new trends in communication technologies: radio astronomy and the search for extraterrestrial intelligence

"Man's first step toward maturity may be to contact life beyond the solar system."

—Bernard M. Oliver

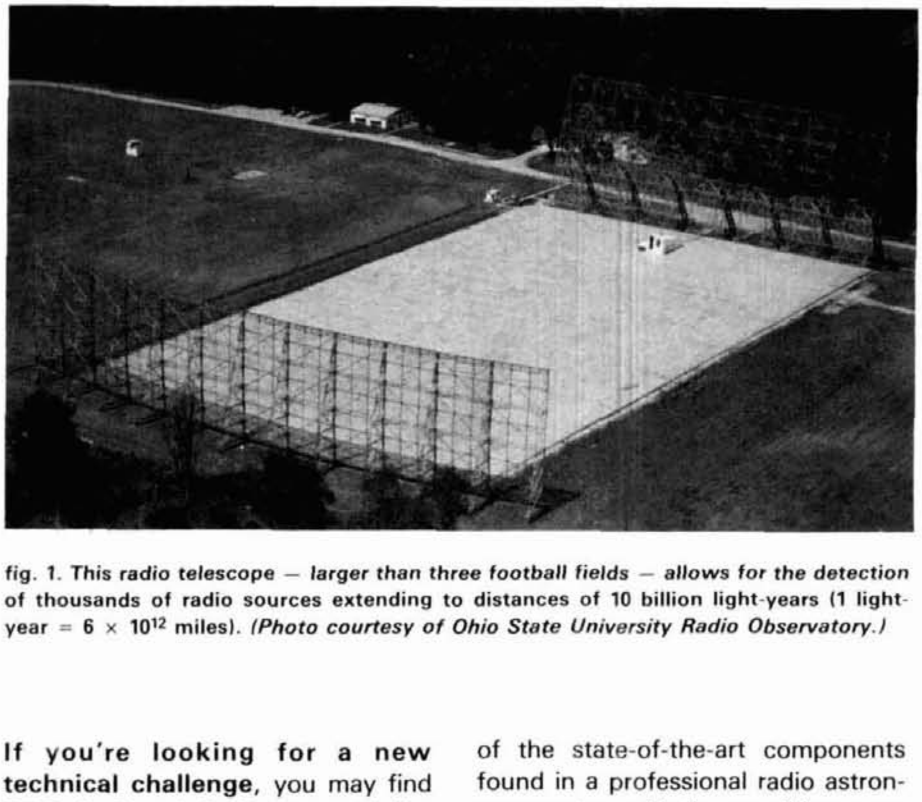

fig. 1. This radio telescope — *larger than three football fields* — *allows for the detection* of thousands of radio sources extending to distances of 10 billion light-years (1 light-year = 6×10^{12} miles). *(Photo courtesy of Ohio State University Radio Observatory.)*

If you're looking for a new technical challenge, you may find SETI, the Search for Extraterrestrial Intelligence, to be just the frontier you've been seeking. With today's microwave technology, it is possible to communicate anywhere within our galaxy. And although radio astronomy is still a relatively young science*, Amateur Radio operators have access to most of the state-of-the-art components found in a professional radio astronomy center, with the possible exception of the very large antennas. Because nobody knows what the first extraterrestrial signal will be like, there is ample room for ham ingenuity. After all, if hams were to be the first to communicate with extraterrestrials, it wouldn't be the first time a major scientific breakthrough had been made by hams — remember, not too long ago hams discovered the ionosphere.[1]

For several years I have been contemplating the construction of a system that would allow the reception of intelligent information generated by a hypothetical 1-Gigawatt EIRP (real power times antenna gain) transmitter located approximately 25 light-years away. I prepared this article in order to share some of the knowledge gained during this process and to provide a comprehensive overview of recent progress in radio astronomy (including SETI) and to assess what Amateurs can do with even limited resources.

*Unlike other events in science, the birth of radio astronomy can be traced precisely — to the early 1930's when Carl B. Jansky, a Bell Telephone radio engineer, performed antenna noise studies for long-range communications at the wavelength of 14.6 meters. With these studies, Jansky proved that extraterrestrial radiation can be received. Jansky's experiments were followed, in the late 1930's, by Grote Reber, W9GFZ, an amateur astronomer who designed and built the first parabolic radiotelescope and performed a survey of the galaxy at the wavelength of 1.9 meters.

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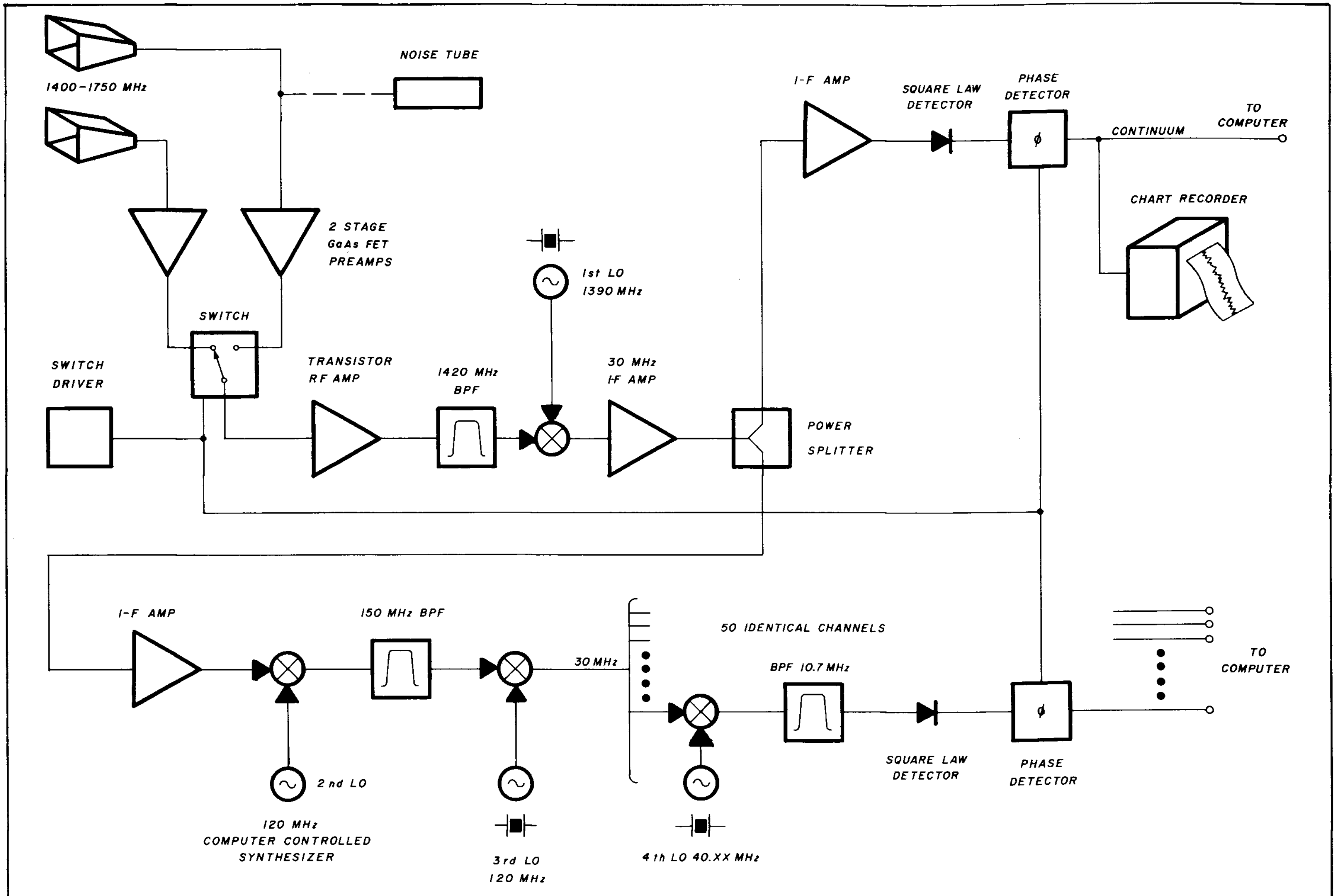


fig. 1B. Block diagram of the Ohio State University radio telescope configured for SETI. The system covers an instantaneous bandwidth of 500 kHz through a bank of 50-channel IF filters at 10.7 MHz (individual filter bandwidth is 10 kHz). (*Courtesy of Ohio State University Radio Observatory.*)

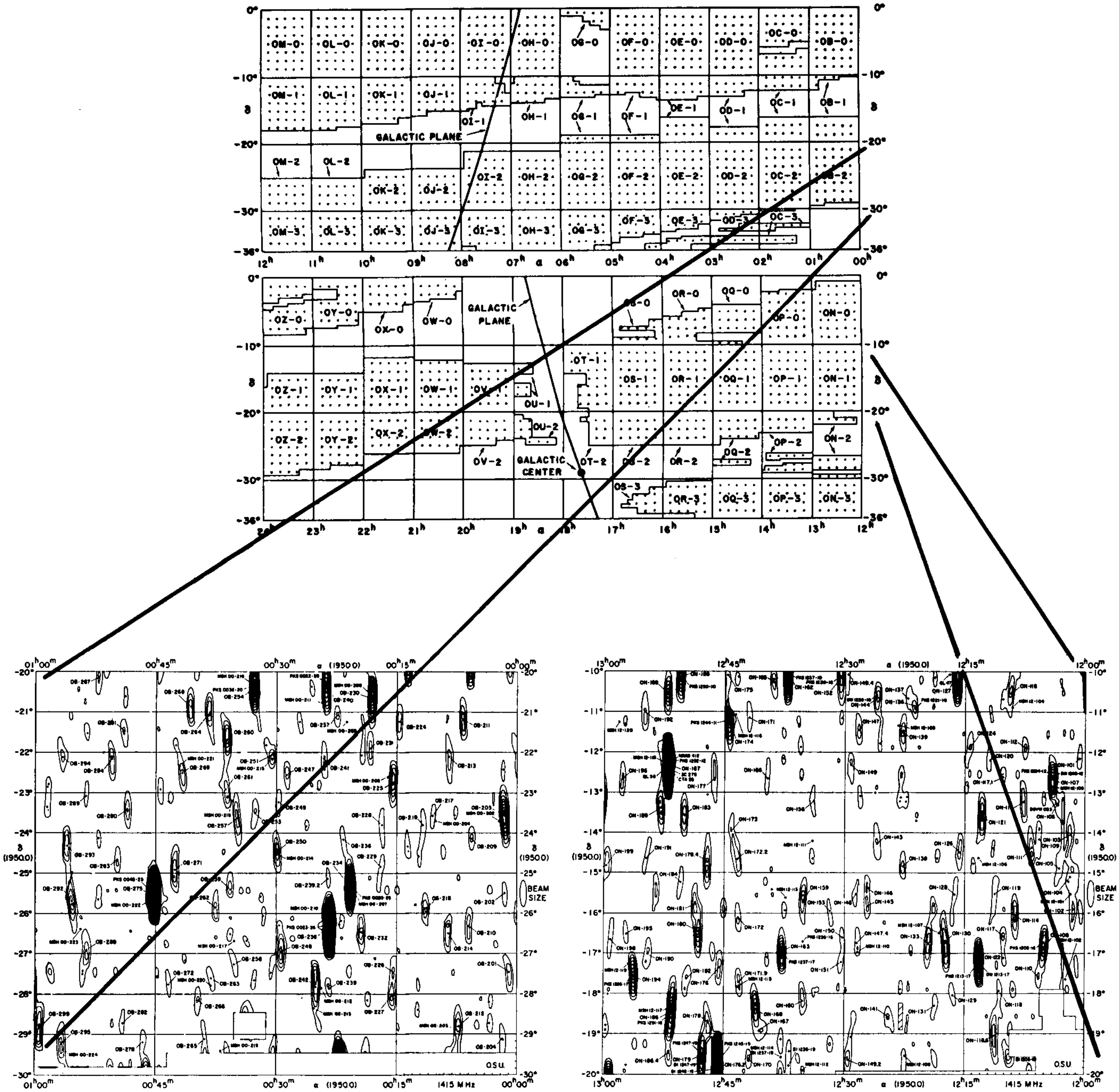


fig. 2. Master map of an Ohio University radiometer search. Maps below illustrate details of two sections indicated above. (*Courtesy of Ohio State University Radio Observatory.*)

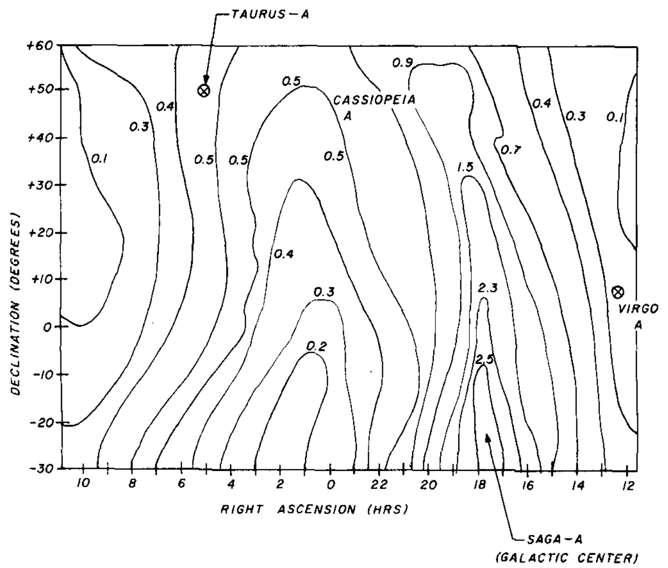


fig. 3. A map of the radio sky obtained with a simple amateur radiometer. Because of the antenna's low resolution, discrete radio sources appear as a set of signal gradient lines resembling a surveyor's map.

conventional radio astronomy

There are two current trends in radio astronomy. The first, and by far most popular, involves the study of wide-band noise generated by powerful sources within our galaxy or in other galaxies. The second, which occupies only a small fraction of the total activity, employs extremely narrow band-width receivers designed for the detection of intelligent monochromatic signals in the microwave regions of the frequency spectrum where the level of intergalactic noise is lowest.

Within the context of the first trend, it is relatively easy for an Amateur to build a radiometer receiver intended for casual observations of very strong radio sources. Because of the uniform distribution of wide-band noise over the receiver's bandwidth, no particular attention to local oscillator stability is required. There would likewise be no need for precise tuning to compensate for the Doppler shift in the incoming signals caused by Earth's rotation and by the relative motion between the observed celestial object and our own solar system.

Professional radiometers employ giant steerable antenna arrays that allow for the detection of natural radio sources located at great distances from Earth. A continuum survey of the sky was made by the Ohio University Radio Observatory, using the installation shown in **fig. 1A** and **1B**. The receiver employed a liquid nitrogen-cooled parametric amplifier with a calculated system temperature of 95 degrees K. The bandwidth was 8 MHz and the output was integrated over a 10-second period. Concurrent recording was performed after processing the data through IBM 7094 and 1620 computers. The entire system was synchronized with a sidereal clock accurate to within 0.05 second. Results have been plotted in maps of the region surveyed as shown in **fig. 2**. In its search of almost the entire sky, from −36 to +63 degrees, the Ohio State project found 20,000 radio sources.

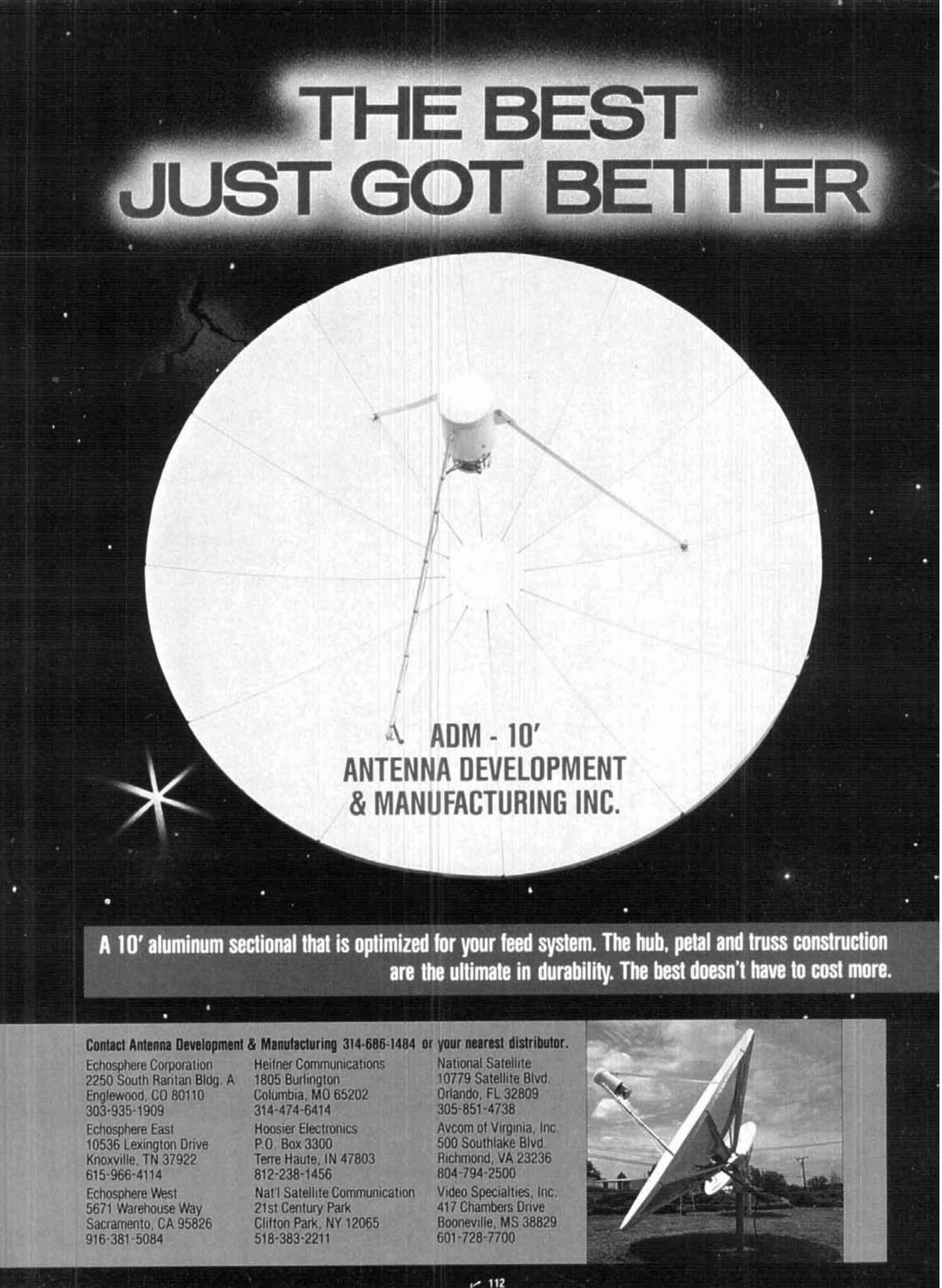
While such performance cannot be duplicated by the backyard radio astronomer, remarkable results can be obtained with relatively modest installations. An Amateur radiometer is usually a high-gain VHF/UHF superheterodyne receiver that features simple amplitude modulation detection followed by a DC amplifier equipped with an integrator. The output transducer can take the form of a conventional chart recorder or some other measuring device, or can be an analog-to-digital (A/D) converter connected to a microcomputer using a dot matrix printer for the output. The format would be digitized flux samples (values from 0V to 9V) at, for example, 1-second intervals printed out in 60-second columns for a total of 1 hour of information per page. With such a receiver and a multi-element beam antenna — and with considerable skill and patience — a serious Amateur can map the radio sky in a short time.

The methodology employed involves pointing the antenna at a known celestial location and then relying on the Earth's rotation to bring in the various natural radio sources. This requires knowing celestial coordinates and times as well as converting the recorded information and antenna position into the right ascension and declination values in order to plot the signal onto a celestial map that would resemble the actual sky (see **fig. 3**).

A typical multi-element beam antenna with a major lobe beamwidth between the half power points of approximately 30 degrees would allow a natural radio source to pass through its beam in approximately two hours (the apparent rate of movement of a celestial object is 15 degrees per hour at the equator). This in turn would be sufficient to allow for the reception of strong Milky Way sources such as Cygnus A, located approximately 500 light-years away, and Cassiopeia A, located approximately 200 light-years away, regardless of the system's bandwidth or operating frequency.

very-long-baseline interferometry (VLBI)

In order to increase the resolution of a simple radiometer so that much smaller or more distant objects can be distinguished, increased antenna directivity is required. This, in turn, dictates large physical installations, which are difficult and costly to build. To overcome this problem, a new kind of a receiving system, the interferometer,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was developed. This system uses a pair of antennas and transmission lines separated by a specific horizontal distance (i.e., the "baseline") extended to an even multiple of the operating wavelength, preferably more than fifteen wavelengths. The system is usually configured in an east-west orientation. The idea is that a radio signal from a celestial source arrives at two antennas successively, in phase and out of phase, because of Doppler shifts caused by the Earth's rotation. If the two signals are combined through a zero-degree RF combiner, a fringe pattern of interference results, breaking up the large central antenna lobe into a variety of smaller ones. The longer the baseline, the narrower the lobe, or "aperture" (see **fig. 4**).

Very-long-baseline interferometry (VLBI) is possible today through observations made simultaneously by radio telescopes thousands of miles apart, with local oscillators and subsequently recorded data synchronized within a fraction of a microsecond through the use of atomic clocks. This eliminates the need for running coaxial cables from the antenna sites to the central location for processing, and the result can be a beamwidth of 0.0001 arc-second, which is far superior to optical telescopes previously used. For comparison, the 200-inch optical telescope on Palomar Mountain has a theoretical resolution of 0.023 arc-second. Yet because of the effects of atmospheric phenomena, its practical resolution is only about 1.0 arc-second. A block diagram of a VLBI system is shown in **fig. 5**.

Using a special hybrid mapping technique and several radio telescopes located in California, Texas, West Virginia, Massachusetts, and West Germany, astronomers have recently made some exciting new discoveries. The first quasar (3C 147) ever observed with this method has been effectively mapped; it is located some seven billion light-years away. The resolution was in the order of 0.01 arc-second — a considerable improvement over the resolution of the Palomar optical telescope, which detects 3C 147 as no more than a faint star. The radio picture revealed a jet 5000 light-years long emanating from a bright core. Another quasar (3C 273) was observed with a resolution of 0.001 arc-second; its observation recorded matter being ejected from a bright core traveling at nearly the speed of light, a previously suspected phenomenon called *superluminal motion*. (Superluminal motion has been found in two additional quasars and in a distant galaxy as well.)

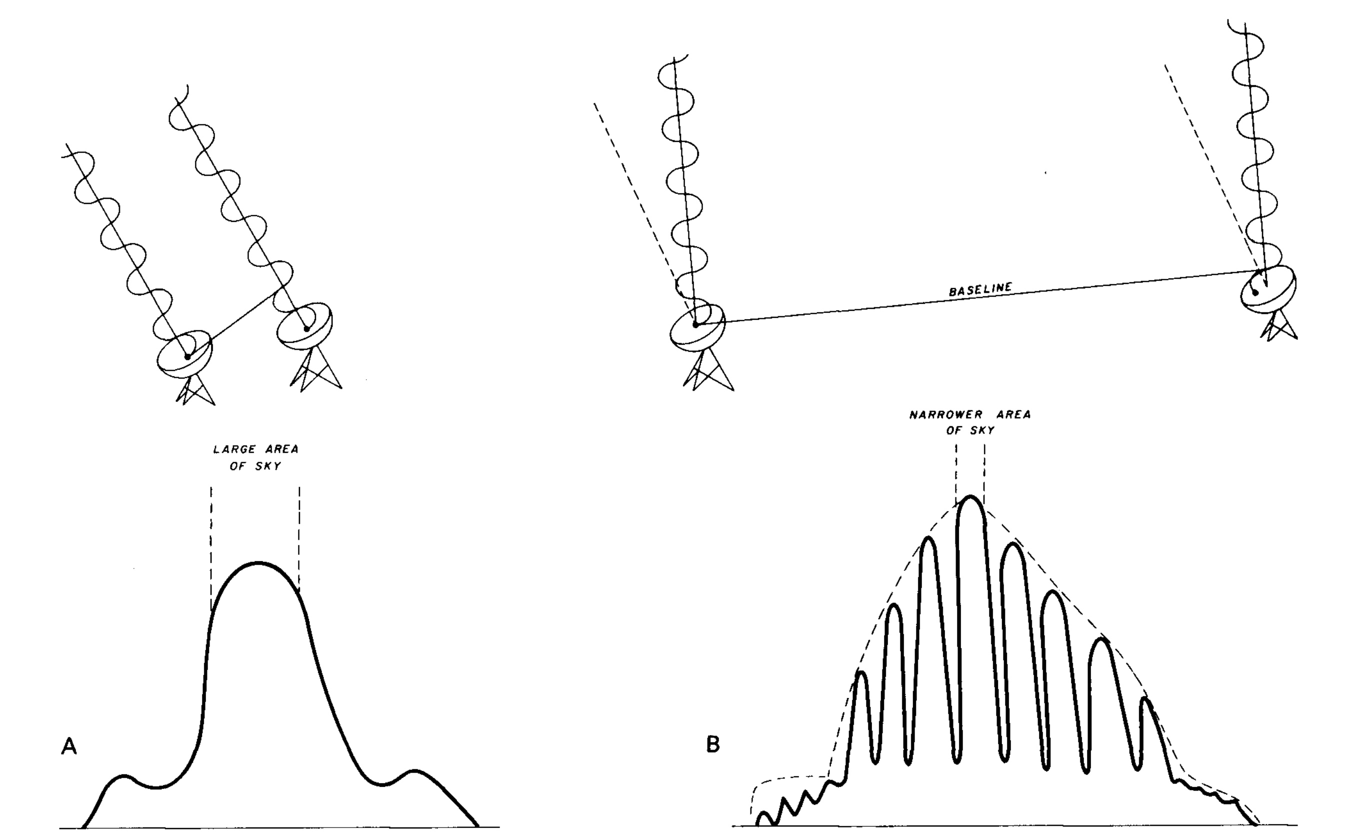

fig. 4. The principle of the radio interferometer telescope. At (A), the signal received by an antenna system peaks over a broad area of the sky. At (B), the signal received by interfering signals from each antenna peaks over a narrower area of the sky.

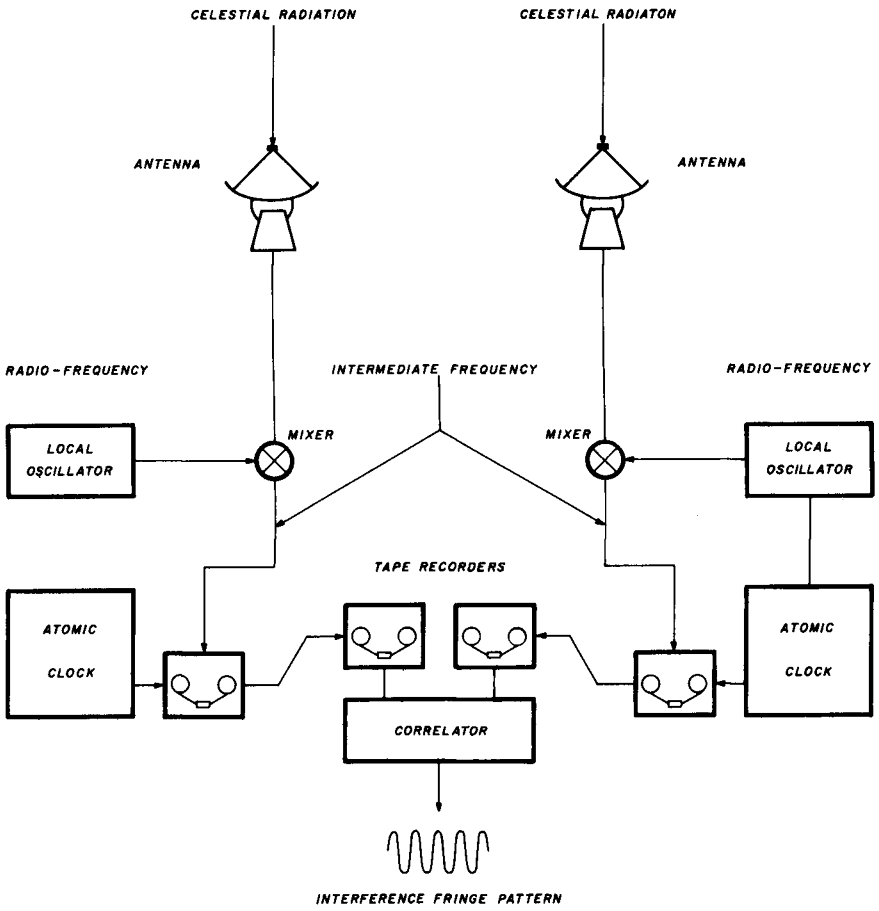

fig. 5. Very-long-baseline interferometry (VLBI) eliminates the need for the antennas to be (hard) connected to a single receiver. Atomic clocks allow the synchronization of separate local oscillators at all locations to a fraction of a microsecond. The final correlation of the data is achieved later at a central processor by playing back and synchronizing the wide-band video information.

We will now turn not to the probability of life elsewhere — the subject has already been discussed in great detail — but to the possibility of receiving intelligent transmissions (see **fig. 7**). Assume that extraterrestrial life exists. Assume also that the only reason we haven't yet discovered extraterrestrial life is because radio technology has only recently matured sufficiently to allow low noise amplifiers and high resolution microwave synthesizers to be used.

To make the best possible effort in searching for extraterrestrial signals, we would have to cover the microwave frequency range between 10^9 to 10^{10} Hz (1-10 GHz) in narrow steps of, say, 1 Hz. (Ultra-narrow bandwidths are necessary to obtain the best signal-to-noise ratios in SETI.) This means 9×10^9 steps. If we would spend one second per frequency step, and search with one thousand frequencies at once, thereby reducing the number of steps to 9×10^6, it would take approximately three months to search the sky in a single direction. The other condition for our nearly ideal search would be very narrow antenna beamwidths. If our radio telescope would allow a resolution of three million different directions, an all-sky, all-frequency search within the above parameters would be completed in approxi-

Although it is impossible for a Radio Amateur to perform such high resolution experiments, simple backyard interferometers can provide beamwidths as narrow as five degrees, depending upon the frequency of operation and the length of the baseline. (See **fig 6**.)

the search for intelligence

So far we have discussed only one aspect of radio astronomy, that of receiving and studying wide-band radio noise from non-intelligent sources located hundreds and even thousands of light-years away. The powerful nuclear reactions within these systems result in natural transmissions of formidable amounts of RF power to be detected by our rather primitive radio equipment.

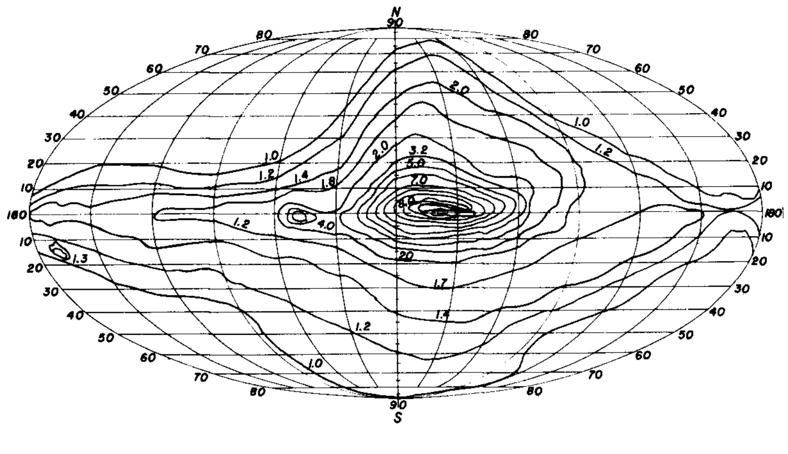

fig. 6. Higher (but still low) resolution mapping of the radio sky than in the case of simple radiometry can be obtained with narrower beamwidth antennas as in the case of amateur interferometry.

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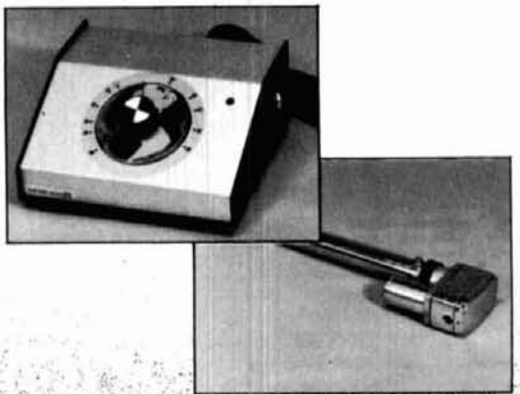

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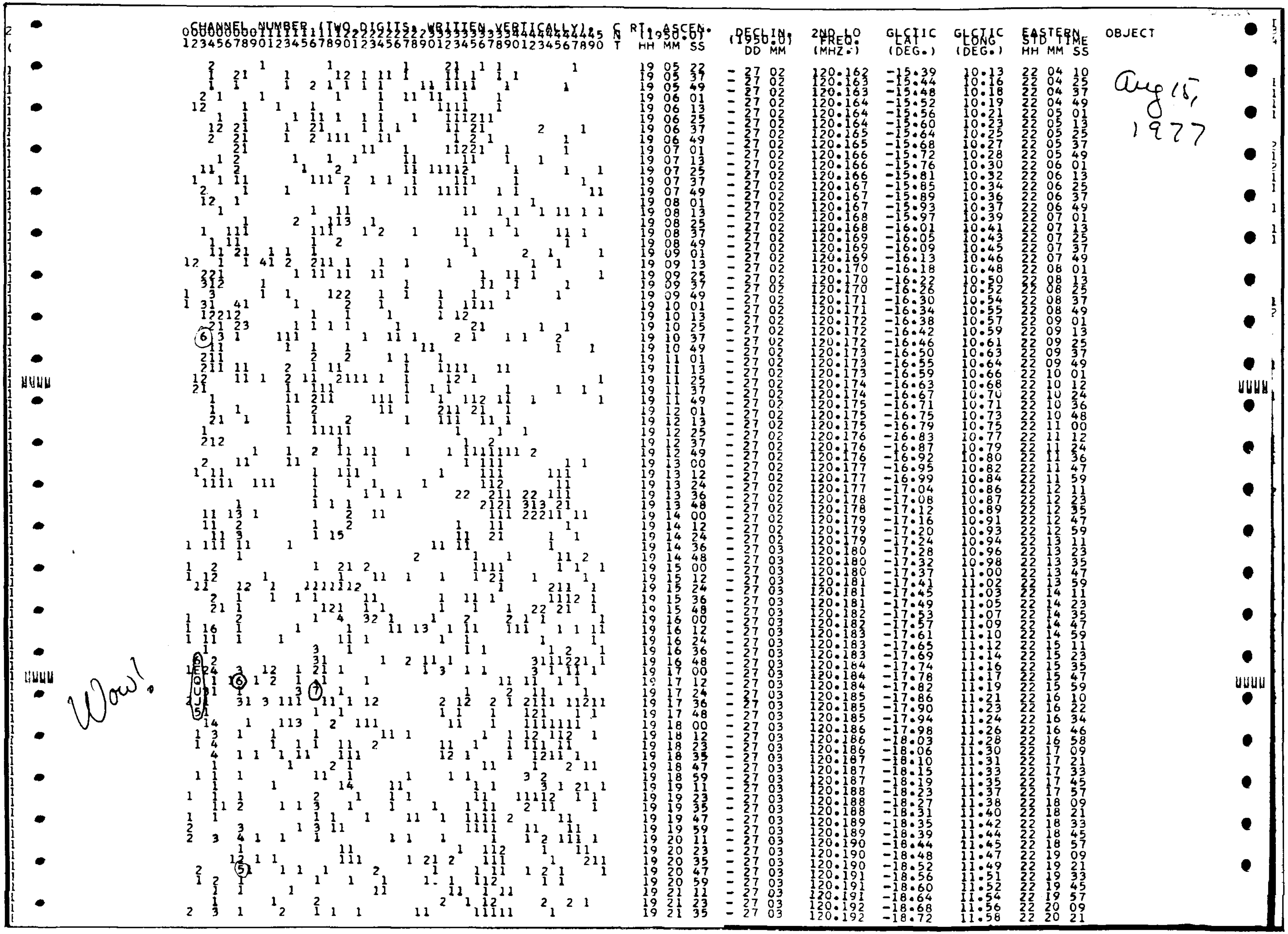
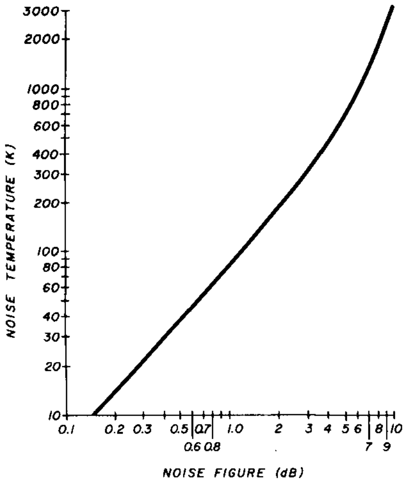


fig. 7. The famous "WOW" signal was received by the Ohio State Radio Observatory on August 15, 1977, at 22 hours 15 minutes and 35 seconds Eastern Standard Time. This signal is one of several mysterious signals received from outer space. Although it lasted only a minute, never to reappear, scientists are certain that the signal was of intelligent origin, and was issued from a source at least as distant as the moon. (*Courtesy of Ohio State University Radio Observatory.*)



$$T = 290\left[10^{\frac{NF}{10}} - 1\right]$$

$$NF = 10 \log\left(1 + \frac{T}{290}\right)$$

fig. 8. The logarithmic relationship between sky noise temperature expressed in degrees Kelvin and equivalent system noise figure expressed in decibels (dB).

mately ten million years — a rather impractical proposition for any mortal. We have to reduce the scope of our search, therefore, to match our time and technological limitations. Let's look at some of these limitations.

We can expect that in comparison with the natural RF sources previously discussed, intelligent signals transmitted from outer space would be of much lower power levels. Low power, in this case, could mean extraterrestrial transmitters of powers comparable to our strongest transmitters — one Gigawatt EIRP or more. Consequently, a terrestrial system intended for receiving these signals would have to operate against a quiet background so that its range would be limited only by its own noise figure, which should be no greater than the intergalactic noise level present at its antenna. See **fig. 8.**)

Although "intelligent" transmitters could be expected at almost any microwave frequency, radio astronomers have found a quiet range in the frequency spectrum that would be ideal for communication with civilizations attempting to communicate with us by radio. (This judgment is based upon our limited idea of what life is. It does not extend to other possibilities such as life forms based on elements other than carbon.)

Located between 1.4 GHz and 1.7 GHz, this area of the spectrum is the "water hole" frequency range. It exhibits a noise temperature of 6 to 8 degrees K (3 to 5 degrees K measured in space). This temperature would allow a 1-Gigawatt EIRP transmitter located approximately 26 light-years away to be heard with a modest backyard SETI radio telescope. (See **fig. 9.**)

The term "water hole" was suggested by the existence of two natural frequencies at each end of the band. Interest in persuing this concept was triggered in 1959 with the publication, in *Nature*, of a paper by Guiseppe Cocconi and Philip Morrison entitled "Searching for Interstellar Communications." Cocconi and Morrison pointed out the importance of radiation from hydrogen atoms reaching the Earth at an ideal spot on the frequency spectrum which coincides with the minimum background noise. At 1.42 GHz there is a natural radio beacon caused by interstellar hydrogen (H); another natural beacon exists at 1.66 GHz. This one is caused by hydroxyl (OH) ions traveling in space. When chemically combined on Earth, the two produce water (H_2O) — thus the terminology "water hole." Because hydrogen is the simplest, most abundant element in the universe, and because water is one

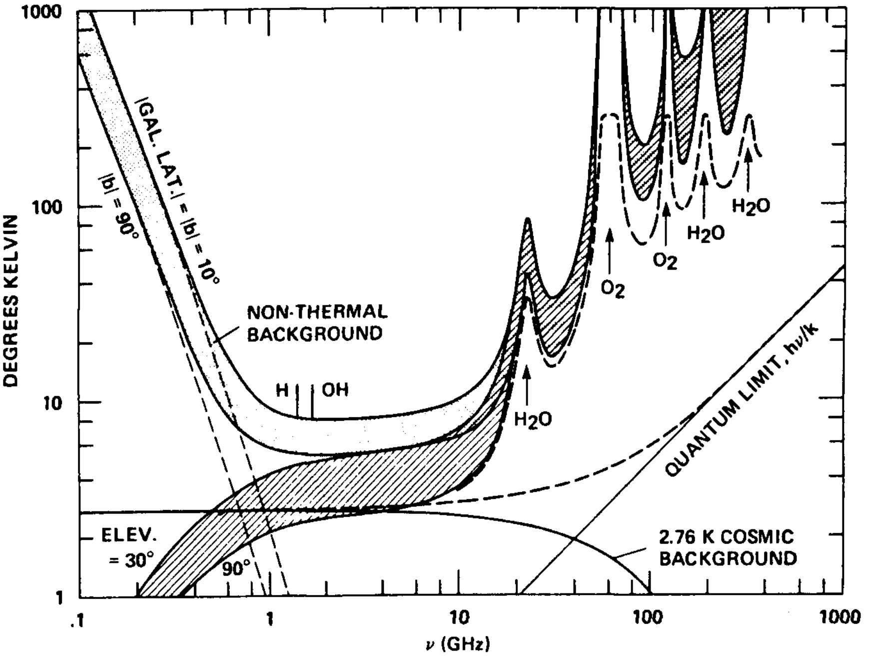


fig. 9. The "water hole" window provides the best overall noise performance for receiving intelligent transmissions from outer space. This frequency band has been suggested by astronomers as a possible radio meeting point for extraterrestrial civilizations which base their existence on water (see text).

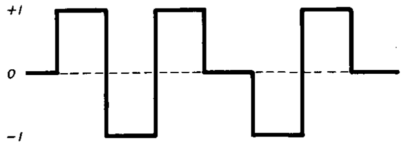


fig. 10. The concept of information obtained at the output of a circularly polarized, sense-switched receiver which is responding to a hypothetical binary circular polarization modulated signal and using a single frequency.

of the basic requirements of life as we know it, this frequency range has been favored by scientists as the "magic" band for interstellar communications. The concept of the water hole assumes two things: first, that all life in the universe is a function of water, and second, that any extraterrestrial civilization attempting to communicate with us would select this frequency band for the same reasons we did.

One important factor in receiving intelligent transmissions would be the signaling protocol and the rate of transmission used by the sending civilization and consequently the modulation scheme. If we may judge by our own experience, it is reasonable to assume that the sender would choose a simple two-state binary signaling scheme that could be modulated slowly (and therefore compatible with signal-to-noise bandwidth requirements) in one of four modulation schemes: amplitude, frequency, phase, and polarization.

A careful analysis of these modulation techniques indicates that the first three would be difficult to receive. If amplitude modulation were used, a binary "1" would be detected as the transmitter would be turned on. However, positive identification of the reverse state (i.e., 0) would be less probable because there would be no signal to reveal this information. While this method is acceptable in casual CW signaling, anti-cryptographic studies indicate that information would be lost if such a method were used (a true −1 state would be required for positive identification).

Two distinct binary states could be obtained with conventional frequency shift keying. However, the introduction of a new element — the second frequency — would make the search more difficult in view of the narrow bandwidths used. While phase modulation is a superior method for carrying data communication in that it requires only half the signal-to-noise ratio of the other modulation schemes for the same amount of information, it is thought to be the least likely to be used in searching for unknown signals.

The most likely method of radio communication that might be used by an extraterrestrial civilization is binary antenna polarization modulation using the same frequency. By properly changing between two orthogonal polarizations such as two perpendicular linear polarizations, or between left and right circular polarizations, the two binary states could be transmitted on the same frequency by switching the transmitter's output as shown in **fig. 10**. This in turn would allow for reversely polarized receiving antenna arrays on earth to receive the binary information and process it through two distinctive radio receivers as shown in **fig. 11** — or one receiver that would switch between two properly polarized antennas. Most searches for intelligent signals to date have been performed in the water hole frequency range using the latter method.

designing receivers

Over the past few years several methods have been suggested for receiving ETI signals. One technique — based on the "pulse" theory — stands a good chance of acceptance and is of interest to Amateurs because it requires simpler receiving equipment than other methods. This technique assumes the transmission of high power pulses of one second or longer in a digital binary format, as previously discussed. This concept makes sense because the average power available from a hypothetical extraterrestrial transmitter would probably be limited by thermal inefficiencies. (Although the topic is debatable, we assume that extraterrestrials would have technological problems similar to ours.) Much more peak power could be obtained from pulsed binary transmitters, which can overcome the noise figure limitations of target receivers and can be spread over relatively wider bandwidths so that complicated Doppler corrections would be minimized. Pulse receivers with ultimate bandwidths of up to 10 kHz have been used in the "magic" frequency range.

On the other hand, recent experiments favor the very narrow bandwidth/beamwidth beacon approach because of the superior signal-to-noise ratio obtainable. Using this concept, powerful beacons would be directed at the solar system chosen as an appropriate "target" by the sending civilization. The signal would be transmitted frequency-corrected so that it would be received on earth near the laboratory neutral hydrogen-line frequency (1.42 GHz/21 cm), thereby simplifying our search. The correction would include the source's Doppler shift and the frequency shift caused by the radial velocity of our sun, known by the sender from long-term astronomical observations of our solar system.

A terrestrial receiver would be equipped with multiple ultra-narrowband IF filters. The theoretical minimum bandwidth for interstellar communications has been recently calculated by Drake and Helou[2,3], who indicate that its limit is determined by the effects of the multipath scattering phenomenon resulting from turbulent ionized gases — the same effect that causes pulsar scintillation. Consequently, a pure carrier in the water hole will have a tendency to be wider at the arrival point than its originated bandwidth, say 0.01 Hz, after traveling 100 Parsecs (1 Parsec = 3.26 light-years). This can be important in the selection of bandwidth set as the limitation for practical filter design in SETI receivers.

Ultra-narrowband searches have been conducted at the Arecibo Observatory and at Harvard University by a ham radio operator, Professor Paul Horowitz, W1HFA. In 1978 Horowitz observed nearly 200 nearby stars similar to our sun at the 21-cm neutral hydrogen line wavelength by using the observatory's 305-meter dish (see **fig. 12**). The receiver (**figs. 13A, B,** and **C**) used a dual circular polarization feed which gave an effective antenna area of 22,000-m^2 (with 68-dB gain). The overall system temperature was 80 degrees K.

As shown in **fig. 13D** parametric amplifiers were used for the front end (new GaAs FET amplifiers have since

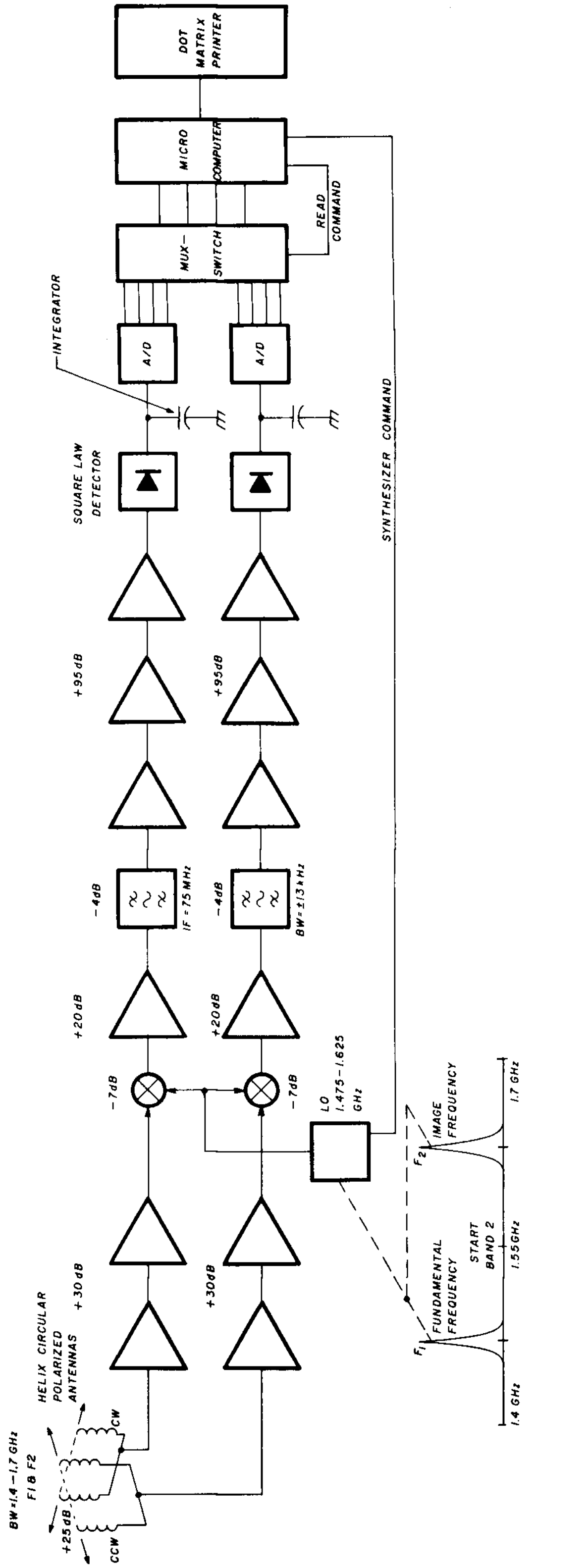


fig. 11. Block diagram of the author's SETI receiver, under construction. The system assumes circular polarization modulation (clockwise and counterclockwise). Dual diversity is achieved through the strategic choice of the 75-MHz IF, which allows image recovery in both modulation senses. Consequently, the entire 300-MHz water hole frequency band can be viewed in half the time it would otherwise take. Final selectivity is achieved with two crystal filters (4171-F monolithic from Piezo Technology) at 75 MHz. The bandwidth is ±13 kHz. The signal-to-noise problem introduced by the image recovery technique can be compensated for through longer integration time. The preamplifiers have a calculated noise figure of 0.4 dB (NEC NE 71083 and NEC 72084).

been installed) along with a dual conversion scheme having a first IF at 260 MHz and a second IF at 30 MHz. Crystal filters with bandwidths of 5 kHz were present in the second IF, followed by IF amplifiers. The final conversion to the sine and cosine basebands was achieved with a 30-MHz third oscillator. All local oscillators in the system were synthesized with a final resolution of 0.01 Hz and a short-term stability of $\Delta f/f = 5 \times 10^{-12}$ provided by a rubidium-referenced clock.

The quadrature baseband signals were then filtered by four-pole Butterworth low-pass tunable filters which were sampled under computer control with an analog multiplexer and 12-bit analog-to-digital converters. A single observation consisted of 64-K (65,536) complex samples at 1 millisecond intervals from each of two polarizations. The samples were digitized and recorded in real time onto nine-track digital magnetic tape for follow-up processing, which included a fast Fourier transform (FFT) on the quadrature signals.* A complete 64-K complex FFT and computation of power spectrum with the instantaneous resolution of 0.015-Hz per bin (compatible with minimum theoretical bandwidth discussed earlier) took about 15 seconds.

In the observations, it was assumed that a true celestial signal would have already been frequency-compensated for Doppler by the originating civilization. This included the sender's own velocity and the radial velocity of our solar system as observed by the sender, but not the residual Doppler resulting from the Earth's own rotation (not known to sender), which can shift such a signal through another 0.15 Hz of bandwidth at 1.5 GHz. This correction was implemented in the receiver's synthesized local oscillators (first LO and third LO) which were swept via real-time computer control — that is, the local oscillator was updated several thousand times during each observation. The synthesizer control mechanism set the first LO frequency at the beginning of each observation so that the third LO began at 30 MHz; the third LO was then updated at 20-millisecond intervals by computing frequency offsets in real time according to a polynomial algorithm which approximated the Earth's velocity according to data obtained from the Lincoln Laboratory planetary ephemeris.

One positive side effect resulting from this frequency sweeping through the ultranarrow bandwidths of the receiver was that earth-generated interference (which is generally not frequency swept) is completely rejected by the system. This was confirmed throughout the search by the absence of false alarms.

The Arecibo experiments revealed no evidence of ETI: Today the search

*FFT is usually used to break down complex waves.

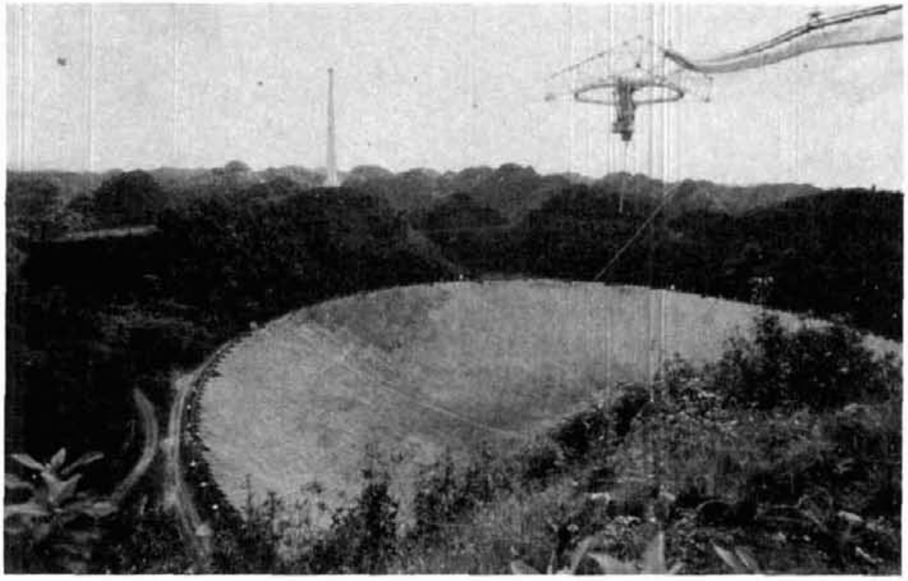


fig. 12A. Overview of the Arecibo Observatory, where in 1978, Paul Horowitz, W1HFA, observed nearly 200 nearby stars similar to our own sun at the 21-cm neutral hydrogen line wavelength. (*Photo courtesy of College of St. Thomas, St. Paul, Minnesota.*)

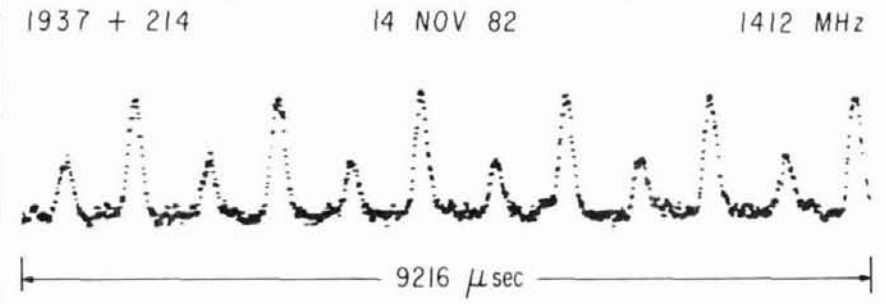


fig. 12B. Pulsar profile PSR 1937+214, discovered at Arecibo in 1982, measures only 3 miles across but releases 10 to 100 million times the energy of the Sun. Rotating around its gravitational axis at 642 revolutions per second, it pulses at 1.558-millisecond intervals; each pulse consists of two signal peaks or flashes of radio energy streaming out from its magnetic poles. Pulsars were first thought to be of intelligent origin because of their precise repetition rate. At Cambridge University in 1967, a signal was recorded at 1.33730-second intervals. Code-named *LGM* — "Little Green Men" — it was later proved to be the first known pulsating neutron star, or pulsar. (*Courtesy of Arecibo Observatory, part of the National Astronomy and Ionospheric Center operated by Cornell University under contract with the National Science Foundation.*)

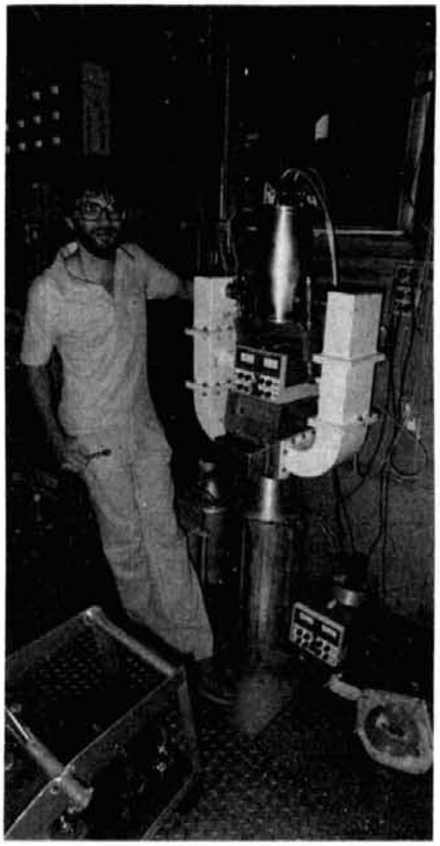


fig. 13A. Inside the carriage house of the Arecibo Observatory — suspended above the 1000-foot dish — engineer Bob Zimmerman, NP4B, proudly displays the new dual-channel 18-cm receiver front end (left and right circular polarizations). (*Photo courtesy of Arecibo Observatory.*)

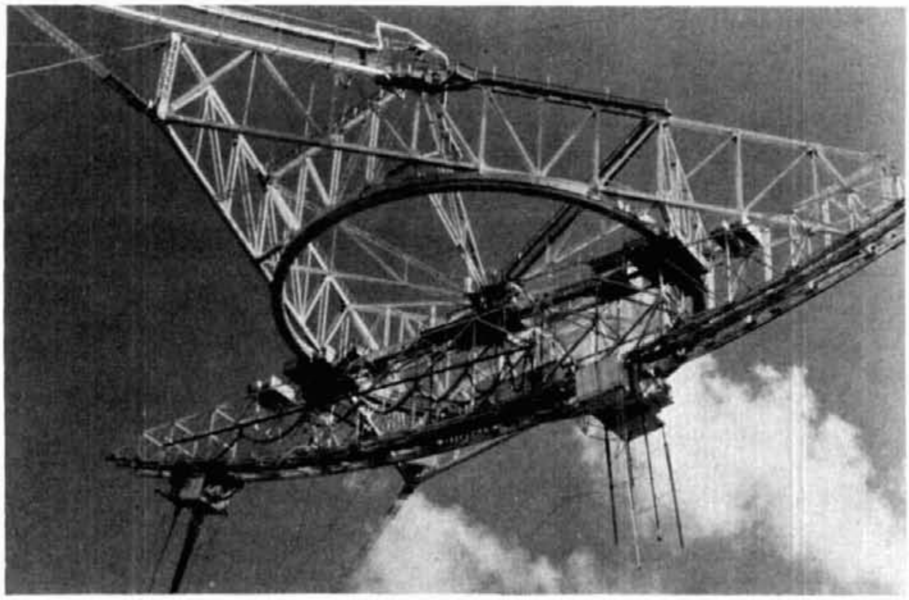


fig. 13B. The antenna feed passes through the floor of the carriage house and is focused in the dish, 430 feet (131.06 meters) below. The temperature inside the metal dome is held at 80 degrees Kelvin with liquid nitrogen in order to reduce the noise temperature of the front end. (*Photo courtesy of College of St. Thomas, St. Paul, Minnesota.*)

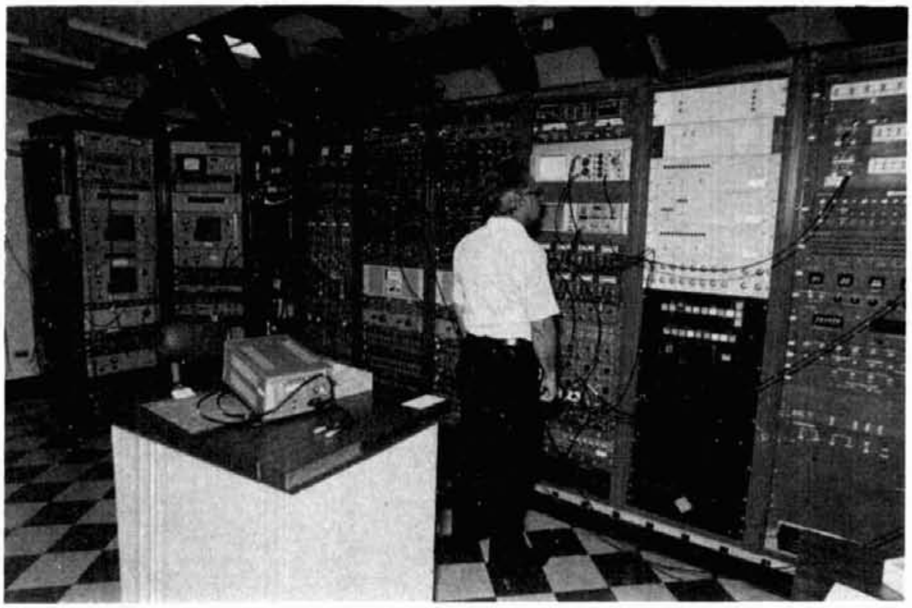


fig. 13C. The receiver room at Arecibo Observatory. The equipment contains oscillators, HP synthesizers, Rubidium standards, detectors, amplifiers, A/D converters — just about any electronic device needed by an astrophysicist. About 200 hours per year are dedicated to SETI. Searches have been made of approximately 1000 nearby stars at the Water Hole frequency. (*Photo courtesy of Arecibo Observatory.*)

continues with a special receiver in operation at the Planetary Society/SAI/Harvard project "Sentinel" as shown in **fig. 14**. This system matches the natural minimum bandwidth discussed earlier by also resolving the input bandwidth into 64K (65,536) complex frequency bins of 0.03 Hz each. The 84-foot radiotelescope is equipped with two dual-circularly polarized feedhorns (5 bands) connected to two receivers. The front end consists of two identical 35-dB gain, 55 degrees K (uncooled), 10 degrees K (cooled) GaAs FET preamplifiers operating in the waterhole frequency band. (Other frequencies can be tuned.)

The receiver uses a conventional single conversion scheme with an IF of 30 MHz. Image rejection mixers, broadband IF amplifiers and filters are used in conjunction with a computer-controlled synthesizer. The 30 MHz IF signals are then sent to the back end of the receiver, located in the control building via low-loss rigid coaxial cables. As in the case of Arecibo, the back end is responsible for sweeping through the 30 MHz IF to compensate for the Doppler shift caused by the Earth's rotation. The result is a quadrature baseband combination of signals which is further filtered through 6-pole low-pass anti-aliasing filters. The control computer updates the LO 40 times per second based on an ephemeris table calculated at the beginning of each run. Sample-and-hold amplifiers and 8-bit analog-to-digital (A/D) converters are used to feed the FFT processors via interrupt-driven parallel ports.

Although the Harvard installation surpasses, by at least an order of magnitude, the combined efforts of all previous SETI (in terms of system sensitivity, the number of sky positions observed, and the number of concurrent channels), scientists feel that the search should be expanded in frequency by a factor of at least 100.

This would mean increasing the present 64-K channels used in each of two polarizations to about 8.4 million channels of 0.05-Hz resolution, thus increasing the probability of intercept (POI) by a factor of 100. Consequently, the instantaneous bandwidth would increase from the present 2 kHz to 420 kHz. Although this would be quite an improvement, it would still be insufficient to cover the 300-MHz bandwidth of the water hole at once. An all-sky water hole search with the new receiver would still require 1200 instantaneous bandwidths of 420 kHz times the number of sky locations.

Because no receiving system can cover the entire sky at all frequencies at once, much more work remains to be done in SETI, and while omnidirectional wideband pulses have been suggested as a SETI method, the narrowband beacon concept gives superior S/N ratios not achievable otherwise. On the other hand, Doppler corrections associated with the beacon approach, which would require hard-to-design high-resolution microwave synthesizers, make the pulse concept attractive at least for the Radio Amateur. New methods of observing many RF sources simultaneously using Bragg-Cell technology have been suggested. However, the relatively wide channel bandwidth produced by today's Bragg technology, combined with the low receiver dynamic range, limits the applicability of this technology.

We have looked at several radio astronomy systems, from a simple radiometer to the ultra-narrowband receivers used by professional radio astronomers. Although this article is not intended as a construction paper (ample details are provided in the references), some elements of design should be considered before a system approach is chosen. The block diagram shown in **fig. 15** shows an economical approach to designing an Amateur Radio astronomy center operating in the water hole frequency band. It could be used as a wideband radiometer, an interferometer, or as a tunable narrowband receiver intended for the reception of pulses if care is taken in providing short-term stability for the local oscillators along with narrowband filtering in a third conversion.

This system would consist of a two-stage GaAs FET preamplifier with a low noise figure. Several designs have been recently published in the literature. The expected gain from such amplifiers is typically in the 30 dB range or better. This would be sufficient to overcome the high noise figure of the following mixer (7 dB). Recent designs using the Mitsubishi MGF 1412-11-09 and MGF-1412-11-10 GaAs FET transistors claim noise figures of about 0.5 dB (35 degrees K). Older designs pro-

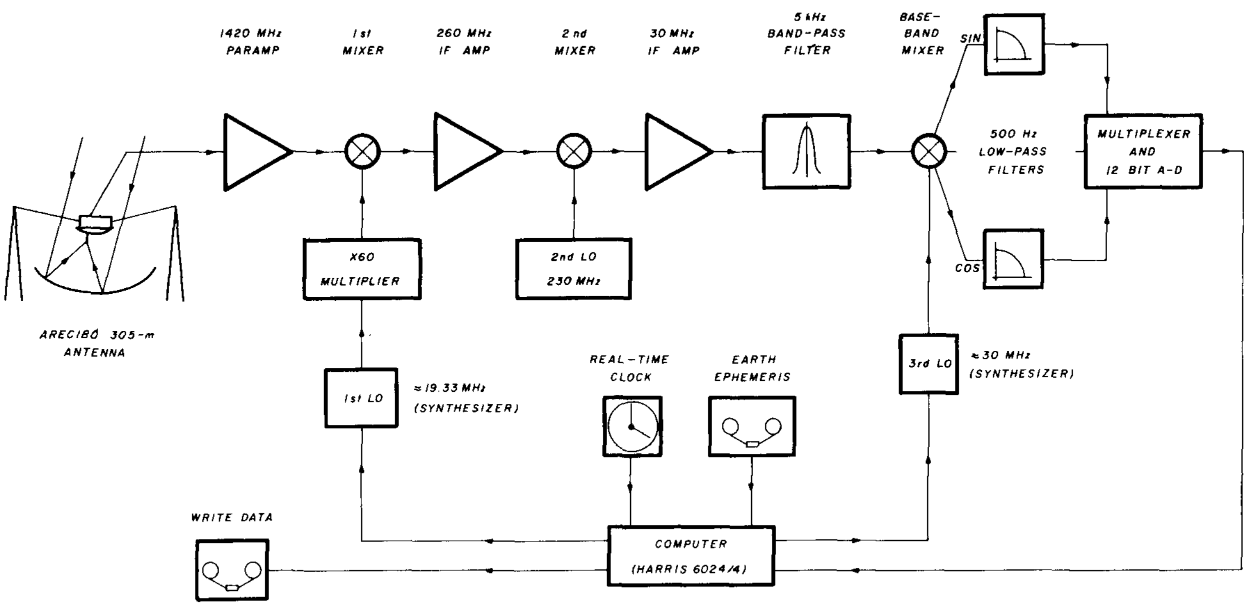


fig. 13D. Block diagram of the Arecibo system as used for SETI in 1978 by Professor Paul Horowitz (W1HFA). Frequency sweeping of the local oscillators was used to compensate for Doppler shifts caused by the earth's rotation. (See text).

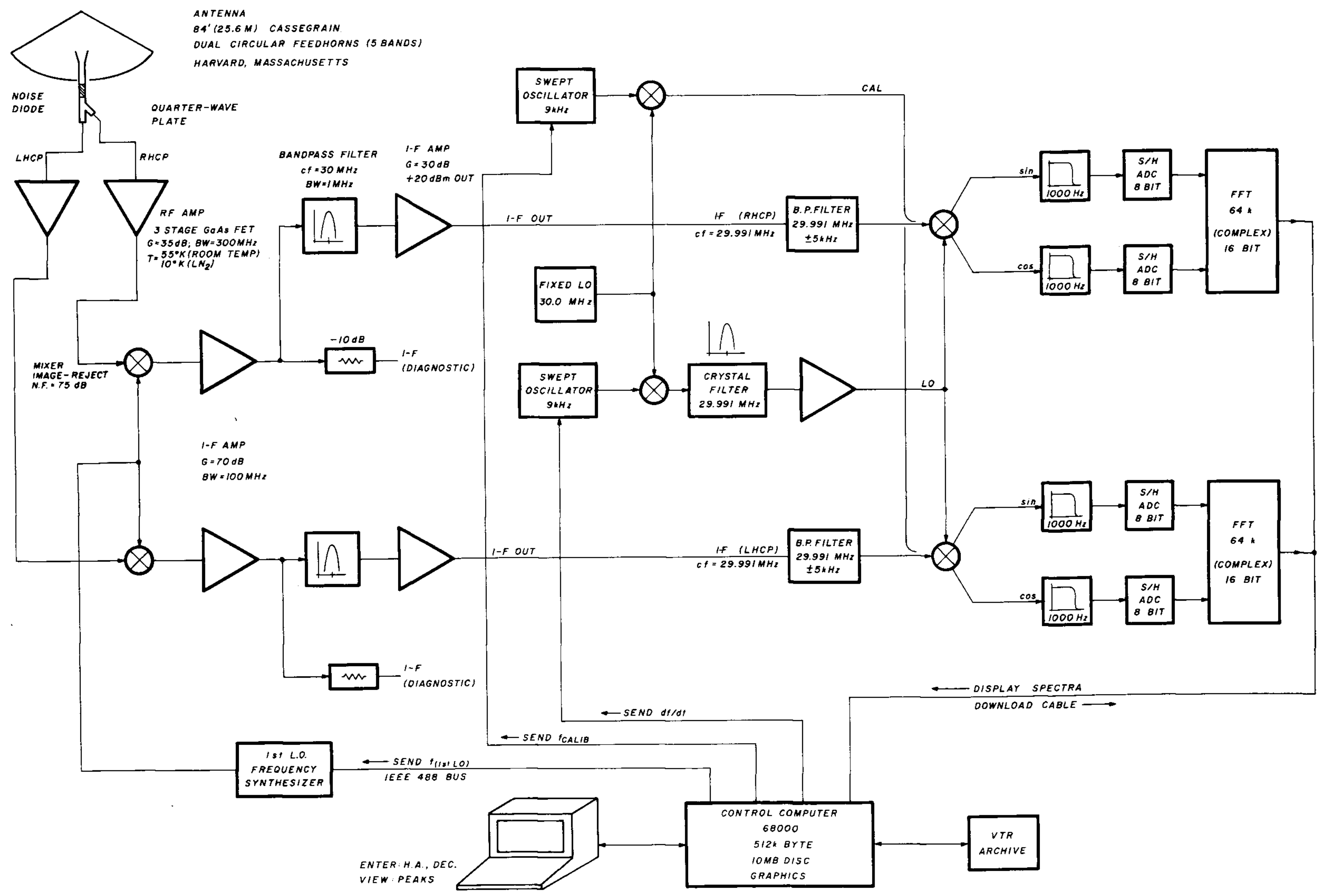
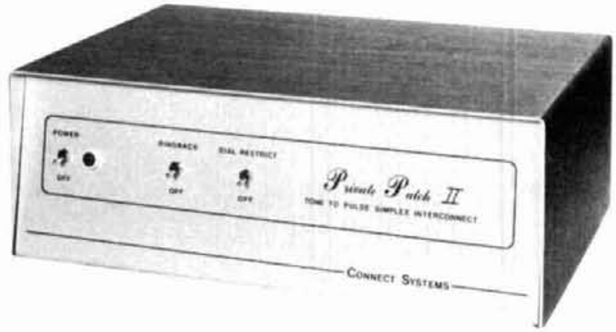


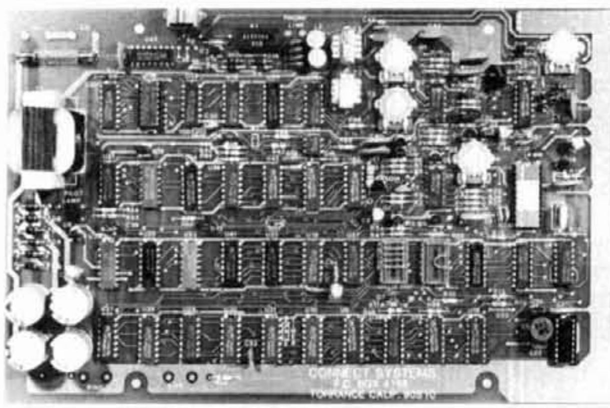
fig. 14. Block diagram of the Ultra-Narrowband SETI receiver used at Harvard University. The system uses an 84-foot (25.6 meter) equatorial radiotelescope with a single conversion dual polarization receiver intended for processing left and right circular polarizations at the same time. (*Courtesy of Harvard University Physics Department.*)

WITH **PRIVATE PATCH II** YOU SPEND YOUR TIME COMMUNICATING . . . <u>**NOT**</u> *WAITING TO TAKE CONTROL*

PRIVATE PATCH II allows communications to proceed back and forth as rapidly as on a telephone. There is ***no waiting for sampling circuits to acquire each time the mobile transmits.***



THE SMARTER AUTOPATCH



AEROSPACE LEVEL QUALITY

The **PRIVATE PATCH II VOX system offers a substantial improvement over sampling autopatches in time spent** *waiting for control!*

EXAMPLE: Suppose you made 10 phone calls — 9 completed, 1 busy — assume the completed calls average 20 talk exchanges each, 180 total.

You would spend 360 seconds (6 minutes!) *waiting for control* if you were using a sampling patch that samples every two seconds (180 waits × 2 seconds = 360 seconds). **It is a *severe inconvenience to have to press the button for a seeming eternity before you can be heard on each and every mobile reply.***

With **PRIVATE PATCH II** there is **no lost time waiting for control on all 9 completed calls.** However, the busy call would cause a 15 second wait for the control interrupt timer to return control to the mobile.

SUMMARY

	CONTROL WAITS	TIME WAITED
Private Patch II	1	15 seconds
Sampling	180	6 minutes

If the sampling patch has a circuit that ***"slows the sample rate when telephone audio is present,"*** the speed of acquisition is made even slower. The wait time increases, and the phone party can say perhaps 25 or more words before they can be cut off.

WHY LAND MOBILE PROFESSIONALS **AVOID** SAMPLING PATCHES . . .

The majority of radios on the market (especially synthesized and relay switched types) **do not T/R quickly enough to give acceptable results.** Often engineering level modifications are required to improve T/R response time.

The slower the T/R response time, the longer the sample must last. And of course no telephone audio is heard during the sample. ***Just noise.*** The result is ***lost words and syllables*** which are proportional to T/R response.

Acquiring and maintaining control (in order to communicate) becomes erratic when the mobile is less than full quieting. This causes *a severe loss of range.*

The base station radio can not be equipped with a linear amplifier, and operation through repeaters (that have hangtime) is not possible with a noise sampled patch.

VOX autopatches overcome each of these shortcomings. In fact, nearly all simplex patches sold in commercial service are the VOX type.

Could these be some of the reasons that the competition refers to their VOX patch as **"our favorite commercial simplex patch"**?

FORGET AMATEUR GRADE SAMPLING AND STEP UP TO A COMMERCIAL GRADE PATCH. PRIVATE PATCH II!

FEATURES

• CW ID (free ID chip) • Selectable tone or pulse dialing • User programmable toll restrict • Five digit access code • Ringback (reverse patch) • Busy channel ringback inhibit (will not transmit on top of someone) • Three/six minute "time-out" timer is resettable from the mobile • Modular phone jack and seven foot cord • Available in 12 VDC or 115 VAC version

ALSO

✓ 14 day return privilege — when ordered factory direct.
✓ One year warranty — compare to their six months.

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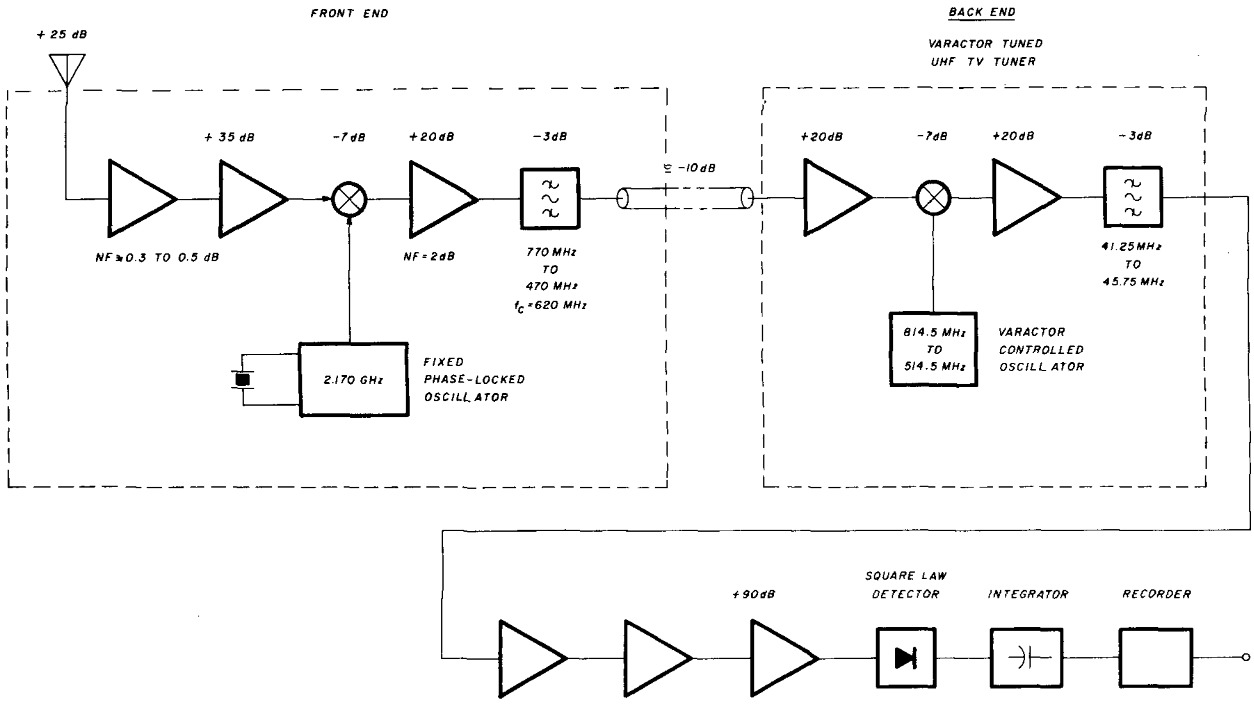


fig. 15. Block diagram of an economical amateur radio astronomy receiver.

vide noise figures in the 0.8 dB (58 degrees K) range with about the same gain. Stripline approaches on G-10 material or open frame designs have been extensively covered in the reference material at the end of this article along with simple rat-race mixers intended for 1.296 GHz or 2.3 GHz. (Mixers can also be purchased from a variety of manufacturers.)

Our receiver would use the first mixer in conjunction with a fixed phased-locked loop or multiple chain synthesizer at 2.170 GHz. (Such designs are popular in satellite converters and other devices.) The first IF would be purposely chosen to fall in the UHF range where an inexpensive varactor-type TV-tuner could be used as a second tunable IF over the entire water hole frequency of 300 MHz. The part investigated was a Mitsumi UES-A 56F, which is marketed by several companies, including Radio Shack. This tunable converter exhibited a total noise figure of about 6 dB and 15 dB of gain, with an acceptable short-term stability at room temperature compatible with an ultimate bandwidth of 10 kHz (care should be exercised to provide isolation of this unit from the front end because harmonics of local oscillator fall in the input range of the receiver).The tests were performed with a precision power supply having a range of 0 to 28 volts. If only a radiometer is contemplated, the phase-locked first LO is not mandatory and the control voltage applied to the second converter should be chosen about halfway on the voltage curve and should be double regulated.

The UHF converter provides a TV-compatible IF, centered at 44.5 MHz, with a bandwidth of 6.5 MHz. This output could be used directly with a modified high-gain TV-IF with the

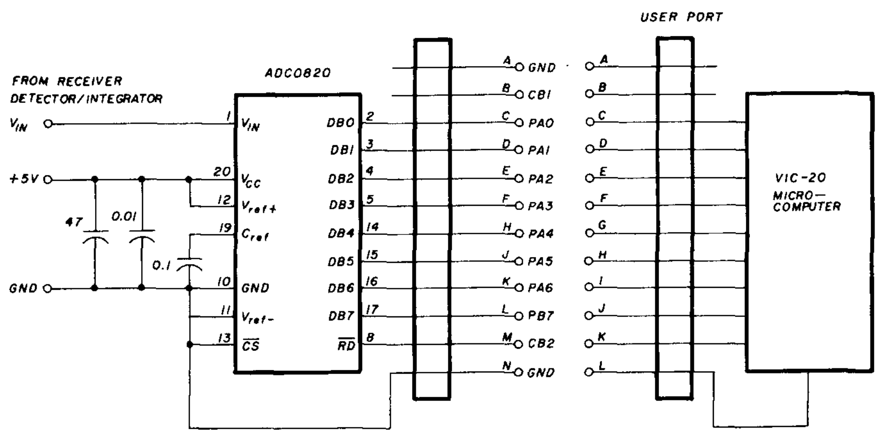


fig. 16. Schematic diagram of a simple A/D interface for a radio telescope. No additional parts are needed to perform consecutive readings; the information can be printed out as relative flux data by a dot-matrix printer directly from the microcomputer.

the candidate stars:

which stars might support life?

Although our knowledge is limited, it appears that the universe is expanding — that is, the galaxies are moving apart from each other. This movement suggests a "time of beginning" in a cycle (known as the "big bang" event) that began with an explosive fireball of matter inside a huge black hole with no conceivable limits some fifteen billion years ago.

Certain stars of various sizes evolved from the cold gas of a previous cycle; these are now in their "main sequence," but approaching a "finale" as shown in **fig. A**. Depending on their mass and temperatures, they are classified by letters, with the hottest designated by the letter O, and followed in descending order by other spectral types such as B, A, F, G, K, and M. In the search for extraterrestrial intelligence only type F, G, and K stars are of interest to us because they are the right size and temperature for supporting life on planets similar to our own. (Our sun is a type G2 yellow star.) With some three hundred billion stars in the Milky Way galaxy alone — and ten billion other galaxies in the known universe — we can identify approximately one million nearby candidate stars (within 1000 light-years) of spectral type F, G, or K that could conceivably support life. Despite the magnitude of this number, only a handful of stars (see **table 1**) are within the Amateur's technological reach. Of this handful, the nearest are in Alpha Centauri. Located some 4.3 light-years away, Alpha Centauri is a triple system containing two massive suns (Type G4 and Type K1) separated by some 20 astronomical units (1 A.U. equals the mean distance of the Earth from the sun) and revolving around each other along with a smaller third star, Alpha Centauri C (a type M star). Recent investigations indicate that this system may be much younger than ours, suggesting that advanced forms of life would probably not have developed even if a planetary system did exist within its complex rotational setup. Other theories, however, might explain a heightened probability of life on Alpha Centauri as shown in **fig. B**.

Of approximately 40 stars located not more than 16.7 light-years from Earth, only two — Epsilon Eridani (type K2) and Tau Ceti (type G4) — have been identified as meeting the conditions necessary for the existence of advanced forms of life. Similar to our sun but somewhat smaller, Epsilon Eridani is located 10.5 light-years away in the constellation Eridanus. Tau Ceti is located approximately 10.8 light-years away in the constellation of the Whale. Rather dim compared to our sun, it is visible from Earth's northern hemisphere only during the winter months. These two stars were among the first to be observed by Frank Drake and his team at the National Radio Astronomy Observatory (NRAO) in Green Bank, West Virginia, in 1960 under the project name *Ozma*, a name borrowed from the Wizard of Oz. No evidence of extraterrestrial intelligence has been observed to date.

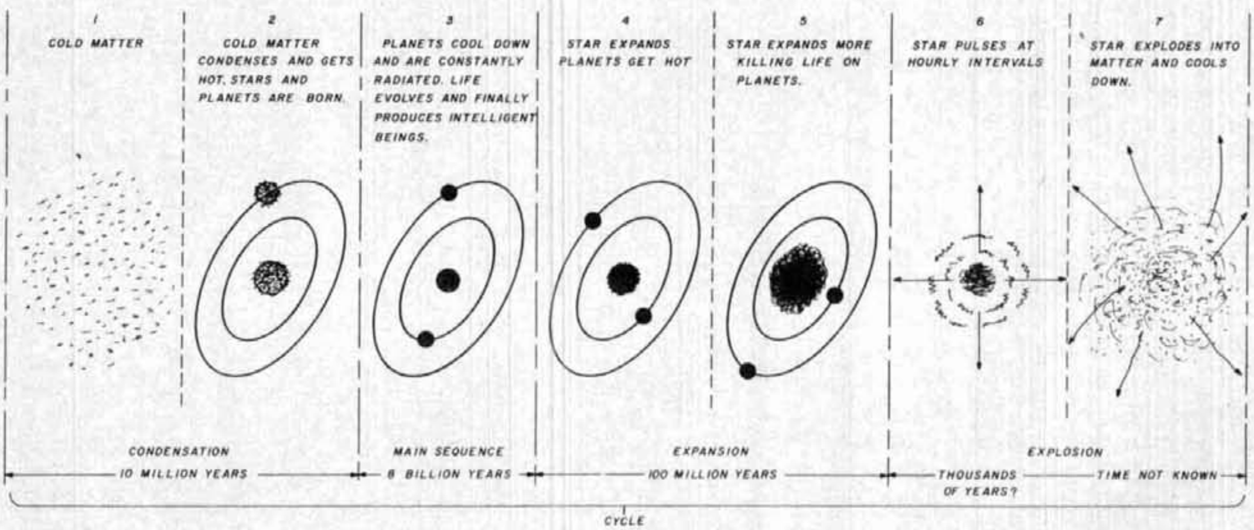


fig. A. One concept of star evolution suggests that the possibility of life on planets revolving around a type G yellow star occurs during its "main sequence". This type of star is similar to our own sun. A "lucky" planet similar to Earth would need approximately four billion years of continuous energy flow from this star to allow the random process of mutation on elements to produce the complexity of the human brain, which has made possible the development of communication technologies.

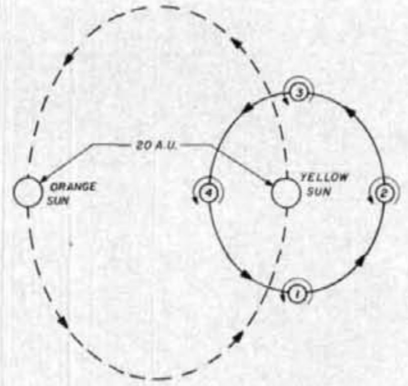


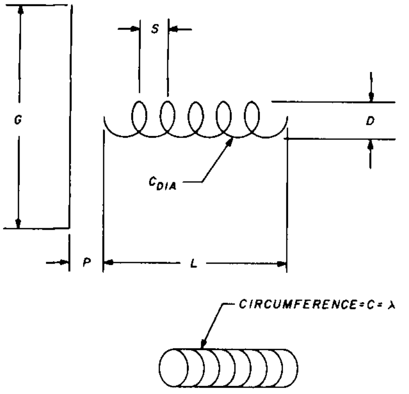
***fig. B.* The concept of two suns — one yellow (Alpha Centauri A, type G) and the other orange (Alpha Centauri B, type K) — rotating around each other in the triple star system Alpha Centauri, located some 4.3 light-years away. If an *earth-like planet were to exist at the* same distance from the yellow star as the earth is from the sun, it is conceivable that the complex rotational relationship would allow for long alternating yellow and orange days — with no *nights — which may accelerate the* development of life on this relatively young system.**

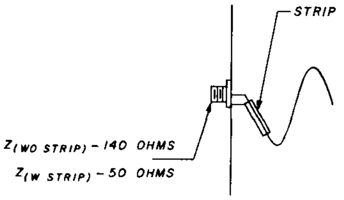
One of the more recent additions to the list of "interesting" stars is Vega, located 26 light-years away from Earth in the constellation Lyre (Lyra). Vega is the third brightest star in the sky. Although twice the size of the sun, its surface temperature has been measured and found to be almost the same. A relatively young star — at only one billion years old — Vega is important to us because of the discovery, in 1983, of a possible planetary system around it by the infrared astronomical satellite (IRAS). According to astronomers, while the infrared telescope aboard IRAS was sensitive enough to detect a mass rotating around Vega equivalent to the combined mass of all nine planets in our solar system, it could not resolve the objects precisely enough to distinguish among them. Nonetheless, this is one of the most compelling pieces of data suggesting that we may have another planetary system in the universe. (This theory is now being challenged by another interpretation; some investigators view the phenomenon as a belt of dust consisting of "pellets" that reradiate the star's infrared energy.)

table 1. Stars within 26 light-years which could have habitable planets (adapted from Stephen H. Dole, 1964.)

name of star	spectral class	approximate distance (light years)
Alpha Centauri A	G4	4.3
Alpha Centauri B	K1	4.3
Alpha Centauri C	M1	4.3
Lal 21185 (A)	M1	8.2
ϵ Eridani	K2	10.8
61 Cygni A	K5	11.1
61 Cygni B	K8	11.1
ϵ Indi	K5	11.3
Grm 34 A	M2	11.7
Lac 9352	M1	12.0
τ Ceti	G8	12.2
Lac 8760	M0	12.6
Cin 3161	M3	14.9
Grm 1618	K8	14.9
CC 1290	M3	15.4
Cin 18,2354	M3	16.1
+15° 2620	M1	16.9
70 Ophiuchi A	K1	17.3
70 Ophiuchi B	K5	17.3
η Cassiopeiae A	F9	18.0
η Cassiopeiae B	K6	18.0
σ Draconis	G9	18.2
36 Ophiuchi A	K2	18.2
36 Ophiuchi B	K1	18.2
36 Ophiuchi C	K6	18.2
HR 7703 A	K2	18.6
HR 5568 A	K4	18.8
HR 5568 B	M0	18.8
δ Pavonis	G7	19.2
−21° 1377	M0	19.2
+44° 2051 A	M0	19.2
+4° 4048 (A)	M3	19.4
HD 36395	M1	20.0
+1° 4774	M2	20.2
+53° 1320	K7	20.2
+53° 1321	K9	20.2
−45° 13677	M0	20.6
82 Eridani	G5	20.9
β Hydri	G1	21.3
HR 8832	K3	21.4
+15° 4733	M2	21.8
ρ Eridani A	K2	22.0
ρ Eridani B	K2	22.0
HR 753 A	K3	22.0
Vega	G4	26.0

sound trap removed or with a homebrewed IF of a lower noise figure. Full rectification could be implemented for detection in conjunction with simple integrators and DC amplifiers. Fast Fourier transforms (FFT) could also be implemented by using inexpensive microcomputers. The receiver's output transducer could be one of the newer A/D converters — such as National's ADC0820 — connected to a microcomputer and a dot matrix printer. This converter eliminates the extra circuitry normally associated with interfacing A/Ds to microcomputers as shown in **fig. 16.** It was specifically designed to appear as memory locations or I/O ports to a standard microprocessor, with no other logic needed. In addition, the converter's input acquisition time is much faster than its conversion time, lending its use to measuring many analog signals upon software commands without the aid of additional sample-and-hold devices. The resolution is 8 bits, with a





$C_{DIA} = 0.017\lambda$	*conductor diameter*
$D = \frac{\lambda}{3}$ OD	*loop diameter*
$G \geq 0.8\lambda$	*ground plane*
$N \geq 3$	*N = 9 for 14.8 dB* *N = 12 for 16 dB*
$S = \frac{\lambda}{4}$	*space between turns*
$\lambda_{(IN)} = \frac{11{,}810}{f(MHz)}$	*wavelength free space*
$P = 0.12\lambda$	*space from reflector to first turn**

**observe impedance matching stub*

(A) Theoretical formula for designing a helical antenna.

F_{RANGE} = 1400 MHz to 1700 MHz
BW = 300 MHz
C_f = 1550 MHz
if $C = \lambda$

$$BW \text{ is } \left| \; \underset{-20\% \quad C_f \quad +30\%}{1550 \text{ MHz}} \; \right|$$

ANTENNA BANDWIDTH 3 dB POINTS (C_f = 1550 MHz) IS:
BW 1240 MHz to 1860 MHz

$$\lambda = \frac{11{,}810}{1550} = 7.6193 \text{ INCH}$$

$$C_{DIA} = 0.017\lambda = 7.619 \times 0.017 = 0.1295 \text{ inch}$$

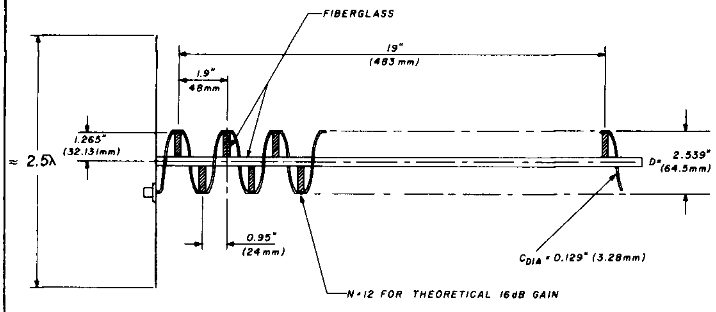
$$D = \frac{\lambda}{3} = \frac{7.6193}{3} = 2.539 \text{ inch}$$

$$G \geq 0.8\lambda \geq 0.8 \times 7.6193 \geq 6.09544 \text{ inch}$$

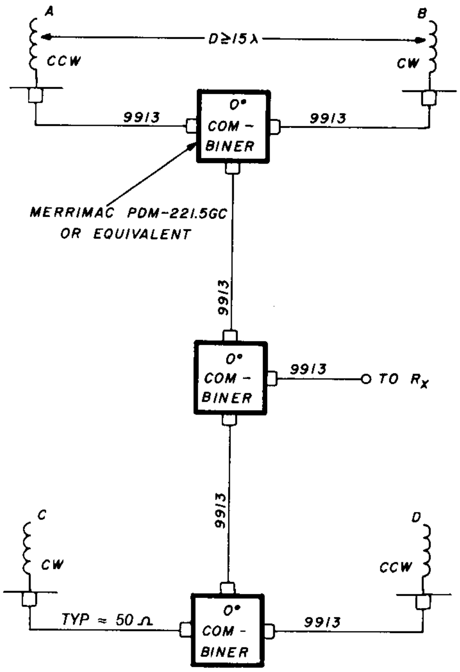
$$P = 0.12\lambda = 0.12 \times 7.6193 = 0.9143 \text{ inch}$$

$$S = \frac{\lambda}{4} = \frac{7.6193}{4} = 1.90 \text{ inch}$$

(B) Actual design of a helical antenna for the water hole frequency band.



(C) Construction details.



summary of polarization combinations

A + B → Horizontal
A + C → Vertical
A + D → Clockwise
B + C → Counterclockwise
A + B + C + D → Linear

(D) An array of four helical antennas can be arranged to provide narrow beam width and many different polarization patterns. Additional LNA's can be introduced in each of the antenna legs to overcome the noise figure of the combiners.

fig. 17. Design of a helical antenna system for the water hole frequency range.

maximum conversion time of 1.2 microseconds, an ideal application for a radio astronomy center. The ADC0820 chip was tested with the VIC-20 microcomputer, but would be equally applicable to any microcomputer having a latched data bus. With the proper software, the output of the computer can be printed out at equal time intervals in relative flux units on a scale of 0 to 5 volts (or 0 to 9 volts with a modified reference).

what antenna to use

The best antenna for radio astronomy is still the parabolic dish, as proven by most professional radio astronomy centers. Some Amateurs are reportedly using computer-controlled steerable dishes as large as 60 feet in diameter. But unless Amateurs have access to large backyards and friendly neighbors, they cannot proceed to construct such large arrays. Reasonable gains, however, can be obtained with arrays of axial mode helix antennas. The helix is attractive at 1.5 GHz mainly because of its relatively small size. The design shown in **figs. 17A, B**, and **C** indicates that the length of a helical beam at this frequency would be about 19 inches with a 2.5-inch diameter and a minimum reflector size of only 0.8 wavelength. This would make an inconspicuous installation. Although the helical antenna is not known for its gain, it has been used extensively by professional radio astronomers. A nine-turn helix antenna can provide about 14.8 dB, and a twelve-turn helix, about 16 dB of gain.

Helix antennas have also been used in more moderate arrays with gains in excess of 25 dB. Depending on which way they are wound in regard to each other, several polarization schemes can be accomplished. For example, using a pair of helices with the same sense (both clockwise or vice-versa) can provide circular polarization. Using opposed windings allows for horizontal polarization. A four-antenna array with clockwise and counterclockwise components can be interconnected so that several choices of polarizations could be obtained, as shown in **fig. 17D**. In addition, beamwidths of 10 to 15 degrees have been achieved.

The main characteristic of the helix antenna is its relatively wide bandwidth (-20 percent and $+30$ percent of the center frequency), which makes it suitable for the water hole band. Unless terminated with a matching strip or at a special point on the back plane, a helix exhibits a high impedance output of about 140 ohms. Inasmuch as this could be a disadvantage in a single-antenna design, parallel arrays using high-impedance coaxial cables can produce composite outputs of 75 ohms without the use of RF combiners.

On the other hand, a helix antenna can exhibit a much higher noise figure than the parabolic dish. Because the noise temperature of an antenna is determined by the noise power available in its lobes (this includes its minor lobes), if the antenna is "looking" at the ground — which has a typical noise temperature of 290 degrees K (17 degrees C) — it will have a noise figure of approximately 3 dB, which would be much higher than that of a preamplifier. In this respect the parabolic antenna would be better (lower side lobes). Careful consideration for the location of helical array is recommended; the choice of polarization, explained earlier, can also greatly improve the system. Fourier transforms performed with simple microcomputers will also help in separating the desired components from the noise in these lobes.

conclusion

Although it may be difficult for Radio Amateurs to accept the seemingly impractical nature of radio astronomy projects, the experience gained in developing one's own system could provide a complete education in contemporary radio communication.

Detailed information on the construction of radio astronomy and SETI projects, including low-noise amplifiers, and fast Fourier transform (FFT) programs for simple microcomputers can be obtained from The Society of Amateur Radio Astronomers (SARA) which publishes several books on the subject along with a monthly newsletter. At present, The Society has 168 members worldwide, many of whom are hams as well as scientists and engineers working in related fields. For more information, write to Robert M. Sickels, Secretary, SARA, 7605 Deland Avenue, Fort Pierce, Florida 33451.

There are many arguments about the existence of extraterrestrial intelligence. Some scientists believe that intelligent life exists elsewhere in the universe, while others mathematically analyze the probabilities and conclude that we could very well be the only advanced civilization in our galaxy. While this is a discouraging thought, we cannot rule out the possibility that there may be a few others out there — perhaps many others. Although we have no evidence yet to support the claim that ETI may exist, many scientists have been taking the task of SETI very seriously, and an increased number of receiving stations built by Radio Amateurs would only improve the chance of receiving that first intelligent signal from beyond our own solar system. We know that the laws of physics are the same throughout the universe; an advanced civilization, therefore, regardless of what it used to produce RF energy, would radiate the same kind of RF energy we know here on Earth. Our modern RF technology is now producing receivers with noise figures that approach the limitations of intergalactic noise. The gap has finally been closed; *we can now begin the final search*.

acknowledgements

I wish to thank Garred Giles (ex KP4EPM) of the Arecibo Observatory for providing key photographs taken especially for this article. My appreciation is also extended to Dr. Harry Webb of the College of St. Thomas in St. Paul, Minnesota, for sharing his collection of photographs taken in his many trips to the Arecibo Observatory. I would also like to thank Dr. Robert S. Dixon, W8ERD, Assistant Director of the Ohio State Radio Observatory;