MULTIPLE-INPUT MULTIPLE OUTPUT SYSTEM ON A SPINNING VEHICLE WITH UNKNOWN CHANNEL STATE INFORMATION

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ABSTRACT

This paper presents the investigations into the performance of a multiple-input multiple-output (MIMO) system with its transmitters on a spinning vehicle and no available channel state information (CSI) at the transmitter or the receiver. The linear least squares approach is used to estimate the channel and the estimation error is measured. Spinning gives rise to a periodic component in the channel which can be estimated based on the spin rate relative to the data rate of the system. It is also determined that spinning causes the bit error rate of the system to degrade by a few dB.

Keywords: Multiple-Input Multiple-Output Systems, Channel State Information, Channel Estimation

INTRODUCTION

One of the applications of MIMO is in the area of aerospace telemetry. The reason this technology can be beneficial is the geometry of the situation. Suppose an aircraft has only one transmitting antenna, then when it travels and turns at high altitudes there will be instances when the transmitted power towards the receiver is very low due to the transmitter pointing in a direction that is opposite to the receiver. Thus, the receiver loses connection with the transmitter for certain amount of time which can prove to be a very critical problem. This problem can be overcome by placing another antenna on the aircraft in such a way that at any instant, atleast one antenna will radiate signals towards the receiver. This will ensure that the receiver does not lose contact with the aircraft. The possible downside of this approach is that signals from the two antennas might interact with each other destructively and cancel out before the signals reach the receiver. However, the probability of this happening is extremely small.

This paper presents the investigations into the performance of an Alamouti space time coding scheme with its transmitters on a spinning vehicle and no available channel state information (CSI) at the transmitter or the receiver. The channel is estimated based on the least-squares approach. The spinning vehicle can be thought of as an aircraft or a missile with its body spinning at a constant spin rate. The spinning frequency is assumed constant relative to the spin axis. The geometry of the problem is depicted by Figure 1. The transmitters are assumed to be mounted on a spinning vehicle, and the receivers located on ground.

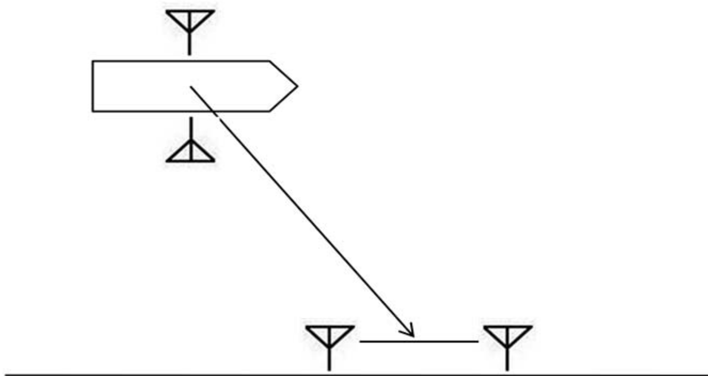

Figure 1 – Problem Geometry

It is assumed that the antennas at the transmitters and the receivers are placed sufficiently far apart, at least $\lambda_c/2$, where λ_c is the wavelength of the carrier, so that the channel paths are independent [1], [2]. The Rayleigh flat fading channel model is considered in this problem.

MODELLING OF A MIMO SYSTEM

Consider a MIMO system with N_t transmit antennas and N_r receive antennas. When a continuous wave signal, s, is transmitted from the j^{th} transmit antenna each of the N_r receive antennas observes a complex weighted version of the transmitted signal. The signal received by the i^{th} antenna can be given by $h_{ij}s$ where h_{ij} is the complex channel gain between j^{th} transmit and i^{th} receive antenna. The MIMO channel matrix can be denoted as [2]

$$H = \begin{bmatrix} h_{11} & \cdots & h_{1N_t} \\ \vdots & \ddots & \vdots \\ h_{N_r1} & \cdots & h_{N_r\,N_t} \end{bmatrix} \tag{1}$$

where $h_{i,j}$ is the complex channel gain between the i^{th} receive antenna and the j^{th} transmit antenna. If a signal vector $x = [x_1\ x_2 \ldots x_{Nt}]^T$ is sent from the transmit antenna array, that is x_j is sent from the j^{th} transmit antenna, the received signal $y = [y_1\ y_2 \ldots y_{Nr}]^T$ can be written as

$$y = Hx + n \tag{2}$$

where n is the N_r x1 noise vector. The elements of the noise vector are independent complex Gaussian distributed with zero mean and variance $\sigma^2 = N_o/2$. The elements of the channel matrix H are assumed to be independent, zero mean, complex Gaussian random variables. Since the elements of H are complex, it can be written as

$$h_{ij} = \alpha_{ij} e^{\theta_{ij}} \tag{3}$$

where α_{ij} is the amplitude gain between the j^{th} transmitter and the i^{th} receiver and θ_{ij} is the change in phase in those paths. The distribution of elements of H can be given as

$$f(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} \tag{4}$$

THE ALAMOUTI SCHEME FOR 2X2 SYSTEM

Alamouti [3] proposed a simple scheme for a system with two transmit antennas that could achieve full diversity and had a simple decoding algorithm. In this scheme, the binary data bits are first modulated using an M-ary modulation scheme. A block of two symbols, s_0 and s_1 is transmitted from each antenna in the same time slot. In the next time slot, $-s_1$* and s_0* is transmitted where (.)* denotes the conjugate operation. The transmit chain consists of a source data generator, a modulator and an Alamouti encoder. The receive chain comprises of a channel estimator, combiner and a maximum likelihood detector. The transmit matrix can be mathematically written as

$$S = \begin{bmatrix} s_0 & -s_1^* \\ s_1 & s_0^* \end{bmatrix} \tag{5}$$

For a 2x2 system, the system equation can be written as

$$R = H * S + N \tag{6}$$

where R is the 2x2 received matrix whose elements are represented by r_{ij}, N is the 2x2 noise matrix and H is the 2x2 channel matrix as described by (1).

The knowledge of channel is required at the receiver to decode the received signal. Let the estimated 2x2 channel matrix be given by $H_{est..}$ The receiver combining scheme can be written as

$$s_1^{\sim} = h_{11}^* r_{11} + h_{12} r_{12}^* + h_{21}^* r_{21} + h_{22} r_{22}^* \tag{7}$$
$$s_2^{\sim} = h_{12}^* r_{11} - h_{11} r_{12}^* + h_{22}^* r_{21} - h_{21} r_{22}^* \tag{8}$$

where h_{ij} are elements of the channel matrix H_{est} and $s_i^{\sim}$ is the i^{th} combined signal output

Let the channel gain in each path be given by

$$\alpha_1 = |h_{11}|, \alpha_2 = |h_{12}|, \alpha_3 = |h_{21}|, \alpha_4 = |h_{22}| \tag{9}$$

The output from the combiner and the channel estimates are input to the maximum likelihood detector which uses the following decision criteria for decoding.

for s_0 choose s_i if

$$(\alpha_1^2 + \alpha_2^2 + \alpha_3^2 + \alpha_4^2 - 1)|s_i|^2 + d^2(s_0^{\sim}, s_i) \leq (\alpha_1^2 + \alpha_2^2 + \alpha_3^2 + \alpha_4^2 - 1)|s_k|^2 + d^2(s_0^{\sim}, s_k) \quad \forall i \neq k \tag{10}$$

$$(\alpha_1^2 + \alpha_2^2 + \alpha_3^2 + \alpha_4^2 - 1)|s_i|^2 + d^2(s_1^{\sim}, s_i) \leq \quad (\alpha_1^2 + \alpha_2^2 + \alpha_3^2 + \alpha_4^2 - 1)|s_k|^2 + d^2(s_1^{\sim}, s_k) \qquad \forall i \neq k \qquad (11)$$

where $d^2(x,y) = (x-y)(x^*-y^*)$ which is the squared Euclidean distance between x and y in (10) and (11).

CHANNEL ESTIMATION: THE LEAST SQUARES APPROACH

The pilot-symbol-aided technique of least squares is used for channel estimation. In this method, based on the transmitted and the received data the maximum likelihood estimate of the channel is calculated.

Suppose the channel matrix be denoted by H, the training transmit matrix be X and the noise matrix be N, then the system equation can be written based on (2) and (6) as

$$S = HX + N$$

According to the LS algorithm, the channel matrix can be estimated as

$$H_{ls} = \; SX^{\dagger} \qquad (12)$$

where $X^{\dagger}$ represents $X^H(XX^H)^{-1}$ and $(.)^H$ denotes the Hermitian transpose

It is shown in [4] that if the power transmit constraint used is :

$$\|P\|^2 = \; P_t \qquad (13)$$

where ||.|| is the Frobenius matrix norm and P_t is a constant, then the estimate is given by

$$H_{ls} = H + \frac{N_t}{P_t} N X^H \qquad (14)$$

with N_t being the number of transmit antennas.

SPINNING OF VEHICLE

One of the assumptions for all the techniques described above is the transmitters and the receivers are stationary. But, if the transmitters are mounted on a rotating vehicle there will be a few changes to the system. The most significant change would be in the channel. Due to rotation, the channel gain between the transmitter and the receiver will continuously change depending on the speed of rotation and the angle between the transmitter and the receiver. The performance of the system will depend on not only the spinning, but also the radiation pattern of the antennas. We will look at two different radiation models. The first will be a mathematically simple model of a half cycle of a sinusoid. Then we will examine a more realistic model, where a sample patch antenna radiation pattern is used.

Half-Sine Wave Model. One easy way to model this is the 'half-sine wave model'. This assumes that full power is received by the receiver when the transmitter is facing the receiver, and as it moves away due to rotation the power received degrades as a sinusoidal function until it rotates about 90 degrees after which the receiver does not receive any power since the transmitter points in the opposite direction. As the transmitter rotates again towards the receiver, it will start receiving power based on the sine of the angle between the transmitter and the receiver. Figure 2 illustrates this concept. Since the system under consideration contains two transmitting antennas placed π radians apart, the pattern of the second antenna leads or lags the first antenna by a phase of π radians. Figure 3 and Figure 4 illustrate the half-sine wave pattern of two antennas for one rotation.

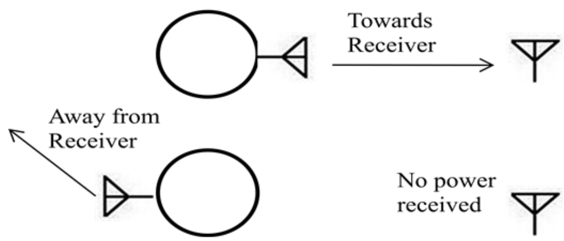

Figure 2: Radiated Power Direction

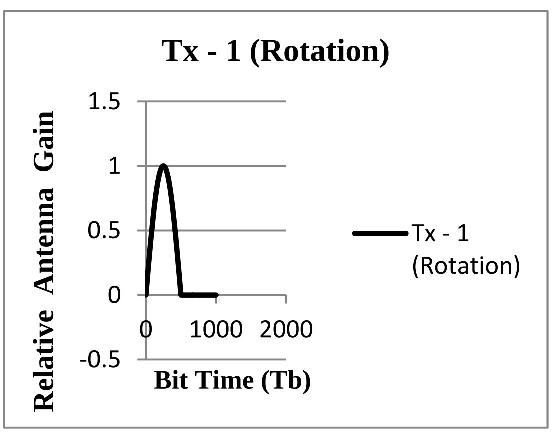

Figure 3: Antenna Gain w.r.t. Tx-1

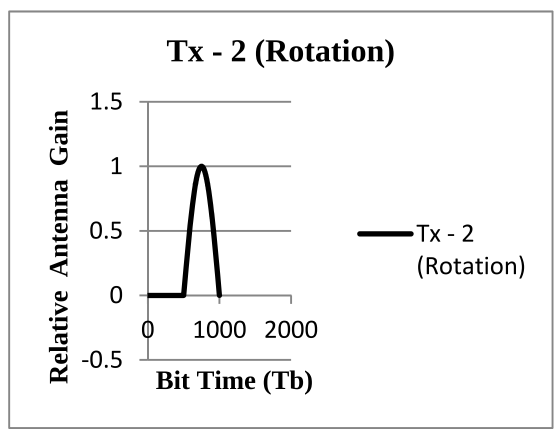

Figure 4: Antenna Gain w.r.t. Tx-2

Patch Antenna. A more practical case for modeling the spin of the transmitters would be replacing the values obtained from the half-sine-wave model by sample radiation pattern of patch antennas. Patch antennas are antennas which radiate maximum power in a certain direction Figure 5 and Figure 6 show the gain pattern of the transmitters for a sample radiation pattern of patch antennas with a rotation speed of 5 rot/1000 bits.

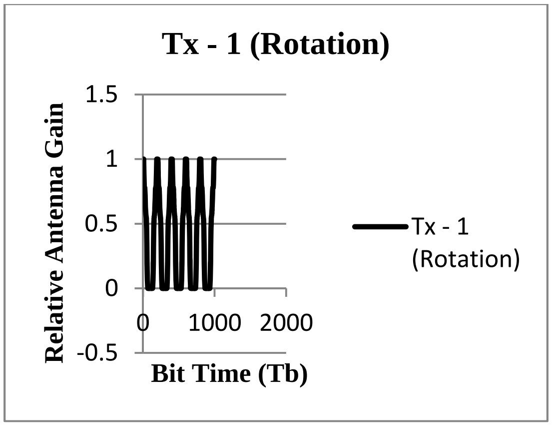

Figure 5: Antenna Gain w.r.t Tx-1

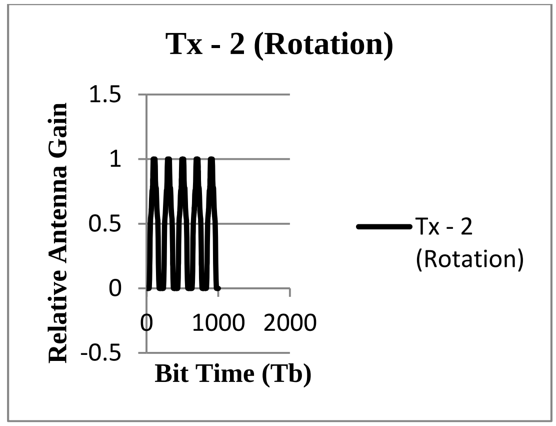

Figure 6: Antenna Gain w.r.t Tx-2

RESULTS AND DISCUSSION

BIT ERROR RATE (BER) CURVES

Figure 7 and Figure 8 show the bit error rate of a 2x2 system which assumes stationary transmitters with no CSI at the receiver and known CSI at the receiver respectively for BPSK modulation with Alamouti Coding. It matches well with the results obtained in [3] and [4]. A 95% confidence interval is used to generate the error bars.

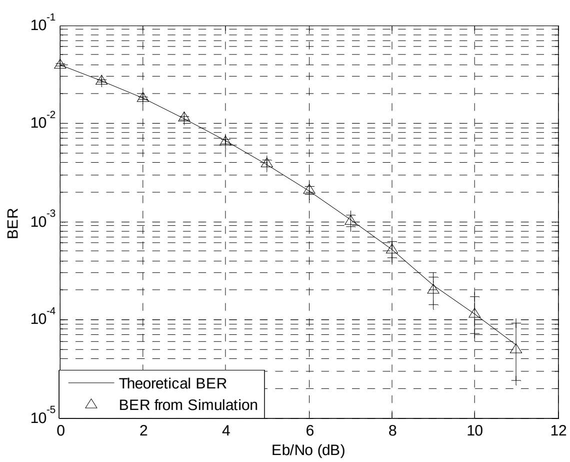

Figure 7: BER of 2x2 System with Stationary Transmitters and No CSI (BPSK)

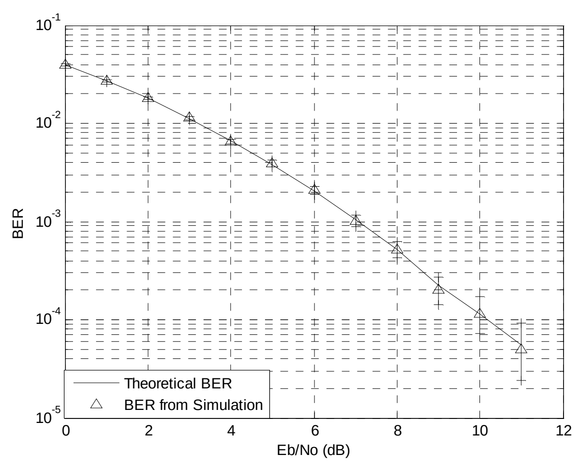

Figure 8: BER of 2x2 System with Stationary Transmitters and Known CSI (BPSK)

Figure 9 illustrates the channel error in least squares estimation and compares it (14).

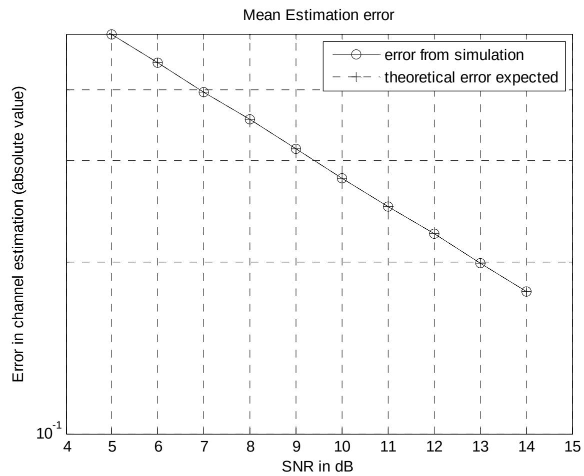

Figure 9: Channel Error in Least Squares Estimation

CHANNEL ESTIMATE

Figure 10 shows the channel estimate of a half-sine model for a sine wave frequency of $f_b/300$ Hz where f_b is the bit rate of the system which is assumed to be 1 kbps. Figure 11 shows the channel estimate when a sample radiation radiation pattern of a patch antenna is used. The rotation speed is assumed to be 20 rotations/1000 bits.

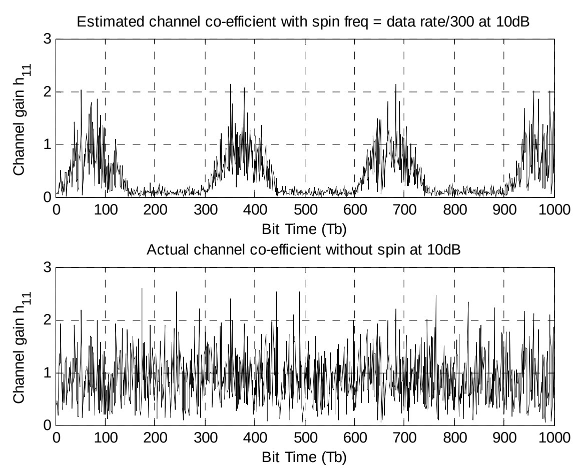

Figure 10: Channel Estimate for Rotating Transmitters at 10dB (half-sine model)

It is clear from Figures 10 and Figure 11 that there is a periodic component in the channel based on the spin rate relative to the data rate of the system.

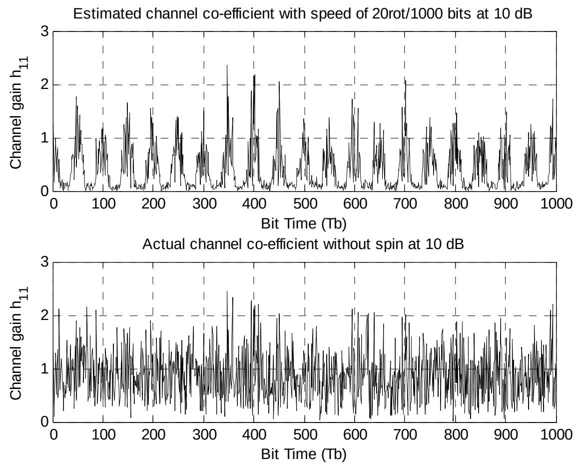

Figure 11: Channel Estimate for Rotating Transmitters (patch antennas)

BER CURVES FOR ROTATING TRANSMITTERS

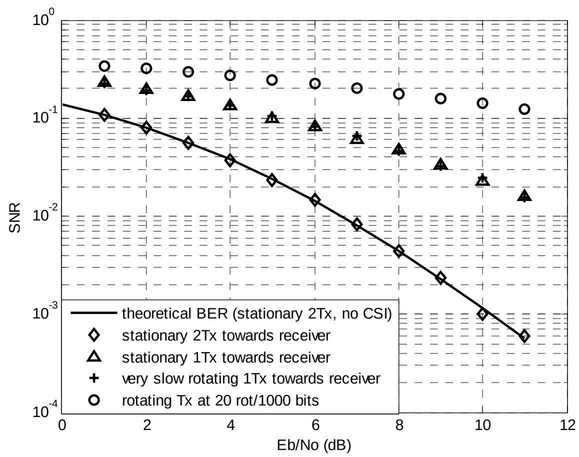

Figure 12: BER Comparison for Half-Sine Model (BPSK)

Figures12 and 13 show the bit error rate comparison when the half-sine model and the patch antenna model is used. It can be seen that the bit error rate of the system degrades by about 4 dB if the transmitters are kept stationary but one of the transmitters points away from the receiver. For a system which rotates the bit error rate further degrades by a few dB depending on the spinning model and the radiation pattern used. Also, when the system is rotating at 20 rot/1000 bits the half-sine gives a higher error rate. From the simulations, for this particular speed, it was found that the average antenna gain value for the half-sine model is 31.87%. This means that when the transmitters are rotating at 20 rot/1000 bits and the half-sine model is used for spinning, the power received from each antenna on an average is 0.3187 times the power received from them if they were stationary and pointing towards the receiver. The average channel gain value for rotating transmitters at a speed of 20 rot/1000 bits and when a sample radiation pattern is used for spinning is 42.32%. This could be the cause for the change in bit-error rates when different models for spinning are used.

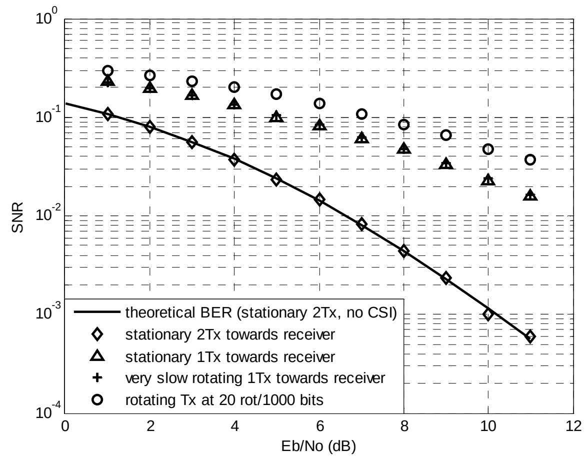

Figure 13: BER Comparison for Patch Antennas (BPSK)

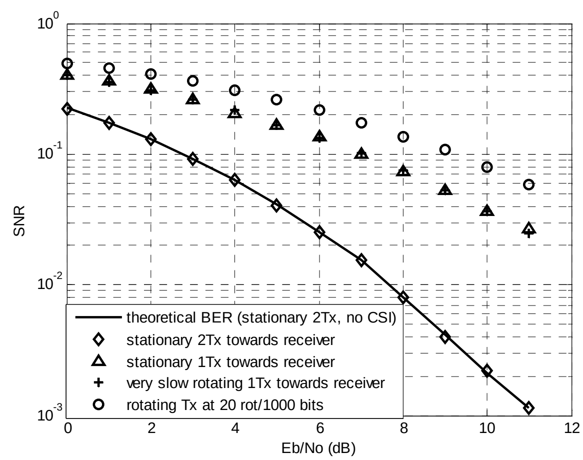

Figure 14: BER Comparison for Patch Antennas (QPSK)

It can also be seen that at extremely slow rotation speeds, the performance of the system is equivalent to a system with one stationary transmitter pointing towards the receiver. Figure 14 shows the results for system when Alamouti coding with QPSK is used. The bit error rate of the system is higher when Alamouti coding with QPSK is used as compared to BPSK. Therefore there is a tighter limit on spin velocity of the body if QPSK modulation is used. High rotation speeds might significantly degrade the overall performance of the system.

CONCLUSION

The performance of a Multiple-input multiple-output (MIMO) communication system with the transmitters on a spinning vehicle is investigated. It is assumed that no Channel State Information is available at the transmitter or the receiver. The linear least squares channel estimation was used to estimate the channel. It is found that spinning causes a periodic component to occur in the channel which can be predicted based on the spin rate relative to the data rate. It is also found that spinning degrades the bit error rate of the system by a few dB depending on the spinning model used and the radiation pattern of the antennas. Further, it is also seen that Alamouti coding with QPSK modulation has a higher bit error rate than Alamouti coding with BPSK modulation.

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