Developments in the Radio Search for Extraterrestrial Intelligence

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Abstract

We present developments in the search for engineered radio emissions from advanced extraterrestrial life. Our group is currently engaging in both targeted and sky survey searches for extraterrestrial intelligence (SETI), covering a wide variety of narrow-band and pulsed signal types. We are also developing new SETI instrumentation, designed to be flexible, modular and to employ commodity components that lower cost and enhance upgradability. Here we will discuss the status of these observational and engineering projects, as well as prospects for future radio SETI endeavors.

1 Introduction

For the past 75 years, humans have produced radio emissions that could readily be recognized as having come from no known natural source if transmitted at sufficient power from another star and received on Earth. These emissions include spectrally narrow signals, e.g. the sinusoidal carrier waves associated with frequency modulated or amplitude modulated telecommunications, as well as temporally narrow radio pulses used for radar. Further, the interstellar medium is relatively transparent at radio wavelengths, especially in the cm band, making radio transmission well suited for interplanetary or interstellar communication. The frequency band between $\sim$500 MHz and 10 GHz is especially attractive for terrestrial transmission or reception, in that it represents a relatively quiet radio window between the synchrotron-dominated low frequency spectrum and atmospheric H_2O and O_2 emission and absorption, as shown in Figure 1.

Natural astrophysical electromagnetic emissions are inherently spectrally broadened by the random processes underlying natural emission physics, with the spectrally narrowest known natural sources having a minimum frequency spread of 500 Hz [2] (astrophysical masers). Emission no more than a few Hz in spectral width is an unmistakable indicator of engineering by an intelligent civilization. While scintillation effects can render an intrinsically amplitude-stable narrow-band signal intermittent [4], broad band radio pulses can overcome intermittency due to scintillation, if sufficiently broadband. Broad band pulsed emission is known from a variety of astrophysical sources, usually from strong magnetospheres, but intelligent modulation of pulsed emission would be apparent. Further, natural sources of pulsed emission are relatively rare and do not represent a significant interfering background to searches for pulsed emission from intelligent civilizations. The most prevalent source of strong pulsed radio emission are pulsars, of which around 2000 are currently known. Current estimates of the potentially observable number of radio pulsars is around 100,000 [7], versus the approximately 10^{11} stars in the Milky Way.

While the technologies associated with engineered radio emissions from Earth are developed by humans, similar signal types may be used by extraterrestrial intelligent civilizations as well. It is difficult to predict the

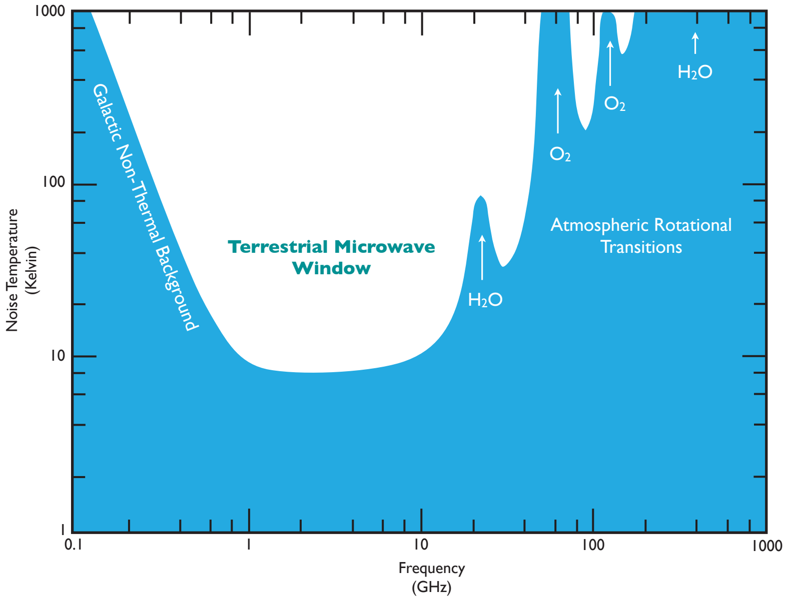

Figure 1: The "terrestrial microwave window": a relatively quiet radio window between non-thermal galactic synchrotron emission and molecular rotational transitions in the Earth's atmosphere.

specific properties of electromagnetic emissions from extraterrestrial technologies, but if an extraterrestrial civilization is intentionally indicating its presence via such emission, it would be beneficial to make the signal discriminable. In terms of distinguishability, both pulsed signals and narrow band signals possess merit, and it is prudent to search for both.

2 Radio SETI Searches

Our ongoing commensal searches at Arecibo Observatory, SETI@home and the Search for Extraterrestrial Radio Emissions from Nearby Developed Intelligent Populations (SERENDIP), are sensitive to a rich variety of narrow band and pulsed signals. SETI@home is a distributed computing effort, in which a 2.5 MHz band of raw voltage data are recorded onto disk at the telescope, shipped to a distribution point at UC Berkeley and transmitted to SETI@home volunteers for processing. Launched in 1999, SETI@home has engaged over 5 million people in 226 countries in the search for life on other worlds. Currently, participants in the project are generating the collective equivalent of 200 TeraFLOPs/sec, having performed over 1.4×10^{22} FLOPs to date. This immense computing power is used to conduct a commensal sky survey in which Doppler effects and astrophysical dispersion are corrected for coherently, dramatically increasing sensitivity to drifting narrow band signals and very short pulses [6]. The SERENDIP project [8], now in its fifth generation, uses a high performance FPGA-based spectrometer to carry out a search for narrow band signals across a 200 MHz band in real time, complementing SETI@home's more sensitive, but more confined search.

In February 2011, it was announced [1] that the Kepler Transiting Planet Survey had identified 54 planet candidates located in or near the so-called 'habitable zone,' the region around a host star where liquid water could exist on a planet's surface. Many of these planet candidates are just marginally larger than the Earth. In March of 2011, we will look for evidence of intelligent extraterrestrial life in this population by searching it for radio sources indicative of an engineered origin. This search will be conducted using the 100 meter Green Bank Telescope, the most sensitive single dish radio telescope on the planet capable of viewing this field. Baseband voltages will be recorded over a 400 MHz band centered at 1.4 GHz and will be searched using the distributed computing projects SETI@home II and AstroPulse.

Although it is difficult to constrain the luminosity function of engineered emitters, we can estimate the intrinsic equivalent isotropic radiated power (EIRP) that we could detect with these searches.

The minimum detectable flux, F_i, of a narrow band signal in a single polarization is roughly given by[1]:

$$F_i = \sigma_{\mathrm{thresh}} S_{\mathrm{sys}} \sqrt{\frac{\Delta b}{t}} \tag{1}$$

Where σ_{thresh} is the signal/noise threshold, S_{sys} is the system equivalent flux density (SEFD) of the receiving telescope, Δb is the spectral channel bandwidth and t the integration time. For the coherent doppler detection algorithm used in SETI@home, Δb is effectively t^{-1} [5].

The most powerful radio transmitter on Earth, the Arecibo planetary radar, has an equivalent isotropic radiated power (EIRP) equal to approximately 1 x 10^{20} erg s^{-1}. Figure 2 shows the distance from which a narrow band signal with equivalent power could be detected using available receivers at Arecibo and the Green Bank Telescope. Here we assume $\sigma_{\mathrm{thresh}} = 16$, $\Delta b = 1$ Hz, and the integration time $t = 60$ s. Nominal system temperatures have been taken from each telescope's published observing guide; atmospheric effects have been neglected.

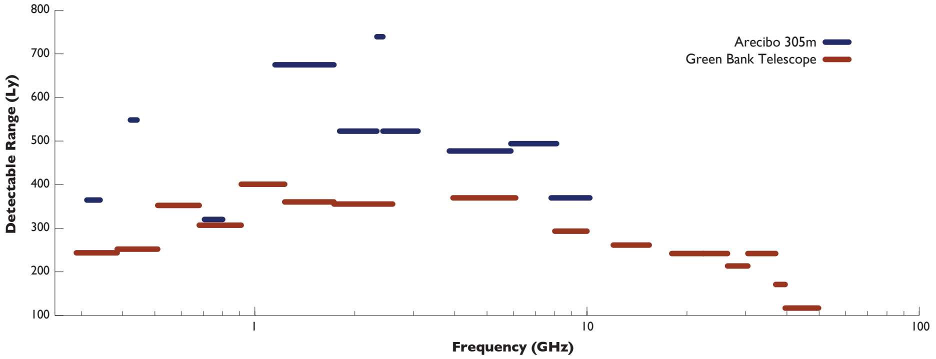

Figure 2: The detectable range of an Arecibo planetary radar-like transmitter (5 MW continuous wave transmitted through a 305m antenna) received with available receivers at Arecibo and the Green Bank Telescope using a 1 Hz resolution spectrometer and 60 seconds of integration.

3 Radio SETI Instrumentation

For the past several decades, the performance of radio SETI instrumentation has closely tracked the Moore's Law growth in the electronic industry, leading to spectrometers capable of processing progressively larger instantaneous bandwidths with higher resolution channelization. Such advances have dramatically improved the effectiveness of SETI searches, both in terms of sensitivity and completeness. Because we can only guess at the frequencies at which extraterrestrial transmitters operate, many frequencies must be searched. Extending the bandwidth of SETI spectrometers enables the search of wide swaths of frequency space simultaneously.

Our most recent instrumentation efforts pair high speed analog to digital converters (ADCs) and field programmable gate arrays (FPGAs) with commodity compute servers and graphics processing units (GPUs) to create a scalable signal processing platform capable of covering many GHz of bandwidth. In this architecture, digitized samples are filtered and packetized using an FPGA and transmitted to commodity compute components via a 10 gigabit Ethernet network, enabling intricate candidate identification and interference

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[1] Assuming the intrinsic received signal width is $< \Delta b$, the spectral channel bandwidth

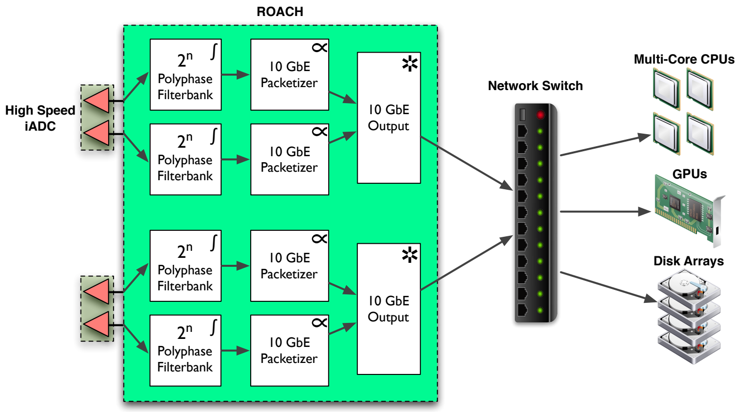

Figure 3: Heterogeneous Instrument Architecture: Multiple compute elements can be attached to Heterogeneous Radio SETI Spectrometers (HeRSS) via a multicast switch.

rejection algorithms to be implemented in high level CPU languages (C, CUDA) rather than low level hardware languages (Verilog, VHDL). Figure 3 shows an example configuration of the Heterogeneous Radio SETI Spectrometer (HeRSS). This instrument uses iADC and ROACH (Reconfigurable Open Architecture Computing Hardware) boards developed by the Center for Astronomy Signal Processing and Electronics Research [3] to digitize and transmit coarse channelized voltage data to any combination of commodity storage and compute resources. The HeRSS architecture is both economical, through its use of commodity components, and extensible, owing to its modular construction.

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