Radio Leakage: Is anybody listening?

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Introduction

On September 8, 1966, American television viewers were launched into a new era, as the Galactic exploits of fictional 23rd Century astronauts James T. Kirk, Spock, and Leonard H, Mc Coy went to air in the first regular episode of *Star Trek* , the original series.

Three years later on July 20, 1969, the people of planet Earth watched real-life astronauts Neil Armstrong and Buzz Aldrin set foot on the surface of the Moon as live TV pictures were broadcast to an estimated audience of one billion viewers.

Figure 1. Apollo 11 television picture transmitted from the surface of the moon and broadcast for viewers on Earth.

The exploration of space has not been limited to human astronauts and television actors. Robotic spacecraft have explored the outer planets and transmitted images and data to Earth-bound scientists and astronomers. Even now, the Pioneer spacecraft remains in regular radio communication with terrestrial controllers as it speeds on its way out of the Solar System, long after the completion of its principal mission.

While Pioneer's transmissions were intended for scientists on Earth, might an alien civilization someday intercept its signal and clandestinely listen in as Pioneer's scientific travelogue through the outer planets propagates outwards into space?

Similarly, through reruns and news broadcasts, countless humans have witnessed the exploits of Armstrong, Kirk and the others; but have any non-human viewers been tuning in as television signals meant for an Earth-bound audience make their way into deep space?

With the advent of powerful television broadcasts in the middle of the 20th century, Earth's TV signals have been leaking into space at the speed of light. Although broadcast in 1966, the initial episode of *Star Trek* would have reached Alpha Centauri in January of 1971, as this nearby neighbor is only 4.3 light years distant. At a distance of 26 light years, citizens of Vega would have had to wait until 1992 to see their first *Star Trek* episode; that is, of course, assuming that anybody with an antenna of sufficient size and sensitivity was listening.

In a Hollywood drama based on Carl Sagan's book Contact, fictional SETI researchers receive an alien transmission from Vega. Embedded in the transmission are images of Adolph Hitler opening the 1936 Olympic games in Berlin. The scientists realize that sending Hitler images was neither an apocalyptic message nor an alien warning intended for the people of Earth. Instead, the film's characters understand that the broadcast of the '36 Olympics was one of humanity's first powerful television transmissions leaked into space. By sending it back to us, the Vegans were simply saying "we heard you".

Although this film is a work of fiction, is there any scientific basis to the proposition that aliens might be eavesdropping on Earth's television transmissions? Turning the tables, might humans someday be able to watch an alien version of Star Trek, I Love Lucy, or Who Wants to Be a Millionaire?

If extraterrestrial civilizations do exist, then why haven't there been any positive detections of leaked extraterrestrial signals?

To answer these questions, it is necessary to first consider the physics of electromagnetic radiation, the detection range of current radio telescopes on Earth, and the power output of typical broadcast transmissions

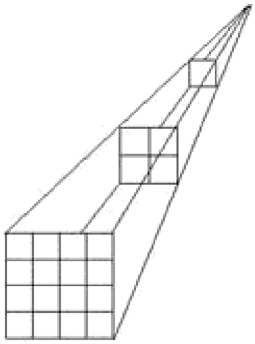

Figure 2. As electromagnetic radiation propagates outward into space, it is spread out over an ever increasing area.

The Detection of Electromagnetic Radiation

As electromagnetic energy propagates outward into space, its energy can be visualized as spreading out in an ever increasing spherical shell centered on the source. The apparent flux is therefore characterized by Equation 1 [Kaufmann and Freedman, 1999, p 460]

$$b = \frac{L}{4\pi R^2}$$ **[Equation 1]**

b = Apparent flux (W / m^2)
L = Luminosity of the source (W)
R = Distance to source (m)

Doubling the distance between the source and the detector reduces the apparent flux by a factor of 4 as shown in Figure 2. This relationship applies to any electromagnetic energy propagating through space, regardless of whether it is naturally or artificially produced.

As a consequence, a leaked signal is attenuated in a manner inversely proportional to the square of the distance from the source. Antennas of ever increasing size and sensitivity would be required by aliens hoping to detect a leaked signal while listening from further and further into deep space.

Just how big an antenna would be required to detect a leaked isotropic signal? As shown by Aburto and Woolley, the detection range **R** for a radio telescope of known size and efficiency is given by the following set of equations:

$$R = \sqrt{\frac{EIRP \times A_{er} \times twc}{4\pi \times SNR \times B_r \times k \times T_{sys}}}$$ **[Equation 2]**

$$A_{er} = \frac{\eta_r d^2}{4}$$ **[Equation 3]**

where:

EIRP	=	Effective Isotropic Radiated Power
A_{er}	=	Effective area of the receiving antenna (m^{-2})
twc	=	Integration or averaging gain
SNR	=	Signal to Noise Ratio
B_r	=	Receiver bandwidth (Hertz)
k	=	Boltzman's constant (Joules/Kelvin)
T_{sys}	=	System temperature (Kelvin)
η_I	=	Efficiency of the antenna (real number between 0 and 1, inclusive)
d	=	Diameter of antenna (m)

Armed with Equation 2, and knowing the typical transmitting power of terrestrial signals, we're now in a position to determine how far into deep space Earth's leaked electromagnetic radiation could be detected, assuming that it was possible to estimate the basic characteristics of the receiving instrument. Typical results are shown in Table 1 and Figure 3 for an Arecibo-like detector. In keeping with the estimates of Aburto and Woolley, the Signal to Noise Ratio for all calculations was taken to be 25 since this is between the SNR of SETI@home (SNR=22) and the maximum SNR used by Project META (SNR=33).

	AM Radio	FM Radio	UHF Picture	UHF Carrier	WSR-88D Weather Radar	Arecibo S-Band (CW)	Arecibo S-Band (CW)	Arecibo S-Band (CW)	Pioneer 11 Carrier
EIRP (MW)	1.00E-01	5.00E+00	5.00E+00	5.00E+00	3.20E+04	2.20E+07	2.20E+07	1.00E+06	1.60E-03
Br (MHz)	1.00E-02	1.50E-01	6.00E+00	1.00E-07	6.30E-01	1.00E-07	1.00E-07	1.00E-07	1.00E-06
Tsys (Kelvin)	6.80E+07	4.30E+02	5.00E+01	5.00E+01	4.00E+01	4.00E+01	4.00E+01	4.00E+01	4.00E+01
dr (m)	3.05E+02	3.05E+02	3.05E+02	3.05E+02	3.05E+02	3.05E+02	3.05E+02	3.05E+02	3.05E+02
twp	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
SNR	2.50E+01	2.50E+01	2.50E+01	2.50E+01	2.50E+01	2.50E+01	2.50E+01	2.50E+01	2.50E+01
η_I	5.00E-01	5.00E-01	5.00E-01	5.00E-01	5.00E-01	5.00E-01	5.00E-01	5.00E-01	5.00E-01
Detection Range (ly)	**1.18E-07**	**8.54E-05**	**3.96E-05**	**3.07E-01**	**1.09E-02**	**7.19E+02**	**7.19E+02**	**1.53E+02**	**1.94E-03**
Detection Range (AU)	**7.44E-03**	**5.40E+00**	**2.50E+00**	**1.94E+04**	**6.91E+02**	**4.55E+07**	**4.55E+07**	**9.70E+06**	**1.23E+02**

TABLE 1. The detection range of various terrestrial signals, calculated using Equation 2 and assuming a remote Arecibo-like detector. Data has been adapted from Aburto and Woolley

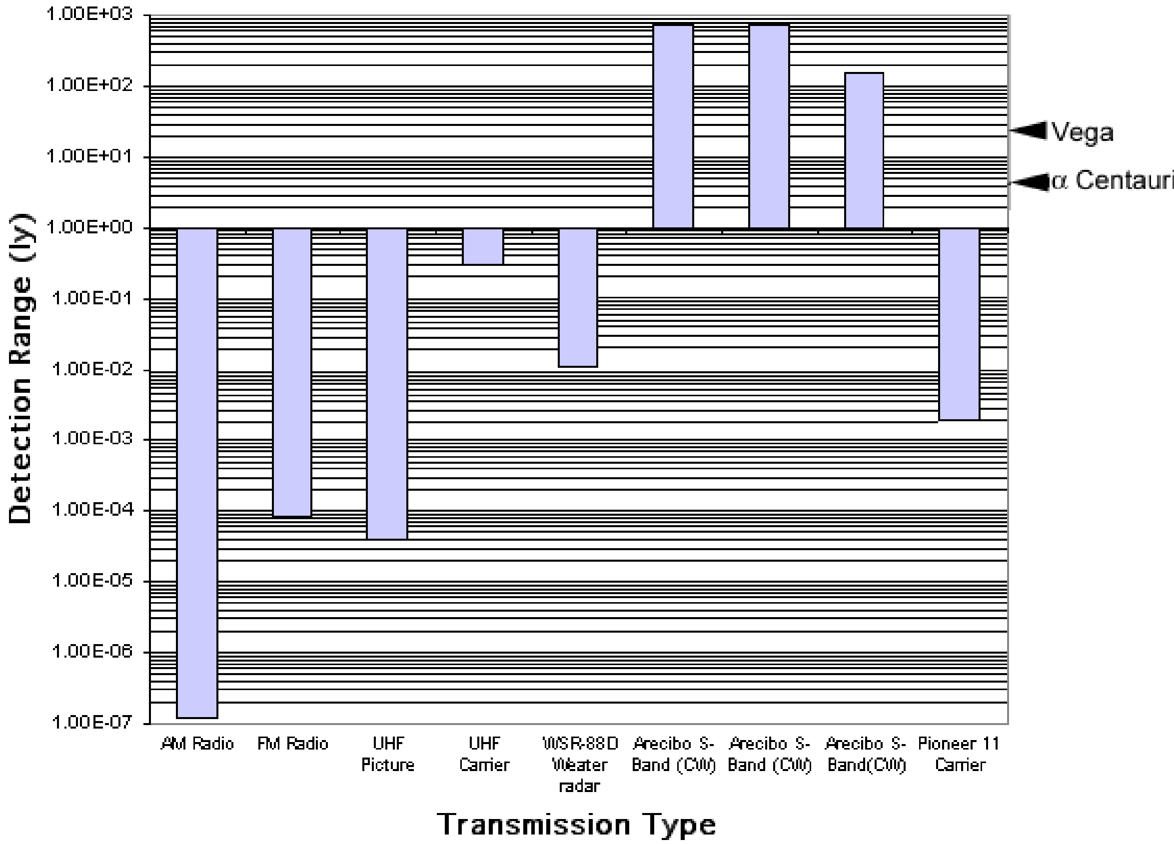

FIGURE 3. Log plot showing the detection range results for an Arecibo like-dish and various terrestrial transmission types assuming an Arecibo-like detector. The minimum detection range to receive a signal on Alpha Centauri and Vega is indicated with arrows.

Hypothetically, assume that the Arecibo telescope was put on the back of a starship making its way into deep space. If it was possible to point the telescope back towards Earth, how far could the starship travel and still be able to detect terrestrial electromagnetic radiation leaking into space? If we were planning on catching up on our favorite soap, cheering for the home footie team, or grooving to the top ten, the answer is ***not very far.***

Neglecting atmospheric effects, Table 1 and Figure 3 show the following:

- An AM radio broadcast could only be detected out to 0.0074 Astronomical Units (AU).
- FM Radio could be detected out to 5.4 AU.
- A 5 Megawatt UHF television picture could be detected out to 2.5 AU, although the carrier wave could be detected much further; out to 0.3 light years.
- The Pioneer 11 can only be detected to 120 AU.

To put this into perspective, consider the following:

- 1 light year is equivalent to 63,240 AU.
- Jupiter is 5.2 AU from the Sun.
- Alpha Centauri is 4.3 light years away.
- Vega is 26.3 light years from Earth.

On our hypothetical starship cruise, we'd be hard pressed to enjoy entertainment leaked from Earth while cruising though the outer reaches of our own Solar System, much less from in the vicinity of the Sun's nearest stellar neighbor.

We'd have better luck detecting occasional military or range finding radar with characteristics more like those shown in the Arecibo S-Band columns of Table 1. These signals are of significantly higher power and transmitted in a manner that concentrates the energy into a relatively narrow directional beam. Even if our hypothetical starship was lucky enough to be along the beam's line of sight, current SETI protocols would probably reject such a signal since it would be of short duration and not likely to be verified by other observers.

In 1977, SETI researchers operating the Big Ear Radio Observatory at the University of Ohio recorded a Gaussian signal of great intensity. The researcher that inspected the computer output from the observation was so impressed that he wrote "WOW!" in the printout margin. Despite over 50 repeat attempts, the signal was never observed again. One can only speculate about the source of the mystery signal. Perhaps it was a leaked radar signal from an extraterrestrial source. Even in the absence of any other evidence to the contrary, however, scientists are forced to invoke the principle of Occam's razor. This asserts that all things being equal, the simplest explanation is usually the correct one. Without other supporting evidence, the simplest explanation is that the "WOW!" signal was not produced by an alien civilization, but was merely a chance reflection from a source of terrestrial origin.

SETI researchers have been looking for a signal generated by an extraterrestrial intelligence for over forty years. Beginning with Frank Drake's pioneering work on Project Ozma, and including more contemporary searches like Project META, Phoenix, SERENDIP, and SETI@home, no conclusive signal has been detected and verified. This has led many to question the value and wisdom of continuing to invest in SETI research. In this climate, the US government withdrew funding from NASA's SETI activities, citing better uses for limited funds.

The lack of a positive detection might lead some to conclude that humanity is alone in the Universe. However, a reasonable alternate explanation is that we presently lack an instrument sensitive enough to detect most alien leakage, since the signal is attenuated inversely with the square of the immense distance between stars. As shown in Table 2 and Figure 3, it would be extremely difficult to detect our own civilization using Earth's largest radio telescope if it were possible to transport it to a nearby extrasolar planet. With present instruments, it would only be possible to detect the occasional stray radar beam, or similar high power, narrow beam transmissions. We would not be able to detect leakage from Earth's communication and broadcast systems intended for a terrestrial audience.

Given this limitation, what type of instrument would be required to detect our own radio and television leakage from the nearest stars using technology similar to that presently available on Earth? One solution would be to increase the effective size of the detector collecting area. If an Arecibo-like dish were to be scaled up in size for this purpose, how big would it have to be?

Inserting Equation 3 into Equation 2 and rearranging produces Equation 4, which can be used to calculate the minimum diameter **d** of a radio dish able to detect a signal from a distance **R** .

[Equation 4]

$$d = 4R\sqrt{\frac{SNR \times B_r \times k \times T_{sys}}{EIRP \times \eta_r \times twc}}$$

	Max UHF Detection Range for Arecibo	Alpha Centauri	Vega
Distance (ly)	3.96E-05	4.30E+00	2.64E+01
η_I	5.00E-01	5.00E-01	5.00E-01
EIRP (MW)	5.00E+00	5.00E+00	5.00E+00
Br (MHz)	6.00E+00	6.00E+00	6.00E+00
Tsys (Kelvin)	5.00E+01	5.00E+01	5.00E+01
twp	1.00E+00	1.00E+00	1.00E+00
SNR	2.50E+01	2.50E+01	2.50E+01
dish diameter (M)	**3.05E+02**	**3.31E+07**	**2.03E+08**
dish diameter (AU)	**2.04E-09**	**2.21E-04**	**1.36E-03**
dish diameter (MU)	**7.93E-07**	**8.61E-02**	**5.29E-01**

TABLE 2. The dish diameter **d** required to detect a 5 MWatt UHF television picture using an Arecibo-like SETI receiver at various distances from Earth, calculated using equation 4. Diameters are shown in meters (m), Astronomical Units (AU), and the average distance from the Earth to the Moon (MU). 1 MU is equivalent to 384,400 km.

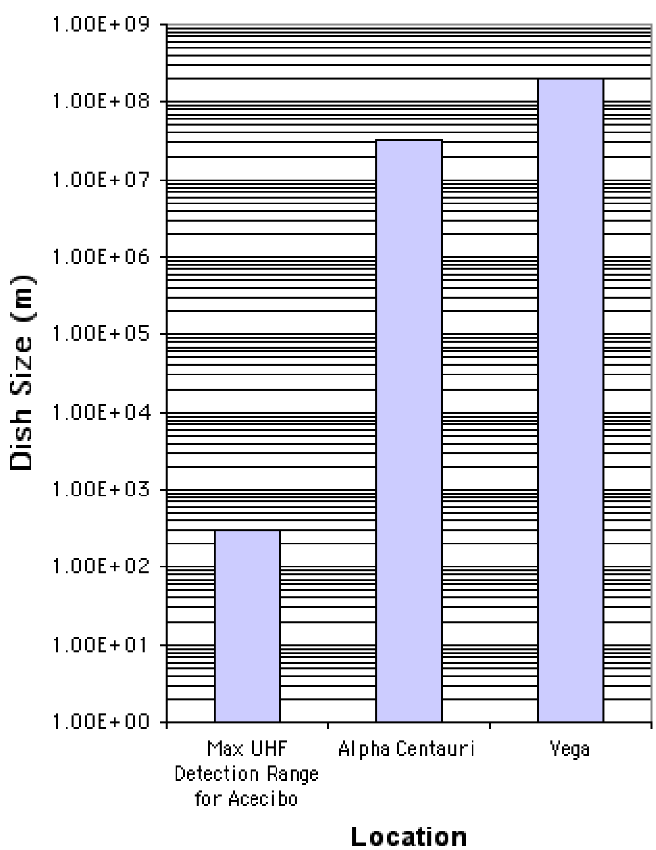

FIGURE 4. Log plot of minimum dish size required to receive a UHF signal leaked from Earth at various locations, assuming a receiving instrument similar to the Arecibo telescope.

Table 2 and Figure 4 show the minimum dish diameter **d** required to detect a UHF television signal from a distance **R** using Equation 4 for various dish characteristics.

To verify that spreadsheets generating Tables 1 and 2 and Figures 3 and 4 produced consistent results, the minimum dish diameter required to detect a UHF transmission for a receiving instrument placed at the detection limit of the Arecibo telescope was calculated in the corresponding spreadsheet. As expected, a dish diameter of 305 meters would be required, consistent with the diameter of the Arecibo dish.

Table 2 and Figure 4 further demonstrate that if the Arecibo radio telescope could be transported to Alpha Centauri, scaled up in size and then pointed back towards Earth, then a telescope with a diameter of over 33,000 kilometers would be required to detect UHF television pictures leaked from Earth. This is equivalent to a dish diameter just over two and a half times the diameter of the entire Earth.

Table 2 also shows that if the Arecibo telescope were transported to Vega and scaled up in size, then a telescope with a diameter equivalent to roughly half the distance from the Earth to the Moon would be required to detect UHF television pictures leaked from Earth.

Discussion

To detect leaked extraterrestrial signals consistent with those used on Earth to transmit local radio and television programming will require the construction of detectors with large effective collecting areas and sensitivity. There will clearly be a number of engineering challenges in building adequate systems.

- **Building large single dish systems-** Building large single dish systems presents considerable challenges for engineers, particularly when constructed on the Earth's surface where it is subject to the influences of gravity and weather. Deformations of the dish shape under the influence of gravity can impede the quality of the signal. Mechanical faults and gradual deterioration through unnoticed wear can cause the demise of an instrument. Large instruments are particularly susceptible. For example, the 300 foot Greenbank telescope collapsed following following the structural failure of a key component. Even so, all other characteristics of the receiving instrument being equal, it would not be possible to build a dish of sufficient size on the surface of the Earth using current technology.
- **Multiple dish radio telescopes-** Built for imaging the effect of black holes, VLBI Space Observatory Program (VSOP) has used Very Long Baseline Interferometry (VLBI) to combine radio telescopes on the ground with an Earth orbiting Japanese radio telescope. Together they produce a virtual telescope three times the size of the Earth. Although VSOP was not developed for SETI research, it suggests that space-based instruments with adequate collecting areas and sensitivity are technologically feasible.
- **Gravitational Lensing-** It has been suggested that the Sun might be used as a gravitational lens to focus weak signals working in conjunction with a radio telescope in deep space.
- **Interference and Noise-** An attempt to improve the Signal to Noise Ratio and limit radio interference from terrestrial sources has lead researchers to seek out radio quiet zones. Remote Western Australia is currently being considered as a potential site for the Square Kilometer Array (SKA). A crater on the far side of the Moon has also been suggested as a potential site for a future radio telescope.
- **Terrestrial Planet Finder (TFP)-** The feasibility of an space-based optical interferometry mission is currently being studied by NASA's Terrestrial Planet Finder program. This mission is expected to have the ability to image Earth-like extrasolar planets. This would enable scientists to look for the spectrographic signature of life through an analysis of the atmosphere enveloping the remote worlds TFP is designed to detect. Ironically, we may know if nearby extrasolar planets harbor life before we know if that life is also intelligent.

Conclusion

SETI research programs today are designed to detect high power transmissions concentrated in relatively narrow beams. Typically, these would fall into one of two categories:

- **leaked signals-** These would be intercepted signals produced by high power military or range finding radar. We would have to be extraordinarily lucky to detect, recognize and confirm a high power radar signal of extraterrestrial origin.
- **beacon signals-** These non-leaked signals would be intentionally designed to attract the attention of observers in the direction of Earth. If there are advance civilizations that choose to make themselves known in this way, then it is possible that present SETI efforts may one day produce a positive detection. However, these beams must be aimed at Earth at a time when we are listening for a positive detection to occur.

Either way, humanity will have to be very lucky if current SETI strategies are to be successful, even if the Galaxy is teaming with intelligent life.

As a closing thought, in 1977 a high power, directional signal was sent from the Arecibo observatory towards the globular cluster M13. If technologically advanced beings on one of the 300,000 stars in that cluster happens to be listening towards the direction of Earth at the exact time that the message arrives with an instrument of adequate size and sensitivity, then we could expect a reply as early as 50,000 AD given that the cluster is at a distance of 24,000 light years. Why target such a distant group of stars? First, because it is distant, all stars in the cluster will lie along the narrow beam path. Second, because it is so far away, it is unlikely that any Independence Day-like aliens will arrive on Earth anytime soon as a result of the transmission. Selfishly, it would appear that humanity expects everyone else to do all the talking; for now, we'll just listen.

Perhaps one day, we'll be up to the challenge of building an instrument large and sensitive enough to detect non-directional, leaked communication and broadcast signals intended for a remote alien audience. Until then, our stellar neighbors will have to shout.

References

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Appendix

The Microsoft Excel spreadsheet used to produce Tables 1 and 2 and Figures 3 and 4 can be downloaded in the zip archive available at http://www.computing.edu.au/~bvk/astronomy/HET608/essay/excel/data.zip [8 K Bytes].

Copyright Statement

Figure 1 is part of a longer video clip available in quicktime format that can be downloaded from the NASA Langley Research Center Animation and Video Archive at http://lava.larc.nasa.gov/ABSTRACTS/LV-1999-00001.html