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Orthogonal Transmit Diversity for Self-Interference Suppression in Multi-Antenna Telemetry Links *

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1 Introduction

One problem encountered in aeronautical telemetry is that during aircraft maneuvering, the transmission path is often obstructed by the air vehicle. Therefore, a second antenna is commonly placed on the aircraft to ensure a clear transmission path for all attitudes. However, when both antennas are in view of the receiver, this leads to an array interference pattern generally characterized by a large number of transmission nulls. Orthogonal transmit diversity schemes (space-time codes) can be used to overcome this interference without requiring additional bandwidth and with relatively straightforward implementation. In this paper, we illustrate how the Alamouti [1] and unitary differential space-time codes [2] can be used for this application.

2 Diversity Transmission

Consider a transmission system with two antennas (1 and 2) located at (x_1, y_1, z_1) and (x_2, y_2, z_2) respectively in the local coordinate frame of the air vehicle. If the receiving ground station is located at the point (r, θ, ϕ) in spherical coordinates, then the transfer function between the ith antenna, $i \in [1, 2]$, and the ground receiver station may be expressed as $h_i = e^{jk(x_i \sin\theta\cos\phi + y_i \sin\theta\sin\phi + z_i \cos\theta)}$ where $k = 2\pi/\lambda$ is the free-space wavenumber with λ the free-space wavelength. Note that we have neglected the term e^{-jkr}/r in the transfer function as this term is the same for all i.

For standard two-antenna transmission, each symbol is simultaneously radiated from both antennas. For an average symbol energy of E_s and noise power spectral density (PSD) of N_o, it can be shown that the received signal-to-noise ratio (SNR) is

$$\mathrm{SNR}_T = \frac{1}{2}\left|h_1 + h_2\right|^2 \frac{E_s}{N_o} \tag{1}$$

where the factor of 1/2 stems from equally dividing the power between the two transmit antennas. For widely-spaced antennas (typical for aeronautical telemetry), the coherent addition of the two transfer functions leads to severe nulls in the gain pattern at certain angles which significantly degrades communication reliability.

In contrast, consider the Alamouti transmit diversity scheme [1] originally introduced to combat multipath fading for wireless systems. Let two consecutive symbols be denoted as s_1 and s_2. During the first symbol time, antenna 1 transmits s_1 while antenna 2 simultaneously transmits s_2. During the second time slot, antenna 1 transmits $-s_2^*$ while antenna 2 simultaneously transmits s_1^*. The received signal in the two slots can be expressed as

$$\mathbf{r}_A = \begin{bmatrix} r_1 \\ r_2^* \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} \eta_1 \\ \eta_2^* \end{bmatrix} = \mathbf{H}_A \mathbf{s} + \boldsymbol{\eta}. \tag{2}$$

Using this form, it is simple to show that symbol detection can be performed using the operation $\hat{\mathbf{r}}_A = \mathbf{H}_A^\dagger \mathbf{r}_A$. The received SNR for this scheme can be computed to be

$$\mathrm{SNR}_A = \frac{1}{2}\left(|h_1|^2 + |h_2|^2\right) \frac{E_s}{N_o} \tag{3}$$

which, for our transfer functions equals the SNR of a single antenna transmission system. Therefore, this Alamouti scheme can completely remove the detrimental effects of the coherent interference

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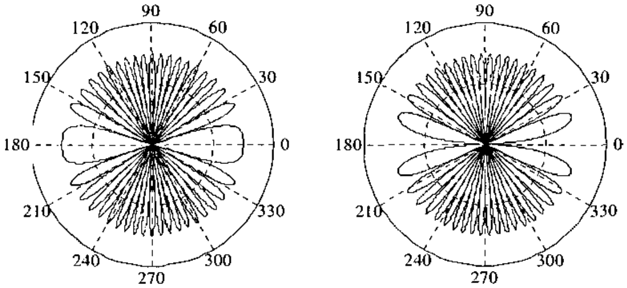


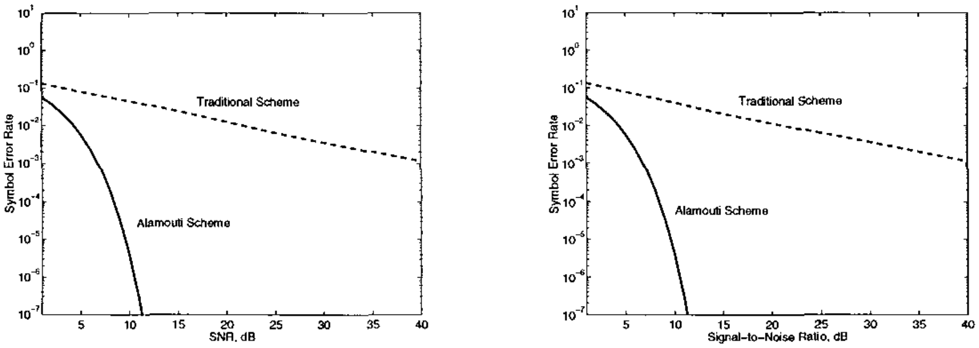
Figure 1: Gain pattern resulting from 2 antennas separated by 10λ for $\theta = 90°$. The two plots are for when the two antennas are in phase and out of phase, respectively.

created by the introduction of multiple antennas. Note that this performance gain stems from creating orthogonal transmit radiation patterns during the two consecutive symbol times (see the two patterns in Figure 1 which correspond to the patterns during the two symbol times for a specific example). Similar analysis reveals that other orthgonal transmission schemes, including those that do not require the receiver to know the channel matrix $\mathbf{H}_A$ [2], can be used with a similar outcome.

3 Results

In all simulations, we assume a horizontal antenna spacing of 20 ft., a vertical separation of 8 ft., a frequency of 1.5 GHz, and a ground antenna 400 ft. in front of the aircraft. For a given aircraft altitude, pitch, and yaw, we spin the aircraft a full rotation in the horizontal plane, calculating the transfer functions h_1 and h_2 at each of 36,000 angular sample points. The symbol error rate is then computed based on the statistics of the signal-to-noise ratio observed over this "maneuver" [3].

Figure 2(a) and (b) plots the probability of symbol error versus the single-symbol SNR for BPSK modulation when the aircraft is at 0 ft elevation with 0° roll (a), and 2000 ft elevation with 30° roll (b). As can be seen, the average symbol error rate performance for the traditional dual-antenna transmission scheme is quite poor. On the other hand, application of the Alamouti scheme for transmit diversity provides much better performance, achieving symbol error rates of 10^{-6} for SNR values on the order of 10 to 15 dB, which is identical to what would be observed with a single antenna (unobstructed) transmission. This confirms the dramatic performance gains offered by orthogonal diversity transmission.



(a) (b)

Figure 2: Symbol error rate for Traditional and Alamouti transmission schemes for BPSK modulation with (a) no aircraft elevation and (b) the aircraft at 2000 ft. in elevation and at a 30° roll angle.

References

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