RRS News

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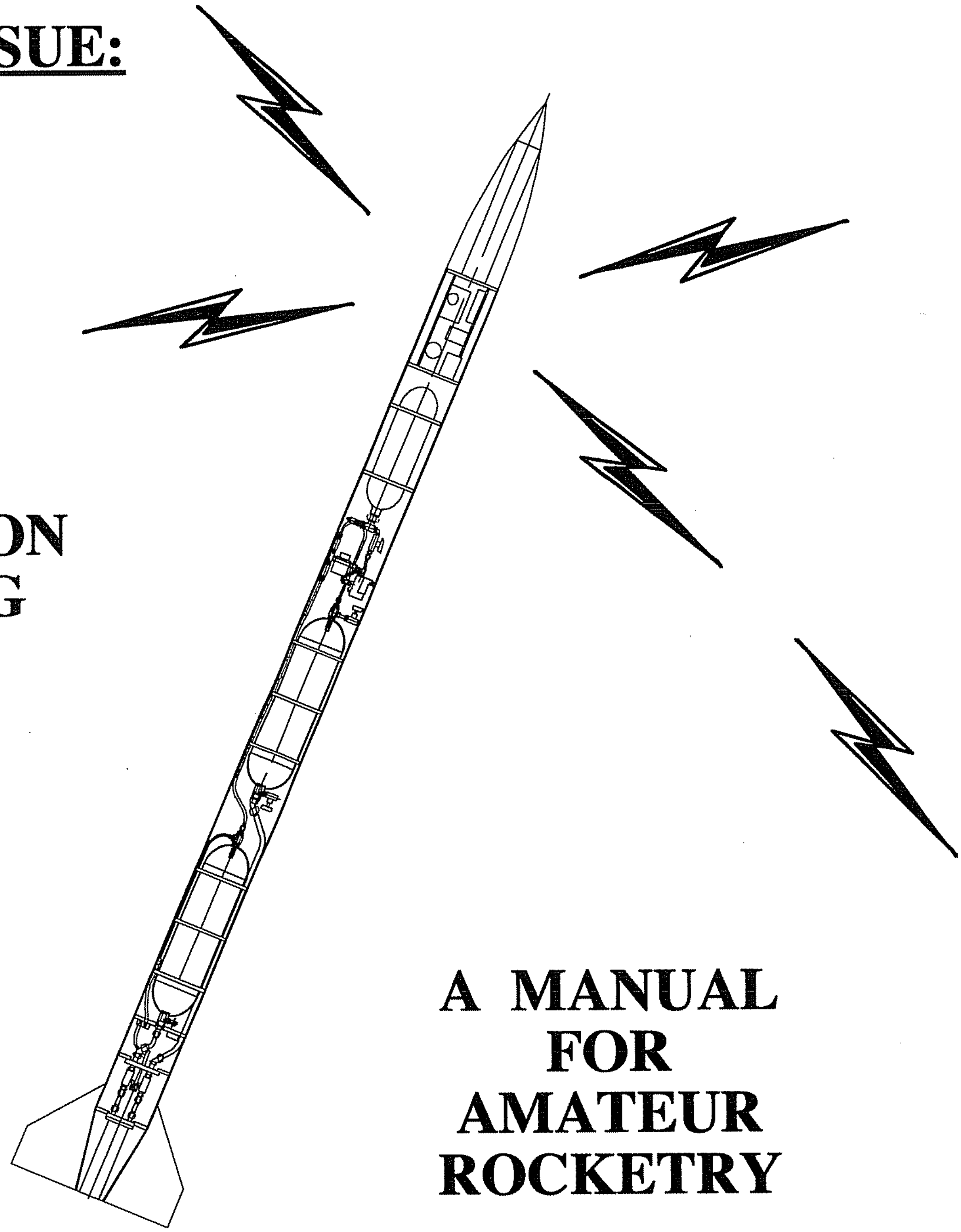
SPECIAL ISSUE:

RADIO DIRECTION FINDING



A MANUAL FOR AMATEUR ROCKETRY

RRS News

VOLUME 56, NUMBER 3, SEPTEMBER 1999

The Reaction Research Society is the oldest continously operating amateur rocket group in the nation. Founded in 1943 as a nonprofit civilian organization, its purpose has been to aid in the development of reaction propulsion and to promote interest and education in this science as well as its applications. The Society owns and operates the Mojave Test Area, a 40 acre site located two and a half hours north of Los Angeles. Over the years, thousands of solid, hybrid, and recently, liquid propellant rockets have been static and flight tested. Currently, there are over 250 active RRS members throughout the United States and in several foreign countries.

This newsletter is a, more-or-less, quarterly publication issued by the Society as a technical journal and is intended to be educational and to provide communication between members and other societies. It is also the historical documentation of the activities conducted by the Society, as a whole, and by its individual members. Information regarding the RRS can be obtained by writing to:

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Special Issue: Radio Direction Finding

RADIO DIRECTION FINDING: A MANUAL FOR AMATEUR ROCKETRY

by Michael D. Cohan

INTRODUCTION

There are many anecdotes of recovery teams searching after dark with flashlights to find lost rockets. If the payload carries a radio transmitter the rocket will actually "tell" you where it is, if you are equipped to listen for it. Radio Direction Finding (RDF) is an easy skill to learn, and the hardware is usually not very costly. In recent years the amateur radio community has developed RDF into a competitive sport, called "Foxhunting" in which a transmitter is deliberately hidden and RDF teams try to see which of them can find the "Bunny" in the shortest time. This competition has led to the application of considerable ingenuity in the development of affordable, home-built RDF hardware. Amateur rocketry is thus in an excellent position to benefit from the accomplishments of our friends in amateur radio.

The people involved in amateur rocketry are in general an intelligent and inquisitive group yet many of them seem unwilling to explore the field of electronics. Perhaps this is because electronics appears so daunting with its heavy reliance on unfamiliar acronyms and jargon. Many authors of electronics publications seem unable to convey their knowledge in a manner understandable to the novice. And some of the so called "introductory" books barely gloss over the basics before getting into subjects requiring much more background than they have provided. Unfortunately this manual is not the proper venue to attempt to remedy this situation. Nevertheless it has been written with the novice in mind. Anyone who is interested in RDF and wishes to acquire the minimal background necessary to utilize this manual is urged to purchase a copy of "Basic Electronics" by McWhorter and Evans or "Understanding Electronics" by R. H. Warring. They are both well written and thorough introductions to the field. "Basic Electronics" is a self-teaching manual with exercises at the end of each chapter. It does emphasize the mathematical aspects of electronics which is actually an advantage. The calculations involved are basic algebra and far less complex than those involved in rocket propulsion or trajectory calculations. The book also contains a glossary and helpful appendices.

HISTORICAL BACKGROUND AND USES OF RDF

The use of directional antennas to find radio transmitter locations began around the turn of the 20th Century. The first practical application of RDF was for plotting the position of ships based on bearings taken from known land-based broadcast stations. Marconi was the first to patent such a system. In World War I the British Navy successfully tracked the movements of the German fleet with coastal RDF stations. The British victory at the battle of Jutland was enabled by intelligence from RDF tracking of the German fleet. Following that war RDF became commonplace on military and merchant vessels. In the mid-1920's the Federal Communications Commission (FCC) began using RDF as an enforcement tool to locate illegal transmitters. Other law enforcement agencies now use RDF for surveillance and tracking in criminal investigations, hostage situations, and kidnappings. At the outbreak of World War II RDF was an established part of the intelligence services of all the combatant nations. In the U.S. civilian Ham radio operators were forbidden to use their transmitters, but many of them participated in the war effort by assisting the Radio Intelligence Division of the FCC with its RDF monitoring. The military use of RDF continues to the present with tactical level equipment built into tanks and other vehicles, and strategic level RDF from aircraft and satellites. All U.S. military aircraft, commercial flights, and many private aircraft now carry Emergency Locator Transmitters (ELT's) which provide radio beacon signals to aid in finding downed aircraft by RDF. Pocket sized ELT's are also carried by skiers and other back-country enthusiasts. RDF equipment is thus part of most search-and-rescue teams' gear. The marine use of RDF is no longer confined to large merchant and military vessels. Advances in technology have made small, efficient RDF units available for pleasure craft as well. The lifeboats of military and commercial vessels are equipped with ELT's for rescue operations by RDF. The science of zoology and the field of wildlife management have both benefited greatly from the introduction of ultraminiature tracking transmitters (radio beacons). RDF is now very commonly used to track animal migrations, establish predator territories, and to keep track of study subjects. Marine fauna such as giant sea turtles and whales are also studied using RDF. In the early 1950's mobile transceivers became popular in amateur radio and at that time RDF as a sport was launched, although the available equipment was still crude. The sport of Foxhunting is now international with established rules and prizes awarded to the winning teams. Improvements in radio and electronics technology have enabled the design of some highly sophisticated and compact RDF equipment for civilian use. Today's Hams have developed RDF equipment with motor driven antenna arrays and computer readouts.

RULES AND REGULATIONS

Anyone can purchase and operate RDF equipment without a license, but the FCC has very strict rules and very stiff penalties concerning the operation of radio transmitters. Furthermore since the use of "tracking transmitters" or radio beacons for illegal personal surveillance has been increasing there have been some crackdowns on the manufacturers and users of these devices. Thus anyone who intends to use a radio beacon in a rocket must be aware of, and comply with, all applicable laws. Several of the transmitters shown in this manual may only be used by licensed amateur radio operators. The FCC has made it easier to obtain an entry-level license, and the Morse code requirement has been dropped. Anyone who is willing to read an informative, well-written and non-technical book, then devote a few hours to studying and taking some practice exams can easily get a license. An added benefit is that you will learn a little basic electronics and radio theory along the way. The total cost, including the book and exam fee will be less than $50.00. Your participation in amateur radio, at any level, can only strengthen their ranks, and benefit amateur rocketry as well. Once licensed you can also explore the possibilities of tracking systems and data telemetry with high performance equipment. Begin by contacting a Ham radio club in your area. Without exception these people are friendly and helpful. In Ham radio parlance someone who helps a newcomer is called an "Elmer" which is a highly regarded title. If you have difficulty finding a club contact the American Radio Relay League (ARRL) at 1-800-32NEWHAM and they will provide a list of contacts.

Not all radio beacons require a license to operate. FCC Regulations Part 15 Subsections 15.116 through 15.141 define the conditions under which unlicensed transmitters may be operated. The essentials of this regulation are that unlicensed transmitters may not have an output greater than 100 mW, and that antenna lengths may not exceed 36 inches. Low power FM broadcast band transmitters which comply with these regulations can have an effective range on the ground up to 1/2 mile and more than 4 miles in the air. A more detailed discussion of transmitters and their characteristics is contained in a subsequent section of this manual.

GETTING STARTED

There is only one book in print on RDF, "Transmitter Hunting" by Moell and Curlee. It is written with the assumption that the reader has some background in amateur radio, and the majority of its contents dwell on the Foxhunting aspects of RDF. Nevertheless the first several chapters do contain much useful information on the basics of theory, technique, and equipment. Some of the later chapters also discuss technique in conjunction with particular types of equipment. There are numerous detailed plans for various types of RDF antennas and circuits. It is well worth the investment. The monthly magazine "73 Amateur Radio" has a column called *Homing In* devoted to RDF, but its content will vary from anecdotes about some Foxhunt in Europe to construction plans for RDF equipment. It is worth browsing at a newsstand or library.

The Internet has literally hundreds of sites devoted to RDF. A good starting point with links to many of the best RDF sites is maintained by Joe Moell at http://members.aol.com/homingin If you are seriously interested in learning about RDF from the resources on the Web be prepared to spend many hours exploring the wealth of material available.

An excellent way to learn about RDF is to observe or participate in a Foxhunt with a local amateur radio club. These people have considerable experience and will have developed equipment and techniques that will not be found in any book. Be forewarned that much of the equipment and techniques you will see are far more complex than will be needed to track and locate a rocket. Keep in mind that Foxhunt transmitters are deliberately hidden, and that these events are usually not held in flat, open country like rocket launches.

Finally, you can purchase an inexpensive RDF kit and a radio beacon kit and learn with them the old fashioned way, trial and error. There are several simple, inexpensive RDF units and radio beacons shown in this manual which would be suitable as entry-level equipment. Most of these kits and scratch-built devices can be completed in an evenings' work. Some of these basic units would be all that is needed for rocket recovery in the typical open country in which most launches are held.

DO IT YOURSELF

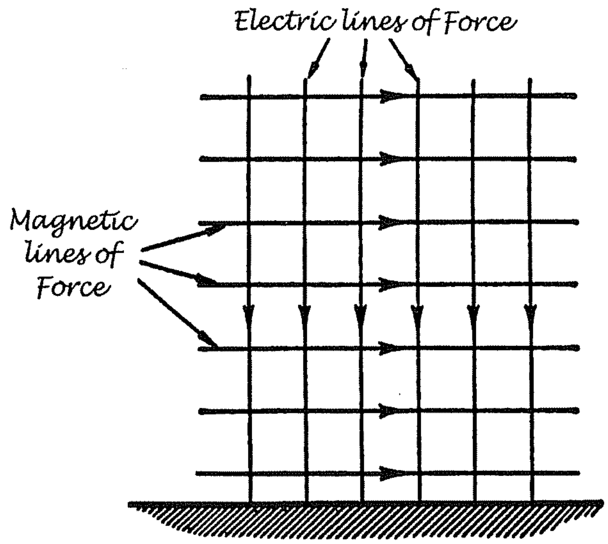
There is nothing magical about constructing electronics devices, either from kits or by scratch-building. All that is required are a few small tools, a low wattage pencil-type soldering iron, and a little patience. The trick is to tackle projects commensurate with your experience so that you will not become frustrated and give up. The kits and scratch-built devices in this manual are rated according to their level of difficulty. Skill Level 1 is for beginners. If you have never attempted to assemble electronics before a kit will be easier to build than a scratch-built circuit. Skill Level 2 is intermediate, although none of the projects are too difficult for a beginner who has built a few kits and has good mechanical skills. Skill Level 3 is for advanced, highly experienced electronics hobbyists, or they are projects which require specialized equipment. If you have no experience with electronics construction see Appendix A - Soldering, for some help getting started.

BASIC THEORY

Radio waves and antennas have been studied extensively, and they are the subjects of many highly technical publications. Some understanding of the basics is essential to successful RDF. The intention here is to provide sufficient background for newcomers to get started in the field.

RADIO WAVES

Radio waves are in the lower frequency range of the electromagnetic spectrum. The characteristics of radio waves are therefore defined by the same principles as infrared, visible light, ultraviolet, x-rays and gamma rays. Electromagnetic energy consists of electric and magnetic components between which the energy oscillates. Propagation of an electromagnetic field is perpendicular to the electric and magnetic lines of force. Radio frequency (RF) waves can be reflected, refracted, and diffracted in the same way as visible light. A radio wave can bounce off a large object (reflection), or it can be bent by passing over (refraction), or around (diffraction) an object. These phenomena can result in *multipath reception* where the signal will arrive from multiple directions, and at differing times. The *dielectric* is a non-conductive material through which electromagnetic energy propagates. In the case of radio waves the dielectric is air, and the properties of the air (dielectric constant) will have an effect on the propagation of the radio waves. An RF signal will be slowed by the moist air above a body of water. It is therefore possible for a direct signal which has passed over a body of water to arrive later than an indirect signal which has been reflected off a hillside. These characteristics of radio waves have been known to confound many RDF users. The *ground wave* is that portion of a radio signal which travels nearest to, and parallel with the earth's surface. The lower portion of the ground wave is distorted and attenuated by its



The electric and magnetic fields of a vertically polarized ground wave. The arrows show the directions of the fields for a plane wave viewed from its front. Reversal of the directions occurs at each half cycle of the frequency of the wave. A *plane wave* is one which has radiated far enough from its source to appear flat at the wavefront. The direction of travel of a radio wave is always perpendicular to its wavefront. In this illustration the wave is moving towards the reader.

contact with the surface. Ground wave propagation becomes less efficient as frequency increases. Direct waves are propagated in a straight line from the signal source. This is also called *line-of-sight (LOS)* propagation. Direct waves are most efficient at higher frequencies and do not suffer from attenuation or distortion by the earth. LOS propagation therefore has much greater range than ground waves. Sounding rockets provide an excellent opportunity to take advantage of LOS propagation.

The frequency (*f*) of a radio wave is defined as the number of cycles per second (Hertz) at which its fields oscillate. The wavelength (λ *lambda*) is the distance between two corresponding peaks of the wave. The relationship of frequency versus wavelength is defined by the following equations:

$$f = \frac{300{,}000}{\lambda} \quad \text{and} \quad \lambda = \frac{300{,}000}{f}$$

where f is expressed in kilohertz and λ is in meters, or

$$f = \frac{984{,}000}{\lambda} \quad \text{and} \quad \lambda = \frac{984{,}000}{f}$$

where f is expressed in kilohertz and λ is in feet.

Thus the wavelength of a commercial FM radio signal at 100 megahertz (100,000 kilohertz) is 3.00 meters, or 9.84 feet. This relationship will be important later in calculating the appropriate lengths of antennas.

ANTENNAS

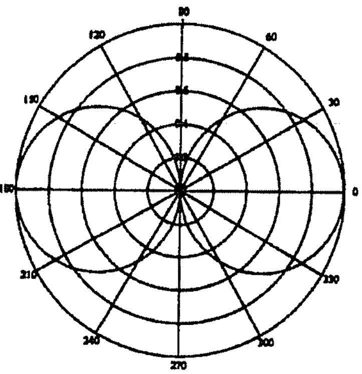
In order to function efficiently an antenna must be more than a metal rod of indeterminate length. Antenna engineering is a recognized subspecialty of electrical engineering and there are many professionals who have devoted their entire careers to the design of antenna systems. Always keep in mind that the performance of any antenna is determined by the accuracy used in calculating its dimensions, and the precision applied to its construction and tuning.

In a radio communications system an antenna is that component which converts a received signal to an electrical current or radiates a transmitted signal by converting an alternating current into radio waves. The *Reciprocity Theorem of Antennas* tells us that other factors being equal any antenna can function with equal efficiency in a transmitter or receiver application. The range obtained with a transmitter is a function of (in order of importance): Antenna design, path of propagation, topographical or man-made obstructions, signal interference, and transmitter output. That antenna design is first, and transmitter output is last is a surprise to many. Experience has shown that good antennas are far more effective than brute force, and increasing transmitter power to achieve greater range is always the least efficient method. The steps to increase the efficiency of a transmitter/receiver system, in order of priority are: Use a higher gain receiver antenna, add a low-noise preamp to the receiver, increase the height of the receiver or transmitter antenna above ground, use a more efficient transmitter antenna, increase transmitter power. The practical application of some of these principles will be addressed in subsequent sections.

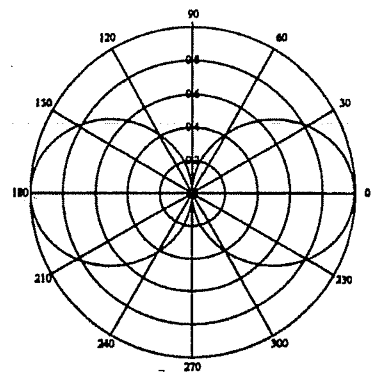
An antenna which is operating at its maximum efficiency is said to be *resonant.* Resonance is a function of the relationship of the antenna's *radiation resistance* to its *terminal impedance*. Radiation resistance is the ability of an antenna to radiate an applied signal into free space or to receive a signal from free space. In a transmitter it is a measure of the power radiated into free space for a given input current at the antenna terminal. The terminal impedance is the opposition offered by an antenna at its terminal to the flow of current. The symbol for impedance is *Z* and it is expressed in ohms. Resonance is achieved when the radiation resistance and terminal impedance are equal. Radiation resistance is length dependent. For a quarter-wave monopole (see below) it is 37 ohms. Calculating the dimensions of an antenna to achieve resonance is a complicated process. In practice the physical length of a resonant antenna is shorter than its theoretical electrical length by a factor, *K*, based on the antenna type and its length/cross section area ratio, and radiation resistance. It is much easier to accomplish resonance empirically by "pruning" or removing small increments from the end of the antenna until maximum range is obtained.

There are many types of antennas. The monopole, a.k.a. single-wire or whip antenna, consists of a single element the length of which is determined by its operating frequency. The theoretical resonant length of a quarter-wave monopole antenna is $1/4\lambda=246/f(MHz)$ in feet or $2952/f(MHz)$ in inches. When the calculation is adjusted for *K* the formula for a quarter-wave monopole becomes $1/4\lambda=2808/f(MHz)$ in inches. From these formulas it is apparent that a transmitter operating at a higher frequency will require a shorter antenna. Monopole antennas are highly efficient and easy to construct. The drawbacks are that they are often too large for rocket payloads, and they are more susceptible to the parasitic effects of nearby metallic objects than other types of antennas. A dipole antenna consists of two elements which are 180 degrees out of phase. The lengths of the elements of a dipole are calculated using the same formulas as the monopole. Dipoles are impractical in sounding rockets because of their size, but they are highly efficient and practical for receivers and RDF systems. The helical antenna can be a good compromise for use in sounding rockets. Although not as efficient as a monopole it is much smaller and has higher immunity to parasitics. It consists of one or more elements wrapped in a spiral around a non-conductive form. Calculating the length of the elements, the circumference of the coil and the pitch of the spiral is beyond the scope of this manual. A rocket which utilizes a fiberglass or phenolic payload tube is a perfect candidate for a helical antenna. Helical antennas can be constructed empirically by wrapping a half or quarter wavelength of wire or narrow strip of adhesive metal foil around the payload tube at a pitch of approximately 12 degrees and then pruning it for maximum output. Other types of antennas, such as the loop, cone, and dish are not practical for small sounding rockets although the directivity of loop antennas makes them useful for RDF. The dimensions for a 2-Meter loop antenna are given in the RDF Equipment section.

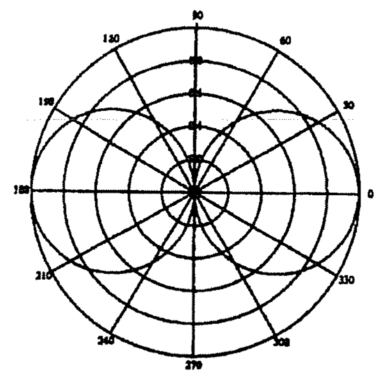
The efficiency of the various types of antennas is called *antenna gain.* This is the ratio of the antenna's performance relative to a standardized reference antenna, usually a dipole. The unit of gain is the *decibel (dB)* or 0.1 Bel. One Bel (named for Alexander Graham Bell) is equivalent to a power gain of 10 and a decibel is a power gain of 1. The decibel is equal to $10log10Po/Pi$ where *Po* is output power and *Pi* is input power. The *effective radiated power (ERP)* of a transmitter/antenna system is the output of the transmitter in Watts multiplied by the antenna gain in decibels. Thus a 100 mW transmitter which uses a +5 dB gain antenna can have an ERP of 1/2 Watt. Inefficient antennas can have a signal loss which is



Monopole



Dipole



Helical

expressed in negative decibels, e.g. -5 dB.

The orientation and alignment of the antennas in a communications system will also affect efficiency. Antenna types all have their own radiation pattern in the three-dimensional space surrounding them. The theoretical radiation patterns for a $1/4\lambda$ monopole, a $1/2\lambda$ dipole, and a $1/4\lambda$ helical antenna in their x-y axis are illustrated below.

The x-z axis (3rd dimension, coming up from the paper) is a torus pattern which wraps around the length of the antenna. The lobes of these radiation patterns indicate energy peaks (lobe maximums) and nulls (lobe minimums). From this it can be seen that the most efficient communications system will be one in which the transmitter and receiver antennas are oriented such that their radiation patterns (lobe maximums) are aligned. It should also be noted from the radiation pattern illustrations that the monopole is the least directional. An isotropic antenna is omni-directional; i.e. it will transmit or receive equally in all directions regardless of its orientation. The ideal isotropic antenna would be a metal sphere with a transmitter at its center. Since this is a practical impossibility any omni-directional antenna will be less than ideal. In a sounding rocket the transmitter antenna needs to be as nearly isotropic as possible since the orientation of the vehicle (and the antenna) will change during flight and recovery. Thus the transmitter antenna must radiate efficiently in any number of possible directions to be received by a ground station. Monopole and helical antennas are omni-directional. Unlike ordinary receiver antennas, RDF system antennas need to have a vertical orientation and be directional in their design or made to function in a directional manner by electronic circuitry in order to indicate the received energy peaks and nulls, and thereby the direction of the transmitter. The radiation patterns also show that the energy is distributed equally in opposite directions, i.e. at any two points 180 degrees apart. This is the origin of the *180 degree ambiguity* which is characteristic of most RDF systems. Without altering the antenna form or the electronics of the RDF/receiver system it is impossible to determine whether the radio wave peaks or nulls are directly in front of or directly behind the receiver. Some RDF units include antenna modifiers, a.k.a. sense antennas, transmission line modifiers, a.k.a. delay lines, or special circuit designs to compensate for the 180 degree ambiguity. Examples of these are discussed in the RDF Equipment section of this manual.

The best method for connecting an antenna to a transmitter is simply to solder the antenna directly to the RF output terminal of the transmitter PC board. While the output impedance of the transmitter, typically 50 ohms, may not equal the terminal impedance of the antenna the signal loss from this impedance mismatch will be minimal. When the antenna must be mounted remotely from the transmitter and connected by wire this will compound the signal loss. The *standing wave ratio (SWR)* is a measure of the relationship between the amount of power traveling to the antenna and the power reflected back to the transmitter. The standing wave is the stationary distribution of power along a line. It is characterized by maximum amplitude points (loops) and minimum amplitude or zero points (nodes). The SWR between the voltage or current at the loops and nodes will be 1:1 in a perfectly matched antenna. The SWR will be less than 1:1 when there is an excessive amount of signal reflected back to the transmitter. This reflection is caused by impedance mismatches in the antenna system. To correct this the impedances of the transmitter, connecting wire, and antenna need to be matched. The connecting wire, called a *transmission line or feed line,* should be the shortest possible length of coaxial (or simply coax) cable which has an impedance of 50 ohms. For the space and weight considerations in a sounding rocket Type RG-174/U coax is preferred. Matching the impedance of the transmission line to the antenna will require the addition of an inductor/capacitor (L/C) circuit and tuning with an SWR meter for optimum performance. These are tasks best left to someone with experience. In many cases a transmitter and its antenna system will perform adequately even when there is significant standing wave loss.

Many RDF units employ two dipole antennas spaced apart on a boom. Ideally the distance between the antenna elements is equal to the sum of their lengths, e.g. $1/2\lambda$ apart for $1/4\lambda$ antennas. At that spacing the RDF unit will be most sensitive.

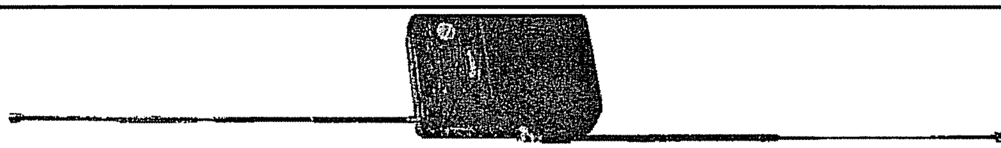
In practice is it actually better to use a boom that is about 5-10% less than $1/4\lambda$. A 17.25 or 17.5 inch boom is perfect for the $1/4\lambda$ 2-Meter dipole antennas of most of the RDF units in this manual. In addition to being easier to use and much more portable the closer element spacing will provide immunity to multipath signal errors with only slight loss of overall sensitivity.

RDF SYSTEMS

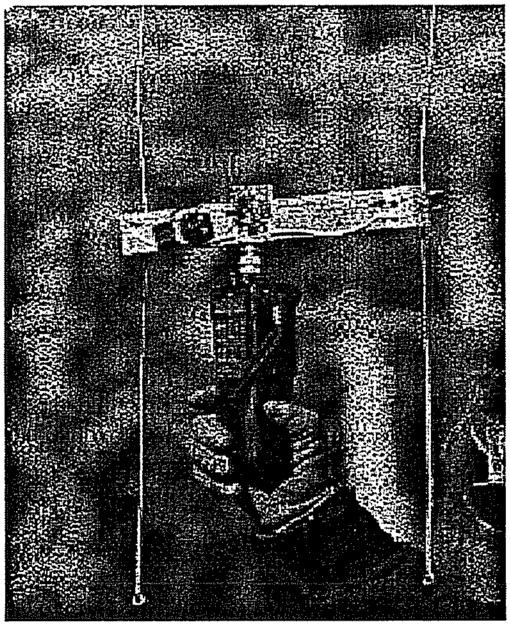
The directional antenna RDF system operates on the principle that a received signal will be stronger in the direction from which it originates. A directional antenna can be a loop, a dipole, a quad, or an array of elements on a beam (Yagi antenna). As outlined above, the dimensions of the antenna are determined by the radio frequency for which the system is intended. The directional antenna RDF is usually used with a receiver which has a built-in signal strength meter or LED bar graph signal strength indicator. It can also be used with headphones although this is a much less accurate method. This is the simplest form of RDF. They are highly sensitive, easy to use, and usually inexpensive. These units lack the accuracy of the other two types and they have a 180 degree ambiguity. They are especially useful for finding weak signals over long distances of open country, thus this type of RDF may be particularly suited for finding rockets on the ground.

The Time Difference of Arrival (TDOA) finder utilizes two antennas and a circuit which switches back and forth between them. They operate on the principle that when the antennas are slightly differing distances from the signal source there will be a detectable time delay between the signal's arrival at each antenna. When both antennas are receiving the strongest signal at the same time, and thus the unit is pointing perpendicular to the source, a null readout is obtained. The null indicator is usually an audible signal, although signal strength meters are sometimes included. TDOA units are usually small, inexpensive and accurate to within one degree. They also have the 180 degree ambiguity, but some of them can be modified to remedy this deficiency.

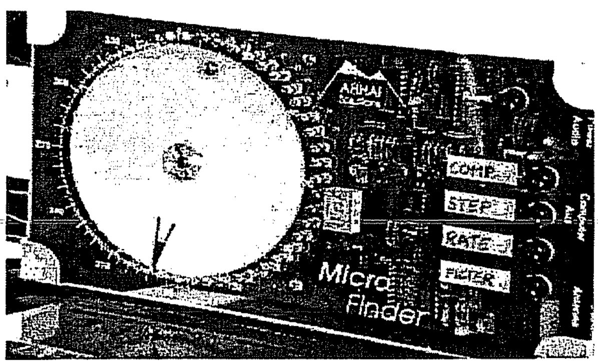
A Doppler RDF operates on the phase shift between two or more antennas. The Doppler effect is the apparent signal frequency change resulting from the relative motion between a signal source and a receiver. When the operator rotates a Doppler RDF antenna from side to side each of its ele-



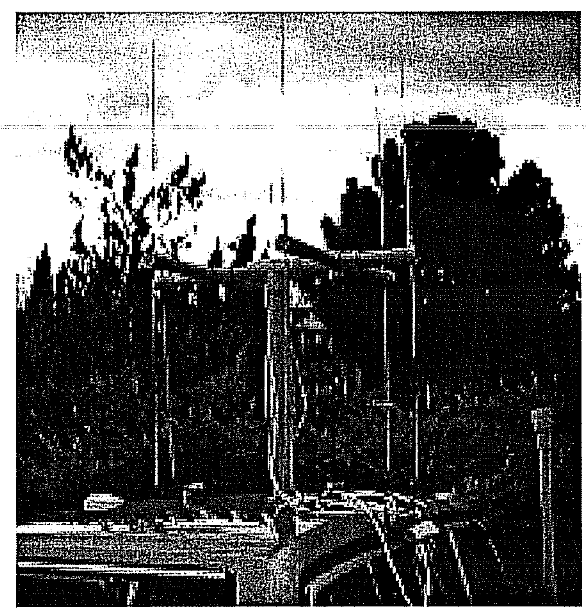
This is an inexpensive FM radio which has been converted to a directional antenna RDF unit by the addition of a collapsible whip antenna. Instructions for building it are contained in the next chapter.



Prototype of the "555 RDF" designed by Joe Leggio, WB2HOL. The unit is mounted directly onto the antenna connector of a scanner radio. Complete plans for building an upgraded version, dubbed the "Sawbuck RDF" are shown in the following chapter.



The MicroFinder Doppler RDF kit by AHHA! Solutions is a sophisticated, high-performance unit. It is designed for vehicular use and mounts easily on the dashboard.



A typical Doppler antenna array. This is a six element vertical dipole. Other types of antennas used with Doppler systems include multiple element ground planes and quads.

ments will go in phase then out of phase with the signal. The null point in the middle will be the direction of the transmitter. Doppler units are much more complex, and therefore more expensive, than directional antennas and TDOA RDF. Because of the size of their antennas Dopplers are usually intended for vehicular use, while the other two types can be either hand held or vehicle mounted.

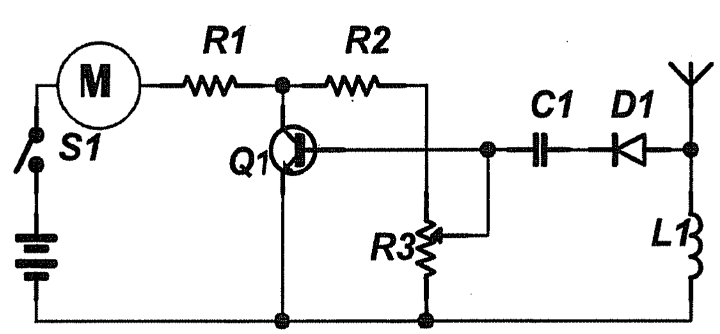
RDF EQUIPMENT

There are many devices available for RDF, costing from around $40.00 for some of the kits, to hundreds of dollars for highly sophisticated units. There is even one manufacturer who has designed RDF systems which are marketed specifically for rocket retrieval and which they sell for more than $450.00 at the lower end, and over $900.00 for their high end system! Don't waste your money. Anyone can assemble a kit, add it to an ordinary portable scanner radio and have a system of equal performance to their best unit. And if you find kit building enjoyable you can save even more by assembling your own receiver. There is a superb little 2-Meter band receiver kit available from Gateway Electronics, KIT-008, for $34.95. For an additional $14.95 a very convenient, predrilled case is also available. This receiver, a set of headphones and a scratch-built directional antenna would be the least expensive, home-built system. The rig is lightweight, fully portable, and operates from a 9 volt battery. It would be an excellent kit for beginners in electronics. And for those who don't enjoy soldering components onto printed circuit boards on cold Winter nights there are some reasonably priced off-the-shelf RDF units and receivers.

DIRECTIONAL ANTENNAS

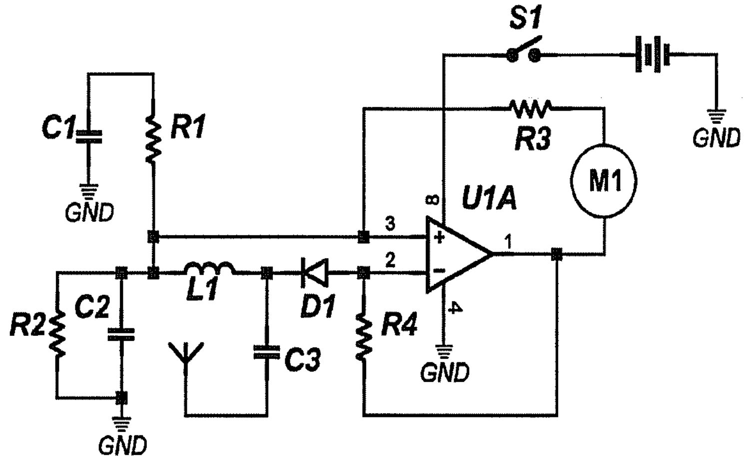
SIMPLE RF SNIFFER (Skill Level 1)

When the search gets close to the radio beacon it is possible that the RDF unit and receiver will be "swamped" by a strong signal. Built-in or add-on signal attenuators can be used to correct this problem. Foxhunters will often switch to using a simple RF detector or "Sniffer" when they are close to the hidden transmitter. These devices consist of a directional antenna, a radio frequency rectifier and an amplified signal strength meter. Because of their size and the fact that they are not deliberately hidden it is not often that a sniffer will be needed to find a rocket. Nevertheless it is a handy piece of equipment to have in the event that the rocket is obscured from view by vegetation or small topographic features. Something that should be mentioned is that these devices are not only handy for finding transmitters at close range, they are useful tools for tuning and adjusting transmitter/antenna systems for maximum performance. Of course much greater precision in tuning transmitters can be achieved with more specialized equipment such as spectrum analyzers, grid dip meters and SWR meters, but a basic RF detector with a meter readout like this one is



PARTS LIST:
Q1 - 2N2222 NPN Transistor
D1 - 1N60 Germanium Diode
R1 - 1 Meg 1/4W 5% Resistor
R2 - 22 K 1/4W 5% Resistor
R3 - 100 K Potentiometer
C1 - .01 uF Ceramic Capacitor
L1 - 470 uH RF Choke
S1 - SPST Switch
M - 0-200 uA DC Meter

Circuit Notes: If a bargain-priced meter is obtained from one of the surplus catalogs this little device could be built for less than $5.00. The circuit is pre-tuned (according to the values of C1 and L1) for the FM Broadcast band. The antenna does not need to be any more than a 5 to 20 inch length of solid copper wire. It is easily built on a small proto-board and there is nothing critical about component placement. Power can be from any 3 to 6 volt DC source. A LED and suitable voltage dropping resistor can be added for power-on indication if desired.



Parts List:

U1 - LM1458 IC
D1 - 1N34 or 1N60 Diode
C1 - 0.1 uF Monolithic Capacitor
C2 - 0.1 uF Monolithic Capacitor
C3 - 680 pF NPO Ceramic Capacitor
R1 & R2 - 1K 1/4W Resistor
R3 - 2.2K 1/4W Resistor
R4 - 1 Meg 1/4W Resistor
L1 - 2 mH Molded Choke
S1 - SPST Toggle Switch
M1 - 50 uA DC Meter
ANTENNA - See Circuit Notes
BATTERY - 9 Volt Alkaline

Circuit Notes: This device is simply an amplified field strength meter. It is useful from the low end of the AM broadcast band through the 2-Meter amateur band. Security electronics companies sell similar units as "bug detectors" for hundreds of dollars. RF detectors are not suitable for primary RDF as they cannot detect weak signals at all or even good signals over any distance. A 1 Watt transmitter will be difficult to "sniff out" at more than 50 yards with this unit. The antenna can be any collapsible whip type, such as Radio Shack Part #270-1405. The entire circuit will fit easily onto a small piece of perfboard or a PC proto board (Radio Shack #276-159). A plastic case should be used as the enclosure to avoid any metal contact with the user's hands. Greater sensitivity can be achieved at any specific frequency range with a dipole or Yagi antenna of the correct dimensions in place of the whip. A 25 uA meter will provide more deflection. For convenience a LED and voltage dropping resistor can be added as a power-on indicator.

far less expensive, much easier to use, and fairly efficient. Simply place the device a few feet away from the transmitter and have an assistant watch the meter while you are tweaking coils, adjusting trimmer capacitors or pruning antennas.

HOME-BREW SNIFFER (Skill Level 1)

If one made a concerted effort it would be easy to find dozens of slightly differing circuits for relative field strength meters, a.k.a. RF detectors, or "Sniffers" in various electronics publications. This particular one is about as easy as it gets.

LED READOUT RF DETECTOR (Skill Level 1)

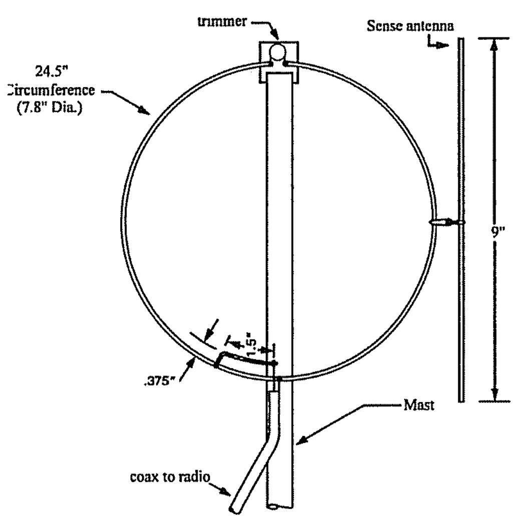
CAVEAT! The author has neither built, nor tested, nor observed this unit in operation. The July, 1999 issue of "Electronics Now" featured an article titled, *"Sniff" Out Transmitters with the RF Informant*, by Rick Duker. The device presented in the article is a wideband receiver which indicates relative signal strength on a series of LED's. A unique feature is that it has an audio (earphones) output as well as the LED readout. It has an amplifier circuit that increases sensitivity on the FM Broadcast Band which merits its inclusion here since there are so many radio beacons available for that band. The instructions in the article are quite clear and it appears that this would be a good first-time project. A camera-ready foil pattern for making PC boards is included. Quantum Research, 17919 77th Ave., Edmonton, AB T5T-2S1 CANADA sells bare PC boards for $10.00, complete kits including the enclosure for $69.95, and fully assembled units for $99.95. Shipping for any of these is $5.00 extra. All of the components and hardware are readily available and inexpensive, and the prices for kits and completed units are out of line. The PC board price is fair, given the amount of effort and equipment necessary to make your own.

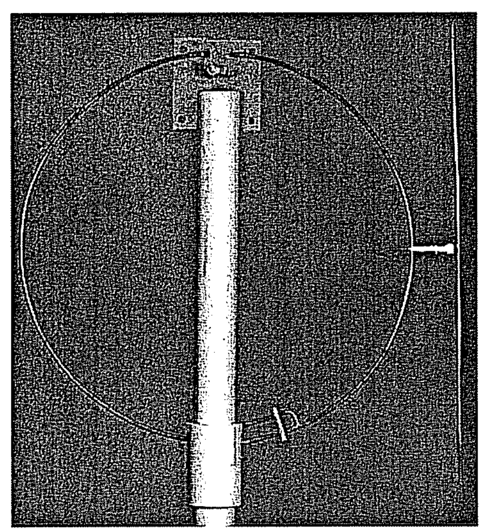
INSTANT RDF (Skill Level 1)

Any portable FM radio which has a whip antenna can be used to demonstrate the principle of RDF. Other receivers which have telescoping whip antennas will work as well. A generic "replacement" antenna purchased from Radio Shack (#270-1406), a small ring terminal, and a machine screw are the only parts needed. Crush the sleeve portion of the terminal so that it will fit tightly into the earphone jack of the FM radio. Attach the antenna to the ring terminal. Insert this assembly into the earphone jack and then point the antenna at 180 degrees from the original antenna in the radio. A heavy rubber band or electrical tape can be used to keep the added antenna in place. Extend both antennas to an equal length. Turn on the radio and tune to a strong station. Hold the unit so that the antennas are horizontal. By slowly rotating the radio from side to side you will discover the strongest reception occurs when the pair of antennas are perpendicular to the direction of the signal source. This rig is surprisingly sensitive and could actually be used in the field. A picture of this unit is shown in the previous chapter.

TWO METER LOOP ANTENNA (Skill Level 1)

The original design for this very inexpensive but highly sensitive RDF loop antenna comes from the book "Transmitter Hunting" by Moell & Curlee. It has been modified slightly to make it more functional and easier to construct. The directional loop antenna is intended for the amateur radio 2-Meter band and will not work well at other frequencies. This design is especially useful for finding weak signals over open territory which is perfect for finding rockets. All that is needed is an ordinary portable scanner receiver with built-in signal strength meter (S meter) or LED bargraph signal strength indicator, and a pair of headphones. It can be used with a receiver and headphones alone but this will result in less sensitivity. Moell's book also has instructions for adding a meter or LED bargraph to various types of receivers. These loop antennas are so easy to construct that several of them can be cranked out in a few hours. Materials will cost less than $5.00 for the basic unit and less than $10.00 for the modified unit shown here. A simple fix for the 180 degree ambiguity is also included in this example.





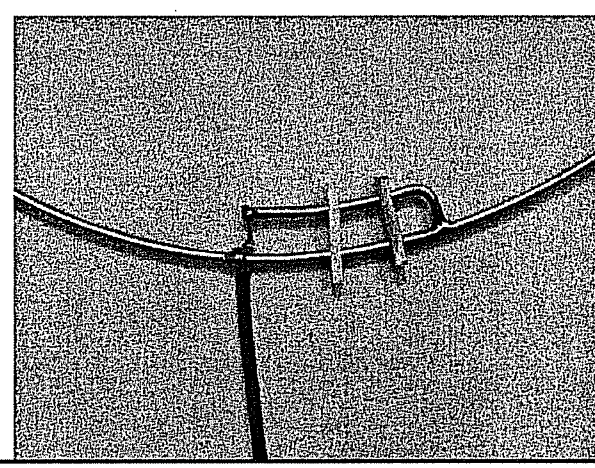
Materials List:

36" Length of 1/2" PVC Pipe
7-1/4" Length of 1/2" PVC Pipe
40" Length of 50 ohm Coax Cable
36" Length of 12 Gauge Solid Copper Wire
1/2" PVC Coupling
Chassis Mount BNC Female Connector
PC Board, Radio Shack #276-159
0-10 pF Piston Trimmer Capacitor
Coax Cable Assembly, Jameco Part #111472
Small Alligator Clip
Bicycle Handlebar Grip & Cap

Construction:

Cut a pair of opposing slots 1/16" wide by 3/4" deep into one end of the 1/2" coupling. Do the same for both ends of the 7-1/4" PVC pipe making sure that the slots are all in line. Solder the trimmer capacitor to the PC board. A piston type capacitor (available from Dan's Parts & Small Kits) is best, but a ceramic trimmer can also be used. Some of the holes on the board may need to be reamed in order to accommodate the capacitor's pins and the thickness of the 12 gauge wire. Glue the PC board into one set of slots in the PVC pipe. Next cut a 24.5" length of 12 gauge wire and remove the insulation. This is the loop wire. Make a mark at exactly the center (12.25") then bend 1/4" of the ends of the wire to matching right angles. Solder the braided shield of the 50 ohm coax at the center mark on the copper wire. Type RG174/U coax is preferred for less weight and working flexibility but any 50 ohm coax will suffice. Now cut a precise 1-7/8" length of 12 gauge wire and bend it to a right angle at 1.5" from one end. This part is called the "gamma match" and together with the trimmer capacitor enables impedance matching of the antenna. Solder the short end of the gamma match onto the longer wire so that its free end will be exactly above the center mark. Solder the center conductor of the coax to the free end of the gamma match making sure that its distance from the loop wire is 0.375" Small spacers made from any non-conductive material will help. Once this assembly is completed insert it into the slots at the lower end of the PVC pipe. Slip the coupling over the coax and glue it into place on the pipe. Curve the ends of the loop wire up to the PC board and insert them into the board 1/2" apart. Solder each end into place then cut off any protruding wire. Apply liberal amounts of epoxy to the coupling slots and the loop wire where it lays across the PC board for greater stability. After it has dried place this assembly on top of the 36" PVC pipe (mast). DO NOT use glue. Slip the handlebar grip over the lower end of the mast. Now trim down the diameter of the handlebar cap to fit inside the mast. Drill a 3/8" hole into the cap and attach the BNC connector and solder the coax to the connector. Glue the cap into place in the mast. The coax is slightly longer than the mast so that the loop assembly can be removed from the mast and folded down for more convenient storage. Straighten the remaining piece of 12 gauge copper wire and cut it to exactly 9" Solder it onto the end of the alligator clip at its midpoint (4.5"). This is the "sense antenna" which is used to correct for the 180 degree ambiguity. Use the Coax Cable Assembly to connect the unit to the receiver. The capacitor needs to be tuned for maximum performance. Use a plastic tuning tool, available from Radio Shack and most other electronics suppliers. Tune the receiver to a relatively strong station and rotate the loop so that it is end-on toward the signal, then slowly adjust the capacitor 1/4 turn at a time for maximum signal reception.

The photo shows a close-up of the gamma match and its attachment to the coax feed line. The spacers are made from 5/16" x 9/16" PVC sheet, 1/8"



RADIO ENGINEERS TYPE 2-MQ PORTA-QUAD

Directional quad antennas are usually big and bulky. Their use is thus restricted to mounting on top of a vehicle. The Portaquad is a patented design which can be completely collapsed into its 18.5" long by 3.5" dia. mast for storage. It can be erected in less than a minute. If the vehicle on which it is mounted will remain stationary the antenna can be rotated manually, or the vehicle can be driven in an increasingly tight search pattern to find the transmitter. The Portaquad is designed for use from 144-148 MHz (2-Meter band) and provides a gain of +8 dB. It can be used with a scanner radio or any other receiver which has a signal strength indicator. The Portaquad would be an ideal antenna to mount on a mast on top of the launch control facility with some means of rotating it from inside the shelter. The cost is $89.95 + $5.00 shipping.

ARROW 146 SERIES ANTENNAS

Several ingenious 3 and 4 element Yagi directional antennas are manufactured by Arrow. The 146 Series are designed for the 2-Meter band. Two models of them are used by the FAA for ELT searches. The largest, Model 146-4 is a 4 element beam which collapses into a 4 ft. long walking stick for convenience. Model 146-4BP is also a 4 element beam which will fold down to about 20" for easy storage and transportation. The Arrow II Model 146-3 is a small, hand held, 3-element antenna weighing only 15 oz. Prices are $79.00 for the 146-4, $89.00 for the 146-4BP and $49.00 for the 146-3. These are among the highest quality, easiest to use, ready-to-go antennas currently on the market. They can be used with any receiver which has a signal strength indicator.

WALSTON TRX SERIES

This equipment is a series of receivers which have built-in LED bargraphs (TRX-3S & TRX-16S) and S meters (TRX-64S & TRX-200S) which is being marketed to the High Power Rocketry and Model Rocketry communities. Prices start at $399.00 for the TRX-3S, $499.00 for the TRX-16S, $662.00 for the TRX-64S, and go up to $839.00 for the TRX-1000S. The escalating prices are based on the units' ability to receive 3, 16, 64 and 200 channels respectively. Radio Shack sells a 1000 channel scanner radio for $199.95. If a headphone jack is desired on the Walston TRX-16S this costs $39.00 extra (for a 29 cent part!). The directional antennas are not included in the base price. Two models of Yagi antennas, a rigid 3-element beam, and a collapsible 3-element beam, cost $79.00 or $99.00. Much better quality antennas can be had from Arrow or Ramsey for less cost.

RAMSEY YAGI ANTENNAS

Ramsey Electronics has recently begun production of three models of Yagi antennas designed by Joe Reisert, W1JR, who is a leading authority in VHF amateur radio. Ramsey claims that these are the finest small Yagi's on the market, and they could well be right. The designer has included a ferrite sleeve balun and sealed feed point coax which insure near perfect impedance matching at 50 ohms, and virtually no coax radiation loss. The antennas are sold as kits which are easily constructed in about 15 minutes. There is no

Model	Elements	Gain	F/B Ratio	Length	Frequency	Price
140-3	3	5 dB min.	20 dB min.	36"	140-300 MHz	$59.95
400-4	4	7 dB min.	15 dB min.	24"	300-500 MHz	$59.95
918-4	4	7 dB min.	14 dB min.	14.5"	902-928 MHz	$99.95

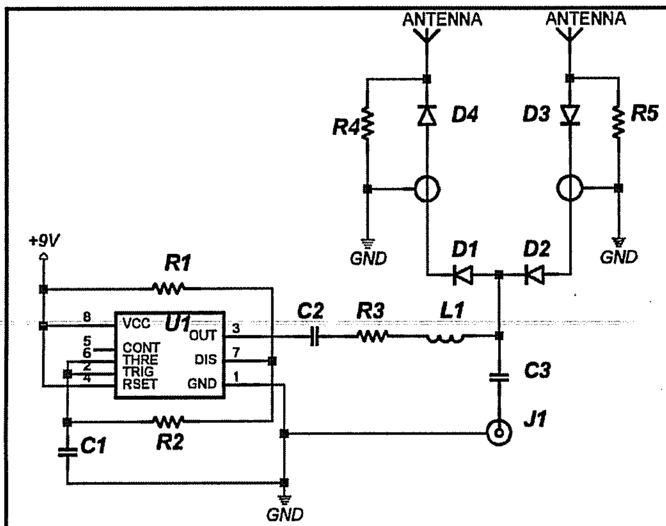
TIME DIFFERENCE OF ARRIVAL RDF UNITS

RAMSEY DF-1 FOXHOUND (Skill Level 2)

The Foxhound is available as a kit for $59.99 plus shipping. It has excellent sensitivity and accuracy, and uses a meter and two LED's to indicate direction. Antenna switching is accomplished with PIN diodes. The manufacturer claims it is compatible with any receiver although the antennas and boom dimensions are based on 2 meters. Unfortunately it also has the 180 deg. ambiguity and at present no one has published a fix for this unit. The kit consists only of the PC board and electronic components. A case in which to mount it, the antenna boom, and power source are left to the builder. This will increase the total cost to around $70.00. The Foxhound is considerably bulkier than other units and is not nearly as popular among the amateur radio RDF enthusiasts as the HANDI-Finder & Debco DF-1005 (see below). There have been reports of bugs in the circuit which require post-assembly fixes.

SAWBUCK RDF (Skill Level 1)

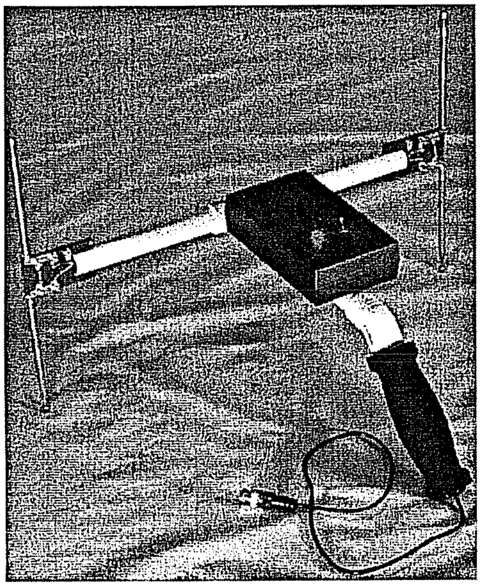
It doesn't get any easier than this. The unit is so named because it can be built for less than a ten-dollar bill. Obviously this simple circuit will not provide the performance of more complex and expensive units, but it is quite functional and reliable. This is an excellent entry-level unit with which to learn the skills of RDF. Depending upon the terrain of the launch site and the type of radio beacon employed this little rig may be all that is needed for many rocket recovery operations. It is so inexpensive and easy to build that several of them could be distributed among the members of a field team to enable quick triangulation and much faster rocket recovery.



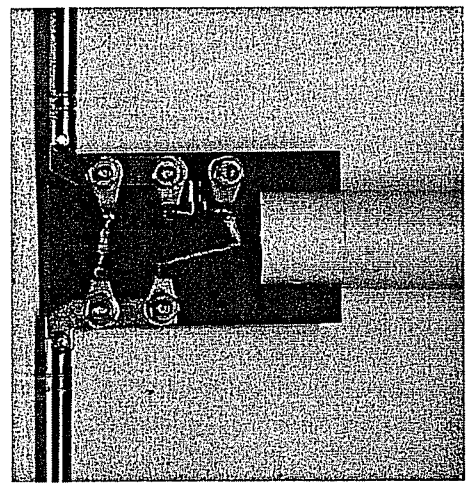
Parts List:

R1 & R3 - 1K 1/4W 1% Metal Film Resistor
R2 - 33K 1/4W 1% Metal Film Resistor
R4 & R5 - 820 ohm 1/4W 1% Resistor
C1 - .047 uF Monolithic Capacitor
C2 - 47 uF Electrolytic Capacitor
C3 - 470 pF Ceramic Capacitor
U1 - NE555 IC
D1, D2, D3, D4 - 1N4007 Diode
L1 - See Circuit Notes
J1 - Female BNC Connector
ANTENNAS - See Circuit Notes
MISC - 50 ohm Coax Cable, Circuit Board (Radio Shack #276-159), 9V Battery Snap, 9V Battery Holder, Assorted Hardware

Circuit Notes: The 1% resistors are specified for their low noise and low drift characteristics. Five percent carbon film resistors will function quite well in this circuit. L1 is 10 turns of #24 magnet wire (enameled wire) close wound on a 1/8" non-conductive core. The diodes MUST be 1N4007 because they are the only ones in the 4000 series with an internal PIN structure which is essential for the efficient switching of RF signals. PIN diodes, e.g. MPN3404 available from Dan's Small Parts & Kits, will improve performance slightly, but they are much more costly than the 1N4007. The antennas must all be exactly 19 inches in length and can be made from any metal rod. Collapsible whip antennas (Radio Shack # 270-1409) will make the unit easier to store and transport although they will add considerably to the cost. The prototype used coat hanger wire, but copper clad brazing rod, or thin aluminum rod will work as well. The boom is made from a 17.5" length of any non-conductive material. The original design used a piece of wood although a 1" wide strip of plastic or length of 1/2" PVC pipe is more convenient. The length of the coax cables from the circuit board to the antennas is not critical, but both cables must be cut exactly the same. If these cables differ in length this will introduce significant error into the response of the unit. While designed for 2 Meters the Sawbuck RDF is easily modified for use on the FM broadcast band by lengthening the antenna elements and boom. See Part 2 - Basic Theory for calculating the antenna element and boom lengths. With a little ingenuity a delay line can be added to correct for the 180 degree ambiguity (See Debco DF-1005 below).



The author splurged when building his test model of the Sawbuck RDF. The unit was constructed with collapsible antennas. 1/2" PVC pipe was used for the boom, and the PC board and battery are enclosed in a case. A power switch and LED indicator were added. The original design had no handle so one was made from 1/2" PVC pipe and a bicycle handlebar grip slipped onto the bottom for comfort. A 3' coax cable assembly (Jameco #111472) with one of its connectors snipped off is used in place of the BNC connector. Genuine RF diodes (Motorola MPN3404) were used for greater sensitivity. The total cost was still under $25.00 for a very functional, highly sensitive RDF unit.



This is a close-up of one end of the antenna boom. Spacing of the diode and resistor are not critical although they must be exactly the same on both ends of the boom.

DEBCO MODEL DF-1005 & DF SYSTEMS HANDI-FINDER (Skill Levels 1 & 2)

This is a hand-held RDF unit available in kit form for $34.95 plus shipping. It offers the advantages of high sensitivity and accuracy, and low cost. Also it is not frequency dependent and can be used with any receiver including FM broadcast band. The unit sends a 1 KHz audio tone through the receiver and direction is indicated by a null, or disappearance, of this tone. If the receiver has a signal strength indicator this will add slightly to the unit's effectiveness but it is not really necessary. Watching a meter while walking over rough terrain in search of a rocket can be dangerous. The unit has a 180 degree ambiguity but this problem has been addressed by Joe Moell, author of "Transmitter Hunting" and the Homing In column. On his website there are detailed plans for modifying the Debco unit to correct for the 180 deg. ambiguity. The URL is http://members.aol.com/homingin The Debco DF-1005 is a clone of an original design by Bob Leskovek, K8DTS, and sold by him as the Handy Finder. DF Systems now markets another clone, the HANDI-Finder, as a kit for $21.00 postpaid, but unlike the Debco unit the DF Systems kit does not have an antenna boom or case. Adding these to the cost, plus the precise cutting and drilling necessary makes the DF Systems unit somewhat less attractive. Bare PC boards and full instructions for the original Handy Finder are also available from FAR Circuits for $8.50 plus shipping. There are literally thousands of these units in use and they are highly regarded by the amateur radio community. There can be no better recommendation.

ELECTRONIC RAINBOW SDF-1 SEARCHER (Skill Level 1)

The Searcher design is similar to the HANDI-Finder. The complete kit, including case and all components is priced at $44.95 plus shipping.

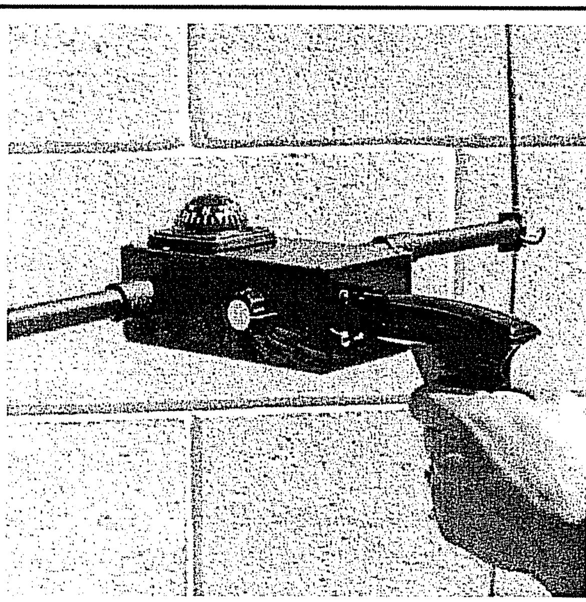
Sensitivity and accuracy are excellent on the 2-Meter amateur band. The unit is advertised for use on any UHF or VHF bands, but in truth it does not perform as well at other frequencies. The antennas and their spacing are based on 2-Meters. This unit also features a tone control to adjust the audio signal for maximum response. It suffers from the 180 deg. ambiguity like other TDOA units, and its case has no provision for a comfortable handle. The fix published for the Debco DF-1005 on the "Homing In" website could be adapted to correct the ambiguity problem. Aside from this it is a very functional and reliable RDF. The instructions supplied with the kit are very understandable and this would be an excellent first-time project. There have been no reports of defects in its design.

RADIO ENGINEERS VECTOR-FINDER SERIES

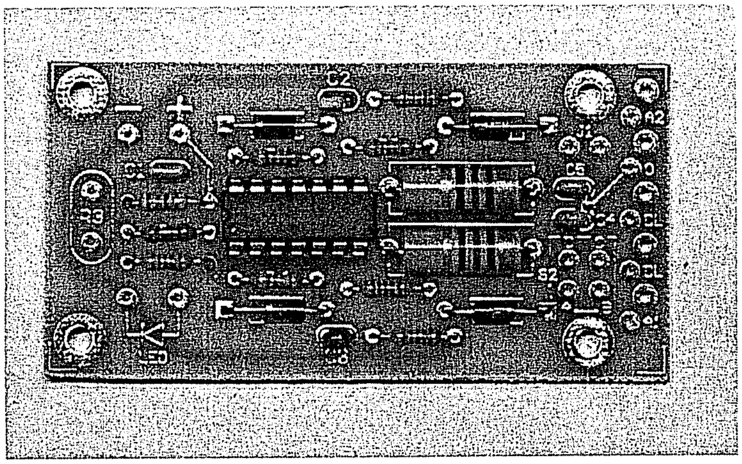
If building electronics kits is not your forte then the VF-142 and VF-142Q RDF units will be of interest. This is professional level equipment designed for use by the aviation industry and emergency rescue teams. They are surprisingly affordable at $139.95 and $239.95 respectively. Shipping is an additional $4.50. Both are intended for use on the 2-Meter amateur radio band, although the company offers several other models with expanded frequency coverage. They will work with any 2-Meter receiver or scanner radio. The VF-142 uses an audible response while the VF-142Q has both audible response and LED indicators. The antennas are collapsible for easy storage and both units have a built-in, fully compensated magnetic compass for sighting and triangulation. They are small, lightweight and feature a comfortable pistol-grip handle. This is top notch gear for a very reasonable cost.

R.R.S. E-Z FINDER (Skill Level 1)

The E-Z Finder is similar in design to the Handy Finder and other TDOA units with several improvements. It operates from a pair of 1.5 volt AA batteries for cost savings and utilizes a very low power consumption IC to provide many more hours of continuous use before changing batteries. It is supplied with PIN structure diodes for efficient RF switching and less signal loss. The fix for the 180 degree ambiguity is designed onto the PC board and the necessary components are supplied with the kit. For greater utility a power-on indicator and audio tone control are also included. Unlike all the other kits in its price range the E-Z Finder will not need any after-market modifications. When assembled with care and precision this device is more sensitive than other designs and will provide comparable or better accuracy. The kit is available from the R.R.S. and comes with PC board, components, and cable. The



The photo shows a fully assembled Searcher RDF which the author has modified for greater utility. A LED and resistor have been added for power-on indication. A larger case has been substituted for the original supplied with the kit and a new boom was made so that the unit could be oriented perpendicular to the antennas. This was done to accommodate a handle, salvaged from an old broken soldering iron, and the small compensated automotive compass which will enable compass readings directly from the unit. A 3' coax cable assembly (Jameco #111472) connects the unit to the receiver. The kit does not come with a connecting cable. A battery holder (Keystone #1295) was mounted inside the case. The kit has only a 9 volt type battery snap and a small piece of double-sided tape for attaching the battery.



The assembly of the E-Z Finder PC board should only take about a half hour. There are no coils to wind, nor is any tuning required. The layout and drilling of a case to house the unit will take about the same amount of time. If the antenna cables, delay line, and boom are built with precision the unit can achieve 1 degree accuracy. The instructions are written with novice builders in mind.

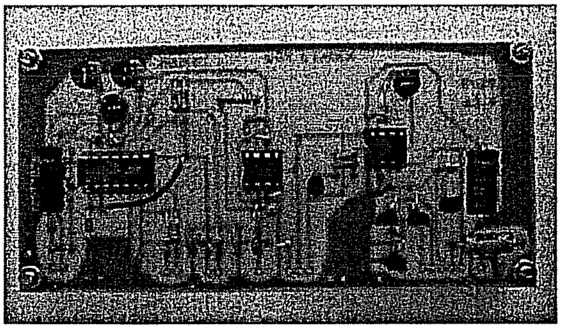
builder must supply a case, a boom (1/2" PVC pipe and fittings), batteries, and antennas.

BMG ENGINEERING SuperDF (Skill Level 3)

The manufacturer calls this device a "Phase Front Detection" RDF but it is simply a variant of TDOA to which has been added a number of improvements. According to its designer the SuperDF can be used at any frequency from 100 to 1300 MHz depending on the antenna, and with any type of modulation. It gives both an audible and LED readout at 2 degree accuracy without a 180 degree ambiguity. Most of the other features of the unit are directed toward the needs of Fox-hunting. It is offered as a kit for $155.00 or fully assembled and tested for $255.50. A series of compatible antennas which cover different frequency ranges cost from $62.00 to $85.00 for kits and $82.00 to $100.00 fully assembled. Assembled "Professional Units" are also available, costing $350.00 with their antennas ranging from $100.00 to $175.00 extra. If your only need for a radio direction finder is rocket recovery the SuperDF system is an unnecessary expense.

FOX FINDER RDF (Skill Level 2+)

The designer of this device, Paul Bohrer, W9DUU, is an engineer for a TV station in Indianapolis, and an avid Foxhunter. After reading his article, *Foxhunt Radio Direction Finder: Homing in by Sight and Sound,* in the July, 1990 issue of "73 Amateur Radio" magazine (available from the publisher) I decided to build and test his RDF unit. The circuit design is ingenious and includes about every feature that could possibly be desired: There are audio, LED and meter direction indicators; built-in multipath rejection; built-in antenna delay; an audio signal polarity switch to accommodate different receivers; dual batteries for many hours of continuous use without recharging; a battery charging circuit with external jack; and even the option for a vehicular antenna array. An outstanding feature is its signal averaging that helps when tracking "kerchunkers" (intermittent signals) which is exactly what most radio beacons are. The unit is not frequency dependent and will operate on any band by simply making each of the antenna elements 1/4 wavelength long. The only problem I saw, at first, was that the original design is a two-handed RDF. A photo in the article shows Mr. Bohrer walking along in a field carefully watching the meter with the antenna assembly in one hand and the circuit box in the other. Several cables connected the antenna, the RDF unit, and the receiver. I hope there were no gopher holes in that field. Fortunately that problem is easily corrected by constructing the unit with the circuit box mounted on the antenna mast, like all the other units in this manual, and thereby eliminating one of the cables. Once it had been built and tested Mr. Bohrer's design proved to be the best TDOA homing type RDF unit I have seen. It has excellent sensitivity and accuracy, and its added features make it very easy to use. Getting to that point however is much more difficult than first impressions. There were numerous problems, confusing directions, and glitches to be dealt with



A photo of the completed FAR Circuits PC board for the Fox Finder. The FAR board does not reflect the improvements made in the website version and it does not exactly match the original in the magazine article either. Once built the tuning of this unit is fairly complex and tedious.

along the way. The instructions in the article leave a lot to the imagination. On the schematic the transistors are numbered to Q7, but there are only 5 of them. In particular the PC board layout is poor. (Bare PC boards are available from FAR Circuits for $7.00.) There is a lot of wasted space, making the board about twice as large as it needs to be, but even so some components are jammed together. Twelve of the eighteen resistors on the board are mounted vertically. This is called "Japanese style" in reference to the use of this mounting technique in cheap, compact transistor radios to conserve board space. There is no reason for it on a board as large as the Fox Finder's. Numerous components are not even mounted on the board at all. They are soldered to panel mounted devices, like the switches and the meter, or they simply dangle from loose wires. The board contains several holes for which there are no components on the schematic. The original layout includes 6 jumper wires, some of them quite long, but FAR Circuits eliminated one jumper when they produced the boards. Because so many components are wired back and forth to the PC board several noise producing ground loops will result. While all of these problems can be corrected by the builder it should never have been necessary to do so. Reverse-engineering someone else's design is a hassle. What could have been a pleasant, easy, beginners' level project was made much more difficult by poor design. Apparently Mr. Bohrer has received enough complaints about this to have made some changes. On his website at http://www.qsl.net/pa3eik/rdfinder he has published an improved (downloadable) PC board layout, re-numbered the transistors, and provided much more readable schematics and assembly drawing. Unfortunately the problem of too many off-board components has yet to be resolved. He has also published two fixes for circuit bugs; changing the value of C5 from .003 uF to .002 uF, and changing the values of R2 and R3 from 100K to 4.7K.

DOPPLER RDF

ROANOKE DOPPLER (Skill Level 2)

Chuck Travis, N4FQ, a member of the Roanoke, Virginia amateur radio club, designed this unit which was subsequently published in "Transmitter Hunting" by Moell and Curlee. The Roanoke Doppler is the standard against which all other Doppler's are judged. It has become the most popular RDF among Foxhunters and there are thousands of them in use worldwide. Mr. Travis' ingenious design has undergone numerous minor revisions and upgrades since its introduction in 1987, but it remains the best Doppler RDF in its price range. The unit itself is quite small, but the antenna array must be vehicle mounted. Kits including the PC board, manual, and all components (less antenna array, case and battery) are available from DF Systems for $128.00. DF also sells bare PC boards with manual for $38.00. FAR Circuits sells the bare PC board and instructions for $19.50 plus shipping. Dopplers by Greany sells the bare PC boards and manual for $29.95 plus $3.00 shipping. The Greany board includes all of the latest modifications and improvements while the FAR board does not. The circuit is easy to build and can be completed in an evenings' work. Calibration and operation is also very easy. The most difficult part of the project is building the antenna array which will require an additional $50.00 in parts and several evenings. Nevertheless for under $200.00 a very sophisticated Doppler RDF can be constructed that is compatible with any 2-Meter band receiver. One minor criticism is that the LED readout only gives a relative bearing with 20 degree resolution. A wide range modification published by Joe Moell on his website at http://members.aol.com/homingin will allow the Roanoke Doppler to work at other frequencies. Because of its immense popularity and versatility the Roanoke Doppler has become the basis for more complex RDF systems. There are published plans for RS-232 interface for IBM compatible computers, motor driven antennas, and GPS interface. Most of these add-ons are not really needed for recovering rockets but they could be used to develop a flight tracking system.

MicroFinder DOPPLER KIT (Skill Level 2)

AHHA! Solutions is a company formed by two Hams who are also engineers. Their Doppler RDF system is state-of-the-art and incorporates several features which are only available for the Roanoke Doppler as add-ons. The LED display provides 7.2 degrees of resolution, or 1.8 degrees with an optional dial indicator. A Hall effect option is also available for true magnetic, rather than relative, bearings. Once calibrated the MicroFinder will not drift thereby correcting a problem which has been encountered with the Roanoke Doppler. The circuit includes two filters to provide resistance to reflected signals and intermittent transmissions. The unit is programmable for various modes of operation and is fully compatible with GPS receivers. When used with a laptop computer this system is the most sophisticated Doppler RDF available on the civilian market. The antenna array is not included with the kit, but the manufacturer provides eight different designs to choose from for scratch building. Something unique to AHHA! Solutions is their technical support. Unlike all the other vendors of RDF kits these folks stand by their product and provide excellent service after the sale. The basic kit is $249.00 plus $11.00 shipping. The PC board (no components included) for the magnetic compass is $10.00 and the stepper motor for the dial indicator is $5.00. Add to this the cost of a case, cables, and antenna array and for around $300.00 you can have a Doppler RDF that performs as well as professional equipment costing much more. The MicroFinder and its antenna array are pictured in the previous chapter.

AGRELO Dfjr DOPPLER RDF

Although somewhat expensive at $549.95 the Dfjr is a highly advanced microprocessor based system which is fully assembled and tested. It is professional grade equipment and has some features not available in any of the kits. The Dfjr is compatible with IBM PC's and GPS/APRS systems. When used with an APRS/PC map program it will give instant triangulation even while the transmitter or receiver, or both, are moving. It has built-in false signal rejection and a statistical analysis feature that allows it to show only the most accurate data received. A unique antenna system allows the Dfjr to operate at any frequency from 100 to 700 MHz. The unit itself is compact and lightweight and its antennas are easily collapsed and stored. It comes with antennas, operators' manual, cables and software. Optional accessories include a multi-port adapter ($50.00) which is required for interface to GPS or PC's, a dashboard mounting bracket ($30.00), and a storage case ($85.00). It is available from SWS Security, the exclusive agent for Agrelo products.

RAMSEY MODEL DDF-1 DOPPLER (Skill Level Undetermined)

CAVEAT! The author has neither built, nor tested, nor observed this unit in operation. If it performs according to the manufacturer's claims this kit is a bargain at $149.95 + shipping. According to an article in the April/May 1999 issue of QST magazine the design has achieved enthusiastic acceptance among amateur radio Foxhunters. It is a basic Doppler RDF without the computer and GPS interface "frills" of other units, but it does come complete with a pre-drilled and painted case, antenna array and cables. Ramsey claims that it can be used at any frequency between 130 to 1000 MHz by pruning the antennas.

A completed Ramsey DDF-1 Doppler RDF

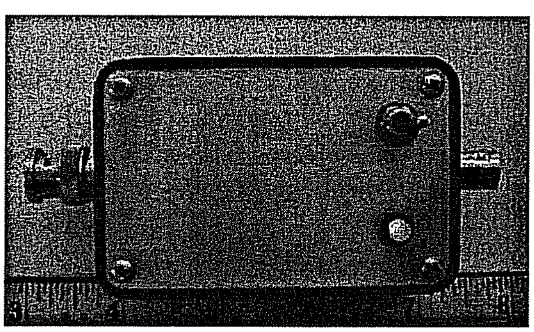
The rooftop antenna array.

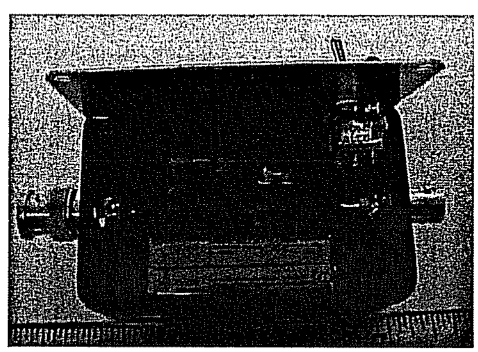
It is also claimed that the DDF-1 is easy to build and has performance comparable to that of commercial units costing upwards of $1000.00. A drawback is that it is only capable of 22.5 degree relative bearings by LED readout.

ACCESSORY GEAR

RAMSEY PR-10 PREAMP (Skill Level 1)

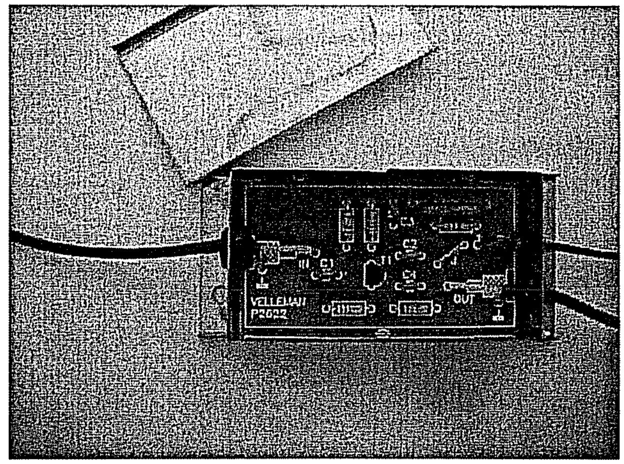
Amateur radio Foxhunters expend considerable effort to deal with signals that become too strong as their proximity narrows. Various techniques and signal attenuator circuits have been developed to address the problem. Searching for rockets is much more likely to involve weak signals. An easy solution for this is to add a pre-amplifier or "preamp" to the RDF/Receiver system. Ramsey Electronics sells several preamp kits, the best of which is their Model PR-10 2-Meter Low Noise unit. Because the preamp is tuned for 144 to 148 MHz it will not amplify noise or other out-of-band signals. Adding this preamp in between a Yagi antenna and an RF Sniffer would make a fairly useful 2-Meter RDF unit for close range work. The kit consists of a PC board and components. Builders must supply a case, battery holder, power switch, a few inches of 50 ohm coax cable, and BNC connectors. The PC board can be assembled in about 15 minutes and the whole unit can be put together in less than an hour. After completion an adjustable coil must be tuned for maximum performance. The instructions supplied with the kit are quite clear and the kit is suitable for novice builders. Cost is $17.95 plus shipping. As shown below the PR-10 can be assembled into a very small package which can be attached directly in line with the receiver's antenna by means of BNC connectors.



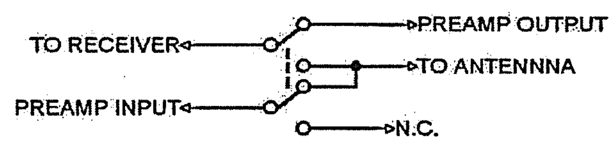


VELLEMAN MODEL K2622 AM-FM ANTENNA AMPLIFIER KIT (Skill Level 1)

This is a broad-band preamp that is suitable for use in the FM Broadcast band as well as the 2 Meter amateur band. It has a gain of approximately 22 dB. The unit is designed to operate on 12 Volts and is intended for use in mobile (vehicular) applications but is not well suited to hand-held portable use. It would be perfect for use with any of the Doppler units shown above. The case is only 1-1/2" x 3" x 1" high.



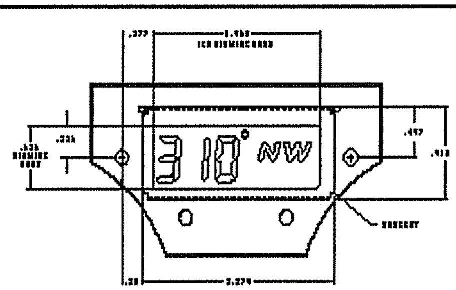
The K2622 is supplied with an old-fashioned metal shielding enclosure. The three cutouts for the RF and power cables are rough-edged metal and will require the addition of rubber grommets.



The switching circuit above will be needed if the unit is mounted inside the case of a dashboard RDF so that the preamp can be switched in and out of the antenna feed line as necessary.

NAVIFINDER-200

The Navifinder-200 is a solid-state electronic compass module with liquid crystal display (LCD) readout that was designed for use in small boats and automobiles. They are in use in Bayliner boats and in the dashboards of GM, Chrysler, and Ford vehicles. Although designed for 12 volt systems the module will operate from any unregulated DC source between 6 and 18 volts, with a current draw of only 5 mA. At 3-1/2" X 1-3/4" it can be easily mounted into an RDF unit's enclosure. While not as precise as a magnetic compass the Navifinder-200 has 5 degree resolution with an accuracy of +/- 2 degrees which is significantly better than the electronic direction Indicators in the Roanoke, MicroFinder, and Ramsey Doppler RDF kits. The only drawback to this compact, well-made, functional, and reliable module is its cost. They are available from Jameco Electronics for $79.95, or directly from the manufacturer, Precision Navigation, Inc., at that same price through their website at http://www.precisionnavigation.com.

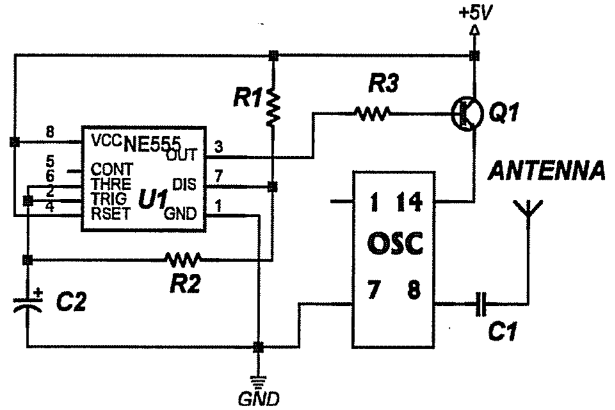


RADIO BEACONS

In some ways a radio direction finder is no better than the transmitter it is tracking. An inefficient transmitter-antenna system will be difficult to find even with the most sophisticated equipment. Selecting a transmitter with capabilities appropriate for the mission is an important key to successful RDF. One advantage in amateur rocketry is that the radio will have line-of-sight (LOS) transmission which is significantly greater than ground transmission. A very low power transmitter can be received at great distances when it reaches high altitudes. There have been reports of 10 milliwatt weather balloon transponders being picked up by stations as far away as 300 miles. The first amateur radio satellite, Project OSCAR, carried a 140 mW beacon which was received by more than 750 monitoring stations in 28 countries. In this section there are plans for several radio beacons as well as reports on some kits and off-the-shelf transmitters suitable for use in sounding rockets. Unlike analog and digital circuits, RF circuits often require the hand winding of coils, the "tweaking" of those coils for maximum performance, and the tuning of inductor-capacitor "tank" circuits. These are special skills and the assistance of an experienced amateur radio operator is strongly advised. Furthermore some of the transmitters shown here cannot be operated by anyone other than a licensed Ham. Anyone who intends to scratch-build any of these circuits is advised that after building, tuning and testing them they need to be thoroughly coated with epoxy to insure that they will continue to function in the high shock and vibration environment of a sounding rocket. Even kits built on PC boards and some factory made transmitters will need this added protection if they are to operate reliably. Additional reliability considerations are addressed in appendix C.

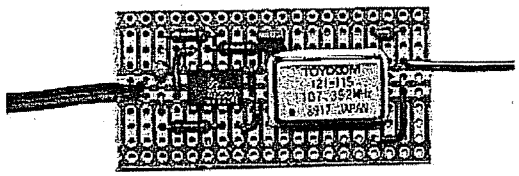
E-Z-T RADIO BEACON (Skill Level 1)

This is perhaps the simplest radio beacon ever devised, and thus the acronym E-Z-T for "easy transmitter." It has been adapted from an original design intended for use in weather balloons. The output is approximately 10 milliwatts which complies with FCC Regulations Part 15 for unlicensed operation. The transmitter will operate at the precise frequency of the crystal oscillator module. In order to avoid interference from powerful broadcast stations it is advisable to select a frequency at either the lower or upper ends of the FM band. A 107.352 MHz oscillator is available from Hosfelt Electronics, part #23-147. By substituting oscillators of different frequencies the beacon can also be operated on amateur radio bands. It can be powered by 2 lithium batteries (3.5 volt and 1.5 volt) in series which will provide a duration of several days. It would be a good beacon to practice RDF skills in a park, athletic field or large parking lot. The circuit is a basic astable multivibrator which pulses at approximately 1 Hz and turns on the oscillator for the length of each pulse. Its maximum effective range is about 1/4 mile on the ground, and up to 2+ miles LOS.



Parts List:

U1 - NE555 IC
R1 - 1K 1/4W Resistor
R2 - 100K 1/4W Resistor
R3 - 1K 1/4W Resistor
C1 - .01 uF Monolithic Capacitor
C2 - 4.7 uF Tantalum Capacitor
Q1 - 2N3904 NPN Transistor
OSC - Crystal Oscillator Module
ANTENNA - See Circuit Notes



Circuit Notes: There is nothing critical about the construction of this little circuit. It can be built on perfboard or a pad-per-hole PC board (Radio Shack Part #276-159) using hookup wire or wire wrap technique. If wire wrapping is used the components and all joints and connections should still be soldered. The entire board should then be coated with potting epoxy to secure the circuit against shock. The antenna is a 10 to 12 inch length of bare 22 gauge solid copper wire.

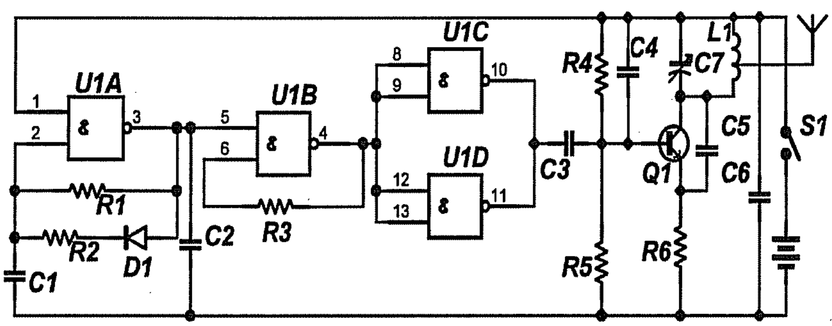
LITTLE BEEPER (Skill Level 2)

Here's an easy one. This little radio beacon operates on the FM broadcast band and has an output slightly less than 100 mW when powered by a 9 volt lithium battery. It has an effective range of about 1/2 mile over open ground and up to several miles LOS.

Parts List:

U1 - CD4093

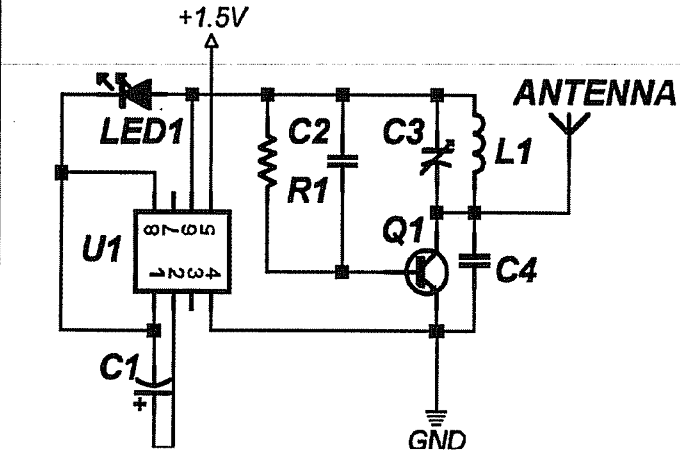
Q1 - 2N2222 NPN Transistor
D1 - 1N4148 Diode
R1 - 2.2 Meg 1/4W 5%
R2 - 100K 1/4W 5%
R3 - 47K 1/4W 5%
R4 - 10K 1/4W 5%
R5 - 5.6K 1/4W 5%
R6 - 120 Ohm 1/4W 5%
C1 - 1 uF 16V Electrolytic or Tantalum
C2 - .022 uF Ceramic Disk
C3 - .01 uF Ceramic Disk
C4 - .0047 uF Ceramic Disk
C5 - 4.7 pF NPO Ceramic Disk
C6 - 0.1 uF Ceramic Disk
C7 - 10-40 pF Trimmer Capacitor
L1 - See Circuit Notes



Circuit Notes: Some experimentation is needed to set the transmit frequency. L1 is made from 2 to 4 turns of 22 ga. magnet wire wound on a 1 cm. dia nonconductive core. The antenna is wired to the middle of the coil (center tapped) and can be a piece of bare 20 ga. wire up to 15" long. Once the coil has been tweaked and the transmit frequency and output power are set the coil should be secured in place with epoxy. The remainder of the circuit should be potted, taking care to see that C7 remains un-coated

DUAL PURPOSE BEACON (Skill Level 1)

The simple circuit shown here incorporates a flashing light and a radio beacon. U1 is a specialized IC designed to flash LED's, but it can also be used as a general purpose low-frequency oscillator. The circuit will operate for several days on a 1.5 or 3 volt lithium battery. It transmits on the FM broadcast band in accordance with FCC Regulations Part 15 and thus requires no license to operate. For greater visibility an ultra-high brightness LED, such as the Toshiba TLxx190 Series, is recommended. As it requires the hand winding and tweaking of an inductor this circuit is slightly more difficult to build and operate than the previous example. The effective range is approx. 1/4 mile on the ground and up to 2+ miles LOS.



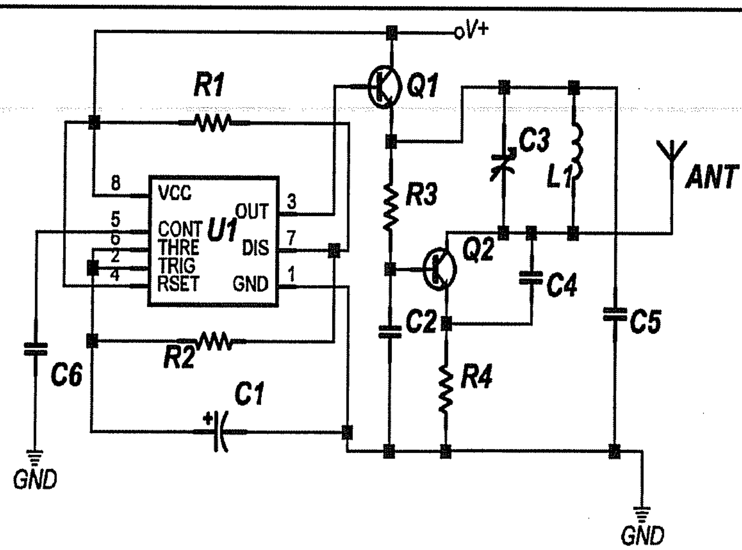
Parts List:

R1 - 1K 1/4W 5% Resistor
C1 - 100 uF Electrolytic Capacitor
C2 - .01 uF Monolithic Capacitor
C3 - 4 to 40 pF Trimmer Capacitor
C4 - 4.7 pF NPO Ceramic Capacitor
U1 - LM 3909 IC
Q1 - 2N3904 NPN Transistor
L1 - See Circuit Notes
LED1 - Toshiba TLxx190 Series
ANTENNA - See Circuit Notes

Circuit Notes: The specification of an NPO type capacitor for C4 is necessary to prevent drift. C3 allows tuning across the entire FM band. The antenna can be 10 to 12 inches of 22 gauge solid copper wire. L1 is 6 to 8 turns of 22 gauge magnet wire close wound around a 1/4" non-conductive core. Spreading these turns apart slightly (a.k.a. "tweaking"), about 0.5 mm, will lower the transmit frequency. The entire circuit will fit onto a Radio Shack PC board, #276-159. After completion the entire assembly, except C3, should be coated with potting epoxy to insure against shock and vibration.

RRS RB-1 RADIO BEACON (Skill Level 2)

This is a very efficient yet small transmitter suitable for use up to 1/2 mile on the ground and 20,000+ ft. altitude. It can be scratch-built on perfboard with consumer grade components for around $6.00, or purchased as a kit with a 0.75" X 1.75" Mil. Spec. PC board and high reliability components from the R.R.S. Successful construction and operation of this circuit will require the hand winding and tweaking of a coil, as well as the tuning of a tank circuit.



Parts List:

C1 - 4.7 uF 10V Tantalum Capacitor
L1 - See Circuit Notes
C2 & C5 - .001 uF Precision Monolithic Capacitor
R1 - 100K 1/4W 1% Metal Film Resistor
C3 - 10-40 pF Trimmer Capacitor
R2 - 10K 1/4W 1% Metal Film Resistor
C4 - 4.7 pF NPO Type Ceramic Disc Capacitor
C6 - .01 uF Precision Monolithic Capacitor
R3 - 47K 1/4W 1% Metal Film Resistor
Q1 & Q2 - 2N3904 NPN Transistor
U1 - NE555 Timer/Oscillator IC
R4 - 220 Ohm 1/4W 1% Metal Film Resistor
ANTENNA - See Circuit Notes

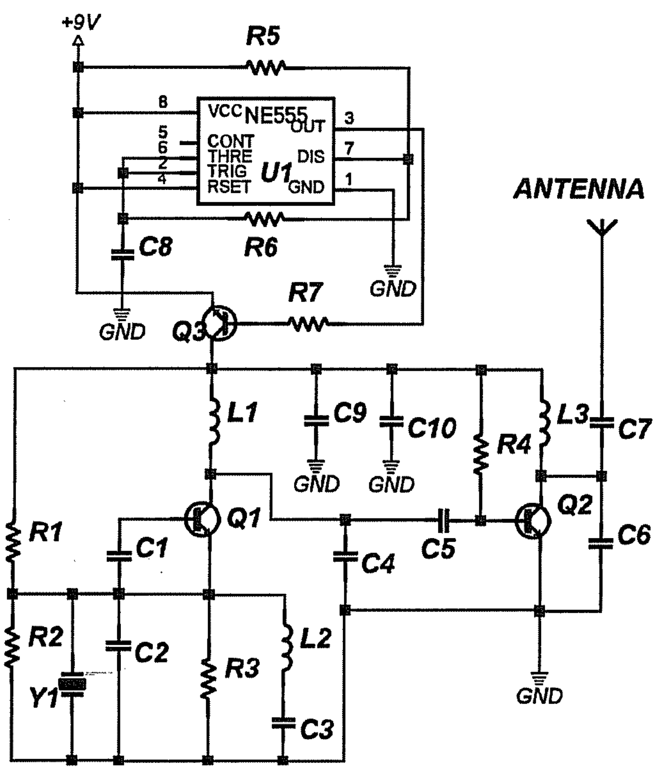
Circuit Notes: This transmitter can be powered by any battery from 6 volts to 9 volts. A high-density 9 volt lithium battery is recommended for maximum performance. The metal film resistors are specified for their low noise and stability. Capacitor C4 must be an NPO type to prevent drift. The antenna can be a 10 to 12" length of 22 gauge solid hookup wire. L1 is 5 turns of 22 gauge magnet wire (enameled wire) close wound around a 1/8" non-conductive core. After assembly the PC board should be potted taking special care to insure that L1 is sufficiently covered to keep the coil windings from changing their alignment during rugged use. Trimmer capacitor C3 must be protected against getting any epoxy inside its case. The transmit frequency is fine tuned by adjusting C3. The photo shows a completed rig, with the optional power cable connector installed. This is the smallest radio beacon kit on the market.

AGRELO MicroPLL

If you have $389.00 to spend this is the radio to buy. The MicroPLL transmits on the 2-Meter band at up to 1 Watt giving it a range of 3+ miles on the ground and 30+ miles LOS. It is the only transmitter which is fully programmable for carrier wave or frequency modulation, I/O logic, Morse code conversion, and transmit frequency. If the payload utilizes a microcontroller (flight computer) it can program the MicroPLL for various modes of operation while in flight. With the addition of a terminal node controller (see below) it is also the only unit designed specifically for rocket use which will transmit data. The rig can be programmed to switch between radio beacon and data transmission at any interval. The PC board measures 1.588" X 1.622" and utilizes surface mount technology as well as high reliability components throughout. Power can be supplied by any 9 volt type battery, although a 9.6 volt NiMH battery, available from Plainview Batteries, will provide greater output for as long as 255 hours. The price includes Windows compatible software, manual, data cable and adapter. All Agrelo products are distributed exclusively by SWS Security.

N.E.R.O. TINY T TRANSMITTER (Skill Level 3)

The Dutch amateur rocketry organization (N.E.R.O.) adapted this circuit from a design by Ken Bauer, KB6TTS, which was published in the May, 1993 *Homing In* column of "73 Amateur Radio" magazine (available from the publisher). Both the original and the N.E.R.O. transmitters utilize surface mount components which are



Parts List:

C1 - 22 pF NPO Ceramic Capacitor
C2 - 100 pF NPO Ceramic Capacitor
C3 - 1 nF NPO Ceramic Capacitor
C4 - 47 pF NPO Ceramic Capacitor
C5 - 10 pF NPO Ceramic Capacitor
C6 - 33 pF NPO Ceramic Capacitor
C7 - 4.7 pF NPO Ceramic Capacitor
C8 - 100 nF NPO Ceramic Capacitor
C9 & C10 - 1 nF NPO Ceramic Capacitor
R1 - 10K 1/4W 1% Resistor
R2 & R7 - 5.1K 1/4W 1% Resistor
R3 - 330 Ohm 1/4W 1% Resistor
R4 - 22K 1/4W 1% Resistor
R5 - 10M 1/4W 1% Resistor
R6 - 1M 1/4W 1% Resistor
Q1 & Q2 - 2N3053 RF Transistor
Q3 - 2N3906 NPN Transistor
U1 - NE555 IC
Y1 - 48.855 MHz Crystal
L1 - 4 Turns, See Circuit Notes
L2 - 270 nH Molded Choke

Circuit Notes: The NPO type capacitors and 1% metal film resistors are specified for their stability and low noise characteristics. Y1 is a 3rd overtone type crystal having a frequency tolerance of 25 ppm or better, a load capacitance of 20 pF, and a series resistance of less than 60 ohms. L1 and L3 are made from 32 gauge magnet wire (enameled wire) close wound over a 1.5 mm core. A metric drill bit will work nicely. The coils are then slipped off the bit and soldered onto the board. Both of these coils will need to be tweaked after assembly to tune the transmitter for maximum output. This is an operation which requires technical expertise and patience, or the assistance of an experienced Ham. Once this is accomplished the coils must be potted to insure that their spacing will not be altered during flight.

highly superior for shock and vibration environments. Complete plans for the N.E.R.O. version, including the PC board layout, is downloadable from their website at http://www.IAEhv.nl/users/nero Unfortunately this technology is beyond the abilities of all but the most experienced and well equipped builders. The author has re-engineered the circuit to use standard through-hole type components while keeping its dimensions as small as possible. Nevertheless it still requires hand winding and tweaking two inductors, and a license for operation on the 2-Meter band. When properly tuned the range of this beacon is 3+ miles on the ground and 25+ miles LOS.

ADEPT ELECTRONICS MODELS T100 & T110

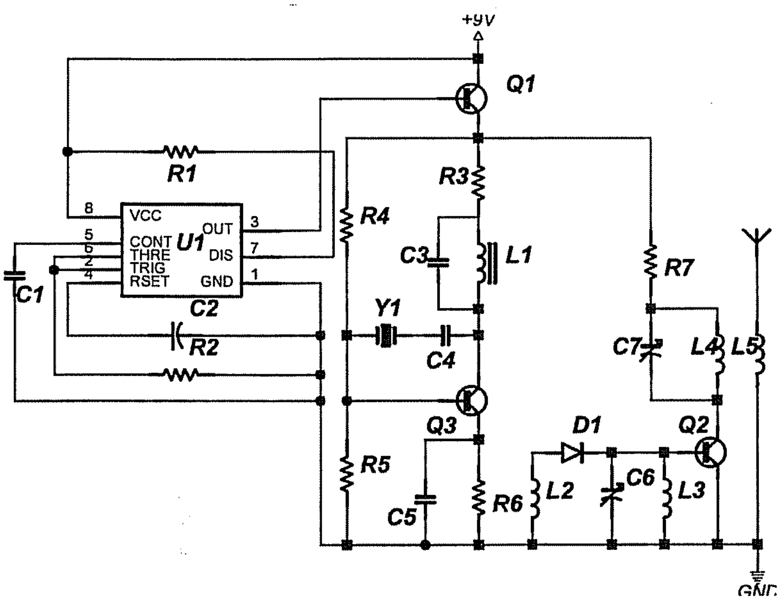
At the time of this writing Adept has suspended production of these transmitters. According to the manufacturer they will be re-introduced in the near future along with a directional antenna RDF unit. Both of these transmitters are designed for the 2-Meter amateur band, and as their output exceeds the limits of FCC Regulations Part 15, they require a license to operate. The manufacturer claims 20 miles LOS for the T100 and 30 miles for the T110. The T100 measures 0.85" X 3.6" and the T110 measures 1.3" X 4.5". Their principal advantage is that there is no assembly required, however neither of these rigs are manufactured according to high reliability criteria. All their components are consumer grade, and the assemblies are not potted. Anyone using these transmitters in a high performance rocket will need to coat them with epoxy. For use at altitudes above 35,000 ft. the electrolytic capacitors should be replaced with tantalums.

2-METER TRACKING TRANSMITTER (Skill Level 2)

This little transmitter was designed by Carl Lyster, WA4ADG, for the Tennessee Wildlife Resources Agency. It was published in the July, 1990 issue of "73 Amateur Radio" magazine (available from the publisher) in an article titled, *Two Meter Tracking Transmitter: Low-cost Beacon,* and has since been used in weather balloons and Ham radio Foxhunts. The designer claims that its 10 mW output was clearly received from a balloon at 60,000 feet by stations as far away as 300 miles. The beacon is intended for use with a digital keyer although it can be keyed by a 555 timer IC in astable operation. The schematic below shows Mr. Lyster's original circuit combined with a 555. Power can be supplied by any source from 6 to 9 volts but for maximum performance a 9 volt lithium battery is preferred.

ALLTRONICS T-HUNT TRANSMITTER (Skill Level 3)

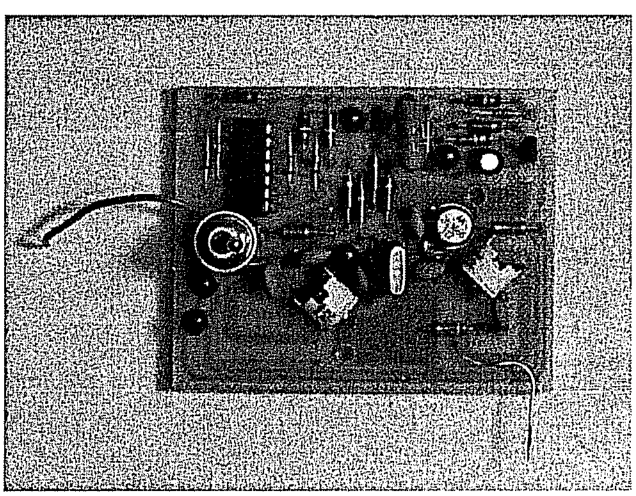
Alltronics sells surplus ELT transmitters (Catalog #97K003) which operate on an assigned frequency of 121.5 MHz. They are supplied with schematics, parts and instructions for modifying them to transmit on the 2-Meter amateur radio band. The output will be approximately 1 Watt thus the operation of these beacons requires a license. The effective range is 3+ miles on the ground and 25+ miles LOS. The modifications require hand winding two coils, replacing the crystal, and some experimentation to tune the circuit. At 2.5" by 3.0" it is a little large for some payloads, and the PC board does not have adequate provision for mounting it in a rocket. Therefore some creativity is needed to adapt it for use in a payload. The components are mounted to the PC board in a manner which absolutely requires potting with epoxy before use in a rocket. For use at altitudes above 35,000 ft. the electrolytic capacitor should be replaced with a tantalum. The power switch should also be replaced as it will not tolerate more than 25 G's of shock or vibration. It is not a project for the uninitiated, but at $24.95 each they are well worth the trouble. This is one of the most powerful radio beacons available, at less than 1/6th the cost of comparable units, if you have the skills to make it work.



Parts List:

Q1 & Q2 - 2N2222 NPN Transistor
Q3 - MPSH10 RF Transistor
U1 - NE555 Timer IC
R1 - 1K 1/4W 5%
R2 - 100K 1/4W 5%
R3 - 470 Ohm 1/4W 5%
R4 - 47K 1/4W 5%
R5 - 4.7K 1/4W 5%
R6 - 47 Ohm 1/4W 5%
R7 - 10 Ohm 1/4W 5%
C1 - 0.1 uF Ceramic Disk
C2 - 4.7 uF Electrolytic or Tantalum
C3 - 47 pF NPO Ceramic Disk
C4 & C5 - .001 uF Ceramic Disk
C6 & C7 - 1-10 pF Trimmer
L1 - 6T #28 on 1/4" slug tuned form
L2 - 4T #32
L3 - 4 T #28 1/4" dia. core
L4 - 4T #28 1/4" dia. core
L5 - 2T #32
Y1 - See Circuit Notes

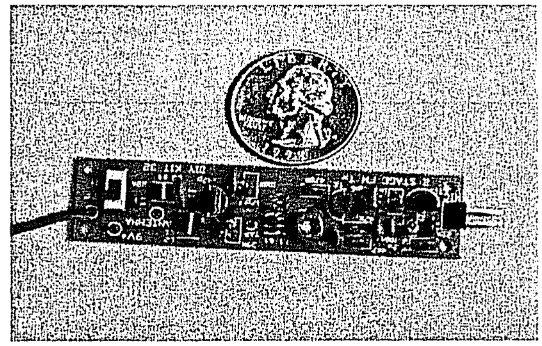
Circuit Notes: Unfortunately this is another one of those projects which is better in its design than its execution. The PC board (available from FAR Circuits for $3.00) is entirely too large, and the component layout is atrocious. Despite there being acres of open real estate on the board two of the five resistors are mounted vertically, and a ceramic capacitor is actually mounted directly on top of a resistor! The assembly diagram does not identify components by their value or number, and it shows six fixed capacitors although the schematic and parts list have only three. In order to construct this transmitter you will have to reverse-engineer the PC board from the schematic. Once you have figured out which three capacitors are correct you can ignore the others, they don't exist. There is a transistor and resistor on the schematic which are not on the PC board. You will have to include these on a separate board with the 555 circuit. Y1 is a 3rd overtone scanner crystal with a frequency anywhere from 154.8 to 158.7 MHz. Tuning this transmitter is far more complicated than the designer's instructions would lead you to believe. The assistance of an experienced Ham is strongly advised. Although there are no screw holes for mounting the board there is plenty of open space to put three #2 screw holes. The FAR Circuits PC board is single-sided FR-4 fiberglass. Because of this, and the manner in which the components are mounted, this device must be thoroughly potted with epoxy before use in a rocket.



This is the ELT radio beacon as supplied by Alltronics. The switch can be replaced by a jumper wire or a single-pole DIP switch. A 9 volt lithium battery is its power source. There is a ground pad located next to the antenna. By drilling a hole in the ground pad a length of RG174/U coax can be used to connect a 2-Meter antenna. All the component leads protrude about 1/8" below the bottom of the board and will need to be snipped off. The two #6 mounting holes will not provide sufficient stability for use in a sounding rocket. There is a small area near the power switch which will accommodate drilling a #4 hole for more stable, 3-point mounting.

FM WIRELESS MIKE KIT (Skill Level 2)

This is an inexpensive kit that can be modified for use as a radio beacon or even data telemetry. It is made by D-I-Y Kits and is available from Hosfelt Electronics for $9.29, and from All Electronics, Marlin P. Jones & Assoc., and All-tronics for $10.95. A very efficient circuit design utilizing an RF transistor gives this transmitter an effective range of more than 1/2 mile on the ground and 4+ miles LOS. The PC board measures 11/16" X 2-3/4" and has 4 #2 machine screw holes for secure mounting. For use as a radio beacon the electret microphone is eliminated and the tone burst generator circuit shown below is wired in its place. Adaptation for data telemetry is easily accomplished by wiring the output of a terminal node controller (see below) in place of the kit's microphone. The PC board is designed so that the resistors are mounted vertically to conserve space which is not acceptable practice in dynamic environments. Anyone planning to use this transmitter in a sounding rocket must insure that all components except the power switch, if used, and the trimmer capacitor are thoroughly coated with potting epoxy to provide protection from shock and vibration. Furthermore some means of strain relief must be devised for the power input cable.



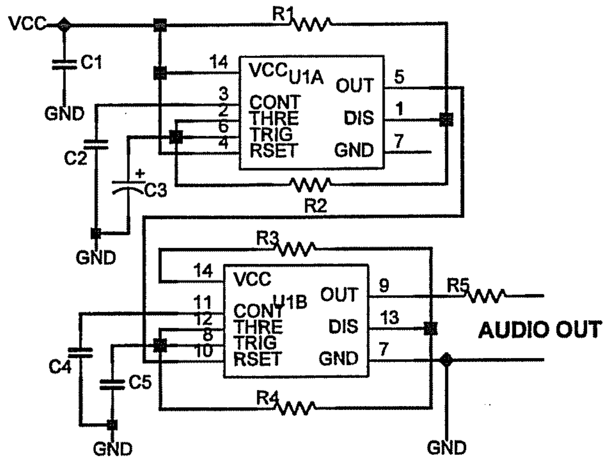
A completed transmitter is shown with the electret microphone replaced by a 2-pin header to allow connection to a packet modem for data telemetry. It can also be used with the tone burst generator shown below. Assembly can be completed in about a half hour. The coil (L1) at the center of the board will require tweaking for maximum output.

TONE BURST GENERATOR (Skill Level 1)

There are many small, low-power FM Broadcast Band transmitters available in either kit form or fully assembled. Most often they are sold as "wireless bugs" for clandestine broadcasting of conversations. Any of these transmitters can be adapted for telemetry by replacing the microphone with a terminal node controller (see below) or modified into beacons by replacing the microphone with the tone burst generator shown here. The circuit is built around an LM556 Dual Timer/Oscillator IC which is simply two 555's in one 14-pin DIP package. The first 555 is configured to pulse at ~2 Hertz which triggers the second 555. The output of the second oscillator is set for ~1 KHz in this example. The audio output of the circuit is then wired in place of the microphone on the transmitter PC board. This will make an ideal beacon because its signal will not be an intermittent "kerchunker" as are many of the examples in this manual. The transmitter's carrier wave will be a continuous signal that is modulated by an intermittent audio frequency.

ECHO-1 TRANSMITTER

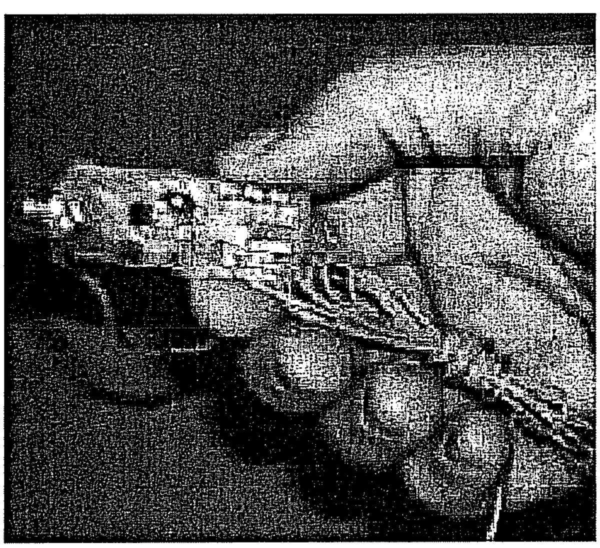
"Listen to Your Rocket" is the heading for the Echo-1 transmitter in Pratt Hobbies on-line catalog. (Pratt Hobbies, 2513 Iron Forge Rd., Herndon, VA 20171 (703) 689-3541 http://www.pratthobbies.com). Obviously things are getting pretty silly out there if a company is marketing this little low-power FM transmitter to send back the sounds inside a payload compartment. The Echo-1 is simply another one of many tiny FM transmitters as discussed above. The particular advantages of the Echo-1 over other little FM transmitters is that it utilizes surface mount components and it is fully assembled, tested, and potted for use in a rocket.



Parts List:

U1 - LM556 Dual Oscillator/Timer IC
C1 - 0.1 uF Monolithic
C2 & C4 - 0.01 uF Ceramic
C3 - 1 uF Tantalum
C5 - 0.1 uF Ceramic
R1 - 680K 1/4W 1% Resistor
R2 & R4 - 1K 1/4W 1% Resistor
R3 - 10K 1/4W 1% Resistor
R5 - See Circuit Notes

Circuit Notes: It may be possible to reduce the component count by eliminating C1, C2 and C4. C1 is merely a power supply filter. C2 and C4 protect the two oscillators against false triggering by spurious signals, i. e. noise. Since the circuit will be used in an RF environment it is advisable to experiment with it before deciding to eliminate these capacitors. The value of output resistor R5 will also require some experimentation. In order to avoid overloading the front end (audio amplifier) of the transmitter you will need to use a 1K trimpot for R5. Start at 1K and back the pot down until the overload threshold is reached. Measure the resistance of the trimpot and use a fixed resistor slightly above that value. In many experiments the author has found that the value for R5 will be between 220 and 470 ohms (e.g. 220, 270, 330, 390 or 470).



The Echo-1 is about the size of a 9 V battery and Pratt Hobbies recommends that it be taped onto its battery for use. The transmitter costs $29.95 + shipping. Range is about 1/2 mile on the ground and up to 2 miles LOS.

LOW POWER 2-METER BEACON (Skill Level 1)

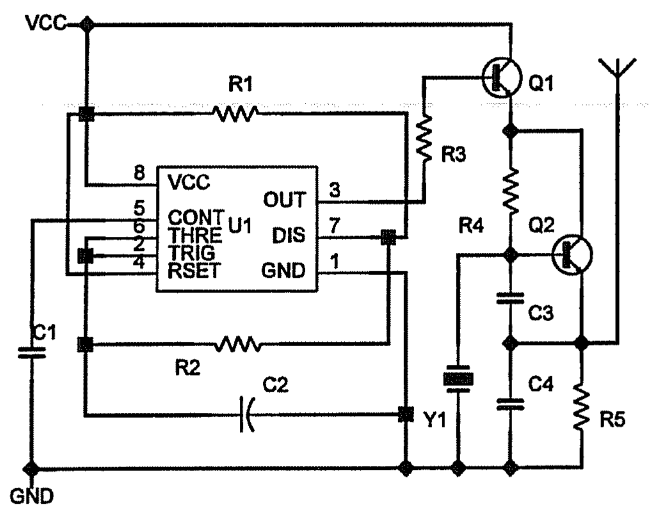
This little transmitter was originally designed to be used on the test bench for tuning 2-Meter receiver and preamp circuits. It was converted to a beacon by adding a 2 Hertz keyer circuit. When powered by a 3 Volt battery its output is less than 10 mW but its performance is excellent. Remember that many weather balloon transponders and wildlife tracking transmitters operate at only 10 mW. The circuit is easily upgraded for increased output It offers the advantage of a crystal controlled transmit frequency which requires no tuning or tweaking of coils. This is one of the smallest, most efficient, and easiest to construct radio beacons

ONE ON TWO BEACON (Skill Level 2)

This is a 1 Watt radio beacon that transmits on 2-Meters and requires a license to operate. It was originally designed for Ham radio Morse code transmitting and was intended to be powered by a 12 Volt car battery or any other type of high density 12 Volt battery. Powering the transmitter from a 9.6 Volt NiCad will lower its RF output considerably but it is still a very efficient and powerful little rig. Using a 9.6 Volt 170 mAh NiCad from Plainview Batteries (see Sources) this beacon was received over 5 miles away from an altitude of 6,000 ft. AGL. Converting it to a beacon simply involved replacing the telegraphy key with the keyer circuit used in several other beacons shown in this manual.

WALSTON CA MOD-A 2338 HF MVS

This is the radio beacon designed to accompany the Walston TRX Series RDF receivers. Its principal advantage is the use of surface mount technology which enables a very small size and extremely rugged construction. Its output is near 1 Watt and requires a Ham license to operate. Range is approximately 3+ miles ground and 30+ miles LOS. It is priced at an exorbitant $155.00 plus $8.00 shipping



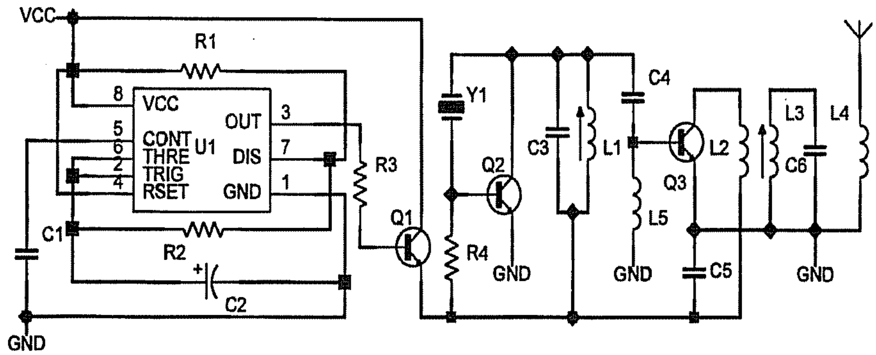
PARTS LIST:

U1 - NE555 Timer/Oscillator IC
Q1 & Q2 - 2N2222 NPN Transistor
Y1 - See Circuit Notes
C1 - 0.01 uF Monolithic Capacitor
C2 - 1 uF Tantalum
C3 - 100 pF NPO Ceramic
C4 - 68 pF NPO Ceramic
R1 - 680K 1/4W 1% Resistor
R2 & R3 - 1K 1/4W 1% Resistor
R4 - 10K 1/4W 1% Resistor
R5 - 390 Ohm 1/4W 1% Resistor

Circuit Notes: Y1 is an 8 MHz fundamental type crystal. Virtually any general purpose NPN transistors can be used for Q1 and Q2. NPO capacitors and 1% resistors are mandatory in the oscillator to prevent transmit frequency drift. Slightly increased performance can be obtained by using a higher frequency transistor for Q2 such as the 2N4401. A 1/4 wave monopole antenna which is pruned for SWR will also help significantly. Power is supplied by a 3.5 Volt lithium coin cell battery. Upgrading the beacon for increased output is easily accomplished. Use a high density 9 Volt lithium battery or 9.6 Volt NiCad. Replace Q1 with the TO-18 metal can packaged version of the 2N2222 for increased current capability. Replace Q2 with a 2N4014 which is also a TO-18 package and is rated up to 300 MHz operation. At this higher input power Y1, Q1 and Q2 will all need to have heat sinks

Parts List:

U1 - NE555 Timer/Oscillator IC
Q1 - 2N2222 NPN TO-18 Metal Can
Q2 - 2N2219 NPN TO-39 Metal Can
Q3 - 2N3053 NPN TO-39 Metal Can
Y1 - See Circuit Notes
C1 & C5 - 0.01 uF Ceramic
C2 - 1 uF Tantalum
C3 - 175 pF NPO Ceramic
C4 - 560 pF NPO Ceramic
C6 - 130 pF NPO Ceramic
R1 - 680K 1/4W 1% Resistor
R2 & R3 - 1K 1/4W 1% Resistor
R4 - 27K 1/4W 1% Resistor
L1 - See Circuit Notes
L2 - See Circuit Notes
L3 - See Circuit Notes
L4 - See Circuit Notes
L5 - 1 mH RF Choke



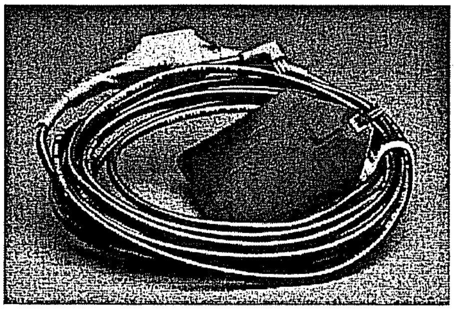
Circuit Notes: Y1 is a 7 MHz fundamental type crystal. The NPO capacitors are required in the oscillator circuit to prevent transmit frequency drift. The coils, L1 through L4, will present some challenge. L1 is 20 turns of 28 ga. magnet wire wound on a 1/4" dia. by 1/2" long slug-tuned form. These are available from Dan's Small Parts and Kits (see Sources section). L3 is 28 turns of 28 ga. magnet wire wound on another 1/4" X 1/2" slug-tuned form. L2 is 5 turns of 24 ga. magnet wire wound on top of and at one end of L3. L4 is 5 turns of 24 ga. magnet wire also wound on top of L3 at the opposite end. If you have no experience winding coils the assistance of a veteran Ham radio operator is advised. Tuning the transmit frequency is accomplished by adjusting the depth of the ferrite slugs in L1 and L4, again a task which may present some challenge to the uninitiated.

TRANSMITTER ANTENNAS

The performance of any transmitter will depend to a large degree on the efficiency of its antenna. The selection of an antenna appropriate for use in a sounding rocket presents some challenges. In addition to choosing an antenna design for maximum efficiency there is also the problem of where to put it. Obviously non-metallic airframes will be easier to work with. There are many well designed, off-the-shelf antennas available for FM and 2-Meter band transmitters. Unfortunately most of them are too large or awkward to be used inside a payload compartment. A quarter wave whip antenna for the 2-Meter band would need to be 19" long, and for the FM broadcast band it would be 28" long. Quarter wave, half wave, and 5/8 wave antennas can sometimes be mounted on the outside of non-metallic airframes. A 5/8 wave whip or half wave dipole will have a gain from 0 to +3 dB. One type of compact, lightweight antenna that is often used with hand-held transceivers is nicknamed the "rubber ducky." It is a type of helical antenna and consists of a coiled wire element inside a flexible rubber casing to which a BNC connector is attached. A typical rubber ducky antenna for 2 meters is 9" long and weighs about 1.5 ounces. Depending upon its design and construction a rubber ducky antenna can have a gain from -2 to +2 dB. This is the easiest, if not the most efficient solution to the problem. A quarter wavelength whip antenna will be much more efficient. Helical antennas can have a gain ranging from -5 to +12 dB depending on their design and tuning. Wrapping a helical antenna on the outside of a non-metallic body tube, or coiling it on the inside wall is one possible method. In order to maximize its efficiency any antenna system must be tuned. The assistance of an experienced amateur radio operator in the design and tuning of antennas will be a great help for those unfamiliar with these skills.

RAMSEY "STEALTH" ANTENNAS

Patch antennas are nothing new. They were first developed in the 1960's for NASA's use in low orbit satellites. Until recently this aerospace technology had only filtered down to military and law enforcement agencies, but now they are



Although Ramsey admits that their patch antennas are not as efficient as a 1/4 wave monopole you can expect better than a 1.5:1 SWR. When tested from my vehicle with a 2-Meter, 5 Watt handheld transceiver I was unable to detect any difference in performance compared to my usual whip antenna. Several models are available for frequencies of 2-Meters, 220 MHz, and 440 MHz. Prices start at $59.95 plus shipping.

finally available on the civilian market. Ramsey Electronics has coined the moniker "stealth antenna" as a marketing gimmick to sell their patch antennas to mobile radio users who do not want to attract the attention of thieves to their vehicles. The Ramsey patch antenna is essentially a helical which has been flattened into a thin sandwich of radiating elements supported by a dielectric layer over a ground plane. It is highly efficient with typical gain of about 6 dB, narrow bandwidth, and an omni-directional radiation pattern. An interesting feature is that since it is designed to mount on a windshield it is built on a flexible substrate and tuned to transmit through glass. The dimensions are only 0.003" thick and 3.5" square. A patch antenna can be sandwiched between sheets of G-10 fiberglass and mounted in a fiberglass payload tube or nose cone or, if the diameter is not too small, it can be laminated directly onto the inside surface

TELEMETRY EQUIPMENT

If the payload will carry both a radio and flight instrumentation it is not too difficult to build them into a telemetry package. A terminal node controller (TNC), a.k.a. "radio modem" converts data into groups of signals called a byte stream and organizes the stream into "packets" which are modulated to audio frequencies for radio transmission. The data can be supplied by a microcontroller (flight computer) or any digital signal source, such as an analog-to-digital converter (ADC) or direct digital output transducers.

CLEMENT ENGINEERING MIM V2.0 TNC MODULE

At 1" X 1.7" the MIM Module is the smallest TNC of its type, and except for the PIC chip it is all surface mount technology. The PIC is socketed to allow for upgrades. When used in a sounding rocket the chip should be potted to protect it against shock. The MIM Module can output 5 analog signals at 8-bit resolution and 8 digital bits of data, and is fully compatible with GPS receivers. It is a transmit-only device with an output rate of 1200 Baud. It can be powered by a regulated 5 volt supply or any unregulated voltage from 6.5 to 40, and consumes less than 15 mA. The $49.95 price includes software and manual.

BAY-PAC MODEL BP-2 PACKET MODEM

Tigertronics and Ramsey Electronics sell this TNC fully assembled with software for $49.95 plus shipping. It is designed for use with IBM compatible computers and amateur radio transceivers. With very minor adaptations it will work well with a microcontroller or other digital signal source, and any voice transmitter such as the FM wireless mike kit discussed above. With a little ingenuity many small, factory-built transceivers could be adapted for use with the BP-2 modem for payload data telemetry. The device measures 2.125" X 2.325" and weighs 1.2 ounces. In normal operation it is powered by the computer's serial port. It will operate on only 9 mW of power and processes data at 1200 Baud. The receiver audio output section of the packet modem is not used in payload applications and does not need to be connected. The BP-2 is easily configured for receive-only operation for use at a base station with a laptop computer. This is one of the least expensive packet modems used in amateur radio. It is easily programmed with the popular BayCom software and it is constructed using surface mount technology for rugged use.

RDF TECHNIQUES

"Practice makes perfect" is an old adage which is certainly applicable to learning RDF skills. The techniques are not complicated, but there are many opportunities for error. Before relying on RDF to recover a rocket it is imperative that you take your equipment into the field and acquire some experience. Train several members of the recovery teams. Develop communications protocols and map plotting methods. A well trained and coordinated RDF recovery operation should take no more time than is required to drive to the rocket's location.

GENERAL PRINCIPLES

The use of RDF in amateur rocketry differs significantly from amateur radio Foxhunting. The good news is that you will have the advantage of line-of-sight propagation during the rocket's flight, and you will know the exact location of the transmitter prior to launch. And unlike the competitive environment of amateur radio Foxhunting all the teams in rocket recovery RDF will be part of a cooperative and coordinated effort. The bad news is that you will have a moving target, and upon landing the transmitter's antenna is not likely to be oriented for maximum efficiency. Unless the rocket carries a very powerful transmitter or it lands relatively nearby it is probable that you will lose the signal when the payload touches down or descends below the horizon. There are some general principles which apply to RDF in all situations and these will be discussed first.

Stand away from any obstacles, topographic clutter or metal objects. Begin by holding the RDF unit as far away from your body as possible. The human body is a huge capacitor and will have a parasitic effect upon the amplitude of radio waves. Keeping the antenna(s) perpendicular to the ground sweep SLOWLY from side to side, a full 180 degrees. It should take about 4 seconds for a full sweep. Beginners have a tendency to sweep too fast, and also to home in on the first signal they detect. Do not abandon the 180 degree sweeps once you have a good signal. It is entirely possible that this is a multipath (false) signal that will lead you astray. If your sweep picks up more than one signal only one of them can be correct. You are receiving multipath signals and the strongest signal may not even be the correct one. Move to a new location at least 10 yards away and start again.

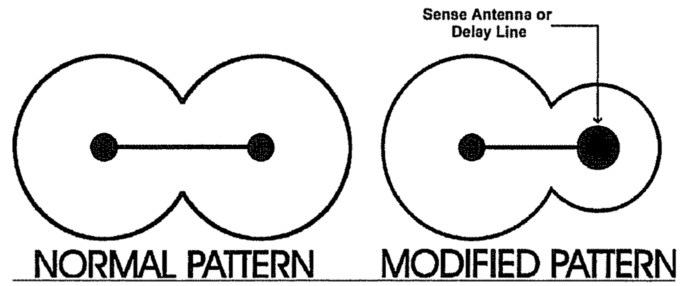
The theoretical horizon of a ground wave is about 2 miles. You can lengthen the horizon by increasing the antenna height above ground thereby reducing ground attenuation and distortion and catching more direct wave (LOS) signal. Find a small hill or a boulder, or climb onto the roof of a vehicle. Even holding the RDF unit as high above your head as you can reach will help. To see how a little height will make a big difference try some small numbers in this formula:

$D = 1.415*H^{0.5}$ where D is distance in miles, and H is height in feet.

At 4 feet (about waist high) the horizon is approximately 2 miles. At 9 feet (waist high on top of a vehicle) it is more than 4 miles. At 50 feet (a small hill) it is almost 10 miles. Remember from the section on antennas that one of the best means of increasing the efficiency of a transmitter/receiver system is to increase the height of one or both of the antennas above ground. If you lose the beacon's signal during RDF increasing antenna height is the first thing you should do.

Triangulation is the means by which the position of the signal source is determined. The bearings taken by the RDF teams are plotted on a map overlay and the point at which these bearings intersect is the presumed location of the signal source. A good quality sighting compass is therefore essential. The best method is to mount the compass directly onto the RDF unit, insuring that it is exactly perpendicular to the antennas. In that way the RDF operator can get an instant magnetic bearing while homing on the signal. If the equipment will not accommodate mounting a compass then some other sighting device, such as a pair of pins perfectly aligned perpendicular to the antennas will need to be added. The most precise RDF units can only achieve about 1 degree of accuracy. If that error is compounded by imprecise magnetic bearings the result can be an unsuccessful recovery operation. An important point to remember is that true north differs from magnetic north. Declination is the angle of deviation of magnetic north from true north and the declination will vary according to location. For example, the approximate declination for the southern portion of California is 15 degrees east. Most topographic maps have the precise declination angle printed on them. Magnetic bearings must be corrected by this angle when they are plotted on the map overlay. Unfortunately triangulation is never as precise as one would wish. In theory all of the bearings taken to a stationary transmitter should intersect at the same point. In practice there will be some error and the intersections will define a circle rather than a precise point. A five degree error at a distance of one mile from the signal source will yield a circle about 150 yards in diameter. The more readings which are taken the smaller this error circle will become.

Dealing with the 180 degree ambiguity of the RDF unit should not be much of a problem in rocket recovery RDF. In fact, as most of your bearings will be triangulated with those of other teams this will automatically eliminate the problem. During the final part of the operation it is possible that you will need to use one of the modifiers discussed previously if your rig is so equipped. The "before and after" reception patterns in the illustration below show how a sense antenna or delay line will affect the operation of the RDF unit. It is easy to visualize how this will enable you to determine the true direction of the signal source.



PREPARATION

A rocket recovery operation should consist of at least two teams each having two members; the RDF operator, and an assistant. The assistant will serve as a map plotter, radio operator, and driver. The more teams that can be fielded the faster and more accurate the recovery operation will be. Each team should be equipped with the items listed below:

RDF Unit & Radio Receiver
Low Noise Preamp (Optional, but highly recommended)
Lensatic or Sighting Compass
2-Way Radio (Do NOT use a frequency close to that of the rocket's beacon!)
Hand-held GPS Unit (Optional, but really useful)
Topographical Map
Clear Plastic Map Overlay
Erasable Marker or Grease Pencil
Protractor
Straightedge or Long Ruler
Clipboard
Binoculars

The actual recovery operation consists of three phases during which the teams are intensely busy and in constant communication. For the purpose of this discussion we will assume that there are at least two RDF teams; one at the launch control facility (LCF) and one or more downrange recovery teams. Usually the LCF team is the primary and its assistant is also the recovery operations coordinator (ROC).

PHASE 1 - PRE-LAUNCH

Prior to launching any rocket you will have calculated its maximum theoretical performance and its trajectory in a free fall (without parachute) descent. And you will have selected and pre-tested a radio beacon that will accommodate this trajectory both in flight and after landing. When the payload is installed during setup the radio beacon should be turned on immediately. Launch towers and other nearby ground control equipment can have parasitic effects on a transmitter's output power so it is important to test equipment and position the recovery teams only after the radio beacon is in place in the rocket. Once all the receivers are tuned into the beacon's signal the downrange recovery teams can proceed to their starting locations. They should be spread apart so that the calculated impact area is a safe distance between them, and they should not go beyond the range of the radio beacon signal. Now they can take bearings and triangulate from a known position to a known position (launch pad) to calibrate the equipment and eliminate false signals. The accuracy of this initial bearing is key to the success of the whole endeavor. A GPS position of each team's starting location will add greatly to the effectiveness of the recovery operation. If any of the downrange teams is having a problem with poor reception or multipath signals they can move to a new location. Once all of the teams are in place, the equipment has been thoroughly checked for accurate function, and good communications have been established the ROC can inform the launch director that the recovery teams are set for launch.

PHASE 2 - MANUAL TRACKING

The ROC will relay the countdown to the downrange recovery teams. All of the teams then begin to take bearings on the signal and transmit them back to the coordinator. Prearranged communications protocols will insure that things go smoothly. The coordinator plots all of the bearings on his map overlay. The assistant in each team will also plot each of the bearings from his RDF operator on his own map. By this continuous triangulation the primary team will be able to track the rocket's flight path. The ROC can inform a downrange team if the rocket appears to be headed in a direction that might compromise their safety. He will also be able to determine the last known position (LKP) once the RDF teams have lost the radio beacon's signal. In the absence of extreme gusting surface winds the rocket will land very near its last known position.

PHASE 3 - HOMING IN

If you are very lucky one or more of the recovery teams will still be able to receive the radio beacon's signal after the rocket has landed. In all probability you will have to work from the last known position. After sufficient time has elapsed to insure that nobody will be driving under a rocket screaming to earth at terminal velocity all the recovery teams should mount up and slowly proceed toward the LKP following the last bearing they have taken. The temptation is simply to rush to the LKP and try to get a visual sighting on the rocket, but a methodical approach will be more successful, if somewhat slower. Stop frequently to allow the RDF operator to dismount, walk away from the vehicle, and attempt to get a bearing on the signal. Install the preamp if needed and use any high ground that is available. If this is successful relay the information to the ROC who can then adjust the LKP accordingly and inform the other teams. A team which is receiving a good signal and has a valid bearing should continue to follow it. This is where eliminating the 180 degree ambiguity becomes important. The other teams should continue to proceed toward the LKP via their last bearing until they too can get a good signal and take a new bearing. In the absence of any team having a signal to follow they should continue to converge on the LKP by following their last bearing. The rocket should be nearby. If it cannot be sighted the RDF teams can initiate a search pattern spreading out from the LKP until visual or radio contact is made.

ADDITIONAL CONSIDERATIONS

The procedure outlined above makes rocket RDF sound fairly simple. If only it were that easy. There are any number of things that can go wrong, and numerous uncontrollable factors that can interfere with a smooth operation. Once the drogue parachute has deployed the rocket may change course abruptly due to winds. Surface winds at the launch site may have no relationship to the winds encountered at 50,000 ft. AGL. Knowing the direction and velocity of winds at the surface and at the predicted apogee will be very helpful. Being able to anticipate course changes will eliminate some confusion when taking RDF bearings. For surface winds it can be accomplished with something as simple as a wind sock. A hand-held anemometer would be ideal, if one is available. Determining high altitude winds is another matter. A small helium-filled pilot balloon tracked by two or more theodolites can be used to achieve very accurate determination of high altitude winds. This method was used by artillery and naval batteries in the days before radar.

Line-of-sight propogation is not always perfect either. You will recall that radio waves can be slowed, reflected, bent, scattered, and attenuated by solid objects. Although not as dense as topographic features clouds can interfere with LOS propogation. Remember the example of a radio wave being slowed by passing through moist air over a body of water? Consider that clouds are made from dust and water and you can imagine the havoc they can cause with a rocket's radio beacon. Of course you are prohibited by FAA Regulation FAR-101 from launching on an overcast day or directly into a cloud, but on a partly cloudy day you can launch. Clouds drifting into the line between the radio beacon and the receiver, or the rocket moving over stationary clouds, can cause propogation disturbances similar to multipath, and the signal can become so attenuated that it is lost. Except on a totally cloudless day you should anticipate this possibility. If the signal is lost during flight continue RDF sweeps, and hope that you will pick it up again once the clouds or the rocket have changed position. In all probability at least one of the several RDF recovery teams will still have a signal even though you may not. As you become more experienced and proficient with RDF techniques you will be able to improvise solutions to problems as they arise.

SOURCES

Adept Rocketry
2545 Overlook Dr.
Broomfield, CO 80020
(303) 466-9605 (Info & Orders)

Agrelo Engineering
P. O. Box 231
Pattersonville, NY 12137
(518) 864-7551 (Orders & Info)
(518) 864-7553 (Fax)
Email: sales@agrelo.com
Website: http://www.agrelo.com

AHHA! Solutions
4429 Guilford Place
Livermore, CA 94550-5059
(925) 447-5414 (Info)
Email: ahha@wenet.net
Website: http://www.wenet.net/~ahha/

All Electronics Corporation
P. O. Box 567
Van Nuys, CA 91408-0567
(800) 826-5432 (Orders)
(818) 904-0524 (Info)
(818) 781-2653 (Fax)
Email: allcorp@allcorp.com
Website: http://www.allcorp.com

Alltronics
2300 Zanker Rd.
San Jose, CA 95131
(408) 943-9773 (Orders & Info)
(408) 943-9776 (Fax)
Website: http://www.alltronics.com

American Radio Relay League
225 Main St.
Newington, CT 06111-1494
(860) 594-0200 (Info)
(860) 594-0303 (Fax)
(800) 326-3942 (Help Line)
Email: newham@arrl.org
Website: http://www.arrl.org

Arrow Antennas
1803 S. Greeley Hwy., #B
Cheyenne, WY 82007
(307) 638-2369 (Info)
(307) 638-3521 (Fax)
Email: ARROW146@aol.com
Website: http://members.aol.com/_ht_a/Arrow146

BMG Engineering, Inc.
9935 Garibaldi Ave.
Temple City, CA 91780
(626) 285-6963 (Info & Orders
(626) 285-1684 (Fax)
Email: grandrews@aol.com
Website: http://members.aol.com/bmgenginc

Clement Engineering, Inc.
1261 Dogwood Rd.
Arnold, MD 21012
(410) 518-6591 (Info)
(410) 518-6597 (Fax)
Email: wclement@toad.net
Website: http:www.agrelo.com/clement.html

Dan's Small Parts & Kits
P. O. Box 3634
Missoula, MT 59806-3634
(406) 258-2782 (Info)
Website: http://www.fix.net/jparker/~dans.html

Debco Electronics, Inc.
4025 Edwards Rd.
Cinncinnati, OH 45209
(800) 423-4499 (Orders)
(513) 531-4499 (Info)
(513) 531-4455 (Fax)
Email: debc@debco.com
Website: http://www.debco.com

DF Systems
Mr. Richard Douglas
P. O. Box 202
Carmichael, CA 95609
Email: orders@dfsystems.com

Directional Systems
Mr. Jim Sorenson, KA4IIA
P. O. Box 81881
Conyers, GA 30094
(770) 922-0867 (Info)
Email: ka4iia@radio.org

Dopplers by Greany
Mr. Ed Greany
P. O. Box 6863
Corona, CA 91718
Email: crest25@ibm.net
Website: http://www.pe.net/~dopplers

Electronic Rainbow, Inc.
6227 Coffman Rd.
Indianapolis, IN 46268
(317) 291-7262 (Orders & Info)
(317) 291-7269 (Fax)
Email: eri@indy.tds.net
Website: http://www.rainbowkits.com

FAR Circuits
18N640 Field Court
Dundee, IL 60118
(847) 836-9148 (Orders & Info)
Email: farcir@ais.net
Website: http://www.cl.ais.net/farcir/anchor#1556184

Gateway Electronics, Inc.
8123 Page Blvd.
St. Louis, MO 63610
(800) 669-5810 (Orders)
(314) 427-6116 (Info)
(314) 427-3147 (Fax)
Email: gateway@mvp.net

Hosfelt Electronics, Inc.
2700 Sunset Blvd.
Steubenville, OH 43952-1158
(800) 524-6464 (Orders & Info)
(800) 524-5414 (Fax)

Jameco Electronics
1355 Shoreway Rd.
Belmont, CA 94002-4100
(800) 831-4242 (Orders)
(650) 592-8097 (Info)
(650) 592-2503 (Fax)

Marlin P. Jones & Assoc., Inc.
P. O. Box 12685
Lake Park, FL 33403-0685
(800) 652-6733 (Orders)
(561) 848-8236 (Info)
(800) 432-9937 (Fax)

Master Publishing, Inc.
7101 N. Ridgeway Ave.
Lincolnwood, IL 60645-2621
(847) 763-0916 (Voice)
(847) 763-0918 (Fax)
Email: MasterPubl@aol.com

Pacer Technology
9420 Santa Anita Ave.
Rancho Cucamonga, CA 91730
(909) 372-0559

Plainview Batteries, Inc.
23 Newtown Rd.
Plainview, NY 11803
(800) 642-2354 (Orders)
(516) 249-2873 (Info)
(516) 249-2876 (Fax)

Radio Engineers-Technitron
7969 Engineer Rd. Suite 102
San Diego, CA 92111
(619) 565-1319 (Orders & Info)
(619) 571-5909 (Fax)

Ramsey Electronics, Inc.
793 Canning Parkway
Victor, NY 14564
(800) 446-2295 (Orders)
(716) 924-4560 (Info)
(716) 924-4555 (Fax)
Website: http://www.ramseyelectronics.com

SWS Security
1300 Boyd Rd.
Street, MD 21154-1836
(410) 879-4035 (Info & Orders)
(410) 836-1190 (Fax)
Website: http://www.swssec.com

Tigertronics, Inc.
400 Daily Lane
P. O. Box 5210
Grants Pass, OR 97527
(503) 474-6700 (main)
(503) 474-6703 (Fax)
(503) 474-6702 (Tech Support)

Walston Retrieval Systems
725 Cooper Lake Rd., S.E.
Smyrna, GA 30082
(800) 657-4672 (Orders)
(404) 434-4905 (Info)

WGE Publishing, Inc.
"73 Amateur Radio" Magazine
WGE Center, Forest Rd.,
Hancock, NH 03449
(603) 525-4201)

BIBLIOGRAPHY

American Radio Relay League. **THE A.R.R.L. ANTENNA BOOK.** *18th Edition.* Newington, CT: A.R.R.L., 1997

Black, Sara, et al, Eds. **HANDBOOK OF ELECTRONICS TABLES AND FORMULAS.** *6th Edition.* Indianapolis: Howard W. Sams & Co., 1989.

Bond, Donald S. **RADIO DIRECTION FINDERS.** *1st Edition.* New York: McGraw-Hill Book Co., 1944.

Brophy, James J. **BASIC ELECTRONICS FOR SCIENTISTS.** *4th Edition.* New York: McGraw-Hill Book Co., 1983.

Carr, Joseph J. **PRACTICAL ANTENNA HANDBOOK.** *3rd Edition.* New York: McGraw-Hill, Inc., 1998.

Department of the Army. **RADIO DIRECTION FINDING.** *Technical Manual TM32-476.* Washington: Government Printing Office, 1972.

Davis, D. et al. **REFERENCE DATA FOR RADIO ENGINEERS.** *6th Edition.* Indianapolis: Howard W. Sams & Co., 1985.

Fuqua, Norman B. **RELIABILITY ENGINEERING FOR ELECTRONIC DESIGN.** *1st Edition.* New York: Marcel Dekker, 1987.

Ginsberg, Gerald L. **PRINTED CIRCUITS DESIGN.** New York: McGraw-Hill, Inc., 1991.

Graf, Rudolf F. & William Sheets. **ENCYCLOPEDIA OF ELECTRONIC CIRCUITS.** *Volumes 1-5.* TAB Books Div. of McGraw-Hill, Inc., 1985-1995.

Horowitz, Paul & Winfield Hill. **THE ART OF ELECTRONICS.** *2nd Edition.* Cambridge University Press, 1995.

Johnson, Richard C. & Henry Jasik. **ANTENNA ENGINEERING HANDBOOK.** *2nd Edition.* New York: McGraw-Hill Book Co., 1984.

Manko, Howard H. **SOLDERS AND SOLDERING: MATERIALS, DESIGN, PRODUCTION AND ANALYSIS FOR RELIABLE BONDING.** *2nd Edition.* New York: McGraw-Hill Book Co., 1979.

McWhorter, Gene & Alvis J. Evans. **BASIC ELECTRONICS.** Lincolnwood, IL: Master Publishing, Inc., 1994.

Miller, Gary M. **MODERN ELECTRONIC COMMUNICATION.** *5th Edition.* Englewood Cliffs: Prentice-Hall, Inc., 1996.

Mims, Forrest M. **LED CIRCUITS AND PROJECTS.** Indianapolis: Howard W. Sams & Co., 1973.

Moell, Joseph D. & Thomas N. Curlee. **TRANSMITTER HUNTING: RADIO DIRECTION FINDING SIMPLIFIED.** TAB Books Div. of McGraw-Hill, Inc., 1987.

Orr, William. **VHF AMATEUR RADIO.** Lakewood: Radio Amateur Callbook Div. of Watson-Guptil Pubs., 1993.

Petruzellis, Thomas. **OPTOELECTRONICS, FIBER OPTICS AND LASER COOKBOOK.** New York: McGraw-Hill, Inc., 1997.

Strock, O. Jud. **INTRODUCTION TO TELEMETRY.** Research Triangle Park, NC: Instrumentation Society of America, 1987.

Turner, Rufus P. & Stan Gilbisco. **THE ILLUSTRATED DICTIONARY OF ELECTRONICS.** *5th Edition.* New York: McGraw-Hill, Inc., 1991.

Villanucci, Robert S., et al. **ELECTRONIC TECHNIQUES: SHOP PRACTICES AND CONSTRUCTION.** *3rd Edition.* Englewood Cliffs: Prentice-Hall, Inc., 1986

Warring, R. H., Edited by G. Randy Slone. **UNDERSTANDING ELECTRONICS.** *3rd Edition.* TAB Books Div. of McGraw-Hill, Inc., 1989.

Wolfgang, Larry D. & Joel P. Kleinman, Eds. **NOW YOU'RE TALKING! ALL YOU NEED TO GET YOUR HAM RADIO TECHNICIAN LICENSE.** *3rd Edition.* Newington, CT: American Radio Relay League, 1998.

APPENDIX A

SOLDERING TECHNIQUE

This is intended for those who have little or no electronics background. Some time ago there was a posting to an Internet rocketry newsgroup which was most disheartening. It was from an electronics professional and his whole letter was an indictment of amateur rocketeers who lack electronics backgrounds. In his words, "They don't even know how to plug a soldering iron into a receptacle, let alone how to use it." While the tone of his letter cannot be condoned it must be admitted that there is some truth in what he had to say. Fortunately the requisite skills are not difficult to learn.

First, it must be said that soldering is the only way to assemble electronics for payloads. Wire-wrapping is a rapid assembly technique developed for the consumer electronics industry. It has no place in a sounding rocket. "Breadboard" circuits which use jumper wires and pins or terminals are intended for benchtop prototyping, not space travel. Soldering is a skill which is often taken for granted. Anyone can melt solder on a hot iron, but NASA, the military services, and all reputable electronics manufacturers require anyone who solders to be trained, tested and certified by demonstrating competence in that skill.

Before soldering any components to a printed circuit (PC) board it is essential to conduct a brief pre-assembly inspection. Using a 2X or 3X hand lens under good light each component should be checked for defects. A swing-arm or gooseneck lighted magnifier is ideal. Components should be checked for chips or cracks which otherwise might not be readily apparent. Enameled or glazed components may appear "crazed" or hazy under magnification if their coatings are defective. Any flaking or other defects around the wire leads is an ominous sign. PC boards deserve special attention. The foil traces on the board may have bubbles, wrinkles or hairline cracks which can only be seen with magnification. Any of these defects means that the board must be discarded. There are methods to repair faulty PC boards, but those measures are not intended for highly dynamic environments like sounding rockets. Depending upon a board's mounting axis even when securely attached it can flex slightly during acceleration. A distortion of only a few thousandths of an inch is enough to spread apart a defective trace and cause a malfunction. PC boards which have been in storage for a long time or subjected to corrosive environments can become tarnished. Prior to assembly any tarnish must be removed with a common rubber ink eraser. A pencil type eraser (Eberhard-Faber #7099B) sharpened to a point and rubbed LIGHTLY over the tarnish should take care of the problem. After inspection any oil, grease or fingerprints must be cleaned from the PC board with a mild solvent. There are special chemicals available from electronics suppliers for this task, but ordinary rubbing alcohol (isopropyl and water) will work just as well. Component leads can also show tarnish and this can be removed by holding the lead between two flat ink erasers and slowly pulling the lead out while exerting finger pressure on the erasers. Several "pulls" may be needed to remove the tarnish. Thorough pre-assembly inspection and prep is a good investment.

After this inspection is finished you are ready to mount the components on the PC board. Components must be mounted flush on the PC board and their leads must be kept as short as possible. The spacing between the mounting holes on solder pads is usually in increments of 1/10 inch. A lead bending tool with pre-measured slots for these dimensions is very helpful. Where the holes are a non-standard dimension the component leads can be bent to size using fine-point calipers. Set the points of the calipers to the mounting hole distance then bend the leads over the points. Smooth jawed, round pointed wire bending pliers are the only type acceptable for working with component leads. Pliers with serrated jaws or sharply angled edges can cause kinks or gouges which could cause the lead to break from shock or vibration. If the PC boards are best quality, double-sided, plated-through-hole (PTH) types the components can be soldered once the leads have been bent to size and the component has been inserted into the mounting holes. The solder will wick up through the holes and onto the upper pad surface for very stable alloying. The leads are then snipped off at the top of the solder mound. If cheaper single-sided boards are used the leads should be bent to approximately 30 degrees above the PC board and in the direction of the trace which leads away from the solder pad. The component leads are snipped off to the same length as the width of the solder pad and the shortened leads are then bent down (fully clinched) onto the pad. The component is now ready for soldering. When there is no PTH this method provides greater rigidity and better solder joints than the common practice of snipping off the unbent leads a slight distance from the pads. Components should be mounted and then soldered one at a time, starting at the center of the board and working out toward the edges. There are a number of important points:

SOLDER TYPES: Not all solders are created equal. The common, thick diameter, rosin core 60/40 tin-lead solder used to assemble consumer electronics is not a good choice. A solder which meets or exceeds Federal Spec. QQ-S-571 is required. This specification is for low temperature, and eutectic composition. It contains 63% tin and 37% lead, melts at 371 deg. F and is stronger than 60/40 solder. According to Villanucci, "It has been shown empirically that the highest joint resistance to stress exists with a 63/37 tin-lead ratio. This concentration...affords the best alloying qualities in addition to the lowest melting point." Another advantage of eutectic solder is that it melts quickly from solid to liquid withoutpassing through the stages of softening called the plastic range. Kester catalog #24-6337-8807 solder exceeds the Federal spec. and offers the additional advantage of a "no clean" organic resin flux which leaves no residue and will not cause corrosion.

SOLDERING IRONS: A low-wattage (approx. 15 W) fine tip, pencil type soldering iron is acceptable for most routine tasks. There is a temptation to use the highest temperature, i.e. highest wattage, iron possible to melt the solder quickly and insure against the dreaded "cold solder" joint. This is a mistake. A 40 Watt soldering iron will have a tip temperature in the range of 750 to 950 deg. F. Most components have very specific tolerances to soldering heat and semiconductors of all types are especially sensitive to damage during soldering. Manufacturers' data sheets usually list the maximum allowable soldering conditions. For example the maximum lead temperature for many common IC's is 260 deg. C for 10 seconds. The 2N3055 power transistor will tolerate 255 deg. C for 10 seconds. Exceeding these limits can permanently damage a component. The best approach is to use eutectic solder and a temperature controlled soldering iron. Cold solder joints are the result of poor technique, not low wattage irons.

HEAT SINKS: Even when the proper iron and solder are used a heat sink must be clipped to every component lead when it is soldered. It should be left on the lead until the joint has completely cooled. The manufacturers' temperature limits are the point at which a component can be destroyed, but damage to its reliable function can occur well below that point. Spring-loaded aluminum clips for heat sinking during soldering are available from most electronics suppliers.

SOLDERING TECHNIQUE: If you are using a temperature controlled iron begin by setting the soldering iron temperature some degrees above the solder melting point. A good range is around 400 to 425 deg. F. When the iron comes up to temperature the tip should be cleaned by wiping it across a cleaning flux cake several times and wiping it off in between passes with a small damp sponge. This procedure should be repeated frequently during circuit assembly. A small drop of solder called the solder bridge is melted onto the tip to promote rapid heat transfer to the joint. The tip is then applied to the pad and the lead simultaneously at an angle which maximizes the tip's surface contact with the joint. After applying heat for 1 to 2 seconds solder is applied to the joint. As soon as solder flows completely into the joint the iron should be withdrawn. It is critical to apply only the minimum amount of solder sufficient to assure proper alloying. Excess solder should be wiped off the tip with a damp sponge after each joint is soldered. When cooled a good solder joint is shiny. If it appears frosted or grainy or there are gaps between the solder and the lead or pad a cold solder joint has resulted. Re-heating this joint and applying a small additional amount of solder (fresh solder bridge) should correct the problem. Each joint must be carefully inspected after it has cooled to determine if there is excessive solder on the joint, or if the joint has been compromised by flux residue or dirt. Other problems found by inspection include solder peaking in which the iron was withdrawn too soon and a pointed mound of solder is left behind. Reheating will correct this. Incomplete wetting is the result of too little solder. It is evidenced by the lead being completely uncovered. Puddling of solder on a joint is usually the result of tarnish or impurities. In this case it is necessary to de-solder the joint, clean the pad and component lead and retry. A good solder joint has no gaps and the lead is completely covered with its profile clearly visible. After all of the assembly is completed it is best to inspect the work one more time under magnification. A final scan for bad solder joints, "cooked" components and damaged PC board traces is indicated. Good soldering technique is only developed by repeated practice. Before attempting to assemble critical payload components it is a good idea to gain some experience with simple consumer kits or by soldering junk components onto a practice PC board.

TOOL KIT:

There is no need to spend a small fortune on equipment. This short list is all the gear that will be needed for most of the projects in this manual. The part numbers given after some items are from Radio Shack. I do not endorse, or even like, Radio Shack, but they are "just around the corner" in virtually every town in America and their part numbers are included for your convenience. If you want better quality at lower prices, shop around.

Pencil Soldering Iron, 15 Watt (64-2051)
63/37% Solder (64-015)
Desoldering Braid (64-2090)
4" Wire Cutting Pliers (64-1930)
4" Fine Point Round Tip Pliers (wire bending)

Wire Stripper (64-1922)
Phillips #0 Screwdriver
Slotted Screwdriver, 1/8" Tip
Clip-on Heat Sinks (2)

Multimeter, Digital (DMM) or AnalogAnd that's it. As your skills progress you may want to acquire a more complete tool kit, but this will get you started. A word about the multimeter. It is the single most useful piece of test equipment you can own. It is absolutely essential. There are many manufacturers and models to choose from, ranging in price from $15 to several thousand. Get the $15 one for now. Learning how to use it (Read the manual!) is an important skill..

APPENDIX B

OPTICAL BEACON CIRCUIT

Sometimes rockets can be difficult to find even when they do not bury themselves into the ground. There are too many anecdotes of recovery teams searching in vain after sunset for lost rockets. And according to the probability of Murphy's Law even the best RDF equipment and technique may fail. The simple optical beacon presented in this article will solve this problem. Its flashing orange light is visible for several miles in darkness.

The phenomenon of semiconductor light emission was discovered in 1907 by H. J. Round. Fifty-three years later the first efficient Light Emitting Diode (LED) was introduced. The semiconductor material, Gallium Arsenide (GaAs) has a quantum efficiency (ratio of emitted photons to incoming electrons) of greater than 80%. The electronics industry was quick to adopt them and by the early 1970's LED's had replaced incandescent bulbs in pilot lights, indicators, and photoelectric controls. The LED offered numerous advantages over other light sources including low power consumption, small size, light weight, high reliability, and low cost. Incandescent bulbs produce light by converting electrical energy to light in a resistive wire filament. Much of their energy is wasted as heat, thus requiring glass enclosures and bulky mounting fixtures. Another advantage is that the LED can be designed to emit light at a specific wavelength allowing it to produce colored light without the use of filters or lenses. Furthermore the LED has a usable life span literally hundreds of times longer than other light sources.

Until recently LED's were limited to electronics applications because their small size and low light outputs, i.e. luminous intensity, made them unsuitable for high visibility or illumination applications. The first generation of LED's could not achieve luminous intensities greater than about 100 milliCandelas (mCd). The Candela is the SI unit of light intensity. It is defined as the luminous intensity of 1/600,000 square meter of a perfect radiator at the temperature of freezing platinum. It is roughly equivalent to the more familiar International Candle, or "candlepower" unit.

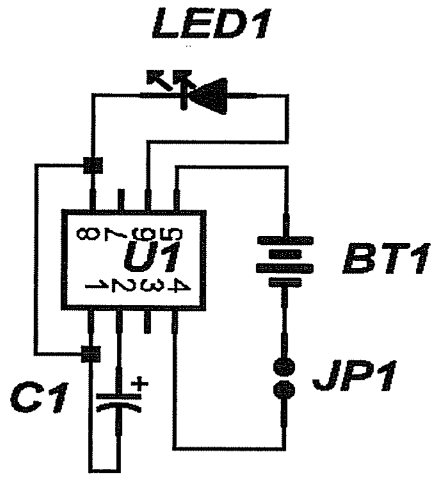
Advances in technology have achieved the development of 10 mm diameter LED's with light intensities up to 36,000 mCd. These new "super-bright" devices are used in automotive turn signals, advertising displays, and emergency "EXIT" signs in public buildings. Numerous other electronics components have been devised to take advantage of the LED's unique talents. One of these is the LM3909 integrated circuit (IC) which is a specialized oscillator designed to flash a LED. The "3909" is a very low power device which requires only one external component, a capacitor, to set its oscillating frequency. By combining a super-bright LED with the 3909 a very powerful beacon will result. The circuit illustrated below is currently used on boat mooring buoys.

SOURCES:

The LM3909 IC, capacitor, header, and shunt can be obtained from many electronics suppliers, including Radio Shack. Sources for the Toshiba LED and the PC mount lithium battery are:

Toshiba TLOH190P LED, Part #25-276, $3.49
Hosfelt Electronics, Inc.
2700 Sunset Blvd.
Steubenville, OH 53952-1158
(888) 264-6464

3 Volt Lithium Battery, Part #P023-ND, $2.18
Digi-Key Corp
701 Brooks Ave. South
Thief River Falls, MN 56701-0677
(800) 344-4539
Website: http://www.digikey.com



PARTS LIST:

U1 - LM3909 IC
C1 - 100 uF 6.3V Capacitor (see circuit notes)
LED1 - Toshiba TLOH190P Orange LED
JP1 - 2-pin header w/shunt
BT1 - 3 Volt Lithium Battery (see circuit notes)

Circuit Notes: This entire circuit will fit onto a small piece of perfboard or it can be constructed by soldering the components directly to each other and then encapsulating it in epoxy. The LED can be connected by suitable lengths of wire to allow it to be mounted remotely. C1 is an electrolytic capacitor which will give the LED a flashing rate of approximately 2 times per second. For greater reliability a tantalum capacitor can be used. JP1 and the shunt serve as a switch. Any battery from 1.5 to 6 volts will work, but the value of the capacitor will need to be adjusted accordingly. A 3 volt lithium battery of the type which can be soldered directly onto the PC board is recommended and will operate the circuit continuously for more than a week. A 1.5 volt AA alkaline battery will operate this circuit for up to 6 months. The LED can be mounted through the tip of a nose cone or the side of a payload tube. If the PC board is adequately potted with epoxy it can also be attached with a short piece of strong cord to the riser-shroud line juncture of the parachute rigging. Its small size and light weight should not interfere with deployment.

APPENDIX C

RELIABILITY CONSIDERATIONS

Electronics malfunctions are entirely too common in amateur rocketry compared to their incidence in the aerospace industry overall. Sounding rockets are by nature very harsh environments and the failure mechanisms are numerous. In order to insure reliability is it important to understand the sources of stress in a particular operating environment and to design the systems accordingly. Shock is a primary consideration since acceleration up to 100 G's is possible. Vibration must also be considered as it can cause erroneous modulation of electrical signals as well as the more obvious physical effects. Thermal stress can be produced by motor heat which is conducted or radiated into the payload compartment, or by cold ambient temperatures at high altitudes. From approximately 35,500 feet through 70,000 feet (isothermal zone) the temperature will be -55 deg. C. It is therefore possible that a payload could be subjected to excessively high temperatures during motor burn followed soon after by excessive cold at high altitude. Thermal stress can cause changes in a component's electrical performance and permanent physical damage as well. Finally, unless the payload compartment is made airtight there is also the problem of low barometric pressure or hypobaric stress. Electronics components are manufactured (and often hermetically sealed) at or near sea level (~14.7 psi). At 35,000 feet the air pressure will be ~3.5 psi. At 120,000 feet it is ~0.06 psi. Components can leak or rupture and normal internal heating can increase due to a lack of cooling medium. Any of these environmental stresses could become a failure mechanism if the operating parameters of a component or device are exceeded.

It is therefore incumbent upon anyone using a scratch-built, kit, or factory-made radio beacon to take steps to insure its reliability. The primary considerations are the effects of shock and vibration. When scratch-building or constructing kits it is imperative that all components be mounted tightly onto the PC board. Many electronics components are quite brittle, e.g. small signal diodes in glass capsules, ceramic capacitors, and carbon film resistors. Other components, e.g. inductors and semiconductors, will cause erroneous modulation in a circuit when they are subjected to vibration. This is an unwanted signal (noise) which can compete with the normal function of the circuit with disastrous results. The best protection from shock and vibration is afforded by the use of an electronics grade potting compound. Any electronics device, other than those utilizing surface mount technology, will need to be potted before use in a sounding rocket. Various types of adhesives are used, including two-part epoxies and sprays. Most electronics suppliers carry at least one brand of electronics adhesive. A suitable substitute can be made with Z-Poxy Finishing Resin made by Pacer Technology (Stock #PT-40) and available from most R-C model airplane suppliers. The two-part mixture can be slightly thinned with isopropyl alcohol to make an inexpensive and effective potting compound.

For rockets which will reach or exceed 35,000 feet ASL it is also important to consider the effects of low barometric pressure. Sealed components, particularly electrolytic capacitors and batteries, can leak or rupture at high altitudes. When building circuits that will reach these altitudes it is important to use tantalum capacitors in place of the electrolytics. Even factory-built electronics should have their electrolytic capacitors replaced before use in high altitude applications. When possible a sealed payload compartment is the best alternative.

Lastly there is the problem of radio frequency interference (RFI) to be addressed. RFI results when a radio signal is picked up by an electronics device creating high frequency noise within the circuit. This can have unpredictable and particularly harmful effects. A common problem is the premature firing of the parachute deployment circuit resulting from RFI. In order to prevent malfunctions of payload electronics due to RFI measures must be taken to physically and electrically isolate the radio beacon from other circuits. Mount the beacon as far away from other electronics as possible. Shield the beacon in a metal enclosure or wrap it in metal foil. Do not power the beacon with the same battery which is used for any other circuit. Do not locate any other payload electronics devices near the antenna. Insure that other circuits have adequate RFI protection designed and built into them. And perhaps most importantly, ground test the payload system thoroughly while the radio beacon is operating. If any malfunctions occur the payload layout may need to be redesigned or additional RFI protection may need to be added to the payload circuits.