DESIGN OF AN L-BAND DUAL FEEDHORN FOR THE PURPOSES OF MICROWAVE SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE

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Abstract

Logic behind the design of a dual feedhorn for the 26-meter Cassegrainian antenna of the Agassiz Station-Harvard-Smithsonian Observatory is presented in the paper. Theoretically predicted and measured results in the "waterhole" band (1.4-1.7 GHz) are presented. The antenna has been utilized in the Harvard Wide-Bandwidth HighResolution Microwave Search for ExtraTerrestrial Intelligence (SETI) Program, with the Observatory as a SETI-dedicated facility.

Keywords:
SETI, Radio astronomy antennas

1. Introduction

With the increasing use of the radio spectrum for communications, navigation and other services, the avoidance of unwanted signals is an essential practical concern in both radio astronomy and SETI. Interference poses particular problems to the radio astronomer/SETI researcher, because the signal levels from cosmic sources are much lower than the operating levels in terrestrial services. Indeed, terrestrial interference is the number one problem in SETI. The antenna system presented here is designed to reject terrestrial interference by exploiting the property that a genuine extraterrestrial transmitter must be both pointlike and exhibit sidereal rotation.

2. Antenna configuration

A two-horn feeding system, with stationary beam lobes oriented east-west, along with a third "terrestrial" low-gain antenna was built. The rationale for employing also the lowgain antenna is the following: Signals in either of the high-gain (21.0 dB) sky horns that coincide in frequency with strong signals in the terrestrial horn will be rejected outright as obvious terrestrial interference, and only the signals that traverse the east sky horn and then the west sky horn, with appropriate beam lobe intensity profiles, will be flagged as possible candidate signals and this information will be forwarded to a workstation for further processing and archival storage.

Although a pair of beams separated by several beamwidths was originally envisioned for the reflector, we have come to favor some degree of overlap (suggested by Prof. Staelin at MIT), such that the handoff from one beam lobe to the other keeps the source in sight continously; this arrangement allows removal of ambiguities caused by fluctuating signal strengths, due to

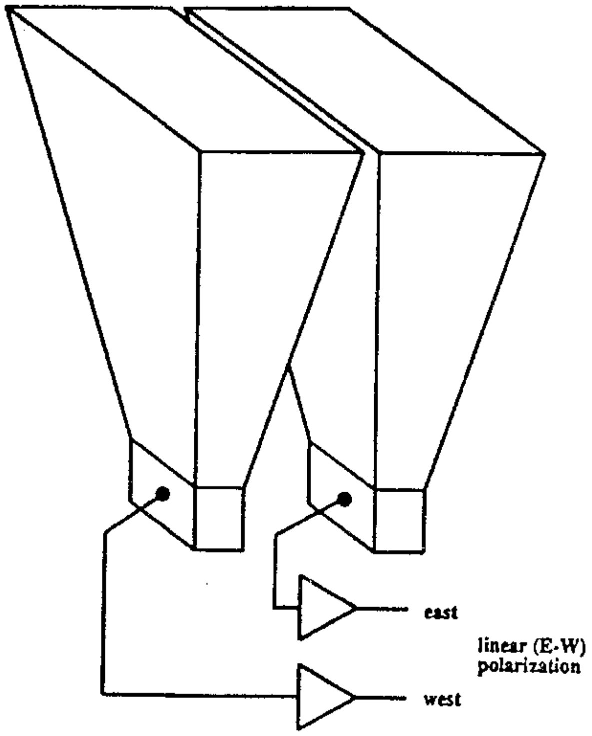

Fig.1
Linear-polarization pyramidal horn pair, stacked along the E-plane.

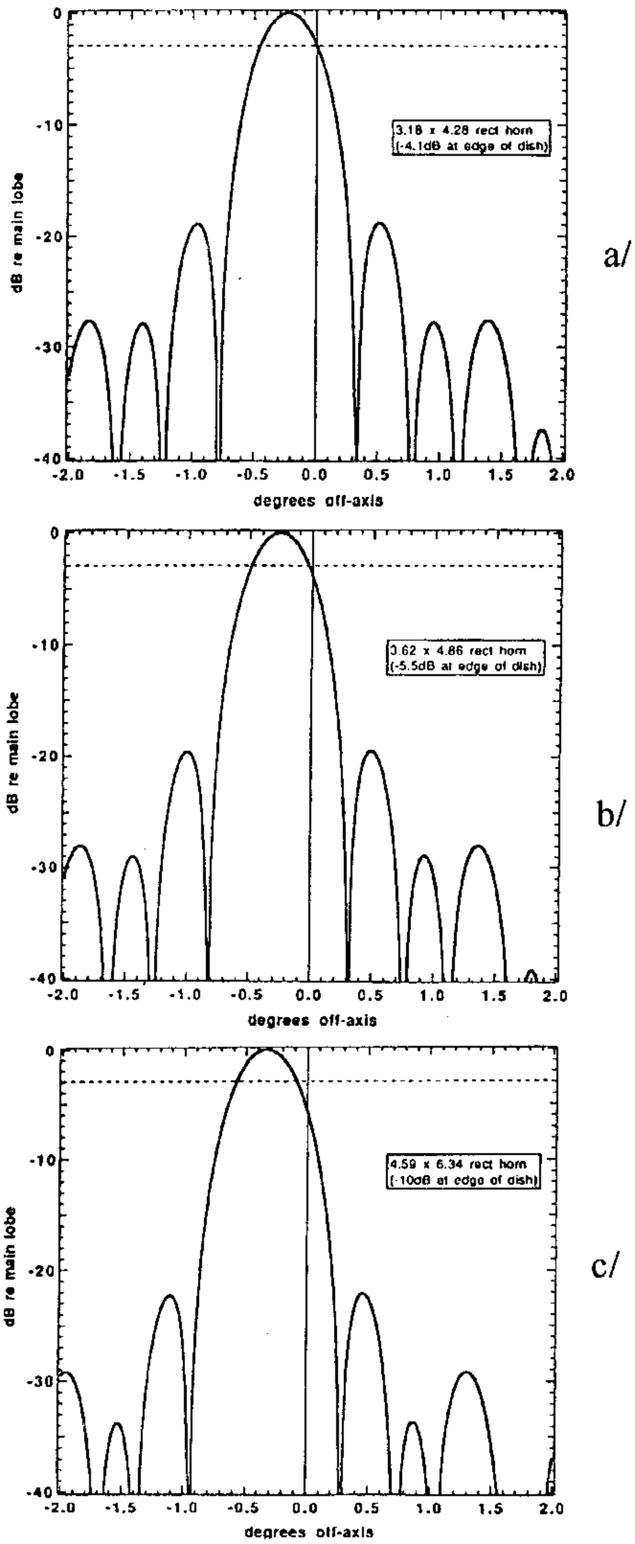

Fig. 2
Far-field antenna pattern for a 26-meter Cassegrain illuminated by a single pyramidal horn that is displaced along its E-plane by half its aperture. The three cases plotted progress to larger apertures, specified in wavelengths, with edge tapers of -4.1dB, -5.5dB, and -10dB, respectively. Each graph is centered on the H-plane, and plotted versus angle in the E-plane, with the vertical solid line indicating the antenna axis, and the horizontal dashed line indicating -3dB relative to maximum gain. The horns are assumed non-interacting; aperture blockage is respected.

interstellar scintillations or polarization shifts. To implement this, two schemes were considered, namely i) multiple-feedhorn hexagonally-packed phased array (each horn could be either linear or dual-circular polarization), and ii) a simpler arrangement of two pyramidal (linear polarization) horns, aligned along their E-plane axes. The multiple-feedhorn arrangement exhibited a remarkable azimuthal symmetry of beam pattern, but would require a major (lengthy and expensive) construction effort and increase aperture blockage significantly; by contrast, the pyramidal pair (Figure 1) is sensitive to only one linear polarization, but is easy to build and test. With either scheme, we were concerned that near-field aperture interactions would cause major distortions of the far-field pattern. To explore this effect, we made some laboratory "test-range" measurements with a pair of pyramidal X-band (3-cm wavelength) horns, driven (via a magic-T hybrid) both alternately and simultaneously with Gunn oscillator sources, while scanning the far-field pattern with a small dipole connected to a spectrum analyzer. We did not observe any interaction effects at the measurement accuracy of approximately 1dB. While favoring the simplicity of the stacked pyramidal horns, we were concerned about two additional issues:

- i) does the far-field pattern have reasonable azimuthal symmetry, and
- ii) is there adequate beam overlap with separate horns (which is assured with the interleaved 7-horn array)?

To answer these questions, we performed radiation pattern calculations, starting with a pyramidal horn design whose H-plane to E-plane dimensions are in the ratio of 1.35 (this ratio produces equal -3dB beamwidths, owing to cosine taper in the H-plane field amplitude, combined with uniform field amplitude along the Eplane). We

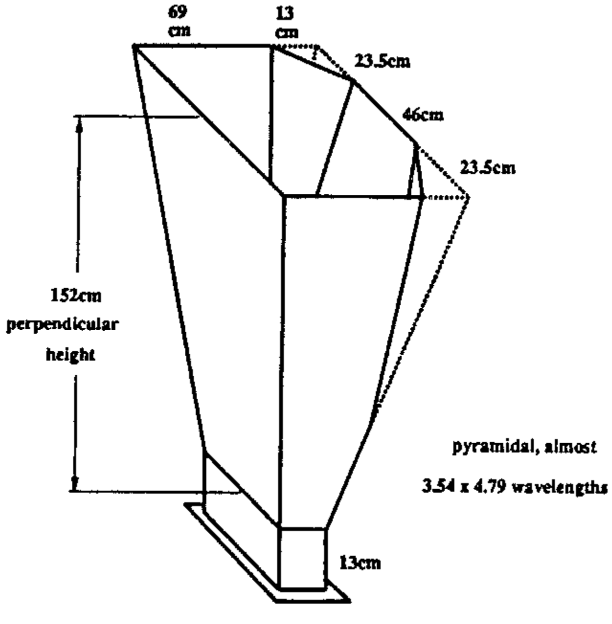

Fig. 3
Pyramidal horn design, with truncated corners to allow placement in our radome. This horn is closest to Figure 2b.

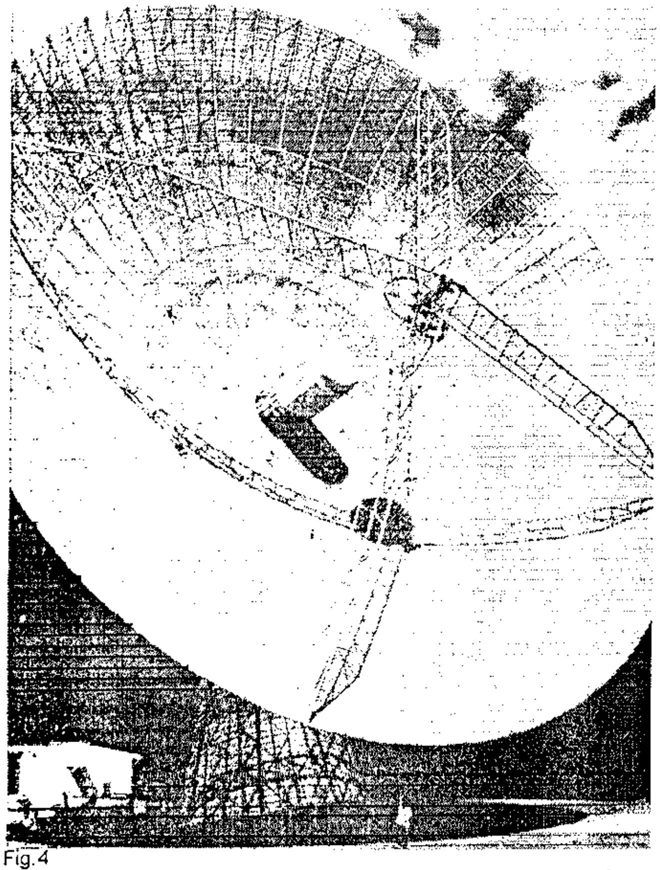

Fig. 4
The 26-meter radio telescope at Harvard. It is being used for a dedicated search for ETI signals. Note the first author's son Jacob at bottom for scale.

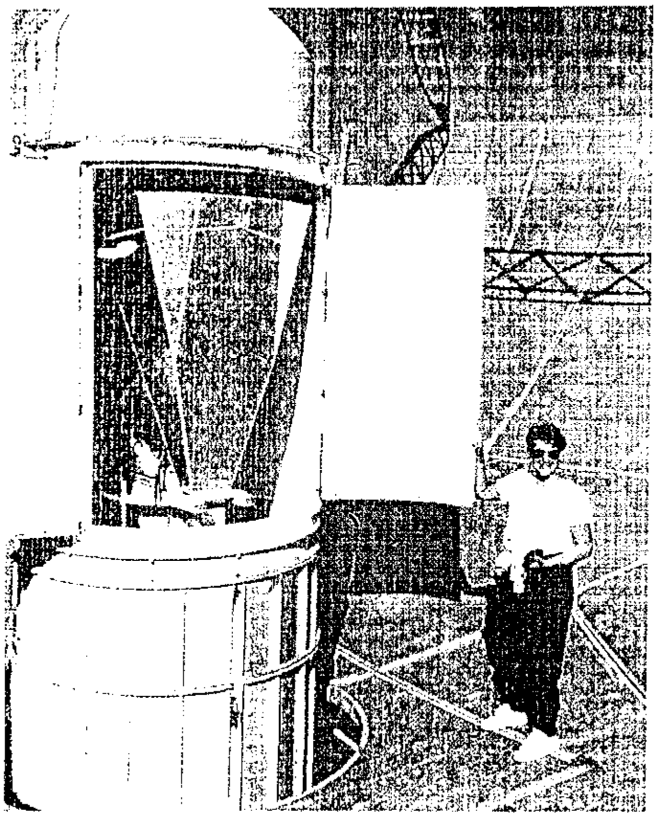

Fig. 5
Dual pyramidal horns, fabricated as in Figure 3, mounted in the 26-meter Cassegrain radome. A portion of the subreflector support truss is visible at top.

assumed no feedhorn interaction, and simply calculated the far-field pattern, using the parameters of our 26-meter antenna (full-width illumination angle of 18.5 degrees). Figure 2 shows the E-plane far-field radiation pattern,

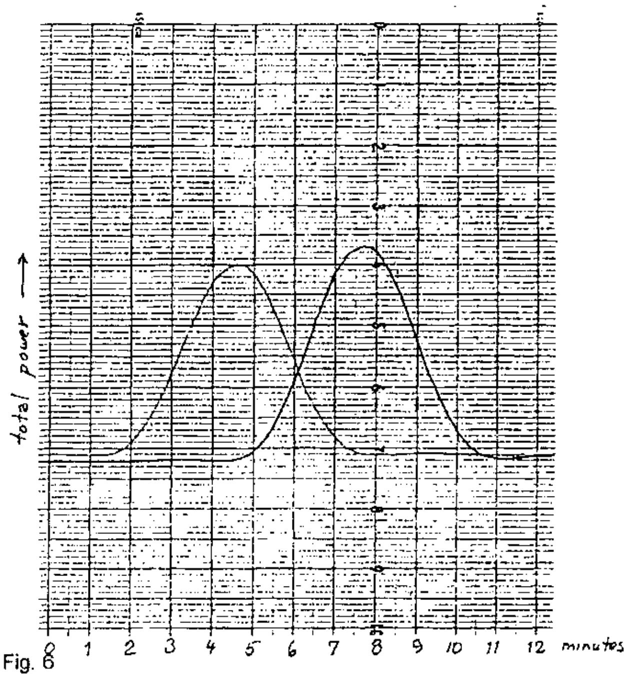

Fig. 6
Sidereal drift scan of Cygnus A (declination _ 40.6 degrees; flux density _ 1,695 Jansky at 1.55 GHz) with dual pyramidal horns, showing the desired lobe pattern and handoff. The true beam separation is 0.5 major divisions larger that shown, due to pen offset in the strip chart recorder.

from a single displaced horn, for three choices of horn aperture. In each case the horn center has been offset along the E-plane, relative to the Cassegrain axis, by half the horn aperture (i.e., stacked horns). A commonly accepted trade-off to achieve reasonable aperture efficiency (thus, also gain) while preserving low sidelobe levels in Cassegrain design is to taper the illumination to approximately -10dB, plus path-length attenuation, at the reflector edge. That corresponds to Figure 2c, producing beam overlap at the -6dB point; it also results in feedhorns that do not fit in the radome! We finally settled on the design in Figure 2b, which we estimated to have the antenna efficiency (i.e., aperture efficiency times spillover efficiency) just 0.6dB less than the ideal; its taper at the edge of the dish is -5.5dB, compared with the conventional -10dB, resulting in somewhat increased sidelobe levels. It fits in the radome if the outside corners are cut diagonally (Figure 3). The feedhorn length was chosen to produce wavefront curvature at about 0.2 by 0.3 wavelengths (E-plane by H-plane), resulting in finished feedhorns that fit in the radome with about 2 centimeters to spare (Figure 5). They are constructed of 3.2mm aluminum sheet (6061-T6), heliarc welded and joined to a WR-650 waveguide section with flange.

3. Antenna performance

We mounted the horns and performed drift scans of astronomical point sources (Sgr A, Cyg A). Figure 6 shows such a scan. The beam shape and overlap are ideal. However, the observed signal strength was lower than expected. It was not clear whether the lower signal-to-noise ratio was due to amplifier and feed losses, or to the compromised aperture illumination. In particular, the amplifiers have been at the focus for a decade, use earlier GaAs FET technology, and their noise figure had not been recently measured. Furthermore, the new horns look through the entire radome cover, including an oblique path through the curved edges, which was never intended; the radome material itself is fiberglass, now exposed to the weather for some 20 years. On the other hand, the dual feedhorn design is novel. Thus we did not know the relative contributions of noise temperature and aperture efficiency to the observed SNR. In the meantime, antenna pioneer Dr. John Kraus became interested in the experiments and devised a "hot load" technique by which both the system noise temperature (due to amplifier and feed losses) and the aperture efficiency could be unambigously measured; furthermore, he even provided us with the "hot load" absorbing material needed for the measurement! The measurments were made in May 1993, comparing cold sky (with and without the radome cover installed) with the hot load absorber, and with the astronomical radio source Tau A (the Crab Nebula). The result is that the antenna efficiency (product of aperture efficiency and spillover efficiency) is as predicted - approximately 45%, compared with the usual 50% - and that the system temperature is a modest 112 Kelvin, of which 60K is likely due to uncooled GaAs amplifiers, perhaps another 30K from feedhorn losses (we noted, but could not easily remove, approximately 8-millimeter-thick "monolayer" of dead flies in the waveguide-to-coax adapter), and the rest probably coming from antenna sidelobes that illuminate the 300K environment. From the measurements, the radome appears to be entirely benign. This performance has been found satisfactory, and will be improved significantly by the new HEMT amplifiers that have now been completed. In particular, uncooled HEMTs, combined with aggresive fly removal, should trim 40K, for a system temperature of about 70K; cooled HEMTs would trim another 20K, producing the system noise temperature of 50K.

4. Conclusions

An L-band dual feedhorn for the specific purposes of microwave Search for ExtraTerrestrial Intelligence has been designed, realized, mounted and tested at the Agassiz Station-Harvard-Smithsonian Observatory. The feedhorn reduces susceptibility to terrestrial interference as well as enables segregation of the objects that do not exhibit sidereal motion over the sky. As part of a 26-meter Cassegrainian antenna (Figure 4), the feedhorn produces desired radiation characteristics and provides aperture illumination resulting in the total antenna efficiency of 45%, which is in agreement with theoretical predictions.

5. Acknowledgements

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About authors, ...

Paul Horowitz is Professor of Physics at Harvard University, where he teaches physics and electronics. His research interests include observational astrophysics, X-ray and particle microscopy, optical interferometry, and SETI. He is the author of some seventy papers and reports and a co-author of the book The Art of Electronics . Dr. Horowitz and his students have been involved in SETI since 1978. Their recent efforts include an 8-million-channel receiver operating at Harvard, MA, and a new 240million-channel system soon to go on line. A twin of the 8-million-channel system was built and is operated by the Instituto Argentino de Radioastronomia at Villa Elisa, Argentina.

Martin Gimerský received the Ing. degree in electrical engineering from the Czech Technical University of Prague, Czechoslovakia, in 1988. Currently he has been working towards the completion of the Ph.D. degree in electrical engineering at the University of Victoria, Canada. His research interest include antennas, numerical methods in electromagnetic theory, and radio astronomy.