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THE DAY THE EARTH STOOD OUT

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ABSTRACT

In a 12 December 2008 publicity stunt, 20th Century Fox, producers of The Day the Earth Stood Still (the 2008 cheesy remake, not the 1951 cheesy original) beamed their science fiction opus toward Alpha Centauri, our nearest stellar neighbor. A Fox spokesman called it the first "galactic motion-picture release." Wide discussions ensued within the SETI community as to the technical feasibility and societal implications of such interstellar transmissions. Many opined that the transmission could not possibly be detected (four years hence) by its intended audience (four light years distant). Others argued that we can not place limits on extraterrestrial technology. This paper explores that question from the perspective of a microwave communications engineer, operating within the currently known laws of nature. A rigorous link analysis is presented, which attempts to determine the optimum receiving system design which might be capable of intercepting and demodulating this particular interstellar message. We conclude that the challenges of reception, although clearly not insurmountable, are daunting to even the most technologically advanced extraterrestrial civilizations which our (admittedly limited) human imaginations can conceive.

KEYWORDS

Active SETI, interstellar transmission, TVRO uplink, microwave receiver, link analysis

INTRODUCTION

The recent transmission, in the direction of Alpha Centauri, of the 2008 science fiction film The Day the Earth Stood Still generated considerable discussion within the SETI community. Rigorous fact checking will ascertain whether the technology used was up to the task of making the film viewable over interstellar distances. However, since the purpose of this supposed interstellar transmission was to promote the release of a motion picture, one could argue that the intended audience was in fact human, rather than extraterrestrial.

THE UPLINK FACILITY

Numerous media reports stated that on 12 December 2008, the newly released 20th Century Fox remake of a 1951 science fiction classic was beamed toward Alpha Centauri from “NASA’s Deep Space Communications Network at Cape Canaveral.” Those reports are factually flawed; Deep Space Communications Network (henceforth DSCN) is a private company, in no way affiliated with NASA, which transmits private messages into space for a fee. Whether by geographical coincidence or marketing design, this company’s uplink facility is located in the municipality of Cape Canaveral, FL, USA, but by no means is it on site at the Kennedy Space Center which shares that address. Mr. Jim Lewis, proprietor of the company in question, asserts that it was never his intention to imply otherwise, a claim which we are inclined to accept at face value.

The transmitter used by DSCN is a conventional portable C-band DOMSAT (Domestic Communications Satellite) uplink system, such as is commonly used for remote news and entertainment broadcasts via satellite. It consists of a trailer-mounted 5.5 meter diameter parabolic reflector and redundant 1 kW klystron FM video transmitters, operating in the 5925-6425 MHz TVRO uplink allocation. The transmitters are typically operated at 500 watts average power (+57 dBm), using 10.25 MHz peak deviation, 30 Hz dithering, and a highest modulating frequency of 6.8 MHz, that being the highest available audio subcarrier frequency. These specifications yield a 99% power bandwidth on the order of:

$$2\Delta f + 2f_m = 34 \text{ MHz}$$

which is wholly compatible with a full 40 MHz DOMSAT transponder, allowing a reasonable guardband for non-significant sidebands.

Note that, DOMSAT video being frequency modulated, the signal's energy components are spread out as sidebands across this entire 34 MHz of spectrum. Thus, to recover and demodulate the transmission, a suitable receiver must be designed with a 34 MHz intermediate frequency (IF) bandwidth.

According to the aforementioned Mr. Lewis, the relevant transmission was made on the frequency band for DOMSAT transponder #1, at the low end of the uplink spectrum; i.e, from 5925 to 5965 MHz. At the center of this channel's passband, transmit wavelength is found as:

$$\begin{aligned}\lambda &= c/\nu \\ &= (3 \times 10^8 \text{ m/s})/(5945 \times 10^6 \text{ Hz}) \\ &= 5.0 \text{ cm}\end{aligned}$$

At that wavelength, the manufacturer's stated gain of the 5.5 meter offset-fed parabolic reflector is +48 dBi, suggesting a commercial-standard 55% illumination efficiency. (The gain of this antenna could be improved by nearly 2 dB through the use of a more highly optimized feed geometry, but that is a subject for another occasion.) The computed antenna half-power beamwidth is on the order of:

$$\theta = \lambda / D = 5.0 \text{ cm} / 5.5 \text{ m} = 9.4 \text{ mRad}$$

or just over half a degree. The uplink effective isotropic radiated power is:

$$\begin{aligned}\text{EIRP} &= P_x + G_a \\ &= (+57 \text{ dBm}) + (+48 \text{ dBi}) \\ &= +105 \text{ dBm}\end{aligned}$$

PATH ANALYSIS

Optical parallax measurements from Earth show the approximate distance to the Alpha Centauri system to be on the order of 1.3 pc, or 4.0 x 10^{16} m. Free space isotropic path loss for transverse electromagnetic radiation is found as:

$$\begin{aligned}\alpha_{FS} &= 10 \times \log_{10} (4\pi D/\lambda)^2 \\ &= 10 \times \log_{10} (4\pi \times 5 \times 10^{16} \text{ m}/5 \text{ cm})^2 \\ &= 380 \text{ dB}\end{aligned}$$

Given the EIRP and free space path loss computed above, one can determine the isotropic power incident upon an assumed planetary body in the Alpha Centauri system as:

$$\begin{aligned}P_{inc} &= \text{EIRP} - \alpha_{FS} \\ &= (+105 \text{ dBm}) - (380 \text{ dB}) \\ &= -275 \text{ dBm}\end{aligned}$$

Thus, to recover the transmission, any receiving system at Alpha Centauri must have a detection threshold (receiver sensitivity) at or below this level.

NOISE ANALYSIS

In order to be detected and demodulated, a signal in any communications system needs to overcome the omnipresent thermal background noise. This noise power can be quantified as:

$$P_n = kTB$$

Where k is Boltzmann's Constant = 1.38×10^{-23} J/K, T is the system thermal temperature in Kelvins, and B is the receiver's bandwidth, in Hz. For a DOMSAT video channel, we have already shown the required detector bandwidth to be on the order of 34 MHz. Let us optimistically assume a theoretically perfect receiver at Alpha Centauri, whose noise threshold is limited only by the 2.7 Kelvin cosmic background radiation. Noise power now becomes:

$$\begin{aligned} P_n &= kTB \\ &= (1.38 \times 10^{-23}\ \text{J/K})(2.7\text{K})(3.4 \times 10^{7}\ \text{Hz}) \\ &= 1.27 \times 10^{-15}\ \text{J/s} \\ &= 1.27 \times 10^{-12}\ \text{mW} = -119\ \text{dBm} \end{aligned}$$

It can be seen from the above that the isotropic signal incident upon Alpha Centauri is weaker than the minimum cosmic thermal background by a factor of:

$$\begin{aligned} &P_n - P_{inc} \\ &= (-119\ \text{dBm}) - (-275\ \text{dBm}) \\ &= 156\ \text{dB} \end{aligned}$$

So, the challenge for the Centaurans becomes one of pulling a viewable TV signal out from beneath 156 dB of excess noise.

RECEIVE ANTENNA

It is axiomatic in telecommunications and radio astronomy alike that there is no substitute for capture area. The previously cited signal to noise deficit assumes an isotropic receive antenna. By creating a directive antenna, one can minimize the isotropic thermal noise intercepted, by the ratio of the antenna gain relative to isotropic. Thus, a big dish is in order.

It would appear at first glance that a receive antenna with a gain of +156 dBi would raise the signal to noise ratio to within detection threshold. In fact, the picture is a little more bleak than that, because demodulation of FM video requires a signal to noise ratio (SNR) somewhat greater than unity. Let us assume that a 10 dB signal margin is required for sparkly-free video reception. This is a level typical of the best phase locked loop detectors available on Earth, and we have no reason to suspect that the Centurans have significantly better detectors for monitoring Earth's TVRO uplinks. Thus, an antenna gain of +166 dBi will prove adequate for reception of this particular transmission, with modest fade margin and detector threshold.

Is an antenna with +166 dBi of gain feasible? Consider that the Arecibo Observatory, Earth's largest radio telescope, has a theoretical gain at the frequency of interest of a mere +74.8 dBi. Although nothing even approaching the required level of performance has ever been achieved on Earth, let us not limit ETI's technological prowess. The laws of physics suggest that, if you build an antenna big enough, any gain figure is achievable.

OK, so how big is "big enough"? The gain of a parabolic reflector antenna, in deciBels relative to isotropic, is found from:

$$G_a = 10 \log_{10} \eta(\pi D/\lambda)^2$$

where η represents illumination efficiency factor (on a scale of 0 to 1), D is the antenna diameter, and λ is wavelength in like units. Giving ETI the benefit of the doubt, let's say their engineers can illuminate a big dish to 100% efficiency. Now, solving for D, an antenna with +166 dBi of gain, at an operating wavelength of 5 cm, needs to be a mere 3200 kilometers in diameter! All these computations are summarized in Table 1.

THEIR AIMING PROBLEM

Although we cannot rule out the possibility of advanced extraterrestrial beings engineering antennas (or arrays of antennas) of continental scale, there still remains the problem of pointing those immense antennas in our direction. Recall that the beamwidth of a parabolic antenna can be estimated from its diameter and operating wavelength. For the Centauran antenna, that half-power beamwidth is on the order of:

$$\begin{aligned}\theta &= \lambda / D \\ &= 5.0 \times 10^{-2}\ \mathrm{m} / 3.2 \times 10^{6}\ \mathrm{m} \\ &= 16\ \mathrm{nRad}\end{aligned}$$

which is on the order of a *millionth* of a degree. One shudders to think how any civilization, no matter how advanced, could aim a whole continent to that level of accuracy, much less track a moving target, from a moving object, for the length of a two-hour movie. But, more significantly, one must ask: why bother?

OUR **AIMING PROBLEM**

One would think that, by comparison to the Centaurans' challenge of aiming an antenna of continental size, our problem on Earth, pointing a tiny 5.5 meter antenna, would be trivial. Not so. Because, although our antenna's half-power beamwidth is a respectable half a degree, we are dealing with an n-body Newtonian motion problem, over interstellar distances.

Consider first that we are aiming our antenna from the surface of a planet that is both spinning on its axis and orbiting its star. That star is, in turn, revolving around the center of the Milky Way galaxy, as is the Alpha Centauri system. Our movie-going audience is ostensibly situated on the surface of a planet somewhere in that triple-star system. Unless it is tidally locked (not a happy circumstance for the emergence of life), that planet is doubtless rotating on its axis, and negotiating a complex orbital dance with respect to its *three* suns. Our own motion is known, or can at least be computed. Having not yet even detected our target planet, we can only guess as to its complex path over time.

And "over time" is our key here. Remember that, when we look at Alpha Centauri in the Southern sky, we are seeing not where it *is,* but rather where it *was* some 4 1/4 years ago. So, when we transmit toward Alpha Centauri, our antenna must aim, and track, not where it *was* 4 1/4 years ago, or even where it *is* today, but rather where it *will be* 4 1/4 years hence.

True, our half-degree transmit beamwidth gives us some leeway. As our beam spreads out conically in interstellar space, there is a chance that we might get lucky, and that part of our electromagnetic wave may indeed wash up on friendly shores. Then again, maybe not. It's not an easy matter for me, or DSCN, to calculate.

RECEPTION VS. DETECTION

The foregoing calculations might well cast a pall over the whole SETI enterprise. How can we expect, one might wonder, to intercept incidental radiation from a distant civilization, when our own broadcasts are most likely not detectable at even the nearest star, save through superhuman efforts and incredible antenna engineering?

The encouraging answer is the SETI science seeks not to watch movies (or, in fact, to demodulate intelligence of any kind) so much as to identify signals of clearly intelligent extraterrestrial origin, providing existence proof of our cosmic companions. Let's think about how the <u>Day the Earth Stood Still</u> uplink might have provided existence proof to our cosmic companions, over far greater distances than Alpha Centauri.

First, and most obviously, while demodulating viewable FM video requires a reputed positive signal to noise ratio on the order of 10 dB, we can detect the presence of an artificial signal at unity SNR, or even less. Thus, dispensing with that assumed 10 dB detector threshold allows us to decrease our receive antenna size by a factor of three, or alternatively, to increase our detection range for the originally computed antenna, also by a factor of three. But, it gets even better.

Significant increases in detectability are achieved in SETI receivers by integrating a received signal over time. The longer the time averaging, the more a signal rises out of the noise. Of course, modulation (that is, information content) is lost in the process, but if we are seeking existence proof rather than video entertainment, this is hardly a factor. In the present example, by integrating our received signal for a mere three seconds, we add an additional 40 dB to our SNR. This would allow us to increase distance by a factor of 100, or decrease receive antenna size by a factor of 100, or some combination of the two.

Finally, although a 40 MHz channel allocation (34 MHz receiver bandwidth) is typical for analog satellite TV, there are many modulation modes which concentrate considerable power into a far narrower bandwidth. Since narrowing receiver bandwidth improves SNR, we might expect to detect these narrower signals over far greater distances, or with significantly smaller antennas. Were our 500 watt carrier, for example, contained within a 10 Hz bandwidth, it could easily be detected over interstellar distances by an Arecibo, within about 100 seconds of integration time.

DSCN RECEPTION RANGE

In view of the above, one wonders over what distance video programming from the DSCN *can* realistically be received, given Earth-level technology. It turns out that an Arecibo could recover clear video from this particular uplink, out to a range of about 3 billion km. That figure represents the approximate distance between the Sun and Uranus at aphelion. Thus, an Arecibo Observatory on Uranus could, if properly aimed, readily be used to monitor Earth's satellite TV uplinks.

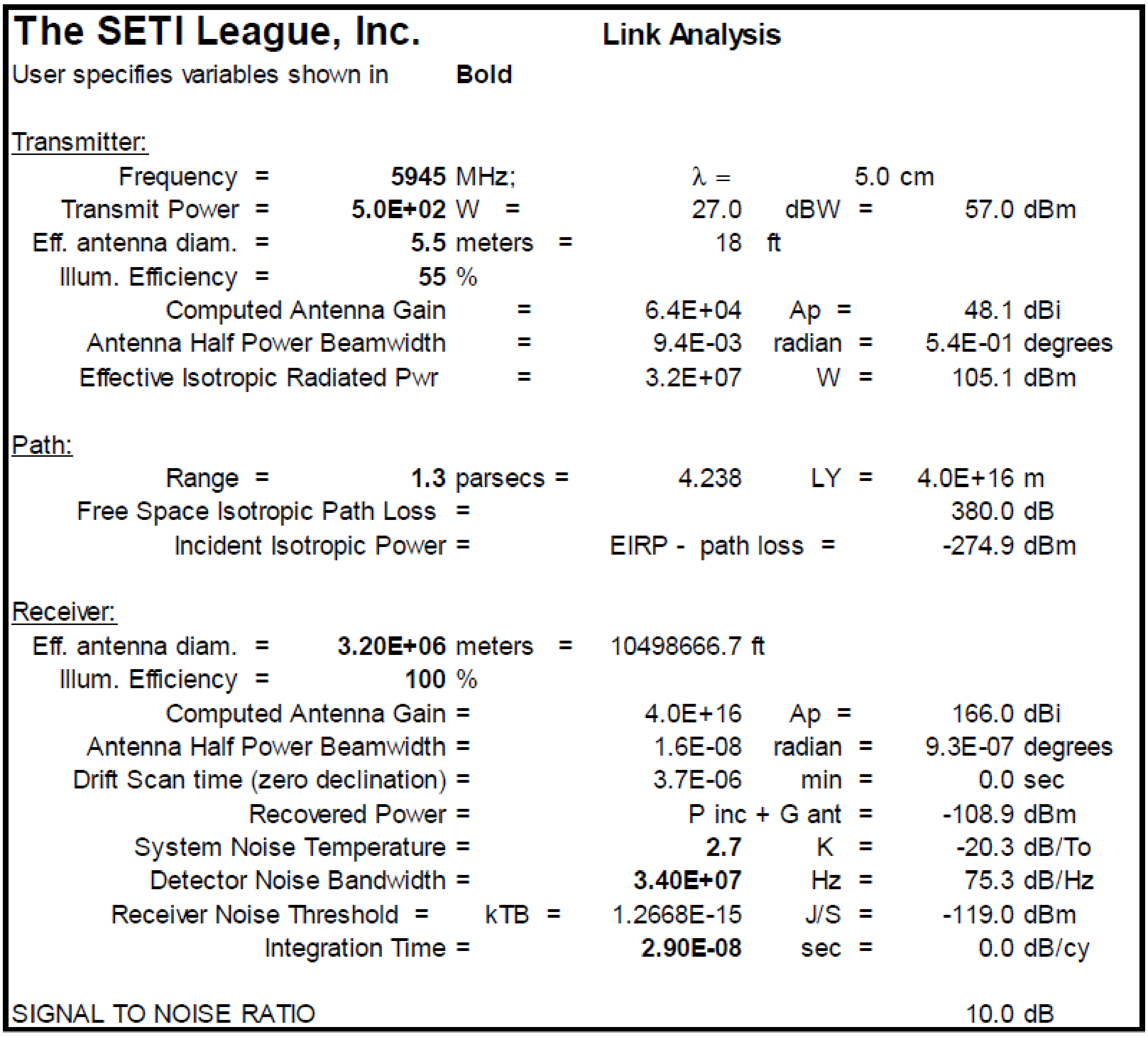
Bear in mind that the uplink facility used at DSCN was initially intended to relay FM video via a communications satellite parked in the Clarke orbital belt, a mere 36,000 km from Earth. This is a facility designed for relatively local communications. That it appears marginally capable of interplanetary video relay is encouraging. It should not disappoint that its utility over interstellar distances seems somewhat suspect.

CONCLUSION

This paper concentrates on the medium, not the message. Although he is decidedly *not* a film critic, the author cannot resist the temptation to comment briefly on the motion picture itself. One wonders why an advanced extraterrestrial would travel all the way to Earth with a message of warning, and then fail to meet with a single scientist, diplomat, or head of state. Had Klaatu, as portrayed by Keanu Reeves, ever bothered to watch any terrestrial television (which question is, in fact, the very focus of this paper), he would surely have learned how to say "take me to your leader." Instead, all he seems to be able to say is "Klaatu Barada Nikto."

The task of viewing The Day the Earth Stood Still, at Alpha Centauri, though not inconsistent with the laws of physics, is nonetheless daunting beyond belief.

Table 1
DSCN Link Analysis for TVRO Video Transmission to Alpha Centauri



The SETI League, Inc. Link Analysis

User specifies variables shown in **Bold**

Transmitter:

Frequency = **5945** MHz; λ = 5.0 cm

Transmit Power = **5.0E+02** W = 27.0 dBW = 57.0 dBm

Eff. antenna diam. = **5.5** meters = 18 ft

Illum. Efficiency = **55** %

Computed Antenna Gain = 6.4E+04 Ap = 48.1 dBi

Antenna Half Power Beamwidth = 9.4E-03 radian = 5.4E-01 degrees

Effective Isotropic Radiated Pwr = 3.2E+07 W = 105.1 dBm

Path:

Range = **1.3** parsecs = 4.238 LY = 4.0E+16 m

Free Space Isotropic Path Loss = 380.0 dB

Incident Isotropic Power = EIRP - path loss = -274.9 dBm

Receiver:

Eff. antenna diam. = **3.20E+06** meters = 10498666.7 ft

Illum. Efficiency = **100** %

Computed Antenna Gain = 4.0E+16 Ap = 166.0 dBi

Antenna Half Power Beamwidth = 1.6E-08 radian = 9.3E-07 degrees

Drift Scan time (zero declination) = 3.7E-06 min = 0.0 sec

Recovered Power = P inc + G ant = -108.9 dBm

System Noise Temperature = **2.7** K = -20.3 dB/To

Detector Noise Bandwidth = **3.40E+07** Hz = 75.3 dB/Hz

Receiver Noise Threshold = kTB = 1.2668E-15 J/S = -119.0 dBm

Integration Time = **2.90E-08** sec = 0.0 dB/cy

SIGNAL TO NOISE RATIO 10.0 dB