The Search for Extraterrestrial Intelligence: Telecommunications Technology

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Efforts to discover evidence of intelligent extraterrestrial life have become not only feasible, but respectable. Fledgling observational projects have begun that will use state-of-the-art hardware to develop sophisticated receiving and data processing systems. The rationale behind the Search for Extraterrestrial Intelligence (SETI), the manner in which the program is taking shape, and the implications for telecommunications are described. We conclude that the breadth of technological development required for the detection of signals from our galactic brethren has particular relevance for the future of telecommunications in earth-oriented uses.

I. Introduction

> *To consider the earth as the only populated world in infinite space is as absurd as to assert that in an entire field sown with millet only one grain will grow.*
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> —Greek philosopher Metrodoros of Chios, 4th Century B.C.

As described by Brunk (Ref. 1), the past 40 years have witnessed a revolution in thought as to the prevalence of planetary systems. The belief that planetary systems are common phenomena has led to a corollary assigning high probability to the presence of currently existing intelligent life.

Many specialists in the disciplines of biological and cultural evolution believe that intelligent life, molded by the pressures of natural selection, shares a common bond of civilization, curiosity, and the urge for exploration and communication (Ref. 2). The possibility of our communicating with another intelligent species depends on the presence of a large number of intelligent races concurrently possessing the means and will to attempt communication. Taking into account the vast volume of the galaxy, and assuming only that intelligent life is spread uniformly over that volume, scientific opinion suggests that for a reasonable chance for success in detection, the average lifetime of a communicating civilization must exceed 100,000 years (Ref. 3). If intelligent life normally expends its physical and spiritual resources in a few hundred years, as we appear to be in danger of doing, then detection becomes

impossible. If, on the other hand, intelligence really is a survival factor, and sentient life prevails, the galaxy may be seething with communicative species.

Since 1959, when Cocconi and Morrison (Ref. 4) recognized that communication with beings thousands of light years from us had become possible through the tools of the radio astronomer, the major obstacle to attempting the discovery of signals has been the enormous dynamic range of the parameter space in which such signals might be found. Today, however, a good start can be made in examining the total physically reasonable range of the variables involved, using the fast moving technologies of the telecommunications industry.

II. Electromagnetic Communications

Communication can be accomplished through the use of any physical phenomenon that propagates in some manner and can be made to exhibit a detectable change of state when desired. By far the most likely communication medium is that of electromagnetic waves. Such transmissions have the advantage of energy efficiency, propagation at the speed of light, ease of detection, and relative immunity to the interstellar magnetic fields. Generally, the major investigations on SETI (Refs. 2, 5 and 6) agree that reception of electromagnetic waves is the most promising approach to the detection of extraterrestrial intelligence.

III. Search Strategies

A. Description of the Parameter Space

The description of a strategy for searching for artificially generated electromagnetic waves involves the specification of the volume examined in the four dimensional signal space of: source location; source modulation, or the manner in which the signal conveys information; transmitted frequency; and the received power flux density. Plausible ranges for these variables can be determined by physical reasoning alone. Further reduction requires assumptions as to the approach and prowess of the transmitting civilization, an audacious step when considering a society 100,000 or more years our senior. Thus, it is highly desirable to investigate the total reasonable parameter space to levels commensurate with the time, facilities, and resources which can be brought to bear, weighting the effort with extrapolation from our own experience, while not neglecting "unlikely" but physically realizable regimes.

Billingham (Ref. 7) discusses the reasoning behind the range of values that must be examined for a truly comprehensive search. Here, we simply note the rationale behind each of the generally reasonable ranges.

1. **Source location.** Although particular types of stars (generally nearby stars of spectral classes F, G, and K) have a high *a priori* weight in a search effort, reasonable scenarios asserting adaptability or capability beyond our own suggest a much wider range of target possibilities, including white dwarf systems, the extended regions of interstellar masers and many more. (Simply adding M stars to the target list, for example, multiplies the target opportunities by a factor of 5 to 10.) When these scenarios are included, the number of possible targets expands to where a comprehensive search must examine the entire sky in addition to looking at *a priori* targets.

2. **Source modulation.** Generally two types of signals may be anticipated from beings attempting to initiate communications with other life: very narrowband continuous signals, or very powerful pulsed transmissions, frequently repeated. The former is a signal compact in frequency, the latter a signal compact in time. Both are logical artifacts of intelligence.

3. **Transmitted frequency.** A search over the entire electromagnetic spectrum for a weak signal whose bandwidth may be less than a hertz is not a feasible undertaking. Fortunately, as Oliver has shown (Ref. 8), a particular spectral region, the band between approximately 1 and 100 GHz, is uniquely attractive for interstellar transmissions. This region, the microwave "window" (Fig. 1), exhibits the minimum interference from interstellar noise sources. The figure demonstrates that the lower range of the microwave window is of primary interest for Earth-based systems, while the higher end, at which the atmosphere is opaque, or at least murky, is of interest for space-borne systems.

Rationales have been offered to further narrow the plausible spectral region, applying various criteria for determining the behavior of the transmitting society. Regardless of how attractive the reasoning may be, it requires extrapolations based on our own experience and biases. However, these rationales are valuable for selecting *a priori* search preferences for specific bands, notably the "water hole," the band between approximately 1.4 to 1.7 GHz (Ref. 5). Generally, the entire window must be examined, but frequency bands of radio astronomical interest might be emphasized as they provide signposts for all species, and are frequencies at which an initiating society might expect radio astronomers to be listening.

4. **Received power flux density.** The received power flux density, ϕ, from a source of effective isotropically radiated power, P_r, at range R is proportional to the ratio, P_r/R^2. Thus,

assumptions as to plausible received power flux density are critically dependent on the power of the interstellar transmitter, the range from which it operates, and the directivity of the transmission. Figure 2 shows the joint transmitter-receiver requirements that would permit a signal detection. There is a multidecibel region that might hold the signals we seek.

B. Choosing Search Strategies

Surprisingly, the work of the last two decades has done relatively little to establish the boundaries of the parameter space outside of which there exists no signal. The available technology, particularly in multichannel spectral analysis, has been insufficient to encompass a wideband, sensitive search. In addition, the majority of sky examinations have been conducted for radio astronomical purposes, thus excluding detected narrowband signals from data analysis. The vast majority of such signals are manmade radio frequency interference, but this exclusion also prevents the detection of signals from other beings.

A full-blown examination of the total range of reasonable parameter values is impractical. Thus, the search strategy must seek to simply bound the volume of the four dimensional space, within the constraints of available time and resources, and emphasize regions that have particular *a priori* promise.

One approach to this problem is to implement a two-fold strategy. The first part is to use existing antennas of moderate size to conduct a full-sky survey over a very wide frequency band, varying the achieved flux levels according to the attractiveness of the frequency for SETI and scientific purposes. The second is to limit both frequency and sky coverage to particular interesting frequency bands and targets and extend the boundaries in power flux density by the use of the largest available antennas and long integration times.

These approaches narrow the unknown parameter space in several dimensions while accomplishing realistic programs with realistic resources. Only when the capabilities of existing facilities are exhausted would dedicated SETI antennas be required to further limit the uninvestigated space until a signal is detected, or until we are convinced that we occupy a nearly unique place in the galaxy. It has been estimated that existing facilities, combined with state-of-the-art instrumentation, can achieve 10^7 more coverage of the parameter space than has been achieved in all combined searches to date (Ref. 9).

C. Implications for System Design

Just as a single system cannot be used for both light and electron microscopy, so a SETI requires different system approaches to the investigation of the available signal regimes. Figure 3 displays the essence of a phased program being developed now by the Ames Research Center and JPL that follows a system building block approach to gradually converge on the place where a signal awaits detection. The approach recognizes that the accomplishment of wideband searches with narrowband resolution depends on our ability to replicate millions or billions of spectral bins inexpensively, and to support this data generation by the reduction of immense quantities of input to a quantity suitable for human examination.

Figure 3 shows the flow of the plan from the definition of the search environment, to the generation of the system requirements it engenders, to a detailed technological progression which permits observation with increasing thoroughness as the state-of-the-art advances. In the next section we enumerate the major technological advances required in order to achieve this program approach.

IV. Telecommunications Technology

Current and future telecommunications technology will achieve systems with the high sensitivity and broad bandwidth required for a search for extraterrestrial intelligence. The major developments required for the SETI activity can be conveniently grouped into four categories: receiver systems; data management; supporting technology; and future directions.

A. Receiver Systems and Data Management

There is a substantial difference in the implementation of the hardware and software requirements for the SETI. The receiver system, including the antenna, amplifiers, and spectrum analyzers, is a straightforward application of the state-of-the-art to achieve high sensitivities and very wide bandwidth simultaneously. The system requirements are known, and the design of prototypes is already underway.

The data management approach has substantially different emphasis. The computational devices to construct operational search systems are off-the-shelf items. The algorithms implemented by these devices will be refined and reconstructed to fit this unexplored environment, once observational experience is gained.

1. Receiver systems. Within the context of a very broad spectral search, the major sensitivity improvement for SETI will be achieved through unprecedented spectrum analysis capabilities. The most straightforward approach to the detection of a signal of unknown frequency and phase requires initial processing by a spectrum analyzer. The choice of minimum useful channel bandwidth is based on several phenomena. Useful bandwidths are constrained by the inter-

stellar medium, which probably degrades any signal to a bandwidth of at least 10^{-3} Hz. Uncertainties in relative velocities between stars will provide more severe constraints on the minimum useful bandwidth. The Doppler shift must remain within the bandpass of the individual bins for some time greater than the reciprocal power bandwidth of the bin. Finally, the expectation that some modulation will be present, resulting in a wider minimum bandwidth signal, also affects the choice of minimum bandwidth. Thus, minimum bin widths may be between 10^{-1} to 10 Hz. However, to be compatible with reasonable search times, the total system instantaneous bandwidth should be about 300 MHz. These considerations may ultimately give rise to requirements for about 10^9 bins of spectrum analyzer capacity.

As a first step commensurate with the state-of-the-art, the SETI program is currently funding the development of a 10^5 bin, fast fourier transform spectrum analyzer which is the prototype of one module of a much larger instrument. The assembly and completion is expected within one year. Although the prototype will have a bandwidth of only 64 kHz, the design will be compatible with easy expansion to a 300 MHz bandwidth device with 10^7 channels. This experimental unit uses only a few types of available chips, and the expected cost is about 50¢ per channel.

To accomplish a system design which does not squander the sensitivity potential of the broadband spectrum analyzer, wideband, low-noise amplifiers are required that can be tuned over the entire search bandwidth. The Jet Propulsion Laboratory, working on contract to the National Radio Astronomy Observatory, has built a 19 to 25 GHz tunable maser amplifier with an instantaneous bandwidth of 300 MHz. When used as a postamplifier for a series of parametric up-converters, this device exhibits a noise temperature of 4 to 8 K. A 300 MHz instantaneous bandwidth with perhaps a 2 K amplifier noise temperature can be achieved in a device which covers the entire band from 1 to 25 GHz using approximately nine up-converters and a single maser.

To maintain the amplifier in its operating regime requires a physical temperature of 4 K or less. Currently used closed-cycle cryostats exhibit mean time between failures (MTBFs) on the order of one year. Thus, a basis exists for the design of cryogenic amplifiers that must perform extended, automated search efforts.

2. Data management. Any SETI observational program must develop methods to pick the plums from the glut of irrelevant signal. A search system, using a 10^9 channel spectrum analyzer, would produce data enough to fill half-a-million 400-page books for every day of operation were we not to discard uninteresting data. Real-time pattern recognition algorithms must be devised which can discard noise, both natural and manmade, and identify promising data. The preservation of data of scientific and SETI interest will require archival systems similar to those foreseen for Earth applications.

Radio frequency interference (RFI) will be an important limitation on the search. Because of the sensitivity required of a SETI receiver, virtually any radiation picked up in the receiver bandwidth will make the conduct of this search more difficult. Earth-based transmissions reflected into the sidelobes of the antenna by artificial satellites or the moon will cause significant problems. Earth satellites above the horizon will almost preclude operation in their bands. Some bands will probably be unusable, and techniques must be developed so that a search can be conducted in spite of the RFI environment.

Fortunately, the characteristics of RFI are substantially different than those of the desired signal, particularly in Doppler signature. Existing technology in data processing can be successfully applied to remove the RFI-corrupted data from consideration.

B. Supporting Technology

Even the modest program underway will involve observations over several years for a possibly elusive signal. In order to minimize life-cycle cost and ensure reliable detection, this program will require the use of antenna facilities that operate unattended. The implementation for automation will be extensive, and future requirements will be even more stringent.

Partially automated facilities exist today. Wherever possible these facilities will be employed, and the specific requirements for automated pattern recognition will be developed as part of the overall antenna application.

C. Future Directions

A modest search for extraterrestrial intelligence can begin almost immediately with current technology, but research and development offer great promise for future efforts through improvements in data processing and antenna and microwave designs.

Since there exists a minimum useful bandwidth for the spectral bins examined in a search, the primary use of mega- or giga-channel spectrum analyzers is to permit a rapid search over the reasonable spectral region, while retaining the highest possible sensitivity. At some point (see Fig. 2), the capabilities of existing antennas will be exhausted, and facilities with improved quality and quantity of aperture will be required. Because this approach involves great capital expense, it is vital

to make effective use of the aperture achieved. Antenna efficiency can be improved, with 95% a realistic goal. These same efficient antennas can contribute to a reduction in system noise temperature and diminished sidelobes would also alleviate RFI pickup. One challenging approach requires the further development of antenna array technology for very wideband operation.

Orbiting antennas offer particular advantages for high frequency operation (see Fig. 1), and may be competitive with ground facilities for very large aperture operation at the lower frequencies (Ref. 2).

V. Consonance With Technology Trends

Because of the stringent requirements for system sensitivity, bandwidth, automation, and operation in an environment of potentially harmful RFI, the SETI program requirements anticipate many of the trends in telecommunication technology.

The technology involved in the development of spectrum analyzers with 10^9 or more bins has immediate application in processing: (1) radiometer data such as that gathered by Earth applications satellites; (2) RFI in particular bands for interference measurements and trend evaluation; and (3) seismological data for scientific and practical applications.

Data processing will be accomplished with devices capable of recognizing characteristic patterns while handling enormous input. This would also have applications to radiometry, RFI, and seismology. The techniques for reducing the quantities of raw data to manageable proportions and for archival recording will have broad industrial application.

Finally, the fulfillment of the telecommunications and Earth applications requirements for large spaceborne antennas and closed-cycle cryogenic systems will produce direct benefits for the Search for Extraterrestrial Intelligence.

VI. Conclusions

A most imaginative and inspiring project, the Search for Extraterrestrial Intelligence can now be tackled with a broad-based, serious observational program. In its initial stages, this program will be supported by the application of what is now the state-of-the-art in telecommunications and electronics technology. Future developments may make SETI a pioneer in the application of a broad array of technology which can expand our horizons to the stars while solving some very down-to-earth problems. In exploring the cosmos we can given some hard tugs to our own bootstraps.

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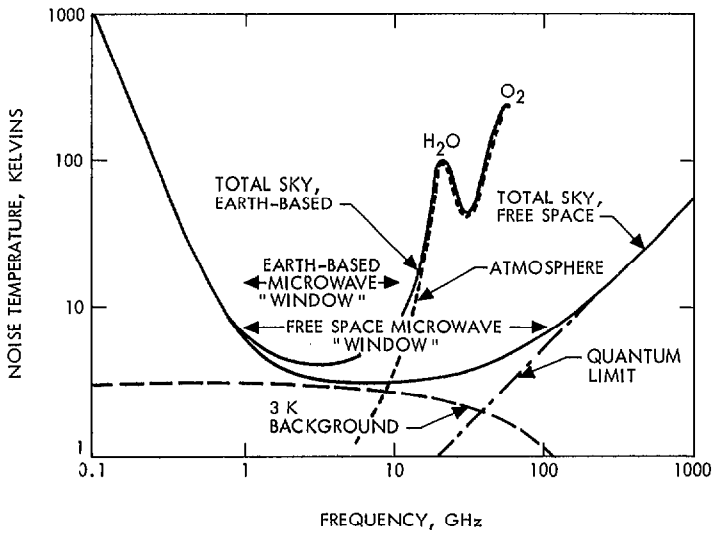

Fig. 1. The Microwave "Window"

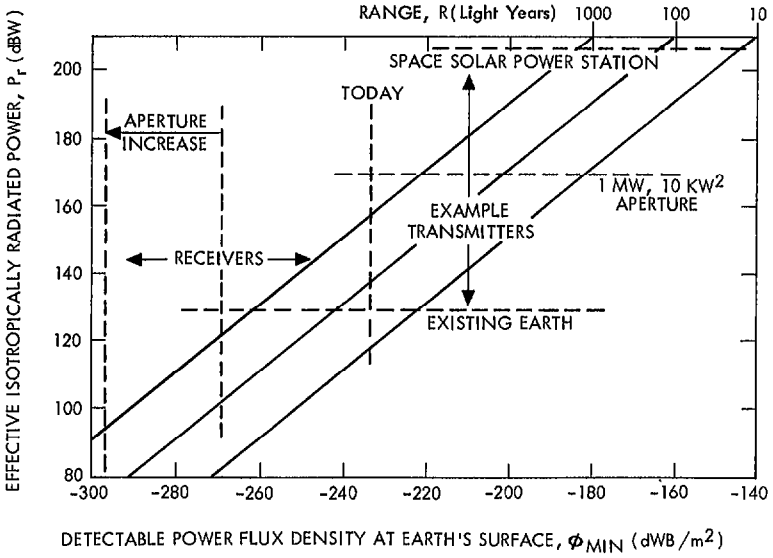

Fig. 2. Joint Transmitter-Receiver Requirements for SETI Detection

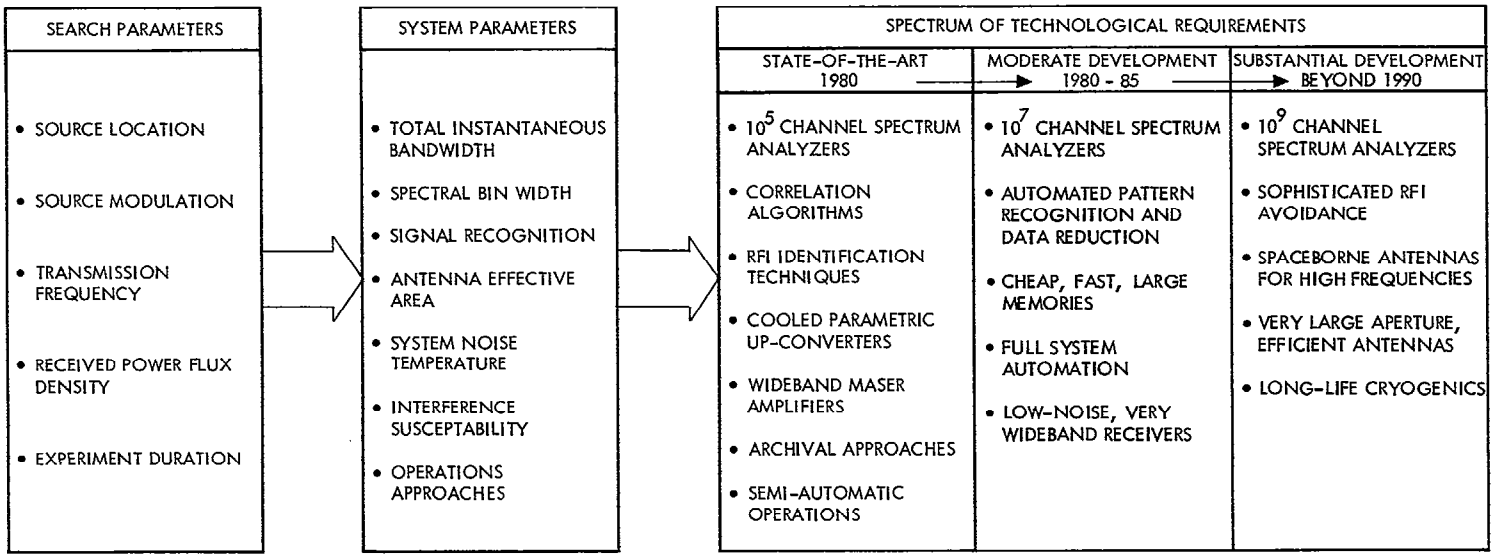

Fig. 3. Implications for Systems Design