Is Amateur Optical SETI a Viable Option?

Member Observatory

Global Network of Optical SETI Observatories

After a few years of research, developing hardware and considering this issue, the following discourse makes a fair case for answering the question in the affirmative. But before getting into the basis for the "yes" answer, it will be helpful to go over a few of the rudiments of Optical SETI.

Several papers over the past decade have described megajoule scale pulsed lasers as being capable of outshining a parent star by several orders of magnitude at distances up to 1000 light years. While those assertions are well founded, for anyone who has not yet done their homework, they can be misleading. What is meant is that during the brief period of a laser pulse there can be several orders of magnitude more laser photons passing through a distant unit of area than photons from a parent star. For example, if the rate of detected stellar photons is 10^6 per second and a laser pulse length is 5 nanoseconds, then on average during that very brief interval one could expect only about 0.005 stellar photons, but there could be tens or even thousands of photons from a laser pulse and these would be sufficient for detection. We also know that a laser signal can have a nearly constant total flux out to 1000 light years (Howard, A.W, et al[4]). That is, there is little in the interstellar medium to degrade or disperse the signal.

The amateur may well hold the trump card for detecting ETI laser signals. Large institutional telescopes are few in number and fewer still have allocated significant blocks of time to Optical SETI searches. OSETI funding is also dearly held. It will be seen that Optical SETI needs many telescopes looking all the time; not just a few large telescopes looking only rarely, albeit with the best equipment.

Laser Signal Detection. Recently, for another paper, I was tasked with comparing the sensitivity of the Boquete Observatory's system to laser signals with that of other Optical SETI projects. Prior to this, I was aware of most of those comparisons, but when the whole picture was laid out a new appreciation was formed for the potential contributions amateurs can make. The Boquete telescope has only a 0.5 meter (20") aperture compared with institutional optical SETI instruments ranging at present from 0.9 meters to 1.8 meters. How can the Boquete system compare favorably with these? Other SETI laser signal detection schemes typically employ two or more photo-detectors (photomultipliers or avalanche photodiodes) whose outputs are compared to reveal photoelectron pulses that are coincident in time (piled up). This method requires fussy design and precise construction using beam splitters to divert portions of the incoming starlight to the photo-detectors. It is expensive, somewhat complicated and not so simple to calibrate and maintain. Using this method, positive detections, false and otherwise, create a time consuming requirement to explain each and every one. Thus, the desire to minimize false positives appears to have driven the experimenters to make sensitivity compromises. Such compromises may not seem so serious if a large enough telescope is available.

Alternatively, coincident (piled up) photons can be detected using a single photo-detector, but that method has generally been dismissed because of the propensity for false positive signals caused by gamma rays, corona and a few other distracting phenomenon. Sorting out a large number of false positives can be a burden, and if it can’t be done timely and unambiguously, the whole experimental effort becomes a useless exercise. So it is clear that the needs for credibility and a reasonable experimental workload have, until the last few years, limited detector designs to multiple photo-detector configurations.

The Boquete photometer uses only a single photomultiplier in combination with a number of unique steps that result in a detection method having improved sensitivity and without concerns for false positive detections. The later is exemplified with the observation of more than 3000 stars during which only a single (presumed) false positive event was experienced. In addition to coincident pulse detection, the photometer is also sensitivity to non-coincident pulsed signals, i.e. photoelectron pulses spread out in time to 25 nanoseconds or more. The single detector photometer is described in more detail in the appendices.

The Boquete Observatory instrument’s minimum detectable limit of 67 photons m^{-2} compared well with most of the larger systems having apertures up to about 1 meter. More recently, improvements to the photometer have reduced that limit down to about 60 photons m^{-2} for stars of magnitude 11 and greater. Thus, we can see that a 0.5 meter telescope and detector can have performance that nearly matches that of current larger systems. Planned photometer improvements at Boquete include a new photomultiplier that will have a greater wavelength range and higher quantum efficiencies over the range. Other minor modifications are expected to yield small percentage improvements as well.

The range of stellar magnitudes is yet another aspect that can favor small telescopes for optical SETI. For example, candidate stars most often include magnitude extremes of ~2 to 14. The 0.5 meter telescope is limited to stars no brighter than about magnitude 5 without the use of an aperture mask or a neutral filter in the photometer. Larger telescopes would be even more constrained without an appropriate light limiting feature. Thus, when flux limited, a small telescope with a single detector can have a sensitivity advantage over a larger one with multiple detectors. A large telescope aperture does have a clear advantage for stars of magnitude ~7 and greater, but only if compromises aren’t made with detection sensitivity. Furthermore, telescopes with apertures as small as 10”- 14” can be applied to SETI searches involving bright stars within ~100 light years such as Rigil Kent, Eps. Iridani, Tau Ceti, etc.

Next it will be useful to review the primary aspects of laser transmissions and to bracket what may be considered a range of expectations regarding the intensity of laser signals at various target distances. The parameters to be considered are the laser pulse energy, the transmitting telescope’s aperture (2 x laser waist) and the distance to the targeted star. The calculation details of these aspects may be found in the appendices. For our purposes, and staying clear of what might now be considered transmission equipment extremes, we will see that a small telescope, 16” aperture for example, can detect laser pulses at distances out to about 300 light years. Of course a more powerful laser using a very large transmitting telescope can extend that distance well beyond 500 ly, but there are practical aspects that argue against these extreme cases; not the least of which is, “what is the point”? It is beyond this author’s imagination why any civilization would consider making blind targeted transmissions for which the earliest chance of contact confirmation might be thousands of years. Even attempting an 800 year round trip communication seems a highly unlikely enterprise. In my opinion, the probability of being targeted is inversely proportional to distance - and more probably to some power of the distance, e.g. $1/r^3$.

The primary advantage of very large (>5m) telescopes for SETI is in searches for chance signals from deep space; those not targeting our solar system but whose beam has, over a great distance, diverged to a relatively large degree. Deep space signal detection requires a different approach with the intention only to establish that something somewhere has sent a signal. Any acquired signal would likely be too brief to establish periodicity and the chances of it being replicated later nearly nonexistent. The criteria to determine such a signal's authenticity is an entirely different matter and not part of this discussion.

These arguments suggest that the greatest likelihood of being targeted would originate from nearby stars, i.e. out to <400 ly. The number of K, G and M type stars in our neighborhood is very roughly:

Distance (ly)	**Total Quantity of K,G,M Stars**
100	3,500
200	27,000
300	90,000
400	215,000
500	420,000

A discussion regarding the probability of being targeted and coincidentally detecting that signal here on earth can be depressing to say the least. Although scientific endeavors disdain the need for luck, there can be little disagreement that a large dose of fortunate happenstance would be most welcome in this case. Presently and worldwide, there may be only one full time OS observatory. Later this year, the Owl Observatory in Michigan will be going full time and the dependence upon luck will have been cut in half. Is it worth mentioning that more are needed?

Laser Transmission Characteristics. A laser's beam divergence angle is inversely proportional to the waist of the beam. For our purposes the waist is the radius of the transmitting telescope's aperture. Tables 1 and 2 will help provide some insight here.

Table 1

Illuminated Disk Diameter (AU)

Distance	Transmitting Telescope Aperture			
(ly)	**2m**	**4m**	**8m**	**16m**
100	2.2	1.1	0.5	0.3
200	4.4	2.1	1	0.5
300	6.6	3.2	1.6	0.8
400	8.8	4.3	2.2	1.1
500	11	5.4	2.7	1.5

It may be seen in Table 1 that at less than 200 ly, a very large aperture telescope could confine a beam too greatly and prevent the illumination of a planetary system's entire habitable zone. At 200 ly, for example, a 2 or 4 meter telescope appears to have reasonable targeting characteristics, but Table 2 indicates that the pulsed energy requirements for those apertures may be excessive. Therefore, a 6 to 8 meter telescope seems a reasonable choice for this example. (Take special notice that the tabular data in table 2 is for a receivable photon flux of 100 photons m^{-2}.) Advanced civilizations could, however, have precise knowledge of a targeted planet's habitability and position. In such case and with the same results, a very large transmitting telescope may be precisely aimed and operate with substantially reduced beam pulse energy.

Table 2

Laser energy required (megajoules, kilojoules)
to present 100 photons m^{-2} at target

Distance (ly)	Transmitting Telescope Aperture			
	2m	**4m**	**8m**	**16m**
100	3 MJ	750 kJ	200 kJ	50 kJ
200	13 MJ	3 MJ	750 kJ	200 kJ
300	-	7 MJ	1.7 MJ	450 MJ
400	-	13 MJ	3 MJ	800 kJ
500	-	-	5 MJ	1.3 MJ

Conclusions. A fair case has been made that small receiving telescopes have sufficient sensitivity to detect laser beacons from nearby stars. Needed now are many small optical SETI observatories. How can this be achieved? The single photo-detector photometer may be an important step in that direction.

Independent of the sensitivity issue, the multiple photo-detector photometer option probably involves the need for a greater range of technical competence and higher costs than may be expected of most amateur SETI researchers. On the other hand, the single photo-detector photometer can be produced relatively inexpensively and used competently by SETI researchers who have little or no background in instrument development. Also, for simplicity, some of the features that are under computer control at the Boquete facility may be set/adjusted manually with some loss in observing time productivity.

Appendices

I. Detector design: coincidence and pulse group detection using a single photomultiplier. For telescopes having 16 to 20 inch apertures, the typical photomultiplier background detection rates for stars having visual magnitudes of 14 to 6 is approximately 10^2 to 10^6 photoelectron pulse counts per second (pps) respectively. For clarity, note that a detected photon and a pmt or apd photoelectron output pulse are used interchangeably.

Within the stellar background, we seek to detect 1+ pmt photoelectron pulse(s) that arrive during intervals from a few nanoseconds up to ~25 ns and which have a low, but precise periodicity, i.e. at $0.05<t<10$ pps. Note that the number of stellar background photoelectron pulses occurring within any selected 25 ns interval will be, at the greatest, only about 1 pulse in 40 seconds. However, since we're examining all 25 ns intervals, without additional restrictions the total count rate would be quite high.

We now apply conditions to the 25 ns intervals such that the photometer will only generate an output pulse when more than 1 photoelectron pulse (i.e., 2, 3, 4) occurs within the interval. This number is often referred to as n, and it is a fundamental factor of the applicable Poisson statistics. Thus, when n = 2, there must be at least two photoelectron pulses detected within the detection interval. For coincidence, the interval is generally something less than 5 ns and for group detection less than 100 ns. The goal was to design a total system that differentiates low rate periodic pulses (signal) from a higher rate of random background pulses (noise).

Many of the multiple photo-detector photometers have attempted to do all of the signal differentiation within the photometer. But to accomplish the desired result of a very low rate of false positive detections, the criterion (threshold setting) was that 2, 3 or more photons, coincident in the time interval, were required to be detected by *each* detector before the photometer would generate an output pulse. That is, a minimum of 4 detected photons were needed for a two detector system, 6 for a three detector system, and so on. This technique works well, but it is complicated, expensive and sacrifices sensitivity to achieve a low rate of false positive detections.

During the first two years of SETI observations at the Boquete Observatory, two embodiments of the multiple photo-detector type of photometer were used. But because these were difficult to calibrate and suspected of having insufficient sensitivity it was decided to put time and effort into the design of a photometer and system having only a single photomultiplier and that used a combination of methods to extract periodic signals from the stellar background. It was also decided that the arbitrary limit of detecting coincident events occurring in less than 5 ns may be too restrictive. That is, longer laser pulse durations may have signaling and other technical advantages. Thus, the new photometer should be capable of detecting unusual temporal photon densities occurring within intervals as great as 100 ns. Over a few years, the single detector photometer and downstream processing methods have evolved into a sensitive means of signal detection and differentiation from a wide range of stellar backgrounds.

The following paragraphs describe the current embodiment of the Boquete optical SETI system.

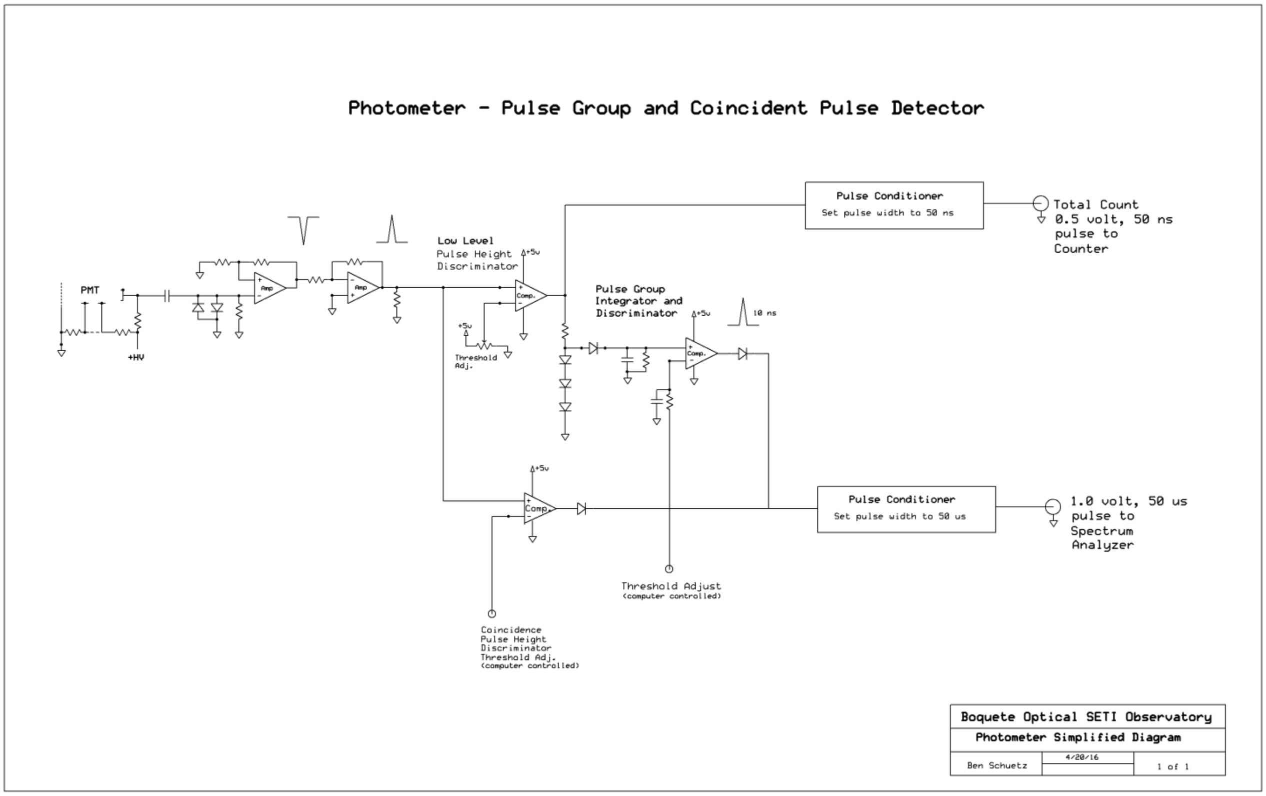

Figure 1

Referring to Figure 1, the photomultiplier output pulses are amplified and inverted then fed to a low level discriminator (comparator) and an adjacent high level discriminator. The high level discriminator passes only those pulses that are greater than about 1.5 times the photomultiplier's pulse amplitude for single photon detection, i.e. coincident photon events and other large amplitude pulse phenomena. The output of the high level discriminator is then conditioned to provide 50 usec, 1 volt output pulses to the spectrum analyzer.

The output of the low level discriminator follows two circuit paths. In one path pulses from the low level discriminator are conditioned and counted as a measure of the total photon flux incident upon the photomultiplier photocathode. A second circuit path performs the following functions:

> the pulses are diode clipped to a uniform pulse height,
> the clipped pulses are integrated and subsequently threshold discriminated,
> the discriminator output pulses are conditioned to 50 usec at 1 volt amplitude
> and are fed to the spectrum analyzer.

The integrator/discriminator functions in a way that, dependent upon the threshold level, detects any two, three or four photoelectron pulses that occur within ~25ns. That is, pulse trains of much longer lengths will be detected so long as the 25 ns criterion is met. The second discriminator threshold level is adjusted by the computer to maintain the highest level of sensitivity consistent with the noise level for stellar magnitudes within the acceptable range, i.e. 5 to 14. Note that for dim stars, and on average, less than two photons are detectable in 25 ns. That's a little confusing; how do you detect 1.5 photons? It is probably better to say that for very low background levels it is possible to detect events where two photons are only intermittently detected, i.e. a marginal signal level. It is also true that when the 2nd discriminator threshold is very low, the 25 ns detection interval gets stretched a bit.

A means of testing the photometer was a key element in establishing the functionality and true sensitivity of the photometer. That need has been satisfied by placing two LEDs in the photometer. One LED is energized by pulses that are variable in amplitude, width and repetition rate. The second LED may be energized to provide simulated stellar background count rates from 0 to 1 megahertz. Importantly, the light output of both LEDs must undergo at least two reflections (with large angular dispersions) off of flat black surfaces before entering a small aperture and ultimately reaching the photomultiplier's photocathode. Thusly, it is a simple matter to demonstrate the detection of 2, 3, 4 photons within the 25 ns time frame. Combining this with the fft detection of pulse periodicity and a wide range of simulated stellar backgrounds one can appreciate that photometer characterization can be done with a high degree of precision.

Figure 2 illustrates the affects of the 2nd discriminator threshold setting on sensitivity.

Next page.

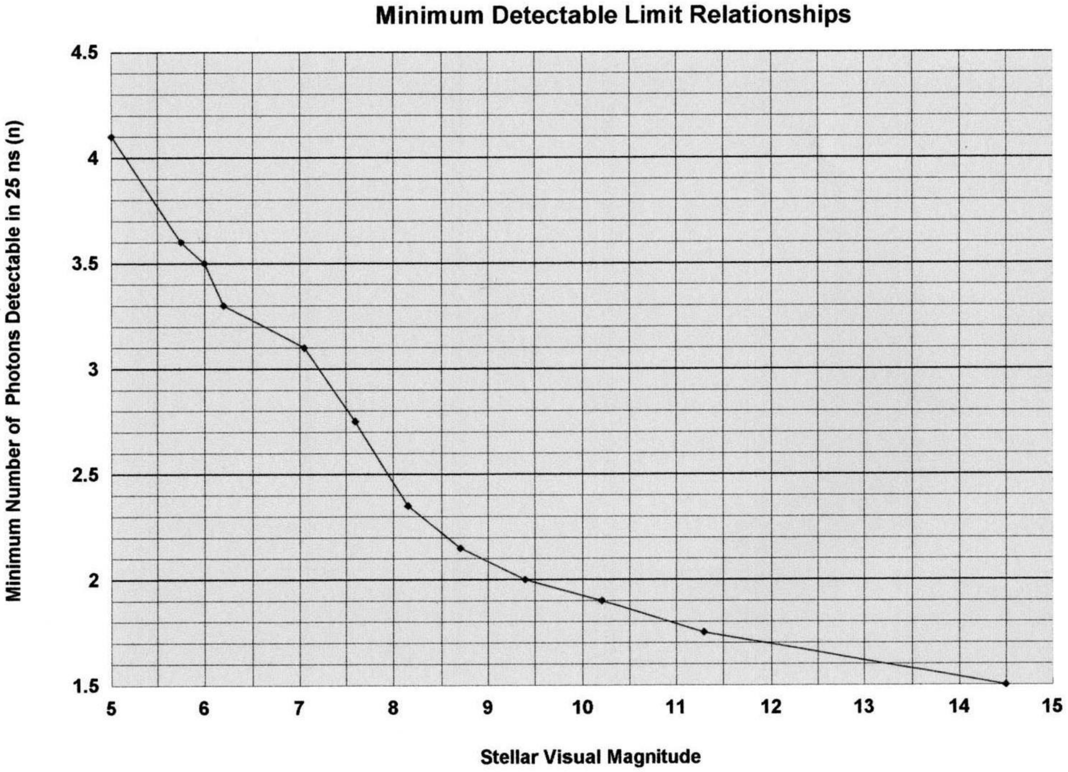

Figure 2.

A computer-based fast Fourier transform (fft) spectrum analyzer (Spectrum Lab software) analyses the photometer (50 us) output pulses and displays any periodic signal found in the range of 0.05 to 10 Hz. The fft autocorrelation feature is helpful in revealing signals that have a signal to background count approaching unity. An example of this may be seen in Figure 3 in which an LED test pulse signal of 0.05 Hz has been embedded in a simulated stellar background of 625 kHz . In the figure, the spectrogram is on the left and the autocorrelator display is on the right. For clarity note that the photometer preprocesses the large count rate, .i.e. 625 kHz; reducing it to only 0.5 to 10 pulses per seconds to be further scrutinized by the fft for periodic pulses.

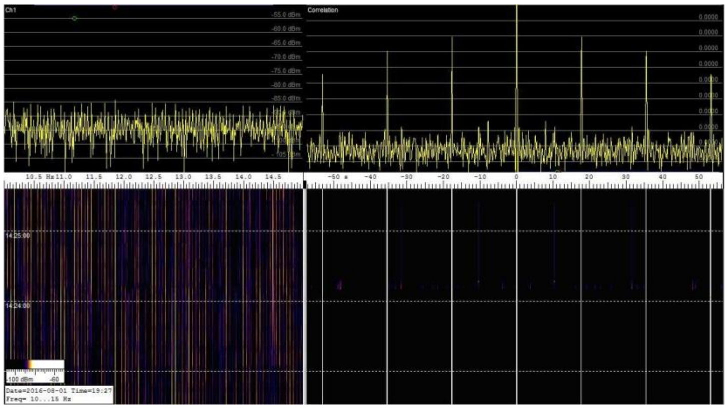

Figure 3.

In addition to improvements in the overall photometer sensitivity, the other advantages of the detector are that it: works equally well with coincidence and longer duty cycle pulse detection, is less complicated and less expensive than multiple pmt or apd photometers, is simpler to calibrate, has optimized sensitivity over the range of stellar backgrounds, eliminates signal losses related to beam splitters and simplifies pmt or apd cooling (if required). Work is underway to extend the range of detectable pulse periodicity down to 0.001 Hz; a regime that many believe holds greater promise than that currently being explored.

II. Laser Transmission Relationships

The total photon flux emitted by a device such as a laser is:

$$\Phi_t = E_o/E_p \qquad \text{(photons per pulse)} \qquad (1)$$

E_o= single pulse energy output of a laser (J)
E_p= $h \cdot c/\lambda$ energy per photon (e.g., $3.6\text{x}10^{-19}$Joules/photon @ $\lambda = 550\text{nm}$)
h = Planck's constant ($6.626 \cdot 10^{-34}$ $\text{m}^2\text{kg/s}$)
c = speed of light ($3 \cdot 10^8$ m/s)
λ = laser output wavelength (m)

And the flux of a beam confined to a uniformly illuminated disk at a distance z is:

$$\Phi = (E_0 \cdot \lambda / \pi \cdot \omega_z^2 \cdot h \cdot c) \qquad \text{(photons m}^{-2}\text{)} \qquad (2)$$

ω_z is the radius of the illuminated disk.

Next, it is useful to examine the elements that characterize laser beam divergence. The parameters needed are the beam waist ω_0, (the radius of the beam where it is at a minimum) and the Raleigh length Z_r, (the distance from the beam waist to where the beam radius has increased by a factor of the square root of two). A laser can be coupled to a telescope via a weak negative lens to match the telescope optical characteristics. Where a transmitting telescope is used for beam collimation, the beam waist becomes the diffraction limited telescope aperture radius (ω_0) and the Raleigh length is:

$$Z_r = \pi \cdot \omega_0^2/\lambda.$$

From this it is a simple matter to calculate the radius of a beam (ω_z) at any distance (z) from the diffraction limited transmitting telescope.

$$\omega_z = z \cdot \omega_0/z_r \qquad (\omega_z >> \omega_0) \qquad (3)$$

and

$$z = \pi \cdot \omega_0 \cdot \omega_z/\lambda \qquad (4)$$

An expression equivalent to (2), but perhaps having more convenient terms is:

$$\Phi = \pi \cdot \omega_0^2 \cdot E_0 / z^2 \cdot \lambda \cdot h \cdot c \qquad \text{(photons m}^{-2}\text{)} \qquad (5)$$

Some of the tabular data found in the body of the text were determined from these relationships.

It has been suggested by Shostak (2002) that for transmitting facilities to be most effective, many thousands of stars need to be targeted sequentially. A consequence of that strategy is that the periodicity of pulse transmissions to any targeted star could be at a much lower rate than 0.05 Hz. If this were generally true then searches with individual observatories could only detect those signals falling outside of this norm. The detection of long term periodicity would require simultaneous observations using two or more observatories.

III. Fast Fourier Transform (fft) Spectrum Analyzer Setup.

The method used herein to detect periodic pulsed signals is substantially different than simply using a spectrum analyzer to detect a fundamental frequency plus lesser harmonics in a noisy background. In this case we are attempting to detect a low rate of periodicity (0.05 to 10 Hz) in a series of pulses that individually have much higher, but generally fixed, frequency components (~20 kHz). There seems to be only fragmentary information in the literature describing the application of fft analysis to this set of features (Smith 1997). It has been found that when this type of pulse train is analyzed, the spectrogram displays the fundamental frequency and all of the harmonics at approximately equal amplitudes.

At very low duty cycles, the fundamental frequency can be determined by measurement of the interval between the equal amplitude harmonics. Thus, one can without penalty, set the center frequency of the displayed spectrogram anywhere over a wide range (5 to 100 Hz) and, so long as the spectrogram displayed range remains small, e.g. 10 Hz, there is little difference in the observed signal or loss of utility.

During the past 6 months, the autocorrelator feature of SpectrumLab has been found to greatly enhance the ability to pull signals cleanly out of a noisy background. This feature is indispensable when ferreting out pulsed signals at very low repetition rates.

These methods have been found to clearly differentiate periodic pulsed signals from transient signals and non-pulsed signals. They provide an unmistakable signature for the signals of interest.

Setup

Spectrum Lab software, www.qsl.net/dl4yhf/spectra1.html
Computer sound card sample rate 5512 Hz, decimated by 1, 16 bits/sample
FFT input size, 131072, decimated by 1 & 2
FFT window, rectangle
FFT bin width, 10.5 mHz and 5.26 mHz
FFT window time, 1.58 min. and 3.17 min.

The observation dwell time per star is typically no less than 4 minutes- adequate time for a signal to be processed and, if present, displayed for more than 2 minutes.

In the near future, apparatus will be developed to extend the low end range of pulsed periodic signal detection from 0.05 Hz down to 0.001 Hz and perhaps even a bit further. For economic and technical reasons, this lower end of laser pulse periodicity has long been thought to be the more likely region for interstellar signal beacons. It is an exciting prospect and soon to be within the grasp of the Boquete Optical SETI Observatory.