method makes it possible to simultaneously estimate arrival direction and delay time. However, this method presents various issues when applied to FM, including increases in the size of the antenna array, and there are no reported instances of its use in the estimation of incoming waves in actual environments using FM broadcast waves.

The MUSIC method using a virtual array antenna was developed in order to resolve these issues, making it possible for the first time to simultaneously estimate the number, arrival direction and delay time of incoming waves in an actual FM propagation environment.

Using the results of these estimations, the sources of reflection for multipath waves assumed to have been reflected once were identified on a map for the first time. This research has already been reported [4, 5].

The research discussed in this paper reproduced the propagation environment characteristics estimated with the MUSIC method using a virtual array antenna in the Two-Stage method, making it possible to evaluate the suitability of an FM receiver for vehicle fitting for the first time using the Two-Stage method.

The multipath distortion rate was defined as an index for the evaluation of sound quality, and this distortion rate was used in the following evaluations of the suitability of FM receivers for vehicle fitting:

1. Comparison of multipath distortion rate characteristics for a non-diversity receiver and a diversity receiver under the same propagation environment characteristics
2. Comparison of the multipath distortion rate characteristics of receivers in relation to differing directivity of vehicle-mounted antennas, under the same propagation environment characteristics

Because the evaluation of sound quality is based on the assessment of sound quality output by speakers, a minimum auditory impression time, $T_{\min}$, is necessary in order to judge the quality of the sound. Reference [6] recommends a $T_{\min}$ of 5 sec from considerations of human engineering perspectives and information recognition. The research discussed in this paper defined $T_{\min}$ as 5 sec, and held the value constant irrespective of changes in vehicle speed.

In contrast with the conventional method of auditory evaluation involving repeated driving tests and a limited range of test subjects, the use of the Two-Stage method made it possible for the first time to evaluate the suitability of FM receivers for vehicle fitting both reproducibly and objectively.

TOOL FOR EVALUATION OF AUTOMOTIVE CONFORMITY OF FM RECEIVERS USING THE TWO-STAGE METHOD

Two-Stage Method

Research on methods of evaluating MIMO terminals has flourished with increases in the speed and capacity of wireless communications systems [7, 8, 9, 10, 11]. An over-the-air (OTA) method that forms a fading environment around the measured terminal is effective in the evaluation of MIMO terminals in actual radio wave environments [12]. Figure 1 shows the configuration of this fading emulator-type evaluation method.

This configuration makes it possible to freely control radio wave environment characteristics including the number, arrival direction, delay time, and desired signal to undesired signal ratio (DUR) of incoming waves, as well as the Doppler shift in relation to speed of motion. However, it has been challenging to use this method in evaluating the reception characteristics of wireless terminals connected to vehicle-mounted antennas due to the following issues:

1. Because a fading emulator is necessary for each probe antenna, the evaluation system becomes complex and high-cost.
2. When a terminal connected to a vehicle-mounted antenna is evaluated, the area for arranging probe antennas around the vehicle becomes larger than the area for measurement via mobile phone as shown in Fig. 1, resulting in a large-scale evaluation system.

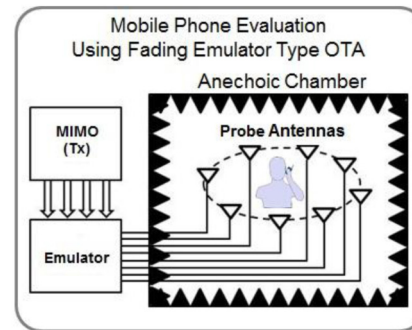


Figure 1. Evaluation Block Diagram of Fading Emulator Type

In order to resolve these issues, the Two-Stage method was applied to the antenna branch control [13] to which the function of controlling the fading emulator signal had been allocated [14].

Figure 2 shows a block diagram of evaluation of the reception characteristics of a vehicle-mounted wireless terminal with the two-stage method applied to antenna branch control (this configuration is termed the “Two-Stage method”) [1,4].

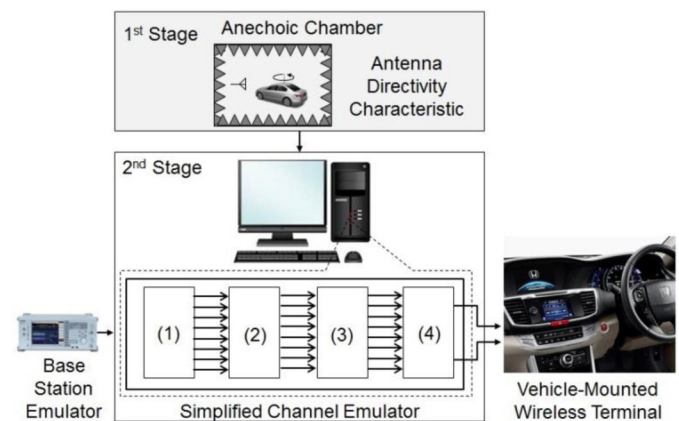


Figure 2. Evaluation Block Diagram of Vehicle-Mounted Wireless Terminal by Using Two-Stage Method

The configuration shown in Fig. 2 evaluates a diversity receiver that uses two vehicle-mounted antennas to receive radio waves transmitted from a single broadcast station. It is composed of two emulators: a base station emulator that transmits the signal, and a channel emulator that generates a fading environment.

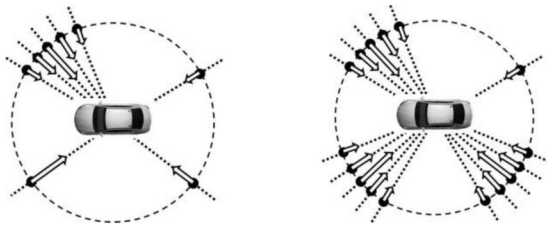
In the 1st stage, the characteristics of the directivity pattern of the vehicle-mounted antenna are measured in a large radio wave anechoic chamber and input to the channel emulator. In the 2nd stage, the base station emulator and the measured terminal are connected to the channel emulator by coaxial cables.

The signal transmitted by the base station therefore passes through the fading environment, and is received by a terminal that possesses the directivity pattern characteristics of the vehicle-mounted antenna.

The channel emulator is made up of the four features (1), (2), (3), and (4) shown in Fig. 2. These features are:

1. Tx connection matrix : a feature that realizes the spatial decorrelation characteristics of the transmitted signal (also acts as a converter for the number of probe antennas, L , in relation to the number of MIMO transmitting antennas)
2. Delay generator : a feature that imparts a delay time to each probe antenna and makes it possible to vary the amplitude of each delayed wave
3. Doppler shifter : a feature that imparts vehicle speed (Doppler frequency) information to each probe antenna
4. Rx connection matrix : a feature that imparts the directivity pattern characteristics measured in the 1st stage and the cross-polarization characteristics of the actual environment to each probe antenna

In the research described here, a software configuration was employed for the channel emulator, and changing the number and characteristics of the probe antennas made it possible to create a virtual radio wave environment conforming to an actual environment. Figure 3 shows incoming wave models when the number of probe antennas, L , is 8 and 16. Because a greater number of probe antennas makes it possible to create a more complex clustering model, a greater number offers the advantage of creating an incoming wave model that is closer to an actual radio wave environment.



a) Number of Probe Antenna $L=8$ b) Number of Probe Antenna $L=16$

Figure 3. Comparison of the Incoming Wave Model by the Number of Probe Antennas

MUSIC Method Using a Virtual Array Antenna

Theory of MUSIC Method Using a Virtual Array Antenna

Figure 4 shows the theory of the method of estimating incoming waves using a virtual array antenna combining an RF recorder and MUSIC processing [15, 16].

A reference antenna is positioned at point P_0 , which offers a clear reception environment, and a reference signal with a high signal to noise ratio (SNR) is received. At the same time, a measurement signal is received by a measurement antenna positioned at an arbitrary point P_m . If the reference signal and the measurement signal are recorded simultaneously by the RF recorder while the measurement antenna is moved, data regarding the phase and amplitude of the measurement

signal in relation to the reference signal can be obtained. Because of this, the MUSIC method using a virtual array antenna can be considered an equivalent method to the MUSIC method using a conventional array antenna, and the arrival direction and delay time of incoming waves can be estimated simultaneously.

If the virtual array antenna is short, the delay times detected by the respective measurement antenna elements are considered equivalent. There is therefore no need to use the signals received by all of the measurement antennas; delay time can be estimated using only the signal received by the measurement antenna at an arbitrary point P_m .

By applying offline spatial smoothing preprocessing (SSP) [17] to the data recorded by the RF recorder and performing a correlation matrix operation, it is possible to simultaneously estimate arrival direction and delay time. The same algorithms can be applied in the estimation of delay time and estimation of arrival direction.

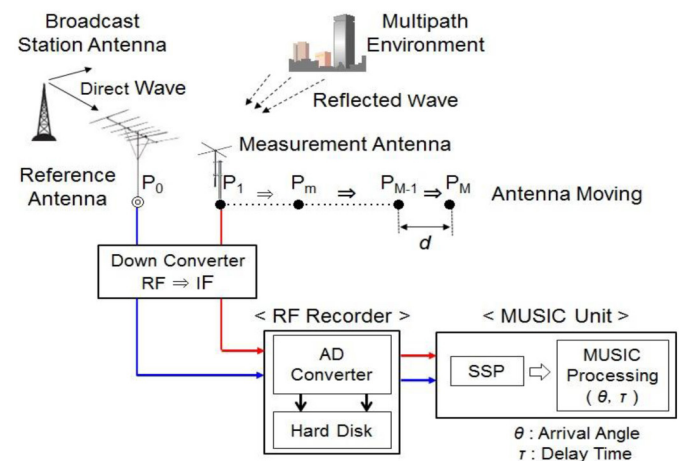


Figure 4. Block Diagram of MUSIC Method by Using Virtual Array Antenna

MUSIC Method for FM Broadcast Waves: Issues and Responses

As a characteristic of FM receivers, when a noise with a flat frequency characteristic is received, the higher the frequency components, the greater the demodulation output. For example, if the frequency components of a sound have their peak at 0.5 to 1 KHz, frequency components higher than that become smaller in inverse proportion to the frequency. Modulation at the broadcasting station in order to emphasize the high-frequency components in the modulation signal (known as Pre-emphasis) and demodulation by the receiver to attenuate the high-frequency components (known as De-emphasis) make it possible to obtain a demodulation signal with an equivalently good SNR. Figure 5 shows the pre-emphasis characteristic of a broadcasting station and the de-emphasis characteristic of a receiver. The overall frequency characteristic is flattened, and the equivalent SNR is improved.

Based on the above, the SNR of FM transmission frequencies differ at high and low frequencies. Thus, the fact that the occupied bandwidth of the transmission frequency is used as the frequency array when delay time is estimated using the MUSIC method means that the method cannot be applied to FM without modification.