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1992

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DESIGN OF A 408 MHz

HELICAL RADIO TELESCOPE

A CAPSTONE PROJECT SUBMITTED TO

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IN CANDIDACY FOR THE DEGREE OF

MASTER OF SCIENCE

DEPARTMENT OF MATH, SCIENCE AND ENGINEERING

BY

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SEPTEMBER 1992

HYPOTHESIS STATEMENT

A radio telescope capable of detecting useful thermal and non-thermal radiation from extraterrestrial sources in the 408 MHz frequency range can be designed with an array of four helical beam antennas.

ABSTRACT

An intermediate amateur class radio telescope is designed, one subsystem at a time. The majority of the design work centers on an array of four helical beam antennas which serve as the antenna subsystem. The telescope's operating frequency is 408 Megahertz and it is able to detect extraterrestrial radio sources at or below the level of 10 Janskys (1×10^{-25} Watts/m^2/Hz.) The design or selection of the other subsystems is also covered. They include the transmission line, the receiver, the signal integrator, and the analog-to-digital converter. The telescope is designed for a generic interface with any computer through the RS-232 serial port for data recording and processing.

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1. INTRODUCTION

This project presents the design of a radio telescope. Such a telescope consists of a number of components, each of which must be designed separately but with the other components in mind, to produce a working system useful to the radio astronomer. This system is similar to larger research radio telescopes, differing only in the antenna array size, component sophistication, and cost. In other words, the value of the work which can be done with this telescope could be improved by increasing the size of the antenna array, or purchasing more sensitive receiving equipment. This project is an outgrowth of my previous experience in astronomy and a new interest in the radio portion of the electromagnetic spectrum. My intent was to gain a much deeper understanding of both subjects by applying one to the other.

RADIO TELESCOPE SYSTEM DESCRIPTION

A radio telescope differs greatly from an optical telescope. An optical telescope may be small enough to carry in one hand and provide the user with a magnified view of distant objects. In contrast, a radio telescope does not present the user with a ready made picture of the particular area of the universe he is trying to observe. A radio telescope simply measures the intensity of noise in a particular area of sky and records it. When intensities are recorded for several adjacent areas of the sky, they can be used to create a radio map of noise contours of the sky at a particular frequency. This concept is illustrated in figure 1.

The radio telescope consists of several subsystems which must work together to gather the data necessary to produce a radio picture. While other components may be added to enhance the system, the following list describes the minimum system required for a radio telescope. These components will be found in all systems:

a. The *antenna* is used to capture and concentrate radio energy from a chosen portion of the sky.

b. A *transmission line* carries the radio energy from the antenna to the receiver.

c. The *receiver* amplifies the radio signal and converts it to sound frequencies for listening or recording.

d. An *integrator* rectifies and averages the signal over a preselected period of time to filter out abrupt changes and spurious noise.

e. A *recorder* is used to record the time (to correlate with location) and the signal level.

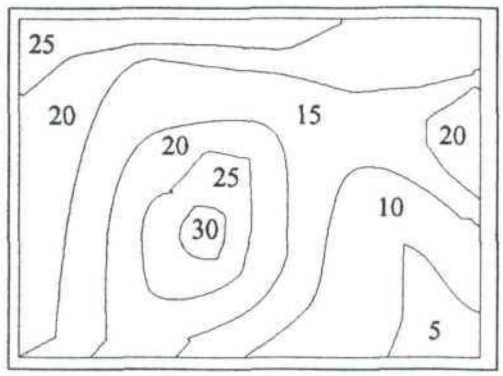


Figure 1 - Example of Radio Map

Most radio telescopes use a parabolic reflector as part of the antenna. These "dishes" provide high gain and a narrow beamwidth but are somewhat difficult to make, mount, and steer. In a previous class I studied three different types of antennas for use in radio astronomy, the parabolic reflector, the Yagi-Uda array, and the helical beam. (See figure 2.) The results, shown in table 1, indicate that a helical beam antenna less than two meters in length has gain and beamwidth characteristics close to those of a two meter diameter parabolic reflector. Because the helix is generally cheaper to make, mount, and steer than a parabola, I chose to design a telescope based on an array of four helix antennas.

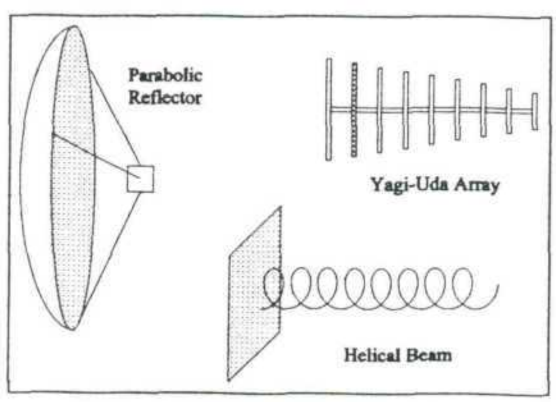


Figure 2 - Different Antenna Types

Antenna	Gain	Beamwidth	Dimension
Parabolic Reflector	16.7 dB	26.5 deg	2.00 m
Yagi-Uda Array (16 element)	13.1 dB	26.0 deg	1.62 m
Helical Beam (12 turn)	15.3 dB	32.9 deg	1.84 m

Table 1 - Antenna Study Results

PROJECT OVERVIEW

This project includes the design or selection of all the components shown in figure 3. While the outline of a computer is shown, I have only presented the serial interface and not the computer itself, nor have I designed storage or processing software. These elements are beyond the scope of this project.

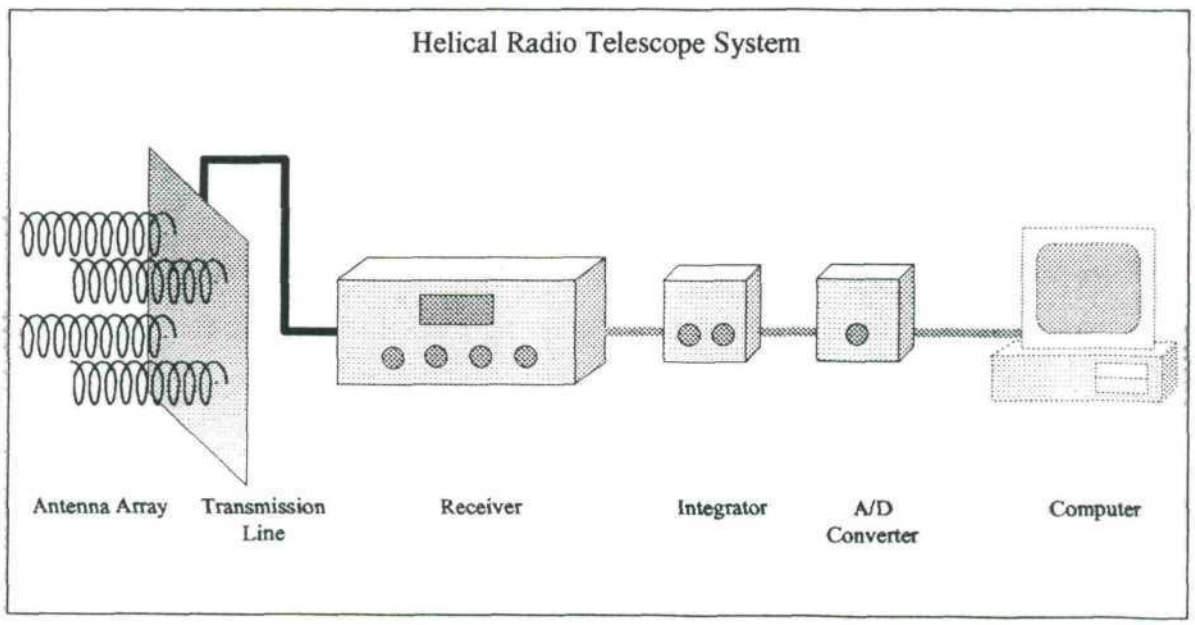


Figure 3 - Radio Telescope System

The next section will discuss the selection of a frequency range used in the design of the subsystems. Following that, each subsystem design or selection will be discussed in detail, and in conclusion, the project results will be summarized.

2. SELECTION OF FREQUENCY RANGE

There are numerous sources of radio energy in the universe. (See appendix C.) Some sources are from nearby planets and Earth's sun. Others, such as quasars, are at the very edge of the visible universe, about 15 billion light-years away. Radiation sources may be classified in two groups, thermal and nonthermal. These two groups are primarily active in different portions of the electromagnetic spectrum (see figure 4) but overlap in the UHF region. (Appendix A lists the radio frequency bands.) Nonthermal radiation results primarily from plasma oscillation and synchrotron radiation and is most intense in the lower VHF region. Thermal radiation is produced by any body above absolute zero and is roughly proportional to the temperature of the radiating body. Thermal radiation becomes noticeable in the VHF region and grows in intensity through the X-ray region, where it then falls off rapidly (Heiserman 1977.)

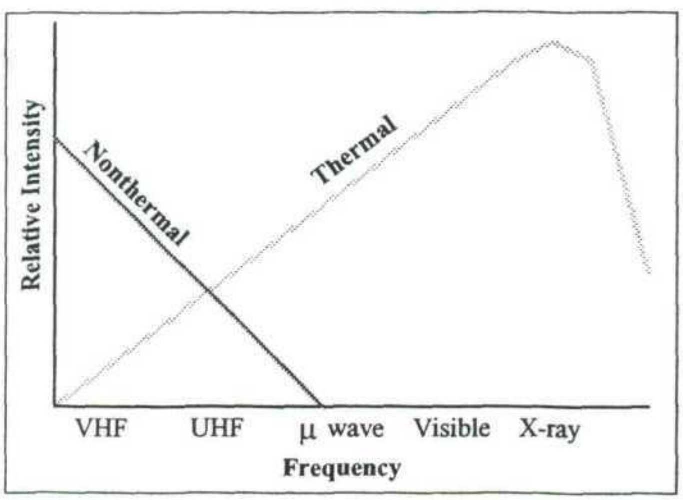


Figure 4 - Relative Intensity of Radiation Sources (Heiserman 1977)

I selected a telescope operating frequency in the UHF region for two reasons. First, I wanted to be able to detect both thermal and nonthermal radio sources, and second, lower frequencies require larger antennas because of the longer wavelength. Specific frequencies have been set aside by the various regulatory agencies for use in different activities, including radio astronomy. After reviewing the frequencies allocated to radio astronomy (see appendix B), I selected 406.1 MHz to 410.0 MHz as the target band for radio observation. Having selected the target radio band, a frequency in the center of that region was chosen to be the target frequency. To find the center frequency I used

$$f_{center} = f_{low} + \frac{f_{hi} - f_{low}}{2} = 408.05MHz$$

where f_{low} is 406.1 MHz and f_{hi} is 410 MHz. Rounding off to 408 MHz is sufficient for this project. Next, the wavelength was determined by dividing the speed of light by the frequency.

$$\lambda = \frac{3\times10^{10} cm/\sec}{408\times10^{6} Hz} = 73.5cm$$

With the target frequency and wavelength selected, the actual design process can begin.

3. ANTENNA ARRAY DESIGN

The antenna is an array of four helical beam antenna elements. The helical beam antenna was invented by John Kraus in 1947 and is usually made from a single conductor wound in a spiral or helix (King & Wong 1984.) In this application the helix functions in the axial mode as an end-fire array of circular antennas with circular polarization. This gives the helix an advantage over some other types of antennas used for radio astronomy because radiation coming from space is randomly polarized. Helical antennas respond to all linearly polarized radiation equally. The design process consists of two parts, the design of a single antenna element and the design of an array of four elements. Since the design is complex, with many design variables, I used *Mathcad*, a mathematical analysis tool, to help in the design. *Mathcad* allowed me to consider several parametric inputs while eliminating the need to recalculate the equations by hand. I used the methods found in the ARRL Antenna Book (1991) for all antenna design, except where noted.

SINGLE ELEMENT DESIGN

The antenna design requires the input of several parameters and from these the remaining dimensions and characteristics can be calculated. Figure 5 illustrates the dimensional variables of the different parts of the helical antenna. Each of these is covered in detail in the following design discussion.

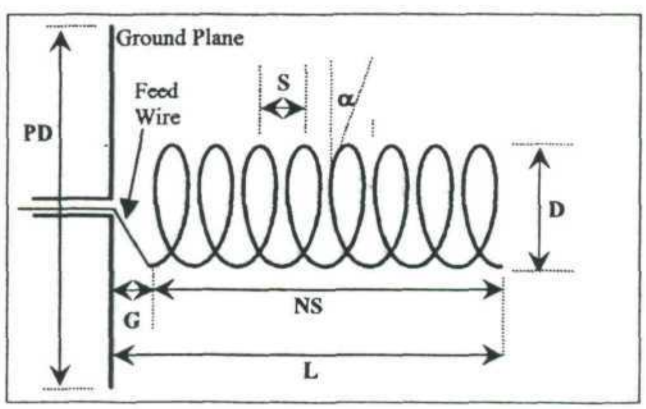


Figure 5 - Antenna Element Dimensions

I selected several other input parameters as well as the frequency as a starting point for the antenna design. I selected the number of turns, N, to be 12. This provides adequate gain and keeps the length of the antenna below 2 meters. An appreciable increase in gain over that achieved with 12 turns would require substantially more turns. (See table 2. The calculation method is shown on page 10.) A total of 24 turns would only result in a 3 dB improvement over a selection of 12 turns.

Turns	Gain (dB)
2.0	7.3
4.0	10.3
6.0	12.1
8.0	13.3
10.0	14.3
12.0	15.1
14.0	15.8
16.0	16.4
18.0	16.9
20.0	17.3
22.0	17.7
24.0	18.1

Table 2 - Helix Turns and Gain

Pitch is the angle, α, at which the helix wire winds forward along the antenna axis. The ARRL Antenna Book (1991) recommends a value for this from 12 to 16 degrees to provide maximum gain. I chose 12 degrees to keep the antenna as short as possible and stay within the recommended limits

The recommended helix circumference, C, is equal to the wavelength:

$$C = \lambda = .735\ m$$

Also important in the design is the circumference given in wavelengths, C_λ. This is found by dividing the circumference by the wavelength.

$$C_\lambda = \frac{C}{\lambda} = 1.0$$

The helix diameter, D, can be calculated from the circumference.

$$D = \frac{C}{\pi} = .234\ m$$

The space between loops, S, can be calculated from the wavelength and the pitch.

$$S = \lambda \sin \alpha = .153\ m$$

It is also useful to know this in terms of wavelength.

$$S_\lambda = \frac{S}{\lambda} = .208$$

The ARRL Antenna Book (1991) recommends the space between the back plane and the first turn, G, be between .12λ and .13λ. Again, I chose the smallest recommended value to minimize the antenna length.

$$G = .12\ \lambda = .088\ m$$

The antenna length, L, is calculated from the number of turns, the space between them, and the space between the first turn and the back plane.

$$L = N\,S + G = 1.923\ m$$

The ground plane diameter for a single helix, PD, should be between .8λ and 1.1λ (ARRL Antenna, 1991). Increasing the diameter increases the side lobes of the radiation pattern. Smaller diameters decrease the gain. I chose the lowest recommended value to keep the antenna more manageable.

$$PD = .8\ \lambda = .588\ m$$

This plane can be solid metal or, to keep it lighter and easier to work with, it can also be a steel mesh screen with a maximum mesh spacing, MS, given by (Hyde 1963)

$$MS \leq .125\ \lambda = .092\ m$$

Metal window screen or chicken wire meets this requirement very nicely. However, a frame will have to be built to support the screen. This can be 3/4" electrical conduit, cut and brazed to form a square.

The diameter of the helix conductor, HD, isn't a precise requirement but should be

$$.006\,\lambda \leq HD \geq .05\,\lambda$$

or between .44 and 3.68 cm. The upper limit is unreasonable. It's too hard to bend pipe into a spiral. The lower limit requires a wire gauge of 5 or larger. This is too heavy when using solid copper or steel but aluminum or copper tubing can be used. However, I elected to use coaxial cable. It is light weight, bends extremely easily, and is low cost. Almost any coax will do. I only found one (RG-174) that was too small in diameter for the .44 cm minimum requirement. The outer and inner conductors should be soldered together at both ends to produce a "single" conductor. A wooden skeleton or cardboard tube is used as a permanent form on which to wind the coaxial cable.

The final dimension of a single element is the linear length, LL, of cable required to produce the helix. This can be found by

$$LL = \frac{L-G}{\sin\alpha} = 8.84\ m$$

A summary of the single element antenna dimensions are given below in table 3.

Dimension	Symbol	Value	Units
Number of turns	N	12	turns
Pitch angle	α	12	deg
Circumference	C	0.735	m
Diameter	D	0.234	m
Circumference in λ	C_λ	1	λ
Space between turns	S	0.153	m
Turn space in λ	S_λ	0.208	λ
Distance to ground plane	G	0.088	m
Length of antenna	L	1.924	m
Ground plane diameter	PD	0.588	m
Max. plane mesh size	MS	7.4	cm
Min. helix conductor diam.	HD	0.44	cm
Linear length of conductor	LL	8.83	m

Table 3 - Single Antenna Element Dimensions

The next step is to determine the characteristics of a single antenna element. The first characteristic is the nominal impedance, Z. The impedance of a helical antenna whose circumference is equal to the wavelength ($C_\lambda = 1$) is 140 Ω and varies as C_λ changes. (See formula below.) Since I have chosen a circumference equal to the wavelength the impedance is 140Ω.

$$Z = 140 \times C_\lambda = 140\Omega$$

The directivity, Dir, is a measurement of the intensity of the forward radiation pattern compared to an isotropic radiator, an ideal antenna that radiates in all directions equally. It is calculated from the circumference and the length of all the antenna loops.

$$Dir = 15\, C_\lambda^2\, N S_\lambda = 37.424$$

The gain, G*, is the directivity multiplied by an antenna efficiency constant. Without actual measurements antenna efficiency, k, is assumed to be 0.9. This rule of thumb was taught in Advanced Electromagnetics.

$$G^* = k\, Dir = 33.682$$

or

$$G = 10\ \log(k\, Dir) = 15.274\ dB$$

The next two parameters are useful in determining how much area of the sky can be seen at one time and how close two objects can be before they appear as one. These parameters are the half power beamwidth and the beamwidth between first nulls. They are shown graphically in figure 6. The half power beamwidth, β, is the diameter of the beam between the points where the gain drops 3 dB from the maximum. The majority of the radio power detected by the telescope falls within these points. The angular diameter of this beam is given by

$$\beta = \frac{52}{C_\lambda \sqrt{N S_\lambda}} = 32.921^o$$

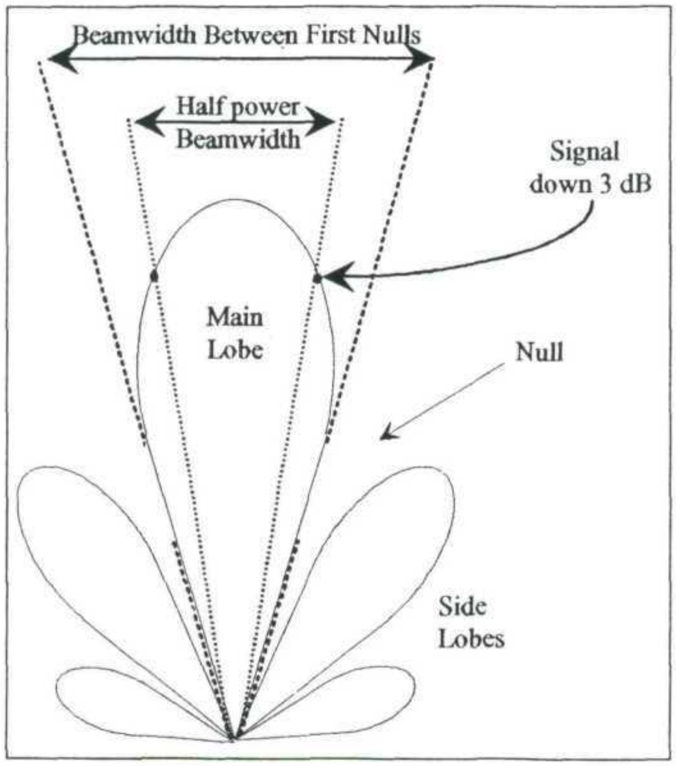


Figure 6 - Antenna Radiation Pattern

Another useful parameter is the beamwidth between first nulls, BWFN. This contains all the power received by the main lobe of the antenna and is used to determine the Rayleigh resolution of the antenna. The Rayleigh resolution is the angle by which two objects must be separated to be seen as two objects and not as a single radio source. The beamwidth between first nulls is given by

$$BWFN = \frac{115}{C_\lambda \sqrt{N S_\lambda}} = 72.806^o$$

The Rayleigh resolution is one half the BWFN (Kraus 1984.)

$$R = \frac{BWFN}{2} = 36.403^o$$

The final parameter of importance is the bandwidth or frequency range over which the antenna can be used. To determine the bandwidth it is first necessary to determine the peak gain, PG, of the antenna. The gain that was determined earlier was the average gain of the main lobe. The peak gain can be used to determine the bandwidth frequency ratio, BFR, which is the ratio of the high frequency limit to the low frequency limit. This method for determining bandwidth was presented by King and Wong (1984) and provides the antenna bandwidth at which the antenna gain is 2 dB down.

$$PG = 8.3\left(\frac{\pi D}{\lambda}\right)^{\sqrt{N+2}-1}(NS_\lambda)^{.8}\quad\left(\frac{\tan 12.5^\circ}{\tan\alpha}\right)^{\frac{\sqrt{N}}{2}} = 18.552\ dB$$

The bandwidth frequency ratio is determined by

$$BFR = 1.07\left(\frac{.91\,PG}{G}\right)^{\frac{4}{3\sqrt{N}}} = 1.112$$

This ratio can be used to determine the half bandwidth, Δf, above and below the nominal frequency.

$$\Delta f = f\,\frac{BFR-1}{BFR+1} = 21.64\ MHz$$

The total bandwidth (2 dB down) of the antenna then is twice the frequency computed above.

$$BW = 2\times\Delta f = 43.29\ MHz$$

This provides several times the bandwidth needed to cover the 406 - 410 MHz frequency allotted to radio astronomy in this region of the spectrum. The actual high and low frequency limits are

$$F_{hi} = f + \Delta f = 429.6\ MHz$$

$$F_{lo} = f - \Delta f = 386.4\ MHz$$

This completes the calculation of the necessary parameters. They are summarized in table 4.

Parameter	Symbol	Value	Units
Impedance	Z	140	Ω
Directivity	Dir	37.42	
Gain (algebraic)	G*	33.68	
Gain	G	15.27	dB
Half Power Beamwidth	β	32.92	deg
Beamwidth - first nulls	BWFN	72.81	deg
Resolution	R	36.4	deg
Bandwidth (2 dB down)	BW	43.29	MHz
High frequency limit	f_{hi}	429.6	MHz
Low frequency limit	f_{lo}	386.4	MHz

Table 4 - Single Antenna Element Parameters

ARRAY DESIGN

The design of the individual antenna element and determining its parameters are the most time consuming and involved parts of the entire project. While a single helix would suffice for good quality entry level radio astronomy explorations, an array of four antennas greatly increases the gain and resolution. Fainter radio sources can be detected and smaller objects or portions of the sky can be discerned. More precise work could be done with a larger array to increase sensitivity or an interferometer of several arrays, spaced several wavelengths apart to improve resolution. This array is built with four of the helical elements designed previously. The methods used in the array design process are also taken from the ARRL Antenna Book (1991) unless otherwise noted.

The four helices are attached to a ground plane made of conduit and screen as mentioned earlier. This ground plane will in turn be attached to an altazimuth mount to allow the telescope antenna to be directed toward any desirable spot in the sky. The dimensions for placement of the helices on the ground plane will be calculated next. Placement is simple and determined solely from the wavelength of the operating frequency (see figure 7.) Again, increasing the size of the reflector will increase the size of the side lobes and decreasing the reflector size will decrease the forward gain.

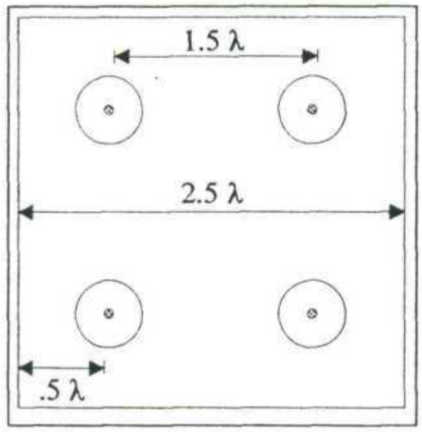


Figure 7 - Array Ground Plane Dimensions

The length of the sides, LS, of the ground plane is

$$LS = 2.5\ \lambda = 1.838\ m$$

The distance, DE, from each antenna element to the edge of the ground plane is

$$DE = .5\ \lambda = .368\ m$$

The distance, DH, between helices along the edge of the ground plane, not diagonally, is

$$DH = 1.5\ \lambda = 1.103\ m$$

Next, the parameters of the array are determined. The simplest is the gain, G_A^*, which is found by multiplying the gain of an individual element by the number of elements.

$$G_A^* = NE \times G^* = 134.727$$

or

$$G_A = 10\ \log(G_A^*) = 21.295\ dB$$

The array half power beamwidth, β_A, is found to be

$$\beta_A = \sqrt{\frac{41250}{G_A^*}} = 17.498\ ^o$$

The helix antenna acts like a radio lens, focusing energy onto itself from a greater area than its actual physical cross section. In other words, the effective aperture is greater than the physical aperture. To determine the resolution I calculated the effective area of the array, E_A, and from that the effective diameter of the array, E_D, and from that the resolution, R_A. The effective area is

$$E_A = \frac{G_A^* \lambda}{4\pi} = 5.797\ m^2$$

This area has an effective diameter of

$$E_D = 2\sqrt{\frac{E_A}{\pi}} = 2.717\ m$$

The resolution is then determined for an antenna with the effective diameter.

$$R_A = \frac{57\,\lambda}{E_D} = 15.428^o$$

The array parameters are summarized in table 6. The antenna has substantially improved gain and resolution over a single element. Additionally, the antenna is less than two meters long on any primary axis. This will allow the telescope to be easily steered and will greatly reduce its sensitivity to wind. The next step in the design process is to connect the antenna to the receiver. This is done via a transmission line.

Parameter	Symbol	Value	Units
Array gain	G_A	21.295	dB
Half power beamwidth	β_A	17.498	deg
Effective area	E_A	5.797	m^2
Effective diameter	E_D	2.717	m
Array resolution	R_A	15.428	deg

Table 5 - Antenna Array Parameters

4. TRANSMISSION LINE DESIGN

The transmission line is the subsystem of the radio telescope which carries the radio energy captured by the antenna to the receiver. It is also a system of several components as shown in figure 8 below. The design methods for this portion of the telescope were taken from the ARRL Antenna Handbook (1991.)

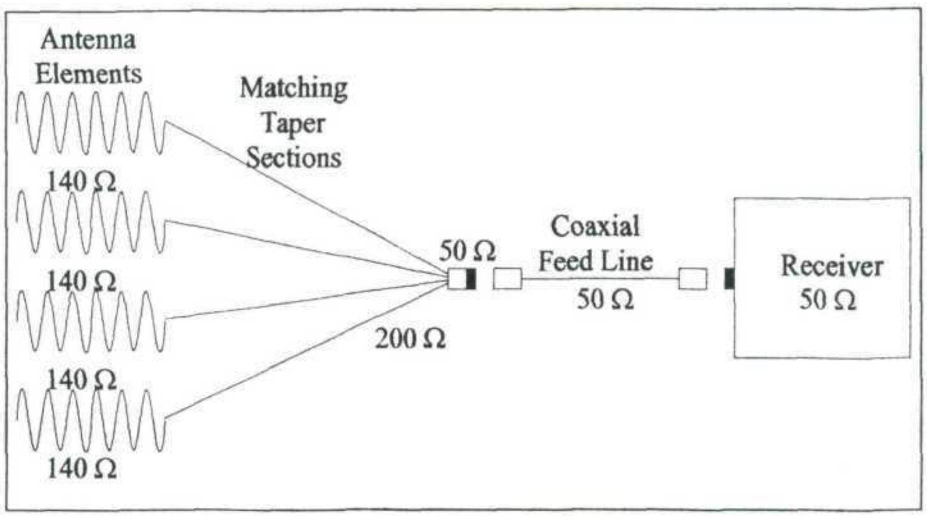


Figure 8 - Transmission Line Subsystem

The primary feed line leading to the radio receiver should be of the same impedance as the nominal impedance of the receiver, 50 Ω. According to the ARRL Electronics Data Book (DeMaw 1988) there are several types of coaxial cable that can be used for this; RG-9B, RG-55A, RG-141, RG-142, RG-174, etc. I chose RG-141 because of its smaller diameter, 0.190 in. This will make it easier to handle. The capacitance per foot, 29.4 pF, is about the same as the others and its velocity factor, VF, is 70% with PTFE dielectric. Its nominal impedance is 50 Ω.

On the other end of the transmission line are four helical antennas, each with a characteristic impedance of 140 Ω. Since there are four antennas feeding into one line the antennas act as four resistors in parallel feeding one point. At this point they must match the impedance of the feed line, 50 Ω. If the antennas are connected directly to the feed line they would have a combined impedance of

$$Z_{total} = \frac{Z_{ant}}{Ant} = \frac{140}{4} = 35\ \Omega$$

Accordingly, there must be a matching section between the antennas and the feed line as shown in figure 7. The impedance at the antenna of these matching sections should be the same as the impedance of the antennas, 140 Ω. The impedance at the other end can be found by multiplying the impedance of the line by the number of antenna feeds.

$$Z_{line} \times Ant = 50 \times 4 = 200\ \Omega$$

Four of these sections in parallel will combine to produce 50 Ω, matching the impedance of the feed line.

The simplest matching transformer I could find for this application is a taper section. These sections connect the antennas to the center of the ground plane (see figure 9) where they are soldered to an appropriate coax connector and the feed line can be connected to this junction point.

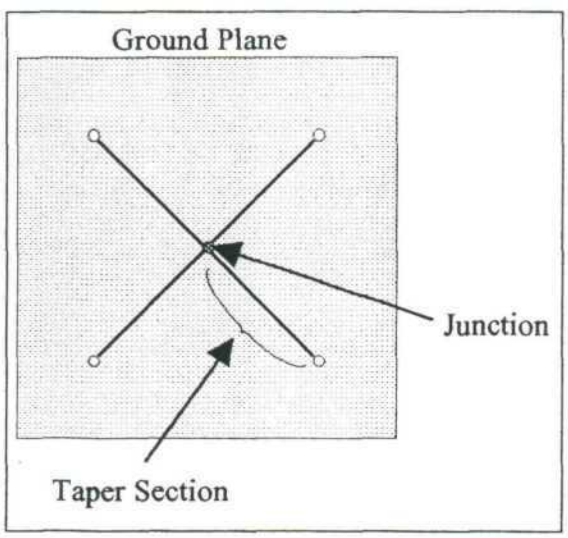


Figure 9 - Taper Sections Layout

The taper sections are on the underside of the ground plane as shown in figure 10. They are constructed of 12 gauge copper wire and are separated from the ground plane by different distances at each end.

The spacing at the antenna end is

$$S_1 = .5\, d\, 10^{\frac{Z_1}{276}} = .33\ cm$$

where d is the diameter of the wire, .206 cm, and Z_1 is the impedance of the antenna, 140 Ω. The impedance, Z_2, at the junction or feed line end is 200 Ω and the spacing is

$$S_2 = .5\, d\, 10^{\frac{Z_2}{276}} = .55\ cm$$

Figure 9 shows a side view of a portion of the ground plane and one of the taper sections. The length, T, of the taper section is half the diagonal distance between two helix elements.

$$T = .5\ \sqrt{2\, S^2} = 1.06\ \lambda = .78\ m$$

where S is the distance between the helices sideways, 1.5 λ.

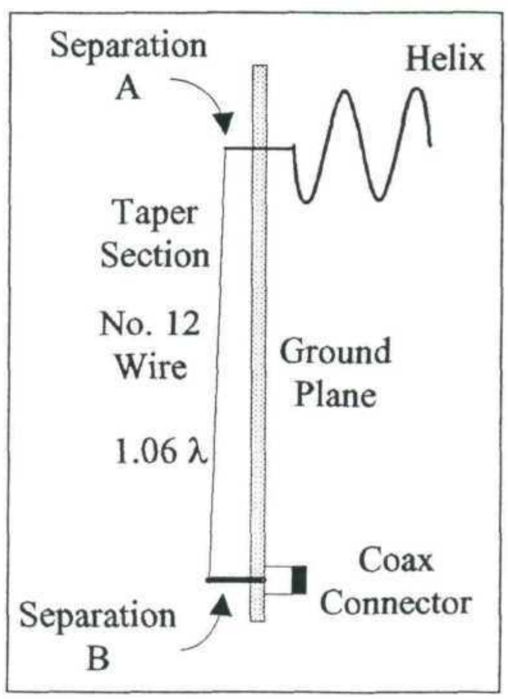


Figure 10 - Single Taper Section, Side View

This transmission line will provide proper matching of impedances to the receiver and the antennas, eliminating most standing wave ratio (SWR) losses in this portion of the system.

Instead of leading to the receiver, the transmission line could be connected to a low noise preamplifier. However, as will be shown in the next section, this is not necessary for the telescope to function properly. A preamplifier would increase the sensitivity of the instrument but is not critical to beginning and intermediate level observations.

5. RECEIVER SELECTION

A simple radio receiver could be built without an undue amount of trouble. The signal being detected is noise and there is not much signal processing involved. One could build a wide band receiver for very little cost, especially with the semiconductors available on today's market (Sickels, The Radio Astronomy Circuit Cookbook 1992.) However, there are receivers already designed in Sickels' books and, even better, there are numerous receivers which can be purchased off the shelf which will satisfy radio astronomy requirements and serve as general purpose receivers for other uses also. The primary purpose of this section is to determine which receiver will function adequately for the telescope. Unless specified otherwise the methods used in this selection process were presented by Heiserman (1977.)

The most important parameter to determine at this time is the receiver sensitivity required to detect useful signals. To do this the lower limit for signal strength must be known. Robert Sickels has compiled a list of 400 celestial radio sources with flux above 10 janskys (The Radio Astronomy Handbook, 1992.) A jansky is a unit of radio power falling upon a square meter of the Earth's surface, per hertz and is named after Karl Jansky who discovered radio emissions from the center of the Milky Way (Shields 1986)

$$1\ jansky = 1 \times 10^{-26} \frac{watts}{m^2\ Hz}$$

I selected 10 janskys as the limit of minimum observable power flux. The next step is to find how much power is available at the antenna. To do this the effective aperture of the antenna in square meters must be known. This was previously determined to be 5.797 m^2. (See table 5.) The other parameter needed is the bandwidth of the receiver. Since a receiver hasn't yet been selected a parameter which is common to several off the shelf receivers should be used. Most receivers have a wide FM bandwidth of 150 - 180 kHz. I chose the lower end (150 kHz) simply because it is the most common wide band FM bandwidth. The power available at the antenna terminals, P_A, is

$$P_A = S\,A_e\,B = 8.696 \times 10^{-20}\ watts$$

S is the flux in watts/m^2/Hz (10 janskys = 1×10^{-25} watts/m^2/Hz), A_e is the effective area, and B is the bandwidth in hertz. An alternate method to determine antenna power uses the antenna gain instead of the effective area and comes extremely close, validating the first method.

$$P_A = 7.17\ \times 10^{\frac{G_A}{10}} \times B \times S \times 10^{-23} \times \frac{1}{f^2} = 8.705 \times 10^{-20}\ watts$$

The variable f is the operating frequency of the antenna in MHz, 408.

Receiver sensitivity is usually given as the number of microvolts at the input which produces an output 10 dB above the internally generated noise. Radio astronomy has much less stringent receiver noise requirements than music or voice radio. In fact, a recording system based on analog-to-digital conversion and computer storage can easily discern signal levels 1% above the receiver noise floor or a signal-to-noise ratio of .01. The power received by the antenna, 8.696 x 10^{-20} watts, the antenna impedance, 140 Ω, and the signal-to-noise ratio of .01 can be used to determine the required receiver sensitivity, S_R.

$$S_R = \frac{9.091 \times 10^6 \sqrt{P_A Z_A}}{SNR} = 3.172\ \mu V$$

This value doesn't take into account any losses. If we assume insertion and attenuation losses in the transmission line of 3 dB, probably a worst case, we will come up with a more realistic sensitivity requirement. This cuts the power from the antenna in half, making the sensitivity requirement one half of that calculated above, or 1.586 μV.

The final step of receiver selection is finding a receiver which meets or exceeds the specifications determined above. These specifications are summarized in table 6.

Specification	Symbol	Value	Units
Bandwidth	B	150	kHz
Receiver sensitivity	S_R	1.59	μV
Frequency range	F	406-410	MHz

Table 6 - Receiver Requirements

I sent for literature on several multiband and UHF receivers. After looking through the specifications, I found several which met the requirements but I chose the Icom IC-R100 multiband receiver over the others for the following reasons:

1. It has very good sensitivity.
2. It has an extremely wide frequency range
3. It's capable of running on battery power.
4. Its very portable, weighing only 3 lbs..
5. It's a relatively inexpensive multiband receiver (about $600.)

It can also be used as a receiver for radio telescopes in other frequency bands as well as general purpose radio scanning and receiving. Selected specifications for the R100 are shown below. The complete specifications are shown in Appendix G.

Specification	Symbol	Value
Bandwidth	B	180 kHz
Receiver sensitivity	S_R	0.63 μV
Frequency range	F	.5 - 1800 MHz

Table 7 - IC-R100 Receiver Specifications

6. INTEGRATOR DESIGN

The radio signal is amplified and converted into sound frequency output by the receiver. While some space music makes interesting listening, Jupiter for example, the majority is nothing more than noise to the human ear. To have something worthwhile from the telescope we need to rectify the noise signal to produce a direct current. This direct current must then be summed over a period of time to remove spurious noise and average the signal strength. The integrated direct current signal may then be amplified to an adequate level for a storage device which records the signal levels. Figure 11 illustrates this process.

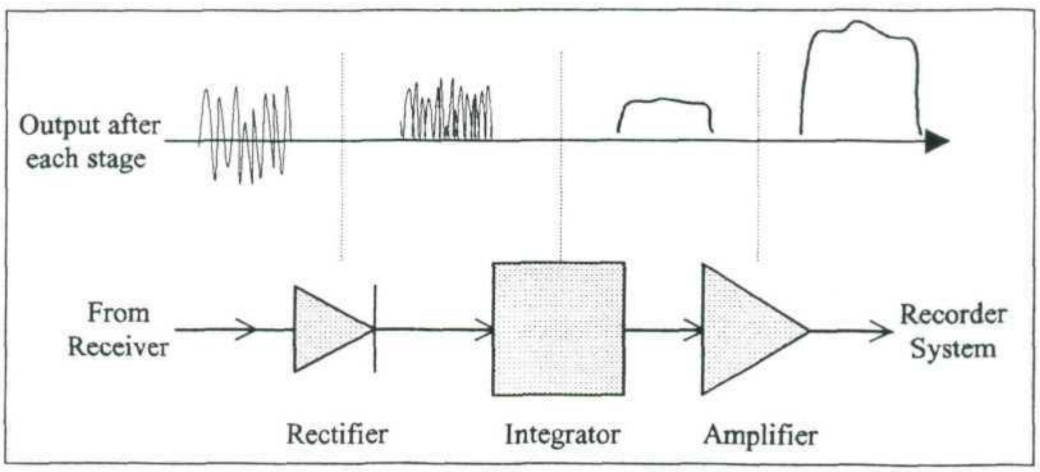


Figure 11 - Integrator Subsystem and Processing

I came across more than 10 different designs for integrators. Not one was accompanied by detailed design information so I considered the purpose of the subsystem and designed my own. Figure 12 shows the rectifier and integrator circuit. Resistor R1 provides a load for the audio output of the receiver. Most receiver outputs are 8 Ω impedance so 16 Ω should work well and reduce any risk of overloading the receiver output. Capacitor C1 stops any direct current from the receiver, allowing only alternating current sound signals to pass. Diodes 1 and 2 form a full wave rectifier passing only positive signal voltage on to the integrator. Capacitor C2 can be switched to any of the four resistors R2, R3, R4, and R5 to smooth (integrate) the signal from the rectifier portion of the circuit. They have time constants of C2 x R, or about .5 second, 1 second, 5 seconds, and 10 seconds. This is variable to enable the telescope to detect different types of objects. Resistor R6 discharges C2 when the signal drops.

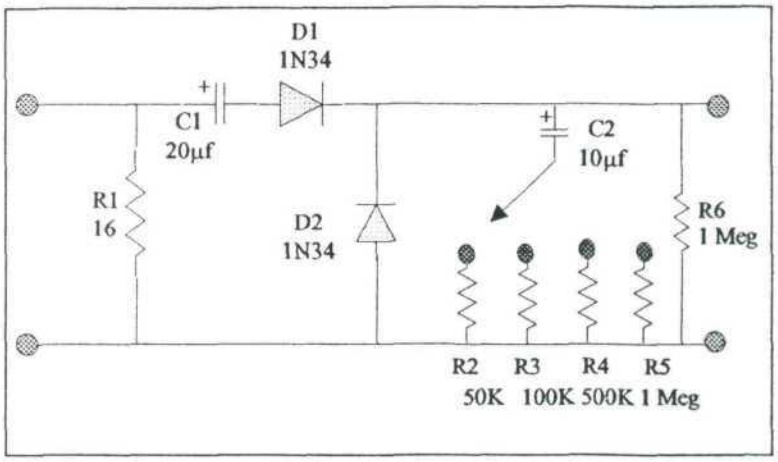


Figure 12 - The Rectifier and Integrator Circuit

The direct current amplifier circuit is shown in figure 13. It is a simple non-inverting amplifier based on an LM 741 or equivalent operational amplifier. Gain is controlled by potentiometer R3 and varies from 1 to 101. This is used to keep the amplifier from being driven to saturation. Another potentiometer, R4, allows the output voltage to be attenuated to avoid saturating the recording subsystem.

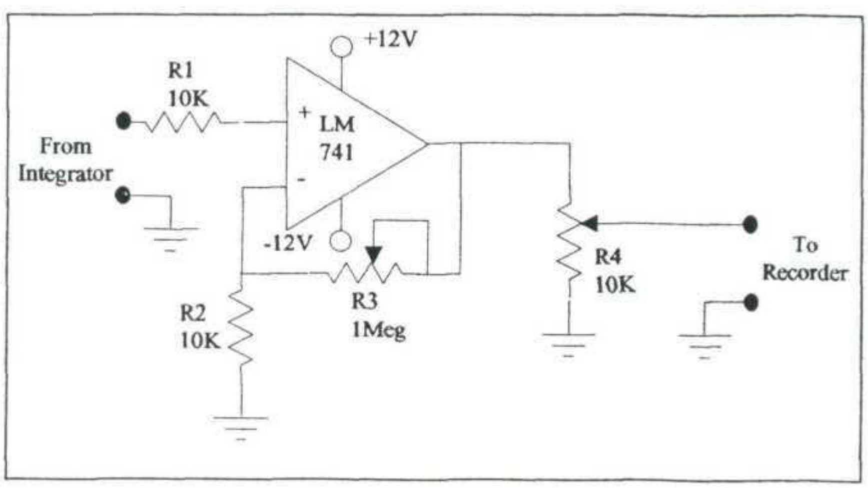


Figure 13 - DC Voltage Amplifier Circuit

The final design for the integrator subsystem is the power supply. This supply (see figure 14) provides plus and minus 12 volts at 1 amp so it could be used to power other components such as a preamplifier, a strip chart recorder, etc. The supply is very simple and uses integrated circuit voltage regulators 7812 and 7912 to provide fairly smooth current.

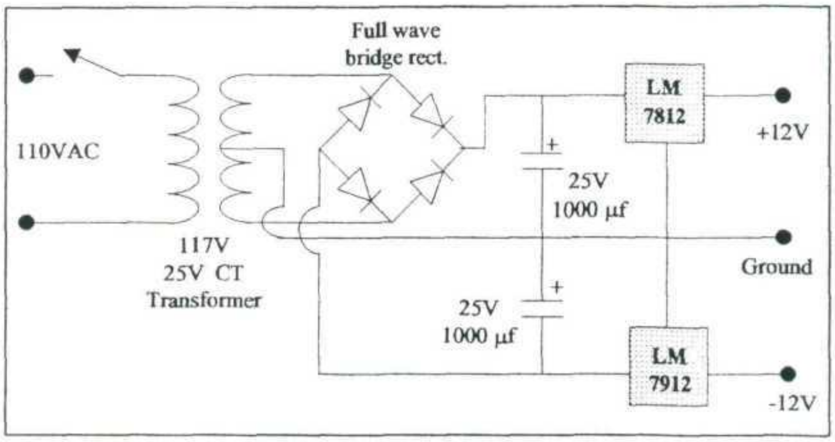


Figure 14 - Integrator Power Supply Circuit

The integrator should be located near the receiver as well as the recording subsystem. Once operational, it will have to be adjusted to provide proper output, depending on the radio source. In addition to the gain and attenuation on the integrator, the volume control on the receiver can and should be used for adjustments. While more sophisticated circuitry has been designed for some telescopes, the circuits here are adequate, inexpensive, and easy to build.

7. RECORDING SYSTEM SELECTION

The final subsystem records the output of the radio telescope. We can't see a nice picture of the universe directly so the data will have to be processed. The easiest way to record and process large amounts of signal intensity data is with a computer. The processing methods are beyond the scope of this project. Neither will I specify particular computer hardware other than a computer with a serial port.

The only thing left to select is an analog-to-digital converter (ADC) to change the analog voltage levels coming from the integrator to digital data and send it to a computer. I examined data acquisition literature from several vendors looking for the best system to meet my needs. My requirements were:

1. The system must have an RS-232 serial port to interface with an appropriate computer.
2. The ADC should be as low cost as possible.
3. The ADC must have a resolution of at least 1024 (10 bits) or .005 volts.
4. The ADC must cover a range of 0 to 5 volts and not more than 15 volts.
5. The ADC should have its own power supply or be capable of using the integrator supply.
6. The software to access the data must be simple and modifiable.

There were many ADC systems but most of them cost over $500 and used special cards to plug into an IBM compatible (ISA) bus. The secret, it seems, is to stay away from the glossy catalogs and look in small column advertisements. The ADC-4 from Electronic Energy Control, Inc. met or exceeded the above requirements. Its specifications of interest are summarized in table 8 and the specification sheets are shown in appendix H. The resolution is substantially better than the requirement and the voltage range is the same as the requirement. Higher or lower voltage levels can be attenuated or amplified by the amplifier section of the integrator. The ADC-4 has 4 channels which will allow for future expansion to a 4 antenna interferometer telescope. The unit can also be powered from the integrator supply. An example of the software required to access the data is shown in appendix H. It is simple and completely modifiable. The ADC-4 will also connect to any computer with a serial port, and even allows the use of a modem for unattended observation. One could leave the telescope in receive mode during vacation time and access the data with a computer over long distance phone lines.

Specification	Value
Resolution (increments)	4096 (12 bit), <.002 V
Input range	0 - 5 V
Channels	4
RS-232 Baud rate	50 - 19,200 baud
Power supply	9-14 V, 300 mA
Cost	$170

Table 8 - ADC-4 Specifications

8. CONCLUSION

This capstone project demonstrates that a radio telescope capable of detecting useful thermal and non-thermal radiation from extraterrestrial sources in the 408 MHz frequency range can be designed around an array of four helical beam antennas. The specifications of the instrument are summarized below in table 9.

Specification	Value
Operating Frequency	408 MHz
Detection	Wideband FM
Receiver Bandwidth	180 kHz
Antenna Bandwidth	43.3 MHz
Antenna Dimensions	1.9 x 1.8 x 1.8 m
Antenna Gain	21.3 dB
Effective Diameter	2.7 m
Resolution	15.43 deg
Sensitivity	.63 μV
Minimum Detectable Signal	< 10 Janskys
A/D Convertor Resolution	12 bits (.002 V)
Cost (excluding computer)	< $1000

Table 9 - System Specifications

If these specifications are compared to Heiserman's (1975) radio telescope parameter classifications (see Table 10) their suitability to serious amateur work becomes apparent.

Parameter	Minimum	Normal	Excellent
Antenna Gain	10 dB	15 dB	20 dB
Receiver Sensitivity	5 μV	1 μV	.5 μV
Receiver Bandwidth	100 kHz	2 MHz	6 MHz

Table 10 - Radio Telescope Specification Ratings

The antenna gain is excellent while the receiver sensitivity is close to the excellent category. Generally, more sensitivity is required to detect usable radio noise. However, this system comes out extremely well because it can detect signals below 10 janskys. Amateur instruments are usually capable of detecting no less than 25 to 50 janskys (Sickels, Radio Astronomy Handbook, 1992.) Because the antenna gain is so high the receiver sensitivity can be lower and still yield excellent detection ability. Originally, I expected a preamplifier would be needed to detect anything in the 10 jansky range. This project has shown it isn't necessary. The use of a low noise preamplifier could easily lower the detection threshold below 1 jansky.

The receiver bandwidth is within the minimum range but well below the "normal." Wide bandwidth is generally required to gather enough radio flux to be detected by the system. Since the telescope's detection capabilities have been shown to be excellent, greater bandwidth is unnecessary. In fact, the system provides greater frequency resolution than most amateur instruments and because the antenna bandwidth is extremely wide the telescope can be used to observe the sky at several different frequencies.

The telescope operating frequency falls in that area of the spectrum where thermal and non-thermal radio noise levels are approximately equal (see figure 4.) This allows the different sources of these two types of radiation to be observed with a single instrument. Further observations could be made at higher or lower frequencies by using the antenna array's wide bandwidth and changing the receiver operating frequency. The antenna's operating frequency could even be changed by placing the antenna end of the taper sections on nylon screws and adjusting the distance and impedance of the sections.

The telescope could also have its resolution increased substantially by using an array of antenna arrays. Figure 15 shows the layout of such an interferometer system.

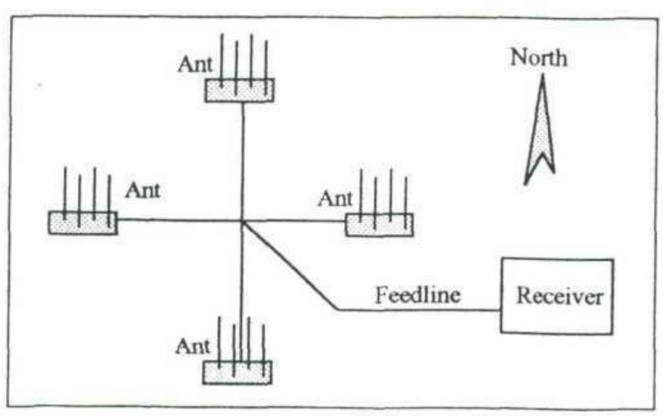


Figure 15 - Interferometer Layout

The antennas in such a system would be separated by several wavelengths of distance and would be lined up on a north-south-east-west grid to provide increased resolution in both dimensions. The resolution of such a system is given by

$$R = \frac{57\lambda}{D}$$

where R is the resolution in degrees, λ is the operating wavelength, and D is the distance between antennas in wavelengths.

The receiver and ADC in the recording subsystem were off-the-shelf items but could be home built if time were available. Several designs can be found in the books referenced in the bibliography, especially Sickels'.

This design shows that a very usable radio telescope can be built with helical beam antennas. When the gain, ease of construction, size, and mounting of such an instrument are compared to a parabolic dish antenna it shows that the helix is an effective, if not better, alternative antenna design.

Robert Sickels is sort of a world wide coordinator of amateur radio astronomy. I found his phone number in an astronomy magazine and talked with him about this project. It seems that there are very few how-to books on the subject and almost none in print. The reason for this is that there are only about 700 amateur radio astronomers in the world. Sickels has several books available, numerous electronic supplies, and publishes a monthly amateur astronomer's magazine called *The Radio Observer.* I have included his company name and address for those readers who might wish to become more involved with this subject.

Bob's Electronic Service
7605 Deland Ave.
Fort Pierce, Florida 34951
Telephone: (407) 464-2118

This project provided an excellent opportunity to learn about designing antenna systems and transmission lines. It also provided a deeper look at radio astronomy, amateur radio, and the electromagnetic spectrum. The systems design process was similar to the communications and computer systems designs I have been involved with at work. I plan to build a radio telescope and also become more involved in amateur radio. Overall, I enjoyed the project and feel it taught me a great deal.

APPENDIX A

RADIO FREQUENCY BANDS

Band	Abbr.	Frequency Range
Very Low Frequency	VLF	3 - 30KHz
Low Frequency	LF	30 - 300 KHz
Medium Frequency	MF	300 - 3000 KHz
High Frequency	HF	3 - 30 MHz
Very High Frequency	VHF	30 - 300 MHz
Ultra High Frequency	UHF	300 - 3000 MHz
Super High Frequency	SHF	3 - 30 GHz
Extremely High Frequency	EHF	30 - 300 GHz

APPENDIX B

FREQUENCIES ALLOCATED TO RADIO ASTRONOMY

Authority	Frequency	Bandwidth	Comments	Center λ
FCC	13.36 - 13.41 MHz	50 KHz		22.04 m
FCC	25.55 - 25.67 MHz	120 KHz		11.71 m
World	37.50 - 38.25 MHz	750 KHz	Shared	7.92 m
FCC	73.0 - 74.6 MHz	1.6 MHz		4.07 m
FCC	406.1 - 410.0 MHz	3.9 MHz		73.5 cm
FCC	608 - 614 MHz	6 MHz		49.1 cm
FCC	1400 - 1427 MHz	27 MHz		21.2 cm
FCC	1660 - 1670 MHz	10 MHz	Shared	18.0 cm
FCC	2665 - 2700 MHz	35 MHz		11.2 cm
FCC	4990 - 5000 MHz	10 MHz		6.0 cm
World, FCC	10.60 - 10.70 GHz	100 MHz	Shared	2.82 cm
FCC	15.35 - 15.40 GHz	50 MHz		1.95 cm
FCC	22.21 - 22.50 GHz	290 MHz		1.34 cm
FCC	23.6 - 24.0 GHz	400 MHz		1.26 cm
FCC	31.3 - 31.8 GHz	500 MHz		9.51 mm
FCC	42.5 - 43.5 GHz	1 GHz		6.98 mm
FCC	58.2 - 59.0 GHz	800 MHz		5.12 mm
FCC	72.72 - 72.91 GHz	190 MHz		4.12 mm
FCC	86 - 92 GHz	6 GHz		3.37 mm
FCC	105 - 116 GHz	11 GHz		2.71 mm
FCC	164 - 168 GHz	4 GHz		1.81 mm
FCC	182 - 185 GHz	3 GHz		1.63 mm
FCC	217 - 231 GHz	14 GHz		1.34 mm
FCC	265 - 275 GHz	10 GHz		1.11 mm

Taken from the Federal Communications Commission's Table of Frequency Allocations (1991)

APPENDIX C

EXTRA-TERRESTRIAL RADIO SOURCES

Source	Type	Frequency	Description
Jupiter-Io	Discrete	20 - 24 MHz	Surf-like sound
Solar Flares	Discrete	80 - 500 MHz	Short bursts
Sun	Extended	50 MHz - 3 GHz	Temperature radiation coming from different layers
Meteors	Indirect	80-150 MHz	Bounce signals off trails like radar
Meteors	Indirect	VHF	Listen to bounced VHF from over the horizon transmitters
Quasars & Radio Galaxies	Discrete	VHF - UHF	Very powerful, non-thermal signals
Milky Way	Discrete	VHF - UHF	Synchrotron radiation
"Hot" Objects (Stars, Galaxies)	Extended	SHF +	Thermal signals, with frequency depending on temperature
Planets	Discrete	EHF	Extremely low power thermal signals
Hydrogen Line	Extended	1.428 GHz	Neutral hydrogen spectral line

APPENDIX D

HELICAL BEAM ANTENNA WORKSHEET

INPUTS:

Frequency:	$F := 408 \cdot 10^6$	Hz
Pitch (input)	$\alpha := 12$	deg
Number of Loops:	$N := 12$	turns
Efficiency:	$k := .9$	
Polarization:	Circular	

ELEMENT CALCULATIONS:

Wavelength:	$\lambda := \frac{300000000}{F}$	$\lambda = 0.735$	m
Diameter:	$Dia := \frac{\lambda}{\pi}$	$Dia = 0.234$	m
Circumference:	$C := \lambda$	$C = 0.735$	m
Circumference in wavelengths:	$C\lambda := \frac{C}{\lambda}$	$C\lambda = 1$	wavel.
Space between Loops:	$S := \lambda \cdot \sin\left(\frac{\alpha}{180} \cdot \pi\right)$	$S = 0.153$	m
Space in wavelengths:	$S\lambda := \frac{S}{\lambda}$	$S\lambda = 0.208$	wavel.
Distance to Backplane:	$DB := .12 \cdot \lambda$	$DB = 0.088$	m
Backplane mesh max:	$MS := .125 \cdot \lambda \cdot 100$	$MS = 9.191$	cm
Antenna Length:	$L := N \cdot S + DB$	$L = 1.923$	m
Directivity:	$D := 15 \cdot (C\lambda)^2 \cdot (N \cdot S\lambda)$	$D = 37.424$	
Gain:	$G := k \cdot D$	$G = 33.682$	
Gain in dB:	$GdB := 10 \cdot \log(G)$	$GdB = 15.274$	dB
Half Power Beam Width:	$\beta := \left(\frac{52}{C\lambda \cdot \sqrt{N \cdot S\lambda}}\right)$	$\beta = 32.921$	deg

Beamwidth to First Nulls:	$BWFN := \frac{115}{C\lambda \cdot \sqrt{N \cdot S\lambda}}$	$BWFN = 72.806$	deg
Rayleigh Resolution:	$RR := \frac{BWFN}{2}$	$RR = 36.403$	deg
Ground plane diameter:	$PD := .8 \cdot \lambda$	$PD = 0.588$	m
Conductor Diameter minimum:	$Cdm := .006 \cdot \lambda \cdot 100$	$Cdm = 0.441$	cm
maximum:	$Cdx := .05 \cdot \lambda \cdot 100$	$Cdx = 3.676$	cm
Linear length of conductor:	$LL := \frac{L - DB}{\sin\left(\alpha \cdot \frac{\pi}{180}\right)}$	$LL = 8.824$	m

Peak Gain:

$$PG := 8.3 \cdot \left(\frac{\pi \cdot Dia}{\lambda}\right)^{\sqrt{N+2}-1} \cdot (N \cdot S\lambda)^{.8} \cdot \left[\frac{\tan\left(12.5 \cdot \frac{\pi}{180}\right)}{\tan\left(\alpha \cdot \frac{\pi}{180}\right)}\right]^{\frac{\sqrt{N}}{2}}$$

$PG = 18.552$ dB

Bandwidth Frequency Ratio: (Hi freq / Lo freq)	$BFR := 1.07 \cdot \left(\frac{.91 \cdot PG}{GdB}\right)^{\frac{4}{3 \cdot \sqrt{N}}}$	$BFR = 1.112$	
Hertz above & below center:	$\Delta f := \frac{F \cdot (BFR - 1)}{BFR + 1}$	$\Delta f = 2.164 \cdot 10^{7}$	Hertz
Bandwidth (2 dB down)	$BW := 2 \cdot \Delta f$	$BW = 4.329 \cdot 10^{7}$	Hertz
High Frequency:	$Fhi := F + \Delta f$	$Fhi = 4.296 \cdot 10^{8}$	Hertz
Low Frequency:	$Flo := F - \Delta f$	$Flo = 3.864 \cdot 10^{8}$	Hertz
Impedance:	$Z := 140 \cdot C\lambda$	$Z = 140$	ohms

ARRAY DESIGN

ARRAY INPUTS:

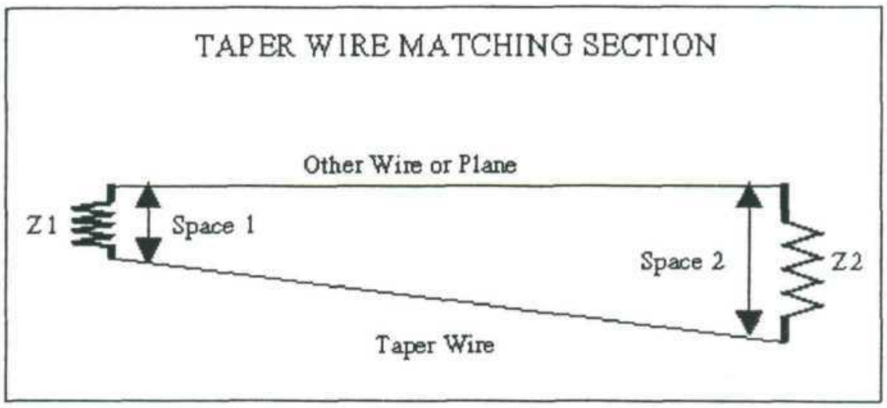
Number of Elements:	$NE := 4$	

ARRAY CALCULATIONS:

Space Between Elements:	$SA := 1.5\cdot\lambda$	$SA = 1.103$ meters
Gain of Array:	$GA := NE\cdot G$	$GA = 134.727$
Gain of Array in dB:	$GAdB := 10\cdot\log(GA)$	$GAdB = 21.295$ dB
Half Power Beam Width:	$HPBW := \sqrt{\frac{41250}{GA}}$	$HPBW = 17.498$ degrees
Effective Area of Array:	$EAA := \frac{GA\cdot\lambda^2}{\pi\cdot 4}$	$EAA = 5.797$ square m
Effective Diameter of Array:	$EDA := 2\cdot\sqrt{\frac{EAA}{\pi}}$	$EDA = 2.717$ meters
Resolution of Array:	$RA := \frac{57\cdot\lambda}{EDA}$	$RA = 15.428$ degrees

APPENDIX E

TAPER WIRE MATCHING SECTION WORKSHEET



Note: The length of the matching section should be approximately 1 wavelength. At frequencies less than .5 wavelength the line acts as an impedance lump instead of a transformer. The transformer is not practical for impedances less than 100 ohms (ARRL Antenna Book.)

INPUTS:

Diameter of taper wire:	$d := .206$	cm	(12 gauge wire)
Impedance of first end:	$Z_1 := 140$	Ω	
Impedance of second end:	$Z_2 := 200$	Ω	

CALCULATIONS:

Spacing at first end: $S_1 := \frac{d \cdot 10^{\frac{Z_1}{276}}}{2}$ $S_1 = 0.331$ cm

Spacing at second end: $S_2 := \frac{d \cdot 10^{\frac{Z_2}{276}}}{2}$ $S_2 = 0.546$ cm

APPENDIX F

RECEIVER SENSITIVITY WORKSHEET

INPUTS:

Frequency:	$F := 408 \cdot 10^{6}$	Hz
Effective Area of Antenna:	$AE := 5.797$	square m
Minimum Signal Intensity:	$S := 10$	Janskys
Predetection Bandwidth:	$B := 150000$	Hertz
Detected Signal to Noise Ratio:	$SNR := .01$	
Antenna Impedance:	$Z := 140$	Ohms

CALCULATIONS:

Antenna Power:	$PA := S \cdot AE \cdot B \cdot 10^{-26}$	$PA = 8.696 \cdot 10^{-20}$	Watts
Required Receiver Sensitivity:	$RS := \frac{9.091 \cdot 10^{6} \cdot \sqrt{PA \cdot Z}}{SNR}$	$RS = 3.172$	μV

APPENDIX G

RECEIVER DESCRIPTION

•Covers 500 kHz~1.8 GHz.*
•Total of 121 memory channels.
•Memory scan.
•Priority scan.
•Selected mode memory scan.
•Auto memory write scan.
•Memory skip function.
•10 programmed scan ranges.
•Direct keyboard entry.
•Clock with a timer function.
•15 dB preamplifier. (50~905 MHz)
•AFC. (above 50 MHz, in FM or wide-FM)
•Optional AC adapter.

* Some versions do not cover the entire frequency range.

On the road, at home or almost anywhere else, the IC-R100 receives the stations you want. In the 500 kHz~1.8 GHz range, listen to medium wave, short wave and FM broadcasts, ham bands, marine or air band and more. For listening at home, Icom offers an optional AD-15A/E/D/V AC ADAPTER.

While driving, receiving is easy. To help you find desired stations quickly, the receiver has programmed, memory, priority, selected mode memory and auto memory write scan functions. Specify undesired frequencies as skip channels. At frequencies above 50 MHz, the AFC function compensates for station frequency drift in FM mode. To enhance weak signals in the 50~905 MHz range, a 15 dB preamplifier is provided. Moreover, the ANL function reduces pulse noise in AM mode.

The IC-R100 provides a 24-hour system clock that includes power ON/OFF and sleep timers. The memory select timer function automatically receives a previously specified memory channel at a programmed time. You need never miss a signal. The 20 dB RF attenuator helps to receive weaker signals more clearly when excessively strong signals exist on adjacent frequencies. Improve your communications immediately. All required accessories — the mobile mounting bracket, DC power cable, wire antenna and telescopic antenna — are included with the IC-R100.

WIDEBAND RECEIVER

IC-R100

		IC-R100
Frequency coverage* *Varies according to version.	Guaranteed	500 kHz–1800 MHz
	Operation	100 kHz–1856 MHz
Modes		AM, FM, Wide-FM
Sensitivity* *Each receiver's sensitivity is less than described value. 10 dB S/N for SSB, CW, FSK (RTTY) and AM modes. 12 dB SINAD for FM and Wide-FM modes.		0.5–1.6295 MHz AM 3.2 μV 1.63–49.9995 MHz AM 1.6 μV FM 0.56 μV 50–904.9995 MHz AM 0.56 μV FM 0.2 μV Wide FM 0.63 μV 905–1380.4875 MHz FM 0.32 μV 1380.5–1800 MHz FM 0.45 μV
Selectivity		AM More than 6.0 kHz/–6 dB FM More than 15 kHz/–6 dB Wide FM More than 180 kHz/–3 dB
Frequency stability		———
Tuning steps		1, 5, 8, 9, 10, 12.5, 20 or 25 kHz (Varies according to frequency range.)
Usable antenna connectors		Below 50 MHz: PL-259 Above 50 MHz: Type N
Dimensions* *Projections not included.		150(W) × 50(H) × 181(D) mm 5.9(W) × 2.0(H) × 7.1(D) in
Weight		1.4 kg; 3.1 lb

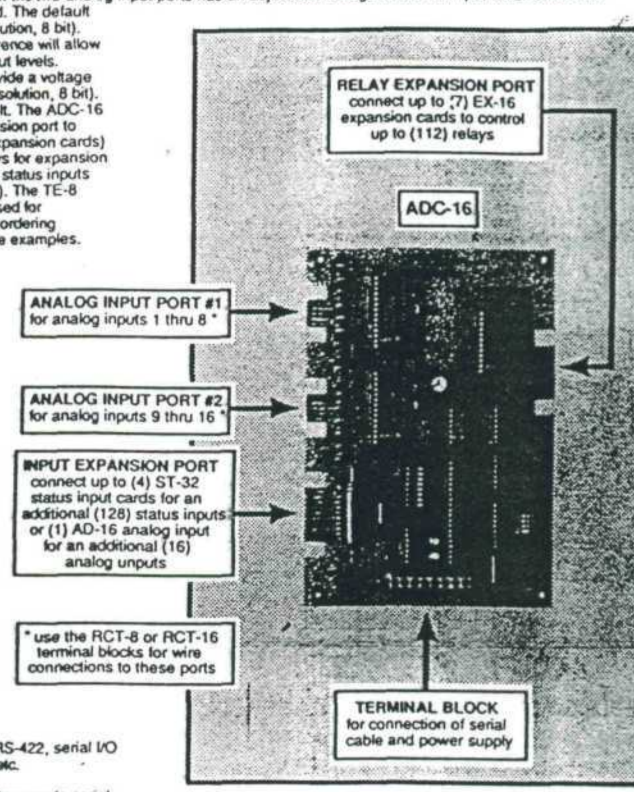
APPENDIX H

A/D CONVERTER DESCRIPTION

ANALOG TO DIGITAL

ADC-16 ANALOG TO DIGITAL CONVERTER... The ADC-16 A/D converter provides two separate 8 channel analog input ports which allow input of a wide variety of analog information into a conventional PC. Applications include temperature input (requires TE-8 temperature input conversion and sensors) and input of energy usage or electrical demand (requires watt transducer & current transformer). Other uses include input of pressure, light, voltage, weight, potentiometer movement, strain gauges, etc. (minimal external hardware required). Connection of a modem will allow these functions to be monitored from a remote site via telephone line (the EX-16 may be used for remote relay control). The A/D output is represented as a single byte number (0 to 255 decimal) with 8 bit resolution or in two byte format (0 to 1023 decimal) with 10 bit resolution. Voltage inputs of 5 millivolts or higher per increment require no additional hardware. The VI-1 or VI-2 voltage amplification modules may be used to input lower millivolt signal levels. Each of the two analog input ports has an adjustable voltage reference input which allows the analog voltage input level to be adjusted. The default level is 0 to 5 volts DC (20 millivolt resolution, 8 bit). The addition of an external voltage reference will allow greater resolution and lower voltage input levels. EXAMPLE: A 1.2 volt reference will provide a voltage input level of 0 to 1.2 volts (5 millivolt resolution, 8 bit). Inputs can be ratiometric or standard volt. The ADC-16 A/D converter provides an output expansion port to control up to 112 relays (using EX-16 expansion cards) and an input expansion port which allows for expansion to 32 analog inputs or an additional 128 status inputs (using AD-16 or ST-32 expansion cards). The TE-8 temperature input conversion may be used for temperature input. See reverse side for ordering information, options and control software examples.

ADC-4 A/D CONVERTER... The ADC-4 provides four 12 bit analog inputs with an optional 8 channel port #2 of 8 or 10 bit resolution. The ADC-4 is identical to the ADC-16 in physical size & layout, I/O functions and expansion capability and provides both the relay expansion and input expansion ports. Analog port #2 may be converted for temperature input using the TE-8 conversion. Port #1 is used for connection of the four 12 bit inputs. The A/D output is represented in two byte format (0 to 4095 decimal) in 4,096 increments. Voltage input range is fixed at 0 to 5 volts DC.



FEATURES

- Low cost...high reliability.
- Use with IBM and compatibles, Apple, Macintosh, Tandy and most other computers.
- Serial data I/O...connects to RS-232, RS-422, serial I/O ports, COM1, COM2, COM3, COM4, etc.
- A wide variety of serial cables and custom made serial cables are available for connection to most computers.
- Full documentation is provided, including connection diagrams, pin-outs, hardware interfacing and control software examples. A disk is provided with each order providing test software and control software examples in Basic, C, and assembly language with .EXE files.
- Full technical support provided.
- Optional RS-422 serial interface available.
- Optional gold plated edge contacts/solder mask available
- Available in 8, 10 & 12 bit resolution.

ACCESSORIES FOR USE WITH THE ADC-4 & ADC-16

AD-16 Analog expansion card
ST-32 Status expansion card
EX-16 Relay expansion card
TE-8 Temperature input conversion
VI-1/VI-2 Voltage amplification modules
PS-8 series port selecters and card racks
CAP-16 Filter capacitor kit
SP-1 Power protector
All relay cards and relay driver cards
All power relays and relay modules
All ribbon cable to terminal block adapters
All connector cables and power supplies
All serial interface cards and converters
All enclosures and mounting hardware

SPECIFICATIONS

Designed for continuous 24 hour operation.

Baud rate is dip switch selectable (50 to 19,200 baud). Default protocol is 8 data bits, 2 stop bits and no parity. Jumpers may be used to select other standard protocols.

Maxim driver/receiver interface IC used for RS-232 I/O. 3486/3487 interface ICs used for RS-422 I/O.

Two 8 channel analog input ports are provided. Inputs are expandable to 32 analog inputs (using the AD-16 analog expansion card) or up to 128 status inputs (using ST-32 status input cards). Up to 112 relays may be controlled (using EX-16 relay expansion cards).

Powered from any power supply with a voltage output of 9 to 14 volts DC. Requires 300 milliamp.

Analog input connections use a standard 10 contact ribbon cable edge connecter (.1" centers). A terminal block is provided for power supply and serial I/O connections.

Dimensions...5" by 7" (rack mountable with other 5" by 7" cards using the CH series card holder racks).

24 HOUR ORDER LINE (800) 842-7714

VOLTAGE AMPLIFICATION MODULES

VI-1 VOLTAGE AMPLIFICATION MODULE... The VI-1 voltage amplification module will amplify lower signal levels for input into the ADC-16 ANALOG TO DIGITAL CONVERTER. The VI-1 module converts a millivolt input (0 to 100 millivolt typical) to a 0 to 5 volt DC output for direct input into one of the 16 analog inputs on the ADC-16 analog to digital converter or AD-16 expansion card. A calibration adjustment is provided to set input scale (down to the 0 to 5 millivolt range). A terminal block is provided on the VI-1 for connections to the power supply and signal I/O. Typical use may include the input of energy usage from a watt transducer, the input of weight from a strain cell or the input of pressure from a pressure transducer. Requires 12 volt power supply, 100 milliamp. Connect to the ADC-16 with the RCT-8 terminal block.

VI-2 VOLTAGE AMPLIFICATION MODULE... The VI-2 is a two channel version of the VI-1 described above. (2) input channels are provided for output to any (2) ADC-16 analog inputs.

ADC-16 ANALOG TO DIGITAL PACKAGE

PAC-B ANALOG TO DIGITAL PACKAGE... The ADC-16 analog to digital package is an assembled package which includes a 10" by 7 1/2" plastic enclosure, the ADC-16 analog to digital converter, the RTC-16 terminal block, power supply and connecter cable. The serial cable supplied will be the CC-DB25S unless specified otherwise.

CONTROL SOFTWARE

CONTROL SOFTWARE FOR THE ADC-16 ANALOG TO DIGITAL CONVERTER

The analog information is transmitted from the ADC-16 upon request from the computer. To initiate the sequence, the A/D channel code must be transmitted by the computer. This is accomplished by using the command: PRINT #1, CHR$(X); (X + 1 = channel #, channel 1 = 0, channel 2 = 1, etc.). This command is then repeated (except when sequencing) to initiate transmission from the ADC-16. The ADC-16 will then transmit a number from 0 to 255 to represent the analog information (0 = 0 voltage, 255 = full scale voltage, 128 = half scale voltage, etc.). The ADC-16 recognizes only the control codes 0 to 15 (or 0 to 31 with the AD-16 or ST-32 connected). The ADC-16 passes all higher control codes to the EX-16 (if attached) for relay functions.

SAMPLE PROGRAM

The following program will continuously display the analog information from each of the 16 analog channels. The screen is updated continuously so that new analog information is displayed at intervals only a few milliseconds apart. (GW Basic, IBM & compatibles)

```
10 CLS
20 DIM A$(20)                                ...specify array
30 OPEN "COM1:9600,N,8,2,DS,CD,CS" AS #1     ...configure serial port
40 FOR X=0 TO 16
50 IF X=8 THEN Z=0:GOTO 80                   ...synchronize
60 IF X=16 THEN Z=15:GOTO 80
70 Z=X
80 PRINT #1,CHR$(Z);                         ...transmit
90 A$(X) = INPUT$(1,1)                       ...receive
100 NEXT X
110 LOCATE 1,1
120 FOR X=1 TO 16
130 PRINT ASC(A$(X));" "                     ...print on screen
140 NEXT X
150 GOTO 40
```

NEED HELP WITH SOFTWARE?
contact us for technical support
or use our custom software.

More detailed information is provided with the documentation supplied with the ADC-16.

ORDERING INFORMATION

Options for the ADC-4, ADC-8 & ADC-16 may be ordered by adding the proper suffix. The following options may be ordered for the Analog to Digital Converters:

/A Option: Serial I/O is configured for the RS-422 interface (distances to 4,000 feet, for use with the ADC-4, ADC-8 & ADC-16).

/B Option: All ribbon cable edge connecter contacts are gold plated and a solder mask is applied to the circuit board surface to insulate the conductive circuit runs. Gold plated edge contacts may be desired if the ribbon cables are connected and removed frequently or if extented life of the contacts is desired. The solder mask will reduce the possibility of a circuit malfunction caused by foreign metal particles and short circuits.

/E Option: Port #1 on the ADC-16 is configured for temperature input (-78° to 146° F) using the TE-8 temperature input conversion (for use with the ADC-8, ADC-16 & AD-16). Includes 8 temperature sensors, 8 trimmers and terminal block.

/F Option: Port #2 is configured for temperature input (same as above, for use with the ADC-4/I, ADC-16 & AD-16).

/G Option: Port #1 is configured for 10 bit resolution (for use with the ADC-8, ADC-16 & AD-16).

/H Option: Port #2 is configured for 10 bit resolution (for use with the ADC-4/I, ADC-16 & AD-16).

/I Option: Optional eight channel analog input port #2 added (for use with the ADC-4).

/Z Option: This option is for use with customized hardware. A 6 digit code will follow the Z suffix to identify the customer and type of modification.

PLEASE NOTE: The ADC-4, ADC-8 & ADC-16 require a power supply, connecter cable and terminal block to function. Select the proper cable, power supply and terminal block for your application and computer from the enclosed data sheets. The EX-16, AD-16 and ST-32 expansion cards require the RC-20 ribbon connecter (sold separately) for connection to the A/D converter.

To order the standard ADC-16 analog to digital converter, specify part number ADC-16. The standard ADC-16 will be supplied with an RS-232 serial interface and tin plated edge contacts.

To order any of the above options, add the proper suffix to the part number. Any number of options may be included by adding the proper suffix to the part number.

EXAMPLE: use ADC-8/E ... to order the ADC-8 with port #1 configured for temperature input.
use ADC-4/A/I ... to order the ADC-4 with RS-422 and the optional 8 bit port #2.
use ADC-16/A/E/F ... to order the ADC-16 with RS-422 and ports #1 & #2 configured for temperature input.

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