Simultaneous Detection of Pulsar Radiation at S- and X-Bands

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The reflex feed system installed in January 1973 on the 64-m-diam antenna at the Goldstone Deep Space Communications Complex was used to receive weak wide-band signals from pulsars. The use of wide-band sources of radiation to test multi-frequency antenna and receiver systems is illustrated briefly.

The 64-m diam antenna at the Goldstone DSCC has been operated at the design frequency (S-band) since 1966. In January 1970, a major modification of the feed system was completed (tricone system). This system provides S-, X-, and K-band sets of feeds, maser amplifiers, and converters, any one of which can be selected by rotating the asymmetric subreflector. In January 1973, the tricone system was enhanced to provide, in addition, simultaneous reception of S- and X-band wavelengths. Immediately thereafter a test of the system was performed using wide-band, pulsed sources of radiation (pulsars). The results not only provide an interesting test of the new antenna feed system, but also a measure of the electron content of interstellar space.

The concept of the antenna feed system is described by Katow (Ref. 1) and a detailed analysis is presented by Potter (Refs. 2 and 3). Some initial performance data are available (Ref. 4). The characteristics of the operating system will be fully described by Bathker (Ref. 5). The S- and X-band masers were tuned to 2.388 and 8.415 GHz, respectively. The full bandwidth of each receiver was mixed down in frequency to 50 MHz and amplified. These IF signals were then added together in a coaxial hybrid. The bandwidth of the total signal was limited to 12 MHz just before detection. The detection process consisted of passing the signal through a square-low detector, then through a low-pass filter to reduce noise fluctuations. A dc amplifier was used to obtain an adequate signal level for an A/D converter. The digitized signals were processed in an on-line XDS 930 computer. This receiver block diagram is shown in Fig. 1.

A simple total-power receiver such as that described above, combined with a computer and program already in existence may be of use in testing new antenna and receiver systems. The power density of pulsar signals is generally very small, so one must use the entire maser bandwidth to obtain detectable signals. This requires a broadband antenna and feed, a low-noise receiver operating properly over its entire bandwidth, and a radio-quiet receiving site. Indeed, similar observations have identified a variety of local interference sources. Excessive disturbance due to receiver problems (e.g., cross-head modulation in the maser) must also be at a minimum.

To briefly describe the nature of the test signals, pulsars emit pulses of radiation at highly regular intervals. These pulses are extremely broadband, radiation being found from less than 20 MHz up to light frequencies, and beyond to gamma rays in some cases. In propagating through free space, the pulse train observed at one frequency is in phase with the pulse train observed at another frequency. However, interstellar space is a dispersive medium, since it contains charged particles (ionized hydrogen), and so the speed of energy propagation in interstellar space changes with frequency. The pulse-train observed at a frequency f_l lags behind a pulse-train observed at a higher frequency f_u by an amount

$$\Delta T = KD\left(\frac{1}{f_l^2} - \frac{1}{f_u^2}\right)$$

where K is a constant depending on the units, and D is the total number of electrons in a column 1 m^2 in cross-section extending between the pulsar and Earth. The quantity D is also known as the dispersion measure. Therefore, the time delay between pulse trains at different frequencies increases with dispersion measure and frequency difference.

Pulse trains observed on February 2, 1973 at S- and X-bands are shown in Fig. 2 for high, medium, and low signal-to-noise (S/N) ratios. The total signal was sampled 5,000 times during one pulse period and stored in the 930 computer. Successive pulse periods were superimposed in the computer until the S/N ratio was adequate. This integrated signal was written onto magnetic tape for further processing.

The signals are inherently stronger at S-band than at X-band. The S-band signals were attenuated 10 to 20 dB before combining the two signals such that the signal strengths would be nearly equal. The S- and X-band signals in Fig. 2 are denoted by "S" and "X," respectively. Time scales are noted for each pulsar. Several pulse periods are represented in pulsar PSR 0833-45, but less than one pulse period in the remaining two. The time interval between the location arrows is that delay expected from the known dispersion measures.

Note that any periodic disturbances present in the receiver could be isolated and studied in the same manner one integrates pulsar signals. One could merely sample 5,000 times during a time T, where T is some multiple of the period of the disturbance being investigated. Superposition of samples taken during successive intervals T sec long increases the S/N ratio. For example, crosshead modulation at 72 rpm suggests T should be a multiple of 0.833 sec. An attempt to isolate 60-Hz disturbances would require T to be a multiple of 0.0166 sec. The present system can easily handle $T \geqq 250$ ms, or approximately 15 cycles of a 60-Hz signal. A typical measurement of the crosshead modulation component in the receiver output might be measured in the following manner. Accepting the full bandwidth of the maser (approximately 12 MHz), the receiver gain is adjusted to produce 2 V output from the dc amplifier, and the time interval T is set to 0.833 sec. Then with a postdetection time constant of 40 msec, this component can be measured within 0.35 mV with 1 min of integration. This sensitivity allows one to see gain changes of about 0.002 dB. The short integration required for this sensitivity may allow this method to be useful in testing maser performance under operating conditions.

Typical flux densities are presented in Table 1 for some pulsars that are either strong or which exhibit large dispersion measures. These values were obtained by averaging the energy in the pulse over the pulse period. All values in Table 1 are expected values, since the energy varies considerably from pulse to pulse.

Expected values of the S/N ratios of these pulsars are presented in Table 2. The time constants of the single-section RC filter used in postdetection filtering are necessary for positive detection. The S/N ratios presented in Table 2 assume:

(1) 12 MHz of predetection bandwidth is used

(2) The detection process is square-law

(3) The post-detection time-constant is that given in the table

(4) 15 min of pulses have been superimposed

(5) System temperatures ranging between 30 and 45°K at S-band and 20 to 40°K at X-band. (These are the temperatures actually measured, and include effects of low elevations and the fact that the S-band maser was tuned to 2388 MHz rather than the design frequency of 2295 MHz.)

References

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2. Potter, P. D., "S- and X-band RF Feed System," in *Deep Space Network Progress Report*, Technical Report 32-1526, Vol. VIII, pp. 53–60, Jet Propulsion Laboratory, Pasadena, Calif., April 15, 1972.
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Table 1. Pulsar radiation energy densities and antenna temperatures

Pulsar	Average flux densities, W/m²/Hz		Average power density, dBmW/Hz		Peak pulsar antenna temperatures, K	
	S-band	X-band	S-band	X-band	S-band	X-band
PRS 0329+54	7.0×0.0^{-28}	0.15×0^{-28}	−212	−229	2.1	0.035
PRS 0823+26	1.0	0.1	−220	−230	0.75	0.06
PSR 0833−45	35.0	1.1	−205	−220	11.5	0.3
PSR 1706−16	0.4	0.15	−224	−229	0.2	0.07
PSR 1749−28	0.9	0.02	−220	−238	0.5	0.09
PSR 1933+16	1.1	0.01	−220	−240	0.45	0.004

Table 2. Signal-to-noise ratios for 15-min integrations (receiver bandwidth of 12 MHz)

Pulsar	Time constant, ms	S/N ratio	
		S-band	X-band
PSR 0329+54	1.0	270	55
PSR 0823+26	2.6[a]	150	18
PSR 0833−45	0.075[a]	450	13
PSR 1706−16	1.0	30	12
PSR 1749−28	1.0	70	16
PSR 1933+16	1.0[a]	80	1

[a]Time constant of data presented in Fig. 2.

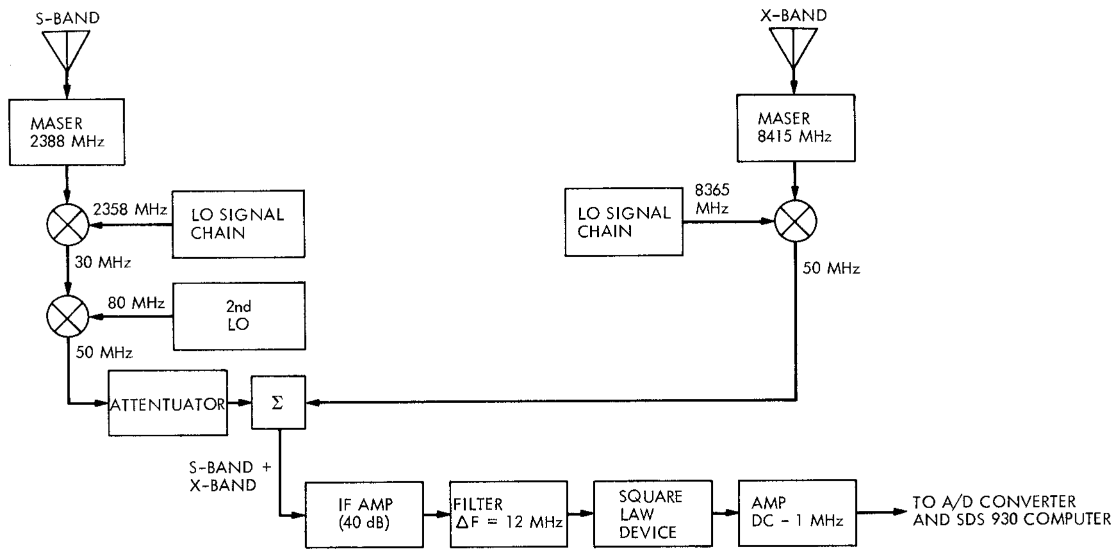

Fig. 1. Block diagram of dual frequency receiver

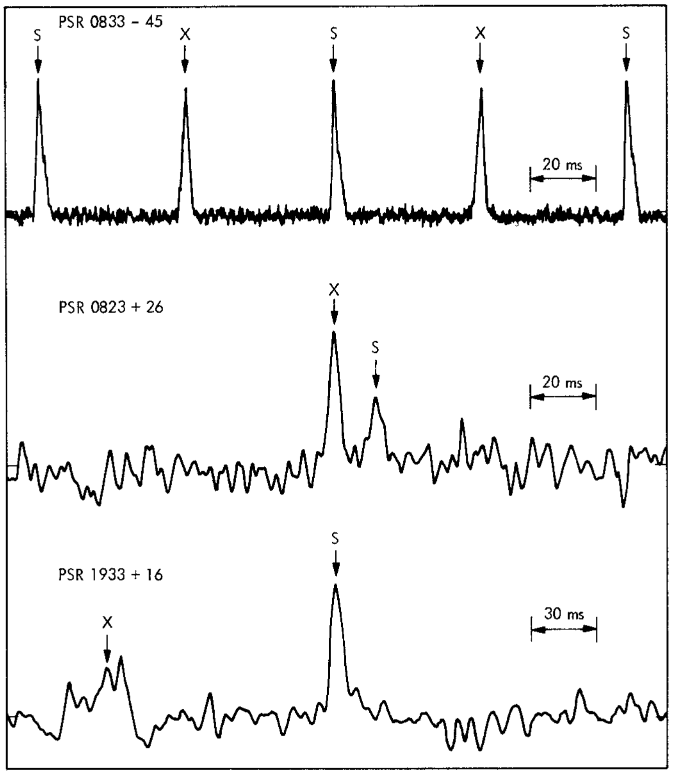

Fig. 2. Pulsar signals observed simultaneously at S- and X-bands