The Superior Conjunction of Mariner 10

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The radio signals from the Mariner 10 spacecraft have been used to probe the turbulence of the north polar regions of the solar corona. Simultaneous bandwidth observations of both S- and X-band were made with a resolution of approximately 0.20 Hz during the period of May 30 to June 26, 1974, from the 64-m antenna at the Mars Deep Space Station in the Goldstone Deep Space Communications Complex.

A mathematical model is given to relate the S- and X-band spectra. It was not possible to successfully correlate the spectra with solar observations such as solar flares, solar active regions and Orbiting Solar Observatory (OSO)-7 white light coronograph data. The bandwidths are generally narrower than previous observations but seem consistent with the reduced solar activity during this period of the solar cycle.

I. Introduction

The telemetry signals transmitted from Mariner 10 to Earth passed through the solar corona during observations taken from May 30 to June 26, 1974. Figure 1 shows a projection of the ray path intercept on a plane perpendicular to the Sun-Earth line. As the Earth-spacecraft line-of-sight approached the Sun, the downlink telemetry carrier signals, transmitted simultaneously and coherently at S- and X-bands passed through increasingly denser regions of the solar corona.

The 64-m-diam antenna of the Goldstone DSCC was used for transmitting S-band (2115 MHz) to and receiving S-band (2295 MHz) and X-band (8415 MHz) from the spacecraft for these two-way measurements. The antenna has a beamwidth of 0.14 deg at S-band and 0.040 deg at X-band. A simplified block diagram of the experiment is shown in Fig. 2. The antenna feed system is capable of simultaneous S- and X-band reception (Ref. 1). The receivers utilize separate S- and X-band masers, mixers and amplifiers which feed the computer. The computer has the capability of simultaneously computing both the Sand X-band signal spectrograms. These data are displayed on an x-y plotter in real time and stored on magnetic tape for further processing.

II. Data

The primary data from our observations are power spectrograms of the S- and X-band carriers. The signals were sampled digitally and converted into power spectra by the discrete Fourier transform. One hundred sample pairs (in phase quadrature) per second were taken. Each spectrum was formed of 512 sample pairs, thus taking 5.12 seconds to complete, and yielding 0.195 Hz resolution.

In order to reduce the fluctuations of the result, we averaged together sets of 120 spectra. Representatives of such spectra for each of the days of observations are reproduced in Fig. 3. In every case, the X-band spectrum was the widest. The curves have all been normalized to unit height.

We have processed these spectrograms to provide three quantities of interest: area under each curve, bandwidths of the spectra, and center frequency of each.

III. Signal Power

Area, when the normalization is removed, represents received signal power. The resulting power estimates for each day are given in Fig. 4, where power is plotted against the Sun-Earth-Mariner 10 angle. Normalization of the spectrograms was with respect to background noise level, and its removal introduced most of the errors in the power estimates. Since the antenna was necessarily aimed close to the sun, minor sidelobes would cause the background noise level to vary erratically. It appears from Fig. 4 that the presence of the solar corona in the ray path did not influence the received power significantly, for either S- or X-band signals.

IV. Bandwidth

It can be seen from Fig. 3 that the bandwidths of the signals, and hence the turbulence of the solar corona, change with angular distance of the ray path to the Sun. Our measure of bandwidth is that central frequency interval which contains half of the received power.

This measure is plotted in Fig. 5, also against angular distance to the Sun. The bandwidth is seen to be a strong inverse function of solar distance, rising sharply between 7 and 6 solar radii. The scatter of the points is not caused by systematic effects, but by the erratic nature of the corona itself. A circularly symmetric model of the corona will not fit the data.

An attempt has been made to correlate the bandwidth measurements with other observations of solar activity and coronal structure. These included flares, solar active regions and OSO-7 white light coronagraph observations. The large day-to-day variations in the bandwidth data could not be identified with any of these observations. The bandwidths measured for the Mariner 10 solar conjunction were substantially less than those measured at corresponding ray offsets for previous solar conjunction experiments such as Mariner 4, Pioneer 6 (Ref. 2), Mariner 9 and Pioneer 10. The Mariner 10 observations were taken very near to the solar cycle activity minimum while Mariner 4 was in the rising portion, Pioneer 6 was near the maximum, and both Mariner 9 and Pioneer 10 were on the declining portion. Since the solar activity during this period of the solar cycle, and in particular during the Mariner 10 observations, was largely confined to the low latitude regions while Mariner 10 probed the relatively quiet north polar region, it is not surprising that the observed bandwidths were generally narrower than those previously reported.

System tests have shown that the stability of the transmitter—programmable local oscillator—spectrum analyzer combination is generally better than 0.1 Hz. The resolution cell of the spectrum analyzer was greater than this. The data point at 13.6 solar radii still shows some influence from the corona.

Since the phase shift induced in a signal by propagation through plasma is inversely proportional to frequency, one might question the greater bandwidths of the X-band signals. We account for this phenomenon as follows:

The uplink signal passes through the solar corona and is thereby modulated in phase and amplitude. Only the phase modulation is retained by the phase-locked receiver on board Mariner 10. Figure 6 is a simplified block diagram of the system. $x(t)$ is a random signal representing the turbulence of the corona. $y(t)$ is retransmitted to Earth as the S-band signal. Simultaneously, $y(t)$ is frequency multiplied by 11/3 and transmitted to Earth as the X-band signal. We can show that the Fourier transform

$R_y(\tau)$ of the (baseband) spectrum of $y(t)$ is related to that of $z(t)$ by

$$R_z(\tau) = R_y^{n^2}(\tau) \tag{1}$$

It was not possible to observe $x(t)$ and $y(t)$ directly, but only through the corona. The effect of this complication is to change the value of the exponent, above.

Thus it should be possible to predict the X-band spectrum using only the S-band spectrum for data. Figure 7 is the result of our attempt. The S-band data from June 1 were processed according to Eq. 1, then retransformed and plotted for several values of the exponent. The actual received X-band spectrum is superimposed on the plot. It appears that this model adequately describes the broadening of the X-band spectrum.

V. Center Frequency

In order to hold the frequency of the signal centered in the receiver passband, automatic tuning was required. This removed the doppler shift caused by the motion of Mariner 10 relative to the Deep Space Station. The predictions were based on tracking data obtained over a 10-day period, May 11, 1974 through May 21, 1974, just after a trajectory adjusting rocket burn.

We have estimated the actual center frequency of the received signals as that frequency which splits the power into equal halves. The results are given in Fig. 8, where center frequency (estimated minus predicted) is plotted against date. As can be seen, the predictions were quite good, having only a small bias of about 2 Hz and, possibly, a small drift rate of about 0.02 Hz/day.

References

1. Howard, H. T., "Venus: Mass, Gravity Field, Atmosphere, and Ionosphere as Measured by the Mariner 10 Dual Frequency Radio System," *Science*, Vol. 183, p. 1297, Mar. 29, 1974.
2. Goldstein, R. M., "Superior Conjunction of Pioneer 6," *Science*, Vol. 166, Oct. 31, 1969, p. 598.

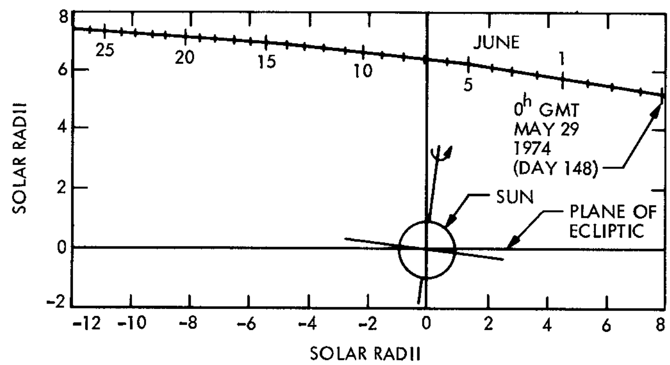

Fig 1. Plot of Mariner 10 to Earth signal ray path intercept on plane perpendicular to Earth Sun line

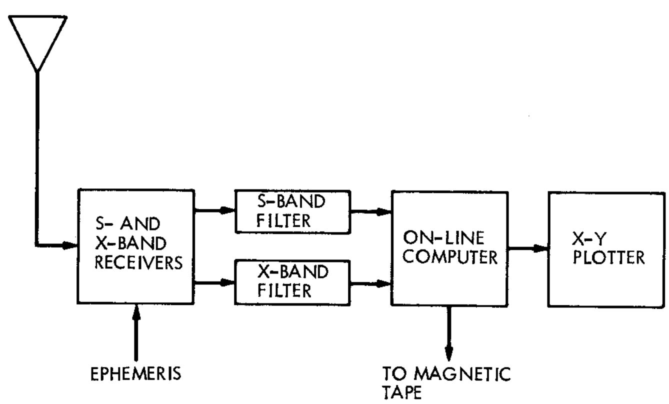

Fig. 2. Simplified block diagram of experimental system

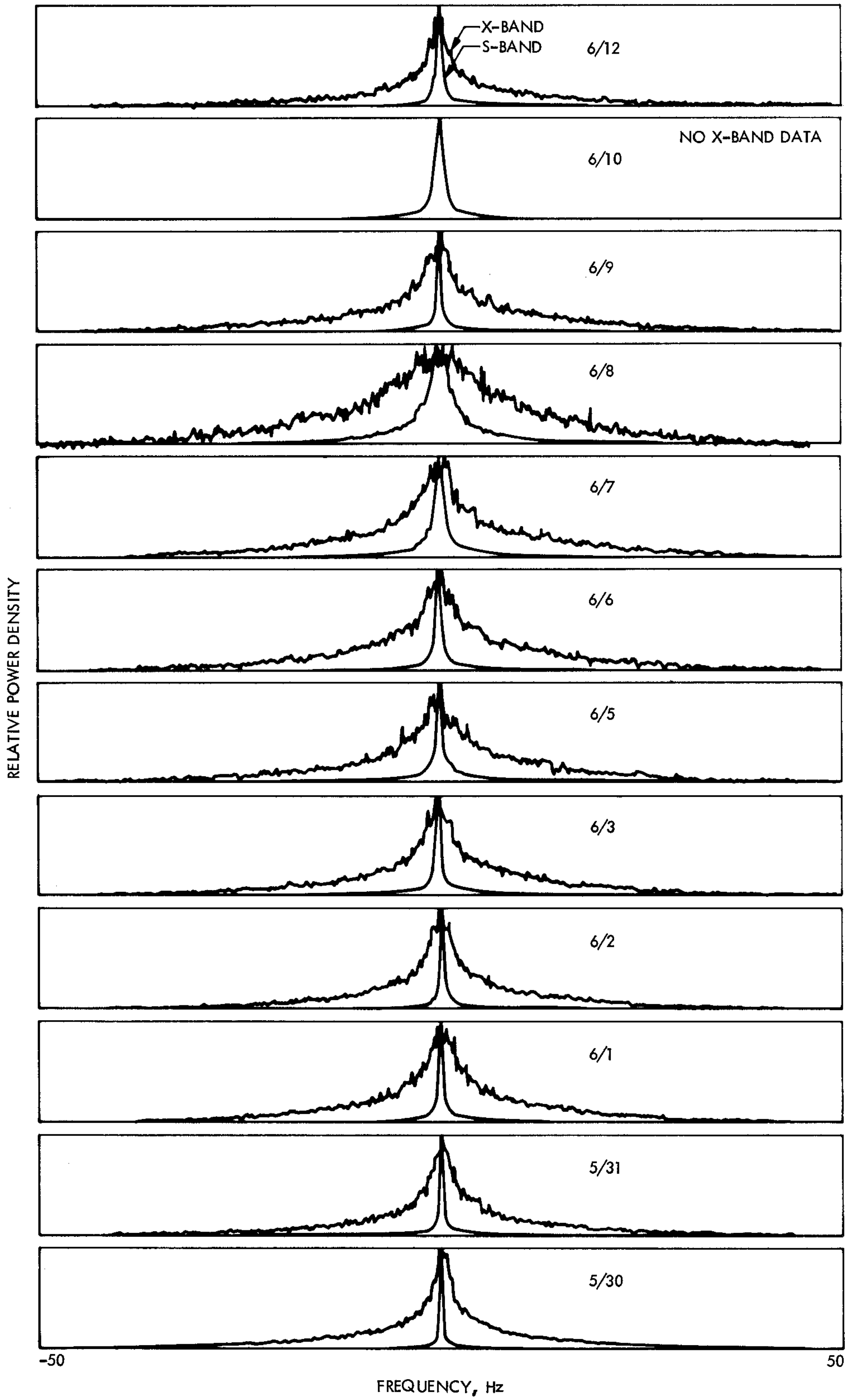

Fig. 3. Spectrograms for each day of observation. S- and X-band spectra are superposed, X always being the widest

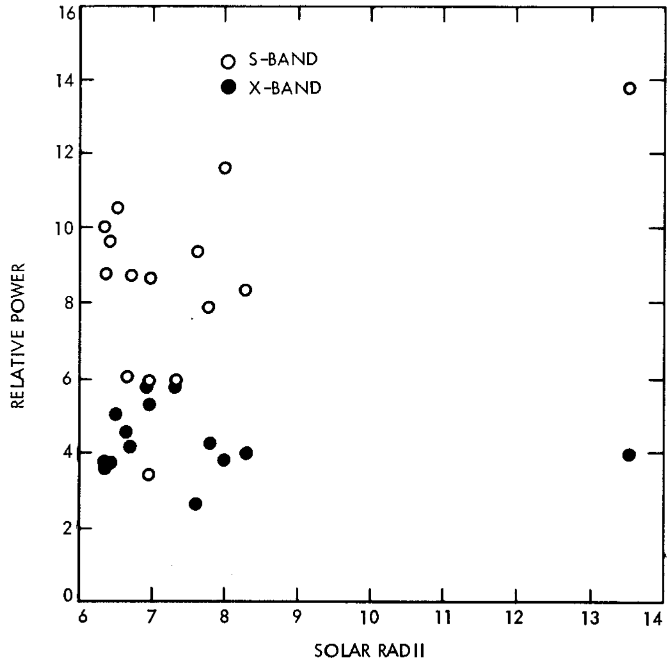

Fig. 4. Received S- and X-band power plotted against the Sun-Earth-Mariner 10 angle

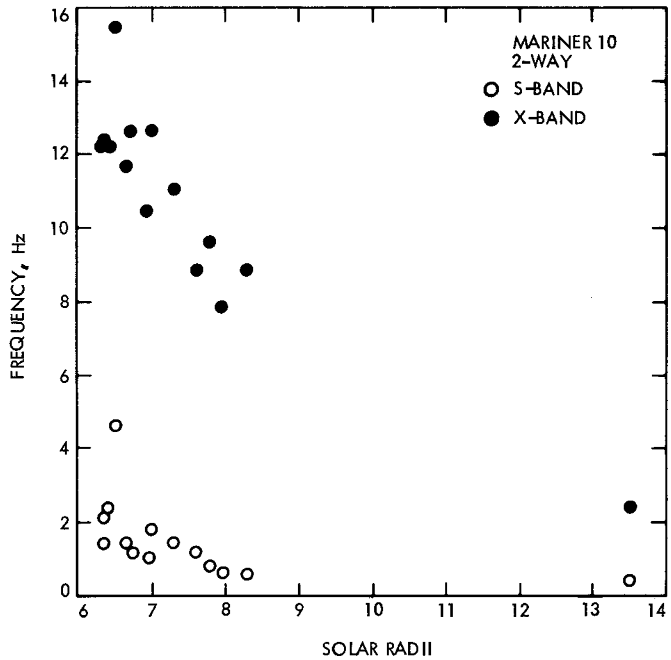

Fig. 5. Bandwidth of the received S- and X-band signals plotted against the Sun-Earth-Mariner 10 angle

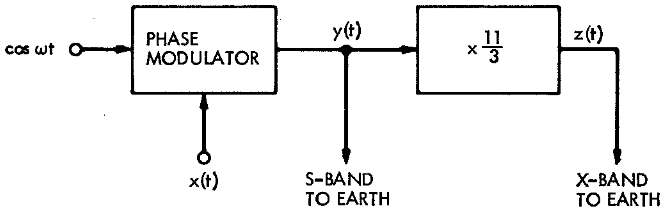

Fig. 6. Equivalent block diagram of corona-induced phase modulation

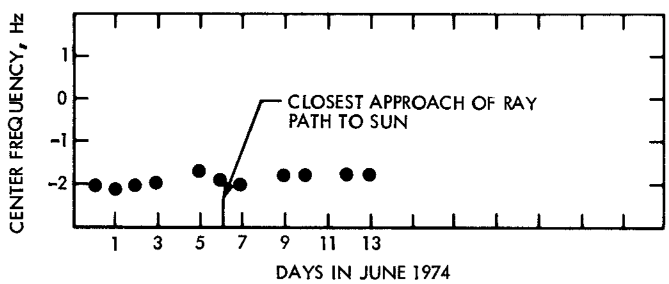

Fig. 8. Center frequency (estimated minus predicted) of the S-band signals as a function of time

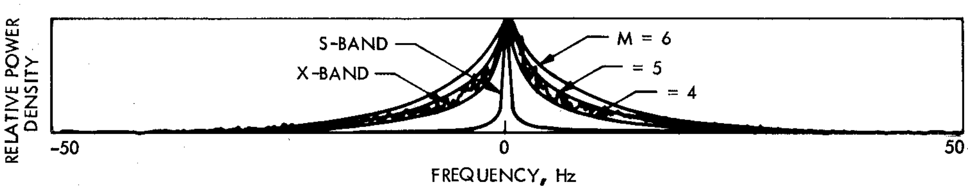

Fig. 7. X-band spectrogram plotted along with theoretical spectra derived from S-band data