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The SETI Observational Plan

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The SETI ("Search for Extraterrestrial Intelligence") Program is a NASA Research and Development Program with primary thrust to search the microwave region of the spectrum for signals of extraterrestrial intelligent origin. The Program will search a well defined volume of "search parameter space" using existing antennae and a new, sophisticated data acquisition and analysis system. The Program includes two major components – the "target survey", which will observe at very high sensitivity all attractive stellar candidates within 75 light years of the sun, and the "sky survey", which will observe the entire celestial sphere at a lower sensitivity.

I. Introduction

Serious scientific concern with detection of extraterrestrial intelligence dates back at least to 1959, with the publication by Cocconi and Morrison (Ref. 1) of a paper entitled "Search for Interstellar Communications." Additional scientific papers on this subject were published during the 1960's. In the 1970's, more intensive and formal studies of the subject were conducted. Notable during this time frame were study efforts which are documented in "Project Cyclops: A Design Study of a System for Detection of Extraterrestrial Life" (Ref. 2) and "The Search for Extraterrestrial Intelligence SETI" (Ref. 3). During the late 1970's, intensive effort was undertaken at the Jet Propulsion Laboratory (JPL) and Ames Research Center (ARC) to obtain the initiation of a formal SETI ("Search for Extraterrestrial Intelligence") Program under NASA sponsorship. Starting in Fiscal (FY) 1980, such a program has come into existence. The NASA SETI Program is a Research and Development effort with primary thrust to search the microwave region of the spectrum for signals of extraterrestrial intelligent origin. The Program is being managed by the Division of Astrophysics in the NASA Headquarters Office of Space Sciences (OSS).

The SETI Program will search a well defined volume of "search parameter space" using existing antennae and a new, sophisticated data acquisition and analysis system. The Program includes two major components – the "target survey," which will observe at very high sensitivity all attractive stellar candidates within 75 light years of the sun, and the "sky survey," which will observe the entire celestial sphere at lower sensitivity. The target survey will require the implementation of a narrowband data acquisition system, which will be used at Arecibo and the DSN 64-m subnet. The sky survey will require implementation of a wideband data acquisition system, which will be used in the DSN 34-m subnet.

II. SETI Search Strategy

In describing the SETI search strategy, one defines a "search parameter space" composed of a relevant set of signal descriptors. Comprising the search space are both primary signal descriptors:

(1) Signal strength

(2) Direction

(3) Frequency

and secondary signal descriptors:

(1) Bandwidth

(2) Polarization

(3) Modulation

(4) Duration

In constructing a SETI search strategy, the primary descriptors provide the basic structure, while the secondary descriptors influence the detailed strategy design.

At this point, the central SETI problem is seen to be in evidence. Obviously, it is not physically possible to search the entire multidimensional SETI search parameter space; hence one must devise a logical methodology in bounding the search parameter space to that parameter subset which is both desirable and practical. In devising bounds, there are three basic categories:

(1) Bounds dictated by physical factors

(2) Bounds dictated by resource limitations

(3) Bounds dictated by a priori assumptions

The very selection of the microwave region for the SETI Program is an example of bounds dictated by physical factors. Figure 1 (from Ref. 3) shows total noise versus frequency. There is immediately apparent in Fig. 1 a "terrestrial microwave window" from about 1 to 10 GHz. Below 1 GHz, galactic noise increases rapidly, while above 10 GHz tropospheric and spontaneous emission noise become quite severe.

As an example of bounds dictated by resource limitations, the program may well choose to first search portions of the frequency spectrum within the microwave window for which we already possess the requisite radio frequency (RF) hardware, i.e., S-band and X-band.

Finally, as an example of bounds dictated by a priori assumptions, one has the "waterhole" and "good suns" concepts. The "waterhole" is defined as the frequency band encompassing the hydrogen line (1.42 GHz) at the lower extent and the hydroxyl lines (1.61 to 1.72 GHz) at the upper extent. Obviously, since these physical constituents are so fundamental to terrestrial life and so well represented throughout the universe, one must consider the possibility of the usage of their spectral line frequencies for communication by extraterrestrial intelligent life; hence, in any SETI search scheme, the waterhole becomes an a priori "preferred" region for observation. Similarly, one may assume that stars like our own sun ("good suns") may be good locations for the presence of intelligent life.

Using such logic, a two-pronged search strategy for the microwave window has gradually evolved; the two elements of this strategy, termed the "target" and "sky" surveys, are described below.

A. The Target Survey

In this *a priori* survey, all attractive stellar candidates within 75 light years of the sun will be subjected to high sensitivity observation. The basic goal here is to achieve a search sensitivity of approximately 10^{-26} W/m^2 in the region of 1.0 to 3.0 GHz.

B. The Sky Survey

The goal of this *non a priori* survey is to systematically search the entire celestial sphere, albeit at a substantially lower sensitivity than the target survey. The sky survey sensitivity goal is approximately 10^{-23} W/m^2 in the region of 1.0 to 10.0 GHz.

A more detailed parametric description of the two search modes is provided in the following sections.

III. The SETI Instrument System

The SETI narrowband and wideband instrument systems will basically consist of:

(1) New Radio Frequency (RF) Equipment

(2) Multi-channel Spectrum Analyzer (MCSA)

(3) Computer-based signal detection unit

The central element of the SETI instrument is the MCSA. The multi-million (8×10^6) channel capability of the MCSA is that which makes the planned SETI search practical, and it is the MCSA which will require the bulk of SETI program new technology development and resources.

High level SETI Instrument functional requirements have been established as follows:

(1) Radio Frequency Range

(a) 1-3 GHz; with "spot bands" between 3 and 10 GHz (target survey)

(b) 1-10 GHz; with "spot bands" between 10 and 25 GHz (sky survey)

(2) Radio Frequency Instantaneous Bandwidth

(a) 8 MHz (target survey)

(b) 256 MHz (sky survey)

(3) Polarization

Right Circular Polarization (RCP) and Left Circular Polarization (LCP) simultaneously

(4) Gain (G) Stability

$\Delta G/G = 10^{-3}$

(5) Frequency (F) Stability

$\Delta F/F = 10^{-13}$ over a 1000 second averaging period

(6) System Noise Temperature (T_s)

$T_s = 20°K$

(7) Required Computerized Control

(a) Antenna drive

(b) Receiver local oscillator

(c) Gain

(d) Polarization

(e) Integration time

(f) Bandwidth

(g) Resolution

(8) Spectrum Analyzer Channels

8×10^6

(9) Minimum Channel Resolution

(a) 1 Hz (target survey)

(b) 32 Hz (sky survey)

Figure 2 presents a functional block diagram of the SETI Instrument System. Starting at the dual polarization antenna feed, signals are separated into RCP and LCP components. These are upconverted prior to low noise amplification by a tunable, cryogenic maser. The maser is expected to operate in the region of 19 to 25 GHz with an instantaneous bandwidth of better than 300 MHz. To achieve the required RF range of 1 to 25 GHz, nine cryogenically cooled parametric upconverters will be required, in the following ranges: 1.1 to 2.0 GHz, 2.0 to 2.8 GHz, 2.8 to 4.0 GHz, 4.0 to 5.6 GHz, 5.6 to 8.0 GHz, 8.0 to 11.0 GHz, 11.0 to 16.0 GHz, and 16.0 to 22.0 GHz. Following low noise amplification, open-loop receivers heterodyne down and filter the signals to instantaneous bandwidths of either 8 or 256 MHz. These signals are digitized by A/D converters, and provided to the MCSA. The MCSA utilizes finite impulse response filters to convert an 8.4 MHz input into 8192 channels of 1024 Hz width each. The transition from 1024 Hz channels to 32 Hz and 1 Hz channels is accomplished through usage of microprocessor-controlled digital fourier transform (DFT) algorithms. The MCSA is modular in construction. One basic channel comprises the narrowband MCSA (8.0 MHz); to achieve the required 256 MHz of the wideband MCSA, 32 8 MHz channels are tied together. Within the MCSA, the data are accumulated for the appropriate time and then passed to the signal detection unit. The signal detection unit is composed of a 32 bit minicomputer and software containing the necessary algorithms for signal detection. The signal detection unit will provide real-time messages and initiate the recording of raw data when possible signals are detected. In addition, data of interest to the Radio Astronomy community will be recorded and archived.

IV. SETI Observational Strategy

As might have been anticipated, the differing requirements and goals of the sky and target surveys lead to substantially different telescope requirements and observational strategies. In the case of the target survey, aperture is by far the overriding concern; for the sky survey, on the other hand, aperture is not nearly so important as the availability of the antenna on nearly a continuous basis for long periods of time (i.e., ~ 12 months).

A. The Target Survey

For the target survey, the minimum detectable flux (in W/m²) is given by (Ref. 4):

$$\phi = (4\alpha k T_s / \pi \eta D^2) \sqrt{b/t}$$

where:

ϕ = flux, W/m²

α = signal-to-noise ratio

k = Boltzman's constant

T_s = system noise temperature, °K

η = aperture efficiency

D = diameter, m

b = bandwidth, Hz

t = integration time, sec

the integration time required to achieve a given flux level thus scales as:

$$t \propto T_s^2 D^{-4}$$

In considering the target survey, Arecibo, located in Puerto Rico with an antenna diameter of 213 m, is clearly the preferred telescope, and can achieve a sensitivity of 3×10^{-27} W/m^2 for 60 second integration times. For star targets not visible to Arecibo, the next largest class of telescopes are 64-m diameter (DSN and Parkes). Since it would not be practical to increase the integration time to achieve 3×10^{-27} W/m^2 (t = 7400 sec), the integration time at 64-m class telescopes will be kept the same as for Arecibo and a sensitivity penalty of a factor of ~ 10 will be accepted.

B. The Sky Survey

For the sky survey, the antenna will be swept at a constant angular tracking rate (ω, in deg/sec). The minimum detectable flux for this case is (Ref. 4):

$$\phi = (4\alpha k T_s/\pi\eta) \sqrt{\omega b \nu/70cD^3}$$

where:

ϕ = flux, W/m^2

α = signal-to-noise ratio

k = Boltzman's constant

T_s = system noise temperature, °K

η = aperture efficiency

ω = angular tracking rate, deg/sec

b = bandwidth, Hz

ν = frequency, Hz

c = speed of light, m/sec

D = diameter, m

for a given total survey time (t, where $t \propto D\omega^{-1}$), sensitivity scales directly with system noise temperature and inversely with diameter:

$$\phi \propto T_s D^{-1}$$

Therefore, the sensitivity penalty in going from a 64-m antenna to a 34-m antenna is less than a factor of 2. Given the far greater likelihood of gaining access, on a nearly continuous basis, of a 34-m telescope versus a 64-m telescope, it is nearly axiomatic that the sky survey will accept the sensitivity penalty and be conducted on the smaller telescope.

C. Observatory Coverage Requirements

Taking into account the SETI Program requirements and the observational considerations as described above for the target and sky surveys, functional requirements for observatory coverage have been developed as follows:

(1) Target Survey Requirements

- (a) Acceptable aperture (diameter) is ≥64 m
- (b) Average telescope time required is 3 hours/day (average) during the period FY 1985.0 to FY 1990.0.
- (c) Observatory time shall be approximately equally divided between northern and southern latitudes.

(2) Sky Survey Requirements

- (a) Acceptable aperture (diameter) is ≥34 m
- (b) Average telescope time required is 16 hours/day (average) during the period FY 1985.0 to FY 1990.0.
- (c) A minimum of 1/3 of the total observatory time shall be spent at a northern latitude complex and a minimum of 1/3 of the total observatory time at a southern latitude complex.
- (d) The SETI wideband instrument will initially be installed at the Goldstone complex.

(3) General Requirements

- (a) The SETI instrument systems will be transferred between antennae at intervals of no less than 12 months. SETI instrument system downtime will not exceed two weeks for intracomplex transfers and six weeks for intercomplex transfers.
- (b) Non-SETI telescope operations will be on a non-interference basis with the SETI system configuration.

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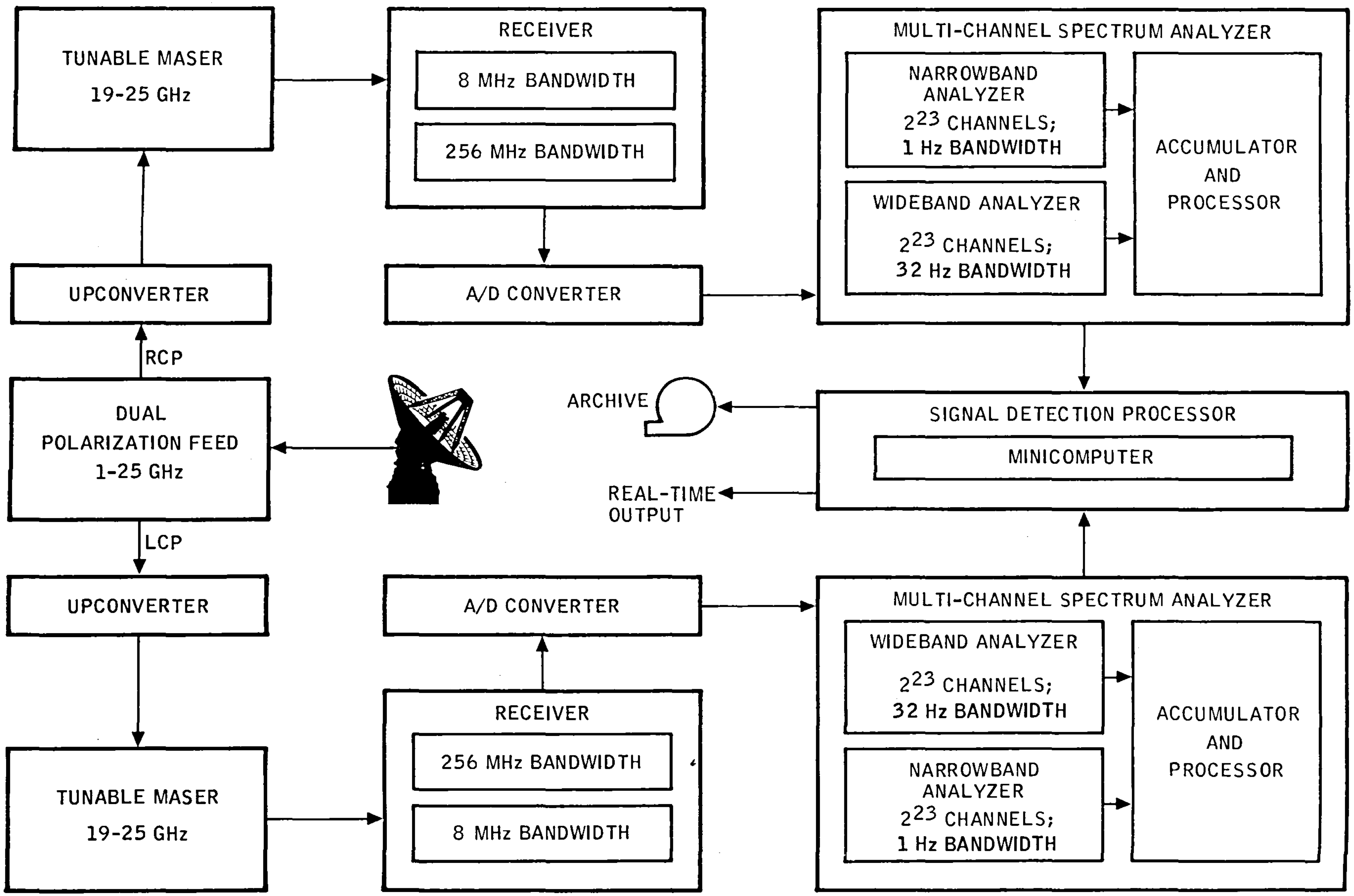

Fig. 1. Terrestrial microwave window

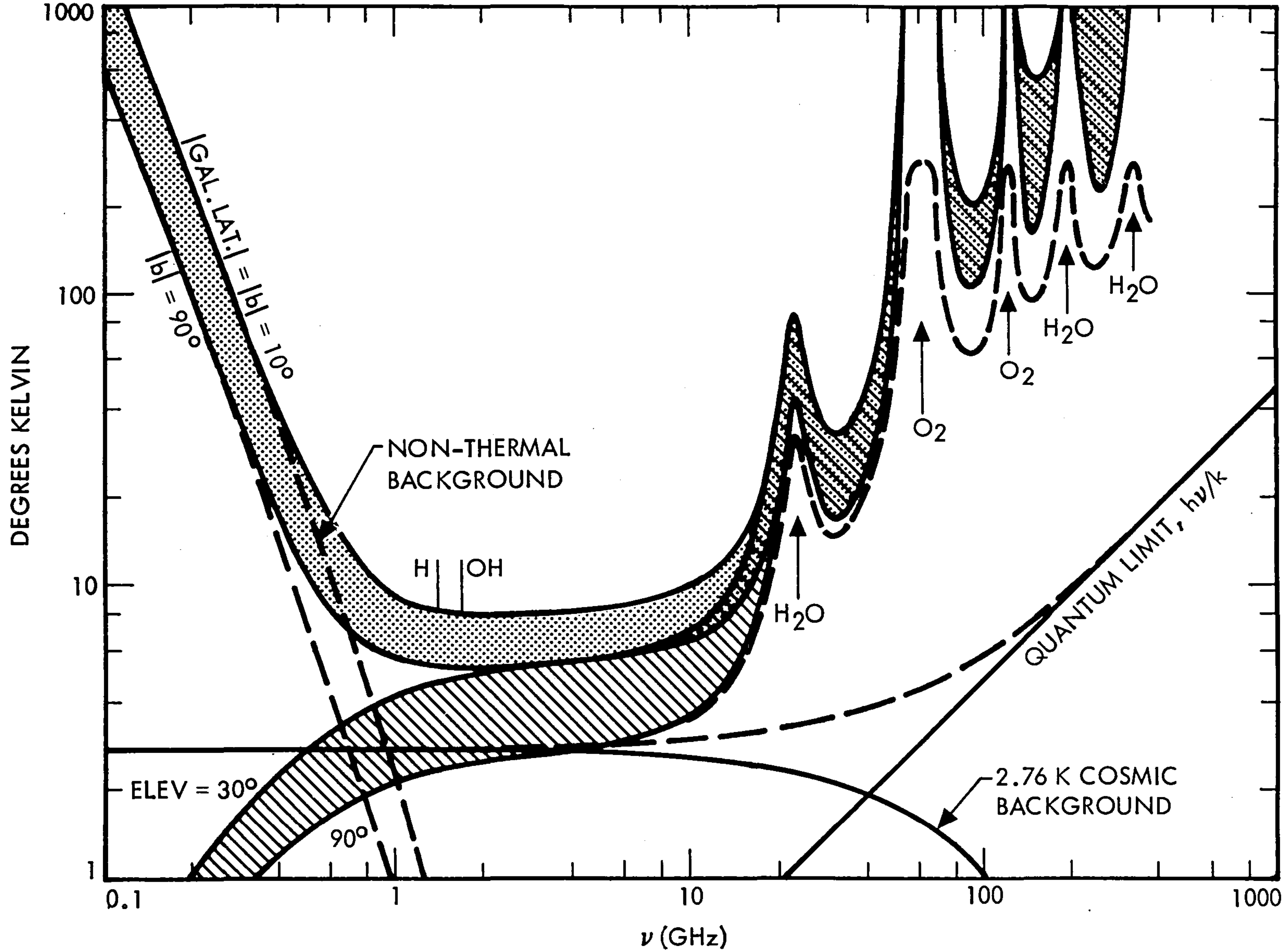

Fig. 2. SETI instrument system functional block diagram