A High Speed Channel Field Test Scheme based on Additional Baseband Processor

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Abstract—**Field test in high speed environments is very difficult. To make the field test more feasible, this paper presents a scheme to extend the low speed field test system to estimate the measured data in high speed condition through an additional baseband processor, without changing the major parts of the base stations. The additional baseband processor changes the characteristics of the low speed signal through adding proper Doppler shift into the signal. In this paper, the system is introduced and the baseband model is discussed in detail. Simulation results are presented and discussed. And the hardware simulation plan is also presented.**

Keywords- Baseband Processor; Doppler shift; Field test; High speed

I. INTRODUCTION

As a major method of performance evaluation of technologies and systems, field test of mobile communication system is very important especially in typical environments such as the intensive commercial, the dense residential areas, the expressways, the high speed trains, etc. Generally, the field tests in these environments are laborious and costly especially in high speed environment because of the limitation of the test equipments and the complexity of the wireless communication channel. To simplify the test, reduce the cost and labour force of field tests becomes a hot topic in the field of mobile communication network operating, management, planning and optimization.

As we know, the major problem of field test in high speed environments is the Doppler shift, which introduces spread of the signal spectrum and faster fading of the signal amplitude. Since the Doppler Effect can be estimated according to the signal transmission theories[1], it is possible to perform field test in low speed environments and estimate the 'field test' data in corresponding high speed environments where the propagation conditions are the same except the speed.

According to the above analysis, in this paper, we discuss the extension from low speed (lower than 60km/h) field test system to high speed test system. In this paper, we conduct the research on the characteristics of small scale fading in different speed, discuss the scheme based on adding Doppler shift to the transmitted signal of the base station through an additional baseband processor, derive the formula of the baseband processor, perform simulations and analyze the simulated results. At the end of this paper, the hardware testing plan is presented as well.

II. THE SYSTEM STRUCTURE AND THE MODEL OF THE ADDITIONAL BASEBAND PROCESSOR

A. The System Structure

As a comprehensive field test system, the presented filed test system contains the base stations, the terminals, the control center, the rail and the rail car, as shown in Fig1.

In our scheme, the test terminal is in the rail car which moves along the rail in a low speed(not higher than 60km/h), the control center learned the characteristics of signal transmission in both low speed conditions and high speed conditions, and send orders to the base station to process the transmitted signal according to the actual speed(reported to the control center by the test terminal in the rail car), so that the received signal by the mobile terminal has similar characteristics as in the high speed environment. It is to be mentioned that, in this paper, we only consider the experience of the terminal in the rail car. Since the signal processing will be easier in baseband, and no change is considered to the major parts of the base station, a baseband processor is added with a pair of frequency converters. As shown in Fig.2.

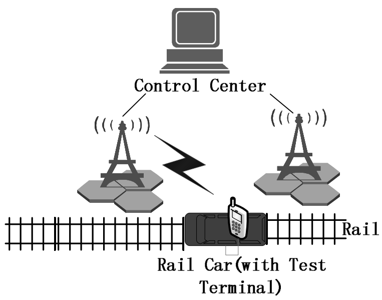

Figure 1. The system structure

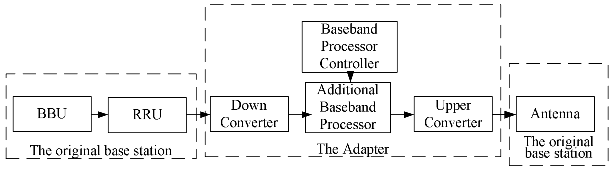

Figure 2. The structure of the base station

In Fig. 2 the Baseband Unit (BBU), the Radio Remote Unit (RRU), and the antenna are the original units of the base station. The adapter contains the down converter, upper converter, and the additional baseband processor. The function of the down converter and upper converter is to change the frequency of the signal to the baseband or the radio frequency. And the function of the additional baseband processor is to change the characteristics of the low speed condition to the high speed condition, especially the Doppler shift, which will be discussed in detail in the next part.

B. The Model of the Additional Baseband Processor

According to the above analysis, the major purpose of the additional baseband processor is illustrated in Fig. 3. As show in Fig. 3(a), the input signal $x_b(t)$ becomes $y_a(t)$ after being processed by the additional baseband processor whose impulse response is defined as $c(t)$, $y_a(t)$ is transmitted by the base station and the received signal by the test terminal in low speed is denoted as $y_b'(t)$, the impulse response of the low speed channel is denoted as $h_b(\tau, t, f_{m1})$. We also present the model of the actual high speed channel in Fig. 3(b), where the channel impulse response is denoted as $h_b(\tau, t, f_{m2})$.

As shown in Fig. 3, the objective of our scheme is that the received signal $y_b'(t)$ through the simulated high speed channel is equal to the received signal $y_b(t)$ through the actual high speed channel. According to the theories of mobile communications[1], since $y_b'(t)$ and $y_b(t)$ can be treated as time variant random processes, this objective becomes to obtain a similar distribution characteristics of these two random processes as much as possible.

C. Theoretical Analysis

Based on the models presented above, we can obtain the impulse response $c(t)$ of the additional baseband processor as follows.

Based on the system structure and the signal transmission theories[1], the transmitted signal can be denoted as (1).

$$x(t) = \mathrm{Re}\{s(t)\exp(j2\pi f_c t)\} \tag{1}$$

Where f_c (in Hz) is the carrier frequency, and $s(t)$ is the baseband signal. According to the signal transmission theories, the wireless channel is a multipath channel and the received signal by the mobile terminal can be denoted as (2).

$$y(t) = \sum_i a_i x(t - d_i/c) \tag{2}$$

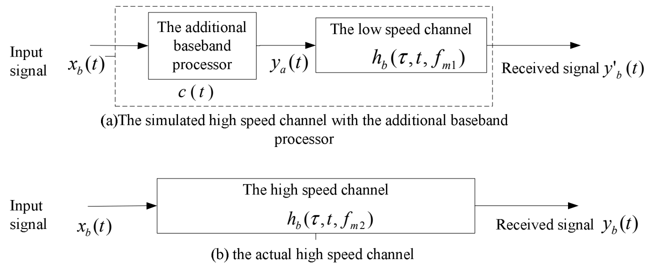

Figure 3. The additional baseband processor

Where d_i (in meter) is the propagation distance of the ith path, a_i is the attenuation of the ith path, and c(in m/s) is the speed of light. Considering (1), the received signal can be denoted as (3).

$$y(t) = \mathrm{Re}\Big\{ \sum_i a_i s(t - d_i/c)\exp(-j2\pi f_c d_i/c) \cdot \exp(j2\pi f_c t)\Big\} \tag{3}$$

Therefore the baseband complex envelope of the received signal is as (4), which describes the attenuation, phase and time delay of the signal. In the following discussion we use the complex envelope model to describe the signal.

$$r(t) = \sum_i a_i \exp(-j2\pi f_c d_i/c) s(t - d_i/c) \tag{4}$$

When the terminal is moving at the speed of v relative to the base station (as shown in Fig. 4), the change of the length of the ith path is denoted as (5).

$$\Delta d_i = -vt\cos\theta_i \tag{5}$$

Where θ_i is the included angle of the arrival direction of the ith path and the moving direction of the terminal.

The propagation distance of the ith path becomes $d_i' = d_i + \Delta d_i$. Substituting d_i with d_i' in (4), we obtain (6).

$$r(t) = \sum_i a_i \exp(-j2\pi f_c d_i/c)\exp(j2\pi f_c vt\cos\theta_i/c) \cdot s(t - d_i/c + vt\cos\theta_i/c) \tag{6}$$

The effect of $vt\cos\theta_i/c$ is small and negligible for $s(t-d_i/c+vt\cos\theta_i/c)$, therefore we obtain (7).

$$r(t) = \sum_i a_i s(t - \tau_i) \cdot \exp(j2\pi f_m t\cos\theta_i) \cdot \exp(-j2\pi f_c \tau_i) \tag{7}$$

Where $\tau_i = d_i/c$ is the delay of the ith path and $f_m = f_c v/c$ is the maximum Doppler frequency.

From the above analysis, the channel impulse response can be denoted as (8).

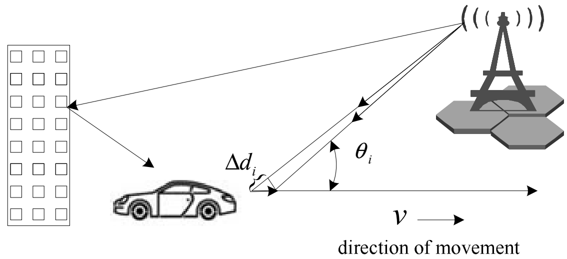

Figure 4. Schematic diagram of Doppler shift

$$h(t,\tau) = \sum_i a_i \cdot \exp\left(-j\varphi_i(t)\right) \cdot \delta(\tau - \tau_i) \tag{8}$$

Where $\delta(\bullet)$ is the impulse response function, $\varphi_i(t)$ is the equivalent synthetic phase of the ith path.

$$\varphi_i(t) = 2\pi f_c \tau_i - 2\pi f_m t \cos\theta_i \tag{9}$$

In (9), the first part represents the effect of the multipath delay and the second part represents the effect of Doppler shift.

According to (8) the varying of the wireless channel is resulted from the random phase $\varphi_i(t)$. Equation (9) shows that it is the Multipath Effect and Doppler Effect that cause the changing of $\varphi_i(t)$ and the fading of the multipath channel.

In this scheme, we assume that the multipath environment is identical for both the high speed channel and the low speed channel. Therefore the differences of these two kinds of channels are mainly resulted from the Doppler Effect, more exactly, from the moving of the mobile terminal. So the research of the baseband processor is focus on the Doppler Effect.

According to the signal transmission theories, in wireless multipath channel the Doppler Effect is described by Doppler spread which results in the time-varying characteristics of the channel. There are two major parameters to describe the time-varying channel, one is Doppler spread spectrum and the other is the time self-correlation function. In our scheme these two parameters are used as evaluation indexes to describe the channel time-varying characteristic.

In the actual mobile communication environment, the characteristics of multi-path channel are influenced by the multi-path condition and the movements in the environments, in this paper, to make the analysis more clear and simply, we only discuss the time-varying characteristics caused by the relative motion between the base station and the mobile terminal. In this situation the wireless multipath channel is generally described as a random process [2], which is a simplified probability channel model. In this model the Doppler spread can be expressed clearly and simply.

According to [2], (8) can be rewritten as (10).

$$\begin{aligned} h_b(\tau,t) = \sum_{l=1}^{L} \sqrt{P_l}\,\delta(\tau-\tau_l) \cdot \\ \sum_{i=1}^{N_l} \frac{1}{\sqrt{N_l}} \exp\left[-j\left(2\pi f_m t \cos\alpha_{l,i} + \varphi_{l,i}\right)\right] \end{aligned} \tag{10}$$

Where L is the number of multipath, P_l is the power of the lth path, N_l is the number of subpaths in each multipath, $\alpha_{l,i}$ and $\varphi_{l,i}$ are the arrival angle and the phase of the ith subpath of the lth path respectively.

Equation (10) shows the time-varying characteristics of the wireless multipath channel that caused by the movement of mobile terminals. In (10) the channel is modeled as a stationary ergodic complex Gaussian process. For the stationary of the channel, the self-correlation functions of low speed and high speed can be expressed as $R_L(\tau)$ and $R_H(\tau)$ respectively, where τ is the time delay. And the self-correlation functions of $y_b'(t)$ and $y_b(t)$ can be expressed as (11) and (12).

$$\begin{aligned} R'(t,t+\tau) &= E[y_b'(t) \cdot y_b'^*(t+\tau)] \\ &= c(t) \cdot c^*(t+\tau) \cdot R_L(\tau) \end{aligned} \tag{11}$$

$$R(t,t+\tau) = E[y_b(t) \cdot y_b^*(t+\tau)] = R_H(\tau) \tag{12}$$

Since the real high speed channel can be modeled as a stationary process, the simulated high speed channel should have the stationary characteristic. Therefore assume $c(t)$ is a periodic function, its circle is T, then $y_b'(t)$ is a cyclostationary process, satisfying the requirement of stationary. Assume the self-correlation function of $c(t)$ as (13).

$$R_c(\tau) = \overline{c(t) \cdot c^*(t+\tau)} \tag{13}$$

Then (11) becomes (14).

$$\begin{aligned} \overline{R'(t,t+\tau)} &= \overline{E[y'_b(t) \cdot y'^*_b(t+\tau)]} \\ &= R_c(\tau) \cdot R_L(\tau) \end{aligned} \tag{14}$$

According to the communication theories[1-2], the self-correlation function and the Doppler power spectral density is a Fourier transform pair, as shown in (15).

$$\begin{aligned} &P_H(f) \Leftrightarrow R_H(\tau) \\ &P_H'(f) = P_c(f) * P_L(f) \Leftrightarrow R_c(\tau) \cdot R_L(\tau) \end{aligned} \tag{15}$$

Where $P_H(f)$ and $P'_H(f)$ is the Doppler power spectral density of $y_b(t)$ and $y_b'(t)$. $P_c(f)$ is the power spectral density of the baseband processor, and $P_L(f)$ is the power spectral density of the real low speed channel. Based on above analysis, the target of the baseband processor is denoted as (16).

$$P_H(f) = P_H'(f) \tag{16}$$

Considering (15), (17) can be obtained.

$$P_H(f) = P_c(f) * P_L(f) \tag{17}$$

From (17) and the power spectral density of high speed channel and low speed channel, the power spectral density of the baseband processor can be obtained.

From the above analysis the baseband processor must meet two requirements. Firstly, $c(t)$ is a periodic process. Secondly, it can extend the Doppler spread spectrum. Thus the expression of $c(t)$ is assumed as (18) in this paper.

$$c(t)=\sum_i c_i \exp\left(j2\pi f_i t\right) \tag{18}$$

The power spectral density of $c(t)$ is denoted by (19).

$$P_c(f)=\sum_i c_i^2 \delta\left(f-f_i\right) \tag{19}$$

For different high speeds and low speeds, when the item f_i is given, the coefficients can be obtained from the equation (17-19) by the method of deconvolution.

III. SIMULATION RESULTS AND ANALYSIS

In order to simulate high speed channel in the testing environment, the Rural Area (RA) channel model introduced by [3] is selected since it can be applied in both low speeds and high speeds.

According to the analysis in section II, Jakes Model[4-6] is selected to describe the Doppler Effect because it represents the statistical properties of the stationary channel well and can be realized simply in simulation. In Jakes Model the input signal is a single-frequency signal. For wideband signal it can be regarded as the accumulation of the single-frequency signal. In simulation, the moving speed of mobile terminal is limited to lower than 60km/h, and the simulated high speed is from 70km/h to 500km/h. The simulation results of self-correlation are shown in Fig.5 and Fig.6.

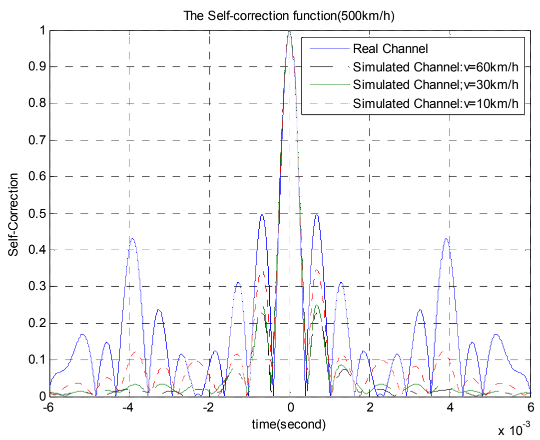

Figure 5. The self-correlation function of the high speed environment (the high speed is 500km/h, and the low speeds are 10km/h, 30km/h and 60km/h)

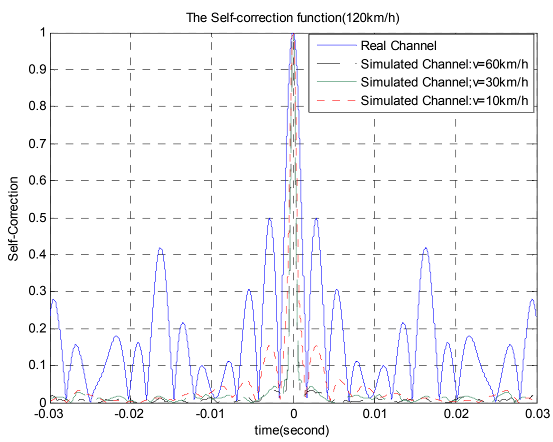

Figure 6. The self-correlation function of the high speed environment ((the high speed is 120km/h, and the low speeds are 10km/h, 30km/h and 60km/h))

From Fig.5, it can be observed that when the channel with a 500km/h speed is simulated, the main lobe of the self-correlation function of the simulated high speed channel coincide with that of the actual high speed channel, while the side lobes of the self-correlation function are lower than that of the actual high speed channel, and the faster the real speed is, the lower the side lobes are. Similar conclusions can be obtained from other high speed and low speed set, for example, in Fig. 6. Compare Fig.5 with Fig.6, it can be also observed that the higher the simulated speed is the closer the simulated self-correlation function is to the actual high speed channel.

Table Ⅰ shows the mean square error of normalized power spectrum between the simulation high speed channel and real high speed channel. The calculation formula of MSE is as (20).

$$MSE=\sqrt{\sum_i\left(p_{1i}-p_{2i}\right)^2 \Big/ n} \tag{20}$$

Where p_{1i} and p_{2i} is the value at the frequency f_i in simulated high speed and real high speed power spectrum. n is the number of samples.

From Table Ⅰ, it can be observed that at the same actual low speed, the higher the simulated high speed is, the smaller the mean square of power spectrum is. When simulating a high speed channel, the lower the actual speed is, the smaller the error is. And with the increase in simulated high speed, the error is downtrend.

From above simulation results of self-correlation and power spectrum, a conclusion can be obtained that the bigger the speed difference between the simulated high speed channel and the real low speed channel is, the closer the Doppler Effect of simulated high speed channel is to the real high speed channel, which proves that, if the assumption of this paper is fulfilled, the characteristics of high speed channel can be obtained through proper process of the filed test data in low speed environment.

IV. HARDWARE TESTING PLAN

To prove the presented scheme from another approach, the hardware testing planning is also designed in this paper. Since there are some restrictions on the input data, some necessary analysis and processing such as the PAPR(Peak to Average Power Ratio) of the baseband processor obtained in section III should be taken into consideration. Since the original PAPR of the baseband processor is too high for hardware testing, we use the Circle Clipping and Filtering [7] to reduce the PAPR, as shown in Fig.7. The Clipping algorithm can be explained as formula (21).

$$y(n)=\begin{cases}\dfrac{A}{\sqrt{\left|x(n)\right|^2}}x(n), \text{if } \left|x(n)\right|^2 > A^2 \\ x(n), \qquad\qquad \text{if } \left|x(n)\right|^2 \le A^2\end{cases} \tag{21}$$

The hardware testing plan is shown in Fig.8.

TABLE I. THE MEAN SQUARE ERROR OF NORMALIZED POWER SPECTRUM BETWEEN THE SIMULATION HIGH SPEED CHANNEL AND REAL HIGH SPEED CHANNEL (*10^{-3})

simulated speed / real speed	**70 km/h**	**120 km/h**	**200 km/h**	**300 km/h**	**400 km/h**	**500 km/h**
10km/h	5.517	4.134	3.184	2.599	2.279	2.048
20km/h	5.776	4.219	3.257	2.638	2.303	2.072
30km/h	5.864	4.257	3.230	2.620	2.305	2.063
40km/h	5.830	4.245	3.292	2.641	2.316	2.088
50km/h	5.944	4.241	3.286	2.655	2.322	2.081
60km/h	6.000	4.286	3.266	2.660	2.303	2.080

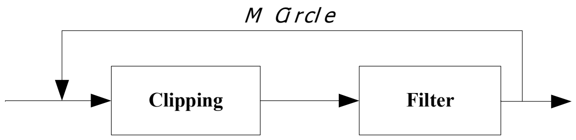

Figure 7. Circle Clipping and Filtering

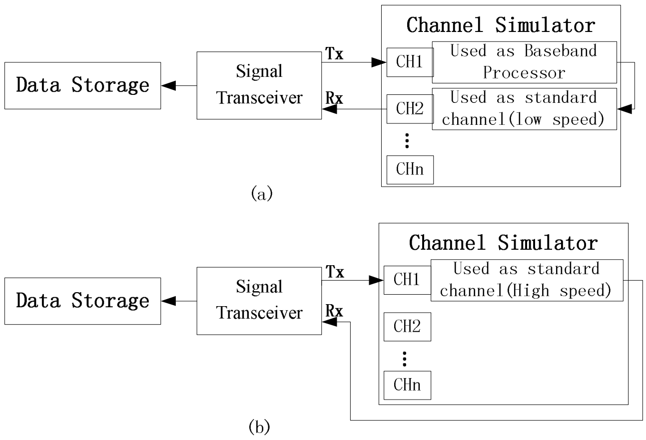

Figure 8. The hardware testing plan

As shown in Fig. 8, the hardware testing system contains three parts, the data storage, the signal transceiver, and the channel simulator. In Fig.8(a) two channel of channel simulator is cascaded, the first channel is used as baseband processor whose impulse response is obtained as the scheme described in section Ⅱ and the second channel is used as standard low speed channel. In Fig.8(b) only one channel of the channel simulator is used as standard high speed channel. The simulation and standard channel signal is received by the signal transceiver and saved in data storage equipment. After the postprocessing of the storage data, we can compare the received signal in Fig.8(a) and Fig.8(b) to verify the simulation scheme discussed in section Ⅱ. It's to be mentioned that, the hardware plan might be changed according to the devices.

V. CONCLUSION

High speed mobile environments are very important environment type for performing field test. But it's hard to perform field test in high speed mobile environments because of the cost and other actual conditions. To solve this problem, a scheme of extending the low speed field test system to high speed field test system is presented. The major idea of the scheme is adding proper Doppler shift to the transmitted signal through additional baseband processing.

From theoretical analysis and simulation, conclusions can be obtained as follows.

(1) The presented scheme simulates the high speed channel characteristics through an additional base band processor, prevents making changes to the major parts of the base station, this will improve the compatibility of the scheme.

(2) The statistical characteristics of high speed channel can be simulated by presented additional baseband processor scheme, and the error is acceptable for engineering application.

(3) The difference between low speed and high speed will influence the simulated error, the bigger the difference, the lower the error.

In further work, the following issues should be considered carefully.

(1) Since channel models are generally based on measurements, errors are inevitable in actual application. It's necessary to perform channel measurements to validate and correct the presented scheme.

(2) In this paper, the changes of the speeds are ignored, but it is an important issue in actual high speed environments and should be analyzed in further work.

(3) If the assumptions of the mobile channel changes, more analysis should be conducted.

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