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To: Deuterium Array Group

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Subject: RFI Amelioration

a) Shielding of local fixed RFI sources

We are trying to shield all local sources of emission from 327.3 to 327.5 MHz. Since these are relatively constant low level signals they will be hard, if not impossible to excise from the data without dropping frequency channels.

b) Transient excision

Data can be excised by calculating the deviation of every point from the average or best fit polynomial in units of the theoretical standard deviation. If any point exceeds a fixed threshold then the entire block of data can be ignored or only those frequency channels which exceed the threshold can be excised so that they are not part of the cumulative sum. The threshold should be set at about 6 sigma in order to make it unlikely that data will be excised due to the noise when no RFI is present. If only a subset of frequency channels are excised systematic errors in the accumulated spectrum can result unless great care is taken to first normalize each spectrum by removing gain and baseline drifts. Since transients are infrequent it may be best not to attempt any frequency selective excision. The loss of SNR is $(1-\beta)^{1/2}$, where β is the fraction of time lost.

c) Time scales for transient excision

The excision can be carried out on all but the very longest time scales. In practice most transients are caught in the 500 second integration period of the recorded data output. It is also necessary to excise data on longer periods to remove the weaker transients. It may be advantageous to continue the excision on time scales of 4, 16, 64 × 500 seconds. The integration time factor increase of 4 is reasonable because a transient at threshold that is not excised will be easily detected in 4 times the integration if the signal is present for the full period. If it is only present for half the full period it will still be at the threshold but its overall effect will be tolerable if the frequency of occurrence is low.

d) Effect of signals not excised

The overall effect of signals which occur at a level of 5, duration τ and frequency k occurrences per second is $s\tau k$

e) Effect of low level quasi constant multipathed RFI

The beam is the phased sum of the individual elements

$$b = N^{-1/2} \sum_k X_k e^{i\theta_k}$$

so that the beam power is

$$bb^* = N^{-1/2} \sum_k \sum_\ell X_k X_e^* e^{i\vec{k} \bullet (\vec{r}_k - \vec{r}_\ell)}$$

where $\vec{k}$ is the direction of the beam in units of $(2\pi/\lambda)$. If the RFI source consists of many coherent multipath components

$$X_k = \sum_n x_n e^{i\phi_n} e^{-i\vec{k}_n \bullet \vec{r}_k}$$

where $\vec{k}_n$ is wave number vector of the multipath

$\vec{r}_k$ is the location of the element

ϕ_n is the phase of the multipath component

If the array elements are many wavelengths apart at random locations the phases of the RFI are random in the beam so that

$$\langle bb^* \rangle = \langle |\chi|^2 \rangle$$

where the $\langle \; \rangle$ denote an ensemble average over many directions of the rfi except the direction of the beam. If the RFI is in the direction of the beam then $bb^* = N|X|^2$.

The noise in the average spectrum from each element is $N^{-1/2}$ times the noise in the beam so that the average spectrum provides a very sensitive measure of the effect of RFI on the spectrum of the beam. For an array with spacing under a wavelength between elements the effect of RFI on the beam is typically less than the effect on the average spectrum. Defining the ratio $R = \langle bb^* \rangle / \langle |X|^2 \rangle$ useful as the RFI susceptibility ratio provides a useful measure of the sensitivity to RFI. For a 5×5 array with uniform spacing and beam normal to the array. Taking an ensemble average of RFI from all directions at the horizon or an ensemble of multipathed RFI with many components in random directions yields the same result.

Spacing (λ)	R
0	25
0.2	0.17
0.4	0.02
0.6	0.01
0.8	0.02
1.0	3.2

Since the R varies rapidly with the beam direction it makes more sense to include a range of beam directions from 60° to 90° elevation in the ensemble average. In this case

Spacing (λ)	R	6 dB gain
0	25	19
0.2	1.0	1.0
0.4	0.15	0.32
0.6	0.15	0.33
0.8	0.53	0.60
1.0	1.7	1.5

The susceptibility increases substantially when the beam is steered away from the normal to the array. Reducing the number of elements from 25 to 24 has a negligible effect. The results for a simulated array with 6 dB rms variation in gain among elements used in the beamforming degrades the RFI immunity as shown in the last column of the table. For our 24 element array with 0.8 λ spacing the RFI susceptibility ratio as about 0.6. This means that the RFI signals in the average spectrum from all elements of all arrays needs to be at the level of about 10^{-6} or about 20 dB below its current level to avoid significant contamination of the deuterium spectrum.