The NASA HRMS Sky Survey X-Band Observations: A Progress Report

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Abstract: The Sky Survey Element of NASA's High Resolution Microwave Survey (HRMS) has been actively engaged in a Search for ExtraTerrestrial Intelligence (SETI) since. October 12, 1992, using a prototype system with a 2097152-channel spectrum analyzer operating primarily at X-Band frequencies. While the frequency coverage of the prototype and the telescope time being, devoted to the search are only a small fraction of our ultimate intentions, they represent a substantial search capability and provide valuable field experience in doing SETI. As of July 30, 1993, we have identified no ETI signals at a sensitivity level of approximately 5x 10^{-22} W/m^2 over a search space of 30 MHz-sr. The prototype system is performing well, with sensitivity and false slam statistics consistent with theoretical predictions in the absence of Radio-Frequency Interference (RFI). There are no known anomalies in the data.

Introduction

As part of the Sky Survey Element of NASA's High Resolution Microwave Survey (HRMS), we have been engaged in a Search for ExtraTerrestrial Intelligence (SETI) since October 12, 1992 (Klein *et al.* 1993, Tarter *et al.* 1993). Our observing, system (called the Sky Survey Prototype System, or SSPS) is intended as a tool to aid in the development of a final operational system. Our primary focus in using the SSPS has been to gain field experience for the design and construction of the Sky Survey Operational System (SSOS). The SSOS will provide 16 times the frequency coverage of the SSPS, and will incorporate lessons learned from our SSPS activities.

As a distinct subset of our SSPS activities, we are conducting an X-Band Survey with the. SSPS, using the 34-m antenna at the Advanced Development (Venus) site of NASA's Goldstone Deep Space Communications Complex. We are using techniques as close as possible to those anticipated for use with the SSOS, and are operating at frequencies between 8300 MHz and 8600 MHz. In this frequency range there is very little Radio Frequency Interference (RFI) at this site., anti we have used minimal RFI rejection algorithms. More elaborate RFI rejection schemes are under development (Olsen *et al.*, 1993). As of July 30, 1993 we had covered 29 MHz-sr, counting each circular polarization separately (e.g., observing a 1 steradian patch of sky with 1 MHz bandwidth in a single circular polarization would increase the total coverage by 1 MHz-sr). in this paper we report the results to date from this X-hand Survey.

Survey Parameters

An overview of the HRMS Sky Survey is given elsewhere (Klein *et al.* 1993, Klein *et al.* *199?.), so* we will concentrate here on details of the X-Band observat ions and assume that the reader is familiar with the broad project outlines, including sky pixelization and the racetrack scanning pattern. The antenna speed is kept constant at 0,2"/See, and the total system temperat ure for a typical observation is about 45 K, including atmospheric emission. Spectra are taken every 52.4 mSec (i.e., at the maximum rate allowed by the 19.(I7 Hz channel width), and accumulated together 2 at a time for an output data rate of 2,097,152 channels every 105 mSec. The data are passed through a convolutional filter of width 524 mSec (5 accumulations) with weights matched to the (Gaussian) antenna gain pattern, thresholded, and recorded on magnetic disk.

As shown in Figure 1, the X-Band SSPS survey is being done with scanline separation of 1 HPBW (0.067") in sky frames of length 30". in order to minimize spatial scalloping, we arc using a Singlet/Doublet detection algorithm, in which events which recur in adjacent scanlines at nearly the same frequency and location are given extra weight. As a result, there arc 3 separate thresholds: T_{HW}, T_S, and T_D. Whenever the reported power in a single channel is greater than T_{HW}, the event is called a "hit". Hits whose reported power is greater than T_S arc saved as Singlets. A pair of hits which are reported in adjacent scanlines within 100 frequency bins (1907 Hz) and within 1 HPBW of each other is considered a Doublet if the sum of their reported powers is greater than T_D. A small number of channels (typically less than 0,01% of each sky frame) is automatically masked when an excess number of hits in the same channel at different spatial locations indicates the presence of RFI.

From each sky frame, the 10 strongest Singlets and the 10 strongest Doublets are chosen for re-observation, If two or more Singlets or Doublets chosen for re-observation are found to be within 1 HPBW, only the strongest is kept and the others arc replaced with spatially distinct targets. The re,-observations are called lookbacks, and they achieve much greater sensitivity than the original apparent detections by spending 30 seconds on each target, where the original sky frame devoted only 0.3 Sec to each 1 IPBW. The full 40 MHz bandwidth is used to rc-observe each location, but a lookback hit is only considered significant if it lies within ±5000 bins (±95 kHz) and ±1 1 IPBW of a Singlet or Doublet from the original sky frame. in the event that one of the lookbacks shows such a repeat, follow-up observat ions are performed.

Lookback observations arc performed as soon as practical after the original sk yframe. Usually the lookback observations begin within 10 minutes of completion of the cm-responding sky frame. The origins] sky frame currently takes 80 minutes to observe and the 20 lookbacks require a total of 25 minutes, so normally a lookback takes place within 2 hours of the original apparent detection. Because of limitations on telescope time and restrictions set by the horizon and limited mobility of the telescope for targets at zen it h, some look backs were performed considerabl y later. The surve y coverage can therefore only be considered complete for sources which remain active for several days.

To do a meaningful survey, we must calculate a limiting sensitivity. The limiting sensitivity of a sky frame is determined by the weakest Singlet and weakest Doublet chosen for re-observation. To get the. limiting sensitivity for the entire survey, we must take the least sensitive sky frame, and then account for spatial and spectral scalloping. in the worst-case sky frame, the. weakest re-observed Singlet has an input Signal to Noise Ratio (SNR) of 5.3, after subtracting the 90% confidence level minimum contribution due to thermal noise. The worst possible spatial location is an across-scanline position just close enough to a scanline to be more readily detected as a Singlet than as a Doublet, while falling exactly on a boundary between accumulations in the (over-sample(i) along-scanline direction. This results in a spatial efficiency factor of 0.49. Similarly, a signal which fell exactly between two frequency channels would (with our present rectangular time-domain windowing) be weaker by a factor of 0.4]. The Singlet sensitivity is thus

$$S_{Singlet} = \frac{SNR_{sing} \, kT_{sys}}{A_{eff}\,\varepsilon_{spatial}\,\varepsilon_{spectral}} = \frac{(5.3)(19\ Hz)(1.4\times10^{-23}\ J/K)(45\ K)}{(0.65)\,\pi\left(\frac{34\ m}{2}\right)^2 (0.49)(0.41)} \approx 5\times10^{-22}\ W/m^2$$

The calculation for Doublets is more complicated. By choosing to re-observe the 10 strongest Doublets, wc arc imposing an additional boundary condition cm the sensitivity, with a corresponding spatial sensitivity. The Doublet spatial efficiency factor is based on the worst-case spatial position which is consistent with both Doublet boundary conditions .

and also does not result in a re-observed Singlet. The net effect is a worst-case Doublet sensitivity of

$$S_{Doublet} = \frac{\alpha_{Doublet}\, b\, k T_{sys}}{A_{eff}\, \varepsilon_{spatial}\, \varepsilon_{spectral}} = \frac{(4.2)(19\ Hz)(1.4x10^{-23} J/K)(45\ K)}{(0.65)\,\pi\,(\frac{34\ m}{2})^2\,(0.42)(0.41)} \approx 5x10^{-22}\ W/m^2$$

The calculated limiting sensitivity of $5x10^{-22}$ W/m^2 is only valid for signals within the search space. We have assumed 100% duty cycle, circular polarization, bandwidth much less than 19 Hz, and a source which is fixed on the. celestial sphere with frequency drift less than 19 Hz in 0.5 Sec ($\dot{f}/f < 4.3x10^{-9}$). Relaxing any of those assumption s degrades the sensitivity. Subject to the assumptions stated, we have searched 29 MHz-sr (see Figure 2).

Results

The data from the X-Band SSPS survey to date are consistent with theoretical predictions based on thermal noise, and contain no known anomalies. As of July 30, 1993, we have observed 57 sky frames and detected no evidence for extraterrestrial intelligence (see Table 1). As a reliability check, several sky frames were observed at a time and frequency such that they contained one of NASA's spacecraft. The spacecraft transmissions were detected at the expected locations, frequencies, and power levels. The Singlets and Doublets resulting from spacecraft have been excluded from Table 1.

Of the 1140 lookback observations, 2 produced repeats of a Singlet or Doublet from the initial sky frame. We re-observed the locations of the two repeats multiple times, and saw no evidence of any transmitters within ±5000 bins (95 kHz) and ±1 HPBW of the initial hits. Based on purely thermal statistics, with no ETI and no RFI, the expected number of repeats for 1140 lookbacks is 3±2.

Table 1. HRMS Sky Survey X-Band Results

	Sky frames	Singlets and Doublets	Lookbacks	Repeats	Candidates
Total as of July 30, 1993	**57**	4598	1140	2	**0**
Notes	40 MHz Single-Pol.	not including 172 from S/C	20 per sky frame	3 expected	

In the absence of signals (whether of terrestrial or extraterrestrial origin) we calculated the expected detection statistics of the SSPS. Using the Singlets from the 57 sky frames, we compare the actual Probability of False Alarm (PFA) with the PFA expected due to thermal noise. The cumulative PFA statistics are consistent with theoretical predictions over a range of PFA from 1 to 10^{-12}. Figure 3 shows the cumulative PFA vs. Threshold for the critical (low PFA) part of the distribution. Similarly, the distribution of Singlets and Doublets over the spectrum analyzer bandpass is consistent with a uniform distribution (Figure 4).

Conclusions

Operating in the nearly IW1-free environment of NASA's Goldstone Deep Space Communications Complex at frequencies between 8300 and 8700 MHz, the HRMS Sky Survey Prototype System is working very well. After 9 months of operation, there are no known anomalies.

Within the 29 MHz-sr we have observed, there are no signals present which have the assumed parameters and are stronger than 5×10^{-22} W-m^{-2}, at the 90% Confidence Level. We have assumed circularly polarized signals with frequency drift less than 19 Hz in 0.5 Sec, bandwidth much less than 19 Hz, and 100% duty cycle, fixed on the celestial sphere.

Acknowledgments

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References

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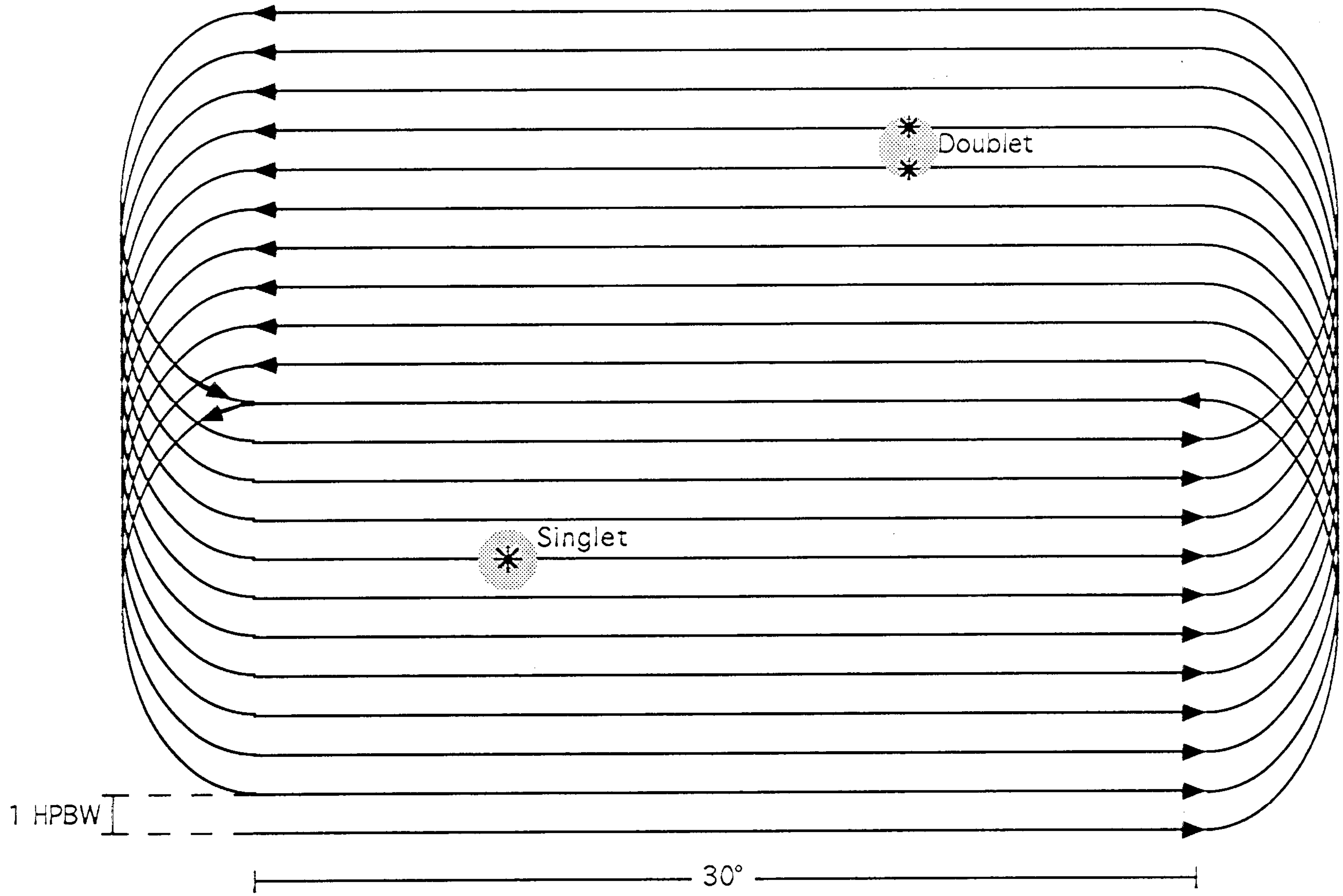
Figure Captions

Figure 1. The standard "racetrack" search pattern. Data are acquired during the straight "scanline" sections. The curved "turnaround " sections account for finite antenna accelerations. If a channel reports power above the Singlet detection threshold the event is saved as a Singlet. If nearby channels in adjacent scanlines at nearby positions both report hits and the sum of the powers is greater than the Doublet theshold, the pair of events is saved as a Doublet.

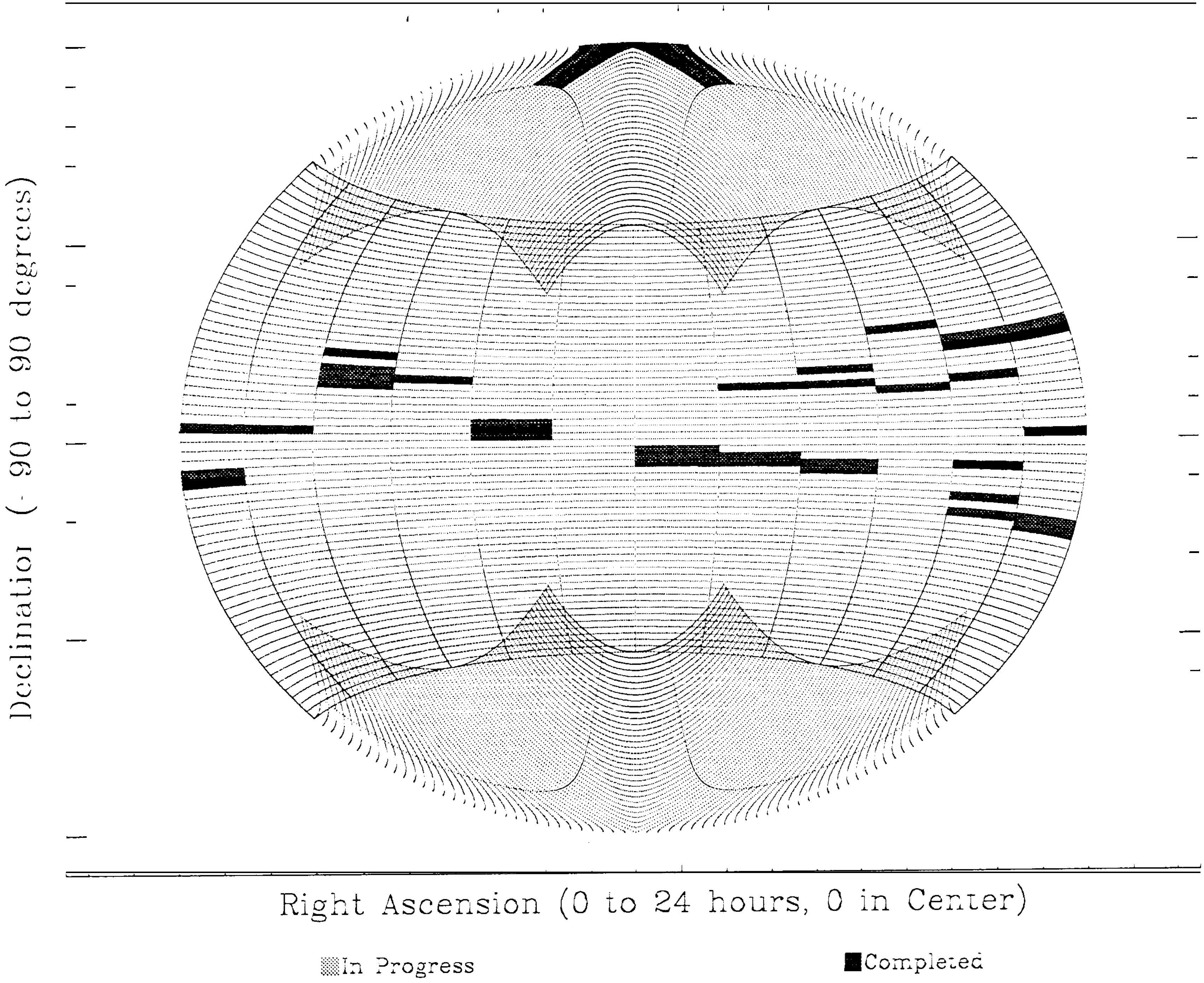
Figure 2. Aitoff projection of the pixellated sky, with observed sky frames shaded. The dark areas have been observed at least twice (*e.g.*, two polarizations at the same center frequency or a single polarization at each of two frequencies), and the lightly shaded areas have been observed in a single polarization over a single 40 MHz bandwidth.

Figure 3. Probability of False Alarm vs. Threshold. The solid line indicates PFA as a function of detection threshold (in units of input Signal to Noise Ratio) inferred from the. Singlet data of 57 X-band sky frames from October 12, 1992 to July 30, 1993. The dashed line indicates the PFA predicted by assuming thermal noise and taking into account the non-Gaussian statistics of the spectral accumulation and convolutional filter. The error bars shown are based solely on measurement statistics. Note the suppressed zero in the ordinate. Cumulative false alarm statistics for the X-Band Sky Survey to elate are consistent with thermal noise over 12 orders of magnitude.

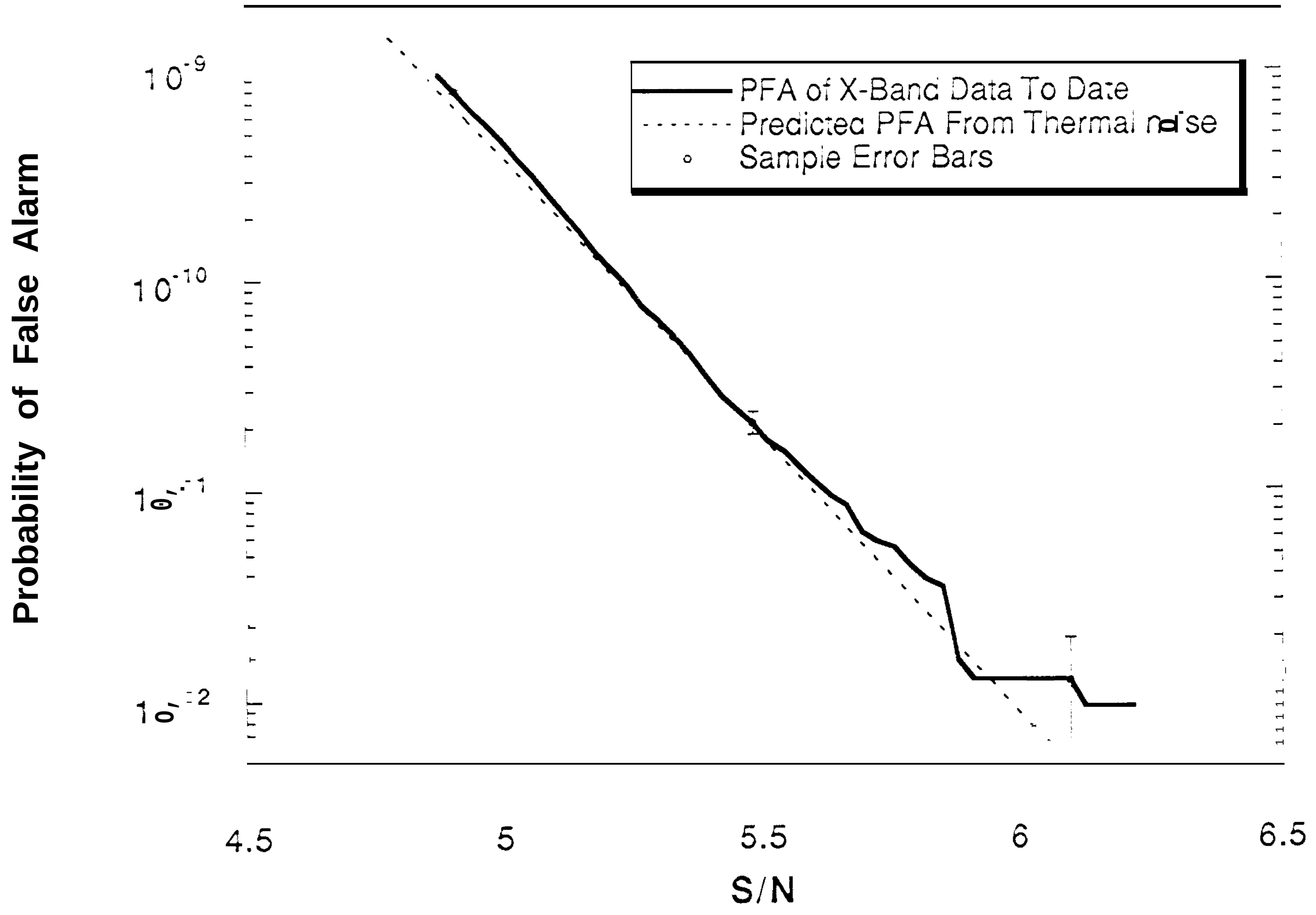
Figure 4. Frequency Distribution of Singlets and Doublets. This figure is a histogram of the number of Singlets and Doublets binned by frequency. Each bin of the histogram is 32,768 frequency channels (625 kHz) wide.


Doublet
Singlet
1 HPBW
30°

NASA/HRMS Sky Survey – Sky Frame Status
8.420 GHz Aug 27, 1993



Cumulative False Alarm Rate vs. Threshold for X-Band Data as of 7/30/93



Frequency Distribution of X-Band Events