SETI: THE MICROWAVE SEARCH PROBLEM AND THE NASA SKY SURVEY APPROACH

Michael J. Klein and Samuel Gulkis
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109

ABSTRACT. NASA's microwave observing program for SETI is presented. This strategy is composed of a high sensitivity, narrow frequency coverage, Target Search and a low sensitivity, broad frequency coverage, Sky Survey. The complementary nature of this dual mode search strategy is discussed. An overview is given of ongoing work in the development of the search strategy for the Sky Survey.

1. INTRODUCTION

The general search strategy recommended by the SETI Science Working Group (Drake 1983), and adopted by the NASA Seti program is a dual approach consisting of a survey for strong signals over a wide range of frequencies over the entire sky, and a more sensitive examination of nearby solar-type stars (and other interesting objects) over a smaller frequency range. This dual approach, known as the Sky Survey (SS) and the Target Search (TS), was selected because it is sensitive to a wide range of scenarios regarding the nature of potential signals. This paper describes the ongoing work in the development of the search strategy for the Sky Survey. A companion paper describing the Target Search was presented by C. Seeger and J. Wolfe. Two important constraints on the NASA program are that it will be done using existing radio telescopes in a time interval of approximately five years.

2. SETI SEARCH SPACE

A comprehensive SETI should examine as much of the multidimensional signal space (Wolfe et al., 1981) as is possible within the constraints of available telescopes and search times. It is difficult to know a priori how much weight to place on each of the dimensions. The component dimensions of this search space are source location, transmission frequency, signal strength, bandwidth, modulation, and polarization. Related parameters are source density, source distribution, and transmitter power. Three principal components of the

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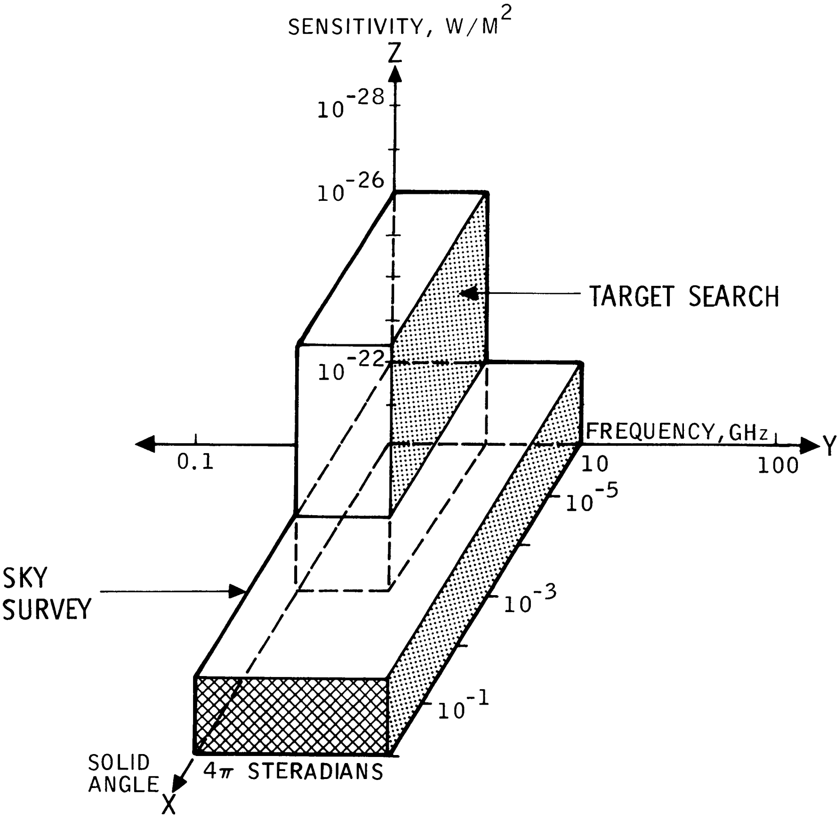
search space are received power, frequency bandwidth, and spatial direction. The three-dimensional Cosmic Haystack (Wolfe et al., 1981) is a graphic representation of this three-dimensional seach space. An alternative representation of the Cosmic Haystack is shown in Figure 1.



1. SETI Search Space and the two 'volumes' that will be searched by the Sky Survey and Target Search components of the NASA SETI Plan.

The two clearly identifiable volumes of the Cosmic Haystack shown in Figure 1 represent the search space that will be examined by the Target Search and the Sky Survey. Using this figure, the principal tradeoffs in search space examined by the two strategies can be compared.

With the TS the emphasis is on sensitivity, measured along the vertical (Z) axis in the figure. The sensitivity of the TS is greater than the SS by about 10^4. Put another way, the minimum detectable distance of a signal with specified equivalent isotropic radiated power (EIRP) is about 100 times greater for the TS.

The emphasis for the SS is complete sky coverage and expanded frequency coverage. The solid angle searched with the SS, measured along the X axis, will be about 1000 times greater than the TS. Note that solid angle is the one dimension of the compressed cosmic haystack that is bounded. The frequency range, measured along the Y axis, will be approximately five times greater.

If we are lucky enough to have selected the right class of targets and the correct frequency range of the transmissions, the greater sensitivity of the TS will be an advantage. In addition, each targeted direction will be searched for up to 1000 seconds, which enables the TS algorithms to look for more complex classes of signals, e.g., pulses with or without Doppler drifts. On the other hand, if we've guessed wrong, the Target Search will fail. The SS relaxes the constraint on direction; it searches the entire sky thereby surveying all potential life site directions. It also expands the frequency range of the search over the TS. A limitation of the SS is that it will fail if it does not have sufficient sensitivity to detect the strongest (SETI) signal in the entire sky even if the signal lies within the search band.

The probability of success of any search strategy requires knowledge of the spatial distribution of civilizations as well as the power and frequency characteristics of their transmitters. (In a related paper, Gulkis (1985) describes the relative probability of success of detecting randomly distributed CW transmitters.) Since none of these are known at this time, the dual search strategy of the NASA-SETI plan is an attempt to optimize the probability of success without trying to guess which of the search parameters is the most important.

3. PROBABILITY OF SUCCESS

Following Drake (1983), the probability of success for either approach can be written:

$$P(s) \propto \frac{\Omega_s}{4\,\pi\ \text{ster}} \frac{\Delta F_s}{\Delta F_c} N\,(S_m^{-1.5}) \qquad 1.$$

where

Ω_s = solid angle of search
ΔF_s = frequency range of search
ΔF_c = frequency range within which signals are confined
N = Space density of transmitters
S_m = Minimum detectable flux (W m^{-2})

The SS concentrates on making the first two terms large, while the TS focuses on the sensitivity term S_m. These are complementary tradeoffs since the total observing time is a common constraint (Gulkis, 1985). For the SS, P(s) is enhanced by setting $\Omega_s = 4\,\pi$ and by expanding ΔF_s. The selected values for the parameters of the SS are listed in Table I.

TABLE I
NASA SKY SURVEY SEARCH SPACE PARAMETERS

Ω_S	4 π steradians
ΔF_S	1-10 GHz plus Spot Bands (to 25 GHz)
S_m	2-6 x 10^{-23} W m^{-2} (34-m ant)
Polarization	RCP & LCP
Signal Type	CW
Time to Complete Search	3 to 5 years

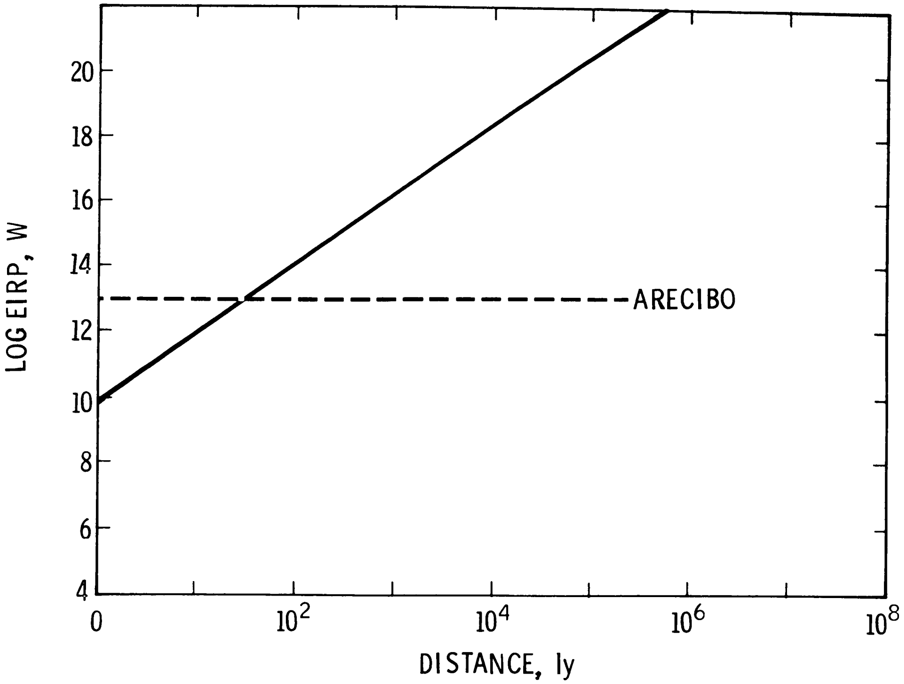
An important problem currently being worked is to find opportunities to enhance P(S) by minimizing losses in sensitivity and still complete the survey within three to five years. That is the underlying question addressed in the following paragraphs of this paper.

4. THE SENSITIVITY OF THE SKY SURVEY

The sensitivity of the Sky Survey depends on the diameter of the telescope, the bandwidth of the receiving system, the system temperature, and on the total observation time. For a given observing time, the sensitivity can be improved by reducing the resolution bandwidth, reducing system temperature and increasing the telescope size. The resolution bandwidth has been chosen to be narrower than any known astronomical sources and consistant with our current capabilities to manufacture wide-bandwidth multichannel spectrometers. System temperatures are approaching theoretical minima for ground based systems. While sensitivity can be improved by using large antennas, the small beam size of large telescopes makes full sky mapping difficult to achieve in a reasonable time. In addition, the largest, existing radio telescopes are not available for large blocks of time. For these two reasons, availability and beam size, relatively small antennas will be used for the All Sky Survey.

Given the sensitivity of the planned search, to what distance will the Sky Survey be effective? Figure 2 is a plot of the relationship between transmitter distance and the minimum detectable EIRP for the SS with a 34-m diameter antenna. Note that a transmitted EIRP similar to the current capability at Arecibo (shown by the dashed line) would be detectable to distances up to 30 light years. This limit may be improved slightly as the search strategy and signal processing algorithms are improved to reduce the false alarm rate.

Even with a sensitivity of a few times 10^{-23} w m^{-2}, the SS will be 100 times more sensitive than previous radio astronomical line surveys (for narrow band CW signals). If a bandwidth of several GHz is synthesized from the narrow band channels, it should be possible to carry out a radio source survey of the entire sky with enough sensitivity to catalog more than 50,000 radio sources. This survey would complement the low frequency (365 MHz) survey conducted at the University of Texas (Douglas et al., 1980).



2. The minimum detectable EIRP for an All Sky Survey with a 34-m antenna. The dashed line indicates the EIRP for an Arecibo-like transmitter.

5. SURVEY SEARCH STRATEGY

One of the problems to be solved during the current research and development phase of the SETI effort is to identify a search strategy for the Sky Survey that will achieve maximum and nearly uniform (or smoothly varying) sensitivity over the entire sky. This is constrained by telescope availability and the maximum time allocated to the search. The elements of this problem are diagrammed in Figure 3.

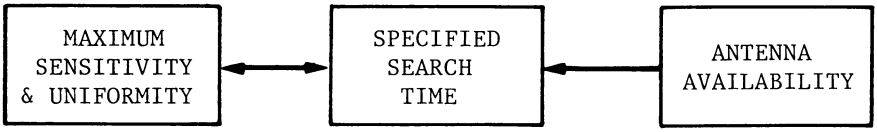


Fig. 3. Search Strategy Tradeoffs

Several 'free parameters' will affect the sensitivity and search time. Among those being considered in the current study are:

1. Scan patterns, including shape and size of search cells
2. Scan rates, which must not exceed mechanical limits
3. Scan separation on the sky
4. Antenna diameter
5. Data accumulation times
6. Threshold statistics
7. System gain and noise temperature vs frequency and antenna orientation
8. Receiver gain stability

The status of some of this work is described in a companion paper presented at this conference (Olsen et al., 1985).

The Sky Survey search strategy will be programmed to achieve efficient use of allotted observing time, which is a valuable commodity for all radio telescopes. The plan calls for the antenna to be systematically scanned over "cells" on the sky. Because observing time for long duration programs is usually scheduled in bits and pieces, the sky will be searched in a patchwork fashion and not, for example, row-by-row or in a continuous spiral. The observing sequences are being designed to achieve a search of the sky with uniform sensitivity from a composite of search cells that may be quasi-randomly distributed in time and date.

The SETI research and development activity is preparing for an important series of field tests. One of the primary objectives of these tests is to identify trade-offs among the various parameters that affect sensitivity, search time and efficiency. Another aspect of the field testing will be to assess the affects of radio frequency interference (RFI). Modifications to the search parameters and algorithms may have to be made to minimize the impact of RFI. Techniques to detect and reject RFI might have to be implemented. Simple discrimination procedures are being written into the current survey plan, but so little is known about the nature of RFI over the wide frequency range (1-10 GHz) of the survey, that we must be prepared for surprises!

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