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Analysis of Rocket Sled Vibration Signal Transmission Based on Zigbee Application

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Abstract. Multi-path effecting and Dopplereffecting on missile-borne tester signal transmission based onZigbee application was researched. The maximum transmission distance was derived based on communication channel loss model and multi-path model. The effecting of multi-path on transmission distance was discussed. The effecting of Doppler shift was researched by speed of rocket sled and receiver position. Transmission speed and error rate of missile-borne tester was studied by Doppler effecting. The measure which reduced multi-path fading and Doppler effecting was gained. These can advance signal transmission quality and improve revamping of equipment.

1. Introduction

In the rocket sled test, due to the track irregularity, the vibration of the rocket working, the aerodynamic instability and so on, the tested product will bear the larger vibration. Even after the vibration damping measures are taken on the tested products, it also needs to monitor the parameters of the vibration and speed of the tested products all the way. The fault location of the test product provides the most original test data to ensure the safety of the tested products. To ensure the safety of test data, test data must be transmitted to ground storage[1,2]. Therefore, the signal transmission quality of skid tester is particularly important in rocket sled test.

This paper analyzes the influence of multipath effect, Doppler frequency deviation and Doppler expansion factors on the transmission quality of sled vehicles at high speed, and puts forward measures to improve the quality of signal transmission, which is of great significance to guide the test of rocket sled.

2. The effect of signal attenuation on the transmission distance

2.1. Influence of Zigbee communication channel loss on signal transmission distance

The Friis free space equation defines the distance as [3,4]:

$$P_R(d) = \frac{P_T \mathrm{G}_T \mathrm{G}_\mathrm{R} \lambda^2}{(4\pi)^2 d^2} \tag{1}$$

In the formula: P_T means power of transmitter. Power of receiver is described by $P_R(d)$. The distance of receiver and transmitter is described by d, and the unit is m. Transmitted antenna gain is described by G_T. Received antenna gain is described by G_R. Length of wave is λ,and the unit is m.

According to characteristics of 802.15.4a channel, IEEE organization has carried out actual measurement in the actual environment, and constructed a channel transmission loss model based on 80215. 4A channels suitable for UWB (2~10GHz) and 100MHz～1000MHz. The formula of loss calculation is [5]:

$$P_R(d) = P_T + G_R + G_T + A_{ant} + P_{Lo} + s - 20(\lg(f_c/5))(k+1) - 10(\lg(d_0))n \quad (2)$$

Among them, the power of transmitter is described by P_T. Distance between transmitter and receiver is described by d. The attenuation factor of antenna is described by A_{ant}. s means standard variance, n means correction coefficient and k means the frequency effect coefficient. d_0 means reference distance, f_c is a reference center frequency , equal to 5 GHZ (UWB2 ~ 10 GHZ frequency band), P_{Lo} is the size of the loss under the reference range.

The logarithm of the formula (2) is expressed as:

$$P_R(d) = P_T + G_R + G_T + A_{ant} + P_{Lo} + s - 20(\lg(f_c/5))(k+1) - 10n\lg(d) \quad (3)$$

The unit for d is m, and the unit of f is GHz.

The maximum distance equation is obtained as follows:

$$d_{\max} = 10^{\frac{1}{10}[P_T - P_R(d) + G_R + G_T + A_{ant} + P_{Lo} + s - 20(\lg(f_c/5))(k+1)]}$$

Measured values [6] was given by IEEE802.15.4a channel model, as shown in Table 1.Tthe maximum distance is:

$$d_{\max} = 10^{\frac{1}{10\times 1.58}[8-(-92)-3-3.96-48.9620\times\lg(2.4/5)]} = 1559m$$

Table 1 measurement of correction factor for channel of IEEE802.15.4a

	Factor of correction	P_{Lo}/db	n	s/db	k	A_{ant}/dB
Boad environment	Sight distance transmission LOS	-	-	-	-	-
	Non sight distance transmission NLOS	-48.96	1.58	-3.96	0	-3
	Remarks	Broad environment				

2.2. The influence of multipath effect on signal transmission distance

In some cases, the amplitude of the vector plus signal is lower than the amplitude of the direct signal due to the mutual cancellation of the direct and reflected signals, which is called the multipath fading [7], which is caused by the multipath effect, as shown in Figure 1[8].

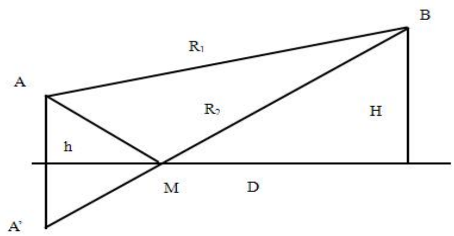

Fig 1 Multi-path effection

Among them, A launches the antenna for the sled tester. B receives the antenna for the gateway. M is the ground reflection point. Transmitting antenna height is h. The height of antenna is H. The distance of horizontal for sled with gateway is D. L is:

$$L = 10\log[\frac{\rho^2 + 1 - 2\rho\cos(\pi - \theta)}{2}] \quad (4)$$

When the signal of direct phase is opposite to the reflection signal, the fading depth of the signal which is received by the receiving antenna is L ,and extreme value of L will appear at this time.

$$2n\pi = 2\pi(\sqrt{D^2+(h+H)^2}-\sqrt{D^2+(h-H)^2})/\lambda \tag{5}$$

The Zigbee wireless transmission module is known to work frequency 2.4GHz , the sled vehicle antenna height 1m, the ground emission coefficient 0.9, the relationship with distance and fading has been shown in Figure 2, by formula (4).

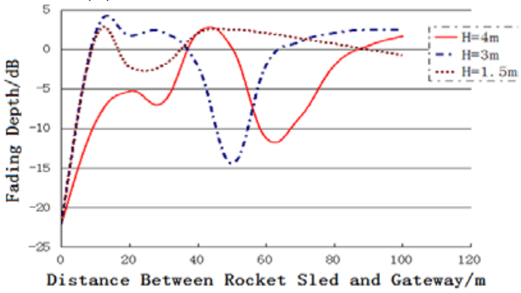

Fig 2 Distance and fading depth

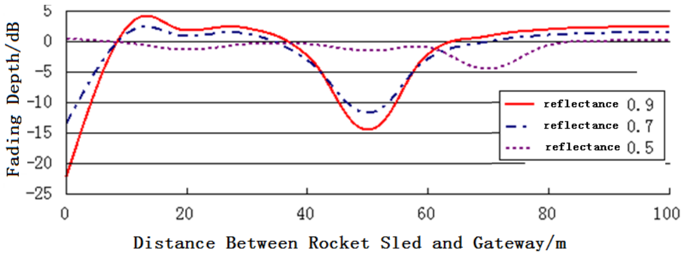

Fig 3 Fading depth and the reflection coefficient

When the horizontal distance between the sled car and the gateway is (11), the fading depth will appear extreme value, the fading depth extremes appear near the 60m, the specific location is related to transmitting antenna height and receiving antenna height, and fading depth is determined by the size of the ground reflection coefficient (Fig 3), and the greater the reflection coefficient, The greater the depth of the decline.

When the sled car and the gateway distance is 60m:

$$P_R = 8-3-48.96-3.96-10\times1.58\times\lg(60)-20\times\lg(2.4/5) = -69.7dB$$

The signal attenuation intensity due to multipath fading L=14.3db, therefore, total signal attenuation at 60m distance is:

$$P_R^{'} = -69.7-14.3 = -84dB > -92dB$$

Through calculation, we can see that when the fading signal is strongest, it can also meet the requirement of 1km communication distance. In order to further reduce the influence of multipath fading, the height of the gateway can be reduced from 4m to 1.5m, and the depth of the fading can be reduced from -14.3dB to -2.2dB, and the fading depth is moved forward to 20m, and the total signal attenuation is reduced to -73.9dB. At the same time, the reflection coefficient can be reduced by maintaining the drying or laying of absorbing materials near the 60m region, and the depth of the fading can be reduced to 2 to 10dB.

3. The influence of Doppler frequency offset on data transmission

The relative motion between the sled and the gateway will make the radio wave undergo an obvious frequency shift process. The frequency offset caused by the Doppler effect is related to the moving speed of the sled, the direction of movement and the angle of the incoming wave of the receiver [9,10]:

$$f_d = \frac{v}{c}\times f_c \times \cos\theta(t) \tag{6}$$

In the form:

f_c - the center frequency of the transmitter, $\theta(t)$ -the angle of arrival of the gateway signal; c - the speed of light.

The direction of the sled is the X axis. the vertical direction is the Y axis. the coordinate system is set up, the speed of the sled running is $v(x)$ .Gateway position is located in (x_0, y_0) . The current position of the sled is $(x,0)$. as shown in Fig 4.

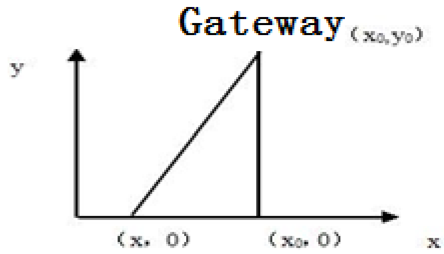

Fig 4 the relative position of the sled and the gateway

According to the trigonometric function formula,the Doppler shift principle formula can be obtained:

$$f_d = \frac{v}{c} \times f_c \times \frac{x_0 - x}{\sqrt{(x_0 - x)^2 + y_0^2}} \tag{7}$$

When the carrier frequency is 2.4 GHz to 2.4835GHz, the Doppler frequency deviation curve of different speed of the sled can be obtained from Figure 5. we can see that the Doppler frequency offset increases with the speed of the sled, the maximum frequency deviation is 5696Hz at 700m/s speed, and the Doppler frequency deviation varies with the change of the sled position. The frequency offset is positive and negative jump, with a maximum value of 11394Hz.

Fig. 6 describes the curve of Doppler frequency deviation as vertical distance between the gateway and the sled. It can be seen from the graph that the Doppler frequency deviation is decreasing from the distance between the gateway and the track.

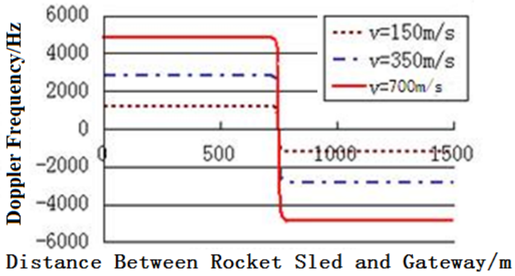

Fig 5 Doppler frequency t and speed

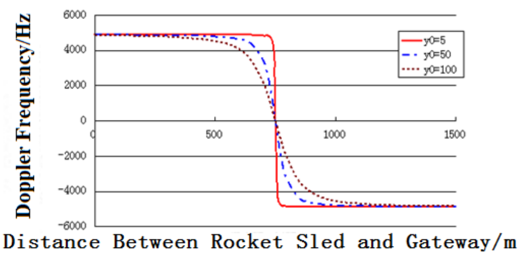

Fig. 6 Doppler frequency and distance

4. Doppler expansion influence on the signal transmission rate

In time domain, there is a quantum correlation time [11] [11], which is the statistical mean of the time interval of the constant channel impulse response, that is, the two time domain signals was amplitude within period of time interval, and the relationship with the Doppler expansion can be expressed as:

$$\lambda / 2v = 0.5 / (v / \lambda) = 0.5 / f_d \approx T_0 \tag{8}$$

The maximum offset frequency of Doppler is f_d .

Therefore, As to avoid the signal distortion which caused by Doppler shift, data rate u exceeding channel fading rate V is necessary to ensure , which makes the channel display slow fading [12]. The carrier frequency is 2.4GHz and the speed of the sled is 700m/s, which can be obtained from(8):

$$T_0 = 1/5969 = 175.6us \tag{9}$$

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That is, the data rate $\frac{1}{T_b} \geq \frac{1}{102us} = 5.7kb/s$. That is to say, if Zigbee wireless transmission, the lower limit of data transmission rate is y (when the data transmission rate is lower than the value, the transmission signal will be distorted). According to reference [13], when the error rate is 10^{-3} to 10^{-4}, the Doppler frequency offset is 0.01 to 0.02 of the signal transmission bandwidth, that is, the data rate should exceed 100~200 times the fading rate. When the data transmission rate reaches 980kb/s to 1960kb/s, the error rate can be guaranteed to be 10^{-3} to 10^{-4}.

5. Conclusions and Countermeasures

(1) the mature Zigbee module in the market can meet the requirement of the data transmission distance. Reducing the height of the gateway and the reflection coefficient in the multipath reflection region by laying the absorbing material can reduce the multipath effect.

(2) the Doppler frequency deviation is proportional to the running speed of the sled, and the vertical distance from the gateway to the orbit is inversely proportional to the gateway.

(3) data transfer rate of Zigbee module will not be able to transmit data at 700m/s speed;

(4) when the data storage space is 128B, and the running speed of the sled car is more than 156m/s, the Zigbee wireless technology is used to realize the data transmission, which can not meet the requirement of the bit error rate of less than 10^{-4}.

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