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SETI Horn of Plenty

An Argus Antenna Alternative

In Greek mythology the giant Argus, who had a hundred eyes, kept them focused on the universe. Today Project Argus keeps its ears on the universe. Here N6TX describes one such "ear."

By Dr. H. Paul Shuch,* N6TX

Deriving its name from the Greek mythological character Argus, the giant with a hundred eyes, Project Argus, a major scientific endeavor of the nonprofit SETI League, Inc., is an attempt to coordinate a global network of amateur radio telescopes in conducting an all-sky survey for microwave emissions of intelligent extraterrestrial origin. The holy grail of SETI (the Search for Extra-Terrestrial Intelligence) is the detection of unambiguous evidence of other technological civilizations in the cosmos (the primary goal). Project Argus participants (the Argonauts), however, are also applying their amateur radio telescopes to the challenges of studying natural astrophysical phenomena through their microwave emissions.

The parabolic reflector has been the antenna of choice for amateur radio astronomers. Project Argus participants are no exception, typically employing discarded backyard C-band satellite TV dishes of 3 to 5 meters in diameter (see photo A).[1] Such antennas perform well, but their size, as well as the complications of municipal zoning restrictions, preclude their use by many a potential Argonaut.

This article presents construction and performance details of an alternative Argus antenna, a portable waveguide horn reminiscent of the one used by Ewen in 1951, the first to detect the 21-cm radiation signature of interstellar hydrogen. Producing +19 to +21 dBi of gain across the 1200–1700 MHz band, the

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Photo A. Typical Project Argus radio telescope. (N6TX photo)

Photo B. W9GFZ radio telescope, vintage 1937. (N6TX photo)

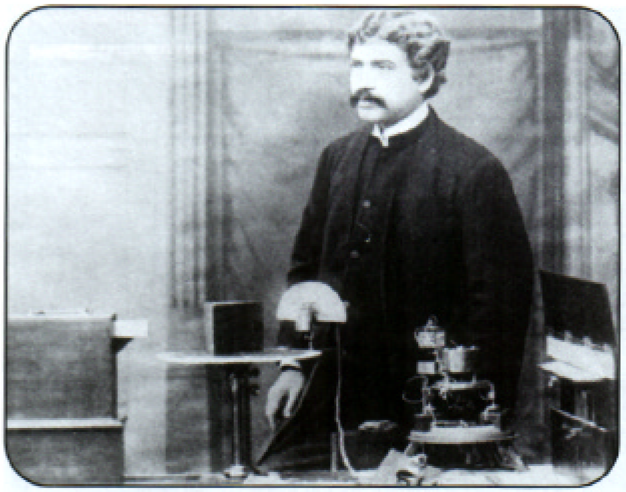


Photo C. Dr. Jagadis Chandra Bose, inventor of the waveguide horn antenna. (Photo from Acharya Jagadis Chandra Bose, Birth Centenary, 1858–1958. Calcutta: published by the Birth Centenary Committee, printed by P. C. Ray, November 1958)

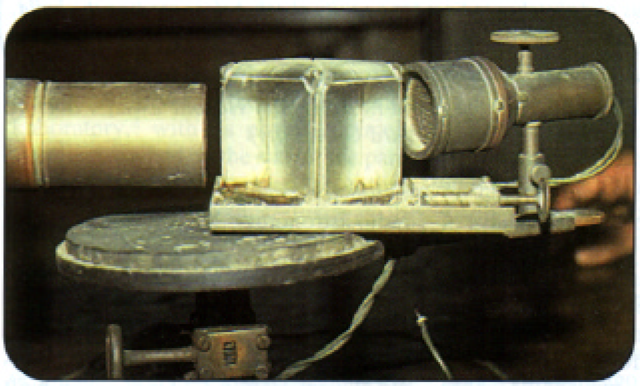


Photo D. Early Bose waveguide horn antenna. (Photo courtesy Dr. D. T. Emerson, AA7FV)

SETI Horn of Plenty rises to the challenge of mapping galactic hydrogen. It also performs well in monitoring the Sun; the Moon; natural radio sources in Cygnus, Cassiopeia, Taurus, and Sagittarius; and (maybe some day) in detecting ETI.

Introduction and Goal

Parabolic reflectors have been the antennas of choice for amateur and professional radio astronomers alike since the 1930s, when the late Grote Reber, ex-W9GFZ (see accompanying sidebar on Reber), constructed a 10-meter diameter dish in the backyard of his mother's house in Wheaton, Illinois (see photo B). He used it to produce the first radio maps of the Milky Way Galaxy.

Although Project Argus has gained widespread participation by hundreds of radio amateurs in dozens of countries, unfortunately it falls far short of its ambitious goal of real-time all-sky coverage, which would require the coordinated efforts of 5000 participating stations properly dispersed around the globe. One barrier to participation for many a perspective Argonaut is the physical structure of the required antenna. These dishes are arguably large and unsightly, and where physical constraints do not preclude their installation, local zoning ordinances often do. A need exists for more compact, portable antennas that can be deployed on demand by those amateurs interested in pursuing radio astronomy and SETI.

In the L-band radio spectrum favored by many amateur radio astronomers, the typical backyard parabolic dish exhibits in excess of +30 dBi of gain. Meaningful research, however, can be done with antennas exhibiting perhaps 10 dB less gain. Because the parabolic reflector is a non-resonant, low-Q structure, it can be made to operate over a wide range of frequencies. Any alternative to the parabolic dish similarly must be capable of operating over a reasonably broad bandwidth.

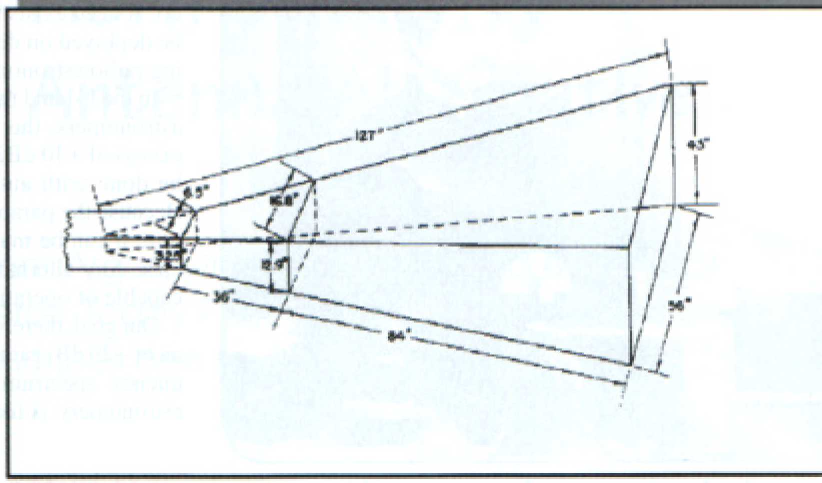
Our goal, therefore, is to develop a readily transportable antenna of +20 dBi gain which covers a reasonable portion of that frequency spectrum of the greatest interest to amateur radio astronomers. A likely contender is the waveguide horn antenna.

Horn History

The first real microwave gain antenna was a cylindrical parabola developed by Heinrich R. Hertz in 1888. Hertz wrote, "As soon as I had succeeded in proving that the action of an electric oscillation spreads out as a wave in space, I planned experiments with the object of concentrating this action and making it perceptible at greater distances by putting the primary conductor in the focal line of a large concave parabolic mirror."[2]

In 1894, Sir Oliver Lodge first demonstrated waveguide microwave transmission lines at London's Royal Institution. Three years later at the University of Calcutta, Indian physicist J. C. Bose (seen in photo C) flared out the end of a waveguide, demonstrating the horn antenna, seen in photo D. Being a low-

Photo E. Harold Ewen with his horn at Harvard University, circa 1951. (Photo courtesy NRAO)



HORN ANTENNA

The design of the horn antenna was based on descriptive information presented in the Rad Lab book on Antennas by Sam Silver. The maximum size was determined by the geometric constraints of the fourth floor parapet at Lyman Lab.

I sent my calculations and sketches to Sam for a sanity check, before sending the build order to the Physics Dept. Model Shop. It was up on the parapet in about three weeks.

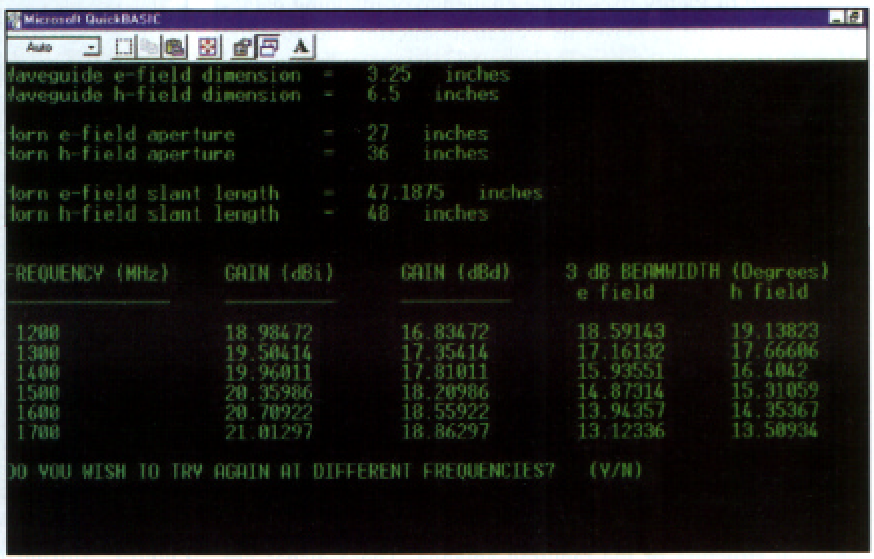
Figure 1. Physical dimensions of the Ewen horn. (From Harold Ewen's doctoral dissertation, Harvard University)

Q structure, the Bose horn offered respectable gain over perhaps an octave of bandwidth.

Numerous experimenters, including Marconi (who in 1897 recovered microwave communications over a 4-mile path in a demonstration for the British post office), employed waveguide horn antennas. It was not until 1951, however, that this promising antenna configuration was applied to the challenges of radio astronomy.

Reverse Engineering Ewen

In one of radio astronomy's landmark experiments, Harvard University graduate student Harold I. "Doc" Ewen built the horn antenna, seen in photo E, first to measure the 1420-MHz hyperfine transi-



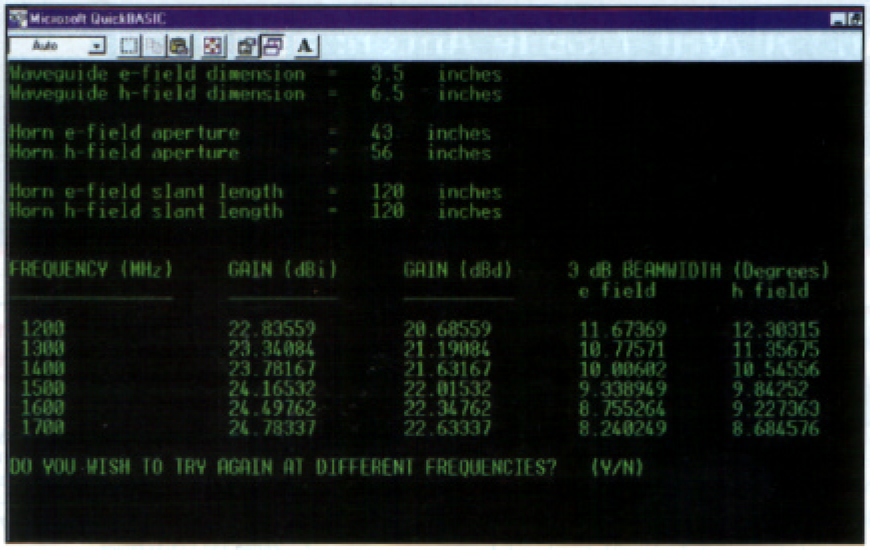
Microsoft QuickBASIC

```
Waveguide e-field dimension   =   3.25   inches
Waveguide h-field dimension   =   6.5    inches

Horn e-field aperture         =   27     inches
Horn h-field aperture         =   36     inches

Horn e-field slant length     =   47.1875   inches
Horn h-field slant length     =   48     inches
```

FREQUENCY (MHz)	GAIN (dBi)	GAIN (dBd)	3 dB BEAMWIDTH (Degrees) e field	h field
1200	18.98472	16.83472	18.59143	19.13823
1300	19.50414	17.35414	17.16132	17.66606
1400	19.96011	17.81011	15.93551	16.4042
1500	20.35986	18.20986	14.87314	15.31059
1600	20.70922	18.55922	13.94357	14.35367
1700	21.01297	18.86297	13.12336	13.50934

DO YOU WISH TO TRY AGAIN AT DIFFERENT FREQUENCIES?   (Y/N)

Figure 2. Gain analysis of the Ewen horn (analyzed using Horngain.bas by N6TX)


Microsoft QuickBASIC

Waveguide e-field dimension = 3.5 inches
Waveguide h-field dimension = 6.5 inches

Horn e-field aperture = 43 inches
Horn h-field aperture = 56 inches

Horn e-field slant length = 120 inches
Horn h-field slant length = 120 inches

FREQUENCY (MHz)	GAIN (dBi)	GAIN (dBd)	3 dB BEAMWIDTH (Degrees) e field	h field
1200	22.83559	20.68559	11.67369	12.30315
1300	23.34084	21.19084	10.77571	11.35675
1400	23.78167	21.63167	10.00602	10.54556
1500	24.16532	22.01532	9.338949	9.84252
1600	24.49762	22.34762	8.755264	9.227363
1700	24.78337	22.63337	8.240249	8.684576

DO YOU WISH TO TRY AGAIN AT DIFFERENT FREQUENCIES? (Y/N)

Figure 3. Gain analysis of the SETI Horn of Plenty (analyzed using Horngain.bas by N6TX).

tion line of interstellar hydrogen.[3] He based his antenna design on the earlier work of University of California professor Samuel Silver, at the MIT Radiation Laboratory,[4] with its physical dimensions constrained by the size of the parapet in Harvard's Lyman laboratory, where his receiver apparatus was installed. This horn is now on display, along with Grote Reber's dish seen in photo B, at the National Radio Astronomy Observatory (NRAO), Green Bank, West Virginia. Because Green Bank is the site of the annual meeting of the Society of Amateur Radio Astronomers (SARA), it is safe to say that these two antennas have inspired a whole generation of amateur radio astronomers.

The radiation characteristics (gain and beamwidth over frequency) of a pyramidal waveguide horn are purely a function of its physical dimensions. Ewen thoroughly documented the physical dimensions of his horn (see figure 1), which allows us to reverse-engineer its performance. I did this analysis using a Microsoft Basic program, which I published 14 years ago.[5] The resulting computed gain, e-field beamwidth, and h-field beamwidth at L-band are shown in figure 2.

Scaling the Ewen Horn

These calculations reveal that Ewen's horn exhibited a gain just under +24 dBi at the hydrogen line, with a nearly symmetrical pattern producing a half-power beamwidth on the order of 10 degrees in both the e-field and the h-field. A replica of the Ewen horn would seem to provide ideal performance for an amateur radio telescope, but for its size. The horn length of 10 feet is definitely unwieldy, providing little advantage over the standard satellite TV dish we are attempting to replace.

It was decided to scale the dimensions of the Ewen horn, in search of a reasonable compromise between performance and size. A somewhat arbitrary horn length of 4 feet and width of 3 feet were selected, constrained by the standard size of available materials (26-gauge galvanized sheet steel is readily available in 3 foot by 4 foot sections at under $10 per sheet from a local fabricator of heating, ventilation, and air-conditioning ductwork).

Scaling all remaining dimensions to the selected horn width and length, and retaining the same L-band waveguide dimensions used by Ewen, allowed us to determine preliminary design dimensions of the SETI Horn of Plenty. The resulting performance was analyzed in

(Continued on page 80)

Photo F. Tony Monteiro's +20 dBi waveguide horn for 2401 MHz AO-40 satellite reception. (AA2TX photo)

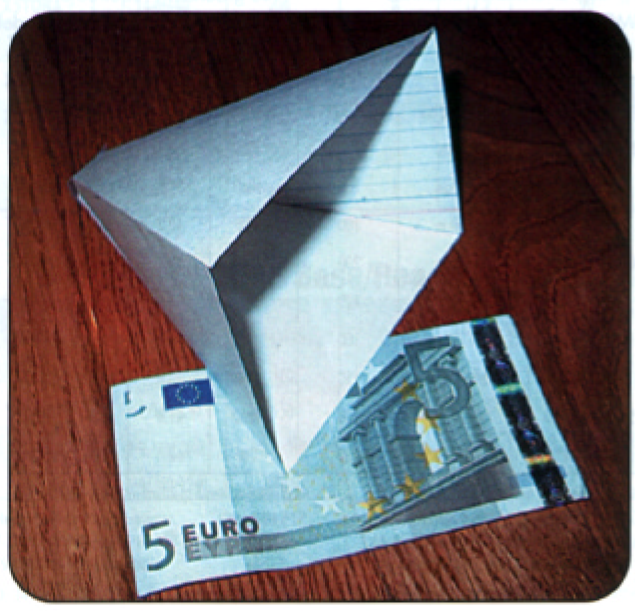


Photo G. One-twelfth scale paper mockup of the proposed SETI Horn of Plenty. (N6TX photo)

Grote Reber, Radio Astronomy Pioneer

Grote Reber, ex-W9GFZ, who is mentioned in this article, was one of the earliest pioneers of radio astronomy. He died in Tasmania, where he had been living since 1954, on December 20, 2002, just two days shy of his 91st birthday.

Reber was the first person to build a radio telescope dedicated to astronomy, opening up a whole new "window" on the universe that eventually produced landmark discoveries such as quasars, pulsars, and the remnant "afterglow" of the Big Bang. His self-financed experiments laid the foundation for today's advanced radio-astronomy facilities.

"Radio astronomy has changed profoundly our understanding of the universe and has earned the Nobel Prize for several major contributions. All radio astronomers who have followed him owe Grote Reber a deep debt for his pioneering work," said Dr. Fred Lo, director of the National Radio Astronomy Observatory (NRAO).

"Reber was the first to systematically study the sky by observing something other than visible light. This gave astronomy a whole new view of the universe. The continuing importance of new ways of looking at the universe is emphasized by this year's Nobel Prizes in physics, which recognized scientists who pioneered X-ray and neutrino observations," Lo added.

Reber was a radio engineer and avid amateur radio operator in Wheaton, Illinois in the 1930s when he read about Karl Jansky's 1932 discovery of natural radio emissions coming from outer space. As an amateur radio operator, Reber had won awards and communicated with other amateurs around the world, and later wrote that he had concluded "there were no more worlds to conquer" in radio.

Learning of Jansky's discovery gave Reber a whole new challenge that he attacked with vigor. Analyzing the problem as an engineer, Reber concluded that what he needed was a parabolic-dish antenna, something quite uncommon in the 1930s. In 1937, using his own funds, he constructed a 31.4-foot diameter dish antenna in his backyard. The strange contraption attracted curious attention from his neighbors and became something of a minor tourist attraction, he later recalled.

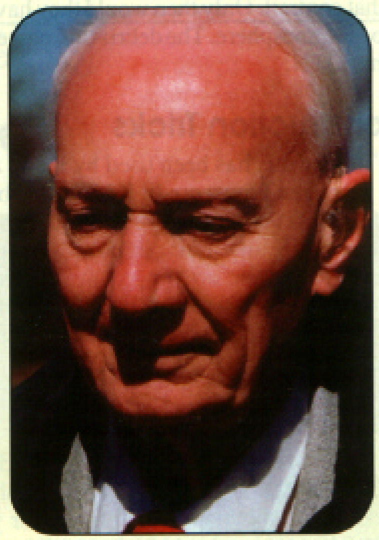
Using electronics he designed and built that pushed the technical capabilities of the era, Reber succeeded in detecting "cosmic static" in 1939.

In 1941, Reber produced the first radio map of the sky, based on a series of systematic observations. His radio-astronomy work continued over the next several years. Although not a professional scientist, his research results were published in a number of prestigious technical journals, including *Nature*, the *Astrophysical Journal*, the *Proceedings of the Institute of Radio Engineers*, and the *Journal of Geophysical Research*.

Reber also received a number of honors normally reserved for scientists professionally trained in astronomy, including the American Astronomical Society's Henry Norris Russell Lectureship and the Astronomical Society of the Pacific's Bruce Medal in 1962, the National Radio Astronomy Observatory's Jansky Lectureship in 1975, and the Royal Astronomical Society's Jackson-Gwilt Medal in 1983. Ohio State University conferred an honorary doctorate on Reber in 1962.

In a 1977 paper "Endless, Boundless, Stable Universe" <http://personal.nbnet.nb.ca/galaxy/G_Reber.html>, Reber concluded: "Time is merely a sequence of events. There is no beginning nor ending. The material universe extends beyond the greatest distances we can observe optically or by radio means. It is boundless."

Reber's original dish antenna now is on display at the National Radio Astronomy Observatory's site in Green Bank, West Virginia, where Reber worked in the late 1950s. All of his scientific papers and records, as well as his personal and scientific correspondence, are held by the NRAO, and will be exhibited in the observatory's planned new library in Charlottesville, Virginia.



Grote Reber, ex-W9GFZ, pioneer radio astronomer, became a Silent Key on December 20, 2002, two days shy of his 91st birthday. (Image courtesy NRAO/AUI)

Reber's amateur radio callsign, W9GFZ, is held by the NRAO Amateur Radio Club. This callsign was used on the air for the first time since the 1930s on August 25, 2000 to mark the dedication of the Robert C. Byrd Green Bank Telescope. Further information on Reber's life work can be found at <http://www.gb.nrao.edu/fgdocs/reber/greber.html>.

The above is a NRAO news release by Dave Finley, N1IRZ, and Tom Crowley, KT4XN, via The ARRL Letter, *Vol. 21, No. 50, December 27, 2002*

software (see figure 3). Gain comes in at 3 to 4 dB below the Ewen horn, with symmetrical beamwidths of 16 degrees in both planes.

Tony's Disposable Horns

At the 2002 AMSAT Space Symposium, Anthony Monteiro, AA2TX, demonstrated a technique for manufacturing disposable horn antennas out of corrugated cardboard, kitchen aluminum foil, and packing tape. The cost of these materials was negligible.[6] One of Tony's antennas, used for 2.4 GHz satellite reception, is shown in photo F. The antenna was an inspiration for the SETI Horn of Plenty.

Unfortunately, cardboard and foil proved insufficiently robust for our purposes, and we had to resort to 26-gauge galvanized sheet steel. In email correspondence with the author, Tony stated, "I agree that while cardboard is fun and a neat demo for a serious radio telescope, the metal antenna is the way to go. After all, what if ET calls and it is raining that day?"

Construction Details

Whereas cardboard construction is inadequate for our purposes, it provides us with an easy way to verify that all the pieces are going to fit together before we take shears or tin snips to $10 sheets of steel. It is not, however, necessary to build a full-size model in order to determine proper fit. Because the largest piece of metal in the proposed design measures 3 feet by 4 feet, it's a simple matter to scale the design by a factor of 12 and make a mock-up out of 3-inch by 5-inch index cards. The result of this exercise, seen in photo G, affirms the compatibility of the proposed dimensions.

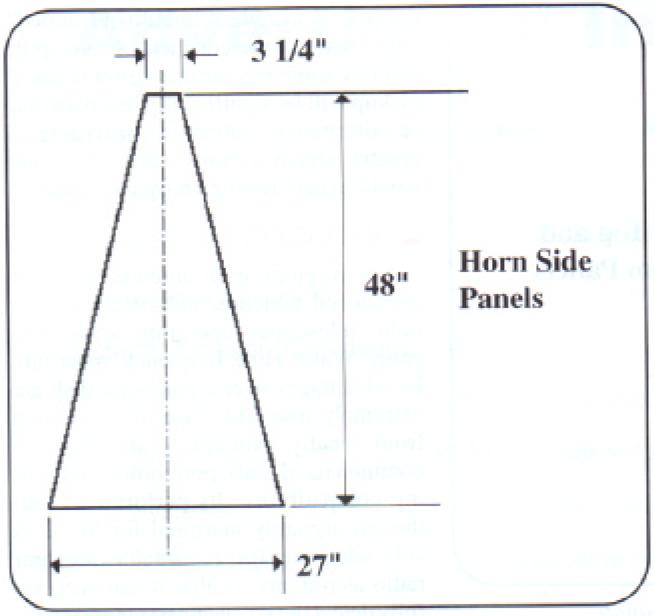


Figure 4. SETI Horn of Plenty side-panel template.

The four sides of the truncated pyramid, dimensioned according to figures 4 and 5, were fabricated at the local sheet metal shop in a matter of minutes. Figure 6 shows the quarter-wavelength monopole probe used to excite the horn, fabricated out of a Type-N flange-mount coaxial connector and a length of brass hobby tubing. The four horn sections are joined to 1-inch wide by $^1/_8$-inch thick aluminum angle stock (sold locally at 75 cents per foot) with pop rivets. I like to place the pop rivets about a quarter wave apart at the operating frequency, which equates to about 2-inch spacing. Don't forget to rivet a $3^1/_4$-inch by $6^1/_2$-inch sheet metal short at the back of the horn.

The completed SETI horn prototype is seen in photo H, ready for testing.

Performance

Although this horn antenna suffers a 3- to 4-dB gain deficit when compared to the Ewen horn, today's receivers are at least

Photo H. Action end of the completed Horn of Plenty prototype. (N6TX photo)

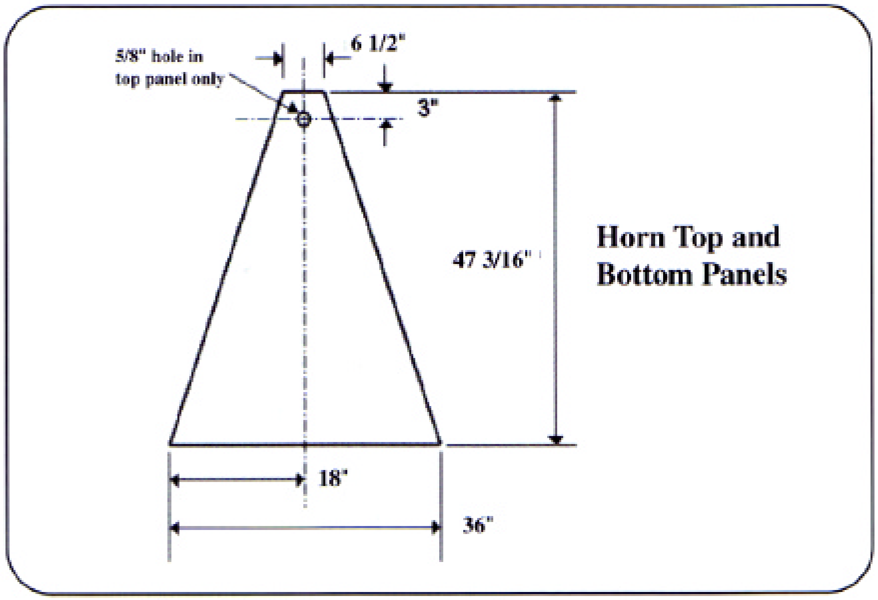


Figure 5. SETI Horn of Plenty top/bottom-panel template.

10 dB more sensitive than the simple diode mixer design used by Ewen a half-century ago. Thus, the Horn of Plenty is entirely capable of detecting interstellar hydrogen radiation, as well as a number of astrophysical thermal sources. It would have quite easily detected the famous Ohio State University "Wow!" signal,[7] suggesting its value as a SETI antenna. It can be used to monitor communications and navigation satellite activity in L-band, to recover amateur signals reflected off the lunar surface at 1296 MHz, and to perform radio-frequency interference surveys. These are valuable scientific endeavors, whether or not the horn ever captures ET's call!

This horn design exhibits gain on a par with that of a quad helix array, a single long Yagi, or a 1-meter dish. However, the horn's excellent broadband impedance match, inherent lack of overspill, and low sidelobes mean its ground noise pickup will be significantly less than that of alternative antennas, providing a greater signal-to-noise ratio than one would expect from gain figures alone.

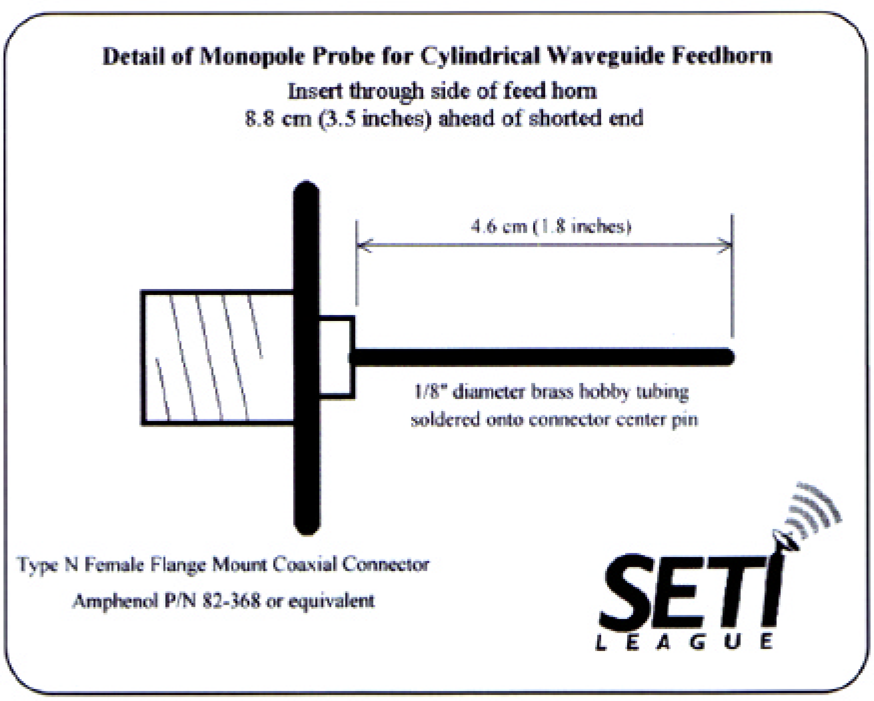


Figure 6. Coax connector and monopole probe assembly.

Conclusion

A waveguide horn antenna has been introduced which acquits itself well in radio telescopes operating across the entire Water Hole frequency spectrum. Its advantages over a parabolic dish are extremely low cost, ease of fabrication from locally available materials with common hand tools, portability, and zoning compatibility. Its performance, although arguably marginal for SETI, is still adequate for reasonable amateur radio astronomy, in that it can successfully detect the six strongest natural astronomical radio sources, clouds of interstellar hydrogen, half a dozen classes of orbital satellites, and moonbounce signals in the 23-cm amateur band. Whether our cosmic companions can radiate sufficient power to make themselves detectable with such an antenna remains to be demonstrated.

Notes

1. Shuch, H. Paul, "A Brief History." Chapter 1 in *The ARRL UHF/Microwave Experimenter's Manual*, American Radio Relay League, Newington CT, 1990.

2. Purcell, Edward Mills and Harold I. Ewen, "Observations of a line in the galactic radio spectrum." *Nature* 168:356, 1951.

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4. Shuch, H. Paul, "HORNGAIN.BAS microwave horn antenna analysis program." *Proceedings, 23rd Conference of the Central States VHF Society:* 129-131, American Radio Relay League, Newington CT, July 1989.

5. Monteiro, Anthony, "A disposable antenna for receiving AO-40 on S-Band." *Proceedings of the AMSAT-NA 20th Space Symposium:* 111-122, American Radio Relay League, Newington CT, November 2002.

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