Experimental Characterizations of an Air to Land Channel over Sea Surface in C Band

***Yee Hui Lee*[1], *Yu Song Meng*[2], *Yew Heng Heng*[3]**

School of Electrical and Electronic Engineering, Nanyang Technological University
Block S1, 50 Nanyang Avenue, Singapore 639798
Email: [1]eyhlee@ntu.edu.sg, [2]meng0006@ntu.edu.sg

Abstract

This paper presents the experimental study of an air to land link at 5.69GHz over the South China Sea. The ground station is located at Seletar airport (1.42°N latitude and 103.87°E longitude) in Singapore. Sounding using continuous tones are recorded at 0.01s intervals. Through the analysis of the experimental results, it was found that for the long range terrestrial (air to land) propagation at low grazing angel, the evaporation duct over the sea surface seems to have little or no influence on the wave propagation. In fact, depending on the placement of the antenna, the aircraft itself can shadow the transmitted signal which results in a low received signal strength. These observations are further verified by a spread spectrum sounding technique.

1. Introduction

Rapid increase in aircraft density is resulting in the saturation of the current air traffic control (ATC) system which operates at VHF frequency bands. It is therefore of great interests to introduce a communication system in an alternative frequency band to satisfy this increasing demand. At present, C band is being assigned for Microwave Landing System-MLS in aviation navigation. Hence, it is very important and useful to perform a thorough air to land channel characterization in the C band in order to optimize the MLS performance.

D. W. Matolak *et al*. [1-2] has started interesting research work on wireless channel characterization for the 5 GHz MLS system. They have covered the characterization of both the small and large size airports, mainly for wideband characterization. In addition to these work, H. D. Tu *et al.* [3] conducted a comparative study of the system in both the current conventional VHF band and the evaluated C band. However, from open literature, little is known about the air to land link for C band at an airport near to the sea. The evaporation duct is a well recognized form of propagation mechanism that can result in a substantial increase in signal strength when signals at frequencies above 3GHz propagate over-water paths [4]. A. Kerans et al. [5] reported that there is typically a larger evaporation duct height in tropical waters as compared to those found in temperate cooler waters. Naturally, great interest arises in the investigation of the air to land link near to a tropical ocean. These results are important to modern military and commercial applications for a seashore country such as Singapore.

The main objective of this paper is to report on the preliminary study of an air to land channel characterization over a sea surface, following the previous investigation of a small airport environment [6]. The environmental effect on the received signal strength is discussed in details. This is helpful for future research work in this area.

2. Measurement Campaign

The equipments used for the continuous wave (CW) tone sounding measurement technique consist of a signal generator and a spectrum analyzer. Details of the measurement setup can be found in previous work [6]. A high power amplifier with a typical gain of 36dB and a blade antenna with a gain of 3dBi were used at the transmitter. The output from the signal generator is set to be -10dBm in signal strength to avoid power saturation. The blade antenna is mounted on top of the aircraft indicated by the black dot in Fig. 1. GPS data was logged continuously through GPS modem installed on the aircraft throughout the experiment so as to obtain instantaneous altitude, longitude, latitude, pitch and roll coordinates of the moving aircraft.

At the receiver, in order to simulate the control tower and ensure a good line of sight (LoS) condition between transmitter and receiver, the receive antenna was mounted on a personal lift at a height of 14m, placed within the airport. A directional antenna is used to capture the transmitted signal from the aircraft. The received signal is amplified by a low noise amplifier, down-converted to an intermediate frequency (IF) of 70MHz, and then recorded through a spectrum analyzer. The total gain of this front end of the receiver is 75dB. The span of the spectrum analyzer is set to be 2 KHz around its center frequency to minimize the noise bandwidth. In order to characterize the air to land link of interest, peak marker readings at 0.01s intervals were recorded by a data logger using a Labview program through a General Purpose Interface Bus (GPIB). All the data recorded was time stamped with the GPS time in order to synchronize the data collected and the aircraft location.

In order to gain a full insight of the air to land link, several measurement profiles have been conducted. Our previous work [6] has characterized the airport environment and reported that the empirical path loss exponent n and standard deviation σ to be 2.10 and 4.12dB for the departure channel, respectively. In this paper, the flight profile analyzed is when the aircraft is about 102km away from the receiver, flying over the South China sea (1.5^{o}N~2^{o}N latitude, 104.5^{o}E~105^{o}E longitude). This profile has an almost constant altitude of 6.4km and a circular flight path of radius 5km. The 3-D profile is represented in Fig.1 briefly. The measurements were conducted on a sunny day under windy weather conditions.

Figure 1. Three dimensional circular flight profile on Google Earth®

3. Results and Analysis

3.1 CW Observations

As can be seen from Fig.1, more than half of the distance between the air to land link is over the South China Sea. In this section, we will exam the received signal strength to investigate the possible effects of evaporation duct on this link. It is found that there is a local mean received power of -44.04dBm and a standard deviation of 0.97dBm. The large power variation may be due to the shadowing induced by the aircraft body and the variation of the link distance. Both effects will be discussed in details with multipath measurements.

For the air to land link in this flight profile, the received power can be predicted through the following basic formulation:

$$P_r = P_t + G_{tx} - L_{ch} + G_{rx} \tag{1}$$

where P_t is the transmitted power by the signal generator (set at -10dBm in this experiment), G_{tx} and G_{rx} are the gains of the transmitter and receiver systems (found to be 39dB and 75dB, respectively), and L_{ch} is the channel loss. In this paper, since it was found from the departure flight profile that path loss exponent (n=2.1) [6] is similar to the free space path loss exponent (n=2) and there is LoS between the transmitter and receiver, the path loss exponent of 2 will be used to estimate the expected received power. The free space loss formula is therefore used for the estimation of the channel of interest.

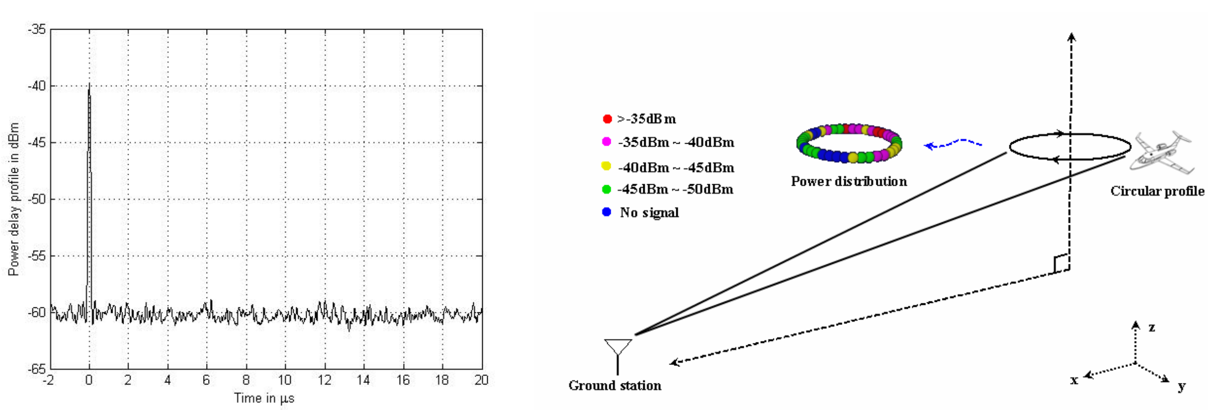
$$L_{ch} = 32.4 + 20\log_{10} f + 20\log_{10} d \tag{2}$$

where f is frequency in MHz and d is distance between transmitter and receiver in km. In this measurement, f is about 5690MHz and distance is around 102km. From (1) and (2), the estimated received power is approximately -43.7dBm.

This estimated received power (-43.7dBm) is compared to the measured local mean received power (-44.04dBm). It is found that the experimental value is slightly lower than that of the theoretical value. This may be due to the shadowing effect from the aircraft as observed in [6] and other unknown effects. The comparison indicates that there is little or no effects from evaporation duct for the air to land link where more than half of the distance is over the sea surface at this flight altitude (6.4km).

3.2 Verification

A multipath measurement campaign was performed with the sounding technique reported in [7] to verify the CW observations. The sounder transmitted a pseudo random sequence at a rate of 10 Mchips/s, giving the sounder a time resolution of around 100ns. The received signal (5.69GHz) was down-converted to an intermediate frequency (IF) of 20MHz and then digitized at a rate of 100Msamples/s. The receiver system was triggered and time stamped by a GPS system once per 4s to log the raw data when the aircraft was flying in a similar circular profile as shown in Fig.1. The similar flight profile is used so that the results reported on the CW measurements can be verified. The stored digitized signal is correlated with an identical sequence providing signal-to-noise ratio (SNR) improvement equal to the sequence length of 511 chips during the post processing. Further, noise reduction was obtained by arithmetically averaging about 32 repetitive power recordings, lasting about 1.64ms. Fig. 2 (a) shows a calibrated and averaged power delay profile at one of the triggered position. As seen, there are no multipath components in the processed results. Only a LoS component within the time resolution of 100ns is observed. This is consistent with the previous observation and assumption that a free space propagation model can be used for the received power estimation. The same processing operation was applied to the data logged at other triggered positions in the circular flight profile. The results are shown in Fig.2 (b) with different colors indicating the power level of the LoS received signal at the various locations on the flight path. The local mean received power for the multipath measurement as shown in Fig.2 (b) is found to be -42.7dBm. The slightly high power as compared to the expected value and the CW measurement results is because raw data with low SNR (low signal quality which is indicated by a "No signal" in Fig.2 (b)) is removed from the data set before the local mean power is calculated.



(a)Typical power delay profile (b) Spatial received power distribution

Figure 10. Results for multipath measurement campaign

However, the spatial power distribution for the LoS component in Fig.2 (b) shows an interesting phenomenon. That is, there is smaller or no signal when the aircraft is closer to the direction where the receiver (ground station) is located, indicated by the region shown (left side of the circular flight profile). This is because the aircraft was flying in a clockwise direction. When the aircraft is turning right (at the left side of the circular flight profile), the aircraft body is tilted in such a way that the propagating signal is blocked by the aircraft body. Similarly, the strongest received signal is located on the opposite side to the weakest received signal. This is because at positions where the received signal is the strongest, the aircraft body is tilted in such a way that the transmitting antenna is directly pointing towards the receiver resulting in a LoS signal with high gain. This is also verified by the recorded roll and pitch data of the flying aricraft.

4. Conclusion

This paper reports the preliminary study of the channel characterization of an air to land link at a single frequency in the C band for the evaluation of the new Microwave Landing System. In this paper, the air to land link that is mostly over the sea surface has been discussed. It is found that the received power can be predicted using the free space model and the effects of evaporation duct on the radio wave propagation over this link is very little and negligible. This observation is verified through the multipath measurement using a spread spectrum sounding technique. It is observed that the aircraft body produces shadowing on the transmitted signal when it is flying in a circular flight profile. The received signal strength is very much dependent on the position of the transmitting antenna and the roll and pitch of the aircraft.

However, further investigation is needed since there may be antenna pattern distortion when the blade antenna is mounted on the aircraft which may also be a reason for the spatial power distribution observed.

5. Acknowledgments

This work was supported in part by DSO National Laboratories, Singapore.

6. References

1. D. W. Matolak, N. T. Yaskoff, I. Sen, W. Xiong, "Characterization of the 5 GHz Wireless Channel for Small Airport Surface Areas," *Proc. 24th Digital Avionics Sys. Conf.*, Washington, DC, Oct.-Nov., 2005.

2. D. W. Matolak, "Wireless Channel Characterization in the 5 GHz Microwave Landing System Extension Band for Airport Surface Areas," *Final Project Report*, NASA CR-2007-214456, May. 2007.

3. H. D. Tu, Y. Tsuda, S. Shimamoto, J. Kitaori, S. Kato, "The Next Generation Air to Ground Communication System for Air Traffic Control," *Proc. IEEE/ACES Int. Conf. on Wirel Comm. and Applied Comput. Electromag.*, Apr. 2005, pp.1010-1013.

4. H. V. Hitney, L. R. Hitney, "Frequency Diversity Effects of Evaporation Duct Propagation," *IEEE Trans. Ant. Prop*, vol. 38, Oct. 1990, pp.1694–1700.

5. A. Kerans, E. Lensson, A. Kulessa, G. French, "Implications for Microwave Radio Path Design of the Evaporation Duct over Tropical Oceans in Northern Australia," *Proc. Workshop on the Applic. of Radio Sci (WARS'02)*., Australia, Feb.2002.

6. Y. S. Meng, Y. H. Lee, Y. H. Heng, "Channel Characterization and Modeling in C Band for a Small Airport," *Proc. 11th URSI Comm. F Open Symp. on Radio Wave Propag. and Remote Sensing*, Rio de Janeiro, Brazil, Oct-Nov, 2007, pp. 113–117.

7. Y. S. Meng, Y. H. Lee, B. C. Ng, "Wideband Channel Characterization in a Tropical Forested Area," *19th Asia-Pacific Microwave Conference (APMC 2007)*, Bangkok, Thailand, Dec, 2007, pp. 645–648.