Properties of RFI Lines in the VLA VHF Band

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One of the challenges of direct observations of the Epoch of Reionization (EOR) is the radio frequency interference (RFI) environment in which the signals are embedded. Features in HI emission are expected to be redshifted to around one or a few hundred MHz, which is a band used heavily for FM radio and television broadcasts. While new instruments such as the Mileura Widefield Array are being built in radio quiet locations to minimize the impact of RFI, current instruments that have the potential to observe or place limits on EOR features do not have this luxury and must try to observe through the busy spectrum. This typically means finding gaps in either frequency, time or both, however many of the new arrays and correlators will offer the flexibility to deal with RFI more directly, by canceling it – for example by steering array nulls in the direction of transmitters.

One EOR experiment involving existing facilities has been attempted at the Very Large Array (VLA) in New Mexico. VHF dipoles were attached to existing P-band dipoles and fed into a receiving system operating in the frequency range 184-198 MHz, and then to the existing VLA correlator. A major source of RFI that affected these observations was the channel 10 television transmission, which has its central frequency at f_0 = 193.25 MHz. Even when observing outside the 6 MHz band shown graphically in figure 1, the NTSC video format has a horizontal sync signal with a rate of 15.734 kHz, which shows up in the VHF spectrum as a comb of RFI lines separated by that frequency. Examples of the horizontal sync comb are given in figure 2.

In this report we demonstrate that the varying phases of the RFI is associated with the natural fringe frequency of the phase-tracking center, and that much of the structure in the observed signal power is explained by the associated decorrelation. The observations presented contain RFI from channel 10 at the upper end of the VLA band at 193-197 MHz, and can be seen in figure 1. The data was taken while tracking the VLA calibrator source J0542+498.

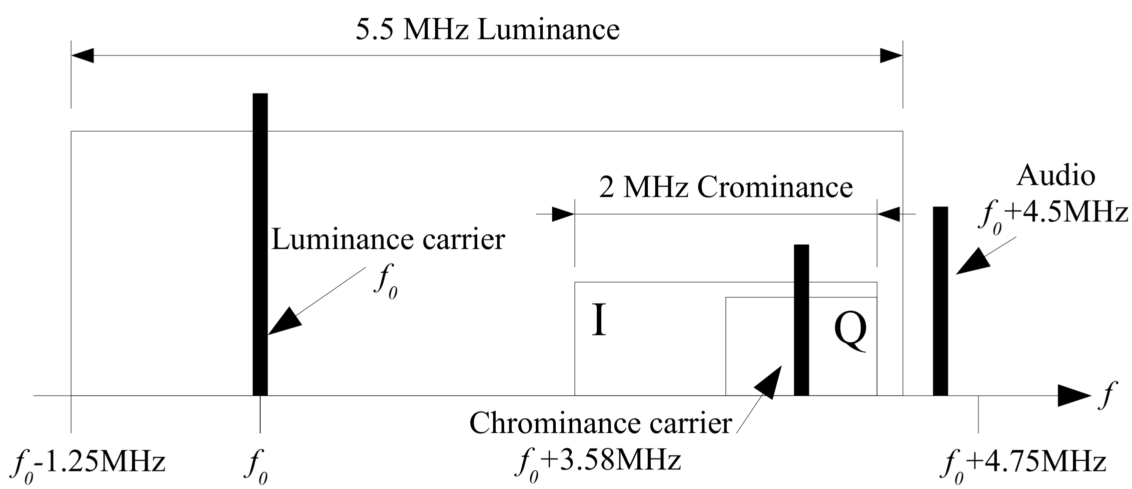

Figure 1: The spectral make up of an NTSC video channel. The luminance controls the black and white picture, with color information added by the crominance sub-bands.

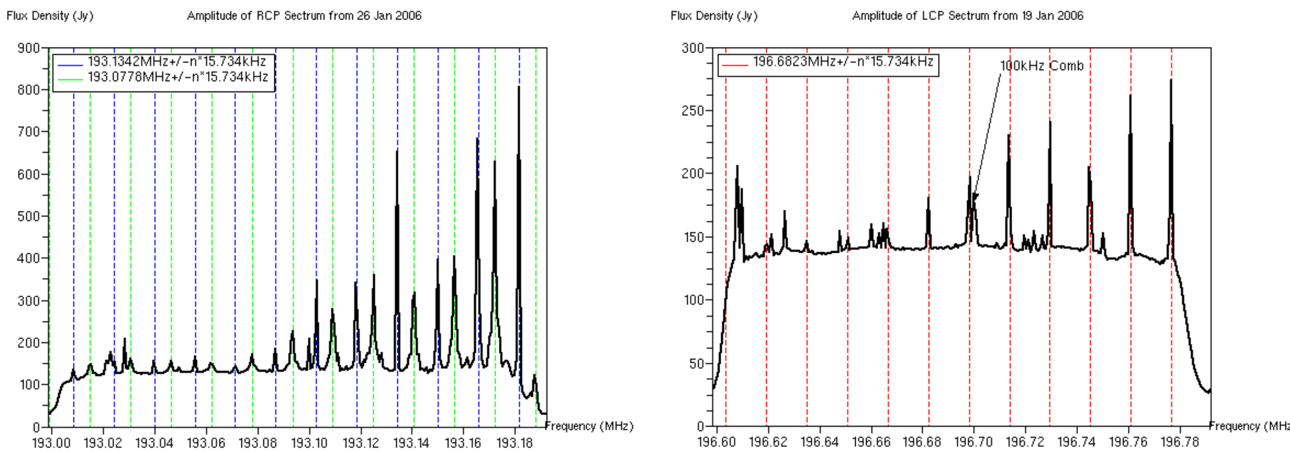

Figure 2: Scalar averaged cross-power spectra in two parts of the VHF band, 192.96-193.29 MHz and 196.58-196.80 MHz.

While the comb nature of the RFI observed in the VHF band means that it occupies a large proportion of the spectrum (every channel if the desired correlator setup for EOR observations is used), it tends to decorrelate due to the fringe rotation applied during down conversion to remove the natural fringe-frequency phase shifts of the desired cosmic signals (Thompson et al., 1986). This fringe stopping introduces negative fringe-frequency phase shifts in any stationary terrestrial RFI signal, leading to decorrelation of the RFI power, *I*, in the visibility measurement:

$$I' = I \left| \frac{\sin(\pi \nu_f \tau)}{\pi \nu_f \tau} \right|, \qquad (1)$$

where

$$\nu_f = dw/dt = \omega_e u \cos\delta, \qquad (2)$$

is the natural fringe frequency of the phase-tracking center given by the angular velocity of the Earth's rotation, ω_e, the declination, δ, and the *u* and *w* components of the visibility *uvw* position.

Time sequences of visibilities from single spectral channels and baselines were taken from the data shown in figure 2 and the FFT algorithm was used to extract the fringe rate from the phase time series. The fringe rate spectra for baseline 09-17, along with fitted Gaussians, are shown in figure 3. Since there is also a cosmic source involved with no fringe rate, the spectrum contains two peaks which may be blended when the RFI fringe rate is small. To avoid any confusion the fringe rates were used to unwrap the phase time series and the gradient of the phase change was measure directly. Table 1 contains the fringe rates obtained from the data as well as the fringe rate calculated using (2).

Baseline:	***08-09***	***08-17***	***08-19***	***08-26***	***09-17***	***09-19***	***09-26***	***17-19***	***17-26***	***19-26***
196.7MHz, 19 Jan 2006, ACTST	2.29 2.25	0.92 0.94	1.87 1.89	1.74 1.73	3.21 3.19	4.12 4.13	0.54 0.52	0.95 0.94	2.65 2.67	3.71 3.62
193.1MHz, 26 Jan 2006, ACTST	1.70 1.63	16.59 16.50	5.79 5.71	2.19 2.11	14.96, 14.88	4.09 4.08	0.50 0.49	11.06 10.80	14.66 14.39	3.61 3.60

Table 1. Average fringe rates (Hz) for RFI observed on various baselines in January 2006. Upper values are calculated from the data, while lower values are calculated with (2).

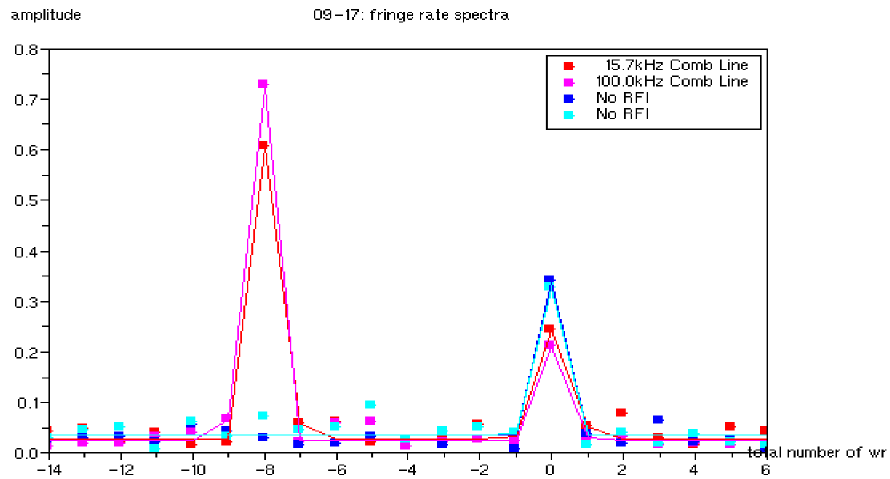

Figure 3. Fringe rate spectra for four frequency channels from the January 19 data. The two RFI lines were separated by a single frequency channel at 196.7 MHz. The peaks at -8 show that the phase of the RFI is changing at a rate that gives about 8 negative wraps in the range [0,2π] radians during the time interval used in the FFT (about 15 minutes). The peaks at zero show the result of fringe stopping for the cosmic source.

The fringe rates from Table 1 were used with (1) to predict decorrelation as a function of time (see figure 4). The dashed lines show the best fit of I' from (1) to the data where ν_f, was calculated using (2) and the fit was run over three parameters: 1. uncorrelated amplitude I; 2. vertical offset; and 3. the time derivative of I (to allow for a slow change in the amplitude). While variation in the RFI power due to factors such as movement of the antennas and transmitted power complicate the observed signal strength, the RFI power has the basic structure given by theory.

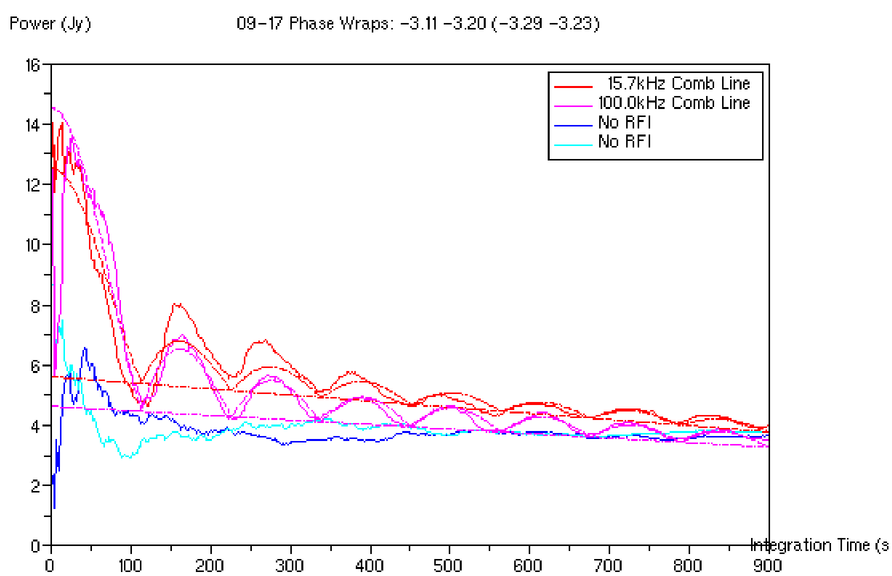

Figure 4. Decorrelation of the RFI comb lines as a function of integration length. The blue and cyan lines are from spectral channels without RFI, and contain the power from the cosmic signal. The flux density has not been calibrated, so the units of Jy are incorrect.

Bibliography

Thompson, A. R., Moran, J. M. and Swenson, G. W., Jr.Interferometry and Synthesis in Radio Astronomy1986