Research on Performance of Marine UV Communication

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***Abstract*—On the basis of analyzing the environment of marine atmosphere, this paper investigated the effects of marine atmospheric environment on the transmittance of Ultraviolet (UV)light, and gained a conclusion that under marine atmospheric environment the effect of wind speed on the UV atmospheric transmittance is very small, but cloud, rain and fog are all disadvantageous. Simulations of two kinds of modulation under various environments using the MODTRAN model shows that the distance of BPSK is 7% farer than that of BFSK.**

Keywords-UV communication; naval vessels; marine environment; transmittance; modulation type

I. Introduction

Ultraviolet(UV) light communication using scattered UV light transmits information by emission solar-blind-region light (200～280nm). The UV communication is a new transmission method developed since 1990's. By taking advantage of the “solar-blind” and its strong scattering characteristic in the air, UV communication is a very hopeful one which can work not only in all-weather and omnibearing mode but also secure and jamproofed. It can works in both line-of-sight (LOS) and non-line-of- sight(NLOS) modes. So the UV communication will be widely used in short range covert communication [1,2]. We can obtain invisible communication between naval vessels by using scattering UV light signal.

Ultraviolet light signal will be influenced by the atmosphere condition while transmitting in the atmosphere[3-5]. The UV communication channel of the naval vessels is the low layer of marine atmosphere, the environment of marine atmosphere will have effect on performance. All of the marine environment, such as sea surface visibility, weather, season, transmit distance and spread direction, elevation height, the background light etc, will have much effect on the UV transmittance [6,7].

II. Analysis of Marine Atmospheric

The main composition of the standard atmosphere is nitrogen (physical volume about 78%) and oxygen (about 20%). The water steam accounts for 1% or so, and the carbon dioxide of 0.03%~0.05%. In addition, methane, carbon monoxide (CO), ozone, and various suspended particulates in the air. The miscellaneous quality particle composition complications in the atmosphere, the appearance is each different, the dimensions distributes very widely, inviting between about 0.03-2000 ums, which generally be divided into solid particles and liquid particles. The main solid particles are dust, smoke, sandstorms and various industrial pollutants, the liquid particles are in the form of cloud droplet, fog, rain, ice, snow, hail, and so on.

Because of temperature difference, breeze etc, the particle in the atmosphere moves continuously, its components, degree of humidity, density are all changing constantly, which often make the atmosphere turbulence. The transmitting property of the atmosphere has very great influence on the light beam, which contains the absorption and scattering of the atmosphere with suspended particles, atmospheric turbulence exercise on the beam disturbance, the former leads to the main beam energy loss, the latter leads to attenuation, which causes the beam intensity flashing beam drift, and the expansion of phenomena such as jitter, the effects of atmospheric turbulence that often. Therefore we have to carry on a research to the atmosphere transmittance and the work environment.

Marine aerosphere at low layer is different from the standard atmosphere, air's temperature, humidity, wind speed at sea surface are obviously different from the ground, the distribution of profile parameter is uneven, which usually causes the atmosphere wave-guide of the electromagnetic wave spread, the most familiar atmosphere wave-guide is evaporate wave-guide[8,9]. Although the times they appears and their height change, there are evaporate wave-guides almost all time and all sea areas, most of it occurs close near the sea surface. Influence has been subjected to the atmospheric refraction rate to rise and fall random, light wave which spreads in the swift flow atmosphere will appear strength to rise and fall, mutually change and as well as coherent light spectrum mobile.

In light of these turbulent atmosphere spread of the phenomenon known as the optical turbulence[10]. Optical refractive index of atmospheric turbulence is usually used to describe the disturbances. But in the atmosphere near the marine strata, Friehe[11] points out that humidity disturbance by temperature and humidity related disturbances have an important impact on the refractive index. According to recent

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formation similar theory, the daily use of meteorological and hydrological observations to determine the refractive index of the atmosphere in recent formation of the Senate quantitative assessment is an important means of optical turbulence.

Small changes of refractive index of the atmosphere is similar to the role of small "lens" in the atmosphere, so that they appear focused and deflection beam transmission phenomenon, leading to the light flicker and image trembles to move. The results of atmospheric turbulence movement, making the speed, temperature, refractive index of atmosphere up and down random on time and space , so that the output of light receiver short while big short while small intensively, in equal to introduce a big noise source into receiver, which has seriously affected the results of UV transmission. This is obviously increases the average error probability of UV communications system of naval vessels.

III. Simulation of Performance of Marine UV Communication System

In order to investigate the effects of marine atmospheric environment on UV transmission, we carried on imitate to the wind, rain and fog etc. weather phenomenon influence upon the atmosphere transmittance. All the simulations are under the United States Navy standards atmosphere mode, at elevation of 10 m transmission about 1 km.

Windy atmosphere on the impact of UV transmittance are shown in Figure 1, the three curves of UV transmission are simulated at wind velocity of 0.9, 12.3 and 20 m / s respectively. Figure 1 shows that, the horizontal transmittance of UV light decrease when wind speed increased, but the reduce degree is very small. So if there are no other factors interfere with, Ultraviolet light communication systems can normal works in the wind weather.

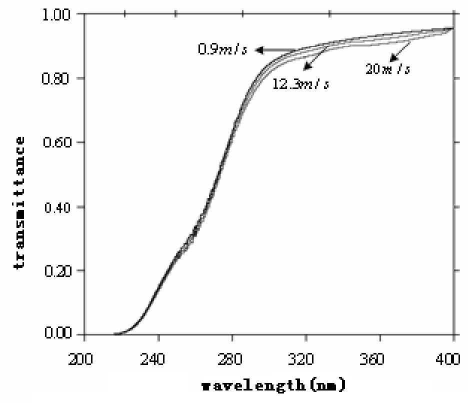

Figure1. Wind rates vs UV transmittance

Rainfall atmosphere on the impact of UV transmittance are shown in Figure 2. Curves of UV transmission are simulated respectively in the diagram in five cases of no rain, 1 mm / hr, 2 mm / hr, 5 mm / hr and 17.5 mm / hr. Figure 2 shows that the horizontal transmittance of UV light decrease when the volume of rainfall enlarge, and the reduce degree is considerable . Therefore, UV light communication is not suitable for marine environment under the rainfall reached a certain volume(more than 2mm/hr).

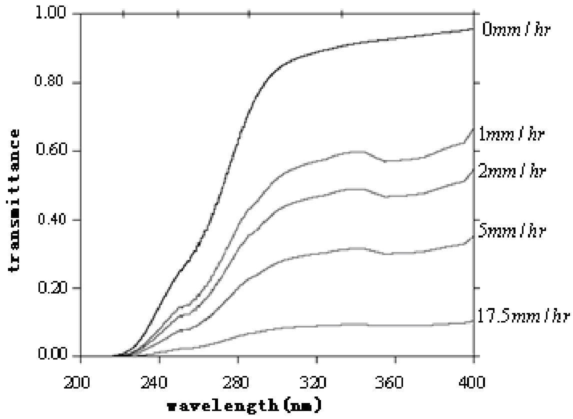

Figure2. Rain rates vs UV transmittance

Figure 3 gives transmission curve both the cases of fog as degree of thickness about 0.2 km and 0.5 km transmission of UV radiation were 100 m and 200 m respective. It is not difficult to get conclusion from Figure 3 that when the fog at a certain distance, UV radiation as the rapid increase in transmission distance of decay, transmission distance is limited.

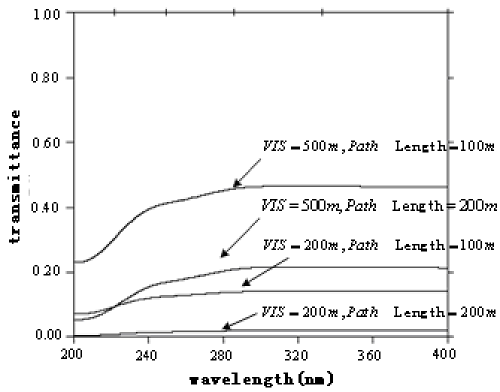

Figure3. Transmission of different VIS and Path Length

Cloudy atmosphere on the impact of UV transmittance are shown in Figure 4. Curves of UV transmission are simulated

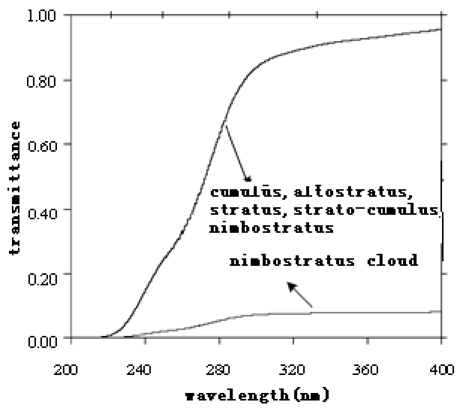

Figure4. Clouds vs UV transmittance

respectively in the diagram in five cases of cumulus cloud with base 0.66 km, top at 2.7 km, altostratus cloud with base 2.4 km, top at 3.0 km, stratus cloud with base 0.33 km, top at 1.0 km, stratocumulus cloud with base 0.66 km, top at 2 km and nimbostratus cloud with base 0.16 km, top at 0.66 km (the United States Navy standard atmosphere mode, at elevation of 10 m transmission about 1 km). For the UV light scattering communication distance is not very far, so higher than the nimbostratus cloud almost no impact. Figure 3 shows that the horizontal transmittance of UV light influenced more and obviously when the volume of cloud in height of 0.16 ~ 0.66 km is considerable, if the height of the cloud reaches a certain volume, the system will not be able to carry out UV communications.

IV. Study of LOS Distance of Marine UV Communication Systems

Part of the simulation results of solar-blind UV light transmittance through near sea surface atmosphere are given below, which gained by using MODTRAN model and compared with the land condition.

As the visibility is 23 km and 5 km, the atmosphere transmittance at wavelength of 253.7 nm are about 20.2% / km and 5.3% / km by using village aerosol model. This shows that low altitudes visibility has great influence in the transmission of ultraviolet radiation. The marine atmosphere transmittance (24.6% / km) is significantly higher than rural model (20.2% / km) at the same atmospheric visibility (23 km), but the atmosphere transmittance of urban model(5.8% / km) is slightly bigger than that of village model (5.3% / km) at the same atmospheric visibility (5 km).

Here, we just discussed the communication distance of LOS conditions, and work-band of systems was chosen within a solar-blind area of 253.7 nm.

Typical systems of the atmosphere optical communication are intensity modulated / direct detection systems, and radiation light source transmit distance d before receiver received. As denotes the receiver's detect area。

According to Lambert's law, the formula is given by

$$P_r = \frac{P_T 10^{\frac{-dT}{10}} A_s}{2\pi d^2} \tag{1}$$

where P_γ is the radiation power received by the detector at the 253.7 nm, P_T is the output power of UV-radiation source at 253.7 nm, and T is the atmosphere transmittance of ultraviolet radiation at 253.7 nm (unit: dB).

If the background radiation power of sun is P_n , we can write β_1 the signal to noise ratio of light wave at detector input as

$$\beta_1 = \frac{P_r}{P_n} \tag{2}$$

When $P_r/P_n >> 1$, the relationship between signal to noise ratio of the output of detector β_2 and input OSNR β_1 would be

$$\beta_2 = \frac{1}{2}\beta_1 \tag{3}$$

This means that the photoelectric conversion causes a signal to noise ratio loss of 3 dB, its derivation sees reference [12,13].

Under the bit error rate requirements of 10^{-4}, different modulation requires different electrical signal to noise ratio. When the signal travels through a Gaussian white noise channel and uses coherent detection, the theoretical value of receiving bit error rate of BPSK demodulator under the premise of signal to noise ratio isβ_2 is:

$$P_{eBPSK} = \frac{1}{2} erfc(\sqrt{\beta_2}) \tag{4}$$

The value of receiving bit error rate of BFSK demodulator is:

$$P_{eFSK} = \frac{1}{2} erfc(\sqrt{\beta_2/2}) \tag{5}$$

So we can use the following formula to calculate the communication distance of UV line-of-sight system (LOS):

$$\frac{10^{\frac{-dT}{10}}}{d^2} = \frac{4\pi\beta_2 P_n}{P_T A_s} \tag{6}$$

Where the atmospheric transmittance T (dB) is determined by the weather and other conditions, and signal to noise ratio β_2 is determined by the modulation. Take it for instance, the atmospheric visibility is 23 km, the atmospheric transmittance of sea surface is about 24.6%/km, whose equivalence T is 5.82 dB, modulation is BFSK, β_2 equals to 13.84. By solving the non-linear equations of formula(6), we can get the communication distance $d = 2.31km$.

Generally, we will add optical systems to the transmitter and receiver in order to increase the communication distance of UV-communications systems. The purpose of adding optical system to transmitter is to control the angle of the vision field and make light more focused and more uniform, but receiver of the optical system might use large-caliber receiver, which gets optical gain. At this case, the distance is:

$$\frac{10^{\frac{-dT}{10}}}{d^2} = \frac{2\beta_2 P_n \Omega_t}{P_T A_s G} \tag{7}$$

Where Ω_t is the field angle of the UV light source, and G is the optical gain of the receiver of optical system.

The calculation conditions of system are given as follows:

$$P_n = 1.0\times10^{-13}W \qquad P_T = 12W$$

$$A_s = \frac{\pi}{4}D^2 = \frac{\pi}{4}\times(15\times10^{-6})^2 = 1.77\times10^{-10}km^2$$

$$\Omega_t = \pi/4 \qquad G = 80$$

We computed the communication distance by using BFSK and BPSK respectively in different weather conditions and aerosol model. (see table 1and table 2).

TABLE I. DISTANCE OF BPSK (MIDLATITUDE SUMMER)

Aerosol model factor				
aerosol model (Clear)	Country VIS=23km	Country VIS=5km	Sea surface VIS=23km	City VIS=5km
LOS distance	5.50km	3.42km	6.20km	3.50km
Weather factor				
Weather condition	Fog VIS=0.2km	Fog VIS=0.5km	Light drizzle 2mm/hr	Light rain 5mm/hr
LOS distance	0.62km	1.31km	2.87km	2.76km
Weather condition	Medium rain 12.5mm/hr	Heavy rain 25mm/hr	Rain-storm 75mm/hr	
LOS distance	2.63km	2.39km	1.51km	

Comparing table 1 with table 2, it is not difficult to argue that there are certain differences in the communication distances between BPSK and BFSK under the same environment, and the differences become larger when conditions are poor. Take a typical marine environment model for example, communication distance of BPSK is 0.41 km further than that of BFSK, and increased by 7% .

TABLE II. DISTANCE OF BFSK (MIDLATITUDE SUMMER)

Aerosol model factor				
aerosol model (Clear)	Country VIS=23km	Country VIS=5km	Sea surface VIS=23km	City VIS=5km
LOS distance	5.14km	3.21km	5.79km	3.29km
Weather factor				
Weather condition	Fog VIS=0.2km	Fog VIS=0.5km	Light drizzle 2mm/hr	Light rain 5mm/hr
LOS distance	0.59km	1.24km	2.70km	2.60km
Weather condition	Medium rain 12.5mm/hr	Heavy rain 25mm/hr	Rain-storm 75mm/hr	
LOS distance	2.49km	2.25km	1.43km	

In addition the power of UV-light source can also affect the distance of UV communication system. Increasing of the source power can extend the distance to some extent. Take the typical mid-latitude summer clear marine environment for example, when the power of low-pressure mercury lamp increased 20 times (from 6 W to 120 W), the distance increase about 1.80 km. If source power increased from 100 W to 1000 W, the distance increase about 1.44 km. In the above-mentioned correspondence linear distance, within the framework of the marine environment source power doubled will lead to distance increasing of about 0.41 km and about 0.21 km under the urban environment.

V. CONCLUSION

We carried on analysis to the environment of marine atmosphere and investigated the influence of marine climatic condition such as wind speeds、rain rates、clouds、degree of fog thickness on the atmosphere transmittance of UV-light. The conclusion is that under marine atmospheric environment influence of wind speeds on UV atmospheric transmittance is smaller, but cloud thickness, rain rates, thickness of fog are all disadvantageous to the Ultraviolet light communication. Calculation is carried on for communication distance of two kinds of modulation under various environment using the MODTRAN model and find that the communication distance of BPSK is 7% farer than that of BFSK.

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