RADIO ASTRONOMY FOR BEGINNERS

Michael E. Valdez

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Michael E. Valdez

Chapter 1

INTRODUCTION

Astronomy is the science that studies the universe. With this definition, Astronomy includes all the other sciences, even the sciences that study man. In general, we understand as Astronomy the science that studies the universe outside the Earth, the external universe. Most people considers Astronomy this way.

The study of the universe can take many forms. Considering the external universe, we have to study it in an indirect way. We cannot go to the Sun and install a thermometer to measure its temperature, although we might one day be able to send a prove to do so. This is not possible, at least in the near future, with the other stars. We need to study them indirectly, by analyzing and studying the signals they send us through space. Astronomy can then be classified depending on the media that is used to study the universe. In this way, Radio Astronomy is the part of Astronomy that studies the universe using radio waves, as opposed to Visual Astronomy that studies the universe using optical instruments, or X-ray Astronomy that studies the universe using x-ray radiations. There are many other branches of astronomy from the point of view of the media they use for the study of the universe.

The different branches of Astronomy, which includes Radio Astronomy, can be divided from the point of view of the part of the universe that is the subject of their study. In this way we have Solar Astronomy, Quasar Astronomy, Jovian Astronomy, Pulsar Astronomy, etc.

We should not forget the very important branches of Astronomy that fall under the headings of Astrophysics, Cosmology, etc. that study the structure of the universe, its evolution, its history, its future. Many radio astronomers are interested only on these branches of astronomy, using radio waves to detect the presence of molecules in space, or to detect the composition of the nebulous material filling many portions of our galaxy, where new stars are forming. Radio astronomy, studying very distant and old objects, has given invaluable data for the study of the origin of the universe as we know it. Very special equipment is also used to map the sky using radio waves. A map developed in this way has an appearance very different from the common appearance under visual observation.

This great variety of branches of Astronomy and Radio Astronomy, some times confuses the beginner, who does not know where to start. You should not feel bad if this happens to you. The author of this book created once a school or shop to build optical telescopes. Over a period of two years some thirty five telescopes were built. Most of the people who spent hours and hours polishing and forming their

mirrors, abandoned them after they were working, simply because they did not know what to do with the telescopes. When they started, they simply wanted to build a telescope.

One of the many purposes of this book is to give you ideas as to what to do with your radio telescope, not really after you have it working, but before you build it. The ideal when writing this book is to try to inspire the readers to design and build a radio telescope with a definite purpose in mind, with a definite idea of what they will do when the equipment is ready to work. In any case, since the subject of Radio Astronomy is our concern, we will concentrate only on the different branches of Radio Astronomy.

Radio Astronomy is the intersection of four very important and vast sciences:

Astronomy, that has already been mentioned;
Radio, which is the science that studies everything that has to do with radio waves, communication, generation, reception, propagation, etc.;
Computers, which is the science that studies the processing of data with a digital computer; and
Electronics, which is the science that studies the design of circuits of any kind, whether for receivers, computers, data processing, etc.

An amateur of Radio Astronomy has to have a working knowledge of all these sciences, to be successful in his work. On the other hand, the depth of knowledge required from the amateur is now too great. What the amateur needs is to be able to understand the different technologies and procedures of these sciences, to be able to use them to maximum advantage during his work. As you develop and gain experience, this knowledge will become deeper in the areas in which you get interested.

Saying the same thing in other words, when you drive a car you do not need to know all the details of how a car works, but a good understanding of how it does it, in a superficial way, will help you be a better driver and help you make your car last longer. The same is true in radio astronomy and in any other hobby. If you have a superficial understanding of the way all the parts of your telescope work, you will be able to get better results, you will be able to judge them when you are out buying parts, you will be able to build better parts that you need to build. As you develop in your hobby, this superficial knowledge will gain depth without too much effort and, before you notice it, you will be making knowledgeable decisions, and giving advice to others.

This brings us to a very important point. The realm of Radio Astronomy is so vast that you cannot possibly cover the whole of it. Very soon you must determine which areas of Radio Astronomy are of interest and concentrate on them. This does not mean that you cannot have several areas of interest, or that from time to time you might not explore some areas you have never studied. What this means is that different areas have different requirements and that the equipment that performs properly in one area might not perform at all in other areas. Throughout this book we will describe some techniques and procedures for different aspects of Radio Astronomy and we will suggest experiments for you to get acquainted with these phases of Radio Astronomy and develop an interest in some of them. It has

already been mentioned that one of the most important objectives of this book is to give you this feeling for the different areas, so you can make up your mind.

Whichever the area of interest, you need a base of knowledge to understand what you are doing and to do it as best as possible. Another of the purposes of this book is to point at this base. No work of this type can possibly cover all the topics that are required, at the required depth. Many of the topics will only be mentioned here at what has been called a superficial level, and you will be referred to other books to get a deeper knowledge, when this knowledge is required. Many topics will be completely ignored, to make room for more important subjects that will be covered in great detail.

The form of this book is the narrative. It will be necessary to give a number of definitions and descriptions. The dictionary, or glossary form are both tedious and boring. All definitions required by our development will be threaded into the narrative whenever is possible. This has the disadvantage that it is difficult to develop an index of definitions with a reference to where they are in the book, so you can refer to them later, when you need them. Our solution is to include references to other books that have good glossaries.

This book has really three parts, although they are not always physically separated. This book covers what could be called theory or principles, although not always to the depth that will be desirable. Most of this theory is threaded into the general narrative of the book and constitute a good share of it. When a formula or equation is required, it will be given without any explicit derivation. Including these derivations will only clutter the book with unnecessary details. The interested reader can find the derivations for the equations in the references cited at the end of the book.

This book also gives design and construction details of the different parts of a radio telescope. Of course, some of these details are skimpy, like when we talk about antennas or receivers. There is little point entering into construction details of an antenna, its structure, rotators, support, control and all the other elements, since most of these details are too complicated for a beginner. The same happens with receivers, low noise amplifiers, etc. whose specific design and construction is a very specialized type of work, attempted only by those with great experience on the field.

On the other hand, when we talk about the signal processing parts of the telescope, we will give complete details of design and construction, since this part of the telescope has to be built by the amateur, whether he likes it or not. There is no other solution. In this case, we will try to develop these examples simultaneously in two forms: we will give the details of design in such a way that those of you with good knowledge of electronics can design your own, the way you like it. At the same time, one or several designs will be covered in complete detail, all the way to the placement of parts and building the unit, so those of you without an electronic expertise will be able to build these units. In this case, list of parts and where to get them will be provided, as well as drawings of the placement of parts and routing of the connections.

Finally, this book also has a number of examples both, of the use of the formulae and theory, as well as

the equipment that is being described. We will also include, wherever is possible, problems, exercises and projects you can perform to acquire the much needed experience to work with your telescope. It is highly recommended that you perform these exercises and problems, and go through the projects before starting the design and construction of your telescope. In this way, you will know what you want, and what to expect. It has been mentioned that this is one of the most important aims of this book.

Since this book starts with the proposition that a computer is an integral part of today's radio telescopes, both for gathering data and for analyzing the results, this book includes analyses of computers, what characteristics are required for the computer at the telescope, what is required for the processing computer, the trade offs, etc.

This book, naturally, includes the topic of programming a computer, that today is a very important part of the operation of a telescope. A computer, by its very nature, can be used in many of the aspects of the observation. It can be used for planning a session, for the presentation of a catalog of sources to select the most appropriate path to follow, calculations of the current coordinates of the sky, actually pointing the telescope to the desired region, adjusting the gain of the data gathering equipment to obtain the desired results, taking the actual data at the proper moment, storing the data for later processing and archiving, processing the data after the observation has been performed, preparing the data for distribution to others, and many others.

Many of these applications of computers are too complex to be attempted by a beginner. On the other hand, many beginners in Radio Astronomy are excellent computer programmers or computer engineers, and will not have any problem implementing any of these applications. This book will provide the necessary descriptions, so the experienced amateur in the computer branches can continue independently, and the amateur that is not experienced in computers will have the exposure to what is going on and later, when the experience has been obtained, face one of these applications.

We have presented something like a summary of all the marvelous things that can be done with a radio telescope. It seems that this is a good moment to talk about the opposite problem. How to start. We have not yet covered details of the equipment but we can talk in general terms.

Whether or not you are an expert mechanic, do not attempt to start with a very complex antenna. If you have a usable antenna, for radio amateur work for example, it is highly recommendable that you start your work with it, and leave the construction or acquisition of a parabolic, steerable antenna for later. We will describe a very simple antenna that can be built in a few hours, if you do not have any antenna. The cost of this antenna is only a few dollars, so the loss is not that great, if you have to trough it away at the end. On the other hand, this little antenna will give you enough experience to determine what type of antenna you want for your permanent observatory.

The same happens with the receiver. You might have a piece of equipment that is ready to be used as it is. This is the case of radio amateur equipment, even CB equipment can be pressed into operation as a

radio telescope, to give you a good understanding of what to expect and how to get it. Another interesting source of ready made equipment is satellite TV. A satellite receiver is really a radio telescope, although without the necessary gain for doing a good work. But, without any modification, you can perform many experiments that will let you taste what is radio astronomy and what are the possible results.

The important point here is to understand that if you work temporarily with the equipment you have, to get the flavor of radio astronomy, you need to consider that the results are also going to be only that, enough to give you a flavor of the thing, but not sufficient to satiate you, or to support your interest on the hobby. If you are working with radio amateur equipment or with satellite television equipment, you can easily see the Sun and Jupiter, but you will have problems getting even the strongest sources in the sky, like Cassiopeia A, Cygnus A, Sagittarius A, etc.

These results should not discourage you. You should learn from the beginning to evaluate the results, to recognize what is what you can expect to get from an observation, before you make the observation, to realize the limitations of your equipment and of your operating skills, and to judge the results in this light. If you do this, and your results match your expectations, you will be satisfied. On the other hand, if you do not do this and you expect a strong signal say from Cygnus A and you do not get any, you will be disappointed.

Many amateurs that abandon their fields every year, do so because they failed in this very simple point. Before doing any observation, plan ahead and know what to expect. Throughout this book we will emphasize this very important point, this very important operating procedure, because we think that this simple procedure is not emphasized enough in amateur publications of any branch. You can consider it a matter of survival.

RADIO ASTRONOMY FOR BEGINNERS

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Chapter 2

THE TELESCOPE

A radio telescope is the instrument that permits us to study the radio waves from the stars, galaxies, nebulae, pulsars, and interstellar matter. From the study of these radio waves it is possible to analyze the source that produces the radio waves and the media through which the radio waves propagate from the source to the Earth. A radio telescope is formed by three very important parts:

The Antenna;
The Receiver; and
The Data Processing Unit.

In the paragraphs that follow we will analyze the most important characteristics of each one of these parts, in a superficial way. We leave for later the detail analyses and the design procedures.

From the point of view of the amateur, there are three main types of radio telescopes. The transit telescope has an antenna that can only move in one axis, elevation. The antenna moves only up or down along the meridian, in such a way that it can point both North or South. The telescope is pointed to the declination of the source we want to observe, and we wait until the apparent motion of the stars in the sky brings the source in front of the telescope. In this way, we can only make one observation per day of each source but this type of antenna is much cheaper to build than the other type.

The second type of radio telescope is the one that can point to any place in the sky, and that can follow the daily apparent path of a source in the sky. This telescope can then point to a source and follow it for probably ten hours, depending on the geographical location of the observatory and the declination of the source. Although this type of telescope can be operated manually, with the amateur moving the antenna every 5 or 10 minutes, most of the advantages are realized when the antenna is moved with motors, controlled by the computer.

The third type of radio telescope has two or more separate antennas installed over a certain area, and their signals are combined, to take advantage of the difference in phase between the signals received by them. In this way, the signals can be added or subtracted, obtaining the performance of a very large antenna, almost the size of the area covered by the antennas. If the installation uses more than two antennas, its operation requires a computer to control the phase between the different elements of the array. By combining the amplitude and phase of the different signals over a period of time, in what is

called the reverse Fourier transform, and using the rotation of the Earth, maps of the sky can be derived. The precision of these maps depends of the dimensions of the array of antennas.

A simple, two-antenna interferometer is within the capabilities of an amateur, since it can be adjusted to high performance for a particular frequency. The main advantage of such an interferometer is to obtain a much narrower beam width and a better resolution than with a single antenna. The main disadvantage is the free space required to mount the two antennas.

The Antenna

The antenna is the element that collects radio waves. The power received on the Earth from any of the radio sources in the sky is very small. Even the Sun, the strongest source in the sky by far, produces only a signal comparable to the minute signals put by the communication satellites.

To be able to understand the mechanism for the operation of the antenna, consider a candle in the night. Although the light or power put out by the candle is small, if you are close enough, you will be able to read by the light of the candle. As you get farther away from the candle, the amount of light put by the candle on a sheet of paper is less and less. This illumination is inversely proportional to the square of the distance. That is, if you are twice away than before you receive only one quarter of the illumination.

Now, at the distance we are from the stars, the illumination we get from them is almost zero, although the power they put out is very large. The Sun, at the distance from the Earth, can burn us, but the Sun is only a medium size star. If the Sun were at the distance of any other star, it will only be a little point of light.

Since we are working with such minute amounts of energy, it is necessary to device ways to increase the amount received from the star. Notice that this is not the same we do in the receiver. In the receiver we use active devices to amplify the power at its input. Here we are talking about getting more, not amplifying what we have. The idea is quite simple, really. The illumination received from the source decreases proportionally to the square of the distance. This indicates that, as the light propagates, the area of the wave front increases. This area is the area of the sphere with a radius equal to the distance from the source. If we want to get more of the available energy, we need only to use an element that has more area, and concentrate that power on the antenna. Then, the power received by a telescope from any source in the sky depends directly on the area of the antenna. The more area, the more power received.

Now, there are other considerations to make. In any place of the Earth, and for that matter of space, there is always noise from the many sources that produce electrical discharges, or even from hot elements. It is interesting to make an apart here into the realm of communications to talk a little about noise. Imagine you are in your living room trying to listen to music. Some other member of your family is in the dining room, adjacent to the living room, trying to maintain a conversation over the phone. For yourself, the conversation constitutes noise, because you are trying to listen to the music. On the other

hand, for the other member of your family, your music is noise because he is trying to have a conversation over the phone. So, noise is not something absolute.

Let us take another example with radio astronomical subjects. Imagine you are interested in receiving signals from the center of our Galaxy; the nearby Jupiter is a source of very strong noise that masks the signals you want to receive. On the other hand, if you wish to study Jupiter, the center of the Galaxy puts odd signals into your observations. Then, what is noise and what is signal depends only on what is you are studying, there is nothing that is intrinsically noise or intrinsically signal. Recall also that all the signals we work with in radio astronomy have the form of the traditional noise, or static, of communications.

This is not a nice situation. So, in order to make a more reasonable scenario, let us agree on what is noise and what is signal. In general, we will have our antenna pointed to a certain part of the sky, where our interest is at the moment. Since the antenna always receives signals from all directions and at all frequencies, let us agree to call noise to those signals that come to our antenna from directions other than the direction we are observing. The above case of Jupiter and the center of the Galaxy will not be noise in this sense. We will agree to call such an occurrence interference. Then, we say Jupiter interferes with our observations of the center of the Galaxy, or the center of the Galaxy interferes with our Jovian studies.

The amount of noise received by a given antenna from directions other than the direction of interest, is more or less constant, because the antenna has what we call directivity. Any antenna receives better in some directions than in others and we point the antenna in such a way that the source of interest is in the direction the antenna works better. Then, a larger antenna also increases the relation between the signal and the noise, producing better results. We will cover these concepts in more detail when we study antennas.

There are other problems that relate to the antenna. One is that the antenna requires a large area of land to install it. It requires a heavy base to prevent the antenna from tipping over under heavy wind. The antenna should also move to point to different parts of the sky. As a minimum, an antenna should be able to move in elevation and wait for the stars of interest to pass its beam. If it is necessary to follow the sources as they traverse the sky in their daily apparent motion, then the antenna should move in two axes. All these reasons make even a simple antenna an expensive, heavy item. The antenna is, consequently, the largest element in a radio telescope, The antenna is also the most expensive single item in a telescope.

The Receiver

The receiver is the part of the telescope that gets the power collected by the antenna, converts it into an electric signal, amplifies it, selects it in frequency, changes its frequency, and finally delivers the amplified power to the Data Processing Unit. The receiver does this by using active linear devices. These devices receive a signal from some source, power from another, and using the power supplied to

them, produce a copy of the signal but with more power. By using several of these active devices, the minute power delivered by the antenna can be converted into a power that can drive our Data Processing Unit equipment. In a later chapter we will study receivers in more detail. Now we need only some general concepts.

The receiver has a number of characteristics that are of great importance: Probably the one that receives the most attention is the internal noise. We call the internal noise of a receiver that noise produced by the receiver itself without any input. Imagine you disconnect the antenna from your receiver and connect instead a pure resistor to ground. If you increase enough the volume of your receiver, you will get some output, that can be quite large. This output comes only from the internal noise of the receiver. This is a very important factor because you cannot detect or measure a signal with a level below the internal noise of your receiver. Actually, you cannot know if the signal is there.

This is not the only important factor. The gain of the receiver is very important. We call gain the relation between the power output from the receiver and its power input. The antenna collects energy in very small amounts. It has been said that the total energy that strikes the surface of the Earth from all the sources in the sky is less than the energy of a snow flake hitting the ground. The gain of the receiver will make this small signal into something we can measure, we can record, we can analyze.

The gain of the receiver is then very important factor. If your receiver has a very low internal noise, and you have a large antenna, you might still not be able to get anything because your receiver does not have enough gain to give an output that can drive your data equipment. All your equipment must match each other.

Another important factor in a receiver is its linearity; that is, if the power input at the antenna doubles, the output of the receiver should double. This is very seldom achieved and then we talk about the range of linearity. The receiver might be linear up to signals of certain level. Above that level, the receiver is no longer linear. This can be translated into a telescope that works linearly for normal radio sources, but when put to work with the stronger sources of the sky, the results are not linear.

Lets make this clear with an example. Let us say you receive a 100 J source and you get a 0.08 volts increase in the output from your detector. The Jansky, which is abbreviated J, is the unit of intensity for the radio sources. You point to a 200 J source and your detector gives you an increase of 0.16 volts, exactly double. But, if you point to a 1000 J source, you get only 0.52 volts increase in the output of your detector, instead of the 0.8 volts you should get. This is what is called nonlinearity.

You should understand this is fairly logical. You cannot expect a receiver circuit to be linear for very large sources because of the physical limitations of the active circuit. If the supply voltage into an active circuit is only 5 volts, you cannot expect an output larger that 5 volts, whatever the input. Recall, the active circuit only makes a copy of the signal with the supplied power. The active circuit does not create power. The receiver described above is fairly good since it is linear for sources in the usual range of interest and there are many sources which can be studied with that instrument.

Another characteristic of the receiver that is very important is the bandwidth; that is, the effective range of frequencies the receiver processes, from one end to the other, with about the same gain. This is one of those values that are at the same time good and bad. The reason is the power received from a source is proportional to the bandwidth of the receiver, simply because it is noise. A large bandwidth is then good because the receiver will process more of the power from the source. That is, a receiver with 30 Khz bandwidth receives 10 times more power than a receiver with 3 Khz bandwidth.

The bandwidth is also bad in that the noise and the interference will enter the receiver in proportion to the bandwidth. Imagine a practical case of an amateur working in the city, say at 900 Mhz. If the neighborhood TV transmitter works at 850 Mhz, a 30 Mhz bandwidth makes that location unsuitable for radio astronomy. On the other hand, a more modest bandwidth will filter out the TV station and will permit you to work.

Remember, the power of a small transmitter can be 1000 Kw, which at a distance of a few miles, puts a terrible signal in your receiver. Remember also, the receiver really receives signals at all frequencies. The frequencies of what we call the bandwidth are received as strong as possible and all other frequencies are attenuated but there is no way to attenuate them to zero. Attenuation is when you multiply a signal by a number less than one. That product cannot give zero.

The Data Processing Unit

The third part of the telescope is the Data Processing Unit. The signal from the receiver is first rectified, then it is filtered to make it into a smoothly varying signal. Then, this signal is captured in some way and stored for later analysis. This whole process is performed by what we want to call the Data Processing Unit of the telescope. Some times this part is called the DC processor of the telescope, because the signals are varying very slowly, in a way that is called DC, or direct current, in electricity. We will use the name of Data Processing Unit when it includes a computer.

Some years back the Data Processing Unit of a telescope used a strip chart recorder and there are still some amateurs that retain strip chart recorders in their telescopes. Today, the logical end of a radio telescope is a computer. The cost of the most complex computer that can be used in a radio telescope, is only a fraction of the cost of the antenna or the receiver. It does not make any sense to have an expensive piece of equipment feeding a strip chart recorder.

The reason is quite simple. Save for admiring the trace of the strip chart recorder or framing it on your wall, it is very difficult to do any useful work with such a recording. Most of the information that is required to preserve the value of an observation should be entered by hand and is susceptible to error. There are many operations that simply cannot be done with strip chart recordings.

On the other hand, a computer can collect data from a telescope at precise intervals of time, store all the required information so the data is valuable years to come, the computer can expand a recording that is too small for observation, can smooth the trace, can add several traces into one to enhance the signals;

etc.

In what follows in this book, we will be considering a computer is an integral part of the radio telescope and we will treat it as such. When we study in more detail the data part of the radio telescope, which will be most of our interest, we will consider the problems and benefits created by the computer.

Final Considerations

Before we finish this introduction, it is necessary to mention that, except for the computations of area, form, etc. there is very little that can be said about the antenna. This is mostly a mechanical problem and there are two ways to face it: If you are mechanically inclined, you do not need more information than what is given here to build your own antenna; if you are not mechanically inclined or you do not have the necessary tools, you are limited to buying a ready made antenna and we will also analyze this problem.

The problem of the receiver is some what similar. Designing and building a receiver for micro waves is not a task that can be done by a beginner. If you are an accomplished designer and builder of micro wave equipment, you will not have any problem designing and building yours. Again, the information given here will be more than sufficient. If this is not true, because your are not an experience micro wave designer and builder, you are much better off buying ready made equipment, and we will also cover this point.

It is important to realize the balance between the different elements. A receiver can do only so much with a signal received from the antenna. The quality of the receiver has much to do with the results but, there is no point to have a very expensive and quiet receiver at medium frequencies, connected to a 4 ft antenna. By the same token, there is no point on having a 16 ft antenna, if your receiver has so much internal noise that swamps the signals coming from the antenna. The Data Processing Unit of your telescope deserves the same considerations. If your antenna and receiver are good, terminating them with a fifty-dollar strip chart recorder is a total waste. A good antenna and receiver deserve a Data Processing Unit that can process the information and that can take advantage of the equipment.

Now we should face the problem of the organization of this book. The logical sequence to follow in the presentations of this book is whatever sequence is logical for the amateur to obtain, design, build, or buy his equipment. This is a touchy subject. Most amateurs will start by building an antenna as good as they can; then, they will start buying or building the receiver, and only then they will face the problems of the Data Processing Unit, almost as an after thought.

There are several problems with this procedure. The most obvious one is that you cannot test and calibrate your antenna until you finish all the equipment. At that moment you will have an antenna you do not know if it works, and you need to test and calibrate, but you will also have a receiver you do not know if it works and that you need to test and calibrate, and a Data Processing Unit equipment in the same situation, you need to test and calibrate.

We will suggest here a more logical approach. We will start our analysis, and we suggest you start working on your equipment from the Data Processing Unit. The Data Processing Unit is very easy to test and calibrate and we will suggest procedures for doing so. The difference in the Data Processing Unit for the different types of observations is not that great and it is always good to have a Data Processing Unit that is flexible and can be changed over a very wide range of conditions.

While we are at the design and construction of the Data Processing Unit of your telescope, we will cover most of the topics of importance for the operation of a telescope and we will suggest experiments that you can perform quite simply, to give you a feeling of what is to have a radio telescope and what kind of work you can do with it.

The antenna and the receiver are very particular to the type of observations you want to do. Different operations need different frequencies, different antennas, different equipment, but, if your Data Processing Unit is good enough, you can use it for all of them.

So, this book will start by describing the Data Processing Unit of your telescope and guiding you on its construction. Later, we will cover antennas and receivers when, also, you have more experience and you will be able to tackle these topics, that are much more complex and difficult.

RADIO ASTRONOMY FOR BEGINNERS

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Chapter 3

A REAL TELESCOPE

Before starting with the description, design and construction of the different parts of a telescope, it is good that we visit a real installation of an amateur. This will serve as motivation for the material that follows. The installation we will visit is the radio telescope I had installed at my house in Davenport, IA. some years back. For the observant reader, let me explain that I am back living in Davenport, IA. although at a different location. You can realize from the description that follows, that there is some years I built that telescope. The advances in computer technology will be evident.

This installation is really two telescopes, one for 432 MHz and another for 1300 MHz. The only common part is the computer. The reason for building this telescope was that the level of noise in Davenport is the highest I have seen in the many places where I have lived. Most of the time I am not able to get any signal from the Sun, that is buried in the noise. The noise does not come from the equipment but from interference from transmitter, cellular phones, and similar equipment. You can imagine there is very little I can do under these conditions.

Reading through old copies of RADIO ASTRONOMY, the Journal of the Society for Amateur Radio Astronomers, I found an interest of the members in what at the time was called High Energy Pulses, or HEP. These were unexplained high amplitude short pulses observed by several members. Several attempts to pin them down by simultaneous observations failed because they were not predictable. One article, written by Gene Greneker, suggested a procedure for determining if the pulses originated on the Earth, or outside. It involved making simultaneous measurements at two frequencies. Pulses from outside the Earth will arrive at different times at the two frequencies. The time differential depends on the path traveled by the signal and the difference in frequencies.

A block diagram of the telescope is shown on Fig. 3.1. All the different blocks have been labeled. As mentioned before, the only common element to the two channels was the computer. This is necessary to assure that the measurements are simultaneous. Each point at each frequency was made by adding a large number of measurements. These measurements were made alternatively and very fast, one for each frequency. The averages for each frequency can be considered as simultaneous.

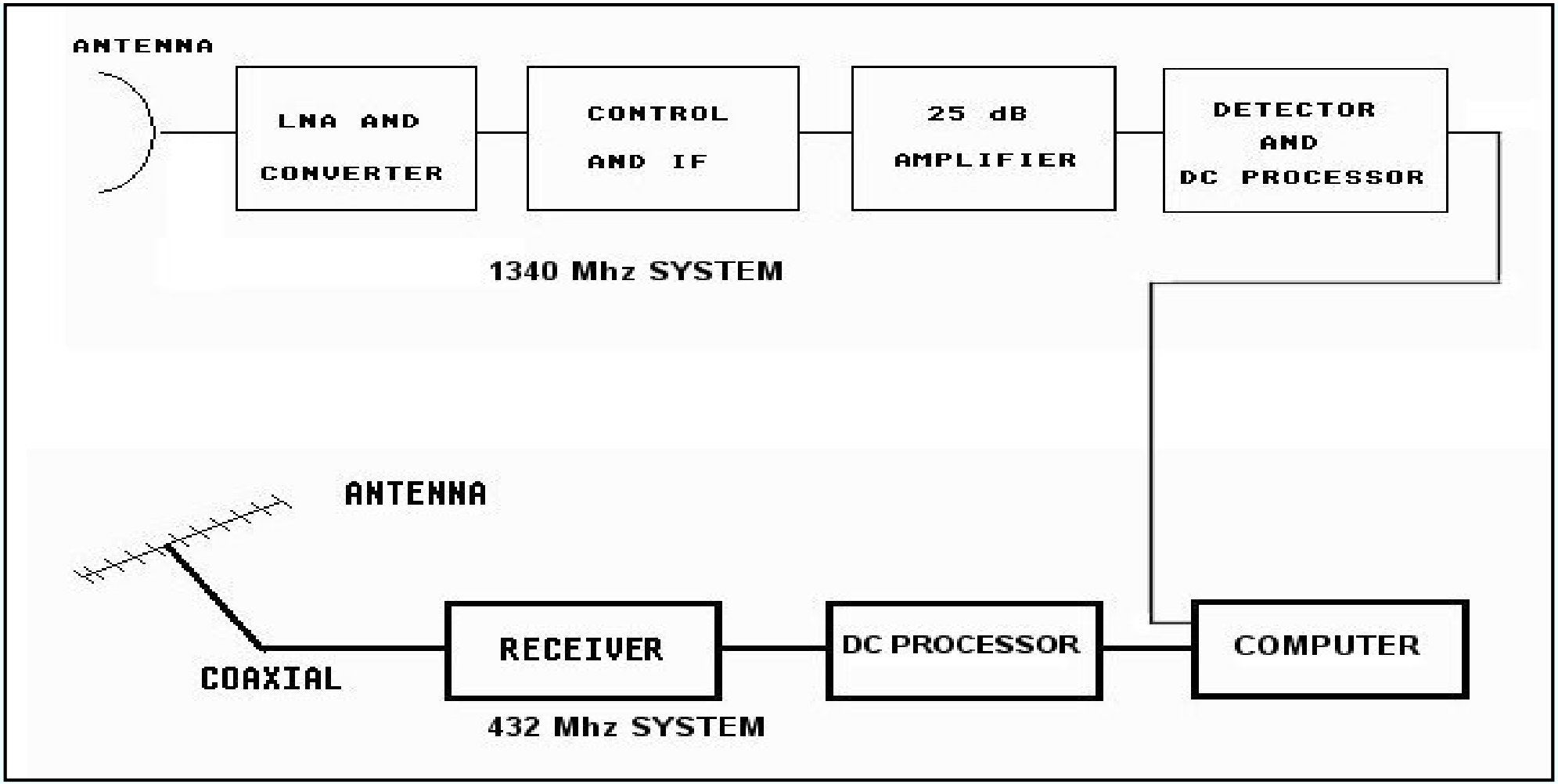

Fig 3 - 1

The 1300 MHz system started with a 6-foot parabolic dish with a cylindrical feeder designed for the frequency. The antenna mounted in a horizontal axis. A rotator permitted varying its elevation. The rotator used was too small and failed at medium winds. The antenna was most of the time locked in one place. The feeder was formed by two parts: the front part was the feeder proper and housed the dipole that collected the energy. The back half of the feeder was a closed box filled with thermal insulation. It housed the pre-amplifier and down converter. A coaxial cable left through a hole on the back of the box. That coaxial carried the signal to the house and the power to the down converter. The down converter was part of a receiver made by PC Electronics.

The 432 MHz antenna was a 24-element Yagi made by Cushcraft. Some of the braces that come with the antenna had not been installed, to permit moving the antenna on a horizontal axis. The boom of the antenna had been reinforced with inserts, but still sags too much. The wind moved the antenna by up to 3 degrees. This antenna was mounted in a small tower and could be moved in azimuth and elevation with a dual rotator. A pre-amplifier for 432 MHz was mounted at the antenna to reduce the losses in the cable. All 432 MHz equipment was made by Advance Receiver Research.

The coaxial cables, the power cables for the pre-amplifiers, and the control cables for the motors came to the house, though a hole in the wall. The coaxial cables ended in a unit that housed the rest of the electronic equipment. The electronic equipment was in a box with cover and shielding. This box had two levels or decks. To the left on the upper deck, there was the control unit for 1300 MHz. It was formed by the other part of the receiver made by PC Electronics for amateur television in the 1296 MHz band. A control knob permitted to adjust the frequency. This knob was not accessible once the box was covered. In the center and to the right the two DC processors were mounted. The center one was for the signals at 1300 MHz. The right one connected to the 432 MHz equipment. Both processors were practically equal, except for adjustments. The front panel had two meters for each DC processor. One meter was connected to the input stage and the other measured the output to the computer. The power supplies sat close to the electronic box. There were two power supplies. One for the DC processors and one to give the 12 volts needed by the 432 MHz equipment.

The lower deck of the box housed the 432 MHz equipment. The receiver was formed by connecting together off-the-shelf units produced by Advanced Receiver Research. A chain of 432 MHz amplifiers fed the 432 to 28 MHz converter. A chain of 28 MHz amplifiers followed the converter and fed a detector housed in a similar box.

Finally, a description of a general view of the whole installation. To the left was the XT-type computer that sampled the signals at regular intervals of time. It had 640 Kb of memory, a floppy disk, a 20 Mb hard disk, serial and parallel ports and a color monitor. I bought it used for less than $ 60. To the right was the electronic equipment box, with its cover in place, of course. Since the box was plastic, it was necessary to use internal shielding. The box only protected the equipment against dirt and mechanical damage. In the center sat the battery backup power supply that fed the whole equipment. It had 250 VA capacity and could carry the equipment through a 15-minute outage. More interesting was the fact that it eliminated all the small variations and interruption that happen all the time in every place of the country.

The XT computer was also connected through the serial port and a 4-wire cable, to my 486 computer, some 30 feet away in another room. From time to time, depending on the work I was doing, I passed all the data from the XT to the 486 computer for analysis and storage. Data was stored in 1.4 Mb diskettes in a metal cabinet originally built to store key punched computer cards.

The function that any equipment performs depends on the software running in the computer. All software was developed in the 486 and passed to the XT through the same connection. I prefer to develop specialized programs for each application, instead of a single program that does everything. I also had one of these programs in the XT. It was used mainly for single observations and for testing.

As a final note, working with this equipment and sampling the signals very fast, I was able to do some work of interest, in spite of the high level of interference. With a sampling rate of 30 samples per second, the records for 432 and 1300 MHz look like noise. When the computer displays the two records on the same graph, it is possible to find a number of pulses that occur at one frequency and not at the other. These are terrestrial pulses. Some times it possible to find pulses that occur at the same time in both frequencies. These are also terrestrial pulses. Once in a while there was a pulse that occurred first at 432 MHz and slightly later at 1300 MHz. These are extraterrestrial pulses. As you can imagine, I could only see pulses that were larger than the noise at my location. A number of extraterrestrial pulses satisfy this condition. Fig 3-2 shows one of these pulses. More details about the equipment and an article I wrote about the results obtained with these telescopes, can be found with the publications in my web page.

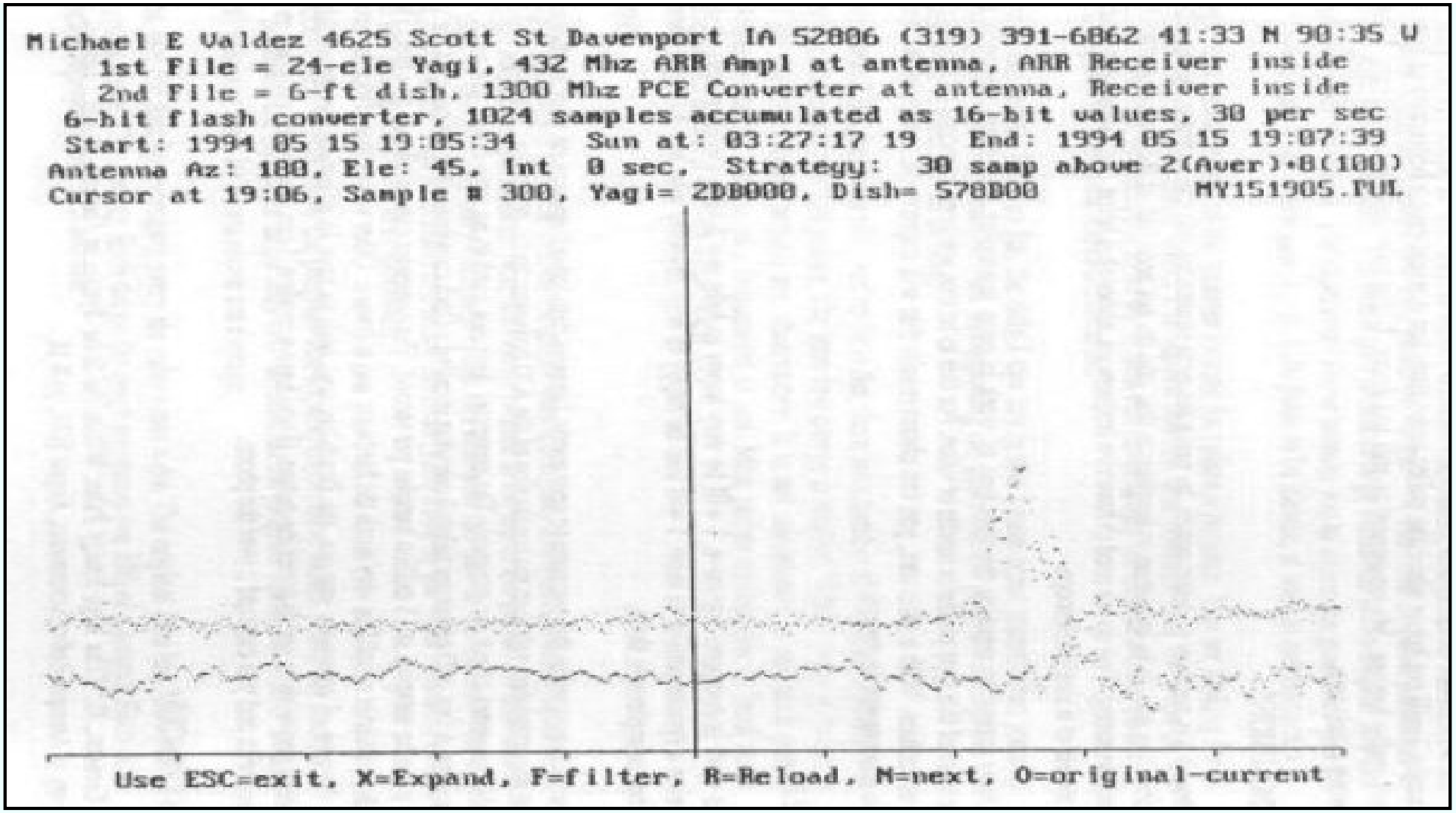

Fig 3 - 2

During my years as amateur radio astronomer I have designed and built many different radio telescopes. He you have a potpourri of pictures of different equipment. Fig 3-3 shows the 6-ft dish and Fig 3-4 shows the 24-element yagi mentioned above. They are both installed in my house in Florida. Fig 3-5 shows one of my first receivers for 432 Mhz, built with Advanced Receiver Research equipment, and a DC-Processor mounted inside metal boxes. You can notice that in that time I used a strip chart recorder.

Fig 3 - 3

Fig 3 - 4

Fig 3 - 5

RADIO ASTRONOMY FOR BEGINNERS

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Chapter 4

THE DATA PROCESSING UNIT

The Data Processing Unit of a telescope is that part that receives the output from the receiver and converts it into something useful for us, both immediately after the observation ends, and in the future.

Notice that this definition of the Data Processing Unit includes not only the immediate analysis of the results of the observation, but also the future analyses; consequently, this definition requires the storage of the data in such a way that will be useful for years to come.

It is not sufficient to observe a source pass through the beam of your telescope and move a needle in your meter, or make a trace on a paper. It is not sufficient, either, to have a computer retrieving values during the observation and putting them on a diskette. For your radio telescope to be any good, it is necessary that you save the information collected in such a way that the coordinates of the sky where the telescope is pointed at every moment of the observation be known or can be computed, the source can be recognized, the conditions of operation can be obtained, the date and time of the observation be known, the equipment in use be recorded, etc. This is to say, the results of the observation should be stored with all the necessary data to make it complete.

Manual data collection has been one of the big problems of science, since scientific observations started. One of the most precious attributes of a scientist was the ability to make observations and record the results in an impersonal way, introducing as little bias as possible. This is quite a difficult task. Any observation that is recorded by hand tends to have the bias of the observer, whether by emphasizing those values supporting his opinion, or by de-emphasizing, or deleting, those values that do not support his opinion.

Today we have a device that can make observations and record the results with total impartiality. At the same time, this device can record all the supporting information in an automatic way, so none of them is lost or forgotten. This device is the computer and, given the cost of today computers, there is very little justification for not using one at the Data Processing Unit of a telescope.

The signal that comes from the receiver has the necessary amplitude, it is hoped, but has one characteristic that is not good: it is what in electricity is called an alternating voltage. The voltage of the signal varies over a wide range, including positive and negative values. The computer is very fast, from the point of view of human reactions. The variations of the signal coming from the receiver are too fast

for even the computer to follow.

There is another point, we are not interested on the instantaneous values of the voltage coming from the receiver, or from the source; we are interested on the power coming from the source. Then, the first task of the Data Processing Unit of our telescope is to extract the power information from the variable voltage that the receiver delivers. This is done with the circuit that is called the detector.

The data output from the detector is still varying too fast either for the computer or for any type of recorder. In general, we are not interested in these fast variations of the signal, most of which may be only noise or interference. Then, the detector is followed with a filter, that smooth out these small variations. This filter is normally called an integrator in a radio telescope. The output of the integrator is a voltage proportional to the integral (instantaneous average) of the input coming from the detector.

At this moment we have a slowly varying voltage with some value, which follows the variations of the power received from the source. If we are using a transit telescope, one that is fixed and lets the star pass through its beam, the signal will increase when the source moves into the beam, and decreases when it goes out of the beam.

The problem that we have at this moment is that this signal is the sum of two signals: the background noise of the sky, the ambient noise, the interference, the receiver noise, etc., and the actual signal coming from the star. In order to separate these two signals we use what is called zeroing. The noise from the background, the ambient, the receiver, etc., are almost constant so we add a voltage of the same magnitude and the opposite sign to cancel it out. After zeroing we have only a signal that represents the power received from the star, if all our equipment works linearly.

This voltage is quite small. The reason is simple, we need to have a small voltage at the detector so it works in the region that produces square law detection. We will study this point later but this voltage is on to order of 0.4 to 0.5 volts. A normal source from the sky produces between 1 and 5% increase in the base output of the detector; so, after zeroing we have a voltage on the order of 5 to 20 millivolts at the peak of the pass of the source. A computer needs a voltage on the order of 5 to 10 volts, so we need some variable amplification, to adjust for the intensity of the different sources we will want to study. The element that produces this amplification is called, quite logically, an amplifier. So, the next element in our Data Processing Unit is an amplifier. In a complete unit we will also have an amplifier between the detector and the integrator, to improve the rejection of noise.

The voltage output from the amplifier is what in electricity is called direct voltage; a voltage that has always the same sign and a magnitude that varies only very slowly. But this voltage can attain any value between zero and its maximum. In computer engineering this type of voltage is called analog voltage, as opposed to digital voltage that can attain only one of two levels, normally either zero or five volts.

The element that converts an analog voltage into a digital value is called an analog-to-digital converter,

which is shorten to A/D converter. Note that now we say digital value, not digital voltage, because the output from an analog-to-digital converter is a digital value representing the instantaneous voltage. A digital value is formed by several digital voltages. The output of the analog-to-digital converter is read directly by the computer.

We can have other elements in the Data Processing Unit of our radio telescope, and some of them makes life easier. Meters should be installed in various points of the data path so we can monitor the values to calibrate the instrument and while we make the observation. Important places to monitor are the output from the detector, and the input of the A/D converter. Most people still want to have a strip chart recorder connected some place. Others want to have an audio tape recorder to save the analog signal before it is sampled by the computer. We will talk about these operations later, when we talk about the operation of the Data Processing Unit as a unit.

In summary, the Data Processing Unit of a telescope is formed, as a minimum, by the following parts:

The Detector;
The Integrator;
The Zeroing;
The Amplifier;
The Analog-to-Digital Converter;
The Computer;
Some Meters; and
Some Accessories.

The chapters that follow are devoted to the analysis of these parts, one by one. We will give the theory of operation, the details of design, experiments to understand their operation, and the complete design of one, or several units.

When we studied the telescope as a whole, we mentioned that it was very convenient start our study from the Data Processing Unit, and we analyzed the advantages. When we face the task of studying, designing, and building the Data Processing Unit, we have a similar problem. If we start studying the parts starting with the detector, we will not be able to present meaningful experiments for the reader to firm up his studies. When we build our unit, we cannot test it until the whole unit is ready.

For this reason, we will start the analysis of the parts of the Data Processing Unit by studying the computer, programming, developing special programs, etc. In this way, when we design and build the analog-to-digital converter, we will have the computer and the programs ready to test it and, at that moment, we will be able to perform a very interesting experiment that will put the reader in front of the computer of a very large radio telescope and analyze the data that is received.

RADIO ASTRONOMY FOR BEGINNERS

Michael E. Valdez

Chapter 5

THE COMPUTER

This chapter studies computers in general, including the characteristics a computer must have to be useful in our work. Subsequent chapters study programming, sampling data from our telescope, storing the data with all relevant information, presenting the data as a graph. These descriptions will be made in such a way, as to give you a feeling of the operation of the telescope, preparing for an observation, saving the results of the observation, etc. The examples presented in the text should give you enough ideas so you will be able to prepare your own procedures, and your own programs.

A digital computer is a device that permits us to manipulate information at a very fast rate. The computer is very good at making repetitive operations without error, making simple decisions based on the available information, making arithmetical computations at a very high speed, and similar tasks. A digital computer is very bad at any of the simple tasks that require judgment.

For example, a computer can perform in a few minutes, millions of computations on the points of a figure, but it cannot recognize a chair in the same figure. The computer can sort a list of several thousand names, alphabetical or in any order we want, in a matter of minutes or seconds, but will have a very hard time recognizing the verb in a sentence. You see the point, give the computer a simple repetitive task and it will perform it fast and efficiently, but do not ask the computer to do anything that requires those logical decisions our brain performs every second, without any effort.

The computer works with information. The information is presented as digital numbers stored in the computer memory, but the computer does not have any way to know the meaning of the information it is working with. A computer will manipulate a number that it retrieves from whatever place we command it to, manipulate it in any way we command it to, regardless of what the number means to us. For us, a number can mean a command from a program, the name of a star, the magnitude of the signal at the given moment, the time of that observation, or whatever we want. For the computer it is only a number. This creates most of the problems with a computer.

All these ideas can be summarized in the statement that the computer does only what its instructions tell it to do; nothing else, nothing more. Exactly what the instructions tell it to do. This is the reason why computers never make mistakes. The person giving the instructions makes the mistakes.

The instructions to a computer are given in a document that is called the program. A program is a

sequence of instructions for the computer to execute. Note the use of the word sequence. The computer executes one instruction at a time, regardless of the current hype about multi processing; when it finishes with that instruction, it goes to the next, until it finishes with the sequence. The last instruction must be to wait for more instructions.

In summary, before you start working with a computer, it is imperative that you understand that the computer will do exactly as told. For example, if you want one of your kids to read you a special page of the paper, say the comics, you will probably tell him or her something like this: "Bill, Read me the comics". The computer does not understand anything like this. The computer needs a detailed explanation of what you mean by "read" as well as a complete description of what is "comics". If you explain the computer that "read" means to produce sounds that represent the words in the particular document it is reading, the computer will ask you simply "How?".

This is the most important characteristic of a computer. You need to explain it what to do, step by step. There is no "You know" for a computer. Of course, you can use a program written by somebody else, that tells the computer how to read, but that program has to tell exactly how to do it, step by step. This, naturally requires that you know exactly how to perform the task, from the computer point of view.

With this point understood, let us concentrate in what the computer can do in the radio astronomical environment. Radio astronomy is one of the many areas where a computer is invaluable, because there are a large number of repetitive operations we can tell the computer exactly how to do and we will be sure, they will be done. We do not have to worry again about those details.

We should not forget that the computer can also have applications outside the observatory, in the home, and we will mention some of these applications.

A computer is very useful for performing the following tasks:

Keeping a catalog of stars;
Showing the catalog of stars;
Showing only a portion of the catalog of stars;
Sorting the catalog any way we want;
Showing the sky coordinates at the moment;
Recording our selection from the catalog;
Recording our instructions for an observation;
Pointing the telescope to the desired coordinates;
Starting an observation at a given time;
Alerting the user of the start of the observation;
Moving the telescope to track a start;
Sampling the signal at a given rate;
Saving the samples in a given way;
Saving all the conditions of operation;

Monitoring the signal for unusual values;
Alerting the user of unusual values;
Stopping the observation at a given time;
Alerting the user of the end of the observation;
Showing the results of the observation;
Adjusting the amplitude of the signal to the display;
Producing copies of the observations;
Maintaining a catalog of observations; and
Many others.

You should also consider whatever other applications you might have for the computer. Among this, we can mention the following:

Writing letters, documents, articles, books, etc.;
Keeping tract of your finances;
Helping your kids in School;
Keeping your wife recipes;
Keeping track of your video tapes;
Letting your kids play games;
Communicating with others over the phone; and
Millions of other applications.

These lists are by no means complete. Many of these applications require special hardware, others require the data to execute the command. For example, for the computer to point the telescope, you need motors that will move the antenna, controllers that will energize the motors, signals that indicate where the antenna is pointing at the moment, etc. In the same way, for the computer to display the sources in a certain region of the sky, it needs a catalog of the sources in a way that it can read and interpret. It is then, the responsibility of the programmer to provide the commands and the information to perform the commands. One without the other worth very little. The same is true with the hardware. The best program cannot move an antenna that has no motors.

Some of the applications mentioned above are quite simple and we will explain how to tell the computer to perform them. Other applications are too complex and will be left for when the beginner is no longer a beginner.

Without entering into a lot of detail, we have to mention the most important parts of a computer, so the reader can have an idea of what we are taking about. The most important parts of a computer are as follows:

The processor. There are many microprocessors in the market, and they are continuously changing. The processor fixes most of the characteristics of a computer from the programming point of view. From the users point of view, they make little difference. By the same token, if you program the computer in

a high level language, like BASIC or C, it does not make too much difference which processor your computer uses. The only real difference is between the two main families of processors, and the effects they have in the system programmers. The programmers used to the Intel family of processors have developed procedures and methods of their own, as happens with the programmers that use the Motorola family. These procedures are very different. While those programming for the Motorola family tend to prefer the use of the mouse and graphics in their programs, traditional programmers of the Intel family tend to prefer the command line for entering instructions to the computer. Intel and Motorola are trade marks and the name of the manufacturers.

One characteristic of the processors that is used very much in propaganda is the speed. Normally, nobody talks about the speed of the processor but of the speed of the clock and then, all the talk about speed is only propaganda. It is not possible to compare two different processor working with the same clock frequency, even in the case that both processors belong to the same family. For example, an Intel Pentium is really faster than an Intel 486 working at the same clock speed.

A processor needs storage space for the instructions and the data of the program. This is called memory. A computer with too few memory locations cannot perform all tasks. For our purpose, this is not too much of a problem, since the most complex program you will ever dream for a totally automatic radio telescope, does not require a lot of memory. Memory is normally measured by the number of bytes, and the abbreviations in common use today are: K for kilo, means 1024 bytes, M for mega, means 1024 K bytes and G for giga, means 1024 M bytes. A salesman will try to sell you as much memory as you can buy, but certain computers, especially the IBM and IBM-compatible computers, have problems using memory above 1 M. IBM is the name of a manufacturer of computers.

The keyboard of the computer is used to enter immediate commands to the computer, whether to load a program or perform a task. IBM-compatible computers have two types of keyboards and the enhanced keyboard has several advantages that are worth the slight premium.

One of the most important problems when buying a computer is the display. The display is the TV-like device that permits you to see what the computer is doing. The IBM-compatible computers have a very large variety of different displays that can be used. The most important characteristics are the size, the resolution and the color capabilities. The size is like in a TV, is the dimension of the diagonal of the display. The resolution of a display (or monitor as it is also called), is the number of dots that the monitor can display horizontally on the screen. It also represents the maximum number of characters that can be displayed per line. Do not get fooled by salesmen that tell you that the monitor they are offering you can display 132 characters per line. This alone means very little. It can be that it displays them, but not at the same time. The best measure is the number of dots. 320 dots is rather rough; 640 is a very nice number; higher numbers are better. Of course, as everything in this life, you have to pay for the higher resolution. This is one of those things that is better to pay for. Try to get from the beginning the best monitor you can afford.

If you are considering an IBM-compatible computer you have to consider that the monitor alone does

not make the display. You must have a card, or interface adapter as is pompously called, to make the display work. The point is that both should match. You can get a 1024 dots resolution display with a card that gives you only 640 dots, and you will be wasting display quality and price. If you want to use the full resolution of your display, you will need to buy a new card. So, card and monitor should match. Note that the capability to support graphics is in the card. Every monitor can display graphics.

Finally, we should mention the color capabilities. These come from both, the monitor and the card. You can have color capabilities with a much larger variety of resolutions than for text. In the case of a color display, you need to be more careful that the monitor itself and the card match characteristics, so they work properly.

After having ways to input and output data to the computer, the next important element is the mass storage device. This is not too expensive and, if you are buying a new computer, it is highly recommended that you get two floppy disk drives. This will permit you to copy data from one disk to the other. Today there are two size of diskettes used in computers, 5 1/4 and 3 1/2 inches. There is no advantage of one over the other. Do not buy one of the older drives that can work only on one side of the disk. If you buy a used one, be sure is double sided. Each one of the drives comes in two different densities. The 5 1/4-inch drives come with double density, 360 K, and with high density, 1.2 M capacity. The 3 1/2-inch drives come with double density, 720 K, and high density, 1.44 M capacity. If you buy new drives, the larger capacity is better because you can also work with lower capacity diskettes. If you buy a used computer, be sure the drives are for the largest capacity. The standard today is the 3 1/2 inch with 1.44 M capacity.

The hard drive is today the normal storage device. At the prices of hard drives today, you can have a very large hard drive that will handle all your storage needs. Finally, the CD-ROM is today a very important accessory since most programs come in this format. With a large hard drive, the only way to back it up is with a Read/Write CD-ROM. You can add these elements later.

A computer communicate with the outside word through ports. There are two types of ports in common use today, serial and parallel. Serial ports are used for practically everything while parallel ports are normally used only for printers. It is good to have at least one of each, but you can add them later.

A printer is a good convenience, especially if you plan to use the computer for writing articles about your observations. A printer is expensive, but there is no alternative. Beware of inexpensive printers that can end up being very expensive. Prefer to wait and buy a good quality printer and not something of less quality.

Another interesting accessory is the modem. A modem permits you to connect your computer to the telephone lines and transmit data as tones. This is one of the interesting uses of a computer. Using a modem you can connect to any other computer and transfer data, programs, messages. Today, the standard procedure is through the Internet, where people gets together to chat, or interchange messages. This is a very useful source of information and help when you have a problem.

The process of designing, building, testing, calibrating, and learning how to use a radio telescope is a task that can take several years, fun filled years. The requirements of the computer for a telescope change during these years and it is very difficult to know, from the beginning, what these requirements are. Consequently, the first requirement of a computer for a radio telescope is that it can be expanded as the need arises. It is important that we can buy a computer with the resources we have at the moment, and later expand it as the need appears. You have to realize that, at the beginning, you will need to get quite a lot of equipment for your telescope. This requirement should be kept in mind, so as not to overstretch your resources to the point that you have to abandon the hobby. This book has this point in mind in its organization, presenting the ideas in an order you can follow, having fun and gaining experience in the mean time.

Not all the computers in the market are expandable. Most of the best computers cannot be expanded. It is highly recommended that if you do not have experience with computers, ask a friend or relative that has that experience. On the other hand, if you have experience with computers, you probably have one.

Most of the explanations in this book refer to what is now called an IBM-clone, or IBM-compatible. The reason is not that these computers are the best in the market for the price, because they are not. The reason is that most IBM-clone users are bitten by the speed bug and change computers continuously. There is a large number of used computers in the market, at reasonable prices. The IBM-clone has expansion slots that permit the addition of different accessories.

The same characteristic that is desirable, creates a problem for the beginner looking for a computer. Some of the computers offered in the market, whether new or used, are only an empty box that cannot do anything. To be useful for radio astronomy applications a computer must have, as a minimum, the following characteristics:

As much memory as you can afford;
At least one floppy disk drive;
At least one hard disk drive;
An operating system;
A monitor that supports graphics;
The card that makes the monitor work; and
Some empty expansion slots.

Color monitors are more expensive than monochrome ones, but the added dimension of the color makes working easier. Very soon you will want to have color and it is not a waste to start with one, if you can afford it.

The values given above are mere minimum. If you find, or can afford more, 640 K of memory is what the computer supports, two disk drives are nice, a parallel and serial ports card is nice, and so on.

Some used computers are sold without an operating system, and you might not find it until you are

home. You have to add the price of the operating system to the price of the computer. You need DOS, a command line operating system. Note that most new computers come with Windows or similar graphic oriented system. It is very difficult to program in one of these operating systems, unless you are a professional programmer.

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Chapter 6

PROGRAMMING

Operating a computer requires knowledge in two different levels, the operating system and programming. When you turn on the computer following the instructions, it will automatically perform a number of operations that receive the name of booting. This name comes from the idea of bootstrap, lifting yourself from the straps of your boots. The idea is that the computer has a very small program, permanently wired, that makes it perform these functions. The core of these operations is loading the operating system. When it finishes, the computer is ready to receive instructions. At this moment, you need to know how to tell the computer what to do. This is the level of the operating system.

Computers differ very much in their operating system and the difference between the families of computers mentioned in the previous chapter, refers mainly to their operating systems. If you have a computer with the Motorola type of computers, Apple, McIntosh, Atari, Commodore, you probably have a mouse and you are presented with a menu where you select the program you want to run. If you have an IBM or compatible computer, you will need to type commands. Whatever computer you have, you need to read the instructions of your computer. All the names mentioned above are names of manufacturers of computers.

A few words about the operating system. The operating system is only a program that controls the computer when it does not have any other task to perform. The operating system permits you to see what is in a disk, call a program to be executed, copy a program or data from one place to another, etc. When a program ends whatever task it executes, it should return control to the operating system.

To understand the world of the operating system, you have to consider that the computer works in two different spaces: the internal memory and the disks. The internal memory is only accessible to you if you write the program. You will normally do not have to worry with the operation of the internal memory of the computer. The disk is your world when you work with a computer. All your programs, data, etc., are stored in disks, whether the type that is removable, or the type that is not, and receives the name of hard disk.

The external space of the computer is then divided into disks and the computer can see only the disks that you put in the drives. The drives are universally called A:, B:, C:, etc. Each drive is for a particular size of disks and each drive has a capacity. In this way we have 5 1/4-inch drives and 3 1/2 inch-drives. A 5 1/4-inch drive can have a capacity of 360 K or 1.2 M; that is to say, a drive can handle only 360 K

disks, or it can handle both sizes. A 3 1/2-inch drive can have a capacity of 720 K or 1.4 M; that is to say, it can handle only 720 K disks, or it can handle both sizes.

The elementary way to work with disks is to put data, programs, etc. in the disk without any order. It is the same idea as when you have a drawer in your desk and you put there, letters, memos, lunch bag, pencils, etc. Very soon you find your lunch on a letter and you never find the memo you need. Then, you need some order and you get some folders, one for letters, one for memos, one for orders, etc. You get another drawer for pencils, erases, and the like. You put your lunch in another drawer.

You do the same thing with the disk. You create several directories in your disk, and you give them names that mean what is inside. If you plan to put all your letters in one directory, do not call it XSMWZ, or anything like that; call it LETTERS. If you plan to put your observations of the Sun in another directory, call it SUN. Very soon, your disks will again be in disorder, because you have many directories. Then, you pack all similar directories into one. You open a directory called OBSERVE, and inside it you open another called SUN, another called JUPITER, and whatever. You can follow this method of directories inside directories to a very deep organization. If you make it too complex, you will again be in trouble because you do not remember where is what you want. A logical arrangement is to have disks dedicated to special topics, directories in the disks, and no more than three levels of subdirectories. Each person has to develop his or her own system; like putting order in one's office, or dormitory, this is a personal task.

The operating system of the computer lets you navigate through the jungle of disks, directories, subdirectories, etc. Inside these directories you store your files. Everything you put in a disk goes in a file. After that, you type a file, print a file, run a file, move a file, copy a file, delete a file, etc.

The operation of programming is the operation of creating a file with a sequence of instructions, in a language the computer understands. You normally start in a language you understand and then use special programs to convert the file into another in a language the computer understands. This is normally stated by saying the you create a source code and then assemble or compile it, to create the object code.

If you plan to use only programs written by others, you do not have to worry about the programming part of the computer. If you will use the computer in your radio telescope, you have three possibilities: one, you write your own programs; two, you pay somebody to write them; and three, you use programs written by others, as they are. Since writing the programs needed at the radio telescope is not too complex, as you will soon see, it seems a waste to pay the high fee required by persons who program for others. By the same token, using programs written by your friends, as they are, have the problem that, sooner or later, you will want things a little different.

Programming a computer is really an art, of the same type of art as writing a book, a poem, or building a dog house. There is no single way to write a program and, although some programs will be better than others, you will find that many of the different ways in which the same program can be written,

are equivalent. A beginner should concentrate first in the quality of his program; that is, that the program performs the desired function. Later he can polish it to perform the same function in a more elegant way, faster, using less memory, or whatever.

In order to be able to write a program it is necessary you understand what is what you want the computer to do, that you understand it exactly, and from the point of view of the computer, not yours.

Writing a program needs planning. Get a piece of paper and write first what you want to achieve. Note that you start with what you want. Then by steps, convert it into a sequence of commands to the computer. At first, the steps in your sequence will be very gross, later you take one step at a time, and reduce it to smaller, simpler steps. You follow this procedure until the computer can understand all your steps. As you get more complex, add comments that will make you recall later the reasons for the particular step.

One of the most important mistakes made by the beginner in programming is to try to start directly by giving instructions to the computer. Imagine you call somebody and you want him to do a complex task. Say, you want him to build a dog house for you. You must start telling him where you want it, what dimensions, what form, etc. Later you will enter into considerations of the type of wood you want, the color of the paint, etc. Now, consider that the computer has never seen a dog house, or anything you want it to do. You need to start in order and in all detail.

Let us take an example. Imagine you have a file from an observation you made yesterday, where all the values are too small. You want to multiply all the values by 2. Let us write a program to do it.

The first point is to visualize the task from the computer point of view. Your observation is for the computer only a bunch of numbers. The first 200 values are a description of the equipment, the date and time, and other information about the observation. The rest are the values of the observation. The computer does not have any way to know this.

Let us define the task:

1.- Multiply all the values by 2.

We need to divide this task is several smaller tasks:

1.1.- Get the file from disk onto memory;
1.2.- Multiply all values by 2;
1.3.- Put the file back on disk.

You can see that we are getting closer and in order. These tasks are still too crude for the computer to handle. If you tell the computer to perform task 1.1, it will ask you "How?" So, we need to break the tasks more:

Step 1.1 is broken into:

1.1.1.- Set a variable to store the observation;
1.1.2.- Open file containing the observation;
1.1.3.- Read the observation into memory;
1.1.4.- Close the file.

Step 1.2 is broken into:

1.2.1.- Set a counter with the number of values;
1.2.2.- Set a pointer with the initial address;
1.2.3.- Add the number of values in the header;
1.2.4.- Get a value from memory;
1.2.5.- Multiply value by 2;
1.2.6.- Put the value back in memory;
1.2.7.- Increment the pointer;
1.2.8.- Decrement the counter of values;
1.2.9.- If counter is not zero, go to 1.2.4.

Step 1.3 is broken into:

1.3.1.- Open a new file for the new data;
1.3.2.- Write the data onto the new file;
1.3.2.- Close new file.

Depending on the language you will use to tell the computer what you want done, each one of these steps will take a different form. In BASIC or C, for example, each line will probably be a command; in assembler language, each line will be a sequence of commands.

The whole philosophy of programming is summarized in the example given above. It is important you study the example in detail. The simple operation we wanted the computer to perform has complicated when we have to tell it what to do. There are still many details we have not included, but that you have to include in any program.

For example, imagine that the disk you specify does not have the file you want to work with. The computer will not know what to do and the results of this program will be unknown. You need to add instructions to test if the computer found the file you want to open, and what you want to be done if it is not found. The same, what if there is an error in reading, what if at the end, the computer finds that there is not enough room in the disk to write the new file. There are a number of undefined statements in the list above.

Do not get discouraged because the example was selected on purpose to look very simple, it can be written in one line, but when converted into a program is quite complex. One point to consider, once you solve each one of the problems of a particular programs, next time you need that operation performed, you know how to do it. It is a good idea to keep a note book handy, and write the solution to each one of the problems you find; not the complex problems, but the simple ones.

For example, you need to open the file so you can read it. How do you open a file? You will have to find it out for the particular language you use, and in your particular computer. When you find it out, write it down in your note book. When you have to open another file, you can find fast how to do it, without having to go through all your manuals.

The BASIC language was developed many years ago with the idea of having a universal language that can be applied to all computers. Practically every language that is developed has the same intention. There is none that has achieved this objective, because all languages suffer modifications on the hands of eager system programmers, who want to leave their personal stamp on them.

This is true with BASIC, C, FORTH, and all other languages. When you see a program written in a language you understand, and want to use it in your computer, the first thing to do is to get the original code; that is, the program written in a way we humans can understand. The point to look in this code, is the dialect of the language that was used. If the program was written for the same computer you have, you can try to use it; if not, you have to convert it. Go through the code with your book on the language and be sure that all the commands used in the program have the intended meaning. If this is not true, you need to change the command.

Some times there is only a minor difference between dialects, like some BASIC dialects use ATAN and others ATN, for arc tangent; or SQRT and SQR, for square root. Similar differences occur in C, FORTH, and all other languages. The program will not work if you do not make these corrections. Do not be confident that a program written for a computer similar to yours will necessarily work. For example, a program written for an IBM-compatible computer in QBASIC, will not work if you are using GWBASIC. In some cases, it is possible to use the computer to find these differences. Simply run the program, if it is BASIC or FORTH, or compile it, if it is in C. The computer will give you a list of errors, that you can find and correct. In most cases, this becomes a frustrating exercise.

A moral of all that has been said above, is that you should get used from the beginning, to put a heather in all your programs, showing what the program does, what dialect is used, who wrote it, and when. Each of your programs should start as follows:

```
100 REM PROGRAM TO SAMPLE A SIGNAL
200 REM WRITTEN IN GWBASIC FOR IBM-COMPATIBLE COMPUTERS
300 REM WRITTEN BY MIKE VALDEZ
400 REM STARTED APRIL 2ND, 1991
500 REM WORKING APRIL 5TH, 1991
```

```
600 REM REVISED APRIL 12TH, 1991 => ADDING GRAPHICS
```

Note the use of REM, for remark, that makes these lines only comments that are not included in the program. If you want these lines to be displayed on the screen when the program runs, you have to change the REM for PRINT, and put the sentence in quotes. The same thing will be as follows:

```
1000 PRINT "PROGRAM TO SAMPLE A SIGNAL"
1100 PRINT "WRITTEN IN GWBASIC FOR IBM-COMPATIBLE
COMPUTERS"
1200 PRINT "WRITTEN BY MIKE VALDEZ"
1300 PRINT "STARTED APRIL 2ND, 1991"
1400 PRINT "WORKING APRIL 5TH, 1991"
1500 PRINT "REVISED APRIL 12TH, 1991 => ADDING GRAPHICS"
```

Notice something else, general REM statements are put at the beginning of the program. Printing a heading is done wherever it is needed. A word of caution. Although adding comments is a very good idea and will save you a lot of aggravation later, you should be careful in languages like BASIC. BASIC reads each line, starting at the beginning, when executing a program. A lot of comments will slow down the operation. One solution to this problem is to put all general comments at the end of the program. This is not true in other languages.

RADIO ASTRONOMY FOR BEGINNERS

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Chapter 7

SAMPLING

These three chapters are devoted to examples of programming. It is to be emphasized that none of these examples constitute a complete program. They are only parts of a program, and they require to be threaded into a program to perform a task. On the other hand, each one of these examples is presented with all detail, first as a narrative, and then using BASIC, to convert it into code.

The process of sampling is a fundamental process in radio astronomy. Later we will study some of the aspects that should be considered when sampling a signal. It is necessary to consider, for example, what we will do with the information we collect, to determine the sampling rate we will use. This is a double edge sword: From one point of view, if the sampling rate is too slow, we loose all the detail in between samples; from the other point of view, a high sampling rate floods us with data points. It is necessary to achieve a compromise, based on the most probably use of our observation. Since at this moment we are concerned with programming, we leave this topic for later.

The moral of this analysis is that it is not possible to use the same sampling rate for all our observations. We could have one program for each type of observation we make. If we do not want to be changing programs continuously, we need a single program that gives us a large flexibility when selecting the sampling rate.

The same could be said about the total number of samples in the observation, or how long the observation will last. It is possible to develop some kind of a standard length for all our files. We could also have different lengths for different observations. In this case, we could write a program that gives us flexibility to choose either the number of samples to be taken, or the total length of the observation, at the moment we run the program.

The final consideration is the procedure we will use for sampling. There are several ways to sample a signal. One is to simply read the output of the converter and store it as it is. This limits us to what the converter can give us. If we want to increase the precision of the measurement, we could perform an average of a number of samples. In certain cases of repetitive signals, like pulsars, we want to perform several measurements of the whole pulse, and add them together. In this last two cases, we reduce the influence of the noise by this process of adding measurements.

Consequently, our sampling program must start by asking for a sampling rate, total number of data

points to get, number of measurements for each data point, number of passes on a repetitive signal. In the way they have been presented, all these values are independent of each other. Notice that if we want to have separate programs for each task with standard values, we need only to replace each question with a statement setting the value of the variable. The next task is to set up a number of programming loops to perform the sampling.

In a list form, these tasks take the following form:

Print a message "Enter Sampling Rate";
Read sampling rate from the keyboard;
Print a message "Enter Total Number of Samples";
Read number of samples from the keyboard;
Print a message "Enter Measurements per sample";
Read measurements per sample from the keyboard;
Print a message "Enter number of passes";
Read number of passes from the keyboard;

The loops are set up the following way:

1.- Store zeros in all variable locations
2.- Set a variable with number of passes
3.- Set a variable with number of points
4.- Clear temporary variable
5.- Set a variable with sampling rate constant
6.- Decrement sampling rate variable
7.- If variable not equal to zero go to 6
8.- Set a variable with measurements per point
9.- Read one sample
10.- Add to temporary variable
11.- Decrement measurements per sample
12.- if not zero, go to 9
13.- Add temporary variable to storage location
14.- Decrement number of points
15.- If not zero, go to 4
16.- Decrement number of passes
17.- If not zero, go to 3

Note that in this program we make measurements as fast as the program can make them to develop the average that constitutes one point. Then, we perform the loop that gives us the sampling rate, before performing the next batch of measurements to get another point. Naturally, if during a particular observation we want to have only one of these loops, we only need to enter 1 as the number for that parameter. For example, if we want to have only one pass, we call for 1 pass; if we do not want to

average several measurements to develop a point, we call for 1 measurement per point; etc.

All operations in this last list are readily convertible to programming steps, with the exception of step 9, read a sample. This operation is too much hardware and language dependent to be able to give general examples. The most we can do is to give some examples under special conditions.

Using GWBASIC, the part of the program that performs the sampling can be as follows:

```
2000 REM SAMPLE THE SIGNAL
2100 REM ASK FOR PARAMETERS
2200 PRINT "ENTER SAMPLING RATE CONSTANT"
2300 INPUT SRC
2400 PRINT "ENTER TOTAL NUMBER OF SAMPLES"
2500 INPUT TNS
2600 PRINT "ENTER MEASUREMENTS PER SAMPLE"
2700 INPUT MPS
2800 PRINT "ENTER NUMBER OF PASSES"
2900 INPUT NOP
3000 REM STORE ZEROS IN ALL VARIABLE LOCATIONS
3100 FOR I=1 TO TNS
3200 V(I)=0
3300 NEXT I
3400 REM WAIT FOR A SIGNAL TO START
3500 PRINT "SIGNAL WHEN READY"
3600 INPUT A$
3700 REM SET UP SAMPLING LOOPS
3800 REM SET UP LOOP FOR PASSES
3900 FOR P=1 TO NOP
4000 REM SET UP LOOP FOR POINTS
4100 FOR J=1 TO TNS
4200 REM CLEAR TEMPORARY VARIABLE
4300 TEMP=0
4400 REM PERFORM DELAY LOOP
4500 FOR K=1 TO SRC
4600 NEXT K
4700 REM SET UP LOOP FOR MEASUREMENTS PER POINT
4800 FOR K=1 TO MPS
4900 REM READ ONE SAMPLE
5000 GOSUB 10000
5100 REM ADD SAMPLE TO TEMP
5200 TEMP=TEMP+SAMP
5300 REM DECREMENT COUNT FOR MEASUREMENTS PER SAMPLE
```

```
5400 NEXT K
5500 REM ADD TEMPORARY VARIABLE TO SAMPLE
5600 V(J)=V(J)+TEMP
5700 REM DECREMENT NUMBER OF POINTS
5800 NEXT J
5900 REM DECREMENT NUMBER OF PASSES
6000 NEXT P
```

You can notice that we have added comments for each line. We commented before that this slows down the program. We recommend that you do this at the beginning, until you become proficient in writing programs. After that, you will be concerned with your programs running too slow and you will want to remove the comments. A good idea is to document your programs in a separate piece of paper, or in another file. You can have a file SAMPLE.BAS and another SAMPLE.DOC, where you explain in all detail how you did to write the program, and what is the meaning of every line. Let us do it. SAMPLE.BAS will look like this:

```
2000 PRINT "ENTER SAMPLING RATE CONSTANT"
2100 INPUT SRC
2200 PRINT "ENTER TOTAL NUMBER OF SAMPLES"
2300 INPUT TNS
2400 PRINT "ENTER MEASUREMENTS PER SAMPLE"
2500 INPUT MPS
2600 PRINT "ENTER NUMBER OF PASSES"
2700 INPUT NOP
2800 FOR I=1 TO TNS
2900 V(I)=0
3000 NEXT I
3100 PRINT "SIGNAL WHEN READY"
3200 INPUT A$
3300 FOR P=1 TO NOP
3400 FOR J=1 TO TNS
3500 TEMP=0
3600 FOR K=1 TO SRC
3700 NEXT K
3800 FOR K=1 TO MPS
3900 GOSUB 10000
4000 TEMP=TEMP+SAMP
4100 NEXT K
4200 V(J)=V(J)+TEMP
4300 NEXT J
4400 NEXT P
```

The document part of our program starts with the two lists of steps presented above, and the detailed documentation of the program will look something like this:

Starting at line 2000 we sample the signal;
Lines 2000 to 2700 ask for the different parameters;
Lines 2800 to 3000 clear all locations of the variable to zeros;
Line 3100 indicates the computer is ready, and line 3200 waits for a signal to start sampling;
Line 3300 sets up the loop for passes;
Line 3400 sets up the loop for points per pass;
Line 3500 clears the temporary variable TEMP;
Lines 3600 and 3700 form a very tight delay loop;
Lines 3800 to 4100 gets the required number of measurements per sample, adding them to TEMP. The subroutine at 10000 gets a sample from the A/D converter and puts it in SAMP;
Line 4200 adds the value accumulated in TEMP to the current point being sampled;
Line 4300 closes the loop of points per pass; and
Line 4400 closes the loop of passes.

As was mentioned before, the sampling of an analog-to-digital converter is very particular of the unit being used and the computer configuration. We will leave this program for later, when we build a particular analog-to-digital converter and we have guidelines to follow.

RADIO ASTRONOMY FOR BEGINNERS

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Chapter 8

DOING GRAPHS

It has been said that a picture is worth 1000 words. In the case of radio astronomical observations there is very little else that can be done to show the result of an observation. A list of numbers is very difficult to interpret.

A strip chart recorder has the advantage of producing directly a graph of the observation, and this is the reason for its popularity. If you have a strip chart recorder, it is not too difficult to install one in your telescope. We will see how this is done in one of the chapters that follow. The problem with the strip chart recorder is that the expense of the paper adds up to a considerable one. Chart paper is expensive.

If you do not have a strip chart recorder, or you want to avoid the expense of the chart paper, the computer can produce a graph of the observation both, during the observation and later, from the file.

There are many ways a computer can produce a graph. The most elementary one is similar to making a graph in a typewriter. We use letters or symbols as the plotting element. Consider that your computer can write 80 characters across the screen. If you scale your measurements in the range from 0 to 79, you can put an asterisk in the column corresponding to the value of the sample. As the computer puts new samples on the screen, the display scrolls up and you will have a graph similar to what you get from a strip chart recorder. Naturally, you can see only the last 24 values.

Let us see how you can do this. First, consider that this plot is produced as the samples are collected by a program similar to the one described in the previous chapter. Then, after you have a sample and store it in its place, you want to plot it. Say the value of the sample is in variable SAMP and has 8-bit resolution. That is to say, the value of the sample can be from 0 to 255. The task is as follows:

1.- Scale the sample;
2.- Send carriage return, line feed to display;
3.- Position cursor in row 24, column given by sample;
4.- Print an asterisk;

You repeat this procedure for every sample. Note that step 2 is used to produce the scrolling of the graph. It is interesting to develop some more the first step. In order to scale the sample from 0-255 to 0-79, we multiply the sample by 79 and divide it by 255. Then, we convert it to an integer.

Using again GWBASIC for this part of a program, we can write:

```
7000 SAMP=INT(SAMP*79/255)
7100 PRINT
7200 LOCATE 24,SAMP
7300 PRINT "*";
```

Note the semicolon after the asterisk. This is to prevent the computer for sending another carriage return, line feed, after printing the asterisk. The reason is that the computer will scroll just before showing the next line and, it shows 25 lines all the time. If this is not important, but the simplicity of the program is, you can write:

```
7000 SAMP=INT(SAMP*79/255)
7100 LOCATE 24,SAMP
7200 PRINT "*"
```

The documentation of this program will be as follows:

Lines 7000 to 7200 plot each observation after it has been stored;
Line 7000 scales the value of the observation from 0-255 to 0-79;
Line 7100 positions the cursor depending on the value of the sample;
Line 7200 displays an asterisk at the proper location, and scrolls the display.

Note that this same program can be used to plot a sample taken from a file. In this case you need first to read the file into memory (you know how to do that!), get a pointer to the first data byte in the file, plot that value, and continue until the file ends. In this case, the display will scroll very fast, and you will not be able to see much. You can add a delay loop (you know how to do that!) after you display each point. By adjusting the delay constant you adjust the speed the display scrolls up.

Exactly the same procedure can be used with a printer. You can plot your observation in a printer using asterisks. The only problem is that a printer does not accept the command LOCATE. You have to make a loop with spaces. The procedure then requires that you scale the value as before; then, use that value in a loop to print that many spaces; then, put an asterisk and a carriage return. The program in GWBASIC is as follows:

```
8000 SAMP=INT(SAMP*79/255)
8100 IF SAMP=0 THEN 8500
8200 FOR I=1 TO SAMP
8300 LPRINT " ";
8400 NEXT I
```

```
8500 LPRINT "*"
```

Note some differences, the scaling is the same but, since a loop is performed at least once, you have to test if the value of SAMP is zero, and skip the loop if it is. Note also the semicolon after the printing of the space, to avoid the carriage return, line feed. The printing of the asterisk does not have a semicolon, because you want a carriage return line feed. As an exercise, let us repeat the documentation for this part of the program:

Lines 8000 to 8500 plot one value on the printer. It is assumed that the printer is connected to the computer and that it is turned on;
Line 8000 scales the value in SAMP from 0-255 to 0-79;
Line 8100 tests if the resulting value of SAMP is zero, and skips the loop if it is;
Lines 8200 to 8400 perform a loop to send to the printer as many spaces as the value of the sample;
Line 8500 sends an asterisk and a carriage return, line feed to the printer.

Note that this plot cannot be used as you get the samples. The reason is that the time it takes to produce the plot of each point depends on the magnitude of the sample. Say, if a sample has a value of zero, it is only necessary to print an asterisk, a carriage return, and a line feed. If the value of the sample is 79, you need to send 79 spaces to the printer, the asterisk, the carriage return, and the line feed. This last operation takes much more time than the previous one. As a result, the time between samples is not uniform.

A uniform time between samples is one of the most important requirements of any sampling procedure, for whatever the reason. Samples taken at unequal intervals of time have much less value than samples taken at regular intervals of time.

A last variation of this program, both on the display and on the printer, is that instead of a single asterisk for showing the magnitude of the sample, the whole line is filled with asterisks, producing a solid appearance. For the display you need a program similar to the one for the printer but using PRINT instead of LPRINT. You change the " "; into "*"; to obtain a line of asterisks. This program cannot be use for getting a plot while getting the sample for the same reasons explained above for the printer.

If your computer has graphic capabilities, you can produce a graph with much more resolution. The first point is to find out what is the resolution that your card supports. This is normally explained in the documentation that comes with the card. For the sake of argument, let us assume that your card is a VGA that supports 640x480 points with 16 colors. GWBASIC has a command PSET which permits you to display a point on the screen. PSET requires parameters as PSET(x,y),color, where x and y are the coordinates of the point and color is a number from 0 to 15 for the color of the point. The coordinates of the display start at the upper left corner of the screen.

Let us analyze a program similar to the above, that will use graphics instead of asterisks. The steps are as follows:

1.- Test if value larger than 480; if so, make it 480 (You could also scale it);
2.- Invert the value with respect to 480;
3.- Plot the value;
4.- Increment x;
5.- If x is equal to 640, make x equal to zero.

This program requires that before we start sampling we make x=0, so our graph starts from the left side of the screen and progresses to the right. Note that if we have more than 640 values, the screen will wrap around and the graph, when it reaches the right end of the screen, jumps to the left side and continues. The display is not erased.

You should work out some of these steps a little more, as follows:

1.1.- If SAMP is smaller than 480, continue to 2.1;
1.2.- Make SAMP equal to 480;
2.1.- Make SAMP equal to 480 menus SAMP;
3.1.- The command is PSET(x,SAMP),COLOR (color must be defined some place);
4.- Is well known;
5.1.- If x less than 640, continue sampling;

5.2.- Make x equal to zero.

IN GWBASIC this can be written as follows:

```
12000 IF SAMP>480 THEN SAMP=480
12100 SAMP=480-SAMP
12200 PSET(X,SAMP),COLOR
12300 X=X+1
12400 IF X=640 THEN X=0
```

Note that the program is simpler this time, than the explanation. Very often this is true. You need the explanation to understand what you want done and how to do it. Once this is achieved, the program is many times simple. This is not true for all programs and for all languages for the same program.

One interesting possibility in the program above is to change colors as we wrap the display around. This is simply done in statement 12400, changing it to:

12400 IF X=640 THEN X=0; COLOR=COLOR+1

You see then, that generating a plot is not too difficult whether with letters or with graphics. Again,

what has been presented above is only the part of the program to make a plot. This code should be threaded into a program that samples the data, or that reads it from disk, or whatever. We leave as an exercise for the reader writing the documentation for this program.

One very useful program is one that reads the data from the disk, displays all the parameters of the observation and plots the data. There are two interesting ways to plot the data: One, is to plot it 640 points at a time (or whatever your display can support); pressing a key makes the program display the next 640 points, until the file ends.

Another interesting possibility is, if the file has more than 640 points, the program can average points together to reduce the data to 640 points. Say your sample has 3200 points. The program can take 5 points at a time, make an average, and plot it. The same program, or another, can plot the file page by page. We leave these programs as exercises for the reader.

RADIO ASTRONOMY FOR BEGINNERS

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Chapter 9

STORING THE DATA

The process of storing the data from an observation is more than copying the data into a disk file. For the data obtained during an observation to be valid, it is necessary to save it with quite a lot of additional information. Let us analyze what information is needed.

Very few computers today do not have what is called a real time clock and adding one is not too expensive. Most of them have a battery that keeps them running when the computer is off. This clock can be read with special commands that exist in all languages. The value read from the clock can be stored with the data.

It is a good practice to read and store the clock at the beginning and at the end of an observation. In this way, the computer can calculate later, not only the actual sampling rate, but the exact time at which each sample was taken.

For the reading of the computer clock to be valuable, it is necessary that we verify before the start of the observation that the clock is actually showing the current time. Note that simply saying that the observation started at 10:55 means very little. It is also necessary to indicate which one of the many different times is used in the clock. The clock can be set with solar time, civil time, day light saving time, universal time, etc. If the clock is set with sidereal time, it is necessary to indicate when it was set, because computer clocks run with civil or solar time and there is a difference of almost four minutes per day, or ten seconds per hour. This error can accumulate during long observations or during long periods of time since the clock was set.

The time of an observation means very little, even with the specification of which time was stored, if the location of the observatory is not recorded. Even in the case we store the time in universal time, different parts of the sky are visible in different locations, at the same universal time.

The location should be stored not only by name, but with the geographical coordinates. Finding the geographical coordinates of your observatory is not too difficult. Many city maps show coordinates. Most state maps have coordinates. Coordinates can also be found in atlases and reference guides. In any case, you can get the coordinates of your house within a mile (one minute), which in most cases is sufficient precision. Some other sources of coordinates are the airports, court house, libraries, fire department, etc. Once you get one point, you can calculate from there, the coordinates of your home.

As mentioned when talking about telescopes, there are two main types of telescopes, transit and steerable. You should store which type you were using for your observation. In the case of a transit telescope, you need only store the elevation of the antenna or the declination the antenna is pointing at, but you should indicate which one you are storing. In the case of a steerable telescope you should store the location of the sky the telescope is pointing at every moment. It is possible to let the telescope be fixed during the observation but not at the meridian, like in a transit telescope, or it is possible to follow the source. If the source is followed, you should indicate how it is followed. In extreme cases, it might be necessary to store with each of the measurements, values that indicate the position of the antenna.

If you only have one antenna, one receiver, etc., that does not relieve you from the responsibility of storing a description of the equipment you used for the observation. Of course, this is much easier than when you have several pieces of equipment. If you have only one, the computer automatically adds the complete description of the equipment to each observation. Never store the description of your equipment as a note saying: "Same equipment as ever", or "Same equipment as last observation".

Most of the information needed to make an observation valuable are repetitive. For example, you might have only two or three combinations of equipment; you might always use standard time; you might always work in transit; etc. In this case, the computer is very valuable for preventing you from forgetting a piece of information and make the process simple.

One procedure that is highly recommendable is that your sample program asks you for all the necessary data, and retrieves automatically all the values it can get by itself. The following session shows only the interaction between the computer and the user, not the values the computer retrieves by itself. A typical session can be like this:

Computer: The time now is XX:XX. Did you set the clock?

You: Yes (The computer continues)

You: No (The computer exits the program so you can set the clock. If you know how to do it, it is possible to put a routine here so you set the clock without leaving the program).

Computer: Are you using Standard, Daylight, Universal time?
You: S

Computer: Are you working from your standard location?
You: Yes (Computer continues)
You: No
....(**Computer**: Enter location
.....**You**: enter location name
.....**Computer**: Geographical longitude

.....**You**: enter longitude
.....**Computer**: Geographical latitude
.....**You**: enter latitude)

Note: If you have several locations from which you regularly observe, the computer can ask you by giving the list of possible locations, as it is done with the equipment.

Computer: You normally use the following equipment:

a) 6 ft dish, 1.3 GHZ, AIM receiver, transit;
b) Yagi, 30 MHZ, Kenwood receiver, transit;
c) Yagi, 432 MHZ, ARR receiver, follow with clock;
d) Other.

Which one you are using now?
You: Anything but d (Computer continues)
You: D (**Computer**: Describe the equipment
....**You**: describe the equipment)

Computer: Gain before the detector?
You: give the gain setting

Computer: Gain before integration?
You: give the gain setting

Computer: Integrator time constant?
You: give the time constant

Computer: Zeroing adjustment?
You: give the zero setting

Computer: Gain after zeroing?
You: give the gain setting

Computer: Analog-to-digital converter in use, 8-bit, 12-bit, flash?
You: indicate which converter you are using

Computer: Declination at the start of the observation?
You: give the declination

Computer: Right Ascension?
You: give the right ascension

Computer: Name of the source?
You: give the name

Computer: Sampling rate constant?
You: give the constant

Computer: Total number of samples?
You: give the number of samples

Computer: Number of measurements per sample?
You: give the number

Computer: Number of passes?
You: give the passes

Computer: Do you wish a plot while sampling?
You: Yes or No as you like

Computer: Name of the file [no extension]?
You: give the name

Computer: Do you wish to add a comment?
You: type the comment, if any

Computer: Working, please wait a moment

Computer: Ready, Signal when to start
You: press a key to start sampling.

Many of the steps mentioned above might not be of your liking, or they might not apply to the particular observations you make. For example, if you never make any observation of pulsars (very few amateurs do), you might want to eliminate the reference to repetitive operation. The same, if all your equipment works in transit, you might eliminate some of the questions. In any case, this is only an idea of how a program can work to gather all the necessary information and prevent you from forgetting some.

Another possibility that is useful is to get the computer to present a table of different combinations. For example, the sampling rate, number of samples, measurements per sample, plotting, determine how long the observation will be and it is not obvious how to find it out. This information can be given in a table before asking all this questions, or permitting to enter a single code for the whole combination.

The procedure for storing this information is very simple. You need to analyze the information you need to store and to assign spaces for every value, depending on its range. For example, a value that can be between 0 and 99, needs two locations; a value between 0 and 65535 needs five locations. Leave enough room for the comments and other values entered by hand, and a 20 % extra for future enhancements. In this way, each piece of information is always in the same location and you can find it years from now. This block of information is followed immediately by the observations and you can store the whole thing in a single operation into the disk file.

One interesting variation of this form is to store each value with its name; for example, instead of storing 30000 in the place for the sampling constant, store the whole thing: "Sampling constant=30000". In this way, if later you feel like changing the format of the observations, you do not need to change all the old observations; each carries its own documentation. Further more, if you add a carriage return, or spaces, your documentation can be properly formatted so you only need a single print statement to get it all in proper order. The number of additional locations used for these niceties is minimal.

In the future, when you want to review your records, you will find all the information without any problem. You can also have a catalog of observations, where you copy the headers, and a program that displays them one by one, or that permits you to search them.

There is a problem that is left and it is the format for storing the data. It is good to store the header in ASCII codes, the codes used by the computer to represent letters and numbers. The problem is in the data. There are two possibilities for storing the values obtained by your observation, in binary or in ASCII. Binary has the advantage that it produces a compact file; ASCII has the advantage that you can review the file with the capabilities of the operating system.

The only case where the format makes a big difference is if your files are long. Imagine that your header is 200 bytes long and your observation has 1600 values. Since each value has 16-bit precision, you need two bytes per value in binary. Your record will have 3400 bytes. If you store the values in ASCII you need between one and five bytes per value plus two bytes for a carriage return and line feed, to separate them; then, your record can be 11400 bytes long.

If your observations require a long record, the difference is more important. Imagine the observation requires 24000 values. Then, storing the record in binary takes 48200 bytes; storing it in ASCII can take 168200 bytes.

The format you use depends then on the type of observation you make and how you use the data afterwards. If all your programs are written in BASIC, it is a lot easier to write a program in BASIC to read a file that is all ASCII, than to read one that is in binary. The opposite is true if all your programs are in assembler language.

The last point we need to make is storage. Your data is valuable simply because, if you loose some,

there is no way you can recover it. It is highly recommendable that you maintain at least two copies of all your observations. Do not make the mistake of making two copies in the same diskette. Make the copies in separate diskettes and store them in separate places. If you have a metal cabinet, store your back up copies in that cabinet.

Something else. Data in a magnetic media is not permanent. At least every year, make a copy of your back up diskettes into new diskettes and move your old back ups to the working area. The old working diskettes can be reformatted and used in some other tasks.

What has been said about the data from the observations is also valid for your programs. Keep back up copies of all your programs in a safe place, a metal cabinet, if possible. This is very important if you have a hard disk. It is a very good idea to keep the back ups in different media. If you have different size of drives, keep back ups in both drives. If you have a digital tape drive, keep also back ups in tape. If any one goes bad, you can still back up your files using the other drives. If you consider how much effort, time, and money you have in those programs and those observations, you will agree that nothing is too much to protect all that effort.

RADIO ASTRONOMY F0R BEGINNERS

Michael E. Valdez

Chapter 10

THE ANALOG-TO-DIGITAL CONVERTER

In the next chapters we will study the processing of the signal that comes from the receiver, first by the detector, to extract the envelope of the signal; then, the signal is amplified, integrated, zeroed, amplified more, and finally it reaches the analog-to-digital converter. Up to this moment, the signal maintains the basic characteristic of an analog signal; that is, the voltage representing the signal can attain any value, within the given range.

Notice that, up to the input of the analog-to-digital converter, all the electronic components are good for processing analog signals. Operational amplifiers were used in analog computers. Our Data Processing Unit is, up to this moment, an analog computer, that processes signals as functions of time. This is the reason this part is normally called a DC processor. We will also use this name.

The next element in our Data Processing Unit is a digital computer. The difference is that a digital computer processes numbers, represented by a number of voltages, 8, 16, or 32 voltages, at the same time. A signal for a digital computer is then a series of 8, 16, or 32 voltages. These voltages cannot attain all the possible values, but only two: either a high voltage near the maximum, or a low voltage, near zero. This is the reason these voltages are called digital voltages: they have only two possible values.

Our task at this moment is to convert the analog voltage of our signal, into a digital value that represents the voltage. This task is performed by an integrated circuit that receives the generic name of analog-to-digital converter. Do not get confused with a digital-to-analog converter, which is used for the opposite conversion: given a sequence of digital values, they generate an analog voltage that follows a pattern in time, equal to the sequence of values.

There are several characteristics that must be considered when selecting a digital-to-analog converter for our Data Processing Unit. The most important of them are the speed of the conversion and the resolution of the digital value that results.

The speed of conversion is the time it takes for the converter to generate a digital value equal to the voltage at its input. Economical converters require on the order of 25 microseconds for the conversion and they are good if all the work we will do is with high values of time constant in the integrating circuit. The reason is simple, the input voltage should not change while the converter is converting.

This speed can be translated in up to 20 to 30 thousand samples per second. If your purpose includes some applications that require faster sampling of the signal, you should select a faster, and more expensive, converter. Flash converters can convert millions of samples per second.

The other important characteristic of a converter is the resolution of the value that the converter produces. Economical converters, which costs a few dollars each, produce values with 8-bit resolution. This means that the computer receives as equal all values that differ less that 1/256 the maximum voltage of the converter input. If the input of the converter is between 0 and 10 volts, the computer receives as equal all voltages that differ by less than 39 millivolts. This resolution is quite gross, if you consider that the signal will be rather low for most of the observation, and that it will rise only when the source is in front of the antenna.

A better resolution requires more bits of data. 10 bits give a resolution of 10 millivolts, 12 bits gives 2 millivolts of resolution, and 16 bits gives 0.15 millivolts, or 150 microvolt. In other words, an 8-bit converter gives you 256 steps between zero and maximum; a 10-bit converter gives you 1024 steps; a 12-bit converter gives you 4096 steps; and a 16-bit converter gives you 65536 steps between zero and maximum. The price you have to pay for a converter of the same speed increases exponentially with the number of bits. If you want to have a large number of bit, you will have to pay a very high price, or you will have to accept a lower speed. For example, an 8-bit, 25-microsecond converter can be obtained by a few dollars. A 16-bit, 10-millisecond converter cost some 300 dollars.

There is more to it. If you have a converter with 16-bit resolution, you cannot mount it in the same box as the rest of the equipment. The reason is simple. If the resolution is 150 microvolt, it will record any noise that low, and it will add it to the signal. The power supply for such a converter has to be quite good, and it requires an additional part, a sample-and-hold amplifier. As its name implies, the purpose of this device is to hold the input to the converter constant while the converter converts.

In most cases, the amateur do not need such a precision and there are ways in which the precision of the measurements can be improved at a lower cost. Mathematics comes to our rescue. There is an extensive mathematical theory of errors and it applies here because we are dealing with errors in the measurements. The idea is to use the common method of averaging. It can be proved mathematically that if we average a number of measurements, its most probable error is reduced or divided by the square root of the number of measurements. In this way, an average of 256 measurements made with an 8-bit converter will have the same precision of a measurement made with a 10-bit converter. The advantage of this procedure is that an 8-bit converter can make measurements as fast as the computer can process them, producing the result much faster than the equivalent converter.

If you must have the best possible equipment, there is no equivalent to a 16-bit converter, that will permit you to sample as fast as required for normal operation of a telescope. If you run into an application that requires faster sampling rate, then you can get a simpler converter, that is faster.

Sampling Rate

It seem logical that we should say something here about the sampling rate, and its importance for our studies. The first point to consider is that once you have sampled a signal with an analog-to-digital converter at a given rate, there is no way you can reconstruct the signal and obtain data at a higher rate. When you sample the signal, you take pictures of the signal at equal intervals of time. Whatever happens in between samples is lost forever. That is the main reason for sampling a signal faster than what we really need, to retain as much of the information in the signal as possible.

The problem is that sampling a signal very fast creates other problems that you must face one way or another. Imagine your telescope works so beautifully that you cannot get away from it and you are constantly getting samples of all the sources in the sky, as they drift in front of your antenna. Say, you take one 20-minute sample each hour, 10-hours a day.

If you sample at a rate of 10 samples per second, each one of your 20-minute record has 12000 samples. If each sample has 16 bits, this means 24000 bytes of storage required per record. A normal 1.44 M diskette will store 60 of these records. So, you will fill 61 diskettes per year.

If your sampling rate is high, to save as much of the signal as possible, say 20000 samples per second, each record will require 48 megabytes of storage, if each value is 16 bytes. In any case, you will need a digital tape or CD-ROM to store these records. A CD-ROM will store 14 of these records. You will fill some 260 CD-ROMs per year.

Now, let us imagine you start the opposite way. You want that each record fills a 1.44 meg diskette. Your sampling rate is only 1000 samples per second. If you are satisfied with this, You still need to consider buying a special cabinet to hold your disk, since you will be producing 3650 disk per year. This is a 40 ft stack of diskettes, without considering back ups.

So, there are advantages to a high sampling rate but, the data produced by such a system will flood you in no time. There is one case that has many people interested, that requires a high sampling rate; this is, the search for signals indicating an extraterrestrial intelligence. It is more or less accepted that intelligent beings out there will produce electrical signals of such characteristics that cannot be produced by nature. For example, it is said that some extraterrestrial listening to our television signals will recognize us as intelligent beings (as long as he really does not watch the TV shows!). So, the search for intelligent life forms looks for repetitive pulses or signals with a very narrow frequency.

For this purpose it is necessary to sample the signal very fast. Since the number of data points that are produced is enormous, it is necessary to process the signal immediately, and only save those portions that seem to have any value. In any case, these are very specialized techniques that are mentioned here only because a large percentage of amateurs enter the field of radio astronomy attracted by the possibility of searching for extraterrestrial. We are not saying that this is not a possibility, but simply that this cannot be the first project of a beginner. RADIO ASTRONOMY, the Journal of SARA, has published several articles by the author of this book, analyzing this problem and suggesting possible solutions.

Going back to the idea of saving as much of the signal as possible for future analyses, the solution of a tape recorder, an audio tape recorder, is more practical. If you record the signal using a stereo tape recorder, you can use one of the channels to store timing pulses that will permit you to recover the data with good characteristics. A single audio cassette can store 6 20-minute observations.

Note, though, that what was said about sampling the data at a low speed is also true about integration. Once you pass your signal through an integrator you lost forever the small variations or pulses that the integrator smoothed.

In summary, we use an analog-to-digital converter to convert the signal from the receiver into values the computer can read and analyze.

RADIO ASTRONOMY FOR BEGINNERS

Michael E. Valdez

Chapter 11

THE DETECTOR

The names detector and rectifier refer to the operation performed by the same circuit under different applications. This circuit is very flexible and is used in many applications. For example, in a power supply, the alternating voltage from the line is rectified and converted into a direct current voltage, using this circuit, thus the name of rectifier. In a communications receiver, this circuit is used to eliminate the carrier of the signal and obtain only the envelope, which has the information we need; thus the name of detector.

In one case, the rectifier, the power of the alternating voltage delivered by the line is converted into a constant voltage power output. The rectifier in then a converter of power. In the case of the detector, the signal is the product of two signals, the carrier and the modulation. The function of the detector is to separate these two powers and destroy or dissipate one of them.

It is clear that the use of the same circuit in our Data Processing Unit is justifiable. Our task is similar to the tasks of the other applications in the sense that we have an alternating voltage we want to convert into a slowly varying voltage proportional to the instantaneous power of the input. We can consider the variations of the signal from the radio source as a modulation of the signal we are observing. We could also consider such variations as changes in the instantaneous power delivered by the receiver. You see that, whatever the way we consider it, the use of this circuit is well justified.

So, our Data Processing Unit starts with what we call the detector. There are two conditions the detector must satisfy to be usable in our circuit: it must be linear in the range we will be using it, and it should give an output voltage proportional to the input power.

From your studies of electricity in High School or College, you will remember the power in an alternating current is proportional to the square of the voltage, for the same circuit. For this reason the detectors used in radio astronomy are called square law detectors. The telescope also receives the name of total power radiometer, although this name is being used less and less as more people understands the real characteristics of a telescope.

The way the circuit of a detector produces the results that are required is rather complex. What happens is that the diode, or rectifier, conducts electricity in one direction and not in the other. Consequently, when the voltage output of the receiver goes in one direction, the diode conducts and power flows through the output resistor of the circuit, developing a voltage output. When the voltage of the output of the receiver changes direction, the diode does not conduct and no power flows in the output resistor of the detector and the output voltage of the detector is zero.

Imagine we apply a voltage to the input of the detector. The voltage we will use has a positive voltage during some time and a negative voltage during some other time, and repeats itself forever, in what is called a cycle. The output of the detector will be positive during some time and zero the rest of the cycle. The output voltage from this detector will never be negative. If we smooth the output of the detector by a procedure we will study later, we will have a voltage that has always the same polarity, positive in our example, a DC voltage.

The simple circuit described above, and shown on the diagram (See Fig. 11-1), produces rectification or detection. Now, what about values?. If the input voltage to the

detector varies from +1 volt to -1 volt, what is the output? This is where the complexity comes. Today, we use solid state diodes, devices that have the property of conducting electricity in one direction, because of the physical nature of the materials used in building the diode, the semiconductors.

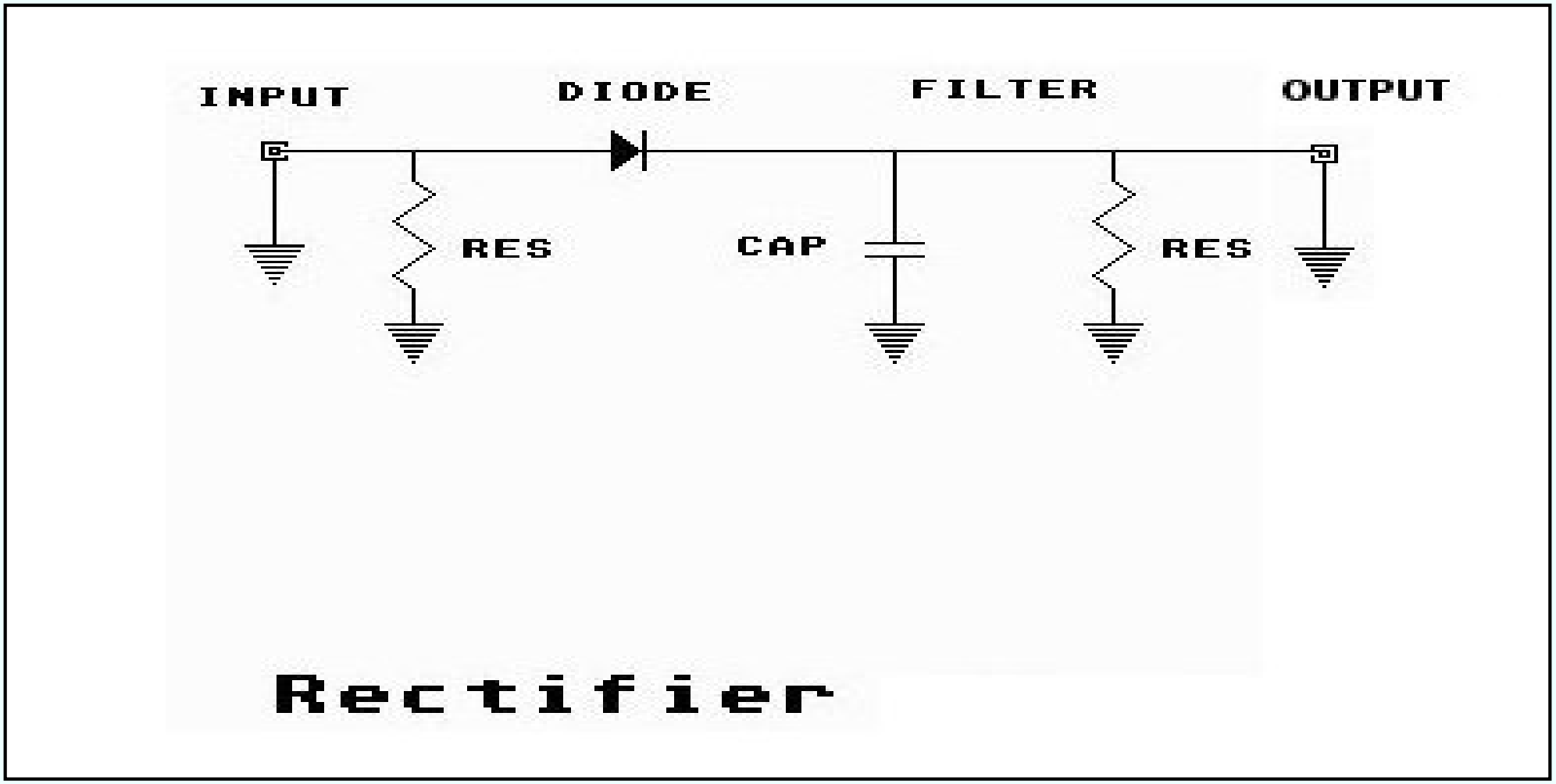

Fig 11 - 1

Take a look at the circuit of the detector again and think in terms of the current that circulates through the output resistor. You know a current has to have a path to follow, that must be a closed circuit. The current that circulates through the output resistor goes through the diode, the output resistor, the input resistor, again and again. This current is driven or pushed by the power that comes from the receiver and that develops a voltage across the input resistor. The input and output resistors are normally fixed, or change very little. This is not true with the internal resistance of the diode. The resistance of the diode varies with the voltage across the diode, and varies in a way that is not linear. This is the reason why the diode is useful; it is a non-linear device.

The current that circulates through a diode is a function of the voltage across the diode. This relationship is exponential but for small changes in the voltage, and for a limited region of voltages, it can be approximated with a parabolic relationship. This parabolic relationship is what gives the square law relation that is needed by the telescope. A diode, or detector, will perform as a square law detector only within a limited region of its operating range.

A few more words about linear and nonlinear. We said the diode must be linear, then we said that the diode works because it is nonlinear. The point is this: the relationship between the voltage across the diode and the current that circulates through the diode is nonlinear, exponential. This is the reason the diode works, this is the reason why there is a region of this relation where we can approximate a parabolic relation. Then, once we approximate the parabolic relation, we have a square law detection: the output current is proportional to the input power. We need that this relation is linear for different values of power; that is, if the power doubles, the output doubles. The relationship is not linear, but the operation is linear. The range of values for which this power relationship holds is the region of linearity of the diode.

Experiment: Rectification

If there is any doubt in your mind about the operation of a detector, it is suggested, you perform the following experiment. You will need a few materials, most of which will be used later in other experiments and in the constructions of the Data Processing Unit of your telescope. Procure the following parts, if you do not already have them:

Two 1.5 volt AA batteries, Radio Shack # 23-252, or equivalent;
Two AA single battery holders, Radio Shack # 270-401, or equivalent;
One 10 K ohm linear potentiometer, Radio Shack # 271-1715, or equivalent;
One 10 K ohm resistor, Radio Shack # 271-1311, or equivalent;
One 1 Megohm resistor, Radio Shack # 271-1356, or equivalent;
One 1N914 switching diode, Radio Shack # 276-112, or equivalent;
Any voltmeter you might have with a low voltage scale.

You might want to mount the parts in a small piece of board, like the Radio Shack # 276-168, or equivalent. Radio Shack is a trade name from Tandy Corporation. Try not to damage the perforated board, so you can use it later for other experiments and for building your Data Processing Unit.

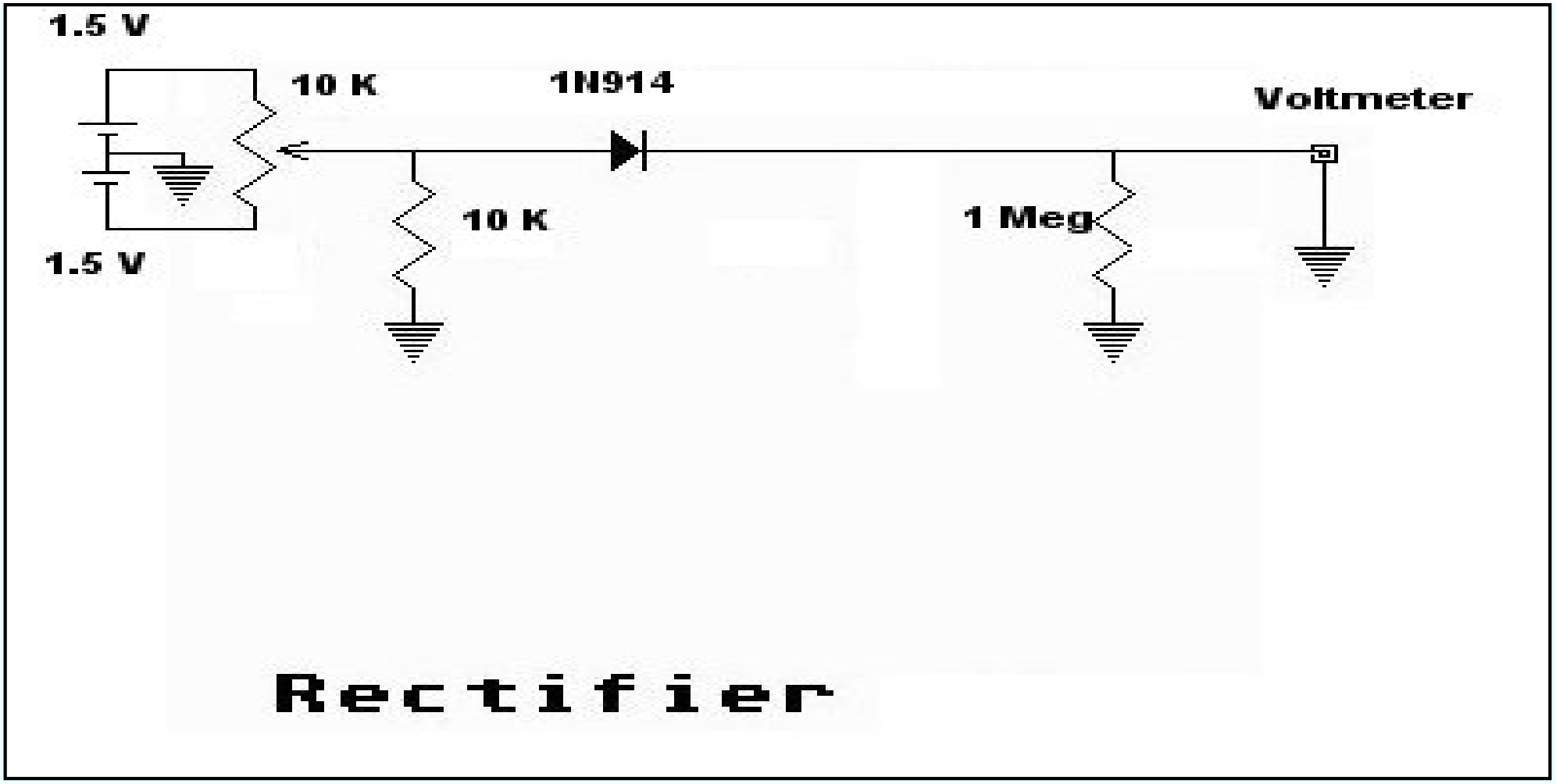

Fig 11 - 2

One interesting way to make the connections without damaging the components or the board, is by using a socket for integrated circuits, like Radio Shack # 276-1994, or equivalent. The wires of the components are the right size to plug into two locations across the socket. The connections can be made to the pins of the socket. If you know about wire wrap, that is a useful technique in this case, because you can remove the connections, and reuse the parts later.

You will need some tools and a procedure for wiring the connections. Any method for wiring that you are familiar with can be used for these experiments. If you wish, you can get a bread board, like Radio Shack # 276-174, or equivalent. This board lets you make the connections by only pushing the wires into the sockets. Neither the sockets or the wires are damaged and can be reused. In any way you do it, you need materials to build the circuits.

Connect all the parts as shown on the diagram (See Fig. 11-2). Be careful to connect the diode with the band as shown. Put the voltmeter in the lowest scale, so you can read about 1 volt. Install the batteries in the holders, observing their polarity, and move the potentiometer from one end to the other. If you have followed the connections as shown on the diagram (See Fig. 11-2), when the arm of the potentiometer is at the top, the voltmeter should read between 1 and 1.5 positive volts. As you move the arm down, the voltage should go down until you get to the center of the potentiometer, where the voltmeter should be reading zero. If you move the

potentiometer further down, the voltmeter should read zero, or very close to zero.

Perform this experiment several times to be sure you see that the diode does not let current pass when the voltage is negative. If you have a second voltmeter, install it across the diode, or at the input of the circuit. You will see then, that the diode does not let current pass when the input voltage is negative. Then, reverse the position of the diode. If your voltmeters reads only in one direction, reverse the connections so they read up scale. You should understand that now, with the diode in the opposite connection, the voltage in the output is negative.

This experiment shows you the operation of the diode. When the input voltage has some polarity, that depends on the position of the band, the diode conducts. When the input voltage is of the opposite polarity, the diode does not conduct. The band on the diode is at the cathode, or negative connection of the diode; the other end is the anode, or positive connection, when the diode is conducting.

Do not disassemble the circuit when you finish, because the same circuit will be used in other experiments.

Experiment: Diode

It will be important that you perform also the following experiment. You will need at least one good voltmeter, digital voltmeters are better for this application. The voltmeter should read below 1 volt. Using the same circuit (See Fig. 11-2) as for the previous experiment, connect the best voltmeter to measure the voltage across the diode. Another voltmeter is used to measure the output voltage; this can be a normal voltmeter.

Vary the position of the arm of the potentiometer very slowly and read both instruments. Repeat until you have a good number of pairs of values. Note that the voltmeter connected at the output is really reading current through the diode. Get a piece of graph paper, or your computer, and plot the pairs of values. If you have been very careful in your measurements, you will be rewarded by a nice graph.

Use voltage across the diode as the horizontal axis, and voltage at the output, that really represents current through the diode, as your vertical axis. The curve should start at 0,0, very flat, and about 0.8 volts rise towards the upper right hand corner of the graph. Depending on the diode that you are using, this curve will have one form or another. If you analyze this curve you can see that it is an exponential, but for small variations (over a small range of values) it can be considered as parabolic.

This experiment shows you how the diode works and why it can be used as a square law detector. If you examine your graph very carefully, you can also see the range of values where the diode works this way.

Experiment: Selection of A Diode

The last experiment can be used to select the best diode in a package. It is always a good idea to do so, in some way or another. The best operating point of a diode is the place where the curve obtained in the experiment matches, as close as possible, a parabola. This can be done approximately by selecting as operating point the knee of the curve, or the place where the curve starts going up fast. A better way is to draw a parabola at the same scale and try to match the curves.

A parabola is a curve where the horizontal axis x and the vertical axis y follow the relationship $x^2=4ay$, where a is a constant that gives the form of the parabola. As you can see, y grows rapidly as x grows. In the case of the diode, y is the current through the diode and x is the voltage across the diode. It is not necessary that you draw a parabola exactly with the same characteristics of the diode but, the idea is to draw one so you have a clear picture of how the parabola looks.

The best diode will have a curve that is as close as possible to the parabola, over a large range of values. Some of your diodes will have curves with a very sharp knee, other with a very soft knee.

Notice that the experiment of the diode, and its use to select the best one you have, requires two good voltmeters. Let us qualify what we understand for good. In this case, a good voltmeter is one that has a very high internal resistance and that is able to read small voltages, millivolts. Digital voltmeters are better in this case. If you have only one digital voltmeter and one normal one, put the digital voltmeter across the diode and the normal one in the output.

If you do not have a voltmeter good enough to perform the experiment and you cannot borrow one, an approximate selection can be made if you have some signal generator, receiver, tape recorder, or any device that can serve as a source for a signal into the detector. Remove the batteries and connect the output of the tape recorder replacing them. The potentiometer will be now something like a volume control. If you use a tape recorder, use the noise of the recorder. Without any tape, increase the volume of the recorder until you have noise output. Adjust the potentiometer and the output control from the tape recorder until the output voltmeter reads about half scale. Without touching any of the controls, change the diodes and separate those that give high readings. Be sure you always connect the diodes with the band in the same direction.

In any case, measure the input and output voltages at the knee of the curve and record it for future reference. This is the ideal output voltage from the decoder. In the second case, try to measure the output voltage from the decoder, so you have an idea of where you are working. Note that this voltage is not too large, normally around half a volt. If you are using a voltage much larger than this, you are driving the diode too hard and it is working in the linear region, not in the parabolic one. A much lower voltage will make the diode also work outside the parabolic region and into the exponential one.

At this moment you have separated some of the diodes in the package as candidates for your telescope. A good diode is one of the most important parts of the telescope. Consider that the diodes used in professional telescopes cost several hundred dollars. Mark the package of selected diodes, including the input and output voltages you have determined.

The Fundamental Circuit

The diagram (See Fig. 11-3) shows the fundamental circuit for a detector with all the necessary parts. Note that there is a capacitor connected in series with the input. This capacitor is required to prevent that the output of the receiver transfers a voltage into the detector and modifies its operation or, even damage the diode. After the capacitor we have connected a resistor of 50 ohms to ground. This is done because of the capacitor. Recall we need a continuous path for the current to flow, and this resistor provides it. The value of 50 ohms is chosen because most receivers have this characteristic impedance. If you work with a TV receiver, you might have to use 75 ohms.

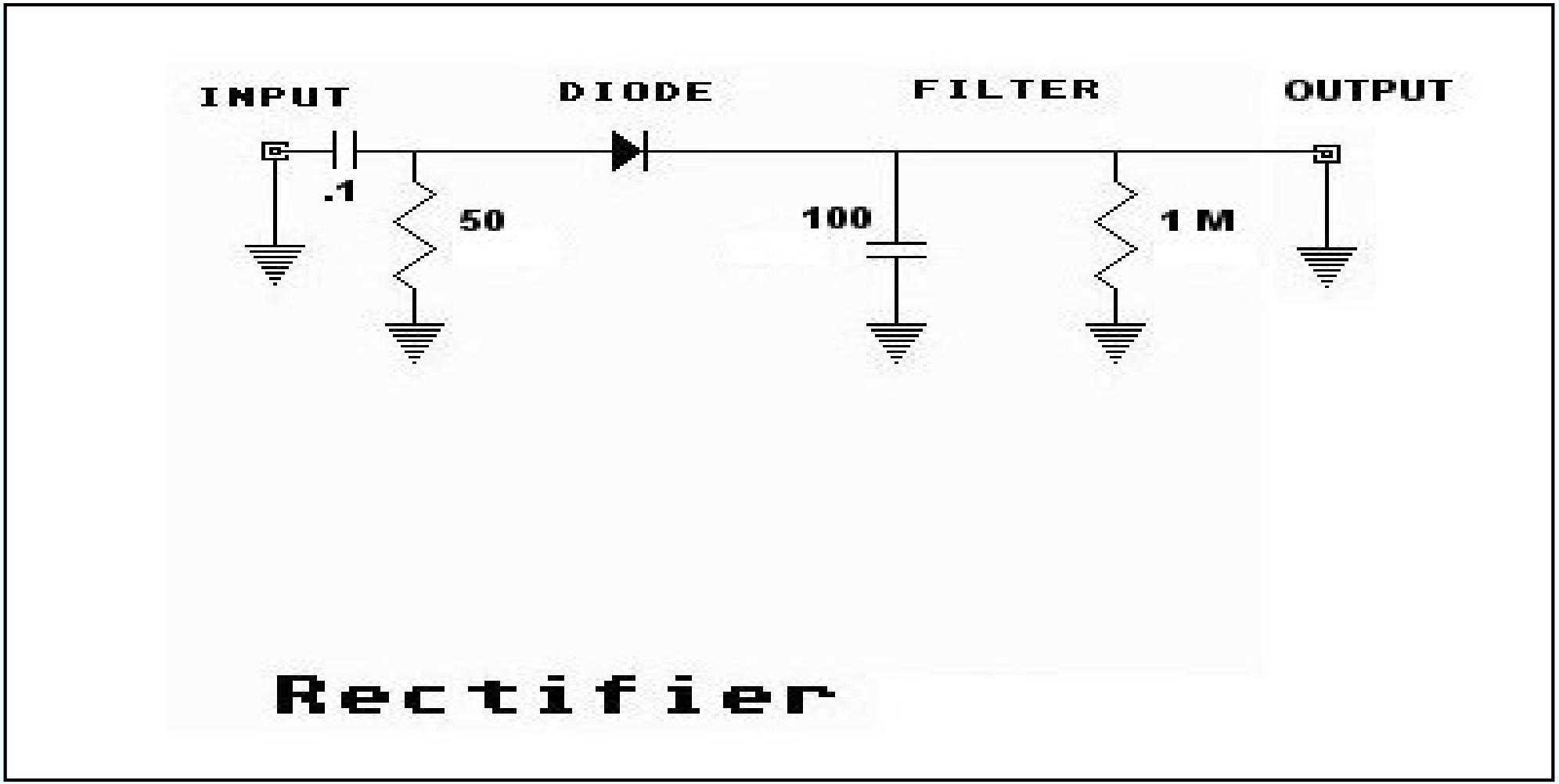

Fig 11 - 3

The diode is then connected in series with the signal, to produce the required rectification. Note that the band is away from the input, producing a positive voltage output. This is a matter of preference and other persons prefer to work with negative voltages. A resistor of 1 Megohm constitute the output resistor for the diode. A capacitor is connected in parallel with this resistor. The purpose of this capacitor is to bypass to ground the high frequency that passes the diode. The output of the circuit is taken across the 1 Meg ohm resistor.

This circuit is seldom built as an independent unit because is so small that can be added to subsequent circuits. In this way, the connections between circuits become shorter and less susceptible to pick up noise.

A few final considerations. This circuit should be driven from the receiver in such a way that the voltage across the diode is in the range determined by the experiments performed with the diode. If these experiments have not been done, you can try to have a voltage on the order of 0.4 to 0.5 volts, without a signal.

The output of this circuit is what is called high impedance; that is, looking into the output of the circuit, we see a high impedance. The input of the circuit that is

connected to this output should also be a high impedance circuit. If this is not done, the detector might not work properly. The typical circuit that follows a detector is an amplifier, that will be studied next.

RADIO ASTRONOMY FOR BEGINNERS

Michael E. Valdez

Chapter 12

THE AMPLIFIER

The operational amplifier is probably the most useful piece of equipment in electronics today. The name comes from the times the only computers were analog computers and the operational amplifier was used to perform mathematical operations. The amplifier can add or subtract signals, can integrate a function represented by a variable voltage, can differentiate a function represented by a voltage, and many others. We will use the operational amplifier as an amplifier, to provide a larger voltage than its input; as a buffer, to provide separation between circuits; as an integrator, to eliminate small variations in the signal; as an adder, to get a signal that is the sum, or difference of two signals; etc.

The operational amplifier is today an integrated circuit packed in a small chip with eight or fourteen pins. The package has normally one, two, or four amplifiers. The one that is most useful for our work is the one with two amplifiers. Since this circuit is used very much, these integrated circuits are not too expensive and you can get good quality amplifiers for around a dollar. We recommend you use the LF353, produced by several manufacturers, which has very good characteristics.

The operational amplifiers have many characteristics of interest, but probably the most important one for our application is that the input impedance is very large, several megohms. This means that the device or circuit driving an operational amplifier has to provide a voltage, but no power. The power required to drive an operational amplifier is practically zero. At the same time, the output impedance of the operational amplifier is very low; this means that all the power produced by the operational amplifier is transferred to the load.

An operational amplifier is quite complex, but we are only interested in understanding how it works. The amplifier has two inputs, one called + and one called -; it has one output and the two power supply inputs, one called +V and the other -V. Note that the amplifier does not have a ground connection. The ground of an operational amplifier is the center point of the two supplies. This requires that the two supplies be of equal voltage, within a good tolerance. The error, or difference between the two supplies is applied as a signal to the amplifier and can destroy its performance.

The operational amplifier has a very high gain. The higher the gain, the better the amplifier. The gain of an operational amplifier is defined as the relation between the output voltage with respect to ground, and the voltage between the + and - input terminals. This could also be expressed as the relation between the output voltage and the difference between the voltages at the two input terminals, all with respect to ground.

Before going further, let us clarify the + and - terminals. The idea is as follows: Imagine all input and output voltages are zero. Now imagine we apply a very minute positive voltage to the + terminal; the output voltage will increase by a value equal to the input voltage multiplied by the amplification. Now, if the applied voltage is negative, the output voltage will decrease. Note that if a signal is applied to the + terminal the output changes in the same direction as the applied voltage. Now, imagine we apply the small voltage to the - terminal. The situation reverses. If the applied voltage is positive, the output voltage decreases and if the applied voltage is negative, the output voltage increases. Now, if we apply a voltage, of the same magnitude and sign to both terminals, the output voltage does not change. This is, in a nut shell, the operation of the operational amplifier.

Now, the gain of the operational amplifier is very large, easily a million; so, if we apply one microvolt (a millionth of a volt) to one of the input terminals, the output

changes by one volt. In general terms this is too much and we will use it later in our studies, but it is useless as an amplifier. The interesting thing is that this characteristic permit us to control the gain of the amplifier in a very simple and reliable way.

The Gain

Consider the circuit of the figure (See Fig. 12-1) where we have an operational amplifier in the usual configuration. Note a resistance in series with the + input and marked INPUT. Note also that there is a resistance, marked FEEDBACK, from the output to the - input and another from the - input to ground.

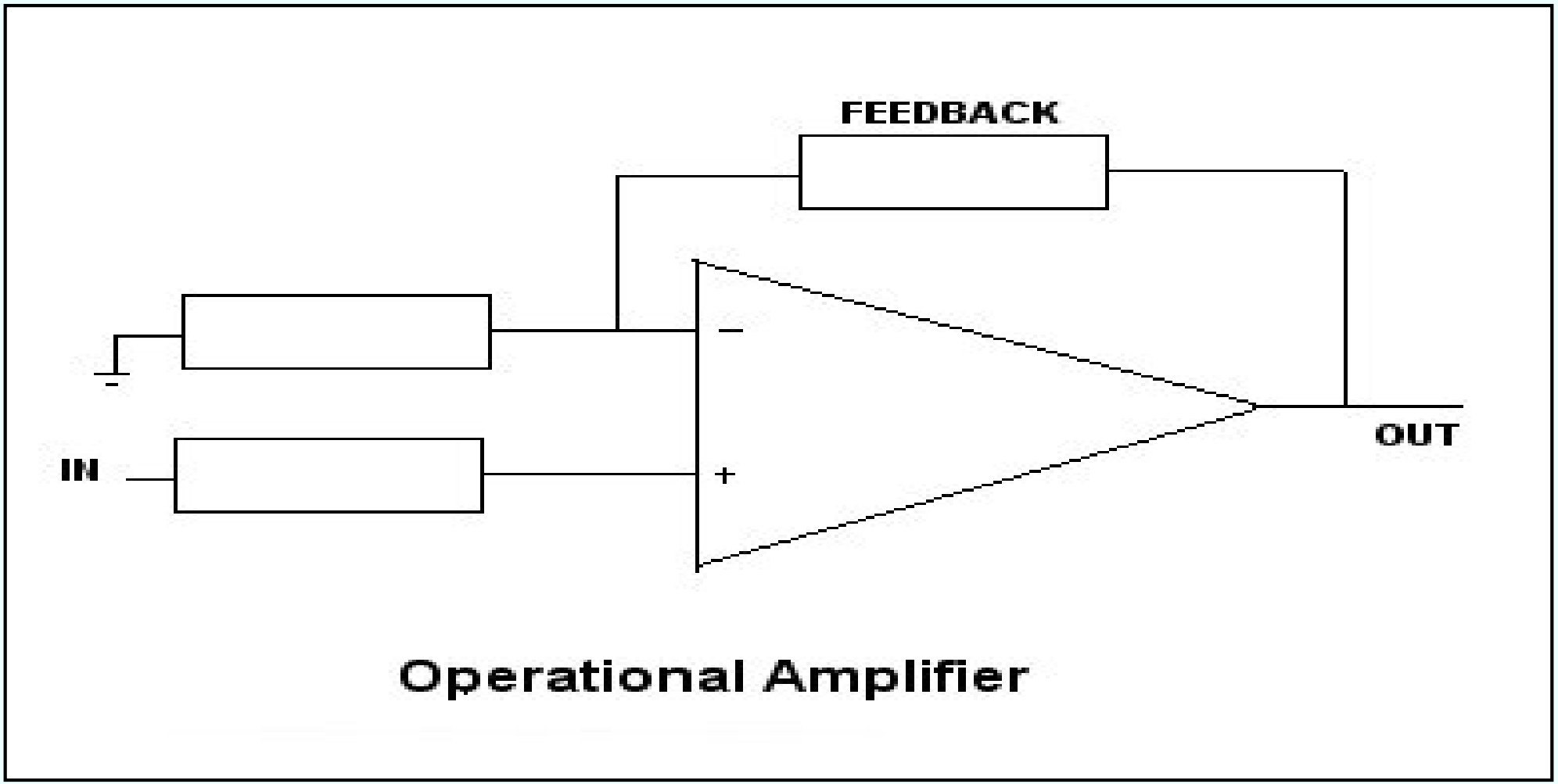

Fig 12 - 1

Imagine we connect the terminal marked INPUT to ground as to have zero volts at the + terminal. Imagine at the moment we look at the circuit the output voltage is 1 volt. This voltage creates a current of 10 microamperes through the two resistors in series, and a voltage of 0.1 volt at the negative terminal. This positive voltage at the - terminal creates a very large negative voltage at the output, that is added to the 1 volt. If the output voltage becomes negative, the voltage at the - terminal becomes negative and creates a large positive voltage in the output. This process ends very soon, when the output voltage is exactly zero, the voltage at the - terminal is also

zero, and the operational amplifier is in equilibrium. This process is called feedback, negative feedback in this case. The two resistors are called the feedback circuit.

Now, consider we apply a voltage of + 0.1 volt to the + terminal, through the resistor. Again, this positive voltage creates a large positive voltage at the output, which creates a voltage one tenth of its value at the - terminal, which drives the output negative. Again, the process ends very soon, when the - terminal has a voltage with respect to ground exactly equal to the voltage of the + terminal with respect to ground; in this case + 0.1 volt. Now, what is the voltage at the output? We know that the resistors force the voltage at the - terminal to be exactly 1/10 of the voltage at the output; the output voltage is then 1 volt and we have an effective amplification of 10. Note that this amplification depends only on the values of the two resistors connected to the - terminal and not on the voltage of the power supply, the temperature of the transistors in the integrated circuit, or any other value. This is the big advantage of the operational amplifier. Normally the gain is between one and 20, as a maximum. If you need a higher gain, it is better to use several amplifiers.

Saturation

Consider again the circuit we studied above (See Fig. 12-1), which has a gain of 10. Assume the power supply voltages are +12 and -12 volts. Consider we apply a voltage of 2 volts at the + terminal, through the series resistor. What will happen? From the analyses we had made before we know the operational amplifier will try to give us an output voltage of 20 volts with respect to ground. But the operational amplifier is only a circuit with a large number of transistors, active devices that generate a copy of their input, using the power provided by the power supply. Transistors do not generates power. Consequently, the operational amplifier will not be able to provide an output of 20 volts and it will go as high as the power supply voltage will permit. In this case, it will give an output somewhere between 10 and 12 volts.

This situation is called saturation, and we say that the amplifier saturates if we apply an input voltage larger than 1.2 volts. The same thing happens if the input voltage is negative, the amplifier saturates with the most negative voltage it can produce.

This effect limits both, the maximum input signal for a given amplifier, and the maximum gain we can obtain with a given signal.

In summary, this basic circuit will be used very much during the design of the Data Processing Unit of the telescope and it will be given different names, depending on the application. Let us reinforce some important points:

The high gain of the amplifier forces the two inputs to have the same voltage with respect to ground, when we connect the feedback circuit;
The gain of the amplifier is determined only by the values of the two resistors connected to the - terminal and is given by the relation between the sum of the two resistors and the value of the one connected to ground;
The input into the + terminal produces an output of the same sign and of a magnitude equal to the magnitude of the signal multiplied by the gain;
The input signal does not require any power; and

The output voltage cannot be larger than the positive supply voltage, nor smaller than the negative supply voltage, regardless of the input. This condition is called saturation.

RADIO ASTRONOMY FOR BEGINNERS

Michael E. Valdez

Chapter 13

THE INTEGRATOR

The Integrator is a circuit that is used to smooth out the small, rapid variations in the signal, in such a way that the resultant signal can be studied and analyzed with easy.

The circuit of an elementary integrator is quite simple, but it is necessary to understand how it works. Consider the circuit on the figure (See Fig. 13-1), that represents only a battery, a switch, a resistor, and a capacitor all in series. Let us consider that when we first look at the circuit, the switch has been in the position shown, and it has been so for a very long time. The voltage at the capacitor is zero.

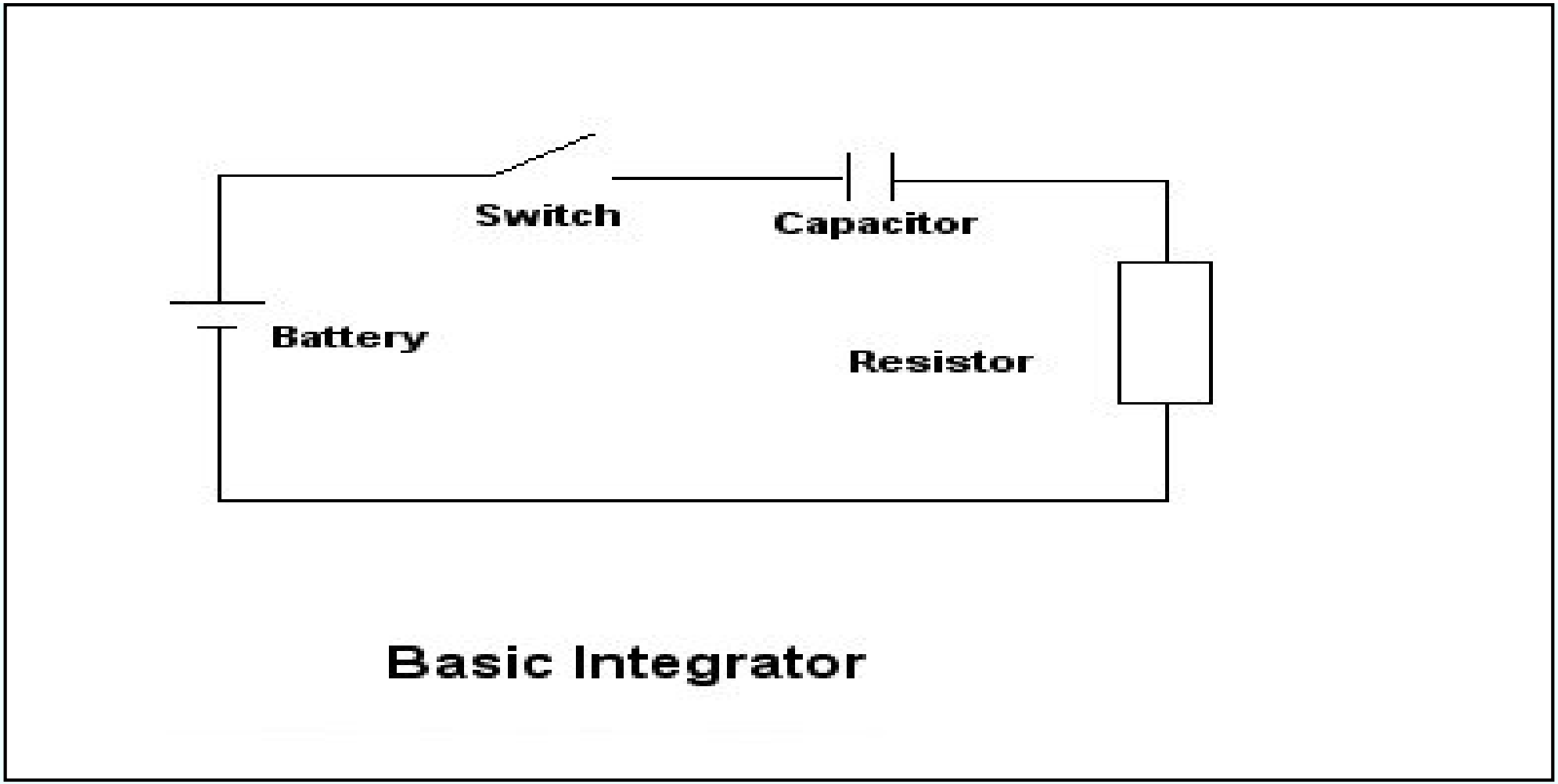

Fig 13 - 1

Let us consider now that we move the switch, so the voltage applied to the resistor and capacitor in series increases abruptly to a certain value V. Since the voltage at the capacitor is zero, the resistor has V volts between its terminals and a current circulates through it, which depends on the voltage V and the value of the resistor. Note that this current does not have any place to go, except to charge the capacitor.

During the first instant of time the charge of the capacitor increases a little, or a lot, depending on the current; the point to consider is that the capacitor charges and develops a voltage across its terminals. Now the resistor has less voltage across its terminals, equal to the difference between V and the charge of the capacitor. The current now is less than before, but there is a current that again, goes to charge more the capacitor. This process continues as long as the capacitor can accept change; that is, as long as the voltage developed by the capacitor is less than the voltage of the source. Eventually this will take place and the process stops, with the capacitor fully charged, developing a voltage V.

This process takes time. How much time, depends on the value of the capacitor and the value of the resistor. The product of these two values characterizes the circuit and it is called the time constant of the circuit. If you are curious, you can go through your knowledge of Physics and recall that the resistance is measured in ohms and

the capacitance in farads; if you go through the calculations you will find that the units of the product is seconds. The time constant of the circuit is the time in seconds that the circuit requires to charge the capacitor to a value of V/e, or about 67% of the input voltage. This process is exponential and that is the reason for the e, the base of the natural logarithms.

What is this good for? Imagine that the battery is the output of a receiver and that is practically constant at a voltage V; the capacitor charges to this voltage. Then, suddenly, a sharp pulse of noise comes, because an old car passes in front of our house. The voltage V becomes V+N, much larger, and the voltage at the capacitor goes up. But the noise is only a pulse and the voltage returns very fast to the value V. The voltage at the capacitor did not have time to increase too much when the input voltage goes back down. Depending of the value of the time constant, the pulse might not appear in the output. Since all our signals are corrupted by noise, an integrator with the proper time constant, will eliminate most of the noise.

The importance of the time constant is very great. If the time constant is too small compared with the duration of the noise pulses, the pulses will have time to pass the integrator into the output. On the other hand, if the time constant is too large, the integrator might mask the signals we want to see. Let us give an example. Imagine we are looking for a pulsar, a signal that is a succession of pulses. If the time constant does not let these pulses pass, we will not see the pulsar at all. We should make another consideration. An integrator will not eliminate a sequence of pulses, like those produced by a lawn mower, because the sequence carries a certain energy and the integrator will show this energy.

Experiment: Integration

Before going further into the practical circuits of an integrator, it is interesting you perform a fast and simple experiment, with many of the same parts used for the detector. You will need some additional parts as follows:

One 1 uf capacitor, Radio Shack # 272-1434, or equivalent;

One 22 uf capacitor, Radio Shack # 272-1437, or equivalent; and

One single-pole-double-throw switch, Radio Shack # 275-603, or equivalent.

Connect the batteries, the switch, the 1 Meg resistor, and the 1 uf capacitor as in the circuit (See Fig. 13-1). Connect the best voltmeter you have across the capacitor. Be sure the switch is as shown before connecting the batteries. Move the switch and observe the voltage increase quite rapidly, but not in zero time. If you want to convince yourself that is not zero time, remove the capacitor and repeat. That is instantaneous. Move the switch to the other position and see the capacitor discharge. Repeat the experiment with the 22 uf capacitor. You will notice that now the time to charge the capacitor is much longer. The time constant is now 22 seconds, while before it was only 1 second.

If your voltmeter is not a digital voltmeter, or a very high impedance voltmeter, you will notice that the times for charging the capacitor are much shorter than what you expect from the calculations. This points to one of the problems of this circuit: it has a very large output impedance and it does not have the capability to drive another circuit. If you want to convince yourself of this fact, mount a resistor of 10 K ohms in parallel with the capacitor and repeat the experiment. You will notice that the capacitor does not charge to the full voltage and it does it much faster than before. Note also that this resistor is taking the place of the leakage resistor of the capacitor. A good capacitor has a very large leakage resistance; a bad capacitor has a low leakage resistance, which discharges the capacitor, preventing the operation of the integrator. The capacitor used in an integrator should the best you can get, or afford. The other problem of this circuit is that the internal impedance of the source is in series, adding, with the resistor of the integrator, thus changing its value.

This experiment should show you how the integrator works and some of the problems of a simple circuit.

Practical Integrator Circuits

The problems studied in the experiment can be solved using operational amplifiers at both sides of the integrator, to separate it from the two circuits, ahead and following it. This application of the operational amplifiers is what is called a buffer. Another possibility, that uses a single operational amplifier, is to put the integrator in the feedback circuit of the operational amplifier (See Fig. 13-2). Imagine that we put the capacitor from the output to the - input of the amplifier and the resistor to ground, or vice versa. When we apply a voltage to the + input, the output voltage tries to go up, but the capacitor produces feedback through the resistor and it does not permit the output voltage to change, except as the capacitor charges. The advantage of this circuit is also that nothing can discharge the capacitor. A voltmeter, any voltmeter connected between the output and ground, does not affect the operation of the integrator. Since the signal is not driving directly the integrator circuit, it cannot affect its operation.

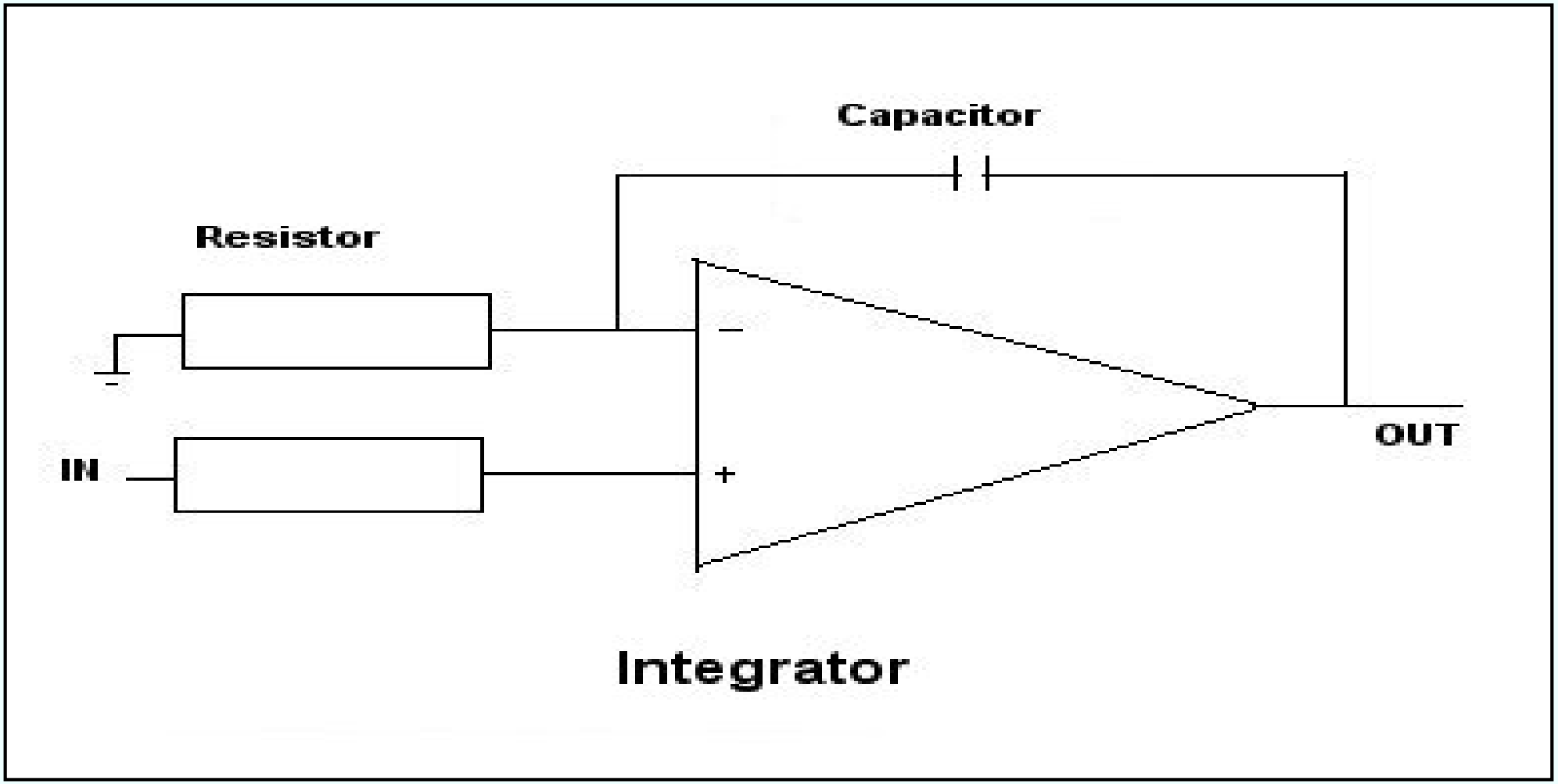

Fig 13 - 2

In a practical circuit, we will want to have a variable time constant. We could use a variable resistor but usually we want to know the value of the time constant. We will need to calibrate very precisely the resistor. It is much better to have a switch to change either the resistor, the capacitor, or several switches to change both. This

permits us to change the time constant of the integrator, choosing between several fixed values, for the particular observation we want to make.

In summary, an integrator is a circuit that includes a capacitor that, by charging and discharging, prevents fast changes in the voltage of the signal. The integrator must be driven by a source of very low impedance to have a reliable time constant. The integrator needs an operational amplifier at its output to separate it from the next circuit. The integrator needs a capacitor of good quality (very high internal resistance), because this internal resistance discharges the capacitor and deteriorates the operation of the integrator.

RADIO ASTRONOMY FOR BEGINNERS

Michael E. Valdez

Chapter 14

ZEROING

The signal coming from the receiver, processed by the detector and the integrator, whether it is amplified or not, is the sum of two parts:

One part is the background, that is formed by the internal noise of the receiver, the background radiation from the sky, the continuous noise of the location where we are working, the sum of all the interference from local transmitters and man made apparatus. This background noise is practically constant, although it varies over long periods of time. For example, interference's might come on or go off the air, the sky background changes depending on the part of the sky we are observing, the temperature of the receiver affects its internal noise, etc. Later, when we study other operating procedures where these changes are important, or the desired signal, we will return to this topic.

The other part of the output of the receiver is the signal we want to record and study. This signal varies during the observation and we want to capture these variations. In general terms, the amplitude of this signal is much smaller than the amplitude of the base voltage.

The process through which we remove the base voltage from the signal we are processing, and leave only the signal we wish to observe, is called zeroing. The reason is simple. Before the observation starts we usually do not have any signal from the source of interest. The whole signal coming from the receiver is the base voltage. The process of zeroing is to add another voltage in such a way as to obtain a zero output.

This is the only place we have to explain why the signal from the source is so small compared to the signal from the background. Let us consider a practical case. Imagine the telescope of an amateur which typically receives signals from a circle of the sky of about 10 degrees in diameter. The area of this circle is close to 80 square degrees. Consider the Sun, which subtends one half a degree of diameter. The area of the Sun is then 0.2 square degrees. Now, the temperature of the Sun is on the order of 8000 degree, giving us a contribution of Ts = 0.2 * 8000 = 1600 or an average over the area of 1600 / 80 = 20 degree of temperature. The background from the sky is on the order of 5 to 10 degree, depending on the frequency. The sum of this background, the receiver noise, etc., rarely gives less than 70 degrees of system temperature. So, the Sun will drive our telescope very hard. The output increases almost 30%.

Now consider the Moon, which might have a temperature of some 200 degree when full. Since the apparent size of the Moon is the same as the Sun, the average contribution of the Moon will only be 0.5 degree of temperature. This is to say, the Moon passing in front of our telescope will produce an increase in the output of the detector of only 0.8%. You can imagine that any other radio source in the sky will produce only minute increases in the power output of the receiver.

The process of zeroing is performed with an operational amplifier, using its capability for adding or subtracting signals. We normally apply our signal to the + input of the amplifier and an adjustable voltage to the - input. This adjustable signal has to be of the same polarity as the signal we want to zero. The amplifier subtracts the two signals with the proper sign. If we adjust the zeroing voltage, we can obtain that the output voltage from the operational amplifier is zero, or any other value we wish.

Experiment: Zeroing

This experiment requires an operational amplifier and its power supply, so it might me necessary to delay it until you have a suitable power supply. In any case, you will need a power supply for your Data Processing Unit, and that power supply is used in this experiment. This experiment can be performed using two 9-volt batteries to supply the operational amplifier, if you wish to do it this way. You also need an operational amplifier. If you already have the LF353's you will use in your circuit, you can use one of them; if not, a cheap one, like Radio Shack # 276- 038 will do it. This is not a waste of money because this operational amplifier has the same connections of the LF353 and it can be used to test circuits. You also need some integrated circuit sockets, Radio Shack # 276-1994, or equivalent, and tools for wiring your circuits.

The procedure we will explain calls for making some connections. You can use any method for wiring you are familiar with. If you wish, you can get a bread board, like Radio Shack # 276-174 or equivalent. This board permits you make the connections by only pushing the wires into the sockets. Neither the wires nor the sockets get damaged, and they can be reused. In any way you do it, you need materials to build circuits.

This experiment will show you first how the amplifier works, and then how you can zero the signal. You will also need a signal source and you can use the same tape recorder you used before. Connect the circuit as shown on the diagram (See Fig. 14-1), but do not install the battery in its carrier. Be sure the arm of the potentiometer is at the ground end. Notice that you have installed two 100 K ohm resistors as a gain control of the amplifier. Turn on the power supply and adjust the volume of the tape recorder to obtain some reading in the output meter. Then, remove the resistor from the - input of the amplifier to the potentiometer. Notice that the output voltage goes down to about half of the previous value. The reason is that you have changed the gain of the amplifier. The gain was 2 when you started and now it is one. The open circuit between the - input and ground acts as a very large resistor and the gain is one. You should verify these computations.

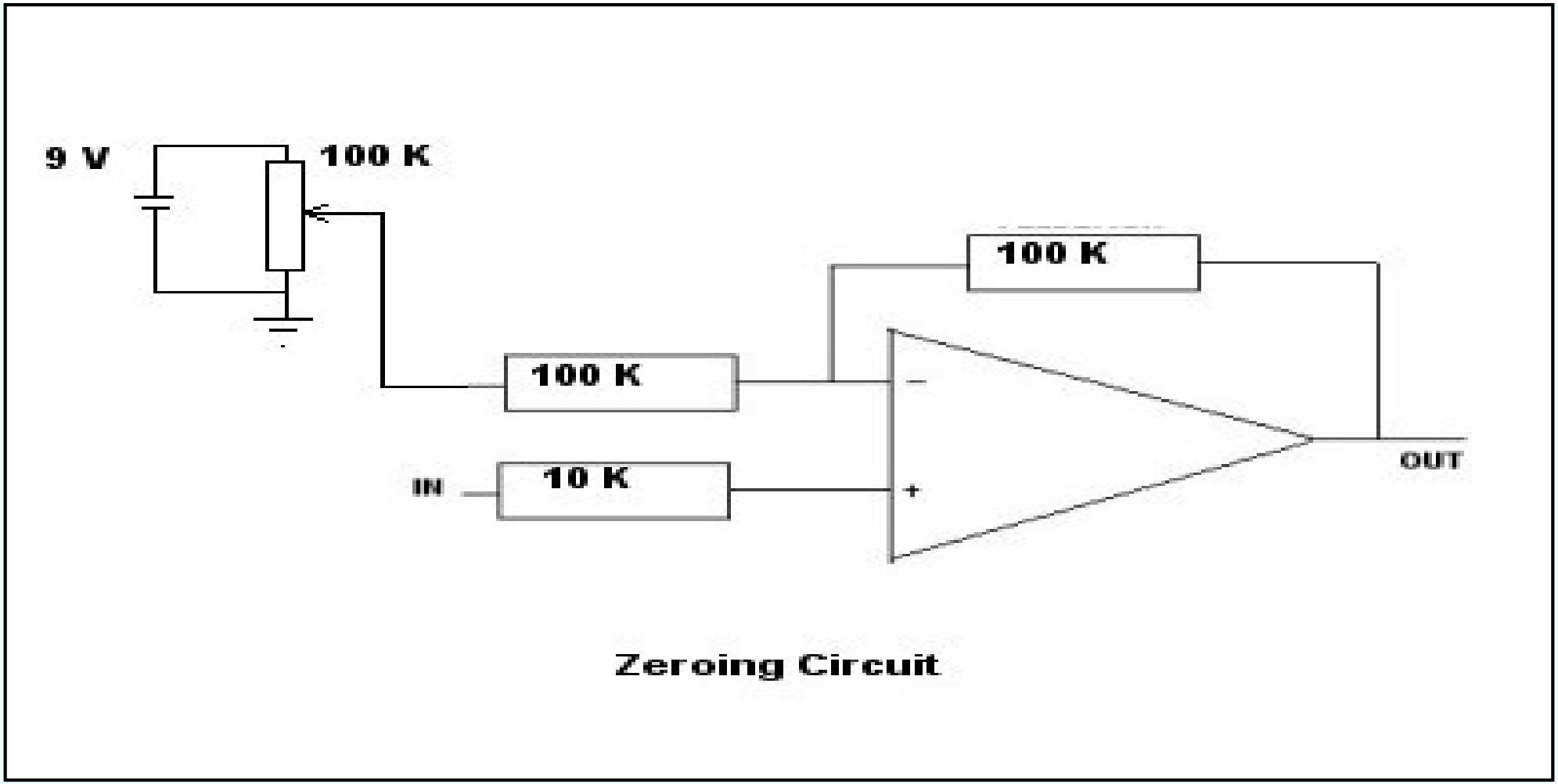

Fig 14 - 1

Change the volume on the tape recorder so the output voltage is quite small but that still can be read. Install a 10 K ohm resistor from the - input to ground. The output voltage should jump to about 10 times as before; actually the gain is 11, as you can compute. Do it.

Now, you will try to zero the output of the amplifier by applying a positive voltage to the - input. For this purpose you need to install the battery. Notice that by varying the position of the arm of the potentiometer you can change the output voltage to any value you want. A particular position gives an output of zero volts.

Change the position of the volume control of the tape recorder, so as to change the magnitude of the signal. The output of the amplifier will change, reflecting the change you have made. If you increase the volume of the tape recorder, the output voltage will go up; if you reduce the volume, it will go down. Recall the output from the tape recorder is connected to the + input of the amplifier.

Notice also that for each position of the volume of the tape recorder, you can find a position of the arm of the potentiometer that will zero the voltage output of the amplifier. There is, of course, the possibility that for some positions of the volume control of the tape recorder, too high or too low, you are not able to zero the output

of the amplifier and this is interesting. If such thing happens, it will teach you that the zeroing process has a limit, not being able to zero signals that, for example, are too large. This limit comes from the voltage you are using to feed the potentiometer. This voltage should be large enough so you can zero the largest signals you expect, but not so large that you cannot control it easily with the potentiometer. In the same way, if you need to zero very low, or negative voltages, the zeroing voltage should also go negative.

A good rule of thumb is to consider that the output from the receiver will be adjusted to drive the detector with about half a volt. You have measured the output voltage of the detector in a previous experiment. Given the amplification you have between the detector and the zeroing circuit, you can compute the voltage you will have at your signal input. In this way, you can know quite close, how much voltage you will need to zero it. Give some latitude for adjustment and you have designed your zeroing circuit.

This is a perfect time to call your attention to one point we made before and that is apparent now. Without any possible example we said before that whenever you do something you must plan ahead and have an idea of what is you will get, before you do anything. You have here one real life example of how this is done. You do not need to guess how much voltage you need to zero your signal; you can compute it. This computation does not need to be exact, because you will end up with some adjustment, any way. So, it is important to recognize that in most of our instances you will not need exact results, but only what is called a ball park figure. If your results are in that ball park figure, that proves your estimate was good. If the results do not come within the ball park figure, something is wrong, and you need to find what it is. This is the marvelous byproduct of this procedure. You have some way to check what you do, and to know if the result is good.

Final Considerations

For this process of zeroing to be useful, it must be performed after the integration. If zeroing is performed before the integration, you need to wait until the integrator settles down, to see the effects of any adjustment in the zeroing voltage.

As was mentioned before, when we discussed the subject of the Data Processing Unit as a unit, the output of this circuit leaves us with a very small signal. In general, this output is less than 10% of the original signal, and in many cases, much less, as we have seen above.

For this reason, the zeroing circuit must be followed by one or several amplifiers, to increase the voltage to whatever is needed at the input of the circuits that follow. It is usual also to have several circuits at this point. It was mentioned that a meter at this point is extremely useful. This is also a good place to put an output to connect a strip chart recorder, etc. Each one of these outputs requires an independent operational amplifier, to isolate one from the others. This is the subject of our next chapter.

RADIO ASTRONOMY FOR BEGINNERS

Michael E. Valdez

Chapter 15

METERS AND ACCESSORIES

It is possible to have a Data Processing Unit without any meter. It will be necessary to connect an external meter to calibrate the unit, but it is possible. The problem is that it is necessary to calibrate the unit every time we start an observation. For example, if we wish to make one observation after another, it is always necessary to calibrate the unit in between the two observations. The reason is simple. Many of the conditions change from one observation to the next, the place in the sky where the different sources are located, changes. The background noise is different at different locations. The intensity of the source is in general not the same, and many other factors of similar importance.

Adding meters to the Data Processing Unit of a telescope can be costly, if we use high quality meters, as is required. Luckily, there is a very simple solution and is to use inexpensive meters and an operational amplifier.

All panel meters of the D'Arsonval type; that is, with a needle that moves to show the measurement, are current meters. Some of them are called voltmeters and are calibrated in volts, simply because they have a resistor in series to convert the voltage into a current.

Imagine now that we take our good friend the operational amplifier and put a meter from the output to the - input, in what we have called the feedback loop, and we connect a resistor from the - input to ground (See Fig. 15-1). Imagine now that we connect the + input to our signal, as always, trough a series resistor. If the voltage of the signal is not zero, the output voltage will follow the signal, but the feedback circuit draws current in such a way that the voltage at the - input terminal is identical to the voltage at the + input terminal. The way this is accomplished is by the voltage drop in the resistor from the - input to ground. At the same time, the meter is indicating how much current is circulating. Since the current is proportional to the voltage, the meter deflection is proportional to the signal voltage.

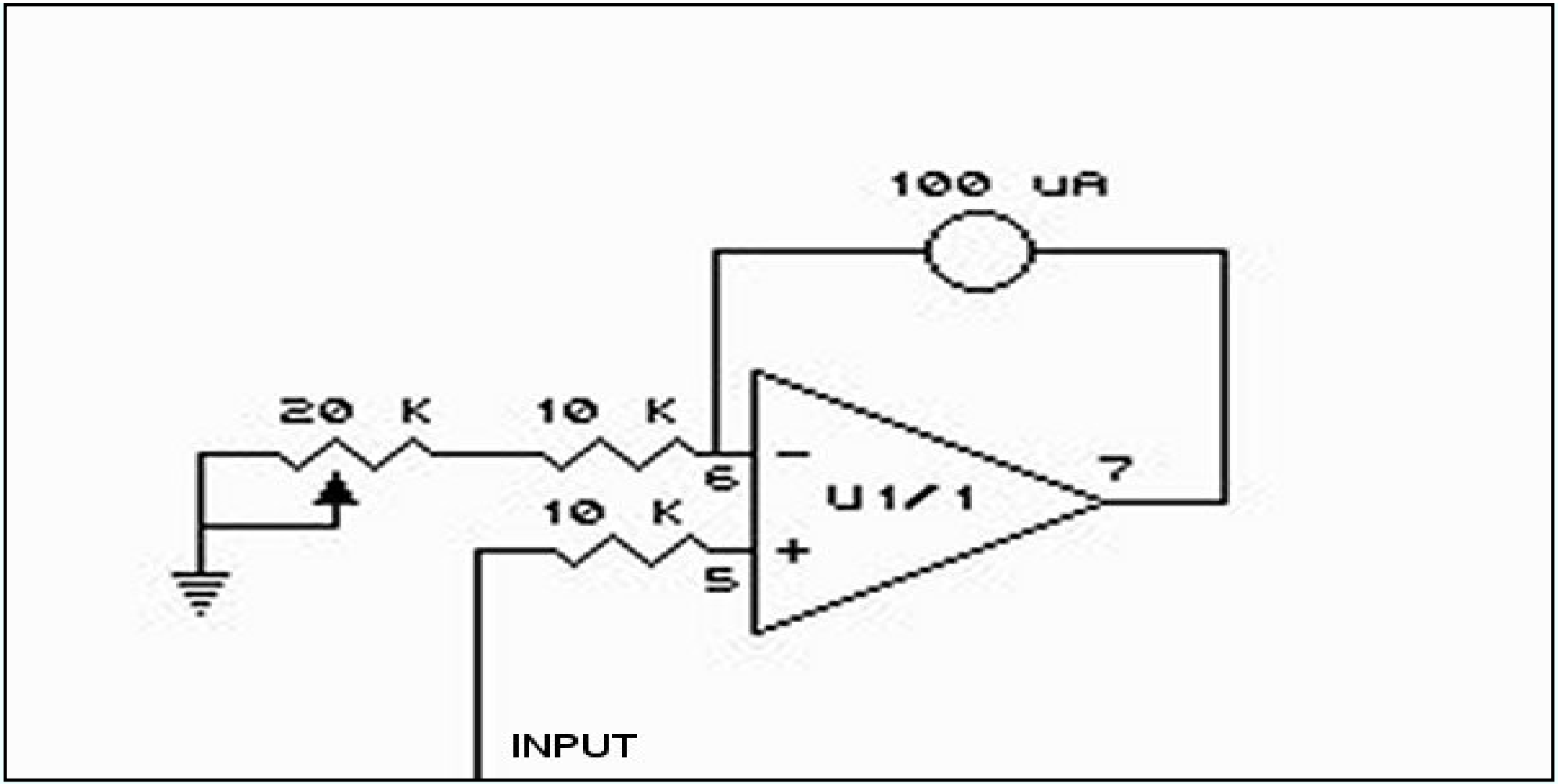

Fig 15 - 1

In this way, we have a circuit that uses an inexpensive meter to show the voltage at the signal. Since we use an operational amplifier, the input impedance of our circuit is very high, so our circuit behaves as a very expensive meter and costs only a few dollars.

The full scale deflection of the meter is adjusted by changing the value of the resistor, that can be made adjustable. If it is desired, the meter could be calibrated by either using the existing scale, or drawing a new one.

There are many places where a meter can be valuable when performing observations. The obvious places are at the detector, the integrator, and the zeroing circuit.

It is difficult to install a meter at the input of the detector because the voltage ahead of the detector is alternating current. We need a rectifier to make any measurement and we introduce the uncertainties of this rectifier. Since the diode used for the detector has been carefully selected and calibrated, one good alternative is to connect the meter at the output of the detector. From the analyses made on the diode we know what is the optimum value of this output voltage, so we can adjust the gain of the receiver to have this value as output for the detector. In this way, we know the detector is working as a square law detector, in the region of linearity.

The next place where a meter is valuable is at the input of the integrator. At this point, the amplitude of the signal is still fairly constant because we are mainly dealing with the background level. There is an interesting reason to have the voltage input to the integrator as large as possible. Let us study it.

Imagine we apply the voltage output of the detector directly to the integrator. We know we do not need to worry about the integrator loading the detector because we use an operational amplifier, one way or another. The problem is the signal voltage is quite low, less than one volt. Experience indicates that people living in a city or town is subject to large noise. This noise can take the form of pulses of energy, that some times are quite large. The time constant of the integrator cannot be made so large as to take care of these large noise pulses. Some of the energy in the pulse charges the capacitor and the pulse passes through the integrator. The amplitude of these pulses can be many times the amplitude of the signal.

Consider now that we put an amplifier and we increase the level of the signal to almost the value of the voltage from the power supply. Say, if we work with +12 and -12 volts, we increase the signal to close to +10 volts. We know from our study of amplifiers, that if we increase the signal more, the output of the amplifier does not increases because it enters into saturation. This is exactly the effect we want to use. If the magnitude of the signal is increased by a large pulse of noise, the amplifier saturates, and the pulse does not reach the capacitor. Things are not perfect, though, because the amplifier takes some time in getting out of saturation, but the net result is still better than if we do not do it this way. This procedure is what is called limiting and the circuit is a limiter. It is used in all FM receivers to reduce the noise. There are other ways to produce limiting but they will not be studied.

Notice that when you observe sources of high intensity, like the Sun, you need to adjust the voltage output of the limiter, so there is room for the signal to increase without being limited. If the Sun increases your signal by 30% and your amplifier saturates with 11 volts, you should adjust your voltage at no more than 8 volts, before the Sun is in your beam.

For this reason, it is interesting to have adjustable gain before the integrator, and a meter there to be sure that we do not put so much gain that the amplifier will saturate with the signal.

The use of a meter at the output of the zeroing circuit is obvious because we need some way to know if the output is zero or not. Some times a meter is not installed there, and the operation is controlled with a meter at the input of the A/D converter, or measuring the value directly with the computer. This is not too bad. Before the observation starts we adjust the input of the A/D converter to a very low value, with the use of the zeroing control. The gain is adjusted to produce the desired results when the source is in front of the antenna. So, the need is for one meter some place between the output of the zeroing circuit and the input of the A/D converter. Note that there is a gain control in this same place that needs to be adjusted, as mentioned above.

In summary, we need three meters as a minimum, if we use the limiter method explained above, two if we do not use a limiter.

Accessories

There are many accessories that can be installed in the Data Processing Unit of a radio telescope. Most of them require power from the signal and should be connected through an operational amplifier so the signal is not loaded. In this way, the operation of the telescope is not affected by connecting or disconnecting the accessory while the observation is in progress.

One interesting accessory to install in any Data Processing Unit, is an oscilloscope, whether at the input of the detector or its output. When designing a Data Processing Unit, it is convenient to consider installing test points, which are accessible without opening the box, for connecting an oscilloscope at these points.

Another interesting accessory is a tape recorder, as to preserve the analog signal, that can be studied later for purposes other than the one of the current observation. A tape recorder can be connected in various points of the data path. The output of the detector is one that normally needs amplification to drive the tape recorder. Note

that a connection at this point for an oscilloscope might not be good for a tape recorder, because of the level requirements. When designing a Data Processing Unit, it might be important to consider one output after the detector for the oscilloscope and another after the amplifier (the input of the integrator) for a tape recorder. This connection of the tape recorder can be made with gain of 1, since the signal at this point resembles audio noise.

After the integrator the signal does not resemble audio noise and it is not possible to use audio techniques to record it. If you wish to record the signal after the integrator, it is necessary to convert it into some form of audio. This can be done with a voltage-controlled-oscillator, that converts the slowly varying voltage into a tone of varying frequency. The frequency of the tone is linearly related to the applied voltage. The design of such a circuit falls outside the realm of a book for beginners.

A strip chart recorder can be connected practically any point after the integrator, but it is better to connect it after the zeroing circuit, to get the advantage of the circuit. The exact point where to connect the operational amplifier that will feed the strip chart recorder depends on the characteristics of the recorder, the most important of which is the required voltage to drive it full scale. In some cases, it might be necessary to give gain to the operational amplifier to produce a voltage that is large enough to drive the strip chart recorder.

Lights can also be installed in any place using the meter circuit and replacing the meter with a light source of some kind. Such a light can indicate that a signal is present at the point.

The same circuit can drive a relay that will close when the signal exceeds a certain magnitude. This could be used to trip an alarm at that moment. A word of advice. The installation of a relay, or any coil, to an operational amplifier requires that you install a diode in the reverse polarity, to prevent damage to the amplifier when the relay is de-energized. As a relay is de- energized, it generates what is called a back electromotive force, a voltage of the opposite polarity. If this voltage of opposite polarity goes through the amplifier, it will damage it. So, we must install a diode to give a path where this reverse polarity voltage can circulate without damage.

In summary, meters, accessories, outputs, lights, relays, etc. can be installed in a Data Processing Unit, by isolating them from the data path, and from each other.

RADIO ASTRONOMY FOR BEGINNERS

Michael E. Valdez

Chapter 16

THE DESIGN

The previous chapters were devoted to the analysis of the different parts that form the Data Processing Unit of a radio telescope. In this chapter we will face the decisions it is necessary to make before we start the construction of our equipment.

With the knowledge we have at this moment, we can consider we have a number of little boxes with different labels. We have some boxes labeled DETECTOR, INTEGRATOR, ZEROING, A/D CONVERTER, and also many boxes labeled AMPLIFIER, METER, etc. The purpose of this chapter is to take a number of these boxes and put them together, to perform the functions we want.

We have some values to start with: We know that the output of the receiver is on the order of 0.5 volts and we know the voltage output of our detector; let us assume that this value is also 0.5 volts, to have something to work with. By the same token, let us assume the analog-to-digital converter we will be using requires 10 volts input, maximum.

So, we start with a terminal marked INPUT and we take the little box marked DETECTOR and we put it next to the input. Then, we must decide if we want to put a limiter or not. For the sake of argument, let us assume we decide we want a limiter. Then we have to take a box marked AMPLIFIER and put it in the data path. Every time we take a box marked amplifier we need to figure out the gain of this amplifier. In this case it is easy; the output from the detector is 0.5 volts, the input to the integrator is 10 volts, the amplifier needs a gain of 20. So, we mark our box with X20, which means a gain of 20. In this case we need to put X20V, because this gain must be variable. Note that this gain will be adjusted only very seldom.

The next box is the one marked INTEGRATOR and we need to mark it with VR+VC because we want to have means to change the resistor and the capacitor. If we want only to change the resistor, we mark it VR.

Then we can put the box marked with ZEROING, that will remove the bias from our signal, making it zero volts when there is no signal. This box does not need any mark because it is implied that it needs a potentiometer to adjust the voltage that zeroes the signal.

Now we need to make some educated guesses. A signal from the sky increments the power at the antenna between 1 and 10% as it passes through the beam. This number depends mainly on the size of the antenna, the noise figure of the receiver, and the intensity of the source. The 1 % figure corresponds to a 100 J source in a 6 ft antenna with a fairly noisy receiver. The larger the antenna, the larger this percentage. The quieter the receiver, the larger this figure. The smaller the source, the smaller the figure.

Let us consider that we want to be able to record sources that produce a 10% enhancement on the noise at the antenna of our radio telescope. This can be translated into, we need to be able to take signals that are 1 volt after the zeroing, and amplify them to the 10 volts needed by the converter. Stronger signals require less amplification. So, we need to add a box marked AMPLIFIER and mark it with a X10V, to indicate that we need a variable gain on the order of 10.

Now we need three boxes marked METER and we connect one at the output of the detector, one at the input of the integrator, and one at the input of the A/D converter. If we want, we can take more boxes marked AMPLIFIER to connect an oscilloscope, a tape recorder, etc. It is probably a good idea to have a couple of amplifiers in the circuit, whose output is connected to audio connectors, and whose input can be connected any place we later find as a good idea. In any case, it is not too difficult to add later more amplifiers.

So, here it is our design and the diagram (See Fig. 16-1) shows the results of our work. Naturally, any one of you can put or remove boxes as you want, but we will continue our analysis of this circuit as an example of how to do it. The idea is that this circuit is a sample of all the circuits we have analyzed.

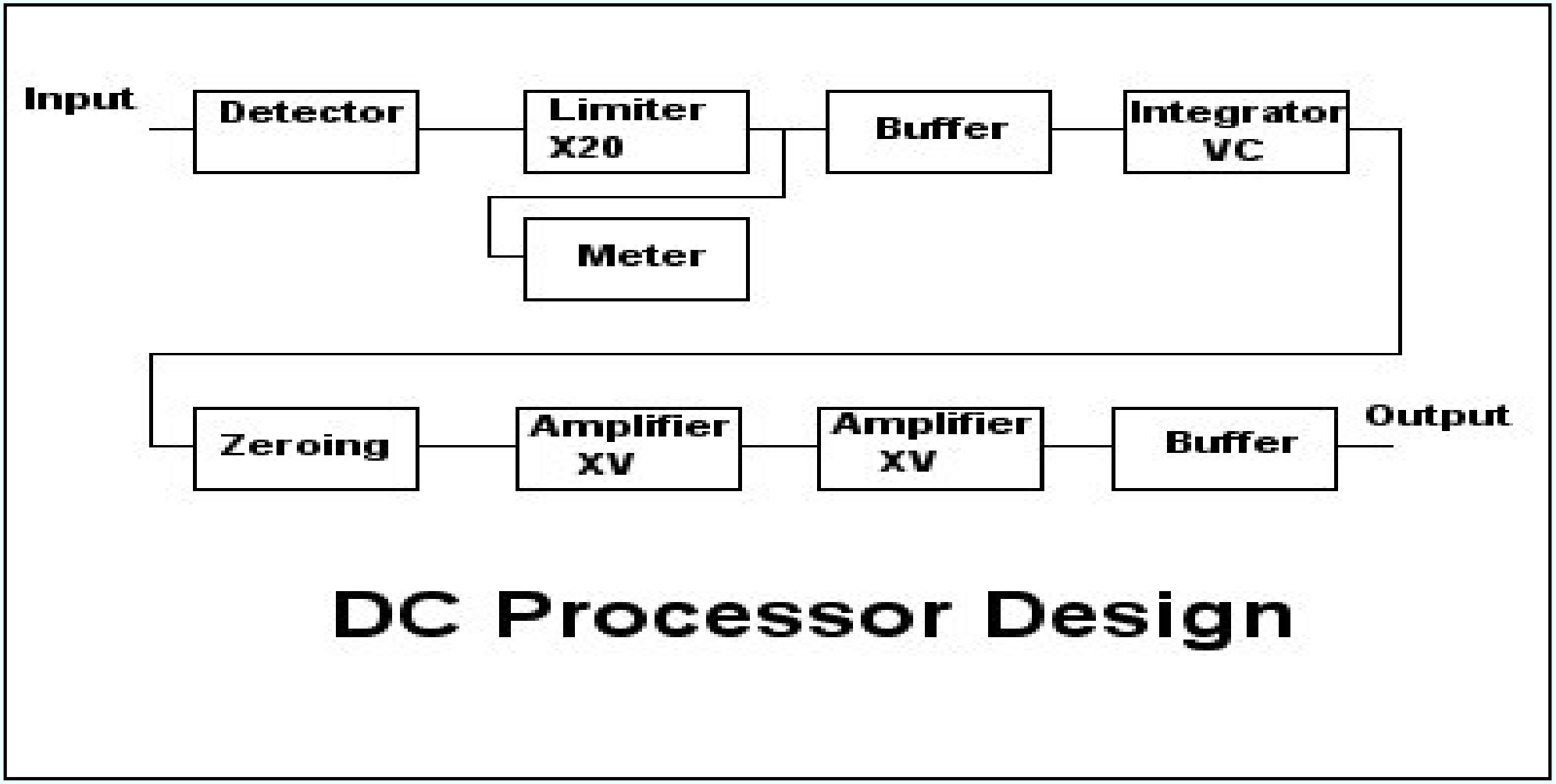

Fig 16 - 1

One of the next chapters will be devoted to the construction of this circuit and those readers with sufficient knowledge of electronics can skip it without any loss.

In summary, the process of design, after we understand the operation of the elementary components of our circuit, is to select which components we need to use and how many.

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Chapter 17

CONSTRUCTION

We have been studying the different elements that constitute the Data Processing Unit of a radio telescope, and in the last chapter we have designed a particular DC Processor. Now, we will face the problems of the construction of such a device.

There many ways of building an electronic circuit. Some of them are permanent and some are temporary. Some of them are appropriate for any kind of circuit and others are only good for certain circuits. Let us study first, what considerations determine the type of building method to use for a particular circuit. This, by no means, is an exhaustive analysis of the subject but, we will only review the topic to give our readers some way to judge. The interested reader is referred to other books where the subject is treated in more detail.

In a nut shell, the most common procedures or techniques to build a circuit, can be summarized as follows:

Printed circuit board;
Wire wrapping the connections;
Soldered connections; and
Bread boarding.

The printed circuit board is, by far, the best construction technique for any kind of circuit. It can be used at any frequency and with any type of circuit. It permits mixing in the same board digital and analog circuits if the proper precautions are taken. The circuit is rigid, not subject to vibration, very durable. The only disadvantage of the printed circuit board is that is very expensive to produce. It takes time to layout a circuit. It takes special equipment to etch the traces and drill the holes. A very serious disadvantage is that it is very difficult to make changes or corrections in the circuit. In most cases, it requires a new board.

It is interesting to indicate that there are procedures for building a single printed circuit board. The quality of the board is not as good as when you use special equipment, but you have the advantages of the permanence and rigidity of this type of construction. There are kits, like Radio Shack # 276-1576, with all the materials to build a printed circuit board.

Wire wrapping is a technique that makes connections by wrapping a wire in a post of the socket. The connection is as permanent as if it were soldered and electrically as good. It permits very easy modifications of the circuit and, if the circuit is disassembled, the parts can be reused, with the exception of the wires. This technique is good for digital circuits and moderately good for DC circuits. Its use in analog circuits requires careful planning to prevent feedback. A slight variation of this technique has been developed by the author. It uses a perforated board to mount integrated circuit sockets for the placement of all the parts, and the connections are wire wrapped. This permits changing values of resistors or capacitors without switches or any change in the circuit. If the circuit is properly laid out, no problems are encountered.

Soldering connections was the standard method of building circuits until some years ago. The development of printed circuit boards and wire wrapping has made this method kind of obsolete. It is only used today for the connection of parts or elements that cannot be mounted on the circuit board, like panel switches, connectors, meters, etc. Soldering is also used when building a circuit in a prototype circuit board.

Another interesting technique is what is called bread boarding. All the techniques mentioned above are permanent, although the wire wrap can be unwrapped. When working with experimental circuits, the bread boarding technique is quite good. A bread board, or prototype board, is one that has a matrix of connectors, usually with a channel in the middle. The connectors at the sides of the channel are connected together in rows. An integrated circuit is mounted on the channels, and the pins are plugged at both sides. It is possible to make a connection to any pin by only pushing a wire, or a component in the same row as the pin. The whole circuit can be built this way. All the parts and the board can be reused many times. This is useful for small circuits like in our experiments. The problem is that the connections are unstable and do not tolerate manipulation.

The most important considerations that determine the construction technique to be used for a given circuit are:

The permanence of the circuit;
The frequency of operation;
The gain of the circuit;
The number of copies to be made; and
The type of device used in the circuit.

Probably the most important consideration is the permanence of the circuit. If the circuit will be used once or twice, like the ones we build for our experiments, it is not logical to go to the trouble of building a very rigid and expensive circuit like in a printed circuit board; in this case, the bread board type of circuit construction is perfect. If the circuit is built only for experimentation, to find the actual values needed to make the circuit work, the same is true. If a circuit will be used for some time, say some months, until we can afford a more complex or permanent circuit, wire wrapping will do it. If the circuit will be in use in your telescope for years to come, it is logical to go to the expense of a printed

circuit board.

The frequency of operation affects the construction of the circuit because each connection acts as an antenna. If the frequency of operation is so high that the distance between the components (the length of the wire) becomes an important fraction of the wave length at that frequency, then special constructions techniques are required for the circuit to work at all. This is the case of the first stages of a receiver that works above 100 Mhz. At audio frequencies and below, the influence of the frequency is not important.

The gain of the circuit is another of the factors that affects the construction techniques. The effect of the gain of the circuit we will build has two aspects: One, is the possibility that the output of the circuit be coupled to its input, creating a positive feedback; the other is that a high gain circuit can pick up noise from the ambient. Both problems appear at any frequency, and should be taken care of by proper construction techniques.

The problem of positive feedback is a very serious problem at high frequencies, but it can be present even when working with very low varying signals, as in the Data Processing Unit of a radio telescope. The basic reason for the problem is that a positive feedback path can be established quite easily, even through the power supply, path that is many times overlooked. The existence of long wires connecting the output of a circuit to the input of the next, creates the possibility of positive feedback loops. Another problem can be produced by wires, or lines, connected to the input of the circuit, running close together with lines connected to the output. In this case, capacitative coupling between the lines can create the positive feedback.

The other influence of the gain on the construction of the circuit is the possibility that the input connections might pick up ambient noise. Since today we live in a see of electromagnetic noise, a high gain circuit must be enclosed in a shielding box, to protect it from interference. This is very true with a radio telescope which, but necessity, is a very high gain system. Every part should be perfectly enclosed in a box.

The actual wiring is also influenced by this factor. Very careful layout is required for the wiring of the high gain circuit. The best technique is the printed circuit board, to be studied next. In most cases, a back plane is required. A back plane is a copper plate at the opposite side of the board, that is connected to ground. This plane produces a shielding, not only of the wires from the outside, but between the wires.

The number of copies to be made of a circuit influences very much the procedure used for wiring the circuit. If we need to build a number of copies of the circuit, the high cost of the printed circuit board is distributed over the number of copies, and the good qualities of the procedure make this technique the preferred one. This is specially true for commercial circuits, or high reliability circuits.

The type of device in the circuit influence very much the construction techniques. There are a number

of devices used in radio telescopes that do not permit using any other technique except the printed circuit board. For example, the amplifiers used at high frequency are made in such a way that they must be mounted on a printed circuit board. All high quality, high resolution A/D converters must also be mounted on printed circuit boards. A circuit using transistors is difficult to build using wire wrap, unless the technique developed by the author, of mounting all the components on integrated circuit sockets, is used.

Before we finish, we need to say a few words about safety. You can never be too careful when you are working with tools. The damage you can receive, or produce in others, is many times irreparable. Consider that some times you will be working with a soldering iron, which is quite hot for humans. Do not put the soldering iron in any place. The best way is to have a stand, made specially for the type of soldering iron you use. Do not put the iron in a place where something can fall between the wires of the stand. Consider that a young children will get burnt if he or she puts a hand on top of the stand, not the iron.

Another dangerous situation is when you clip wires. When you solder parts, like resistors or capacitors, on a printed circuit board, the extra wire sticks in the solder side of the board and must be clipped, flush with the board. This clipping operation is extremely dangerous. The little pieces of wire jump at a high speed and can act as little projectiles. For example, if you are looking at the wire you will be cutting, the clipping can enter your eye, and leave you blind.

If you do not believe this, try the following experiment. Using any old board, solder a resistor, or capacitor to the board. Before you clip the wire, put your finger lightly on the tip of the wire, without doing any pressure, and then clip the wire. The pain you feel will convince you to be careful.

The best way to clip wires is to hold the tip of the wire with your fingers, or a pair of pliers, while you clip it with the other hand. In this way the piece of wire does not fly away and land some unknown place.

There is one big advantage to holding the wire while you are clipping, especially important if you work in a room that has a carpet. The flying pieces of wire normally go into the carpet and a vacuum cleaner will not pick them up. You or your children will pick them up with your feet when you walk bare footed.

For this reason, using safety glasses while clipping wires is not enough. You have to prevent them from flying away, so they do not do any damage while flying, or afterwards.

If you decide to develop your own printed circuit boards, you will be working with chemicals, some of them acids, and it is important you use the necessary precautions to prevent damage to yourself or the members of your family. Etching a board takes some time, do not leave the board in a place where children can reach. The same, of course, is true for the storage of the chemicals.

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Chapter 18

TOOLS

Unless you will not be doing any building, you should get a good set of tools. Consider that, sooner or later, you will start fooling around with your equipment, or you will want to see what is inside the boxes you bought. The number of tools you will need, even if you do all your building, is not too large, so you cannot afford getting poor quality tools. The cheaper tools are those that although they cost more to buy, last so long that the real price is quite low. On the other hand, inexpensive tools is a very poor investment.

You will need a small, pencil type soldering iron, 25 watts is a good size. Get one like Weller, or equivalent, that you can configure the way you want. You buy separately the handle, the element, the tip. In this way you can change tips if they get old, or elements if they burn out. It is good to have several tips, at least one pointed, and one flat. A stand for the soldering iron is inexpensive and provides a large degree of safety. You also need a good solder, Kester, or equivalent, 60% tin, 40% lead, 0.025 inch diameter.

You will need a good set of small pliers, 5 or 5 1/4 inch. You should have at least one straight pliers. A diagonal cutter is a must. A good, simple, wire stripper is also a must have. A set of soldering aid tools is quite helpful. These are metal tools with plastic handle, that permit you to hold wires while you are soldering them, without burning your fingers, and the solder does not stick to them. This tools are also very useful to get integrated circuits out of the sockets, by inserting the tool under the chip and prying it out of the socket without bending the pins.

A good set of screw drives should complete your set. You need a small flat one, a small phillips, a medium flat, and a medium phillips. If you plan to do wire wrapping, you probably have a set of wire wrapping tools, wire stripper, etc.

The final point to consider is some kind of a multimeter; that is, one unit that permits you to measure voltage, current, resistance, etc. The best kind today is what is called a digital voltmeter, not because of the digital display, but because of the internal impedance of the meter, that is normally very high. If you will buy one, pay attention to the scales. Important factors are if the meter is self scaling or you need to move a switch to change scales. The minimum value that the meter reads is another important factor. You seldom care about the maximum value, but the manufacturer emphasizes the maximum, not the minimum. If the same meter can reads ohms, it is a plus. Today, there are small, portable, digital

meters for a few dollars. An example is Radio Shack # 22-171.

This list includes the minimum you need as tools, any other tool you want to have is luxury, but you have the right to provide yourself with as much luxury you can afford.

RADIO ASTRONOMY FOR BEGINNERS

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Chapter 19

AN A/D CONVERTER

The circuit we will describe now is used in a project described later. It is a very simple circuit that performs all the functions of the Data Processing Unit of a telescope and permits the user to practice radio astronomy. At the same time, the circuit is not a toy. It is built in a computer card, to give the computer an analog input. The input of the circuit can be connected to the output of a DC Processor, to convert them into the Data Processing Unit of a radio telescope. The unit to be described here is designed to be used in an IBM-compatible computer, but it is easily modified to work with any other computer. Simply change the card for one that matches your computer.

The circuit as shown on the diagram (See Fig. 19-1), has a diode, whose function is to rectify alternating current input signals, and to prevent a negative voltage from being applied to the input of the circuit. An elementary filter follows the diode. Note that this filter has the form of an integrator. Since the input to the analog-to-digital converter has quite a high impedance, we do not need to worry about loading the integrator. The output of the analog-to-digital converter is connected directly to the computer.

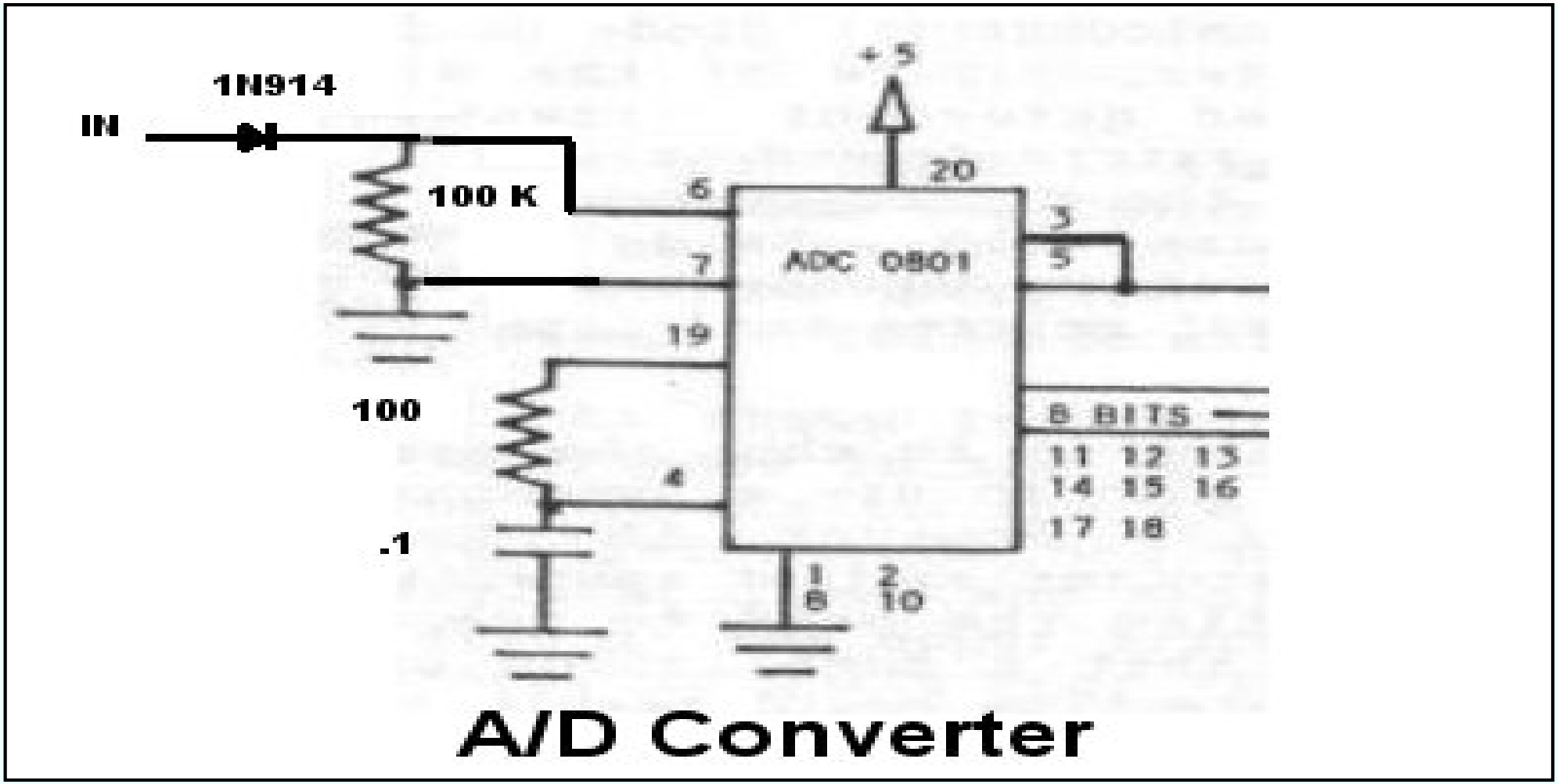

Fig 19 - 1

This circuit has a double function: it can be the connection between the DC processor and the computer, or it can be used to analyze tape recordings made with a telescope, looking for other signals that were not studied during the observation. This last type of application permits us a very interesting experiment, or project, we will study in detail in one of the chapters that follow. We will use this circuit in what we call Arm Chair Radio Astronomy; that is, getting one or several tapes produced by a professional observatory and study them in detail, to gain operating experience.

The circuit will be built in a special board that comes ready to be used in any IBM compatible computer. We need the following parts:

One 8-bit prototype card, JDR Microdevices # JDR-PR2, or equivalent;
One parts kit for the above, JDR-PR2-PK, or equivalent;
One 8-bit A/D converter, JDR Microdevices # ADC-0800;
One 18-pin integrated circuit socket, Radio Shack # 276- 1992, or equivalent;
One 5 volt positive voltage regulator, Radio Shack # 276- 1770, or equivalent;
One 100 ohms resistor, Radio Shack # 271-1311, or equivalent;

One 4.7 K ohms resistor, Radio Shack # 271-1330, or equivalent;
Two 10 K ohms resistor, Radio Shack # 271-1335, or equivalent;
One 100 K ohms resistor, Radio Shack # 271-1347, or equivalent;
One 220 K ohms resistor, Radio Shack # 271-1350, or equivalent;
One 470 K ohms resistor, Radio Shack # 271-1354, or equivalent;
One 1 Meg ohms resistor, Radio Shack # 271-1356, or equivalent;
One 100 pf ceramic capacitor, Radio Shack # 272-123, or equivalent;
Two .1 uf ceramic capacitors, Radio Shack # 272-135, or equivalent;
One 22 uf tantalum capacitors, Radio Shack # 272-1437, or equivalent;
One miniature, close circuit, open frame, audio connector, Radio Shack # 274-248, or equivalent.
JDR Microdevices, 2233 Branham Lane, San Jose, CA 95124, orders phone 800-538-5000, also has resistors and capacitors of different values, and other parts.

The first task is to build the decoder in the part of the circuit board that has its connections already etched. Follow the instructions provided with the board. If you feel bad soldering the integrated circuits directly to the board, you can use sockets. You will need three 20-pin sockets (Radio Shack # 276- 1991), two 16-pin sockets (Radio Shack # 276-1998), and two 14- pin sockets (Radio Shack # 276-1999). Soldering the integrated circuits directly to the board is not that bad, if you are careful.

As a first step, examine carefully the board. Notice that there are drawings on both sides of the board. The rectangles signal the position of the integrated circuits. Inside each of the rectangles there is a number, of the type 74LS245, or whatever. This number identifies the integrated circuit that goes in that position. Each integrated circuit has a number of this type on top of it. Identify which integrated circuit goes where. Notice also that on one side of the board there is the word COMPONENTS and on the other SOLDER. Be sure you identify which is which. Position the integrated circuits, or the sockets, on the side marked COMPONENTS, as suggested by the drawings on the board. Pay attention to match the notches on the integrated circuit with the notches on the drawing. Some integrated circuits have a notch in one end and a circle in the other, ignore the circle.

With a soldering iron quite hot and clean, hold the integrated circuits in place by putting a little solder in two pins, one at each end of a diagonal. Once you have done this with all the integrated circuits, hold the board with one hand, and apply slight pressure on one integrated circuit at a time, while with the other hand, heat up one of the pins you put solder in. If the integrated circuit is not properly sitting on the board, you will feel it going into the hole as you apply heat. Do the same with the pin at the other end of the integrated circuit, and verify that the chip sits flush with the board. Do the same with all the other integrated circuits. Once again, verify that all the chips sit tight on the board.

Put the board on your working table, with the side marked SOLDER up, and carefully apply solder to each and every one of the pins of the integrated circuits. A good procedure is to touch with the soldering iron the pin AND the little circle on the board, at the same time. After a second, touch the pin with the solder. When the solder melts, remove the solder and the soldering iron. Be careful not to apply too much solder to each connection, or to heat the pin too long. Be also careful not too apply to little solder or not heat up enough.

Follow the same procedure with each and every one of the pins of all the integrated circuits. Then, get a strong light to illuminate the board, and a magnifying glass. Examine one by one all the connections to the pins. Look at both sides of the board. A good connection should have solder filling totally the hole but not running out of the hole. If any connection is not good, redo it. Pay attention to solder that runs between two connections. If you find a bridge between two connections, hold the board upside down above your head, and apply the soldering iron to the bridge. As the solder melts, it runs on the soldering iron, leaving the connection clean. The same procedure can be used to remove solder from connections that have too much.

After you finish with the integrated circuits, mount the other parts. Pay attention to the polarity of the two electrolytic capacitor that go near the edge connector. The negative pin is marked with an arrow on the side of the capacitor and it should go in the hole near the edge. The capacitors, and the resistors should mount tight against

the board, as you did with the integrated circuits. The switch should be mounted in such a way the numbers can be read properly if you hold the board with the edge connector down. All parts are mounted on the side marked COMPONENTS. Note that you get five resistors and there are only four marked on the board. The fifth resistor goes in the two holes under the 74LS138. Trim carefully all the leads of the components.

Once you have made all the connections, it is time to go over your board once more. Pay special attention to connections not soldered, bridges between two pads, etc. You should not be left with any extra component. If you have one or more left, find out where they go. Note that three of the resistors are marked "optional"; we recommend that you mount them in place. You might need to use them later. The switch #1 should be up and the other three should be down.

When you are sure that everything is the way it should, it is time to try the board. Do not put any integrated circuit in their sockets, if you used them. Turn the computer off and unplug the power cord. Open carefully the box following the instructions provided with the computer, if any. Before touching anything inside the computer, make a habit of touching the box first, to discharge any static electricity you might be carrying in your body. Then, carefully install the board in one of the empty expansion slots. You will need to remove the vertical plate that closes the back hole of the box. Push gently the board into the slot until it sits fully. Do not apply too much pressure. If the board does not go in, see if you are not trying to put it off center. The board should go in with only a slight pressure. Try not to bend the board, because it can break.

Connect back the power cord and turn the computer on. If the computer does not follow its normal boot up sequence, turn the computer off immediately because you have a serious mistake on the board.

Remove the board from the computer and do not try again until you are positive you have found the mistake. It must be a wrong connection to some of the lines that the computer reads. If you have mounted the integrated circuits provided in the parts kit directly on the board, verify their orientation. Note that you have a drawing of the package on both sides of the board. If you find any other mistake that does not relate to the lines connected to the computer, do not try again. Look for something wrong in these connections. If you do not find anything, ask a fried or relative to take a look. Some times, you cannot see something wrong because you have been working with the circuit board for long.

If everything is right, or when you have corrected all errors, the computer should go through the boot up procedure normally. The computer should ignore totally the empty board that is in one of its expansion slots. If you have mounted the integrated circuits of the decoder on the board, the computer might recognize the active ports. This depends on your BIOS, but it is not too important. Load GWBASIC and type the following line of code:

PRINT INP(768) when you press the ENTER key, the computer should show a number that is quite close to 255. In any case, try the following line of code:

PRINT INP(800)

The number printed by the computer this time should be quite different from the previous one, and quite low. If this is true, your board is working, if not, you have a problem. Check the connections again, probably for one you forgot to make.

Now it is time to start with the circuit we will build. Mount the integrated circuit socket as shown on the diagram (See Fig. 19-1) and follow the same procedure explained above, to solder all the pins. First two in opposite ends of the socket, make the socket sit firmly, then solder all the rest. Position the other components and solder them to the board. Note that in most cases, the wires of the components are used to make some additional connection.

Pay special attention to the numbering of the pins. This numbering starts from the end of the socket that has a notch. Looking at the socket from above, with the socket vertical and the notch on top, pin 1 is the top pin on the left side of the socket. Pin 2 is the one down below, and so on. When you get to the bottom of the socket, the numbers go up the other side. The largest number pin is the one to the right of the notch, on top. Be careful when you count the pins looking from the bottom of the

socket, since the pins reverse.

Carefully follow the connections, as shown on the wiring diagram (See Fig. 19-1). Once you have finished the connections, go over them carefully verifying that they are all made between the proper pins. Pay attention to those cases when there are several connections made to the same pin, since it is quite easy to forget one of them. Make a habit of counting how many connections are there at each pin, and to compare this number with the diagram (See Fig. 19-1). In any case, if you make a change in the wiring from what is shown on the diagram (see Fig 19-1), make the proper correction on the diagram.

After you test the board with the computer, install the A/D converter integrated circuit. Be careful with the pins of the integrated circuit, so they go straight into the socket. Be specially aware of pins that bend inside, hiding under the chip.

When you finish, install the back metal plate, using the small screws provided with it. This time you are left with two bolts and two nuts. They are for holding the output connector, or a plate, which are not provided. You need to make a small plate, long enough to reach from hole to hole, as wide as the plate, and make a hole in it so you can mount the audio connector. Run a piece of shielded wire from the connector to the diode, as shown on the diagram (See Fig. 19-1).

After double checking everything, install the board in the computer. This time you should also install the supporting screw in the back of the board. Turn on the computer and it should boot up normally. If not, turn it off immediately and repeat the procedure of checking. Do not install the board again until you find out what is wrong that the computer did not start. The most common reason is an integrated circuit mounted backwards. Try again only when you are sure there are no mistakes.

When the computer boots up, perform the following test. Load GWBASIC and enter the following program:

```
10 PRINT INP(768)
20 FOR I=1 to 100
30 NEXT I
40 GOTO 10
```

When you run this program, it will give you a continuous flow of numbers. These numbers will be the same, if everything is correct. If you have a wild set of numbers, you have too much noise in your circuit. Connect anything, a piece of wire, at the input of your circuit, through the audio connector. If the wire is long enough, a few inches, the numbers should vary depending on how long is the wire.

There is an alternative to building this circuit, we should mention. There are several cards in the market that are called Analog Cards. These cards carry a reasonable price, including software. If you are not an experienced builder, or you prefer something ready made, these cards offers a viable alternative. For example, the card offered by JDR Microdevices (address above), # PCL-711S, has 16 digital inputs, 16 digital outputs, 8 analog inputs, 1 analog output, both with 12-bit resolution and a maximum sampling rate of 25000 samples per second. There are cards of this type for most of the other computers.

RADIO ASTRONOMY FOR BEGINNERS

Michael E. Valdez

Chapter 20

ARM CHAIR RADIO ASTRONOMY

This project will be used to perform something like a review of all the material we have presented so far, to firm up the ideas. Some of them were presented quite a long time ago, so a review is not a waste of time.

The basic principle of this book had been stated as that it is recommendable to start the design and construction of your telescope from the Data Processing Unit, instead of from the antenna. This permits you to get familiar with the results that can be obtained, before you invest a lot of effort and money in equipment. At the same time, when your Data Processing Unit is working, you will use it to test and calibrate first your receiver, and later your antenna.

To this end, we present here a small project, that can be as big as you like, where you can practice radio astronomy by actually doing observing like if you were at the Data Processing Unit of a radio telescope. This project will familiarize you not only with the operation of the equipment and its limitations, but it will give you experience that you will be able to apply directly when your telescope is working.

The idea is quite simple. Instead of connecting your Data Processing Unit directly to a radio telescope you will connect it through a tape recorder. There are several tapes made from actual radio astronomical observations, and more will be available if the demand for them increases. Check with Vince Caracci, 247 N. Linden St. Massapequa, NY 11758 for an interesting tape he used to have. He is the Secretary for the Society of Amateur Radio Astronomers. You should also check with Sky and Telescope, Astronomy, and other sources. If all else fails, contact the Society for Amateur Radio Astronomers at their web site, and ask for one of the members to make a tape for you.

This project will consider you have minimal equipment, so you can start as early as possible: A detector, an integrator, an analog-to-digital converter and a computer, as described in the previous chapter. Notice that this setup includes the basic elements of a telescope. What is missing is the antenna and the receiver, the expensive, heavy, and space using equipment. This project is then ideal for beginners while they build their equipment, for amateurs who live in an apartment, or those who cannot afford a telescope.

Notice that this project includes a computer. No meaningful radio astronomy can be done today, in

amateur or professional environment, without a computer. Consequently, it is highly recommended that you start with this consideration in mind and get yourself a computer before anything else. For the first few years you will not need a big computer. You can get a second hand computer with some memory, a hard drive, a monitor and one floppy disk for a couple of hundred dollars, at a flee market or through the classified adds of the local paper. The advantage is that later you can sell it through another add, for about the same price. Another advantage is that the programs you develop for this computer will be usable in a bigger brother. Unless you know what you are doing, or you have other uses for it, do not invest a lot of money in a computer.

The other piece of hardware you need is, as mentioned before, a detector, integrator, A/D converter; the card described in the previous chapter, or one equivalent to it. It should be mentioned that this unit is the link between the receiver or the DC processor and the computer; consequently, this is the core of the Data Processing Unit of your radio telescope.

If you have a DC-Processor, you can use it to great advantage. The functions of zeroing the background and the amplification can be useful. In general, you will not need too much amplification because the tape recorder gives enough signal for most A/D converters.

You will need a program to sample the signal from the tape recorder, store it in memory, put it on the disk, display the results.

The program to be presented assumes you have a copy of Caracci's tape. This tape has several recordings of pulsars with periods from milliseconds to almost a second, that are very good subjects for practice. It also has a solar flare and a jovian storm. Consequently we have several needs to satisfy with our program: We need to have a variable sampling rate, and capabilities for sampling several times a repetitive signal accumulating the results. This is required for the pulsars. Notice that this is one of the most important characteristics of a computer in the Data Processing Unit of your telescope. By changing the program you can adapt your Data Processing Unit to widely different tasks. The program we will develop is much simpler that the one studied before.

From these requirements, our program will start by asking for a file name where to store the data to be received. It is a good practice, to name the files with the name of the source under study; in this way, you have one less piece of information to record in your file. Since the computer saves the date and time when it creates a file, we do not need to store this information again. If you have several files for the same source, as you will have here, add consecutive numbers or letters, to distinguish between them. Then, the program will ask for a constant, to be used in a timing loop, to vary the time between samples. The final value to be obtained by the program, is whether we want a single pass collecting data or we want multiple passes; this can be obtained by the program simply asking for how many passes we want.

The development of this program will assume you have a computer with a display that permits graphics. If this is not the case, you could develop graphics using the text mode, using letters or

symbols for plotting, or with a dot matrix printer; this is mentioned in one of the previous chapters.

First, find out how many dots of resolution your display has. Let us assume your display has 640 x 400 dots of resolution. This is the resolution for displaying 80 characters of text and is the normal resolution of a dot matrix printer. This suggests the use of 640 points for our program.

A pseudo-English description of the program is as follows:

1) Ask for name of the file to store the data;
2) Ask for the constant for delay between samples;
3) Ask for the number of passes;
4) Clear the variable to zeros;
5) Signal program ready and wait for a signal to start;
6) Display a "Working" message;
7) Load counter of passes;
8) Load counter of points;
9) Perform delay loop;
10) Sample a point;
11) Add to variable;
12) Decrement counter of points;
13) If not zero go to 9;
14) Decrement counter of passes;
15) If not zero go to 8;
16) Put delay constant and number of passes in file;
17) Store data on disk;
18) Put display in graphics mode;
19) Display file name, delay constant and passes;
20) Plot the data file;
21) Wait for a key;
22) Exit.

The documentation for this program is included in Appendix A. The listing of this program is included as Appendix B. An executable file can also be downloaded from the author's web site under the name of PULSAR.EXE. The reason for this name is that this program is more interesting when working with pulsars, as we will see in a moment. The program has been written in assembler language to have maximum speed. There are more programs on the web site.

A word about how this program works. First run your program to make a single pass with a large time constant. The ideal is to get two peaks on your display. Vary the delay constant until you get two peaks on your display. This might require several trials. When you get two peaks, measure the distance between them on your display. It is only necessary to put a piece of paper on your display and mark the distance from the left end to the right end. Fold the paper in two to obtain half of this distance.

Manipulate the delay constant until the two peaks are this distance apart. When this happens, your constant is very close to twice the value needed to obtain a single peak. Run the program again with half the constant and some 10 passes. Normally, you will need to vary the constant in several experiments, until you get a good graph. Then you can run the program again asking for the maximum number of passes you can get from the tape.

Performing this experiment will give you a lot of experience with your equipment, including the computer, that today needs to be part of any radio telescope.

RADIO ASTRONOMY FOR BEGINNERS

Michael E. Valdez

Chapter 21

A COMPLETE DC PROCESSOR

Our second building project will be the construction of the DC Processor we designed as an example of the design of this type of unit. In order to present some other way of building a unit, we will use the method developed by the author of building in a perforated board, mounting all the components and the integrated circuits in integrated circuit sockets.

The basic idea is that most of the elements needed for a DC Processor have leads that fit in the integrated circuit sockets. Most of the parts have also dimensions that permit them to be mounted that way. One quarter watt resistors, most ceramic capacitor, the diodes, etc. can be mounted this way. This permits a type of construction that is solid enough for most of our purposes, but with the advantage of the bread board; that is, that we can change components, and experiment to get the best possible values.

The advantage of this construction is apparent when you try to adjust to different operating conditions, but you do not want to have the long leads required for switches to change the values of resistors and capacitors. If the circuit is built inside a box that can be open easily, changing components permits to adjust the parameters, without the use of switches or potentiometer.

Since all the connections are wire wrapped, it is possible to change connections without too much of a problem, and without damaging the components. This procedure for construction of small circuits has advantages to warrant our consideration.

Let us summarize the description of the circuit we will be building:

The input connector feeds a diode with a resistor to ground; the purpose of this resistor is to provide for a path for the current of the diode, in the case the output of the receiver is coupled through a capacitor; the diode has a resistor to ground as a load which is bypassed with a capacitor (See Fig. 11-2);

An amplifier follows the detector; its purpose is to increase the gain to the point where the amplifier will be acting as a limiter for very strong pulses of noise; a variable gain of 20 is required (See Fig. 12-1);

The integrator follows the amplifier; this integrator is built around an operational amplifier, to assure that it will not be loaded by the diode or the following circuit (See Fig. 13-2);

The zeroing circuit follows the integrator; this circuit has a control to adjust the zeroing voltage (See Fig. 14-1);

An adjustable amplifier follows the zeroing circuit; this amplifier needs an adjustable gain of 10 (See Fig. 12-1);

Buffers are required for three meters, one at the output of the detector, to adjust the gain of the receiver; one at the input of the integrator, to adjust the gain of the limiter; and one at the output of the circuit, to adjust the gain after the zeroing circuit (See Fig. 12-1);

A buffer will be installed at the output of the detector for the connection of a tape recorder. The gain of this buffer will be on the order of 10, but it can be changed to suit the particular tape recorder in use (See Fig. 12-1).

This circuit requires a power supply that provides two equal voltages of +12 and -12 volts. This is necessary to have a voltage at the output that can be up to +10 volts, for the A/D converter. If this is not possible, the circuit could be fed with two 9 volt batteries, but the cost of the batteries will very soon convince you to build or buy a power supply.

The following graphs are included:

The circuit diagram is shown on Fig 21-1; this is the only thing an amateur experienced in electronics will need to build the circuit.

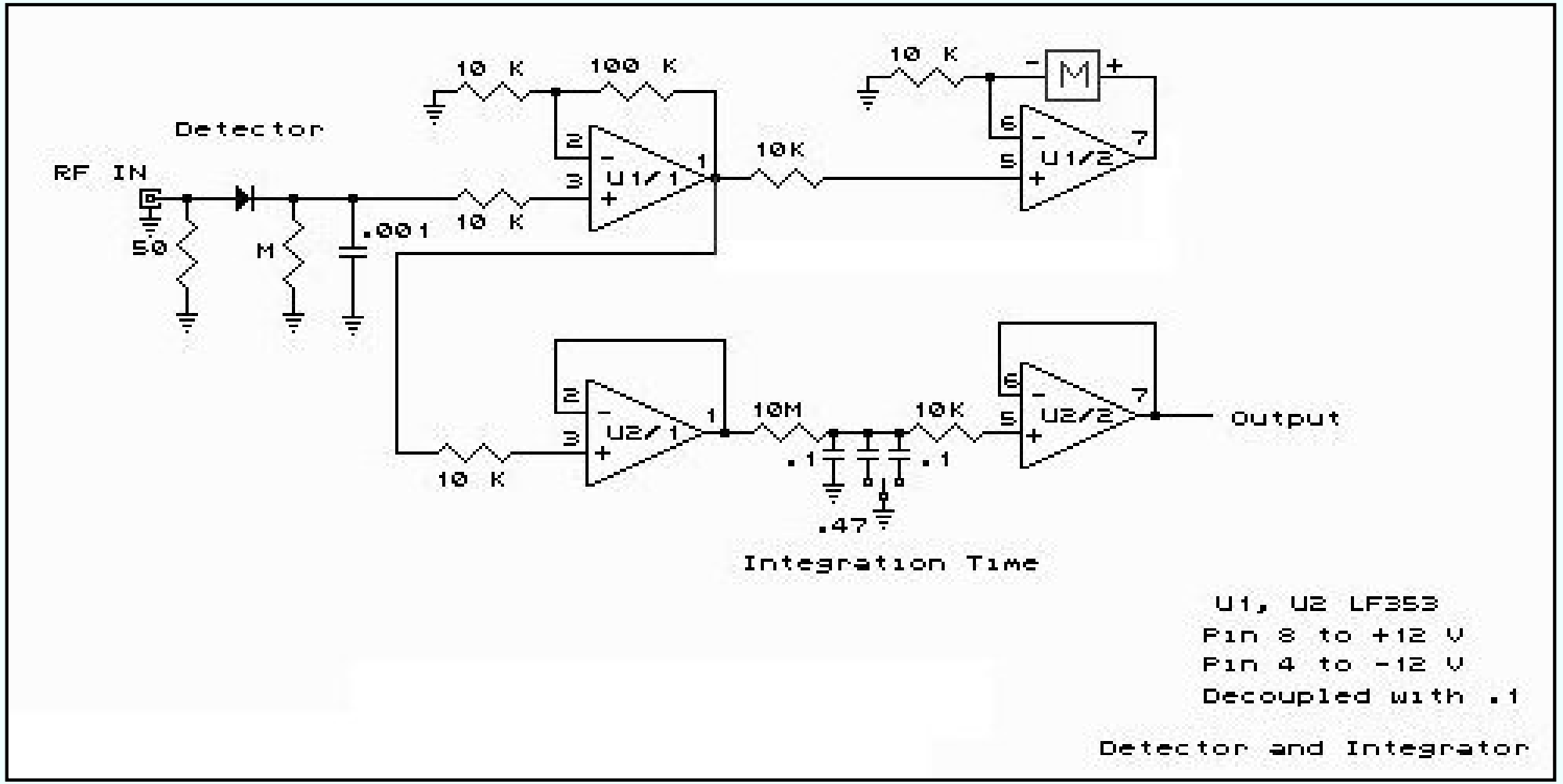

Fig 21 - 1

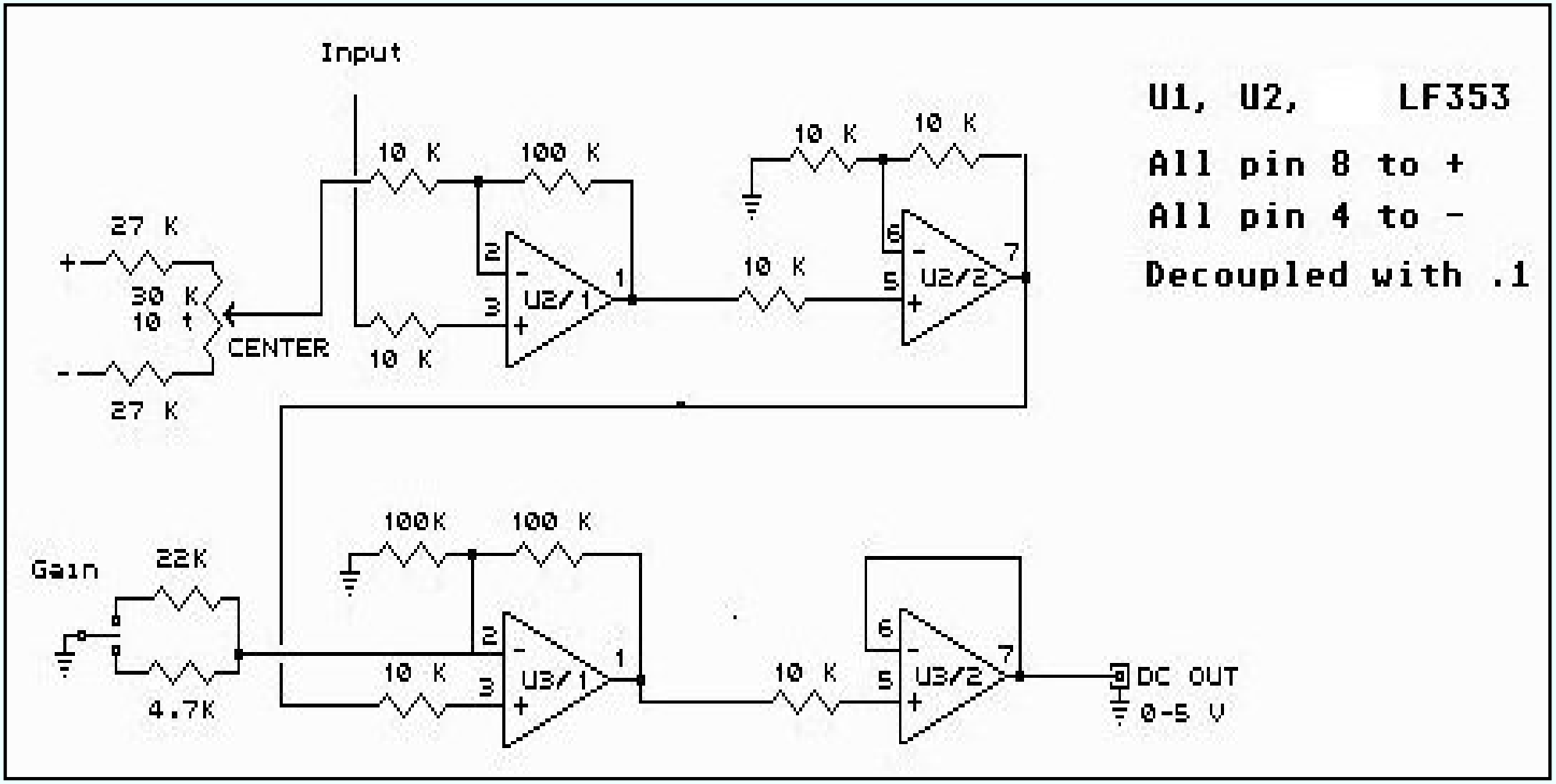

Fig 21 - 1a

The top view of the perforated board (See Fig. 21-2), showing the placement of the integrated circuit sockets and the location of all the parts;

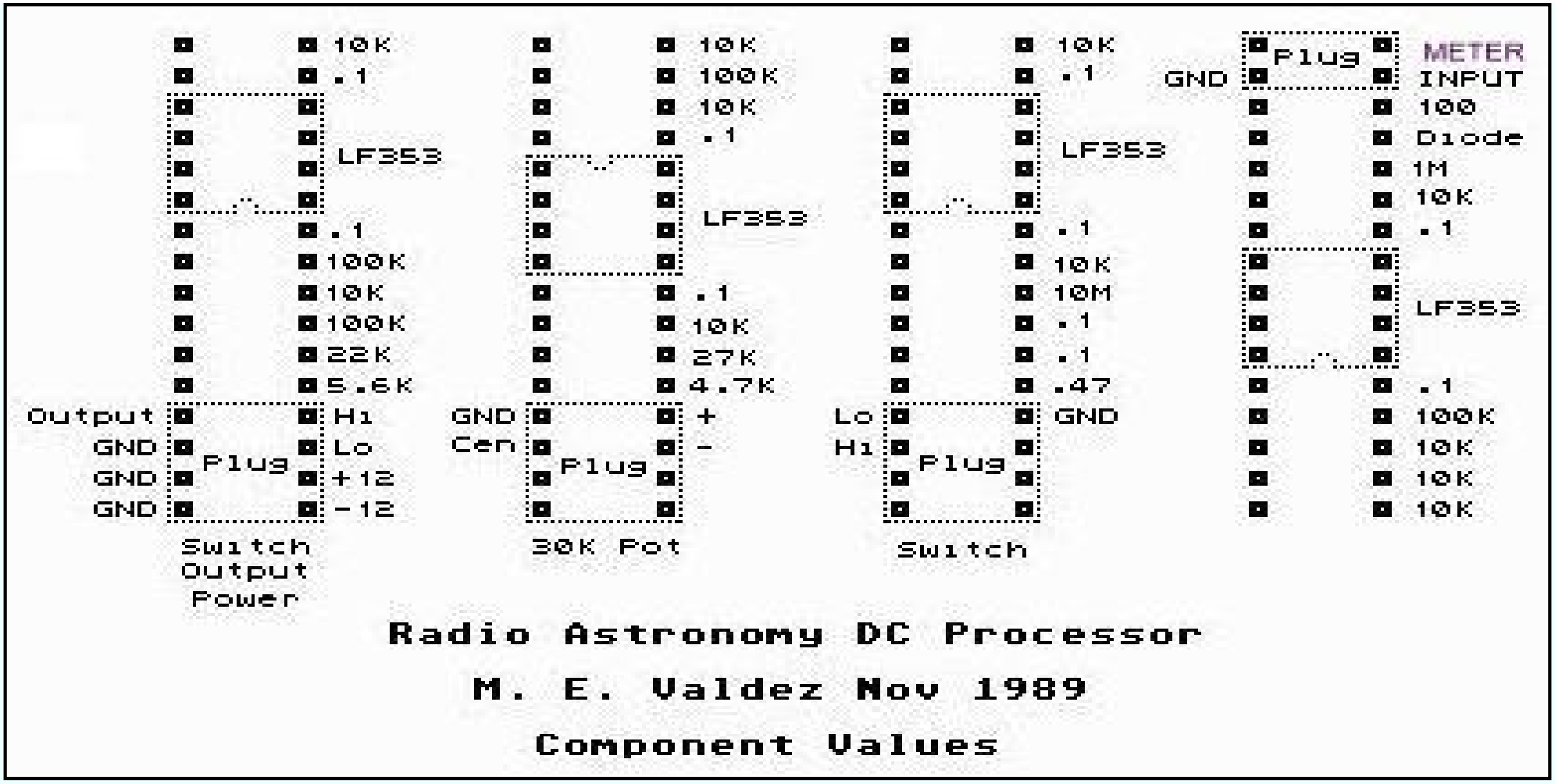

Fig 21 - 2

The bottom view of the board, Fig. 21-3, shows the connections for the +V; Fig 21-4 shows the connections of the -V and Fig 21-5 the connections for ground;

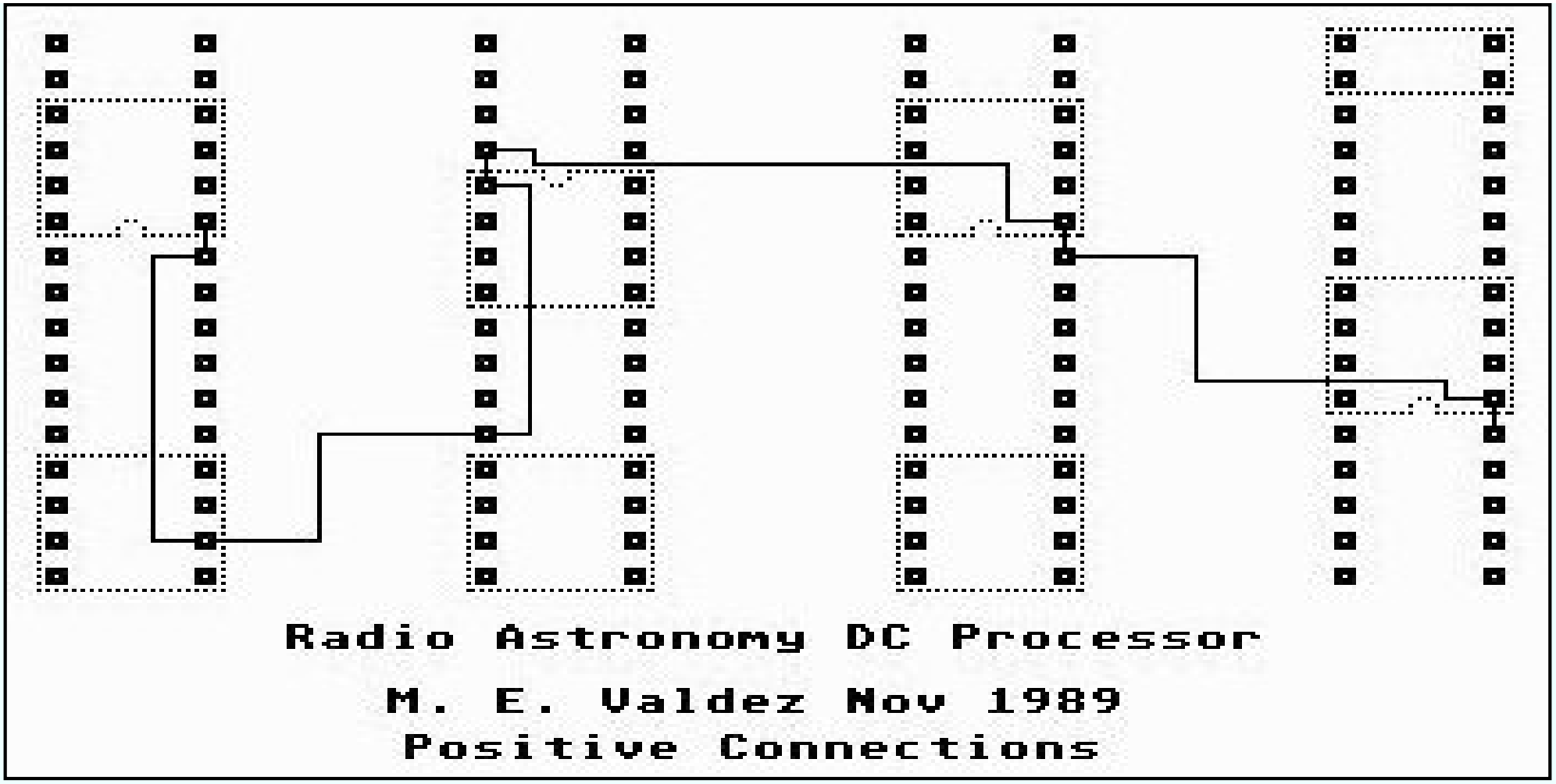
Radio Astronomy DC Processor
M. E. Valdez Nov 1989
Positive Connections

Fig 21 - 3

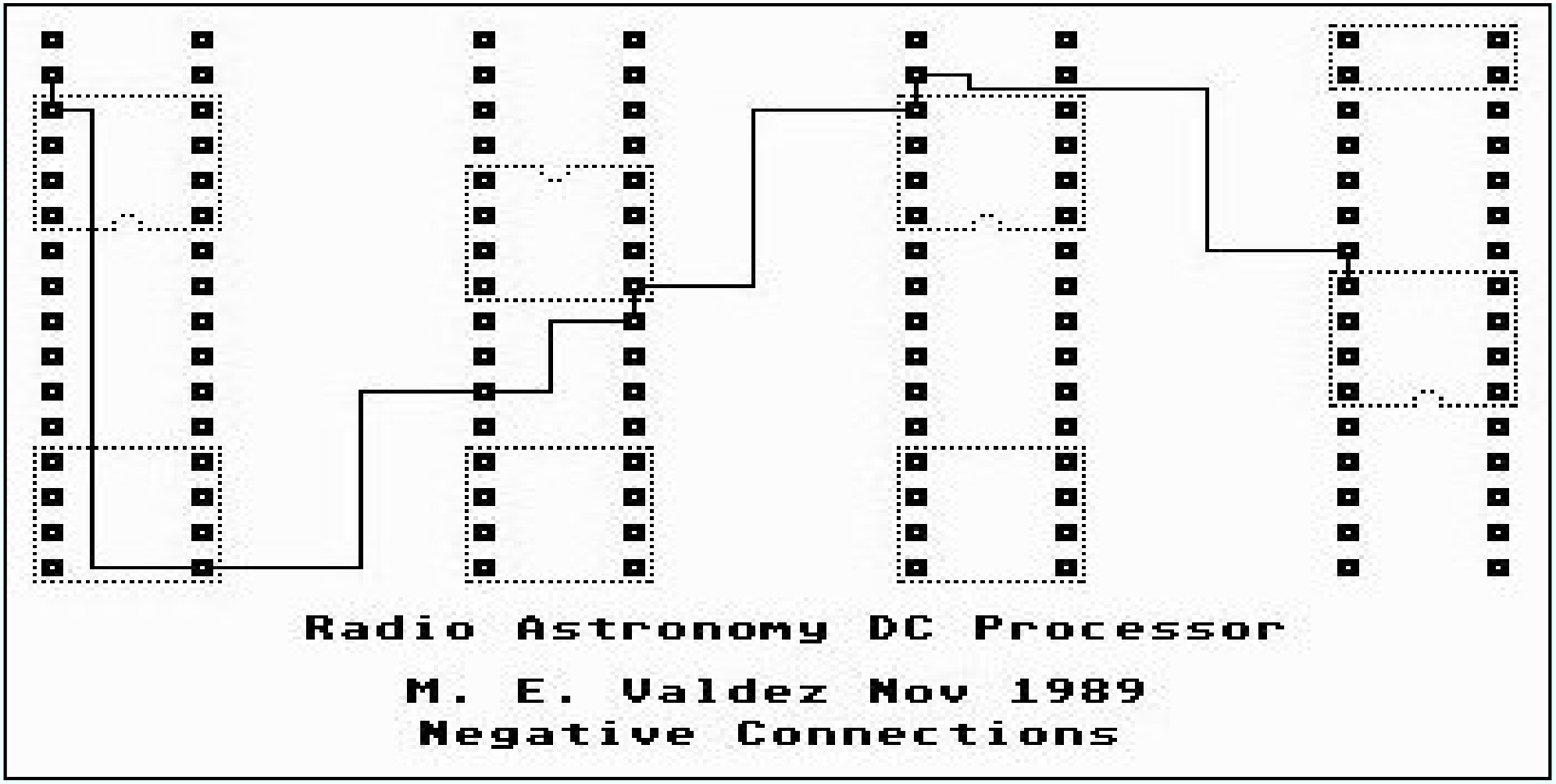
Radio Astronomy DC Processor
M. E. Valdez Nov 1989
Negative Connections

Fig 21 - 4

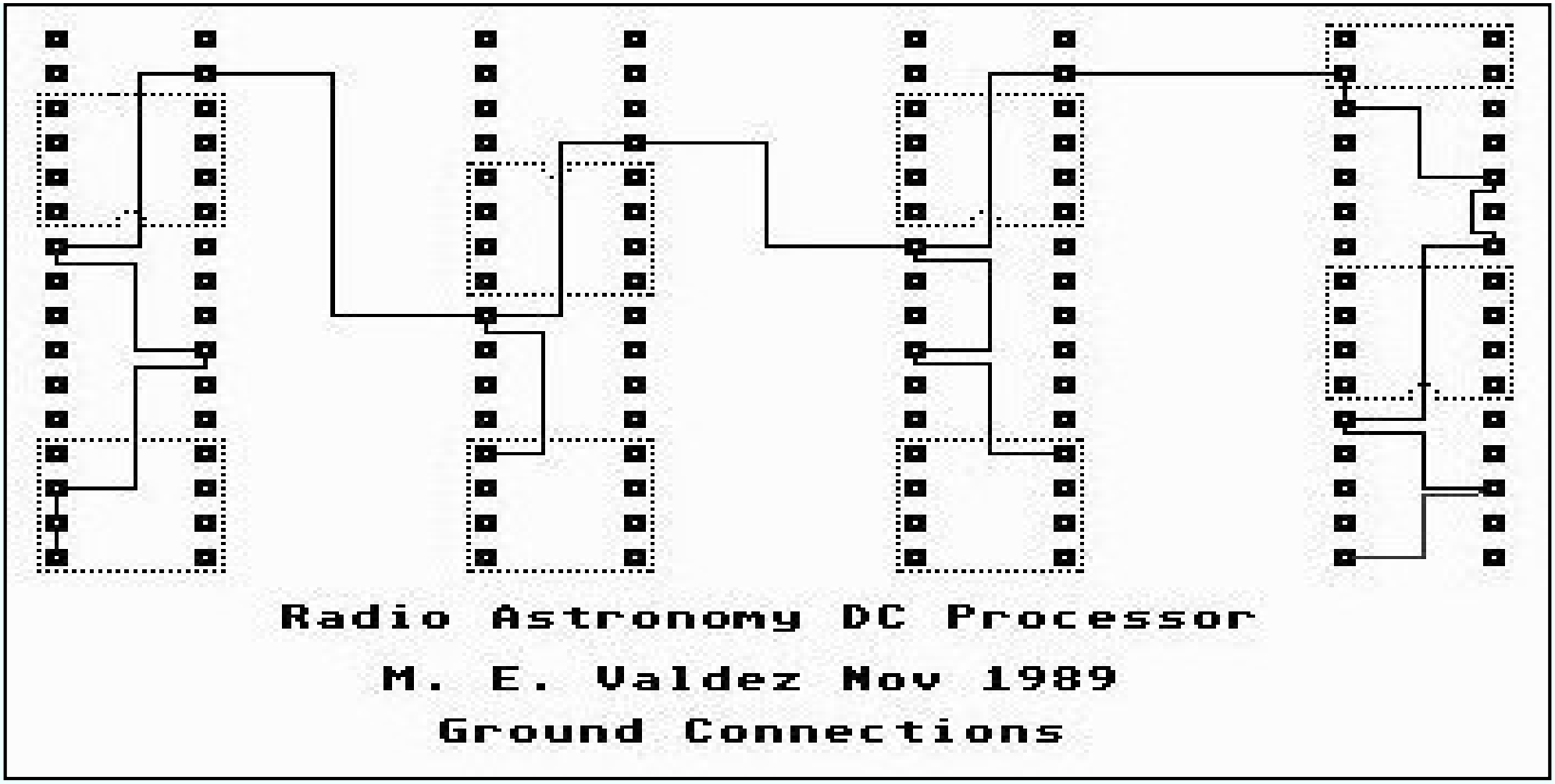

Fig 21 - 5

The bottom view of the board (See Fig. 21-6), showing the connections for the signal;

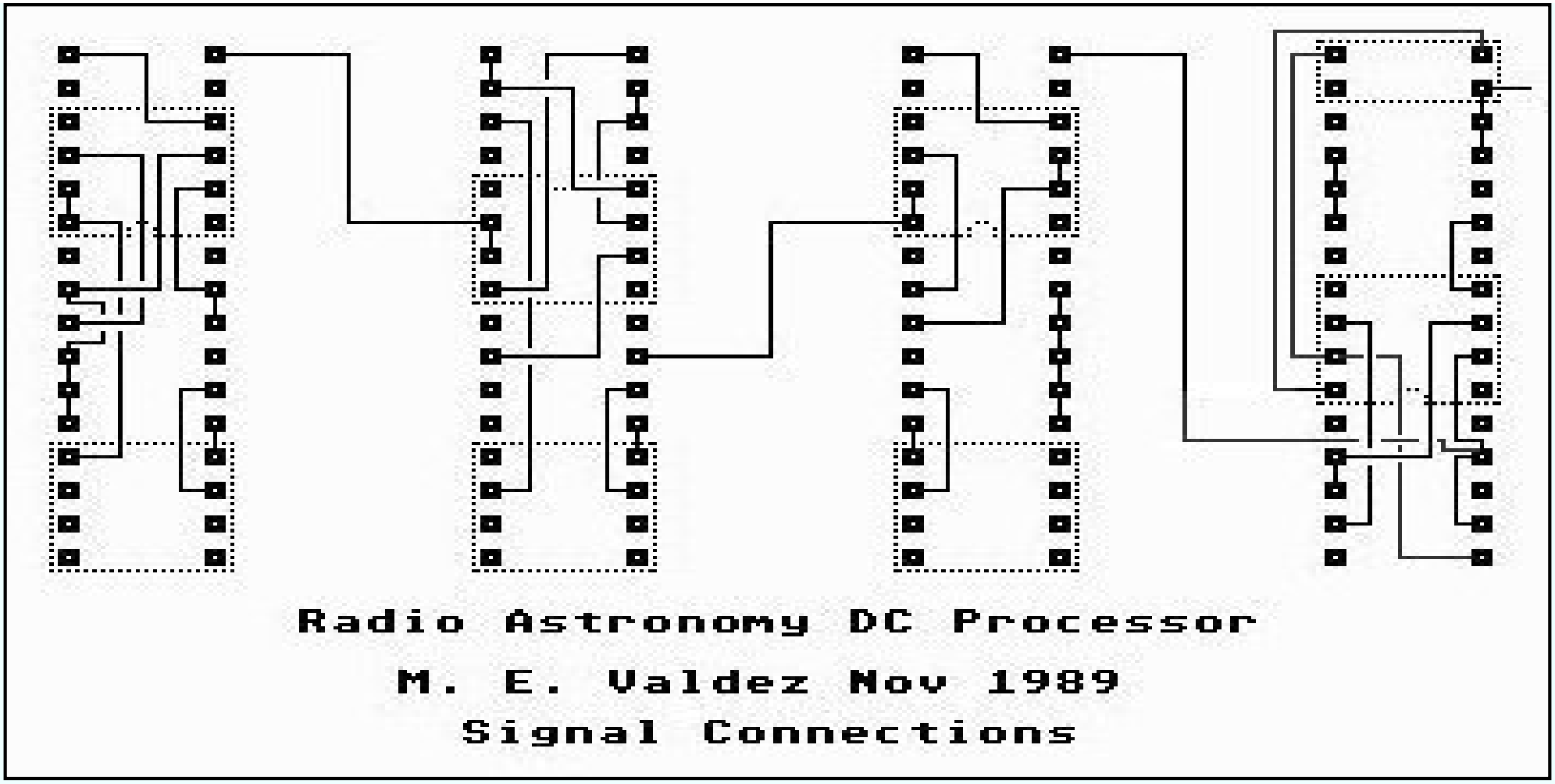

Fig 21 - 6

This description assumes that either now, or in the future, you will want to build a different circuit, using basically the same ideas, but arranged in another way. Then, we will describe the different parts, one by one.

The Detector

You will need the following parts to build the detector part of this circuit:

One miniature, open frame, audio jack, Radio Shack # 274- 248, or equivalent;
Some miniature shielded wire, Radio Shack # 278-752, or equivalent;
One 10 K ohms resistor, Radio Shack # 271-1335, or equivalent;
One switching diode 1N914, Radio Shack # 276-1122, or equivalent;
One 1 Meg ohm resistor, Radio Shack # 271-1356, or equivalent;

One .001 uf ceramic capacitor, Radio Shack # 272-126, or equivalent;
Four locations in an integrated circuit socket.

The Limiter

One half of an LF353 operational amplifier, you can use a 1458, Radio Shack # 276-038, or equivalent, until you get the LF353's;
One 10 K ohms, 15-turn, trimmer, Radio Shack # 271-343, or equivalent, unless you prefer to mount a potentiometer on the panel;
One 10 K ohms resistor, Radio Shack # 271-1335, or equivalent;
One 100 K ohm resistor, Radio Shack # 271-1347, or equivalent;
Two .1 monolithic ceramic capacitors, Radio Shack # 272-109, or equivalent;
Eight locations in an integrated circuit socket.

The other amplifiers and buffers required in the circuit need the same parts.

The Meter Buffer

One half of an LF353 operational amplifier, you can use a 1458, Radio Shack # 276-038, or equivalent, until you get the LF353's;
One 20 K ohms, 15-turn, trimmer, Radio Shack # 271-340, or equivalent;
Two 10 K ohms resistor, Radio Shack # 271-1335, or equivalent;
Two .1 monolithic ceramic capacitors, Radio Shack # 272-109, or equivalent;
One DC Voltmeter, Radio Shack # 270-1754, or equivalent (Remove the series resistor);
Seven locations in an integrated circuit socket.

Each of the meters require the same parts.

The Integrator

One half of an LF353 operational amplifier, you can use a 1458, Radio Shack # 276-038, or equivalent, until you get the LF353's;
One 10 K ohms, 15-turn, trimmer, Radio Shack # 271-343, or equivalent;
One 1 Meg ohms resistor, Radio Shack # 271-1356, or equivalent;
One 10 uf tantalum capacitor, Radio Shack # 272-1436, or equivalent, unless you can find a better quality capacitor with a reasonable size;
Two .1 monolithic ceramic capacitors, Radio Shack # 272-109, or equivalent;
Nine locations in an integrated circuit socket.

The Zeroing Circuit

One half of an LF353 operational amplifier, you can use a 1458, Radio Shack # 276-038, or equivalent, until you get the LF353's;
One 10 K ohms, 15-turn, trimmer, Radio Shack # 271-343, or equivalent, unless you prefer to mount a potentiometer on the panel;
Five 10 K ohms resistor, Radio Shack # 271-1335, or equivalent;
Two .1 monolithic ceramic capacitors, Radio Shack # 272-109, or equivalent;
Eleven locations in an integrated circuit socket.

Now, you must decide what are you going to use in your circuit, and obtain all the necessary parts, unless you already have them.

You will also need, the following:

One miniature, open frame, audio jack, Radio Shack # 274- 248, or equivalent, for each of the outputs of the circuit;
Some miniature shielded wire, Radio Shack # 278-752, or equivalent;
One Four-pin, chassis-mounted, microphone socket, Radio Shack # 274-002, or equivalent, for the power;
One Four-pin, microphone plug, Radio Shack # 274-001, or equivalent, for the power;
One piece of perforated board 2 3/4 x 3 3/4 inches, Radio Shack # 276-158, or equivalent;
One metal cabinet, size large enough to accommodate the meters in the front, the connections in the back.
You could add two lights to indicate the two voltages are working.

Wiring

Follow the wiring diagrams very carefully, first to position the integrated circuit sockets as shown and then to wire the connections. It is recommendable to connect first all the power connections. Follow the power diagram 21-3. Once you finish these connections, stop at check them. This is easier to do with an ohmmeter from the top of the board. Then wire the signals lines following the diagram 21-4. When you finish, check all the connections with an ohmmeter. If you find a connection missing, test to adjacent pins to see if you did not used to wrong pin. Check at both sides of the missing connection. Check also for possible reversing of the pins.

Testing

To test the circuit, install all the operational amplifiers, all the parts, connect the meters, and apply power. If any of the meters go full scale, or in the reverse direction, turn the power off and check the connections of the amplifier. If everything proves to be correct, position the controlling trimming resistor half way through its travel, and try again.

Start testing from the detector. Connect the output of a tape recorder to the input or the circuit. No, this is not an error. We want to use the tape recorder as a noise generator. Increase the gain of the tape recorder until you have noise and connect it to the input jack. The first meter should indicate the presence of noise. With a good quality meter, read the voltage output of the detector. Adjust the volume of the tape recorder until this voltage is the same you determined in your experiment with the diode. Note the reading of the meter in your unit connected to the output of the detector.

Connect the calibrated meter to the output of the limiter. Measure the voltage at the output pin of the limiter and adjust the gain of the limiter until you have 10 volts. Note the reading of the meter of your unit and record it for future reference. While you are changing the gain of the limiter, notice the reading of the meter at the output. As you make a change, the output meter should change more slowly, showing the action of the integrator.

Adjust the zeroing control and you should be able to zero the output of the unit. Change slightly the setting of the volume of the tape recorder and the output meter should show the change. In any case where the results are not as expected, suspect a wiring error if the difference is too large. If the difference is only of degree; for example, if you cannot get to quite 10 volts but only 9.4 volts, you might need more gain and you can try changing the feedback resistor with another of the same nominal value. Remember that the resistors have a nominal tolerance of 5% each. When you compute the gain with this tolerance, you get 15% of variation. Consider a 100 K ohm feedback resistor with a 10 K ohm to ground. The 100 K resistor could be between 95 K and 105 K ohms; the 10 K resistor can be between 9.5 K and 10.5 K ohms. The gain can be then, between 10 and 11.5, a variation of 15 %.

Before you finish, calibrate all your meters, at least for one value near the top of the scale. Measure the voltage at the point the meter is connected and adjust the

trimmer until you have either that value, or an easy multiple.

RADIO ASTRONOMY F0R BEGINNERS

Michael E. Valdez

Chapter 22

USING AVAILABLE EQUIPMENT

It has been mentioned before that the construction of the antenna and the receiver for a radio telescope is a task that cannot be considered as a project for a beginner. Since this book is for beginners, these two topics are outside the scope of this book.

We need to consider, though, that a beginner cannot leave the category, only by reading books or articles. A beginner needs practice, actual practice with a telescope, to graduate out of the category of beginner. The project we presented in a previous chapter should give the beginner some of this experience, in what we called Arm Chair Radio Astronomy. Sooner or later, the beginner wants to have a radio telescope. This chapter, and the two that follow, presents an orderly way by which a beginner can develop his own telescope.

The idea is quite simple. A radio telescope represents a substantial investment, even for a person with resources, and this investment should not be made without due consideration and experience. In order to permit the amateur to make these considerations and gain the necessary experience, we will suggest in this and the following chapters, that the amateur uses whatever equipment at hand, to build a radio telescope.

A radio telescope is a very sensitive instrument but, it is possible to experiment in radio astronomy with equipment that is not that sensitive. Naturally, the amateur must not expect results that will permit him to make discoveries, or to become famous overnight. The idea is only to gain experience.

We are going to assume in the discussion that follows that the amateur has what has been called the Data Processing Unit of a telescope; that is, a system that starts with a detector made with a calibrated diode, amplifiers, integrator with adjustable time constant, a circuit for removing the base voltage from the signal, and analog-to-digital converter, and a computer. It will be assumed that the amateur has built or obtained these parts, but that he has thoroughly tested them. This means, that he is sure they are working properly and that he is quite familiar with their operation.

We are going to assume also, that the amateur is familiar with the operation of the computer and that he has obtained, or created himself, at least one program that permits him to sample a signal under conditions that can be specified at the start of the observation, and the same or other program that permits him to see the results of the observation, as a graph on the computer screen. These programs

have been described in previous chapters and the author also offers a diskette with the required programs, with the hardware described in previous chapters.

Now, the amateur should go through the equipment he has and should select one, or several combinations to test. Before entering into the analysis of the equipment, let us make some general considerations.

One of the main problems of an amateur is the radio frequency interference. This interference takes the form of signals generated by transmitters, and noise generated by machinery. Practically all transmitters create interference. The worst kind is the one that is transient. Some years back it was the CB radio. Today, this type of interference is bad only close to a big highway. In a city or town, CB radios create only an occasional interference.

Much worst is the interference created by radio telephones, radio communication equipment for delivery trucks, the police radio, and similar equipment. The big problem comes from three main facts:

This type of equipment is scattered all over the frequency spectrum and is very difficult to find frequencies not affected by it;

This type of equipment has enough power to block any receiver in a wide area and cause interference even trough stereo equipment and similar; in the case of radio astronomy, you can get interference through your Data Processing Unit, if it has sufficient gain, and it is not properly shielded; and

This type of equipment is operated by personal without training, that cannot realize when the equipment is working properly and when it is not; in many cases, the gain of the modulation is advanced to the maximum, making the equipment to over modulate; in other cases, the self importance of the function the person performs, like with the police, prevents anybody from complaining or prevents any complaint to be effective.

There are very few ways in which you can control this type of interference. I have lived in locations where the police radio came through the power lines into any equipment connected to the 120 V lines. The only way to listen to radio was using batteries, and the TV was full of snow. Many line filters were tried without too much success. This type of interference can be tested with any portable radio: Listen to a weak station with batteries, then connect the power adapter and see what happens. If you listen to interference, suspect the police.

To control interference that comes from the air, you need to study your location. If you have or can borrow a scanner, put it in the place you want to put your antenna, and make it scan the whole range of frequencies it can receive. Scanners normally stops where there is a strong signal. Take note of the frequency. After some time, you will notice a definite pattern. There are frequencies where the scanner stops every time it goes through; there are other frequencies where the scanner stops some times, the frequency changes very much. Move the scanner through out the area you can use, normally the

backyard, to find the spot where the interference is at a minimum. This analysis will give you a pretty good idea of what happens in your area, and will permit you to select a frequency range where you can work.

Now, it is necessary to device ways to improve the situation. You can use your house to shield the antenna from the source of stronger interference, normally a road or highway. Another possibility, although more expensive, is to mount a shield made out to metallic mesh, but very seldom the cost and effort to build one is warranted by the improvement that can be obtained. When we study the antenna, we will points at the types of antennas that are more susceptible to pick up interference of this type.

The interference caused by fixed equipment can normally be controlled. This should be the first task when selecting a location and frequency. If you cannot use a scanner, look around you house, about a mile or so, for any tower or transmitter, and try to determine its frequency from the characteristics of the antenna. Broadcast transmitters normally have signs giving the station call, or name. You can use this information to find the frequency of operation and the power.

It is a very good idea to keep a record of all your findings, specially if you own the house where you live, and you do not plan to move very soon.

RADIO ASTRONOMY F0R BEGINNERS

Michael E. Valdez

Chapter 23

THE ANTENNA

For you to be able to work with a radio telescope, or to select one type of antenna over another, you need to have some knowledge of how an antenna works. For this purpose, you need some theory, and this chapter stars with this theory of signals and antennas.

The first point to consider is that there are two types of signals: One that is repetitive and the other that is not. The repetitive signal, as its name implies, has magnitudes that repeat over time; that is, after a certain period of time, the signal goes through the same set of values. This time is called a cycle and the number of cycles per second is called the frequency of the signal. The frequency of a signal is measured in hertz, where a hertz represents one cycle per second. For practical purposes we use multiples of the hertz, and we talk about kilohertz, megahertz, gigahertz, etc. The kilohertz is one thousand cycles per second; the megahertz is one thousand kilohertz, the gigahertz on thousand megahertz. There are intermediate units.

The random signals are of interest for us, because every radio signal from radio sources in the sky are random in nature. The interesting point comes from the theory of communications, and Fourier proved long time ago, that every signal can be represented by the sum of a number of single frequency signals, of the type studied above.

Let us consider first a theoretical pulse, which is one whose amplitude goes from zero to infinity in zero time, and immediately comes back to zero. The theoretical pulse does not exists, but is very useful for analyses. The theoretical pulse has then an infinite amplitude during zero time. The energy on the pulse can be any value, and it depends on its source. The energy of any pulse is the area under the pulse.

It has been proved mathematically that a pulse of this type is equivalent to the sum of an infinite number of single frequency signals, infinitely close together, and each one with an amplitude proportional to the energy of the pulse. This is the perfect noise pulse. These concepts are very important for all that follows.

Let us repeat the concepts. The theoretical noise pulse is one that is very sharp and very tall. It is equivalent in every respect, to the sum of an infinite number of frequencies, very close together. What this means in practical words, is that if a theoretical pulse is produced some place, any receiver in the vicinity, tuned to any frequency, will receive the pulse. How much energy a given receiver will get depends on the antenna and the characteristics of the receiver.

With these ideas in mind, it is necessary to study the normal, single frequency signals, a little more. Radio signals propagate through space at the velocity of light, or very close to it. In the time it takes the signal to go through a cycle, the signal has propagated through space a certain distance. This distance is then fixed for the signal. From Physics we know that the velocity is the ratio of the distance to the time it takes to travel that distance. The time it takes a signal to perform a cycle is the reciprocal of the frequency (the frequency is cycles per second, its reciprocal is seconds per cycle). Then, the velocity of propagation is equal to the product of the distance the signal travels in one cycle and its frequency.

Let us use the letter f to represent the frequency, and let us agree that we will measure it in Mhz (megahertz). Let us call wave length, the distance the signal travels during one cycle, we will represent it with the letter l, and let us agree to measure it in meters; then, we can state what we said before in a basic law of Physics:

f x l = 300.

To be totally precise, this law applies to a signal traveling in empty space. Since all our signals travel in space, which is almost empty, this law applies to our work. The consequence is simple. If we know the frequency of a signal, we can know its wave length, and vice versa.

Now, the elementary antenna is what we call the dipole (See Fig. 23-1). A dipole is an antenna formed by two pieces of wire, each exactly one quarter of the wave length of the signal of interest, mounted collinear but not touching, and with the center two ends connected to the receiver. This antenna is used as comparison for all other antennas.

Fig 23 - 1

Now, what do we get from a dipole? The first thing we need to understand is that the dipole receives signals at all frequencies and from all directions. This is a very important concept for all that follows. This applies to all antennas or every type. Any antenna receives signals from all directions and at all frequencies.

Let us look again at the dipole and try to make some measurements in our minds. Imagine we have the dipole in the middle of space and we have a small transmitter not too close. We receive the signals from the transmitter and we take note of the output of the receiver. We move the dipole and take note of the output of the receiver with the dipole pointing in all directions.

When we analyze our records we will find that if the line of the dipole is perpendicular to the line from the transmitter to the dipole, the signal is maximum; if the line of the dipole is in the same line as the one from the transmitter, the signal is minimum; if we rotate the dipole on its axis, nothing changes. The ratio between the maximum reading and the minimum is called the directivity of the antenna; the relation between the maximum reading and the average of all readings is called the gain of the antenna.

Now, assume we change the frequency of the transmitter with the dipole in the position of its maximum. Imagine we start with a very low frequency, and we increase the frequency taking readings from time to time. When the frequency of the transmitter is very far from the frequency of the dipole, the receiver shows only a minute reception; as the frequency approaches the frequency of the dipole, the output of the receiver increases and it has a maximum when the transmitter is exactly at the same frequency of the dipole; as we increase the frequency past the frequency of the dipole, the output of the receiver goes down to a very low value.

If we plot these measurements, we will have a curve that looks some what like a bell and is called the resonance curve of the antenna. This curve shows us the selectivity of the antenna, or how good it receives signals of different frequencies.

Why we should be interested on all this? Simply because all antennas behave this way, our antenna will have a gain much larger than a dipole and a much better selectivity but we cannot avoid the fact that our antenna will receive at all frequencies and from all directions.

Let us put some numbers on a paper to see what all this means to us. We mention before that a typical amateur antenna for radio astronomy receives a signal on the order of 50 to 100 degree. This is equivalent to a power of 1 E -21 watts. Now, imagine our antenna has a gain of 30 dB (decibels, 10 times the log of the relation of powers), this means that the power received in the preferred direction is 1000 times larger than the average over all directions.

Now, imagine further that there is a transmitter with 1000 Kw of power, 10000 meters from our antenna. The power of the transmitter at that distance puts a power of 10 milliwatts at our antenna. This is equivalent to a signal putting 10 microwatts (1 E -5 watts) from the same direction of our source. In summary, the TV transmitter puts a signal that is a one with 16 zeros (10000000000000000 times) more powerful than the signals from the sky.

Now, let us improve the situation because it is difficult to imagine an amateur that will try to make radio astronomical observations at the same frequency of a nearby TV transmitter. Imagine we change frequency to one our analyses indicate the signal received at the frequency of observation is 60 db above the signal received at the frequency of the nearby transmitter. Now, 60 dB represents an attenuation of one million times, so the transmitter signals is now only a one with 10 zeros (10000000000 times) more powerful than the signals from the sources in the sky.

It will be interesting that you try to follow these computations. A good source is RADIO ASTRONOMY, by John D. Kraus, published by Cygnus-Quasar Books, P. O. Box 85, Powell, Ohio 43065. This book is practically indispensably for any serious amateur, and you should get your copy as soon as possible. It is also recommended you find a copy of an article by the author of this book, published in August 1990 by RADIO ASTRONOMY, the SARA Journal, under the title The Beginner Amateur. You can get a copy of this issue of the Journal by writing SARA Membership Services, 247 N. Linden St., Massapequa, N.Y. 11758. This article analyzes the same problem we are working with here, how a person can stop being a beginner.

So, it seems that an amateur in the city, has very little chance of making radio astronomical observations. This is true, but using ingenuity and knowledge, you can overcome the most terrible obstacles, and achieve what you want.

We already mentioned one way to overcome problems of noise, by using a limiter in our DC Processor. We also mentioned the need for absolute shielding of all the circuits. We have quite a lot of thing to do with an antenna, and they are the topic of what follows.

Imagine we get the dipole we were studying before, and we enclose it in a metal box, that has only one aperture to one side (See Fig. 23-2). Let us determine it a little more. Imagine we get a cylindrical box or the proper dimensions, open in one side, and we mount the dipole, exactly one quarter of a wave length from the closed end. The only way energy can enter the box is through the open end, the energy that is not captured by the dipole passes true and reflects on the back plate. The travel time is exactly half a cycle and the signal get inverted in the reflection, this makes for a full cycle. So the signal comes back to the dipole exactly in the same part of the cycle as the one coming from the opening, one cycle later. They reinforce each other. This is what is called a feeder, because it is also used to feed power into an antenna.

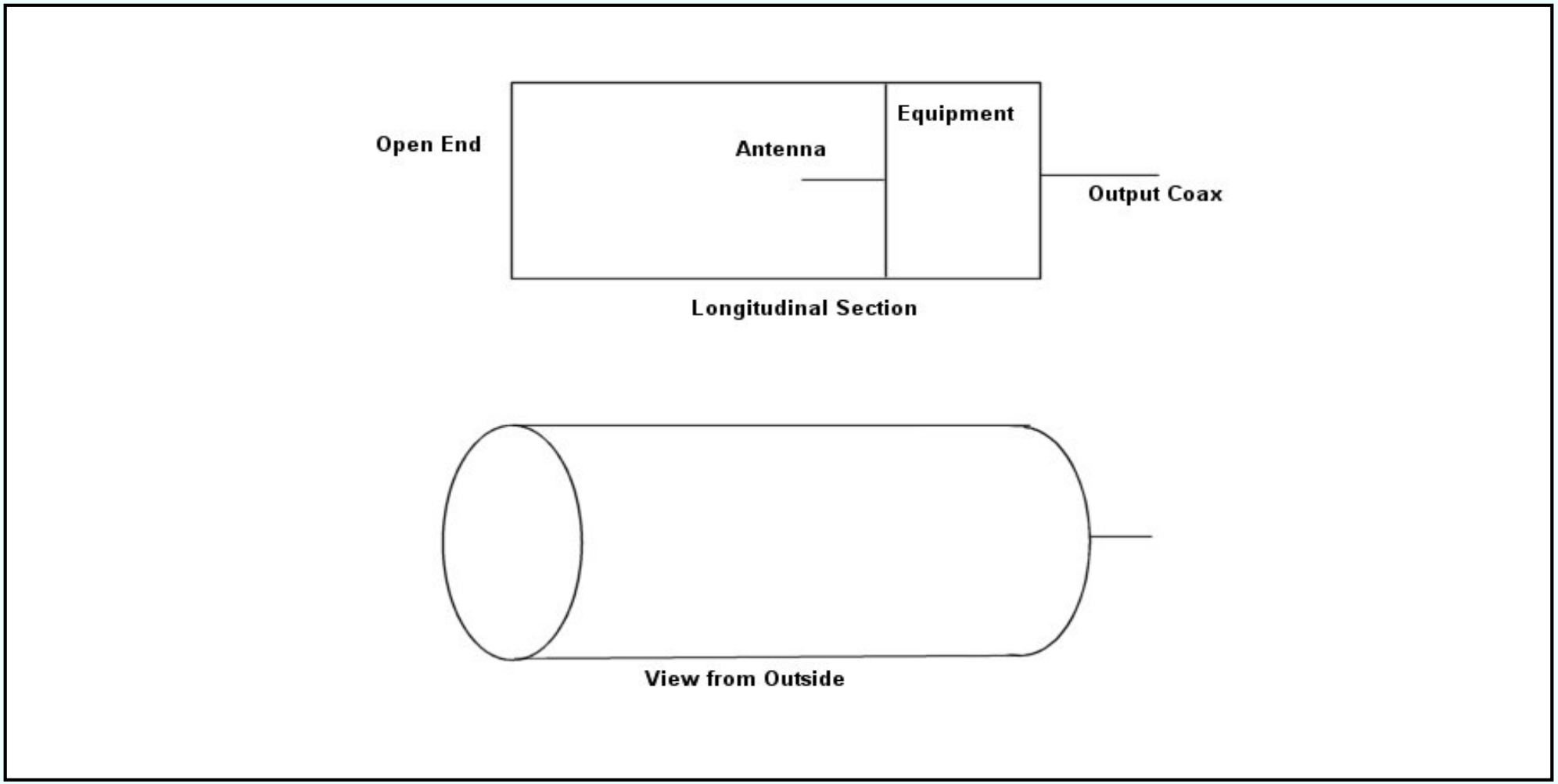

Fig 23 - 2

It should not be to difficult to visualize that although the opening will receive power from all directions, the relation between the power coming from the axis of the cylinder and the average, is quite large. This arrangement has a very high gain. So, most of the energy comes for the direction of the axis of the cylinder and very little from the sides. Before the way it is built, a feeder has also very sharp selectivity curve.

Such an antenna works but is has very small area, a few inches across at normal frequencies of observation. The interesting idea is that this feeder can be put in front of a passive reflector (a metal plate) to increase the collecting area. The metal plate is curved in the form of a paraboloid and we have a dish antenna. This is the reason why a dish antenna is so good for radio astronomy.

You can have high gain in many other ways. If you are a radio amateur (ham), you are probably familiar with the Yagi antennas. In these antennas, we put what is called parasitic elements, that are simply more diodes with the two center end connected together. If these parasitic elements are put in very special distances from the main diode, they act as reflectors of the energy, as the back plate of the feeder, or as directors, guiding the energy in the direction of the dipole. At low or medium frequencies, the Yagi becomes quite large and you can have two to four elements. At higher frequencies, 500 Mhz or above, the dimensions become reasonable (the wave length is shorter) and you can have 20 or more elements. The gain of a Yagi antenna increases with the number of elements.

Something interesting about the Yagi, that every radio amateur interested in DX (long distance communication) knows. The distance from the antenna to ground determines the angle of the main lobe (the direction of maximum reception) with respect to the horizontal. So, to receive signals from Jupiter or the Sun, you do not have to tilt the antenna up, unless the source is very high in the sky. This is interesting when working Jupiter at 20 to 30 Mhz with amateur equipment. Point the antenna in the direction of Jupiter as it rises, and you will receive a strong signal. As Jupiter follows the normal path on the sky, it might get too high and the signal might go down, depending on its declination when it culminates. As Jupiter passes the meridian, the signal will improve again, until it sets. Amateurs that work with OSCAR satellites, have the setup ready to work in radio astronomy, without any change.

Consequently, if you are a radio amateur, or if you have a Yagi antenna, you can use it for radio astronomy, although you cannot expect the same performance of a dish antenna. Radio amateur antennas are not the only source of antennas. TV and FM antennas could be used if you select the frequency with care. TV satellite dishes can be used as they are, or the feeder can be changed to suit our purpose.

A very interesting antenna is the corner reflector, which is practical at medium to high frequencies (See Fig. 23-3 See also Fig. 23-1, on the background, on top of the trailer.). The idea is simply to put two flat reflecting surfaces forming a corner, thus its name, with the dipole in the volume enclosed. The dipole goes parallel to the two surfaces. The size of the two surfaces is not critical but there is little point in making them more than 2 wave lengths is side. The whole thing can be build on a wooden frame with a piece of wood in the center, about 0.4 wave length, from the corner, to hold the dipole. Run the connection to the dipole perpendicular to the corner (and the dipole), and pass it through a hole at the corner. The sides can be made of wire mesh with holes less than 1/20 of the wave length.

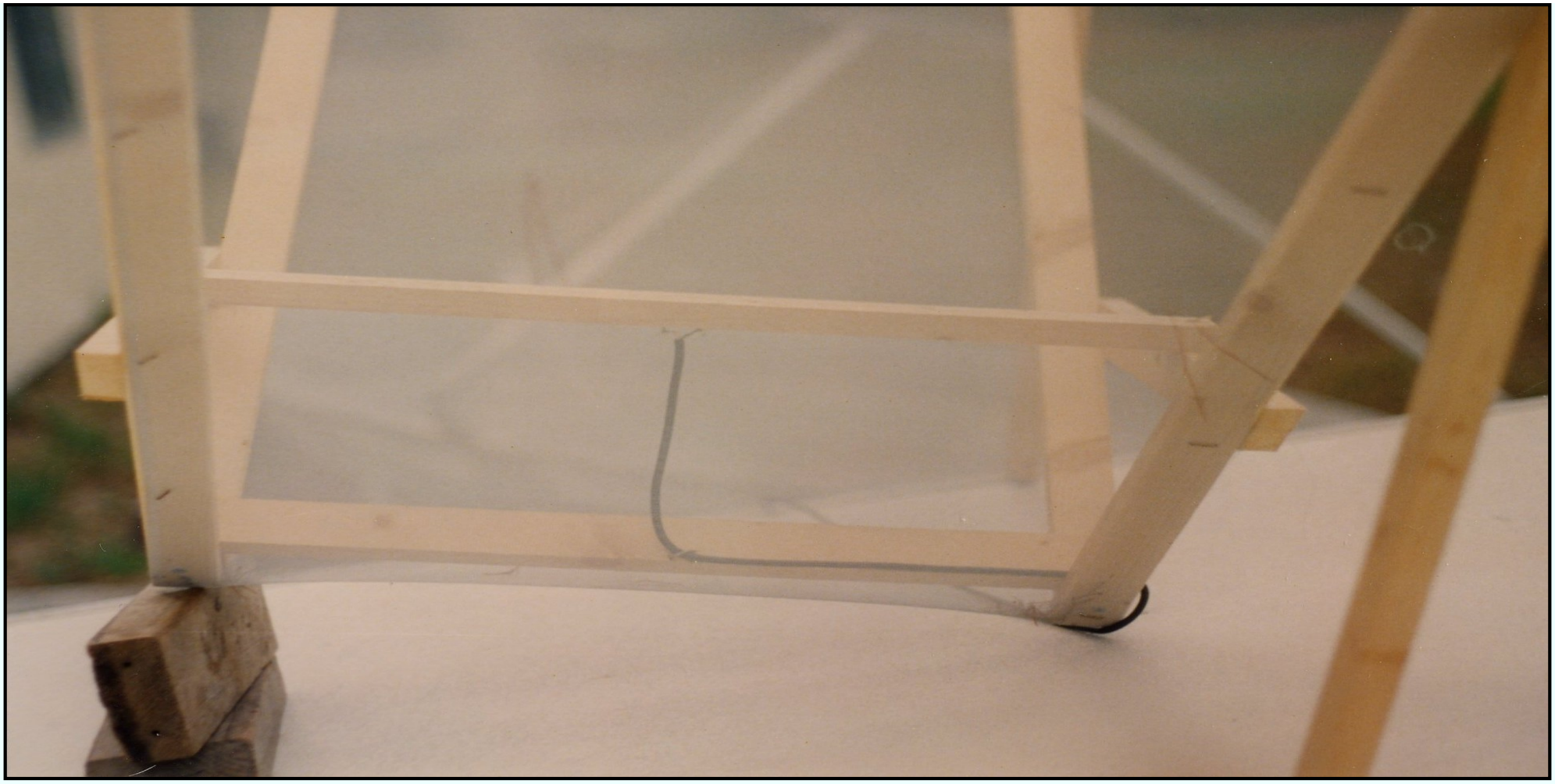

Fig 23 - 3

This little antenna is very easy to build but it does not have too much gain. Since the dipole is open, it receive noise from all directions. In any case, it can be built with materials you have, and in a few hours. This is a good antenna if you do not have any other to work with.

RADIO ASTRONOMY FOR BEGINNERS

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Chapter 24

THE RECEIVER

It has already been mentioned that it is a very good idea that, after you finish and calibrate you Data Processing Unit, you should start working with whatever equipment you have. There are two very good reasons for doing this: One, while you work with the equipment you have you, will gain experience in radio astronomy; two, at the same time, you will find out which areas of radio astronomy attract you and what you need to improve the results of your operation.

If you are a radio amateur, you probably have a lot of equipment that can be used in radio astronomy without any modification. Let us analyze some possibilities, mainly to give you some ideas.

First, if you work with OSCAR satellites, you already have the equipment; the only thing you need to do is, connect the audio output of your receiver to the input of your Data Processing Unit, exactly as you connected the tape recorder when you tested the DC processor. The same programs you used to test your Data Processing Unit in the project explained before, can be used to work with this setup. Do not try to find pulsars, though, but if you use a single pass, you will get nice results. Consider that a source takes some 20 minutes to pass from one end to the other of your antenna. Instead of pointing the antenna to the OSCAR satellite, you will point the antenna to the radio source; that is all you have to do to have a radio telescope.

As has been mentioned several times, this setup will permit you to observe the Sun, Jupiter (may be), and some of the strongest sources in the sky. Try to find Cassiopeia A, Sagittarius A, Cygnus A. The results you get from these observations will tell you if you should try to find other, weaker, sources.

If you do not have equipment for OSCAR, you might have any other receiver and antenna. The normal high frequency receiver can be used for the Sun and Jupiter, with the same antenna you use for communications. If you have a 144 or 432 Mhz equipment, it can also be used. If you do not have any antenna, a corner reflector can be built very easily. A few element Yagi can also be built easily for these frequencies. One kind of equipment that is very interesting, is the amateur TV equipment working at 1300 Mhz. This frequency is quite close to the so called "water hole", at 1.4 Ghz, and the frequency is much more quieter than at lower frequencies. The basic equipment for amateur TV is not too expensive.

If you are not a ham, or you do not have ham radio equipment, you can use a satellite TV receiver

without any modification. Simply point the antenna at the Sun, and you can see the needle of your receiver change as you point exactly to the Sun. Connect the output of the receiver to the input of your Data Processing Unit and you have a radio telescope. You might need to add some gain, because the satellite receivers are made to work with a television receiver, which provides the gain. If your receiver has a video output, you can use it as amplifier. A video tape recorder can also be used as an amplifier. Connect the output of the satellite receiver to the input of the recorder and the output of the recorder to your Data Processing Unit. Better results are obtained using the video output of the recorder, if you have one. The same is true with a TV receiver. The size of your antenna will determine the results you get. With a 5-foot antenna, the Sun drives the needle of the receiver full scale. With larger antennas you can search for the other strong sources in the sky. A 12 or 16-foot antenna can give you many hours of interesting observations.

It was mentioned before that you should not expect very impressive results with any of these types of operation, but it will get your hands on a radio telescope, practically without any expenses. A satellite receiver will give you nice observations of the Sun and probably also of Jupiter. Finding the other sources in the sky can be difficult, depending on the size of the antenna, as mentioned above. Amateur radio equipment will permit you to find many sources in the sky. You need to know where they are and you will need a map or a catalog for this purpose. You can get a very complete radio sources catalog, at a very low price, from SARA Membership Services, 247 N. Linden St., Massapequa, N. Y. 11758.

RADIO ASTRONOMY FOR BEGINNERS

Michael E. Valdez

Chapter 25

FINAL THOUGHTS

Well, this chapter concludes this book for beginners. It is hoped that those of you that have continued with us to this point, are no longer beginners. The task of learning never ends, and as you become more interested in this hobby, you will continue to learn fascinating possibilities of radio astronomy, fascinating new ways of doing old things, many new things you can do now that were not possible when you started, and so on, almost to infinity.

The road ahead is full of interesting things. How to be able to get to them? We have mentioned some of the things you can do to continue improving in the months ahead. We will mention some others now.

After a few more months of experimentation with the equipment you have, you will start seriously thinking on advancing in the hobby, by improving your equipment. This is a very common misconception. Many amateurs think that the only way to advance in the hobby, whatever hobby, is to have more and more equipment, which is more and more expensive and complicated. This is not true. The real way you advance in any hobby is by knowing more about the hobby,

Let us talk about results. Imagine two amateurs, one with a 6-foot dish antenna and an equipment he put together, from different sources, a preamplifier he built, a frequency converter he bought some place, a radio amateur receiver, etc.; the other amateur has a 16-foot dish antenna, a professional pre-amplifier, and a receiver made for professional work. His equipment ends in a very complete digital computer. Can you tell who gets better results? It is difficult, because it does not depend on how much you have, but on how much you know.

The most expensive equipment in the world will not make a radio astronomer out of you and the results you get depend on how good a radio astronomer you are. So, if you want to progress in the hobby, try to learn as much as you can; try to get as much experience as you can; try to obtain the best results you can; whatever equipment you have, make it work at peak performance; calibrate it to perfection; store your data with all necessary precision and information; get audio tape recordings for future analyses; etc.

Something else. The most marvelous observations that you can make have very little value if you let them rotten in your archives. You should share your observations. Is the only way you can find if what you are doing is worth to be done. Let others analyze what you have done, write articles describing

them. Let other criticize your work. From their comments and criticism you can learn much. If they find errors you have never seen, that gives you information you did not have. You should publish for this purpose, not to see your name in print.

There is another sure way to progress, and it is teaching others what you know. The point is, and any teacher knows this, when you try to explain something to others, you increase your knowledge of the subject you try to teach. The questions from the students generally point to subjects you do not have clear, because if you had them clear you would have made a better explanation. So, you will learn where your knowledge needs polishing. The need to answer the questions will force you to learn more.

Going back to improving your equipment, the most important part of the receiver is the front end. The front end determines the noise of the receiver; all the rest only provides gain. Try to improve your front end as much as possible. If the first amplifier is mounted at the antenna, you avoid the losses in the line from the antenna to the receiver.

As we mention while talking about the telescope, the purpose of the antenna is to get as much energy as possible but do not forget that if the antenna is too complicated to move, you will try to make observations without moving the antenna, missing some interesting observations you could have made by moving it. So, it is a matter of balance. If increasing the size of the antenna will make less movable, think if it is not more practical to get by with a smaller, but more movable antenna.

Some times, it might be possible to sacrifice half of the sky to increase the mobility of the antenna. In the Northern hemisphere, pointing South is more interesting that pointing North. So, you might decide to have an antenna that only points South, for example. Some amateurs think, on the other hand, that the possibility of having two transits for each source makes pointing North more interesting.

In extreme cases, where your backyard does not permit you to have an antenna that points to the meridian, good observations can be made by pointing either East or West. In this case you might need to rotate your antenna on a vertical axis, in azimuth, so as to catch different declinations, and you might not need to move the antenna too much in elevation.

The situation mentioned above suggests a solution for the mechanical problem of the antenna. If you do not find a solution on how to move the antenna in elevation, think on pointing the antenna East or West, and rotate it. Rotating an antenna is always easier than moving it in elevation.

This situation also points to a solution to the problem of using satellite TV antennas. Most of these antennas have a large motion in azimuth, to point to the satellite, and a very small motion in elevation. The reason is that all satellites are in a line in the sky, above the Equator. If you point the antenna as high as possible, and then rotate it to get to the declination of the star, you will increase your coverage of the sky.

In these last few cases, the problem is to know where the source will pass when it is not at the

meridian. The book COMPUTATIONS FOR RADIO ASTRONOMY, sold by SARA, 247 N. Linden St., Massapequa, N. Y. 11758, has a very interesting procedure for computing the azimuth and elevation of any source at any time before or after culmination. You can also download this book from the author's web page.

So you see that getting a little out of the current path can solve some problems that might seem without solution. You should consider that any observation you get provides you with a measure of satisfaction that is proportional to the effort you spent trying to get it.

RADIOASTRONY FOR BEGINNERS

Michael E. Valdez

Appendix A

Program PULSAR.EXE Documentation

The program PULSAR.EXE, will run in any IBM-compatible computer, which can run in DOS mode, without the need for any modification or adjustment. The hardware requirements are minimal; some free memory, a graphics monitor, a video display adapter, a disk drive, and an A/D converter connected to port 300h. The program is written in assembler language.

To use the program, download it to your hard disk. Make the drive and directory where you put it, the current or active drive of the computer. When the computer shows the usual prompt, type PULSAR and press the ENTER key; the program will run. If you are running under Windows, use the Explorer to navigate to where you put the program. Double click on its name.

This program is intended to use in the arm chair radio astronomy experiment, but it can be used with any other tape, or with any radio telescope. The only requirement is that you have an A/D converter in your computer, connected to port 300h, as explained in the text.

The program operates exactly the same if the A/D input is connected to a tape recorder or to a telescope. The program first asks you for the name of the file where you want to put the resulting observation. Note that the name should not have an extension, because the program adds the extension .FIL to all the files. Use a name that is meaningful. For example, if you are studying pulsar PSR0392, and this is the seventh run that you make, call the file P0392-07 and the file will be P0392-07.FIL. Note that if you give the computer a name of a file that already exists in the disk, the old file will be destroyed and the new file will replace it. This is useful when you are making preliminary adjustments and you do not want to save all the adjustments. In the previous example, you can call your file P0392-01 until you get to a point the you want to start saving the files, then you start giving consecutive names.

After the program get the file name, it will ask for the sampling constant. A large sampling constant means slower sampling. Roughly speaking, a constant of 1000 will take half the number of samples per second that a constant of 500. Actually, you need a slightly larger constant that 500, say something like 550, to get double the number of samples per second of 1000. Actual numbers cannot be given because they depends on your computer. To have an idea of how many samples per second your computer produces under given conditions, ask for a large number of samples, 30,000 samples with the constant of interest, and time the operation. You might need to have also a large number of passes, like 100, if

your computer is fast.

The total number of samples is the next value required by the computer and its meaning is as its name implies. Is the total number of samples the computer will get for you. When working with pulsars stored in audio tape, you cannot expect to get too many samples.

The measurements per sample is the next value. This is really not too useful for the analysis of pulsar, but it was included so you can use the program in your regular observations, or with other type of recording, like solar flares or jovian storms included with the tape. The use of this value is to increase the precision of the samples. If you add together 1024 measurements with 8 bits precision, you get a measurement with an equivalent precision of 10 bits. When working with pulsar, use one measurement per sample.

The number of passes is a value useful when working with pulsar in a tape, but not too useful when you are working with other type of signals, or with your telescope. Again, it was included so you can do both things. This constant makes the program sample the number of samples you indicate, at the rate you indicate, and then go back and take more samples and add them to the previous set. In this way, noise is eliminated and any pulse that is in synchronism with the sampling, is enhanced. As explained in the text, you should start working with one pass, until you determine a sampling rate that locks on the pulsar rate, then you can start using more passes, first 5, then 10, then the maximum, as you refine your sampling constant locking on the pulsar rate. When working with other type of signals, or with your telescope, simply use one pass.

After the computer has all the information it requires, it asks you for a signal to start working. Press any key and the computer starts sampling and accumulating. At the end of the process, the computer comes back to you with a beautiful graph of the observation, showing on the top of the screen, the name of the file and the sampling constant that was used. The same information has been stored on disk, under the name you gave.

RADIO ASTRONOMY FOR BEGINNERS

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Appendix B

Program PULSAR.EXE Assembler Source

```
; * * * * * * * * * * * * * * * * * * * * * * * * * * *
; *
; * Program Name: PULSAR
; *
; * Purpose: Read pulsar from tape
; *
; * Change the I/O Port if it is not 300h
; *
; * Started: March 20, 1991
; * Working: March 20, 1991
; * Modified: April 6, 1991 for Menolly
; *
; * * * * * * * * * * * * * * * * * * * * * * * * * * *

       dosseg
       .model small
       .stack 100h

; * * * * * * * * * * * * * * * * * * * * * * * * * * *
; *
; * D A T A
; *
; * * * * * * * * * * * * * * * * * * * * * * * * * * *

       .data

count   dw 0
dig2    db 0
dig3    db 0
dig4    db 0
dig5    db 0
handle  dw 0
```

```
mode    dw 0
odd     dw 0
plot    dw 0
row     dw 0
shif    dw 0
some    dw 0
temp    dw 0
temp1   dw 0
where   dw 0
wheres  dw 0
wherdi  dw 0
pass    dw 0
mody    db 10 dup (?)
pasy    db 10 dup (?)
buff    db 10 dup (?)
file    db 18 dup (?)
xata    db 1280 dup (?)
fifi    db '.FIL',0,'$'
namo    db 13,10,10,'PROGRAM SAMPLE A PULSAR (c) 1990'
        db 13,10,'Michael E Valdez P O Box 2382 Melbourne FL 32902'
        db 13,10,'$'
namon   db ' Enter Record Name (No Extension) $'
passs   db 13,10,10,' Enter Number of Passes $'
modem   db 13,10,10,' Enter Sampling Rate Code $'
rrdd    db 13,10,10,' Signal when ready$'
workk   db 13,10,10,' WORKING$'
; * * * * * * * * * * * * * * * * * * * * * * * * * * *
; *
; * C O D E
; *
; * * * * * * * * * * * * * * * * * * * * * * * * * * *
        .code
start:  mov  ax,@data
        mov  ds,ax
begin:  mov  ah,0 ; clear screen
        mov  al,2
        int  10h
        mov  ah,9 ; show name
        lea  dx,namo
        int  21h
        mov  ah,9 ; ask for record name
        lea  dx,namon
        int  21h
```

```
        lea  bx,buff
        mov  al,8
        mov  [bx],al ; prepare buff
        sub  ax,ax
        mov  [bx+2],ax
        mov  [bx+4],ax
        mov  [bx+6],ax
        mov  [bx+8],ax
        lea  dx,buff ; read record name
        mov  ah,0ah
        int  21h
        lea  si,buff
        inc  si
        mov  cl,[si]
        cmp  cl,0
        jne  beg1
        jmp  outz
beg1:   mov  ch,0
        inc  si
        lea  di,file ; copy file name
        mov  dx,ds
        mov  es,dx
        rep  movsb
        lea  si,fifi ; append .fil
        mov  cx,6
        rep  movsb
        mov  ah,9 ; ask for mode
        lea  dx,modem
        int  21h
        lea  bx,mody
        call ridmod
        mov  shif,bx
        lea  dx,passs ; ask for number of passes
        mov  ah,9
        int  21h
        lea  bx,pasy
        call ridmod
        mov  pass,bx
        lea  bx,xata ; clear data
        mov  cx,1280
        sub  al,al
cle2:   mov  [bx],al
        inc  bx
```

```
        loop cle2
        mov  ah,9
        lea  dx,rrdd ; show ready
        int  21h
        mov  ah,7 ; wait for key
        int  21h
        lea  dx,workk ; show working
        mov  ah,9
        int  21h
        mov  ax,pass
        mov  count,ax ; set count for passes
block:  lea  di,xata ; prepare indeces for data
        mov  temp,640
blick:  mov  dx,300h ; read port
        in   al,dx
        add  [di], ; add to buffer
        inc  di
        inc  di
        mov  cx,shif
bluck:  loop bluck
        dec  temp
        jnz  blick
        dec  count ; complete block
        jnz  block
        lea  bx,xata
        mov  ax,shif
        mov  [bx],ax
        mov  ax,pass
        mov  [bx+2],ax
        clc
        mov  ah,3ch ; create file
        lea  dx,file
        mov  cx,0
        int  21h
        mov  handle,ax
        jnc  shiw
        mov  ah,2
        mov  al,7
        int  21h
        jmp  outz
shiw:   mov  ah,40h ; write file
        mov  bx,handle
        lea  dx,xata
```

```
        mov  cx,1280
        int  21h
        mov  ah,3eh ; close file
        mov  bx,handle
        int  21h
        mov  ax,6 ; graphics mode
        int  10h
        lea  dx,namo ; show name
        mov  ah,9
        int  21h
        lea  dx,file ; show file name
        mov  ah,9
        int  21h
        mov  dl,32
        mov  ah,2
        int  21h
        mov  dl,32
        mov  ah,2
        int  21h
        lea  dx,mody+2 ; show mode
        mov  ah,9
        int  21h
        mov  dl,32
        mov  ah,2
        int  21h
        mov  dl,32
        mov  ah,2
        int  21h
        lea  dx,pasy+2 ; show passes
        mov  ah,9
        int  21h
        lea  di,xata+4 ; scale data for plotting
        mov  cx,638
scal:   mov  ax,[di]
        shl  ax,1
        shl  ax,1
        shl  ax,1
        shl  ax,1
        shl  ax,1
        sub  dx,dx
        mov  bx,pass
        div  bx
        mov  [di],ax
```

```
        inc  di
        inc  di
        loop scal
        lea  di,xata ; plot data
        mov  temp,0
show:   mov  ax,[di]
        inc  di
        inc  di
        mov  dx,199 ; set top
        sub  dx,ax ; invert heigth
        jns  shift5
        mov  dx,0
shift5: mov  cx,temp ; set column
        mov  ah,0ch
        mov  al,1
        int  10h
        inc  temp
        cmp  temp,640
        jne  show
        mov  ah,7 ; wait for key
        int  21h
        cmp  al,27
        je   outz
        jmp  begin
outz:   mov  ah,0 ; text mode
        mov  al,2
        int  10h
        mov  ah,4ch
        int  21h ; terminate
ridmod  proc near
        mov  al,8
        mov  [bx],al ; prepare buff
        sub  ax,ax
        mov  [bx+2],ax
        mov  [bx+4],ax
        mov  [bx+6],ax
        mov  [bx+8],ax
        mov  si,bx
        mov  dx,bx ; read record
        mov  ah,0ah
        int  21h
        inc  si
        inc  si
```

```
        mov  bx,0
ridmo:  mov  al,[si] ; read mode
        inc  si
        cmp  al,48 ; below 0 ends
        jb   ridex
        cmp  al,57 ; above 9 ends
        ja   ridex
        mov  cx,bx
        shl  bx,1
        shl  bx,1
        add  bx,cx
        shl  bx,1
        and  ax,15
        add  bx,ax
        jmp  ridmo
ridex:  mov  al,'$'
        mov  [si-1],al
        ret
ridmod  endp
        end  start
```