EAVESDROPPING DETECTION OF RADIO SIGNALS FROM OTHER PLANETS, WITH ONE BIT-IMPLEMENTATION TECHNIQUES USING EXISTING COMPUTERS

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ABSTRACT. Detection of other civilizations by "eavesdropping" on accidental radiation from television and other self-oriented signals is proposed. One-bit spectral analysis techniques to implement this are discussed. These can utilize existing general-purpose computers, and provide flexibility of strategy in the analysis. The first derivative of doppler shift from an unknown planet can be compensated for with increased integration times possible.

Previous proposals for searches for extra-terrestrial intelligence have made excellent arguments for searching for signals at various radio frequencies of significance to radio astronomers. Implicit in this type of proposal is the hypothesis that the other civilization is purposely broadcasting a 'finder' signal. While this is a cogent argument, it seems logical to encourage alternative approaches in a field with as large an inherent uncertainty as the S.E.T.I. search. One such alternative is to assume that any other civilization would have characteristics, both sociological and technical, similar to ours. In this case, it would certainly make sense to look for accidental outputs associated with the civilization. In this connection, an article in Science by W. T. Sullivan et al (1978), has pointed out that the primary radiation by which our civilization could be detected from another star is leakage radiation from UHF and VHF transmitters, rather than any purposeful signal emitted in hopes of communicating with another civilization. It is estimated that the leakage radiation from television transmitters could be detected at a distance of 2 light-years with the existing Arecibo configuration; beamed high-power radars such as the BMEWS and NAVSPASUR systems could be detected at several times that distance. An improvement in the system parameters of 100X from any cause would enable detection of television stations from all stars within 20 light years. Terrestrial television signals also have quite desirable characteristics both as search targets and for extracting useful information once acquisition is made. A large portion (typically 50%) of the radiated energy of a television signal is contained in a carrier that has a very narrow

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spectral bandwidth and accurately controlled frequency, making coherent signal analysis applicable. While the exact frequency of non-targeted extraterrestrial transmitters will be poorly defined, it may be argued again that technological developments are likely to be similar for another civilization. Certainly the basic phenomenon of the existence of an ionosphere is likely to be repeated, which in turn may lead to the location of television signals, military radars, etc. in a similar portion of the spectrum.

The Arecibo antenna and spectrometer have been used to verify the leakage effects by detecting television signals reflected from the moon, as well as the 217 MHz carrier of the NAVSPASUR radar system. Television spectra (Sullivan and Knowles, 1984) were easily detected, with characteristics and signal strength approximately as predicted by Sullivan et al, with the significant exception that signals were present essentially continuously, instead of during limited periods, as predicted from the supposed narrow vertical antenna patterns of the transmitters. This is interpreted as indicating a high side-lobe ratio in television transmitter antennas. The signal spectrum transmitted by terrestrial television stations is quite complicated, but because the video component is amplitude-modulated a relatively strong carrier component always exists, with a significant fraction of the transmitter power. For terrestrial television stations, the technical standards usually followed generate the carrier from a cesium frequency standard, resulting in extremely good frequency stability. While this high accuracy is not inherently necessary, we may with some confidence expect a carrier stability of a small fraction of a hertz, more than sufficient to make coherent signal processing techniques possible. Searching for SETI signals using this method has the strategy disadvantage that there is no readily apparent natural frequency, thus decreasing the chances of success. However, this must be balanced against the increased probability that the accidental signals will be emitted in comparison to the allocation of a civilization's resources to a purposeful emission. Although it may be postulated that our civilization will advance in technology so rapidly that all communications will soon be tight-beam, this assumes a ruthless weeding out of technological anachronisms that has not corresponded to the human experience. In addition, the merits of tight-beam versus broadcast entertainment communications seem to be far from settled, and a strong case can be made that broadcast beams of some kind will always be needed for navigation and position location, as well as for military purposes. While this method has no clearly-defined natural frequency, this disadvantage is not as much as may be suspected. For signals similar to terrestrial television stations, the spectral separation between stations is about 10 MHz, so that this is the search extent needed to have a reasonable probability of detecting a signal. For searches at the hydrogen line frequency that do not presuppose knowledge of the stellar radial velocity, a search range of about +/-0.5 MHz is needed, so that there is only X10 disadvantage. Even if we suppose no knowledge of the desired frequency, a search band of about 200 MHz does not impose an insuperable penalty.

In order to further the analysis of this and other SETI investigations, data analysis techniques using one-bit operations have been developed and implemented on several general-purpose computers. The use of the single-bit method in correlation is well-known Moran (1976). Previous use of this technique in general purpose computers for SETI purposes (Tarter et al 1980) have used a simple very large Fourier transform. However, this technique, with its advantages in processing speed due to the ability to use logical add and multiply operations on 16 or 32 samples at once, can also be used for other signal-processing operations. In particular, we have developed digital one-bit filtering and mixing techniques that enable any general-purpose computer to be used for SETI analysis by dividing the spectrum into a number of sub-spectra that can be analyzed with as high frequency resolution as desired. While sophisticated digital filter-mix routines can be developed, the desire to preserve the processing speed advantage of single-bit operations leads to use of the simplest algorithms possible. This is done by generating a single-bit local oscillator table that is XOR'ed with the data repetitively, and using a low-pass filter consisting of a boxcar averager, which can be implemented by table lookup. This procedure amounts to double-sideband mixing. These techniques can be used to analyze in any desired manner any data recorded on, or transferred to, a computer-compatible digital medium, subject only to the fundamental constraints of information theory. While this method may seem to be inefficient as compared to a dedicated correlator, it has two principal advantages in practice. First, it allows "free time" on any of numerous medium to large scale computers (early-morning, weekend, etc.) to be used to usefully contribute to the SETI search on an essentially cost-free basis. Equally important, the lack of a hardware implementation allows the same data to be easily processsed with alternative search strategies, providing a flexibility not easily attained with an all-hardware realization. This allows, for example, analysis of a set of data with varying bandwidths, or with a set of hypothesized planetary rotation rates, which cause an apparent chirp or frequency drift in the signal. While the assumption that the transmitted signal is essentially CW with only a low information rate is probably best, it is certainly advantageous to be able to preserve the flexibility of looking for, for example, pulse signals. An important advantage of processing in a non-hardwired environment is the ability to compensate for doppler drift rate of signals from another planet caused by unknown rotation speed and phase. For a planet with parameters similar to the earth, the maximum doppler drift rate is about 0.1 Hz/sec at 1 GHz, limiting coherent integration time to 10 seconds if no compensation is made (Figure 1). The amount of this effect will of course depend on planetary size, rotation rate and observing frequency; it is normally greater for planetary rotation than orbital motion because of the shorter period, even though total orbital doppler is greater. While this effect cannot be corrected for

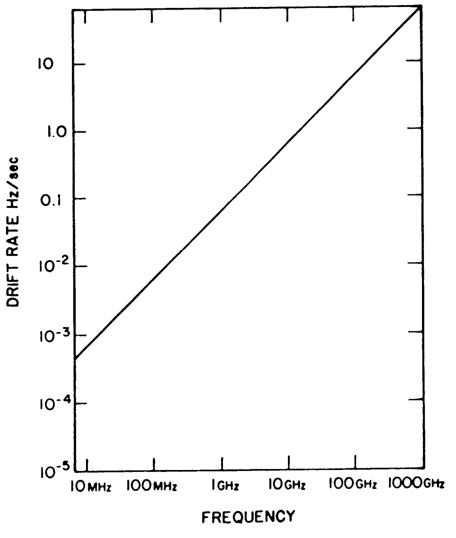

Figure 1. Maximum drift rate of doppler for a planet with earth-similar parameters.

in a unique fashion because of the unknown planetary phase of the emitted signal, it can be compensated for in a general-purpose computer mix and filter routine simply by mixing with a 'chirped' local oscillator (Knowles and Waltman, 1984). This chirping is done simply in a one-bit system by inserting or removing ('sliding') an extra bit in a quadratic fashion when generating the bit table that represents the local oscillator. In this fashion the coherent integration time possible can be extended to a significant portion of a planetary period (several hours).

Any comparison of the processing time and flexibility requirements of dedicated spectrum analyzers versus general-purpose computers must be very approximate because of the present rapid development of digital hardware capability and the increasing ability to implement flexibility in firmware. An approximate present benchmark is that the current Floating Point Systems array processors can execute a 1024-point Fourier transform in about 0.002 seconds; this means that general-purpose computer hardware can keep up with about 500 Hz signal bandwidth. Applying the well-known n log n fast Fourier transform time estimate, the general-purpose machine falls about a factor of 5000 short of the hardware implementation. Thus for a full-scale program, some hardware implementation is desirable. However, if one accepts that data from a limited observing period (say 10 hours of data) is to be analyzed, and that 'waste' time on computer can be utilized, the method certainly seems to be of utility. While present methods do a good job of probing a certain portion of the SETI probability-space, use of more general single-bit techniques with at least partial software implmentation will preserve flexibility for analysis of S.E.T.I. data. A limited sample of data taken with the Mark I VLBI system on nearby stars at Arecibo using this method has been analyzed. While no detections have been made, the method has been checked out satisfactorily.

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