Mariner 9 Doppler Noise Study

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Doppler noise data as calculated by and compiled from the near-real-time 360/75 pseudo-residual program during the Mariner 1971 mission are presented as a function of uplink and downlink signal strength. Some observations are made about the nature of this relationship, as well as about the functional dependence of doppler noise on round-trip light time and ground frequency standards.

I. Introduction

One of the strongest tools in monitoring the performance of the DSN tracking system is the doppler data standard deviation, or, as it is commonly referred to, doppler noise. However, to get maximum use out of this tool, one really needs to have a noise model as a function of the relevant parameters which determine the noise, such as doppler mode, doppler count time, ground station frequency standard, uplink signal strength, downlink signal strength, etc. The DSN is responsible for developing such a model based on the characteristics of the tracking system, but as of this date, a tracking system noise model has been unavailable. Until such time as one becomes available, it was felt that, as an interim solution, an empirical approach could be adopted whereby an attempt would be made to correlate doppler noise during the Mariner mission with ground station frequency standard, uplink signal strength, downlink signal strength, etc.

The study herein described was restricted to two-way, 60-s-count doppler. First, this would reduce the number of variables upon which doppler noise is dependent, and secondly, two-way, 60-s-count doppler data are the predominant data type taken by the DSN and are used almost exclusively by the orbit determination process.

The data base selected to provide the doppler noise during the Mariner 9 mission was the pseudo-residual program. Briefly, the pseudo-residual program is a near-real-time, 360/75 program, which, among other things, computes a running standard deviation of the last 8 to 15 doppler samples received, on a point-by-point basis. No editing is done except for gross blunder points, and the method of computation has remained constant throughout the Mariner 9 mission. The Orbit Determination Program was an alternate source of data, albeit unsatisfactory, because the data were readily available only in compressed form (alternate 600-s samples) and were subject to varying editing techniques.

The statistical technique selected for this study was intended to produce a lower limit of the standard deviation for any given pass, or to determine the least noisy data achieved for some reasonable period of time during any given pass. This was accomplished by searching each two-way, 60-s-count pass for the three lowest groups of approximately 20 points of running standard deviation. The average value of the noise of each 20-sample group was estimated, and then the three groups were averaged to produce a final figure for the pass.

The final noise value produced for each pass is plotted in Figs. 1 through 6 vs. the day of year of each pass; also plotted as a function of day of year is uplink signal strength and downlink signal strength. Finally, included on the graphs are the frequency standards used, uplink and downlink thresholds, and points at which round-trip light time (RTLT) equaled doppler count time (60 s) and when the spacecraft switched to the high-gain antenna.

The initial impression of the results was disappointing, as a strong correlation between noise and uplink and downlink signal strengths was not apparent. However, the study has proved to be useful in three areas, namely:

(1) Observations about noise when RTLT is less than the doppler sample rate (60 s), observations about the relative noise characteristics of the different ground frequency standards, and finally, some observations about noise as a function of signal strength.

(2) As an historical record of the noise encountered during the Mariner 9 mission.

(3) As a data base against which future DSN-produced noise models can be validated. The observations described in (1) above are discussed in the sections that follow.

II. Noise Characteristics When RTLT Is Less Than the Doppler Sample Rate

When the RTLT is less than the sample rate (60 s), noise is lower because any noise in the transmitted signal has an easily calculable probability of being subtracted when the received signal is beat against the transmitted frequency. The amount of noise not subtracted out would be

$$\frac{\text{RTLT}}{60\ \text{s}}$$

so that one might expect that, in this early mission phase, the noise might appear as

$$\text{noise} \approx A + B\left(\frac{\text{RTLT}}{60\ \text{s}}\right)$$

An attempt to roughly fit a linear curve through this region (Figs. 1, 2, 4, and 5) yields the following (approximate) results:

Deep Space Station (DSS)	A, Hz	B, Hz
12	0.0008	0.0023
14	0.0007	0.0032
41	0.0014	0.0048
51	0.0008	0.0019

The figure for DSS 41 is significantly higher than that for the other DSSs; therefore, restricting ourselves to DSS 12, DSS 14, and DSS 51, we would have

$$\text{noise (Hz)} \approx 0.0008 + 0.0025\left(\frac{\text{RTLT}}{60\ \text{s}}\right)$$

when RTLT $\leq$ 1 min and under conditions of great signal strength.

III. Different Ground Frequency Standards

A. Differences Between the R20 and H5065 Rubidium Frequency Standards

At DSS 62, a switch was made from the R20 ("old") to the H5065 ("new") Rubidium on day 301 of the Mariner mission. The spacecraft had switched to the high-gain antenna 35 days earlier, and went into orbit 20 days later, both these events having some effect on the noise. However, if one takes the average noise 30 days prior to the frequency standard change and 20 days after the change, one arrives at the rough figures:

$$\text{average noise prior to change (R20)} \approx 0.0027\ \text{Hz}$$

$$\text{average noise after change (H5056)} \approx 0.0020\ \text{Hz}$$

leading to a difference of

$$\Delta \approx 0.0007\ \text{Hz}$$

$$\Delta\,\% = 26$$

However, since the numbers are so close and the graphical analysis is so rough, the results are subject to some question. All in all, one might say that the R5065 Rubidium certainly appears at least as quiet as the R20, and possibly, somewhat quieter.

B. Differences Between the R20 Rubidium and the Hydrogen Maser

On day 265, three stations, DSS 12, DSS 41, and DSS 51, made a switch from the R20 Rubidium to the Hydrogen Maser. In all three cases, a dramatic drop in the doppler noise occurred (see Figs. 1, 4, and 5). Once again, using rough graphical techniques, the noise levels before and after the switch were as follows:

DSS	R20 Rubidium, Hz	Hydrogen Maser, Hz
12	0.0031	0.0015
41	0.0046	0.0013
51	0.0029	0.0012
Average	0.0035	0.0013

Thus, we have:

average noise prior to change (R20 Rubidium) $\approx$ 0.0035

average noise after change (Hydrogen Maser) $\approx$ 0.0013

$$\Delta \approx 0.0022 \text{ Hz}$$

$$\Delta\,\% \approx 63$$

These figures are, of course, only approximate, but they do indicate a considerable improvement from the R20 Rubidium to the Hydrogen Maser.

IV. Noise as a Function of Signal Strength

It had been hoped to arrive at some definite conclusions regarding the effect of signal strength on doppler noise level. Unfortunately, no specific statements can be made on the basis of the results as presented in Figs. 1 through 6. However, there are two regions in which we might expect to find some signal strength effects.

On day 265, the spacecraft switched to the high-gain antenna, and this produced an increase of 17 dBm in downlink signal strength over about a 2-week period. However, in the case of DSS 12, DSS 41, and DSS 51 this occurred concurrently with the switch to the Hydrogen Maser, so that any minor effect on the noise by the increase in signal strength was totally overshadowed by the noise reduction due to the implementation of the Hydrogen Maser. The one station where the effect of the 17-dBm increase in signal strength can be seen is DSS 62. However, inspection of Fig. 6 leads one to the conclusion that, at the most, it decreased the noise by only 0.0001 or 0.0002 Hz.

The second region showing some effect is where the signal strength came close to threshold. This occurred when Mariner 9 was in orbit, and at a time when the noise bandwidth reported by the pseudo-residual program had widened considerably compared to pre-insertion (day 310; see Figs. 1, 4, and 6) data. The reason was that, after insertion, the predicts supplied to the pseudo-residual program by the Navigation Team had large oscillating trends, and since the program can only fit a second-degree polynominal to the raw residuals (actual data-predicted data), some amount of trend could not be correctly accounted for in the standard deviation computation.

In Figs. 1 and 4, an increase in noise is noted from about day 035 to day 075. In both these cases, the uplink signal strength stayed almost constant at approximately −143 dBm (9 dBm above threshold), while the downlink signal strength fell from −154 (18 dBm above threshold) to −159 dBm (13 dBm above threshold), so that one might guess that the noise was sensitive to downlink signal strength and increased as downlink signal strength approached 10 dBm above threshold. However, this appears to be contradicted by the drop in downlink signal strength to about −165 dBm (7 dBm above threshold) at DSS 62 (see Fig. 6), without a noticeable increase in noise. It is known that noise is sensitive to signal strength, but the results of this study appear to yield little information about that relationship.

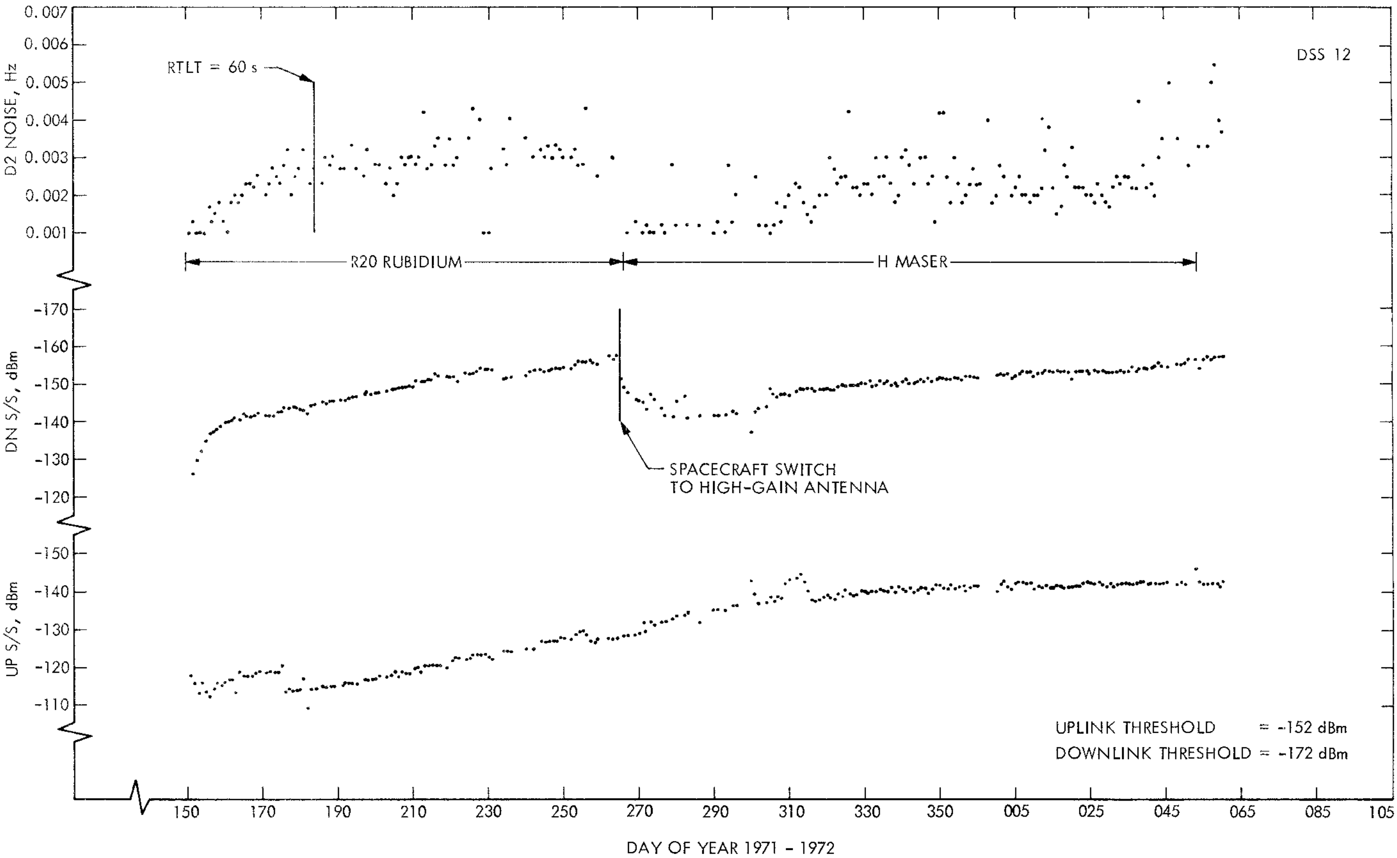

Fig. 1. Mariner 9 doppler noise and uplink and downlink signal strength vs. day of year, DSS 12

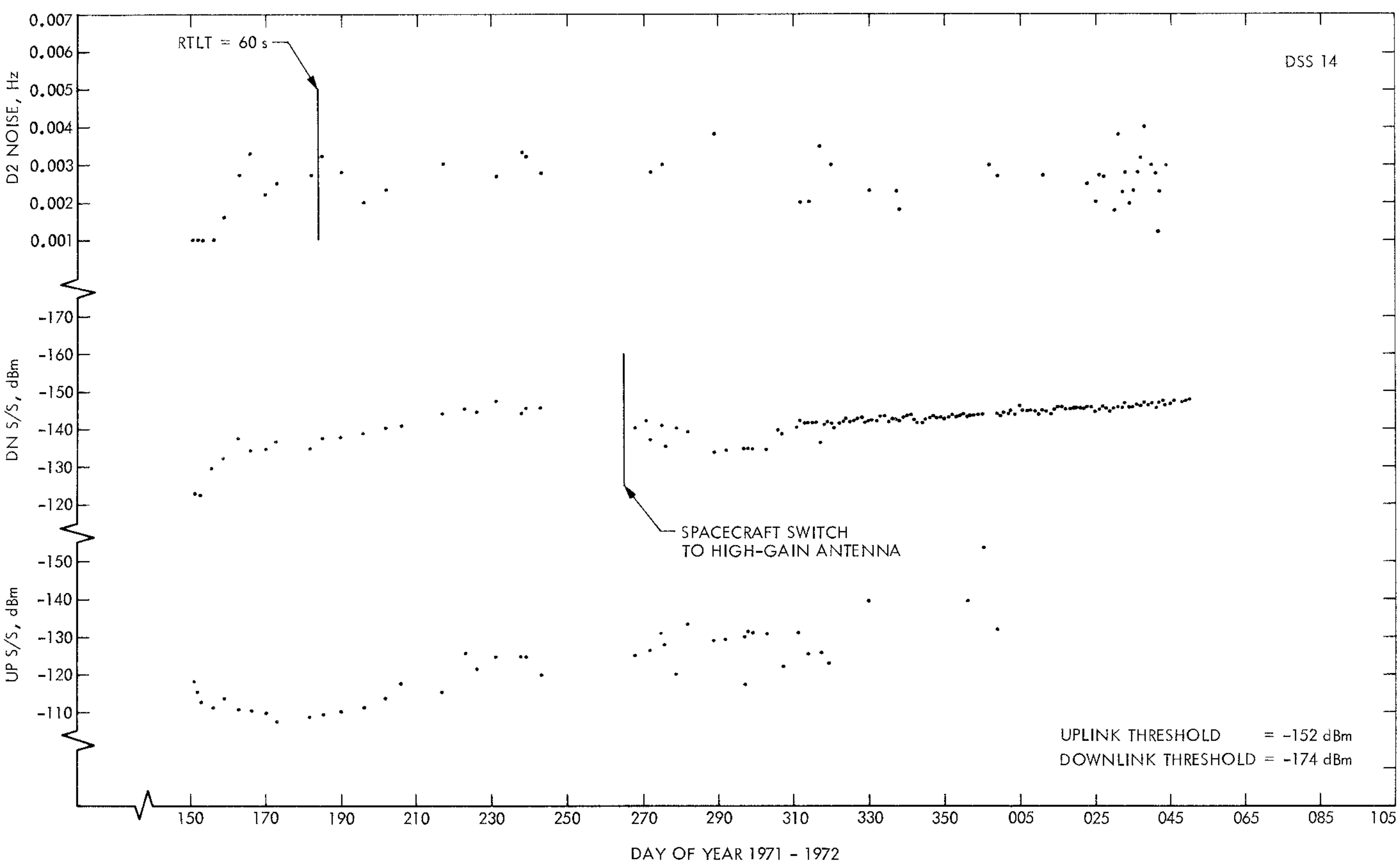

Fig. 2. Mariner 9 doppler noise and uplink and downlink signal strength vs. day of year, DSS 14 (1971–1972)

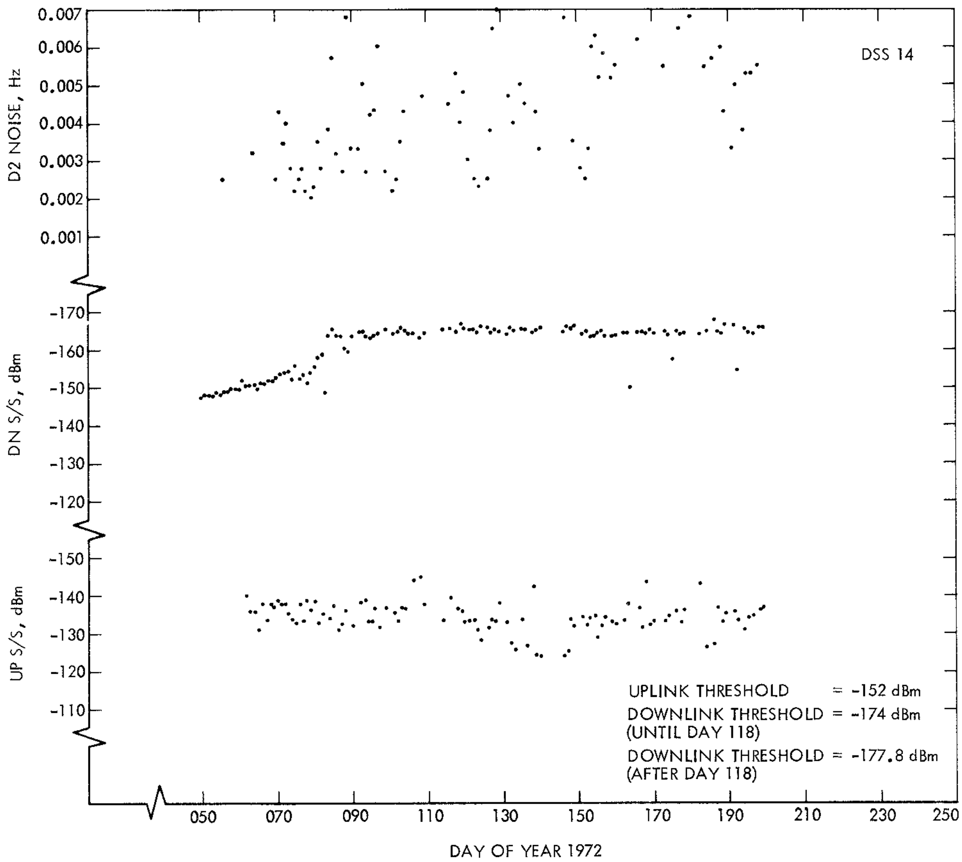

Fig. 3. Mariner 9 doppler noise and uplink and downlink signal strength vs. day of year, DSS 14 (1972)

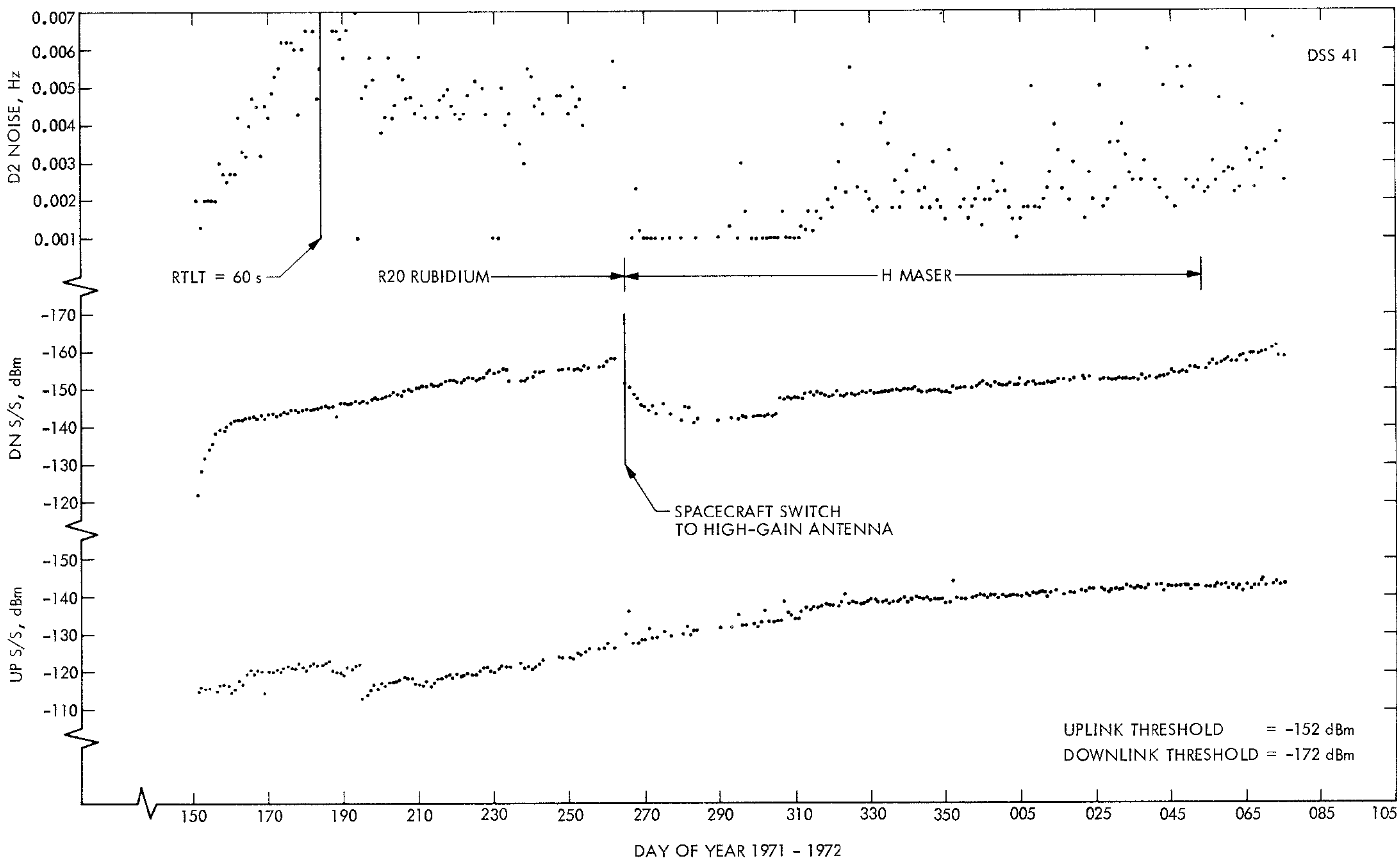

Fig. 4. Mariner 9 doppler noise and uplink and downlink signal strength vs. day of year, DSS 41

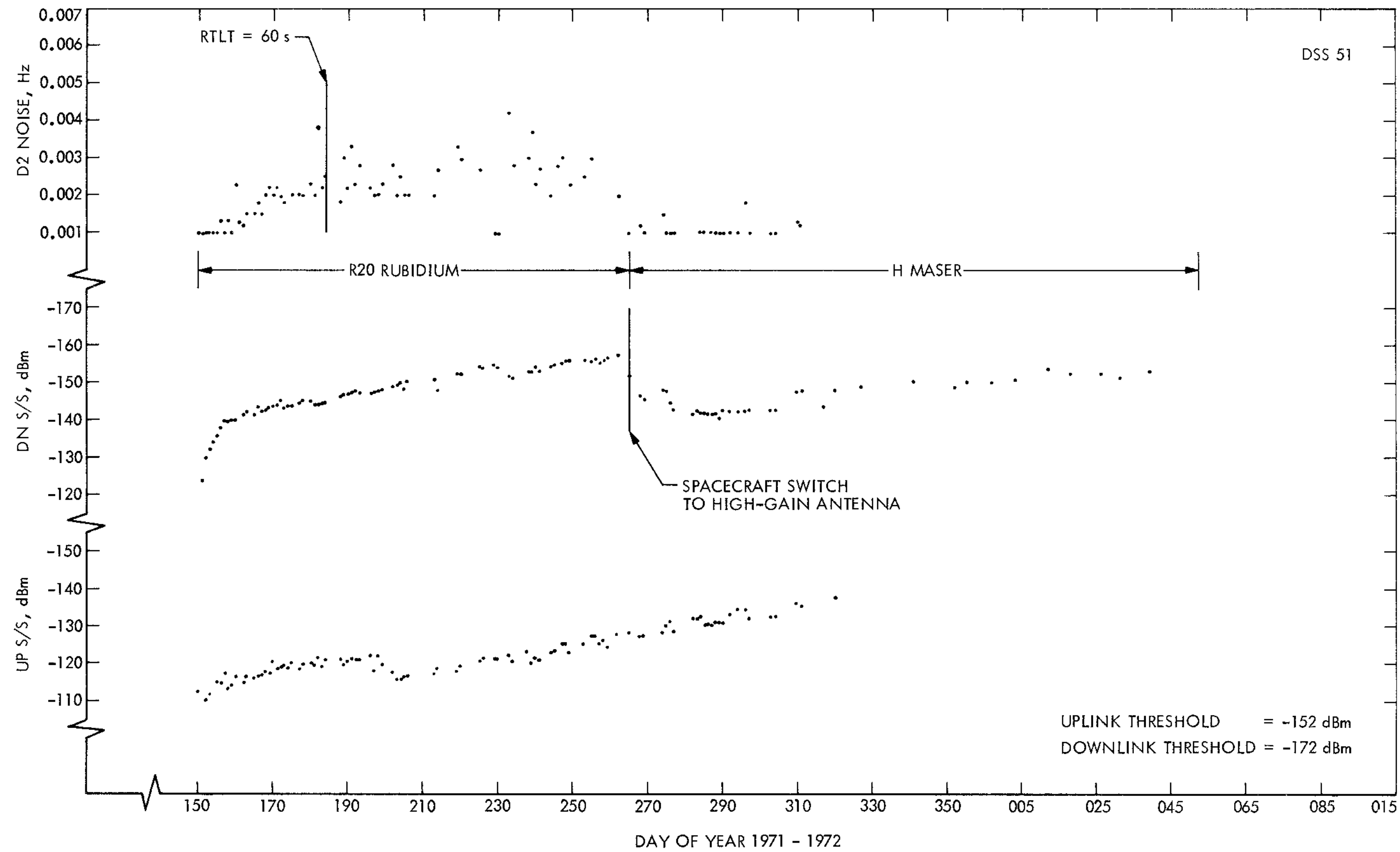

Fig. 5. Mariner 9 doppler noise and uplink and downlink signal strength vs. day of year, DSS 51

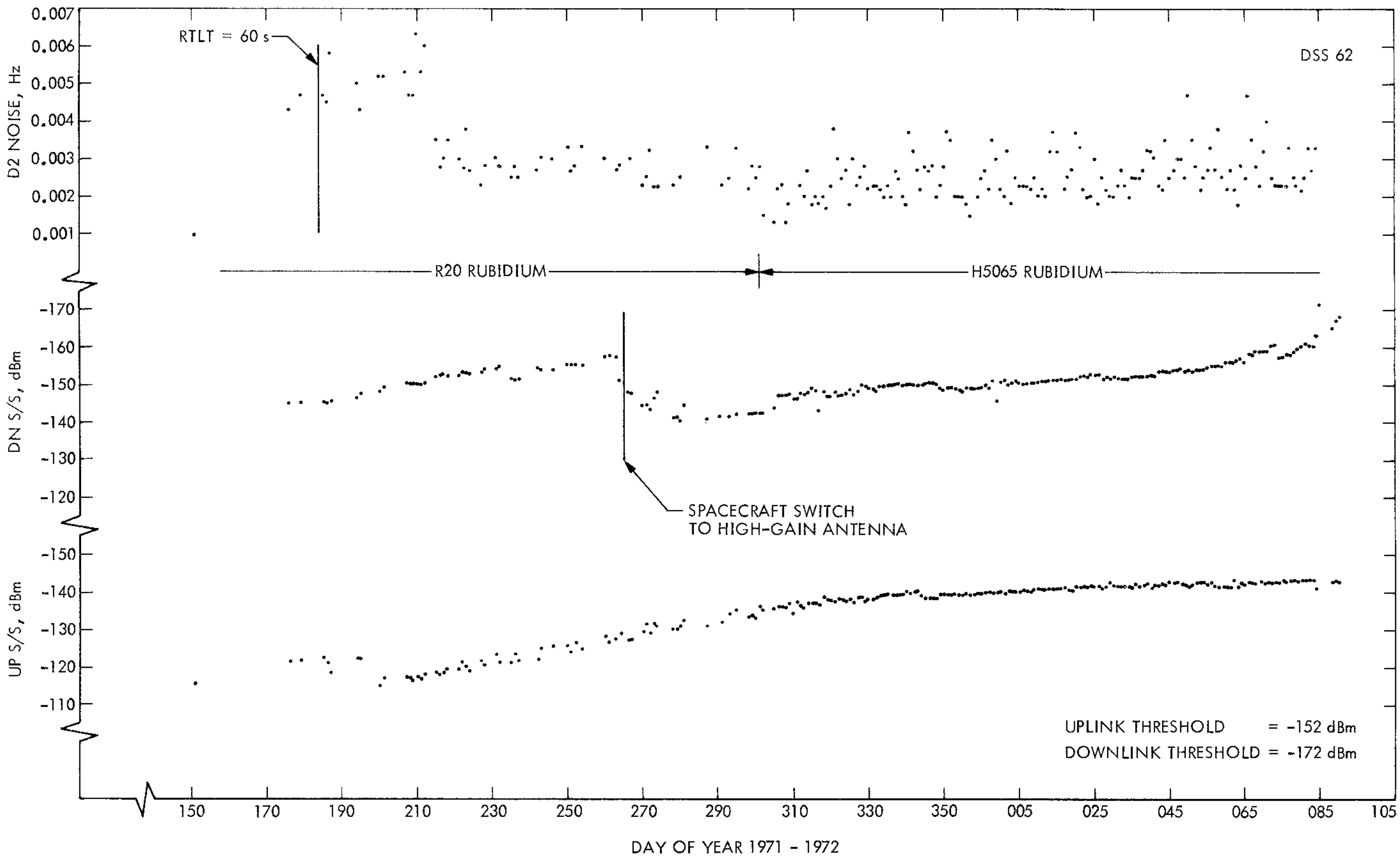

Fig. 6. Mariner 9 doppler noise and uplink and downlink signal strength vs. day of year, DSS 62