Study of Shadowing Effect by Aircraft Maneuvering for Air-to-Ground Communication

Yu Song Meng and Yee Hui Lee

***Abstract*—This paper investigates the shadowing effect induced by an aircraft during maneuvering for air-to-ground communication at C band. Narrowband measurements with a linear flight route and a circular flight route have been conducted and the results are compared in this paper. It is found that, the communication link can easily be shadowed by the aircraft body. Due to this shadowing, the transmitted signal undergoes significant attenuation of up to 28 dB at 5.7 GHz. Results also show that spatial diversity at the ground station is unable to eliminate this shadowing effect caused by the aircraft during maneuvering.**

***Index Terms*—Aircraft maneuvering, Fading, Radio channel, Shadowing, Spatial diversity**

I. Introduction

CURRENT air traffic control (ATC) system that operates at VHF band is facing saturation due to the rapid increase in aircraft density. Therefore, an alternative frequency band, the C band, is assigned for the next generation ATC system to satisfy this increasing demand [1]. In order to optimize the new ATC system performance, knowledge of the C-band channel characteristics in different environments is required. Recently, Matolak *et al.* [2] have contributed extensive studies on the wideband channel measurements and characterizations for the airport surface environments in the 5-GHz band. For the air-to-ground channel, a comparative study of the current VHF system and the up-coming C-band ATC system has been reported by Tu *et al*. [1], where air-to-ground link over land at 5.8 GHz was investigated. In their study, C-band air-to-ground channel over land was estimated as free-space line of sight (LoS) propagation at a maximum altitude of 3 kft.

Although air-to-ground channel can be estimated as LoS propagation, our previous study [3] found that the aircraft during maneuvering can introduce shadowing of the C-band air-to-ground transmission. It is noted that, as compared to the current VHF ATC system, the shadowing by aircraft during maneuvering can affect C-band communication transmission severely. This is because; the C-band signal has a significantly shorter wavelength (*e.g.* 0.06 m at 5 GHz) as compared to VHF signal (*e.g.* 2.4 m at 125 MHz). The shorter wavelength is blocked and reflected by the metallic aircraft body easily. However, there is not much report on the effect of shadowing caused by the aircraft maneuvering at C band.

As a continued work, the main objective of this paper is to perform an experimental study of the shadowing effect induced by the body of the aircraft during maneuvering. Fade mitigation technique at ground station is also investigated. In the following section, a brief description of the measurement setup and experimental plan is given. In Section III, the shadowing effect is discussed with the coordinates (pitch, roll, and yaw) related to the aircraft maneuvering. The effectiveness of spatial diversity at the ground station as a shadowing fade mitigation technique is also evaluated and reported. Finally, Section IV gives a summary of the analysis from this paper.

II. Measurement Campaign

A. Measurement Setup

A vertically polarized, omni-directional blade antenna was mounted on an aircraft (Learjet-35A in this study) with a transmission of Effective Radiated Power (ERP) of 40 dBm. During the flight, GPS data was logged every second to get the instantaneous position (altitude, longitude, latitude) of the aircraft through a GPS modem installed on the aircraft. In order to study the shadowing effect introduced by the body of the aircraft during maneuvering, the pitch, roll, and yaw coordinates of the aircraft as shown in Fig.1 were also recorded.

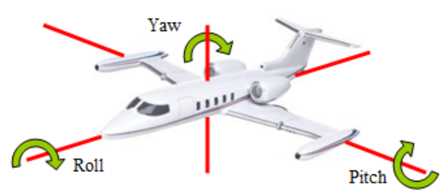

Fig. 1 Pitch, roll and yaw for an aircraft during maneuvering.

Two receivers were used at the ground station, with two identical directional antennas with a beam-width of 20° in the azimuth and 25° in the elevation direction. To create spatial diversity, the two receivers were placed with a height difference of 5.55 m and a horizontal separation difference of 6.46 m as in [4]. The received signals were amplified and

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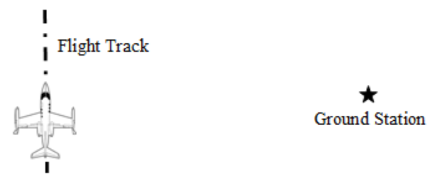
down-converted to 70 MHz IF signals, before they were captured by two spectrum analyzers and recorded into a control computer via GPIB interface at a rate of 5 peak marker readings per second. The total gain of each front-end receiver was about 80 dB. All the data recorded was stamped with the GPS time in order to synchronize the measured data with the location and orientation of the aircraft.

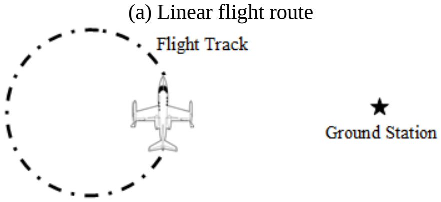
B. Measurement Plan

A significant problem encountered in the air-to-ground communication is the shadowing of the transmitted signal due to aircraft maneuvering. Due to the movement of the body of the aircraft, the propagation path between the antennas can be obstructed by its metallic body easily.

To study the shadowing effect by the aircraft during maneuvering, narrowband channel measurements with two different flight profiles; linear flight route and circular flight route as shown in Fig.2 were carried out over the South-China Sea at 5.7 GHz in February 2009. During the measurement, the aircraft altitude was kept at a constant of 3.2 km. The link distance was 35 km to 42 km for the linear flight route, and was 42 km to 46 km for the circular flight route.



(a) Linear flight route



(b) Circular flight route

Fig.2. Two flight scenarios for the study of shadowing effect by maneuvering.

Fig. 3. Open space in the coastal area

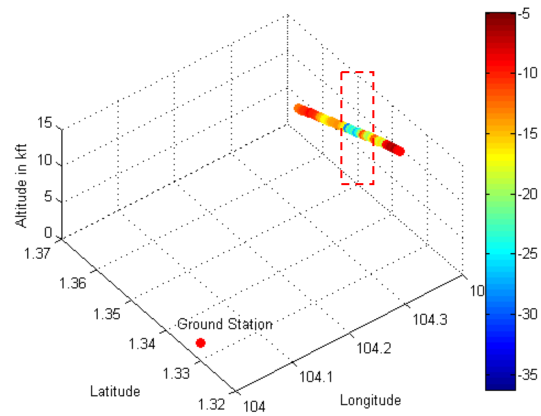
To eliminate possible shadowing/multipath effects from surrounding buildings [3], the ground station in this study is located at an open space at a coastal area on the eastern side of Singapore (1°20'07"N, 104°01'16"E) shown in Fig.3. The signal mainly propagates over the sea-surface and there is no blockage of the signal. During the whole measurement campaign, there was no rainfall.

III. Results and Discussions

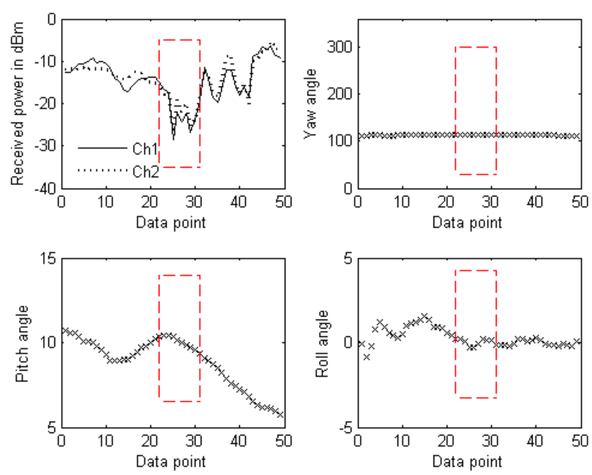
In this part, the measured data is averaged over 1 second time intervals to reduce the effect of noise and also to allow for easy synchronization with the GPS data of the aircraft.

A. Linear Flight Route

The aircraft will adopt its roll and pitch orientations with respect to the airflow even when it is in a linear flight route (*i.e.* no turning). Therefore, the original LoS link can be shadowed by the aircraft's tail or wings even when travelling in a straight line (normal cruise). In this study, measurements with a linear flight route as shown in Fig.2(a) were conducted. Fig.4 shows the received power versus the GPS coordinates and also the pitch, roll, and yaw values. It can be found that the received signal undergoes obvious power fluctuations even when the aircraft flies in the linear track.



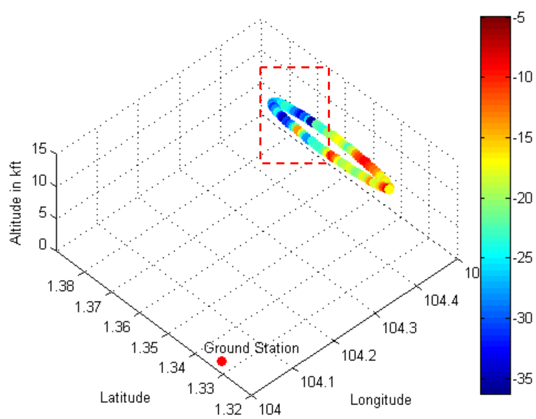
(a) Variation of the received power in 3-D geometry for Channel 1



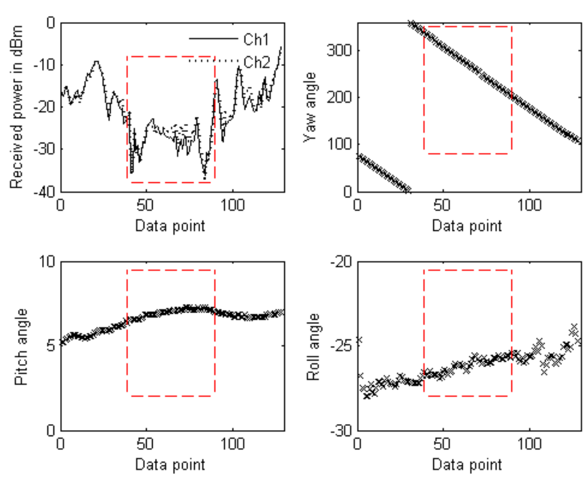
(b) Plots of received power, yaw angle, pitch angle and roll angle

Fig. 4. Results for a linear flight route

When correlating the received power with the pitch, roll, and yaw coordinates in Fig.4(b), it is found that the linear flight route has an almost constant yaw value of 112.7°, a slight variation of the roll angle (<1.5°), and a decreasing pitch angle. It is noted that, the decreasing pitch and an increasing roll angles (from data points 0 to 15) results in an unblocked transmission with an almost direct LoS path, therefore a high received power level is observed. At the region where there is a deep fade (in the red dashed box), the pitch angle reaches a local maximum and the roll angle almost reaches a minimum. In this case, the aircraft's wing is in the line of transmission, causing a fade due to the shadowing of the aircraft's wing. The shadowing caused by the aircraft's wing is found to be around 9.5 dB at 5.7 GHz with the offset of distance effect. As the pitch angle continues to decrease while the roll angle increases slightly (from data points 32 to 50), the transmission path is unblocked partially again and the received signal level then increases. It is noted that, the observed shadowing of 9.5 dB due to the aircraft's wing is during a normal cruise of the aircraft for air-to-ground communication. When the wing crosses the LoS link during a forced maneuvering, the signal shadowing can be up to 15 dB for a 20 GHz link as reported in [5]. Therefore, to have a clear idea of the shadowing effect caused by the aircraft body, a detailed study of a forced maneuvering with a circular flight route is reported in the following part.



(a) Variation of the received power in 3-D geometry for Channel 1



(b) Plots of received power, yaw angle, pitch angle and roll angle

Fig. 5 Results for a circular flight route

B. Circular Flight Route

As compared to the flight in a linear track, the shadowing introduced by the aircraft's tail or wings during a forced turning maneuvering is more severe. In this study, the influence from the turning maneuvering is studied with the measurements in a predefined circular track as shown in Fig.2(b). The measured received power is plotted against the GPS coordinates and also the pitch, roll, and yaw values in Fig.5.

From Fig.5, it is observed that the received signal in the circular track undergoes severe power fluctuations with deeper fades as compared to the linear flight route. The flight in the circular track with an almost constant velocity produce a linear change in the yaw value as shown in Fig.5(b), and results in a much larger angle shift from origin for the roll coordinate (> 24°) as compared to the linear track (<1.5°). The transmitted signal can be heavily blocked by both the aircraft's wing and/or tail. As shown in Fig.5(a), as the aircraft turn towards the ground station (indicated by the red dashed box), the shadowing due to the aircraft tail and/or body results in a significant deep fade. The shadowing can be up to 28 dB (with the offset of the distance effect) relative to the maximum received power during the predefined circular profile. As the aircraft turns away from the ground station (data points 0 to 39 and 90 to 128), there is an almost LoS transmission. Hence, the received signal is significantly high.

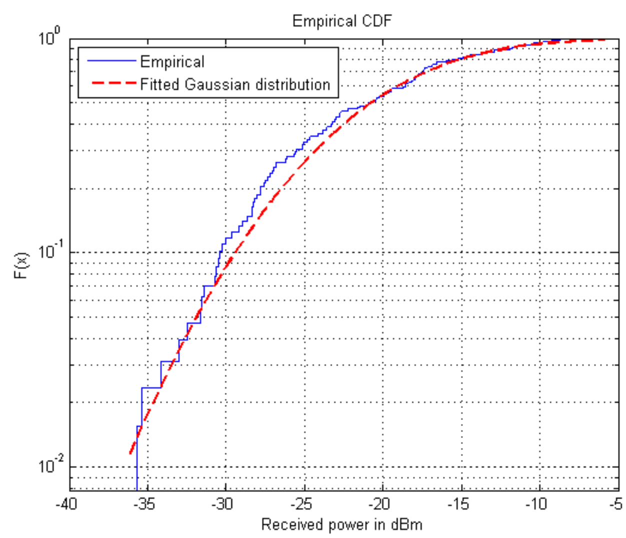


Fig. 6. CDF distribution of the received power for Channel 1 in the circular flight route

Statistical analysis of the received power with the shadowing due to aircraft body is conducted by using the cumulative distribution function (CDF). The CDF distribution of the received power for Channel 1 is shown in Fig.6 as an example. Similar results are observed for Channel 2. From the results, Gaussian distribution is found to be an approximate function to model the shadowing (fading) during the maneuvering of the aircraft in dB, indicated by the dashed line in Fig.6. The Gaussian distribution shows a good fit to the empirical results. The standard deviation about the median received power is found to be 6.77 dB and 6.49 dB for Channel 1 and Channel 2 respectively. It is noted that, the effect of distance on the measured results is small. For our measurements with LoS propagation, the maximum difference in the received power due to the distance is around 0.8 dB ($20\log_{10}(46/42)$ for free-space propagation), and this difference in power can even be smaller if there is some form of signal enhancement from the ducting effect [6]. Therefore, for air-to-ground communication, the shadowing effect due to the aircraft body needs to be taken into account during channel modeling. It was found that this shadowing effect can be approximated by the Gaussian function with a standard derivation of 6.49 dB to 6.77 dB from our measurements.

C. Spatial Diversity at Receiver

From the above-mentioned studies, it can be concluded that, the aircraft during maneuvering can introduce shadowing on the transmitted signal for the air-to-ground communication link. The shadowing can be up to 28 dB for forced turning maneuvering at 5.7 GHz, and can be up to 9.5 dB for the slight maneuvering while in a linear flight route. These levels of shadowing are enough to cause a total lost in link synchronization and connection.

Therefore, fading mitigation techniques such as multiple-antenna communication [7] are required to improve the air-to-ground links. However, in this study, it is found from the measured results that, the spatial diversity at ground station cannot improve the maneuvering-induced-shadowed links. The measured powers at the two receivers (Ch1 and Ch2 as shown in Fig.4(b) and Fig.5(b)) follow the same large-scale trend. Hence, multiple antennas should also be placed on the aircraft to ensure a clear communication path for all flight scenarios. However, when the airborne antennas are in view of the receivers, this could lead to a large number of self-interference nulls as reported in [8], where unitary space-time codes is suggested to overcome this array interference.

IV. Conclusion

In this paper, the shadowing effect introduced by the aircraft during maneuvering is experimentally investigated for the air-to-ground communication at C band. The shadowing effects in a linear flight route and a circular flight route have been discussed and compared. It is found that, the shadowing can be up to 9.5 dB at 5.7 GHz for the linear flight route, and up to 28 dB for forced turning maneuvering.

Moreover, fading mitigation technique with multiple-antenna at ground station is studied. It is found to provide little or no improvement to the maneuvering-shadowed-link. The multiple-antenna system on aircraft can be a useful technique. However, the self-interference of antennas on the aircraft needs to be considered.

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