The SETI Instrument Development Plan

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The SETI (Search for Extraterrestrial Intelligence) Program is a NASA Research and Development Program that will search the microwave region of the spectrum for signals of extraterrestrial intelligent origin. The program includes two versions of an instrument system, a "target survey instrument" that will observe at a very high sensitivity a selected set of "interesting stars" that have particular a priori promise, and a "sky survey instrument" that will be used to observe the entire celestial sphere at a lower sensitivity. This article will briefly describe the architecture of the instrument system and reveal the development approach that will be used to implement the operational instruments.

I. Introduction

The target and sky survey instruments will be designed to be the most sensitive broadband radio telescopes on earth. From the high-efficiency antenna feed, to the cryogenically cooled preamplifiers, to the high-resolution spectrum analyzers, to the signal processor, the utmost care will be taken to deliver the best performance possible. The engineering task that is required will require considerable resources, but is within the state of the art. The SETI challenge, however, will be to handle the massive data output (gigabytes per second – see Table 1) in real time.

This problem is clearly several orders of magnitude beyond present general-purpose computer technology. It is anticipated that there will be several classes of special, high-speed digital processors that will carry out very selective algorithms and produce outputs with dramatically reduced data rates. The determination of the appropriate algorithms and the evaluation of their efficiencies when implemented in hardware is the task that will be accomplished during the SETI breadboard development.

II. Target Survey Instrument

The targeted survey will be conducted using the 305-meter antenna at Arecibo, Puerto Rico, a 64-meter DSN antenna, first at Goldstone and later in Australia, and other large radio telescopes. There are 244 solar-type stars that can be seen from Arecibo. Another 529 solar-type stars will be viewed (at lower sensitivity) by the smaller radio telescopes. The plan is to spend from 100 to 1000 seconds on each star while searching the frequency range from 1.2 to 3 GHz.

The Arecibo instrument (Fig. 1) will provide the highest sensitivity by virtue of the antenna gain. The antenna "line" feeds cover an instantaneous frequency range of 50 MHz (tunable over 100 MHz), while the multichannel spectrum analyzer/signal detector (MCSA/SD) will be capable of analyzing a frequency segment 16 MHz wide with a maximum resolution of 1 Hz. Since both continuously present and pulsed signals are considered reasonable extraterrestrial intelligence (ETI) signals, the MCSA/SD will be designed to have multiple resolutions (1, 2, 4, · · · 2048, 4092 Hz). These outputs represent an approximate set of matched filters to optimally detect pulses while spectrum accumulators will enhance CW signal detection. These capabilities will be explored in more depth in the breadboard description.

At other locations, the target survey instruments (Fig. 2) will provide the facilities to view those stars not visible from Arecibo. The fundamental difference between the two-instrument configuration is that the non-Arecibo versions will be implemented with an 8-MHz bandwidth and offer less sensitivity due to smaller antenna sizes

The DSN is currently undergoing an evaluationary step in the form of the Network Consolidation Project (NCP). One key characteristic of the NCP will be reduced operations cost through automation. The SETI instruments will be designed to capitalize on the automation capability to improve its operational efficiency.

III. Sky Survey Instrument

The sky survey will be conducted first on a listen-only, 34-meter antenna at Goldstone and later in Australia. The sky survey instrument (Fig. 3) exhibits somewhat different characteristics from the target instrument due to its assigned task. The sky survey will cover the entire celestial sphere (at the slew rate of the antenna) over a much wider frequency band (1- to 10-GHz continuous coverage with spot coverage from 10 to 25 GHz). These two requirements modify the instrument characteristics since pulse detection is less practical (due to the slewing of the antenna) while greater analysis bandwidth is required (to search the frequency range in the allowed search time).

IV. SETI Breadboard Development

The SETI breadboard instrument will assist in the development of both the targeted and sky survey instrument systems. Figure 4 is a block diagram of the SETI breadboard instrument. It will be noted that the existing DSS 13 antenna feed, cooled preamplifier, and receiver will be used for the instrument while the development effort will concentrate on the MCSA/SD, signal processor, and SETI instrument automation.

The SETI downconverter (Fig. 5) provides the interface between either a Block III DSN receiver or the receivers at Arecibo to the MCSA/SD. The downconverter will be designed with an AGC circuit with selectable time constants. Computer control of the downconverter gain will also be possible.

The MCSA/SD will function not only as a multichannel spectrum analyzer, but will also provide specialized processing in a high-speed digital processor to reduce the data rate to the signal processor to manageable rates.

The overall architecture of the MCSA is shown in Fig. 6. This figure represents only one (of the 140) legs of the instrument. It will be noted that the design incorporates both digital bandpass filters and discrete Fourier transforms (DFT).

Several levels of "real" bandwidth (i.e., 1, 32, 1024 Hz) are available for use on the data bases shown in the figure along with their accumulators.

Figure 7 graphically represents the planned development approach of the MCSA/SD. It will be noted that the signal processor will be used to develop and test various algorithms in software. Once an algorithm has been selected, it is turned into hardware in the MCSA/SD in the next phase.

A few words should be said about the functions identified in Fig. 7.

(1) Baseline: A baseline determination must be made in order to apply any threshold criteria. The approach that will be taken early in the development will exponentially average the 1024-Hz data. The time constant for this average will be under computer control. A unique baseline value will be available for each 1024-Hz segment of the spectrum. Later work will investigate the use of other resolutions as the reference for the baseline along with possible arbitrary, user-defined baselines.

(2) Threshold: There will be a separate (computer-controlled) threshold for each bandwidth threshold. The threshold value for each particular resolution will be used across the entire analysis bandwidth. There will also be an "override" threshold feature where any 1024-Hz bandwidth segment can be squelched to prohibit known RFI from saturating the signal processor.

(3) Dedrift: This feature will be applied to the threshold data from the various bandwidth resolutions. The concept will be to store the threshold data from several (30 to 100) spectra to determine if there is a recognizable drifting (in frequency) pulse. This process can also be used to search for drifting CW signals by using the accumulator outputs as input to the dedrifters. A third alternative that will be evaluated in the breadboard is to store several complete spectra (before thresholding), dedrift, and then apply the threshold critera. This algorithm will offer the optimal sensitivity, however its cost efficiency must be assessed since it is very expensive in data memory.

(4) Pseudo Resolutions: To form the complete set of resolution bandwidths from 1 Hz to 4096 Hz, each of the "real" resolutions (i.e., output of the digital bandpass filter or DFT, i.e., 1 Hz, 32 Hz, 1024 Hz) are added in frequency to reduce the resolution (i.e., add 2 adjacent 32-Hz cells to get a 64-Hz cell, etc.) while adding the same resolution in time improves the resolution (i.e., adding two 32-Hz spectra with the proper overlap to produce a 16-Hz pseudo resolution).

Figure 8 represents the proposed layout of the breadboard instrument. The LSI-11 in the first equipment rack will be used as a functional part of the MCSA/SD to download programs into RAM memory for the bit-slice microcomputers in the MCSA, to run diagnostic tests, and to interface with the signal processor.

The magnetic tape unit and disc will be used to acquire and store data so that SETI algorithms may be evaluated in a nonreal-time environment.

Remote operation of the signal processor (and thereby the whole system through the signal processor station controller interface) will be possible from either JPL or Ames Research Center (ARC). This feature will allow development of a SETI algorithm on the same instruments in which they will be implemented and for remote SETI tests to be conducted from either JPL or ARC.

A graphic CRT and hardcopy will be available at the local site and at the remote JPL and ARC sites to provide efficient communication between the SETI scientists in their quest for the proper set of SETI algorithms.

The challenge to SETI is to search for extraterrestrial intelligence, and to provide significant improvements in the knowledge of radio astronomy. The instruments that will provide the tools for this search do not exist anywhere in this world, and represent the kind of challenge that JPL has met so well in the past. The breadboard phase has begun and should be available for preliminary testing a year from now. The search has begun.

Table 1. Unprocessed MCSA/SD output data rates

Signal type	Resolution, Hz	Data rate, bytes/s		
		Breadboard	Arecibo target instrument (two polarizations)	Sky instrument (two polarizations)
Power (one byte-floating point)				
Nonaccumulated	1	64k	32M	
	32	64k	32M	512M
	1024	64k	32M	512M
	1024 (baseline)	1k	0.4M	6.4M
	65k	64k	32M	512M
		257k	128.4M	1542M
Accumulated (16 < N < 1000)	1	64 to 4k	0.032M to 2M	
	32	64 to 4k	0.032M to 2M	0.512M to 32M
	1024	64 to 4k	0.032M to 2M	0.512M to 32M
		195 to 12k	0.096M to 6M	1.024M to 64M
Pulses 100 bins/spectra (3-byte address, 1-byte power)	1	0.4k	0.2M	NA[a]
	32	12.8k	6.4M	78.6M
	1024	409.6k	209.5M	2514M
		422.8k	216.1M	2592.6M
Voltage (2 bytes per voltage)				
Nonaccumulated	1	256k	128M	NA
	32	256k	128M	2048M
	1024	256k	128M	2048M
		768k	384M	4096M

[a]Not applicable.

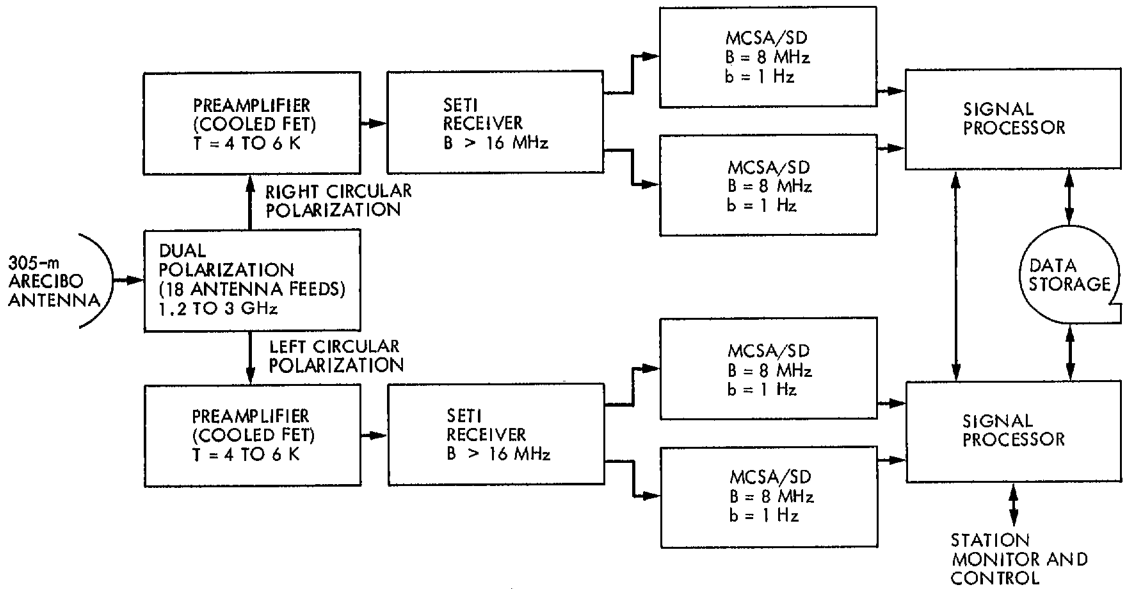

Fig. 1. Target survey instrument installation at Arecibo

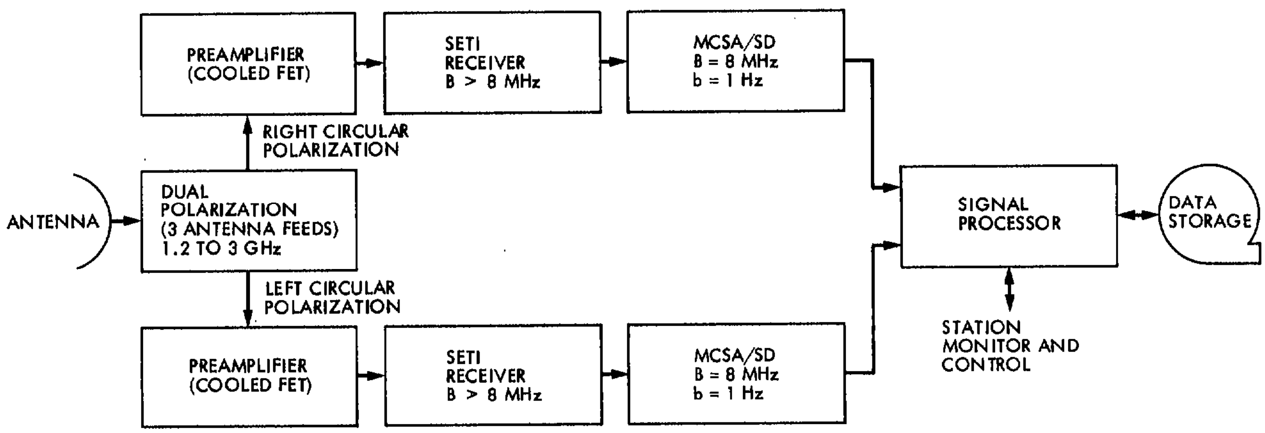

Fig. 2. Typical target survey instrument installation

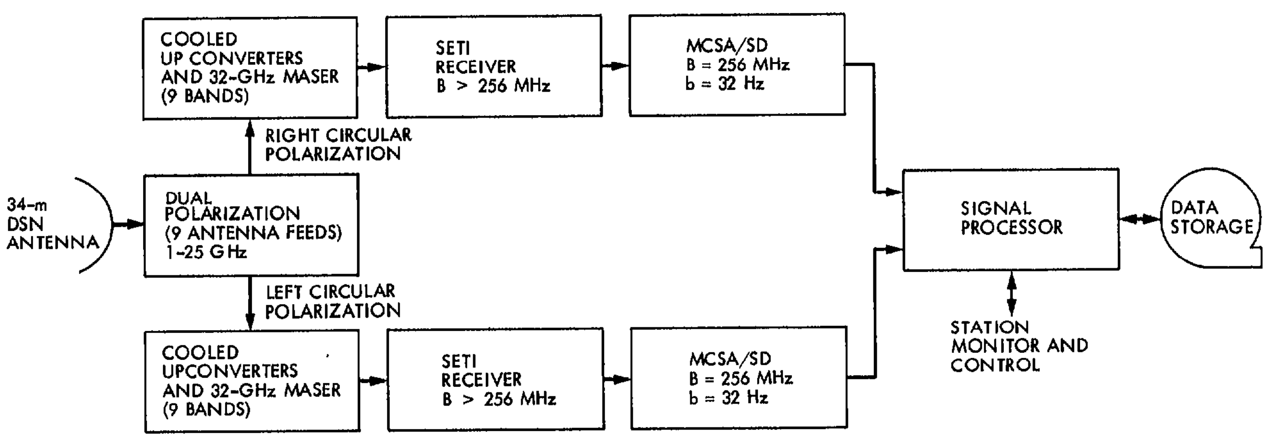

Fig. 3. Sky survey instrument installation at 34-m DSN antenna

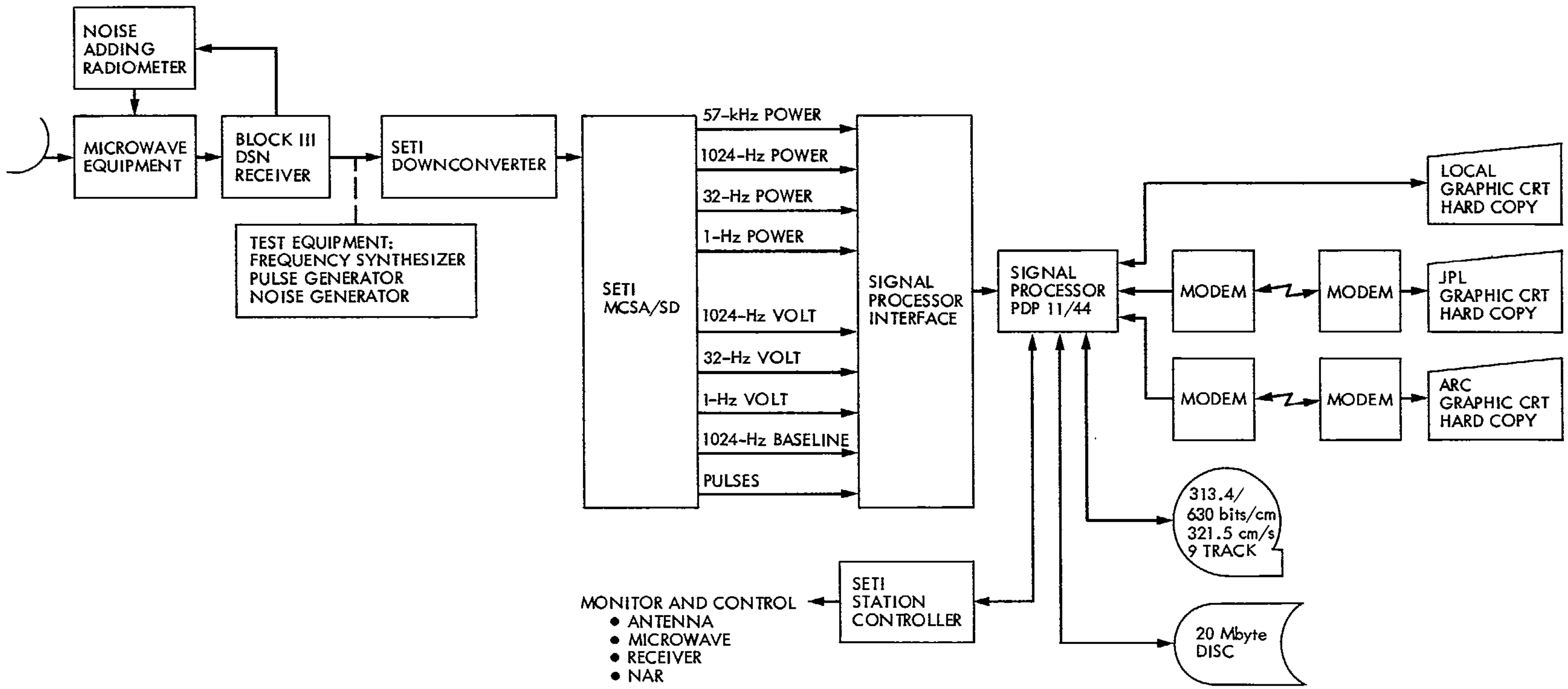

Fig. 4. Block diagram of SETI breadboard instrument

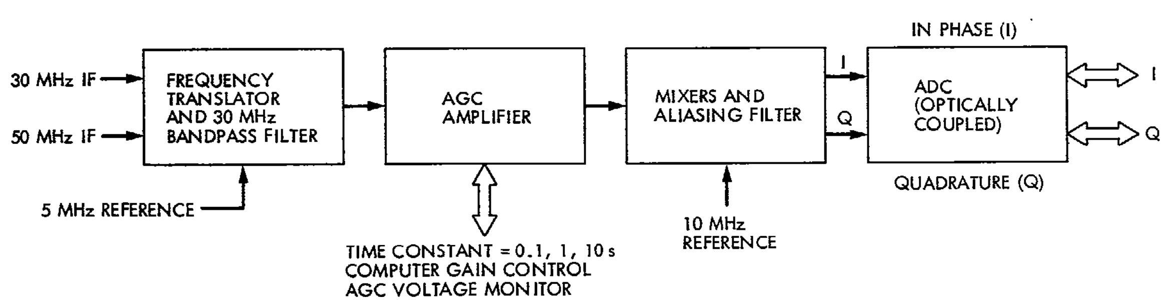

Fig. 5. Block diagram of SETI downconverter

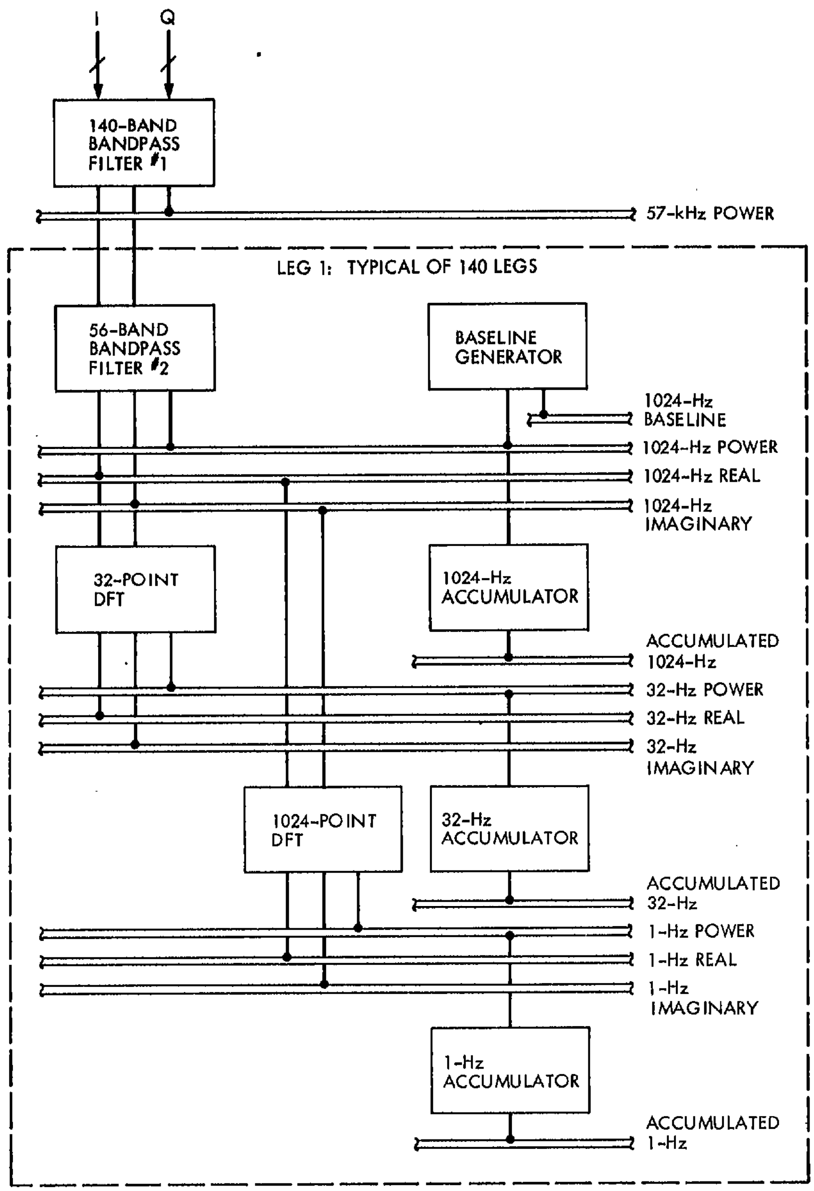

Fig. 6. Architecture of multichannel spectrum analyzer for SETI target instrument

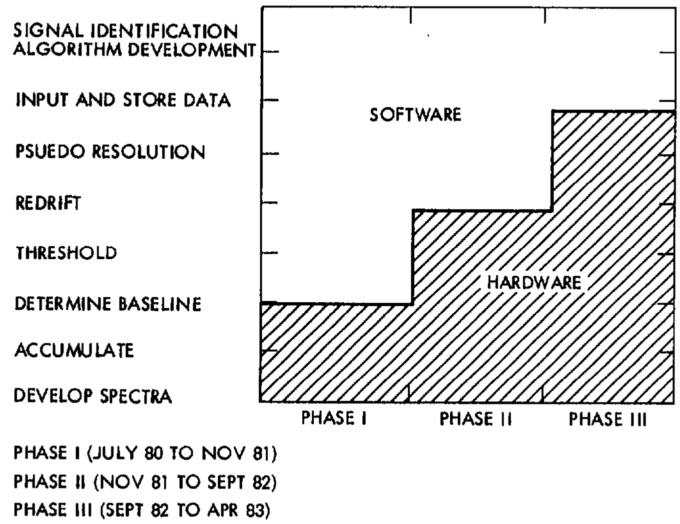

Fig. 7. SETI instrument development plan

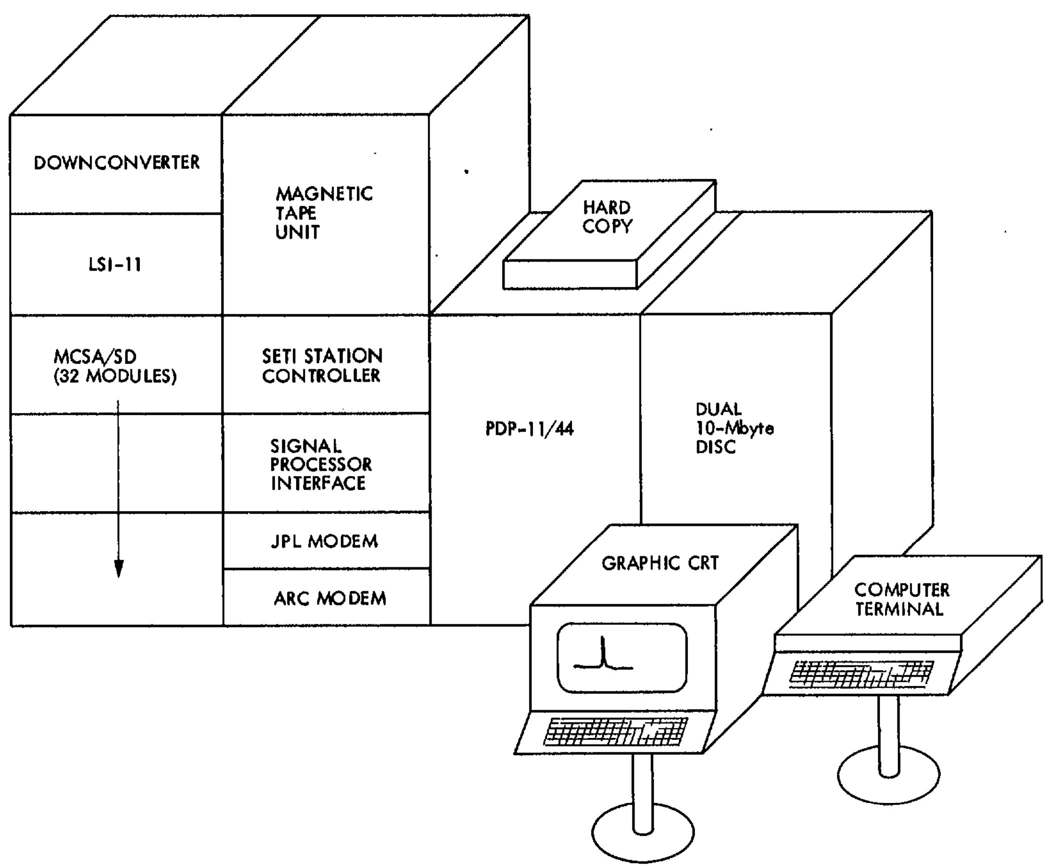

Fig. 8. Proposed layout for SETI breadboard instrument