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DESIGN AND ANALYSIS OF A MODE B AND MODE JD SATELLITE EARTH STATION

THESIS

Presented to the Faculty of the Graduate School of Engineering
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In Partial Fulfillment of the Requirements for the Degree of
Master of Science in Electrical Engineering

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Preface

This is the preface to a thesis on the research, design, and implementation of a satellite earth station for the Air Force Institute of technology's use in educating today's Air Force engineer. Hopefully, the creation of this earth station will serve as a step-off point for future upgrades to the station. This thesis presents a discussion of current requirements for an amateur radio service (ARS) mode B and mode JD satellite earth station. Using existing technologies, off-the-shelf components, commercially designed antennas and preamplifiers, the station components were integrated into a working earth station for communications between the station and orbiting amateur satellites. The station will serve as an AFIT communications training tool. Several techniques were used to test the earth station's performance. For this thesis even to be written, I must thank my advisor, Dr. Mark Mehalic and his wife for their endless patience and enthusiasm for the project. I wish to thank the committee members, Drs. Joseph Sacchini and Martin Desimio for their assistance and advice in completing this thesis. Further, I would like to express my deepest appreciation to Mr. Robert French and Prof. Charles Gauder for their support of this project. Mr. French endured many hours of patiently discussing practical considerations versus theoretical ones. Finally, I need to thank my wife, Pamela, and my family for their support during this crisis period. Without their support and assistance, I could not have completed this project. I must mention, I think my wife deserves the thesis and degree more than I. Throughout this thesis, she cared for our three children, relocated the family to a new city, and built a new house with minimal assistance from the author. Which do you think was the tougher job?

Dennis J. Hance

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Abstract

This thesis focuses on the design, integration, testing, and analysis of an amateur radio service mode B and mode JD satellite earth station. Preliminary designs were investigated to determine the optimum configuration for the earth station. Modern digital modems, cabling structures, an 80836-based computer system, satellite tracking software, transmission and reception antennas, preamplifiers, and sophisticated performance measurement technologies were integrated into a functioning earth station. Initially, component availability and station design dictated the selection and acquisition of the requisite station equipment. Integration of the transmitter, receivers, preamplifiers, antennas, and computer equipment followed.

Preliminary testing of the various components in the integration station occupied a significant amount of time. Empirical test tracking of different amateur and commercial satellites verified proper operation of the earth station. Results are discussed throughout this thesis. In general the result of this thesis is the design and implementation of a functional earth station at the AFIT Graduate School of Electrical Engineering. The earth station successfully collected multiple signals to include SSB and packet data from terrestrial and earth-orbiting amateur satellites. Conclusions and recommendations are presented.

Chapter I Introduction

The purpose of a communications system is to transfer information from one point to another. The means of transferring this information is left to the system designer. Some designers choose terrestrial means. Others choose satellite communications. Each must evaluate the requirements for the system and act accordingly. This thesis focuses on the research, design, and construction of a functional earth station at the Air Force Institute of Technology Graduate School of Engineering.

1.1 Background

The United States Federal Communications Commission defines an amateur radio service satellite earth station as an amateur radio station, located on or within 50 km of the surface of the Earth, intended for communications with space stations or with other earth stations by means of one or more other objects in space [1, 2]. Briefly, this means an earth station is designed to receive signals from, or transmit signal to, an earth-orbiting spacecraft. Typical earth stations can communicate with spacecraft using different signal types, modulation methods, signal power levels, and types of equipment depending upon the operating characteristics of the spacecraft. For the purposes of this thesis, an earth station was designed and built at the Air Force Institute of Technology (AFIT) Graduate School of Engineering. This earth station is designed to communicate with specific terrestrial radio stations and earth-orbiting spacecraft. These targets of interest, or other radio stations, were selected due to their availability and functionality.

1.2 Problem Statement

The problem is the lack of a functional earth station that is useful for engineering research and education. The purpose of the thesis is to solve the problem. That is, the thesis will explore previous efforts to design and build a functional earth station. The earth station must be able to communicate with both terrestrial radio stations and the orbiting satellites carrying amateur radio (OSCAR). Additionally, the earth station must serve as a training tool for future Air Force engineering students to permit them to obtain actual terrestrial radio station and satellite communications experience.

To solve this problem, specific requirements must be met. Additionally, specific objectives were established to solve the stated problem. Among these objectives are the design, integration, testing, and analysis of an amateur radio service satellite earth station. As part of the United States Air Force philosophy and to provide a comprehensive education to graduate students at the Air Force Institute of Technology (AFIT), in-house state-of-the-art satellite communications resources are needed. Additionally, these resources need to employ both analog and digital communications technologies and need to be structured for integration into the classroom environment.

1.3 Assumptions

This study assumes the cabling, receiver, transceiver, and computer circuitry function as specified in the respective manufacturer's performance documentation. Additionally, the tracking software is assumed to give correct data to the tolerances discussed in the software documentation.

1.4 Scope and Approach

Once the problem is identified, then background information on satellite and terrestrial communications will provide a greater understanding of approaches to the solution of the problem. Next, the specific requirements will be established. The requirements will be defined for the satellites and terrestrial radio stations chosen to be targets of interest. The requirements for the selected targets will dictate the requirements for the earth station.

After the background information is obtained for reference purposes and requirements are dictated, the various components for the earth station will be specified. The specifications will be used to obtain the actual components used to build the AFIT earth station. The specifications will be independent of any equipment that currently exists in the AFIT Communications\Radar Laboratory.

The actual selection of the communications devices and testing methodology were dictated by the availability of equipment, state of the current satellite communications technology, and access to the resources at the Air Force Institute of Technology and the University of Dayton. The selection of all equipment is based upon the stated problem and derived requirements.

After the various components are obtained, repeated testing of individual components will be performed before integration into a working earth station. This component-level testing will verify actual operation and functionality of each separate component used in the earth station. Upon integration, the completed earth station will monitor and collect terrestrial communications signals from active terrestrial radio stations to verify operation of the earth station. Initially, voice signals will be targeted. When these signals are acquired satisfactorily, digital data signals will be targeted from the same terrestrial radio stations.

Upon verification of proper terrestrial communications operation for the earth station, earth-orbiting satellites carrying amateur radio payloads will be targeted on a continuous basis for a 14 day period to allow time for system debugging. This earth station checkout phase will verify proper reception of satellite communications signals. Signals of interest will be voice and packetized data signals. At the end of the system checkout phase, realtime satellite communications will be attempted over a 14 day period. The results will be presented.

1.5 Overview

Chapter 2 presents background information on satellite subsystems including information concerning satellite communications, data types, and satellite orbits. Chapter 3 presents the requirements for satellite and terrestrial communications. Rudimentary information on satellite communications is provided to assist the reader in understanding the requirements dictated in this chapter. Specific targets are identified for the AFIT earth station. Requirements are dictated for the earth station. Chapter 3 also includes an analysis of the earth station requirements. Chapter 4 presents the methods used to satisfy the requirements specified in Chapter 3. Also, Chapter 4 documents the methods used to determine the earth station receiver, transmitter, receiving antenna, transmitting antenna, and other earth station components. Chapter 5 presents an analysis of the earth station while discussing the actual installation and empirical testing of the equipment used in the earth station. Results of individual component-level tests are presented. The installation and tests for each major component are discussed in detail. Chapter 6 documents the data intercepts for the terrestrial and satellite communications signal reception events. Each event is logged and discussed. The conclusion to the project and recommendations for future follow-on projects are presented in Chapter 6.

Appendix A provides terminology associated with this thesis. Appendix B presents useful information on the targets selected for this thesis. A users guide for the InstantTrack software program is provided in Appendix C. A users guide to the AFIT earth station is included in Appendix D. Finally, sample of the communications intercepts are presented in Appendix E.

Chapter II Background

2.1 Overview

This chapter presents background information on communications systems, amateur satellites, and earth stations. The targets of interest are presented. Then, satellite orbital parameters, such as the spacecraft apogee (distance on an orbit where the satellite-geocenter is at a maximum), are discussed. The chapter concludes with a summary of the background information.

2.2 Technical Background Information on Satellite Communications

For many years, radio systems have enabled man to communicate over long terrestrial distances. A limiting factor for terrestrial radio communications is the earth's curvature [3]. These terrestrial communication link distances are limited by the effects of ionospheric refraction and reflection. Depending upon the variable atmospheric conditions in the region, as well as upon the transmitting wave length, a radio wave may or may not be returned to the earth by the effects of refraction or reflection. However, propagation enhancement techniques such as the use of optimized, high-gain antennas can overcome the restrictions on communications caused by the earth's curvature.

With the onset of manmade, artificial earth-orbiting satellites in the mid-1950s, the distance limitations involved in terrestrial communications have been overcome. Today, intercontinental communications via these artificial satellites are possible. To understand the selection of the targets of interest for this thesis, some background on satellites and satellite communications is presented.

A satellite is a man-made device that is intended to orbit around the earth or another celestial body. Satellites have been designed for many purposes. Some uses for satellites are for communications (radio, television, etc.), photography purposes, weather tracking, and intelligence systems. For the purposes of this thesis, the term satellite refers to satellites used for communications. Satellite communications are made possible for the amateur radio operator through the use of several orbiting satellites carrying amateur radio (OSCAR). These OSCAR platforms provide a wide range of communications capabilities to the amateur radio operator. On frequencies from 29 MHz to frequencies above 2401 MHz, amateur radio operators can communicate using voice, manual morse (CW), radio teletype (RTTY), and packetized digital data streams [1, 2, 4, 5].

Most of the active amateur satellites operate full-duplex with a combination of receivers and transmitters on-board the satellite. These devices are called transponders. Basically, there are two types of transponders used on amateur satellites - linear and digital transponders. The function of an amateur satellite transponder is to receive radio signals in one segment of the radio spectrum, amplify these received signals, translate the frequency of the signal to another segment of the spectrum, and retransmit the signals to another satellite or to an earth station [1, 2].

2.2.1 Data Types

When radio communications began, they were transmitted in analog form. Even today, most terrestrial and satellite communications are still transmitted in an analog form. Even "digital" communications are transmitted in an "analog" form. Two of the more common analog signals are frequency modulated (FM) signals and single sideband (SSB) amplitude modulated signals. Of these, the SSB mode is of interest for our purposes. In the

SSB technique, voice information is passed from one station to another by using bandwidth as efficiently as possible. Only one of the sidebands is transmitted for a given signal. This produces the benefits of power efficiency and bandwidth savings.

The SSB technique is the dominant communication method used in the orbiting amateur satellites. Using SSB (voice) provides the station operator an immediate reinforcement that the station is operating if the operator can speak to another user at a remote site. These SSB transponders enable an earth station operator to make initial contact with other earth station operators, discuss the parameters desired for digital communications, and then switch to digital communications for high-speed data transfer.

In the digital arena, there are a variety of communication signals of interest. Among these are radioteletype (RTTY), Amateur Teletype Over Radio (AMTOR), and packetized digital data. Packetized digital data is the modulation method focused on for this thesis.

Packet data transfer is one of the most sophisticated forms of digital communications amateur radio operators can use today. Packetizing information provides several advantages. These are increased speed of reliable data transmission, networking between multiple stations, built-in error checking, and a more efficient usage of the available bandwidth [6].

During the 1960s, a research scientist at the Rand Corporation was tasked with developing a secure telephone network for the United States Air Force. This network was to be impervious to wire tapping and warfare. The scientist, Paul Baran, developed the method of first digitizing the information to be transmitted, converting the data from analog to digital form, and transmitting the data along a special network. This network would be unique, in that each node would have a high-speed computer to control the data flow [7].

The network node computers would multiplex small message segments and transmit these small segments along the data path. The network node nearest the destination would reconstruct the message segments into useable information. The research was completed in 1964, but political problems delayed the implementation for several years. Meanwhile, researchers in the United Kingdom named the small message segments of Baran's design packets. Additionally, the term packet switching was used to refer to the method of data transmission for these packets.

Within a packet radio system, digital information is transmitted from one station to another. The terminal or computer sends baseband digital data streams to the terminal node controller (TNC), which encodes the digital stream into small blocks of digital information. These small blocks are called the packets (of digital information). Inside of each packet is the actual data to be transmitted, addressing information, error checking data, and control information. The addressing data contains both the originator and the destination addresses for the data. The error checking data allows the receiving station to ensure it has received the packet of information being transmitted without error. The control information can provide instructions to the TNCs on choosing the proper methods of transmission, e.g., fixed path or variable path transmissions [1, 2].

By breaking the data stream into small packets of data and transmitting these packets in bursts, several users can use the same transmission channel on a time-sharing basis. This scheme is known as time-division multiplexing (TDM). In the amateur satellites, packet data transmission software implements the carrier sensed multiple access with collision detection (CSMA/CD) method. This means that a station using packet data transmission will not transmit any data until it senses that the channel is available for use. The TNC performs this by listening to the channel first. The TNC waits for the channel to clear before transmitting its own burst of packet information. It waits for a variable period of time and listens on the channel to determine whether the packet has been acknowledged or a collision has occurred. If the channel remains free, the packet station continues to transmit bursts of information. In amateur packet data operations, a collision is not acknowledged. Only the receipt of a data packet is acknowledged. If a sending node does not receive an acknowledgement packet within a given amount of time, either a retransmission or link termination may occur.

For the purposes of this thesis, a review of these schemes will be left for peripheral study. This thesis will focus on what packet transmissions allow the earth station to do - transmit digital information from one station to another in a high-speed and reliable manner. Figure 2.1 illustrates the packet data transfer process between two nodes. The first node has information to send to the second node. Therefore, the sending node transmits a call-request packet to the receiving node. This instructs the receiving node to prepare to receive data. Next, a call-accept packet is returned to the node that initiated the call. Then, a data packet is transmitted between the nodes. Finally, an acknowledgement packet is returned to the sending node. This lets the sending station know the data packet arrived intact at its destination. In amateur packet communications a non-acknowledgement packet is not used. If the sending node does not receive an acknowledgement packet within a given time, it retransmits the packet or ceases communications.

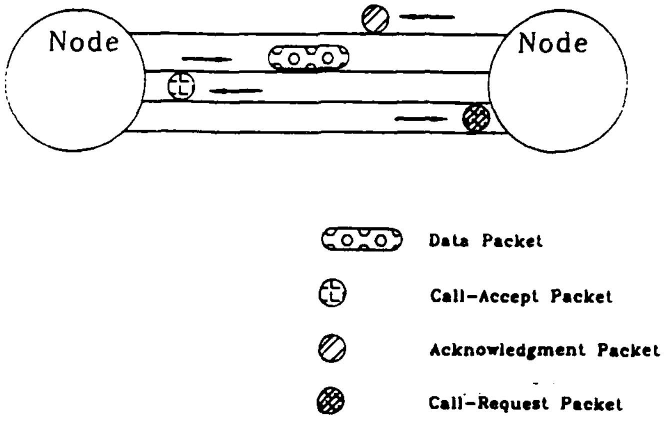


Figure 2.1 Packet Data Transfer

2.2.2 Satellite Orbits

Satellite orbits are elliptical by nature and vary depending upon the eccentricity, inclination, semimajor axis, and argument of perigee. Of course, the function the satellite performs often will dictate some of these orbital parameters. An orbit is the path a satellite follows around the governing body. Some of the more common orbits are the geo-stationary orbit, the polar orbit, the Molniya orbit (highly elliptical), and the circular orbit [1, 2]. Some common satellite orbits are shown in Figure 2.2.

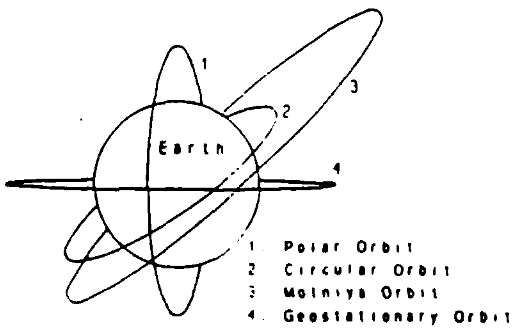


Figure 2.2 Common Satellite Orbits

The orbit used depends upon the function of the satellite. For example, a geo-stationary orbit is used for communications satellites. In a geo-stationary orbit, the satellite appears to hang motionless over a fixed point on the equator. This is achieved by giving the satellite an angular velocity nearly identical to that of the point of interest on the equator.

For amateur satellites, orbits of interest are the circular and the Molniya orbits. These orbits provide earth station operators with the ability to communicate with stations around the world. The circular orbits provide a stable orbit for the spacecraft; the satellite power management complexity is reduced. The satellite will not be subject to the excessive radiation effects of the highly elliptical orbits. The circular orbit is a special case of the Molniya orbit. The three possible circular orbit types are polar, inclined, and equatorial. These are illustrated in Figure 2.2 as orbits 1, 2, and 4, respectively.

Circular orbits differ from the Molniya orbits in several ways. Some of the more important differences are listed in Table 2.1. The table reinforces the point that while circular orbits have near constant orbital velocities and distances from the focus, the elliptical orbits have variable velocities and distances. Because these elliptical orbits are variable, sophisticated control mechanisms must be used to control these satellites.

Table 2.1 Circular Versus Molniya Orbits

PARAMETERS	CIRCULAR	MOLNIYA (ELLIPTICAL)
Orbit eccentricity	0	< 1
Distance from focus	Constant	Variable; Max at apogee; Min at perigee
Orbit velocity	Constant	Variable; Min at apogee; Max at perigee
Orbit inclination	Arbitrary	63.4 degrees (stable orbit)

From Table 2.1, one can see the circular orbit provides a more stable orbit. A stable orbit is one with a predictably constant velocity and constant distance from the focus of orbit. This permits easier tracking from the earth.

The Molniya orbit, on the other hand, does not provide a constant distance from the focus of the orbit. The Molniya orbit does provide additional opportunities to the earth station not provided by the circular orbit. In some cases, the Molniya orbit provides better communications to a specific geographic region due to its closer proximity to the earth than the circular orbits. Molniya orbits provide the additional benefit of allowing earth stations to maintain their tracking devices at a reasonably fixed position. The apogee of the satellite can be set to an angle of about 63.4 degrees to continuously favor the northern or southern hemispheres, depending upon the region of interest [1]. The Molniya orbit allowed the design engineers to minimize the thrust required to reach the high inclination orbit [1]. Also, the sun-angles for this orbit can be reduced. Sun-angle numbers have an impact on the battery recharge time and thus the transmitter power available from the satellite.

One disadvantage of a Molniya orbit is that the antenna pointing and Doppler shifts involved are much more complex with this orbit than with others. Another serious disadvantage to a Molniya orbit is that a satellite will pass through the Van Allen belt twice each orbit [1, 2]. This imposes increased radiation exposure to the spacecraft compared to other orbits. Therefore, the spacecraft subsystems require additional shielding. This adds weight to the system. Therefore, additional thrust is required to move the spacecraft.

2.2.2.1 High-Orbit Satellites

High-orbit satellites are those satellites, such as AO-10 and AO-13, that are launched into highly elliptical orbits that have apogees in the tens of thousands of miles. Because a satellite employs a highly elliptical orbit, the satellite will have fewer passes over a particular earth station. Typically, high-orbit amateur satellites, such as AO-13, provide only one to two passes over an earth station each day. However, each pass will last approximately 12 hours for the northern hemisphere. Because the high-orbit satellites are in view of a particular earth station for a relatively long period of time, earth station operators can maintain intercontinental communications for many hours at a time.

2.2.2.2 Low-Orbit Satellites

Low-orbit satellites are those satellites, such as AO-14, AO-19, and FO-20, that are launched into elliptical orbits that are nearly circular. The apogees for these satellites are often less than a few thousand miles. The low-orbiting amateur satellites, such as FO-20, will pass over an earth station in the northern hemisphere between four to six times each day. The duration of these passes is less than 25 minutes each, however.

2.2.2.3 Geostationary Satellites

Geo-stationary satellites are those launched into a circular orbit at an altitude of about 22,500 miles, in which the orbital track is directly above the equatorial plane of the earth. At present, there are no amateur satellites employing geo-stationary orbits. The Radio Amateur Satellite Organization (AMSAT) plans to launch a geostationary satellite before the end of this decade [1].

2.2.3 Targets of Interest

The specified objective is to communicate with terrestrial stations and space-based amateur satellites. To accomplish this objective, terrestrial amateur radio stations and several amateur radio service earth-orbiting satellites were chosen as targets of interest. These targets were selected after careful review of background information on the target, the operating characteristics of the target, and the applicability of the target to the satisfaction of the problem statement.

The terrestrial targets of interest are the radio station of Mr. Gerd Schrick (whose callsign is WB8IFM), the radio station of Mr. Robert French (whose callsign is N8EHA), and the Dayton Amateur Radio Association Bulletin Board Service (the associated callsign is W8BI). These radio stations are located within a 30 mile radius of the AFIT earth station. The AFIT earth station operator uses the callsign of N8VAT. Except for W8BI, these stations are capable of transmitting in more than one frequency range and can employ multiple communications signal types.

2.2.3.1 Characteristics of Terrestrial Targets of Interest

Terrestrial radio stations serve many purposes. For this project, the selected terrestrial ground stations had to be within line-of-sight of the AFIT earth station. Also, the selected terrestrial stations had to be similarly equipped with equipment capable of transmitting and receiving in the ranges of frequencies dictated by the satellites of interest. Likewise, the terrestrial targets had to be capable of employing the same types of signals used by the satellites of interest. For example, the Dayton Amateur Radio Association BBS was selected specifically for its heavy volume of packetized data. On an average day, the channel used for the Dayton Amateur Radio Association BBS is active every 3 to 4 minutes.

The logic behind this is that these terrestrial stations had to be capable of receiving signals from the same set of satellites as the AFIT earth station. Then, the AFIT earth station could attempt to communicate with these terrestrial stations on the same frequencies used by the selected satellites of interest. This permitted the AFIT earth station to be tested on terrestrial communications on these frequencies, before the AFIT station began to attempt satellite communications.

2.2.3.2 Characteristics of the Earth-Orbiting Targets of Interest

Two characteristics used as primary selection criteria for the earth-orbiting targets were the lifetime of the target and the physical orbit of the satellite. The target lifetime had to be such that it would remain in orbit for the duration of this thesis. Additionally, the selected targets had to be capable of transmitting signals back to the earth and pass over the Dayton, Ohio area. Other characteristics are the operating frequencies, signal power levels, signal types, and types of transponders employed for each target. These characteristics then dictated the requirements for the earth station's equipment.

The designations for the OSCAR targets of interest are the UoSAT-OSCAR 11 (UO-11), AMSAT-OSCAR 13 (AO-13), UoSAT-OSCAR 14 (UO-14), UoSAT-OSCAR 15 (UO-15), Pacsat-OSCAR (AO-16), DOVE-OSCAR 17 (DO-17), Webersat-OSCAR 18 (WO-18), Lusat-OSCAR 19 (LO-19), and Fuji-OSCAR 20 (FO-20) satellites. These satellites are amateur radio service satellites currently employing between 0.8 W and 50 W of transmitting power. All are low earth-orbiting satellites. Each satellite operates in a specific mode (pair of receiving and transmitting frequencies). The following sections discuss the some operating characteristics, such as the modulation methods, and operating power levels.

2.3 Technical Information on Earth Station Components

The following information provides an overview on the standard equipment used in an earth station. Information on typical transmitters, receivers, antennas, modems, and transmission lines is presented.

2.3.1 Transmitters

In long distance communications, a transmitter is required to process, and possibly encode, information to make it suitable for transmission and subsequent reception at the satellite. The function of the transmitter in a earth station is to send electrical energy in the form of electromagnetic radio waves to receiving equipment. Somewhere in a transmitter, the information modulates the carrier. The modulation scheme used will differ depending upon the nature of the communications and the manufacturer's implementation methodology [3].

Optimally, for satellite communications, the transmitter should be a multi-band system. This means that the transmitter can transmit on several different frequency bands at different intervals in time. This eliminates the need to buy several transmitters - each operating at a single frequency to communicate with different satellites.

A transmitter used to communicate with the amateur satellites must provide a reasonable amount of output signal power to offset the resistive line losses, connector losses, and other possible signal losses inherent in a man-made communication system, such as fading [5]. Fading is the process whereby the signal propagation variables such as absorption, refraction, misalignment of the signal polarization with that of the antenna polarization due to the earth's magnetic field (called the Faraday rotation), all combine to reduce the quality and quantity of the RF signal [8, 3]. Usually, this fading loss must be made up for by increased transmitter power output. Typical transmitters provide between 5 - 50 W of signal power [1].

2.3.2 Receivers

There are many types of receivers in the field of communications today. For communications with amateur satellites, receivers should be capable of operating in multiple frequency bands. The following discussion illustrates what a receiver will have to do to provide useable information at the destination. First, a signal that has been transmitted from a satellite to an earth station (having travelled anywhere from 300 to 22,600 miles or more) is on the order of picowatts. Upon reception, the receiver must amplify the signal. However, the associated noise and interfering signals accompanying the desired signal will also be amplified. Therefore, the desired signal must be selected and any undesired signals must be rejected as much as possible. Finally, the receiver must demodulate the received signal and recover the original modulating information to provide actual intelligence to the user. A simple satellite earth station receiver is illustrated in Figure 2.3.

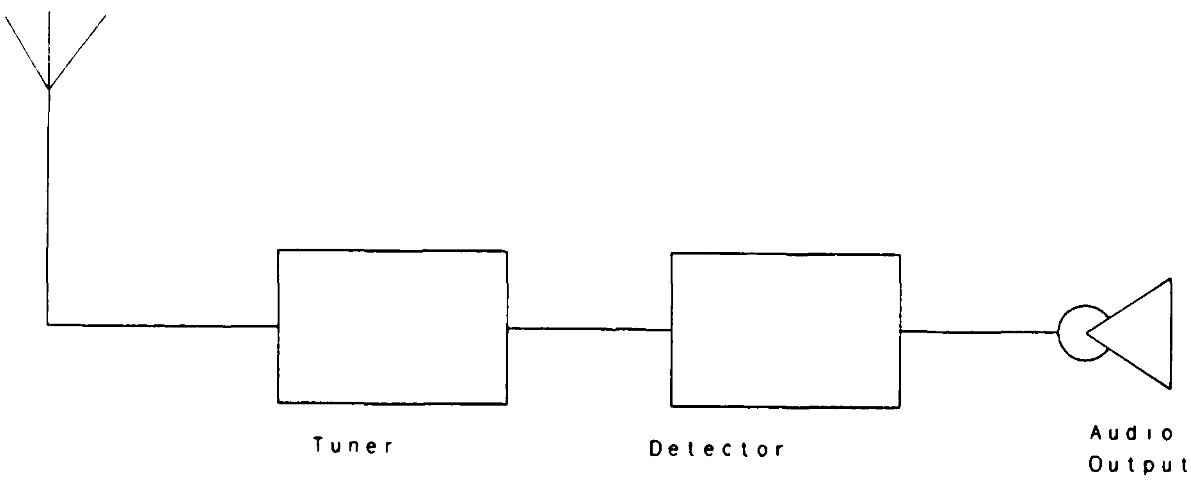


Figure 2.3 Receiver Block Diagram

Different manufacturers have designed and produced receivers based upon their own designs and ability to meet these specifications. A popular receiver architecture since 1930 is the superheterodyne receiver [3]. Figure 2.4 illustrates such a receiver. Referring to Figure 2.4, the information signal voltage is mixed (or heterodyned) with a local oscillator (LO) voltage, producing several signal products.

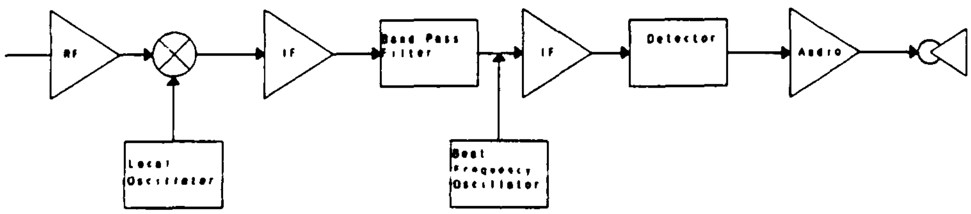


Figure 2.4 Block Diagram of Superheterodyne Receiver

These include the two original signals, their sum, and their difference signals. Typically, only the lower difference frequency is used any further, and is now referred to as the intermediate frequency (IF). The signal at this IF contains the same modulation as the originally received information signal. It is amplified and detected (or demodulated) to reproduce the originally transmitted information. A local oscillator signal injected into the second IF before the detector is referred to as the beat frequency oscillator (BFO). A BFO permits the recovery of the CW signals and the proper demodulation of SSB signals.

The advantage of the superheterodyne receiver is that the frequency conversion process allows signal amplification at the lower frequencies of the IF stage. This technique permits high system gain and selectivity economically in terms of cost and number of components. Further, this gain and selectivity are constant. By using the separate local oscillators the designers can optimize the oscillators for stability.

2.3.3 Antennas

Antennas for any communications should be optimized to the needs of that system. This reasoning is valid for terrestrial and satellite communications. For amateur satellite communications, antennas that can assist the entire transmitting system in achieving an effective radiated isotropic power (EIRP) levels of greater than 20 W as recommended by the AMSAT organization are desirable [2]. The EIRP is the electromagnetic energy radiated out the antenna main beam. The EIRP is determined by the output power of the transmitter, the energy lost in the transmission line, the gain of a power amplifier (if used), and the gain of the transmitting antenna.

There are numerous types of antennas, just as there are various receiver types. Some of these are the dipole, the helix, the beam, and the turnstile antennas. For any type of radio frequency communications, the polarization of the receiving antenna should match the polarization of the transmitting antenna. Most of the amateur satellites employ circularly polarized antennas.

There are two common types of circularly polarized antennas used in amateur satellite communications today. These are the crossed Yagi-Uda and the helix antenna. The Yagi-Uda antenna can be considered as two regular Yagi-Uda antennas that have been assembled onto a common boom. The antenna elements are crossed to form an X shape. The antenna is polarized in a circular fashion when one of the driven elements is fed signal power 1/4 of a cycle later than the other. On the other hand, the helix antenna looks somewhat like a suspension spring on an automobile or the threads of a screw. The helix antenna creates a circularly polarized signal by virtue of its design.

2.3.4 Antenna Rotator

The function of a rotational device, more commonly referred to as a rotor, is to provide the ability to change the azimuthal and elevation pointing angles for the receiving and transmitting antennas. Typically, an antenna rotator is controlled by a separate rotator controller. Modern rotators receive antenna pointing instructions from computer software programs.

2.3.5 Transmission Lines and Connectors

There are two major types of transmission lines. These are the balanced, or parallel conductor, and the unbalanced (or coaxial type) transmission lines [9, 10]. Balanced transmission lines include open-wire lines that are spread apart at a constant interval by some type of insulation and the twin-lead balanced line. The twin-lead line is one in which the lines are encased in a solid or foam insulator. Typical signal power losses result from either poor insulation, natural ohmic radiation losses, or from radiation from the line. Unbalanced (coaxial) lines are those that deviate from this specification. Coaxial lines experience signal power loss due to ohmic resistance and connections to other components.

The following is a brief discussion of connector types for transmission lines. Every transmission line experiences signal power losses. If an incorrect cable termination is made, additional signal power losses occur beyond the expected ohmic resistive power losses. ARRL and AMSAT researchers indicate these additional losses can range from fractions of

1 dB to 5 dB or more of signal power [1, 2, 5]. This degrades the system signal-to-noise ratio and could cause serious problems in satellite communications. Poor connection fittings can cause the entire communications link to fail, where the difference between satisfactory and unsatisfactory communications may be 15 to 20 dBW of power.

There are numerous types of connectors on the market. However, three are commonly used in amateur radio applications. These are the UHF, N-type, and BNC connectors. The factors determining the type of connector to use are the operating frequencies, the physical size of the cable, and the power levels involved [1, 2].

The UHF (the male version is also called the PL-259) connector is used at HF and some VHF frequencies. The female version of the UHF connector is often referred to as the SO-239. Davidoff discusses the apparent misnomer for this connector [1]. The UHF connector does not perform well at UHF because of a lack of constant impedance. UHF (PL-259) connectors are commonly used for RG-8, RG-11, and RG-58 cables. For low power work at VHF and UHF, BNC connectors may be used. BNC connectors can be used with RG-58 and RG-59 cables.

For amateur satellite operations, the N-type connector is recommended because it induces less signal power loss [1, 2, 5, 6, 11]. N-type connectors can be used with RG-8 and RG-213 cables. There are male and female versions of the N-type connector. N-type connectors are designed for constant impedances [2].

2.3.6 The Decibel

Because the parameters dBd, dBi, and dBc may not be familiar to all readers, an overview follows. Recall that the decibel is a term of relative measurement. The decibel when used to measure an absolute voltage, current, or power level, must be used in terms of a reference level. In terms of radio frequency operations and measurements, power is often given in terms of dBW (decibels when referenced to 1 watt) or dBm (decibels referenced to 1 milliwatt). Using this type of system, an operator might find that 2 kilowatts equals about +63dBm or +33 dBW. Also, 5 microwatts would equate to about -23 dBm or -53 dBW. In terms of voltages, these are often shown as decibel values with respect to either 1 volt or 1 microvolt. Therefore, 2 millivolts would equate to +66 dBμV or -54 dBV.

When measuring antenna performance, the gain of the antenna is given with reference to some standard reference element like an isotropic radiator or a half-wave dipole. The units of measurements here are the dBi or the gain over an isotropic antenna and the dBd, the gain over a half-wave dipole. The unit of dBc is used to refer to a gain for a circularly polarized antenna.

2.3.7 Modem

A modulator-demodulator, or modem, is a device that accepts incoming digital electrical signals and produces (modulates) tones (frequencies) for each signal. These different tones will correspond to the present state of each digital bit transmitted over an analog medium [6]. In some systems, these tones are referred to by the historical term "mark" (for the binary 1 - the high bit) and "space" (for the binary 0 - the low bit). Some systems reverse this order.

For amateur satellite communications, a modem must permit Manchester-encoded AFSK and PSK modulation schemes to be employed in the system. Many OSCAR satellites use an uplink with Manchester-encoded AFSK modulation and a downlink using PSK modulation [1, 5]. Because most terrestrial amateur packet controllers use AFSK modulation for both transmission and reception, they will not communicate successfully with some of the OSCAR packet satellites without an external PSK modem. Some satellites, such as the DO-17 platform use normal AFSK (or synthesized voice) downlink signals [1]. Some of the UOSAT satellites use 9600 baud FSK uplink and downlink signals. Others use AFSK for the uplink and PSK for the downlink.

A common modem in amateur earth stations is the Pac-Comm PSK-1 modem. This device performs three primary functions. These are to 1) communicate with packet satellites in conjunction with a packet TNC, 2) to permit terrestrial line-of-sight or satellite communications using PSK modulation, and 3) to permit reception of 400 bps satellite telemetry transmission [12, 13].

A terminal node controller is the interface between a computer and the modem. The function of the TNC is to convert (encode) binary information into a packetized format for presentation to the modem.

2.3.8 Satellite Tracking Software

In order to communicate with an orbiting satellite, an operator must know where to find the satellite at any given instant in time. If the earth station is equipped with a directional satellite antenna, it can be directed toward the satellite by means of an antenna rotator. This will result in successful establishment of a link.

Some of the required information about the location of the satellite include the range of the satellite, the present azimuth, the present elevation, current operating mode, approximate velocities of the satellite, and the access time (the estimated time period the satellite will pass over the tracking earth station) for a given pass of the satellite. The access times should indicate the initial time for the acquisition of signals (AOS) from the satellite and the approximate time for the loss of signals (LOS) from the satellite. An additional criteria for tracking is the epoch time. Epoch time is the reference time at which the orbital parameters (element sets) are specified. An element sets is a collection of six (usually) numbers specified at the epoch time which completely determine the size, shape, and orientation of a satellite orbit [1]. The epoch time and the orbital element sets must be kept as current as possible to provide the most accurate tracking information. If the epoch time is too old, the tracking data may be a few minutes off at the time the station operator tries to communicate with the satellite. With some amateur satellites, the entire time the satellite is in view may be only 5 to 15 minutes. Therefore, the satellite may be out of view before the operator even realizes the situation and communications will fail.

In most cases, these pieces of information require some previous knowledge of the satellite such as the previous orbit used by the satellite, the type of orbit used, the times the satellite is operational and dormant, and the modes the satellite uses at a given period of time. All of this information is readily available from numerous sources such as local computer bulletin boards [1, 2, 5, 11, 14].

2.4 Summary

This chapter presented background information for this thesis. Initially, background information on satellite communications and data types was presented. A discussion of the common orbits for amateur satellites followed. Then, selected targets of interest were introduced. Finally, an overview of common earth station equipment was presented.

Chapter III Requirements

3.1 Overview

This chapter develops the requirements for the AFIT earth station. The requirements are dictated by the capabilities of the targets. Of particular interest are the signal power levels for the targets. Technical issues concerning the targets of interest are presented. Some of these issues are the modes of operation for specific satellites, satellite transponder requirements, and modulation methods employed by the satellites. Requirements to complete a communications link between an earth station and a terrestrial radio station are presented. Then, the requirements for a communications link between an earth station and an earth orbiting amateur satellite are discussed. Because the earth station must be able to communicate both on mode B and mode J, AO-13 is used as the example target in the following discussions. Similar computations and analysis applies to the other targets.

The requirements discussed in the following sections are for the design and implementation of an earth station for the Air Force Institute of Technology. Due to the increase in military satellite communications, Air Force engineers must have improved knowledge of methods to communicate with satellites and with other stations via satellites. The project described in the following chapters must result in a useable training and research tool for future Air Force engineering students at the Air Force Institute of Technology. To provide the flexibility for training future engineering students, the AFIT earth station must be capable of communicating with both satellite and terrestrial radio stations.

Multiple capabilities, to include the ability to communicate via voice or digital data modes, are required to educate the user on the multifaceted needs and abilities of these types of systems. The problem statement and objectives of this thesis focus on the research, design, implementation, testing, and documentation of an earth station for the AFIT Graduate School of Engineering.

The problem of designing and implementing a satellite earth station may appear trivial at first glance. However, numerous technical issues must be answered first. These issues range from the type of transmitter and receivers to employ, to the type of cabling to install, and on to the specific types of connectors to attach to the cabling. Other issues include the selection of computer-based tracking software accurate enough to provide passover windows to within seconds of coverage. These issues, among others, can dictate the success or failure of proper operation for a satellite earth station.

To obtain the necessary information to determine the required station equipment, an exhaustive literature review was conducted at the AFIT, the University of Dayton, the Wright State University, and several area amateur radio service club libraries. Considerable data was obtained from numerous commercial communications publications. Private amateur radio enthusiasts shared invaluable resources from their personal collections. The information used from each of these sources of information is documented throughout this thesis.

3.2 Technical Issues Concerning the Targets of Interest

Technical issues concerning the targets of interest are reviewed in the following sections to provide supplemental data to the reader. One of these issues are the system characteristics for the targets of interest. These target characteristics define the requirements for the earth station equipment. The operating modes for each target will define the precise operating frequencies needed for the earth station transmitter and receiver. The transponders used by the targets of interest will refine the earth station equipment capabilities even further. Other characteristics such as the modulation methods and signal power levels generated for each target are used to produce an accurate list of requirements for the earth station. Appendix B documents the complete operating characteristics of the earth-orbiting amateur satellites for the interested reader.

3.2.1 System Characteristics

System characteristics for the targets of interest are the mode, type of orbit, lifetime, signal power levels, modulation methods/signal types, and types of transponders employed. In general, the terrestrial targets had to employ similar capabilities and characteristics as the selected earth-orbiting satellites. The terrestrial targets were used to check out the operation and capabilities of the earth station before actual satellite communications were attempted. Therefore, the focus of the following discussions is on the earth-orbiting satellites.

These characteristics then dictate the requirements for the earth station equipment. The lifetime of the satellite is important. Each target selected for the thesis had to remain in orbit and to remain functional for the duration of the thesis. Table 3.1 lists the characteristics for the selected targets. Transponder types are dictated by the operating modes. As seen from Table 3.1, most of the amateur satellites employ a low-altitude circular orbit and low signal power output levels in the range of 1 - 4 W EIRP. This combination makes the acquisition of signal from these platforms a difficult task, if the proper equipment is not used at the earth station. Therefore, the requirements for the earth station equipment were obtained from the target performance specifications.

Table 3.1 Target Characteristics

Target	Mode Designator	Orbit	Output Signal Power Levels	Modulation Methods
UO-11	(*Note 1)	low-altitude circular	400 mW - 600 mW	CW, SSB, RTTY
AO-13	B, JL, L, S	Molniya	~ 50 W 1.25 W	RTTY, CW, BPSK, SSB
UO-14	J	low-altitude circular	10 W	AFSK, FSK
UO-15	(*Note 2)	low-altitude circular (*Note 3)	10 W	AFSK, FSK
AO-16	JD	low-altitude circular	1 - 4 W	BPSK
DO-17	JD	low-altitude circular	1 - 4 W	AFSK
WO-18	JD	low-altitude circular	4 W	BPSK
LO-19	JD	low-altitude circular	0.8 - 4 W	BPSK
FO-20	JA, JD	low-altitude elliptical	2 W	PSK, CW

Note 1: UO-11 does not employ open-access transponders. There are three beacons of interest - one at 145.826 MHz, one at 435.025 MHz, and one at 2401.5 MHz.
Note 2: UO-15 does not employ a transponder. It has a beacon at 435.120 MHz.
Note 3: UO-15 suffered serious performance problems after its third orbit. Therefore, it operates only a small portion of each day.

3.2.2 Modes of Operation for Specific Satellites

In some instances, amateur satellites employ more than one operating mode during a satellite passover. This means that an earth station operator can begin to communicate via a high-orbit OSCAR platform using one range of frequencies (such as 435 MHz up and 145 MHz down - mode B) and switch to another range of frequencies (such as 1.2 GHz up and 435 MHz down - mode JL), when the platform switches to that mode.

For example, AO-13 employs the mode B for the predominant portions of its operating day. However, it switches to mode JL and mode S on portions of each day. Specifically, AO-13 operates on mode JL near apogee for about two hours per orbit. AO-13 operates using mode B for the remainder of the orbit, when the spacecraft is in sunlight. Mode S is used by AO-13 near apogee for only 30 minutes per orbit [1].

Details on the various modes of operation used for the targets of interest are found in Table 3.2. From Table 3.2, it can be seen that modes B, J, JA, JD, JL, L, S, and U are used for the satellites of interest for this thesis. These satellite characteristics dictate the earth station requirements such as the operating signal power levels and methods of modulation required for the earth station. Therefore, earth stations wishing to communicate with these satellites must employ equipment capable of transmitting and receiving the proper frequency ranges and operating in one of the modulation methods listed in Table 3.2.

3.2.3 Satellite Transponder Requirements

As mentioned, the orbiting targets of interest are the UO-11, AO-13, UO-14, UO-15, AO-16, DO-17, WO-18, LO-19, and FO-20 satellites. Each satellite was designed to employ specific types of transponders. These transponders dictate the modes (and therefore the operating frequency ranges) and types of signals the satellites can employ. This requirement further dictates that any earth station wishing to communicate with a specific satellite must use equipment capable of communicating with the satellite transponders. Appendix B specifics the transponders used by each of the target satellites. The following paragraphs provide background information on the function and types of transponders employed in the amateur satellites of interest to this thesis.

3.2.3.1 Linear Transponders

A linear transponder is defined as a device which receives a portion of the RF spectrum centered about a specific frequency, amplifies the received signals linearly, and

Table 3.2 Amateur Satellite Transponder Modes

Mode Designator	Satellite Uplink Band	Satellite Downlink Band	Satellites in orbit
A	145 MHz	29 MHz	RS-10/11, RS-12/13
B	435 MHz	145 MHz	AO-10/AO-13
J	145 MHz	435 MHz	FO-20
JA	145 MHz	435 MHz	FO-20
JD	145 MHz	435 MHz	FO-20, AO-16, LO-19, WO-18, UO-14
JL	1.2 GHz/145 MHz	435 MHz	AO-13
K	21 MHz	29 MHz	RS-10/11, RS-12/13
KA	21 MHz/145 MHz	29 MHz	RS-10/11, RS-12/13
KT	21 MHz	29 MHz/145 MHz	RS-10/11, RS-12/13
L	1.2 GHz	435 MHz	AO-13
S	1.2 GHz	2.4 GHz	AO-13
T	21 MHz	145 MHz	RS-10/11
U*	435 MHz	145 MHz	RS-10/11

*Note: Mode U is the same as mode B. German amateur radio operators built the transponder for the RS-10/11 satellite and refer to is as the U-transponder.

translates the received frequency to another segment of the RF spectrum. Once this occurs, the amplified, translated signals are retransmitted to the source [1, 2]. Some of the OSCAR platforms employ transponders that can handle many signals simultaneously, with the input power of each received signal being amplified approximately 10^{13} times (about 130 dB) before the signals are retransmitted to the earth.

In terrestrial applications the term linear translator is used. Publications like the ARRL Handbook refer to linear translators installed in earth-orbiting satellites as linear transponders [2]. Linear transponders can be used for several types of signals. Some of these are amplitude modulation (AM), amplitude-compandored single side band (ACSSB), FM, slow scan television (SSTV), and CW.

There are two common types of linear transponders. These are the linear, inverting and the linear, non-inverting transponders. The linear, inverting transponder, as the name implies, will flip, or invert, the frequency positions of the band edges before retransmitting the signal. The non-inverting, linear transponder simply retransmits the signals shifted to a different frequency [1, 2, 6, 15]. Figure 3.1 illustrates the non-inverting linear transponder. Figure 3.2 shows the inverting linear transponder.

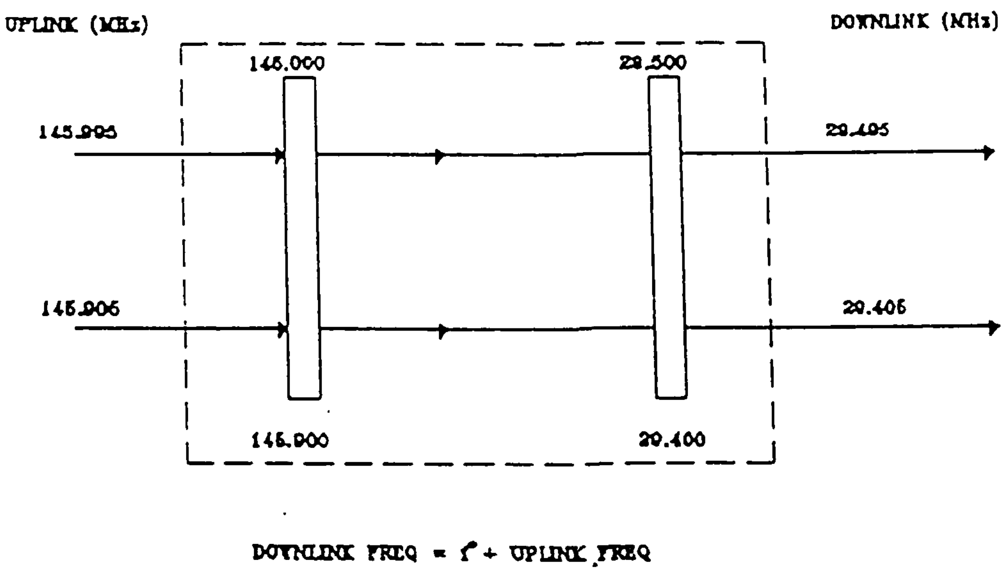


Figure 3.1 Non-inverting Linear Transponder

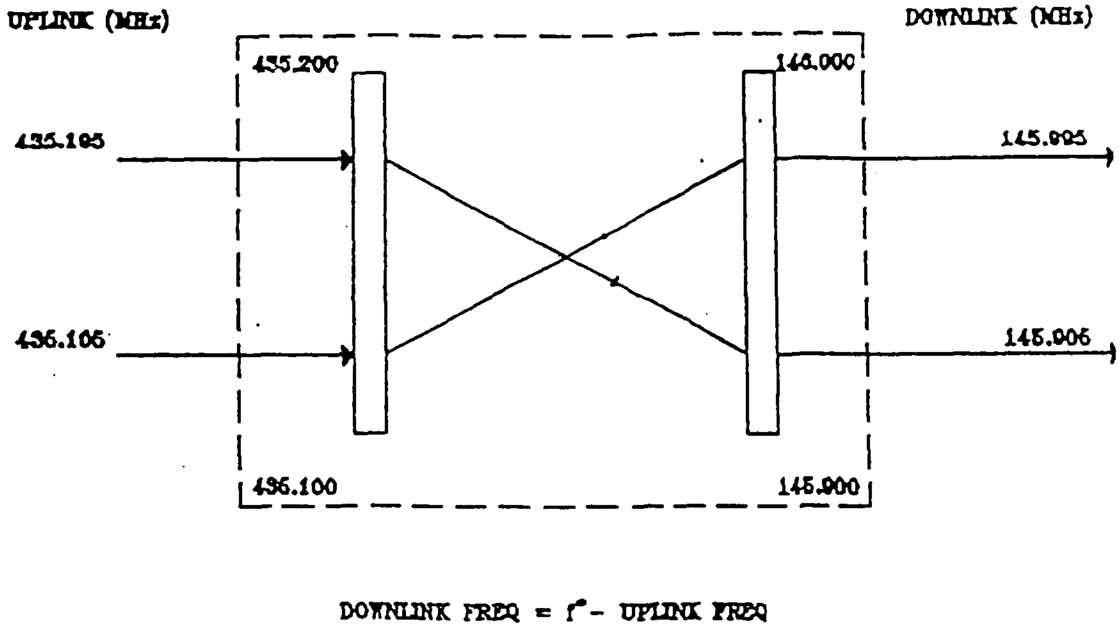


Figure 3.2 Inverting Linear Transponder

3.2.3.2 Digital Transponders

In contrast to linear transponders, digital transponders are non-linear devices. The digital transponder is enhanced to receive, process, and retransmit the captured information using digital signals rather than analog signals [1, 2, 6, 15]. In the amateur satellites employing digital systems (such as FO-20), the entire data link is transmitted in digital, packetized form from the transmitting station to the receiving station. Early amateur radio systems did not packetize the digital data [19]. They used raw data streams with no error checking or correction, resulting in abysmal error rates and poor results. Therefore, more sophisticated methods were needed. Packet transmission and digital transponders are examples of these more sophisticated devices.

3.2.4 Modulation Methods

Modulation is the process of altering some characteristics of a carrier wave in accordance with the instantaneous value of the modulating signal [3]. A carrier wave is a wave having at least one characteristic that can be altered from a known reference level through the process of modulation. Demodulation, as the name implies, is the process of recovering or deriving the original modulation signal from a modulated carrier wave [3]. The major types of modulation are amplitude, angle, and pulse modulation. Within the angle modulation type, there are two common forms - frequency modulation (FM) and phase modulation (PM).

In most cases, the satellite (and the earth station) must employ separate modulation/demodulation devices and associated equipment to process the various types of signals input to the satellite (and the earth station). Devices such as modems (modulator/demodulator) and terminal node controllers (TNCs) provide the ability to process the modulated signals in separate computers on the satellite (and earth station) and permit the computer interfaces (switch boxes, serial interface connectors, etc) to feed the processed signals into the receiver of the satellite. Likewise, when a satellite transmits a modulated signal such as phase-shift keying (PSK) packetized data (mode JD), the satellite transmitter must either have a built-in capability to modulate the signal accordingly or use a separate set of modems, TNCs, and interface connectors to modulate the signal for transmission through the transmitting antenna.

3.2.5 Satellite Transmitting and Receiving Signal Power Levels

The following sections discuss the given range of target transmitting and receiving signal power levels for the satellites. These are established parameters for each target. Also discussed are the types of antenna systems employed for transmitting and receiving. These parameters are used to define the signal power levels the earth station must employ to either transmit signals to or receive signals from a target satellite.

3.2.5.1 Satellite Receiving Signal Power Levels

According to the southwestern Ohio AMSAT coordinator the exact receiving sensitivities for the target satellites have not been published in open literature to date [16]. According to both ARRL publications and the southwestern Ohio AMSAT coordinator, a typical signal power sensitivity for a terrestrial receiver is approximately -143 dBW [2, 16]. This value will be used as the receiving signal power for the target satellites.

3.2.5.2 Satellite Receiving Antennas

The type of antennas used by the target satellite will refine the earth station equipment parameters. For example, the polarity employed in a particular satellite receiving antenna will require the earth station to employ similar capabilities for the transmitting antenna. The types of some of the target satellite receiving antennas are listed in Appendix B [1, 2]. The type and polarization depend upon the mode of operation employed by the satellite. Some of the satellites, such as AO-13, use right hand circularly polarized (RCHP) monopoles with gains of 2 to 15 dBic for mode J reception. For mode B operation, some of the satellites receiving antennas are linearly polarized with gains of -2dBi to 20 dBi. The FO-20 spacecraft employs a 1/4-wavelength monopole for mode J reception. The AO-16, DO-17, WO-18, and LU-19 satellites receive using a linearly polarized stub antenna slightly shorter than a 1/4-wavelength monopole [1, 2].

3.2.5.3 Satellite Transmitting Signal Power Levels

The transmitter power levels for the satellites range from 0.8 W (LO-19) to 50 W

(AO-13) [1]. As with the satellite receiving signal power levels, the satellite transmitting signal power levels can be obtained. Appendix B lists the nominal satellite transmitting EIRP levels computed by the various AMSAT organizations for the target satellites [1, 2]. The transmitting signal power levels for the AO-13 satellite are well documented and are unalterable by the earth station operator.

3.2.5.4 Satellite Transmitting Antennas

Similar to the satellite receiving antennas, the satellite transmitting antennas will require the earth station to obtain similar capabilities. For mode J operation, the AO-16, DO-17, WO-18, and LU-19 satellites use a canted turnstile consisting of four radiating elements mounted on the bottom of the satellite [1]. The FO-20 spacecraft transmits on a canted turnstile mounted on top of the spacecraft. The gains for these transmitting antennas range from 6 to 16 dBi [1, 6].

The AO-13 satellite transmits on three phased two-element beams using RHCP and a linearly polarized monopole for mode J. The antenna gains for mode J operation range from -2 to 6 dBi. For mode B, AO-13 uses a linearly polarized monopole with a gain of -2 dBi and three phased dipoles over ground with a gain of 9.5 dBic. The three phased dipoles use RHCP.

3.3 Earth Station Receiving Equipment Requirements

The earth station receiving equipment requirements are derived from the target selection set. The terrestrial targets include a requirement for FM, not required by the amateur satellites. Other than this requirement, the amateur satellites will dictate the remaining earth station equipment requirements. These requirements include the equipment operating parameters such as operating frequency ranges, modulation methods, and signal power levels for the earth station equipment.

3.3.1 Earth Station Receiving Equipment Power Levels

The output signal power of the target satellites in modes B, JA, JD, and S operation, the free space path loss, the earth station receiving antenna gain, the earth station receiving station preamplifier gain, the losses of the transmission line from the receiving antenna to the earth station receiver are investigated to estimate the signal power delivered to the earth station receiving system by the target satellites. The specific user earth station requirements discussed in the following paragraphs are drawn from research performed by the ARRL, AMSAT, and private amateur radio clubs [1, 2, 17]. Appendix B provides recommended earth station receiving equipment for the target satellites [1, 2, 5].

The satellite transmitting power begins the definition of the requirements for the earth station receiving signal power. The target satellites employ output signal power levels from 0.8 W to 50 W depending upon the mode, orbital parameters, and the selected satellite. For low-earth-orbiting (LEO) satellite communications, the receiver should have some degree of built-in signal tracking capabilities such as an automatic frequency control (AFC) system. Due to the Doppler effect, the actual frequency of the received signal may differ from the frequency being transmitted. If the receiver does not have this capability, a separate component will be required to provide this function. To estimate the required receiving power levels, the AO-13 to earth station downlink is presented for both mode B and mode J.

The AO-13 spacecraft transmitter outputs 12.5 W for the entire 150 KHz passband and the transmitting antenna for mode B has a gain of 4 W [1, 4]. This gives an EIRP of 50 W (17 dbW) for mode B operation for a single user. However, if there are two simultaneous users, then the signal power level is split between the two. Similarly, if four users are active simultaneously, then each would receive 3.125 W of output signal power from the transmitter. Assuming an average loading of three simultaneous users, each would receive 4.2 W. Therefore, the EIRP drops to 12.25 dBW for this loading.

For mode JL, AO-13 has a transmitter output power of 12.5 W and the transmitting antenna has a gain of 9 W (9.5 dBic) [4]. This provides an EIRP of 118.75 W (20.75 dBW) for a single user. Typically, the AO-13 is not heavily loaded for mode J operations [16]. Therefore, the single user value will be assumed as a valid assumption.

At this time, the free space path loss must be computed for the downlink from AO-13 to the earth station. For free space approximations, the amount of power an earth station located at a given distance from a radiating radio frequency source receives is inversely proportional to the square of the distance. Many of the amateur satellites now in orbit have highly elliptical orbits. Therefore, when an amateur satellite is at apogee, the path length and subsequent path loss can range from -120 dB to -190 dB [1, 2, 15]. To compute approximate values for free-space path losses, Equation (1) is used [15].

$$L_{fs} = 32.45 + 20 \log f + 20 \log d \quad (1)$$

where L_{fs} = path loss, dB

d = distance, Km

f = frequency, MHz

Freeman provides a different form of the previous equation which is shown as Equation (2) [15].

$$L_{fs} = 20 \log (4\pi d/\lambda) \quad (2)$$

where L_{fs} = free space path loss, dB d = di·‧ance,

λ = wavelength and d and λ are in the same unit.

The approximate downlink (from AO-13 to the earth station) path losses, when AO-13 is operating in mode JL, are estimated as shown below. The first calculation (Equation (3)) is for the link from AO-13 at its apogee point to the earth station. For AO-13 at apogee in mode JL operation, it can be seen that

$$L_{fs\text{-}down} = 32.45 + 20 \log f + 20 \log d \qquad (3)$$

$$= 32.45 + 20 \log (435) + 20 \log (36{,}265)$$

$$= 176.41 \text{ dB}$$

The second calculation (Equation (4)) is for the path losses between AO-13 at its perigee point and the earth station . For AO-13 at perigee in mode JL operation, it can be see that

$$L_{fs\text{-}down} = 32.45 + 20 \log f + 20 \log d \qquad (4)$$

$$= 32.45 + 20 \log (435) + 20 \log (2545)$$

$$= 153.33 \text{ dB}$$

For mode B operation, values are obtained using Equation (5). These values for AO-13 at apogee are computed to be

$$L_{fs\text{-}down} = 32.45 + 20 \log f + 20 \log d \qquad (5)$$

$$= 32.45 + 20 \log (145) + 20 \log (36{,}265)$$

$$= 166.87 \text{ dB}$$

For AO-13 at perigee in mode B operation, it can be seen that

$$L_{fs\text{-}down} = 32.45 + 20 \log f + 20 \log d \qquad (6)$$

$$= 32.45 + 20 \log (145) + 20 \log (2545)$$

$$= 143.79 \text{dB}$$

Table 3.3 summarizes the path losses for AO-13 at both apogee and perigee.

Table 3.3 Computed Free Space Path Loss for AO-13

Mode Designator	Path Loss at Apogee (dB)	Path Loss at Perigee (dB)
B	166.87	143.79
JL	176.41	153.33

Numerous studies have been conducted on the various atmospheric anomalies contributing to the total path loss between orbiting satellites and an earth station. As a comparison, the results of studies by the ARRL on the path losses for AO-13 at apogee are presented in Table 3.4 [1, 2]. These values include the tropospheric and ionospheric absorption and refraction losses.

As can be seen from both the tabulated data and the computed values, the signal power path losses for AO-13 at apogee and operating in mode JL range from 166 - 169 dB. When AO-13 is at apogee and in mode B operation, the estimated path losses are in the range of 176 - 178 dB. When AO-13 is at perigee, the computations indicate the path losses will not be as severe. In mode B, the free space path losses will be approximately 144 dB. In mode JL, the losses will be approximately 153 dB. These free space path losses require an earth station be able to overcome these losses to even establish contact with AO-13 at the respective frequencies.

Now, the computed path losses can be used in performing preliminary link budget computations for earth station receiving signal power levels necessary to establish AO-13 communications. Figure 3.3 is a diagram of the receiving link from AO-13 to the AFIT earth station.

Table 3.4 Path Loss Attenuation Factors for AO-13 at Apogee

Source of Loss	2 m Band (145MHz)	70 cm Band (435MHz)
Path Loss	168.07 dB	177.57 dB
Tropo/Ionospheric Refraction	0.002 dB	0.0003 dB
Tropo Absorption	0.1 dB	0.7 dB
Ionospheric Absorption D-Layer	0.12 dB	0.013 dB
Ionospheric Absorption F-Layer	0.12 dB	0.013 dB
Ionospheric Absorption Aurora	0.13 dB	0.014 dB
Ionospheric Absorption Polar Cap Absorption	0.47 dB	0.053 dB
Total	169.012 dB	178.36 dB

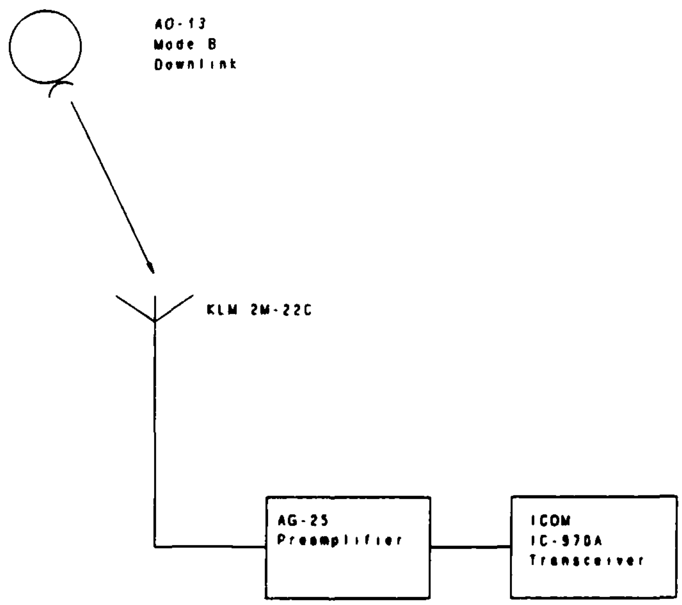


Figure 3.3 Diagram of the AO-13 Downlink to the AFIT Earth Station

Previously, an EIRP of 50 W ($G_{AO\text{-}13EIRP}$ = 17 dBW) was computed for mode B transmitting power (for a single user) from the AO-13 satellite. Also, the mode B free space loss (G_{fs}) is approximately 166.87 dB for the worst case scenario when AO-13 is at apogee. Then, Equation (7) can be used to compute the approximate signal power delivered to the earth station transmitter when AO-13 is at apogee and in mode B operation.

$$G_{AO\text{-}13EIRP} + G_{fs} = P_{AO\text{-}13} \quad (7)$$

17 dBW - 166.87 dB = -149.86 dBW delivered to the earth station

where $G_{AO\text{-}13EIRP}$ = the EIRP of AO-13

$P_{AO\text{-}13}$ = Signal power delivered to the earth station for mode B operation

Using the more realistic loading of three users, the AO-13 output EIRP is reduced to 16.8 W (12.25 dBW). Therefore, Equation (8) indicates the power delivered to an earth station would be

$$12.25\ \text{dBW} - 166.87\ \text{dB} = -154.62\ \text{dBW} \quad (8)$$

Therefore, the heavier loading on the AO-13 satellite produces about 5 dB less signal power.

The mode JL EIRP of 118.75 W (20.75 dBW) for a single user was found when the AO-13 spacecraft was at apogee. For mode JL operation, Equation (9) can be used to compute the signal power delivered to the earth station.

$$G_{AO\text{-}13EIRP} + G_{fs} = P_{AO\text{-}13} \quad (9)$$

20.75 dBW -176.41dB = -155.66 dBW delivered to the earth station

These computations indicate AO-13 in mode B operation delivers to an earth station about -149.86 dBW of signal power for a single user. Approximately -154.62 dBW of signal power is delivered in mode B operation for three simultaneous users. AO-13 delivers about -155.66 dBW for a single user in mode J operation. This analysis dictates a requirement that the earth station receiving equipment must be able to process signals at signal power levels of

-154.62 dBW for mode B and -155.66 dBW for mode J operation.

The combination of the earth station receiving equipment (the receiving antenna, the preamplifier, the transmission lines, and the receiver) must be optimized to process these power levels. As with the satellite transmitter, a terrestrial receiver sensitivity of -143 dBW is assumed for the earth station receiver [16]. Therefore, Equation (10) shows the amount of gain the remaining earth station components must produce to establish satellite to earth station communications while operating in mode B.

$$P_{AO\text{-}13} + G_{Rcvr} = P_{Rcvcmp} \tag{10}$$

where G_{Rcvr} = Sensitivity of the earth station receiver

P_{Rcvcmp} = Gain required from remaining components

-154.62 dBW + 143 dBW = -11.62 dB = P_{Rcvcmp}

Several combinations exist for the receiving system equipment. Numerous antenna types from a Yagi-Uda to a helix could be used. Several types of preamplifiers and transmission lines are available. To reduce the number of possible combinations, a few assumptions are made.

For this computation, the receiving antenna is assumed to be a Yagi-Uda antenna. The preamplifier is assumed to be optimized for the 144 - 146 MHz range. The transmission line is assumed to be hardline type cable and of a typical length of 50'.

Values for these components will now be computed in three ways. First, the receiving antenna will be optimized for high gain. Then, the preamplifier and transmission lines will be optimized to reduce signal power losses. Finally, typical values for all receiving components will be discussed. Research indicates typical gain values of 11.4 - 15 dB are valid for Yagi-Uda antennas optimized for 145 MHz and using 10 - 19 elements. For Yagi-Uda antennas with 15 - 40 elements, the typical antenna gains are between 15.57 - 20.8 dBi [2]. If a high gain, 40-element Yagi-Uda serves as the receiving antenna and produces 20.8 dBi of gain (G_{Rcvant} = 20.8 dBi), then the following computations will ascertain the gains needed for the preamplifier and the transmission lines. If the transmission line is 50' in length and the earth station is receiving in mode J operation, then Equation (11) can be used to find the gain of the transmission line. Then, the gain of the preamplifier can be established.

$$A_L = (L/100)\, A_O \tag{11}$$

where A_L = Attenuation of the transmission line

L = total length of the transmission line

A_O = the attenuation (in dB) of 100' of cable

For 0.5" hardline transmission line, the attenuation (A_L) is about 1.8 dB per 100' [1, 2]. Therefore, Equation (12) indicates the transmission line attenuation is

$$A_L = (50/100)\,(1.8\text{ dB}) \tag{12}$$

$$A_L = 0.9\text{ dB}$$

Now, the preamplifier gain (G_{Preamp}) can be computed as shown in Equation (13),

$$P_{Rcvcmp} = G_{Rcvant} + A_L + G_{Preamp} \tag{13}$$

$$11.62\text{ dBW} = 20.8\text{ dBi} - 0.9\text{ dB} + G_{Preamp}$$

$$\therefore G_{Preamp} = -8.28\text{ dB}$$

Equation (13) suggests the preamplifier could actually attenuate the receiving signal or that a preamplifier is not actually necessary, if a high gain of approximately 20.8 dBi Yagi-Uda type antenna is used.

Next, the preamplifier and the transmission lines will be optimized and a gain value for the receiving antenna will be computed. At 435 MHz, 0.875" hardline transmission line produces approximately 1.3 dB of attenuation [1, 2]. The assumption is made that 50' of this type of transmission line is used in the receiving system. Research indicates that typical preamplifiers in the 430 - 440 MHz range provide between 10 - 22 dB of gain [1].

Assuming the typical value of a preamplifier gain (G_{Preamp}) of 22 dB and an attenuation of only 0.65 dB for the transmission line, then the receiving antenna gain is computed using Equation (14)

$$P_{Rcvcmp} - A_L - G_{Preamp} = G_{Rcvant} \tag{14}$$

$$11.62 \text{ dB} + 0.65 \text{ dB} - 22 \text{ dB} = -9.73 \text{ dB}$$

Therefore, the receiving antenna does not have to produce any gain for the system, if the preamplifier and transmission lines are optimized for gain. The previous analysis suggests that if the system is optimized for a high gain antenna (with a gain $\geq$ 20.8 dBi) is used and a reasonable type of transmission line is used, a preamplifier is not needed for mode J operation on the downlink of an AO-13 to earth station communication link. If the preamplifier is optimized for gains of 22 dB and the transmission line is optimized for minimal attenuations, then a receiving antenna does not have to produce any gain for the receiving system. Realistically, the receiving antenna provides more than gain to the system. The polarization and other features impact whether or not a communications link is established.

A third example assumes nominal values for all components of the receiving system. The antenna is assumed to have a gain of 10 dB. The preamplifier is assumed to produce a gain of 11dB. The transmission line is assumed to produce about 1 dB for 50' of cable. Finally, the receiver is assumed to have a sensitivity of -143 dBW. Using these values, Equation (15) indicates that the receiving system using nominal values can produce a system gain of

$$10\ dB + 11\ dB - 1\ dB = 20\ dB \qquad (15)$$

In summary, if the assumption is used that the receiver has a typical terrestrial receiver sensitivity of approximately -143 dBW, then the remainder of the receiving equipment can be designed using only typical components to produce approximately 20 dB to overcome the required 11.62 dBW of signal power to establish communications on a mode J downlink from AO-13 satellite. As a comparison, the suggested downlink signal power for AO-13 in mode B is 23 dBW [1].

3.3.2 Earth Station Receiving Equipment Characteristics

Now that the signal power levels are established, other receiving equipment characteristics can be discussed. The target satellites employ frequencies from 145 MHz to 1.2 GHz. Also, both linear and digital transponders are used in these systems. Multiple modulation methods are found in the target satellites. These methods include RTTY, CW, SSB, FSK, and PSK. As seen in Appendix B, the satellite transmitting power levels range from 0.8 W to 50 W [1, 2]. Further, the satellites employ linearly polarized, RHCP, and left hand circularly polarized (LHCP) antennas. This set of operating criteria dictate the minimum requirements for the earth station receiving equipment.

The earth station receiving equipment must be able to match these parameters to establish satellite-to-earth communications. Therefore, the minimum requirements for the receiving equipment is discussed below. The receiving antennas should be capable of switching between RCHP, LCHP, and linear polarities. The receiving antenna should have a typical gain of approximately 10 dB. The preamplifier should produce a typical gain of approximately 11 dB and the transmission line should attenuate no more than 1 dB. Finally, the receiver should have as a minimum a sensitivity of -143 dBW to establish satellite communications using the typical receiving components.

3.4 Requirements for Earth Station Transmitting Equipment

As with the receiving equipment, the earth station transmitting equipment derives its requirements from the receiving capabilities of the satellites and the terrestrial targets. The terrestrial targets add in the requirement for FM modulation capability for the transmitting system. The following sections discuss these requirements.

3.4.1 Earth Station Transmitting Equipment Power Levels

To determine the earth station transmitting equipment power levels, an analysis of the AO-13 receiving system and the uplink to the system is presented. A diagram of the uplink is shown in Figure 3.4. Using this model, the required output signal power is calculated for the earth station transmitting equipment. As discussed in Section 3.2.5.1, this model assumes the satellite receiver sensitivity is -143 dBW.

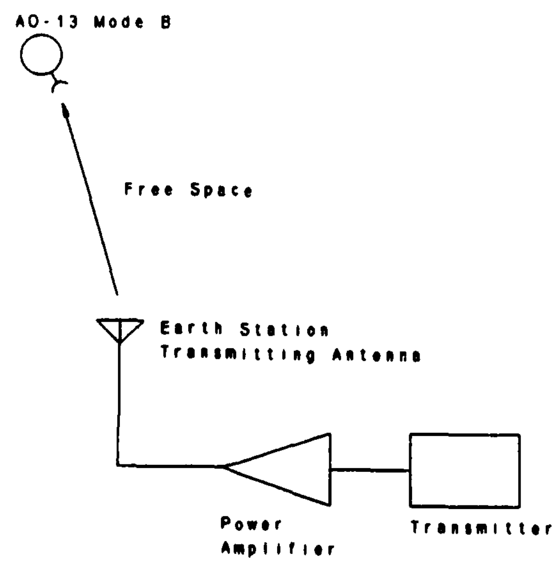


Figure 3.4 Earth Station Uplink to AO-13

As with the receiving system, to find the link budget values for the uplink, the free space losses are important. Equation (16) computes the free space loss between the earth station and AO-13 in mode B at apogee.

$$L_{fs\text{-}down} = 32.45 + 20 \log f + 20 \log d \qquad (16)$$

$$= 32.45 + 20 \log (435) + 20 \log (36{,}265)$$

$$= 176.41 \text{ dB}$$

For AO-13 at perigee in mode B operation, Equation (17) shows that the path loss is

$$L_{fs\text{-}down} = 32.45 + 20 \log f + 20 \log d \qquad (17)$$

$$= 32.45 + 20 \log (435) + 20 \log (2545)$$

$$= 153.33 \text{ dB}$$

For AO-13 at apogee in mode J operation, Equation (18) indicates the path loss is

$$L_{fs\text{-}down} = 32.45 + 20 \log f + 20 \log d \qquad (18)$$

$$= 32.45 + 20 \log (145) + 20 \log (36{,}265)$$

$$= 166.87 \text{ dB}$$

For AO-13 at perigee in mode J operation, Equation (19) indicates the path loss is

$$L_{fs\text{-}down} = 32.45 + 20 \log f + 20 \log d \qquad (19)$$

$$= 32.45 + 20 \log (145) + 20 \log (2545)$$

$$= 143.79 \text{ dB}$$

Table 3.5 summarizes the computed losses for the uplink free space path loss between the earth station and AO-13. The path losses are greater for the mode B uplink when AO-13 is at apogee.

Table 3.5 Computed Free Space Path Loss for Uplink to AO-13

Mode Designator	Path Loss at Apogee (dB)	Path Loss at Perigee (dB)
B	176.41	153.33
JL	166.87	143.79

By assuming a sensitivity of -143 dBW at the AO-13 receiver and computing the path loss, the required signal powers for the earth station transmitting system can be computed. Equation (20) provides the required transmitting signal power.

$$P_{AO\text{-}13} + G_{fs} = G_{Xmt} \qquad (20)$$

where $P_{AO\text{-}13}$ = Sensitivity of the AO-13 receiver (in dBW)

G_{fs} = Free space path loss (in dB)

G_{Xmt} = Power of the transmitting system (in dB)

143 dBW - 176.41 dB = -33.41 dBW

Equation (20) suggests the transmitting system needs to produce more than 33.41 dBW to establish communications to the AO-13 satellite in mode B operation. Mode B was selected for this analysis because it experiences greater free space path losses than mode J. As with the receiving system, the combination of transmitting equipment - the transmitting antenna, the power amplifier, the transmission lines, and the transmitter - must overcome the 33.41 dBW power requirement to establish satellite communications for AO-13 in mode B operations at apogee. As with the receiving system, the system can be optimized for the any of the components.

The transmitting system will be investigated from two approaches. First, the transmitting antenna will be optimized. Then, the transmitter will be optimized. During each computation, the gains of the remaining transmitting system components will be established.

A few assumptions are made to create a realistic earth station transmitting system. First, the assumption is made that the transmitting antenna is a wire antenna of Yagi-Uda construction. Second, the assumption is made that the transmission line is of nominal length of about 50' and is of hardline construction. Finally, the assumption is made that the transmitter is a typical terrestrial transmitter.

Typical gains for Yagi-Uda antennas operating at 435 MHz with 15 - 40 elements, are between 15.6 - 20.8 dBi [2]. Optimizing for the highest gain of 20.8 dB, Equation (22) computes the signal strength required from the remainder of the transmitting system.

$$33.4 \text{ dBW} - 20.8 \text{ dBi} = 12.6 \text{ dBW} \qquad (22)$$

Therefore, the combination of the transmission lines, the power amplifier, and the transmitter must produce at least 12.6 dBW to establish uplink mode B communications with AO-13. Assuming this is split evenly, then each component must produce a gain of 4.2 dB. Realistically, the transmission lines will reduce the signal power. Assuming 0.5" hardline is used, then Equation (23) indicates the signal power loss for the 50' of transmission line is

$$A_L = (L/100)\, A_O \qquad (23)$$

where A_L = Attenuation of the transmission line

L = total length of the transmission line

A_O = the attenuation (in dB) of 100' of cable

For 0.5" hardline transmission line at 435 MHz, the attenuation (A_L) is approximately 1.8 dB per 100' [1, 2]. Therefore, Equation (24) indicates the transmission line attenuation is

$$A_L = (50/100)\,(1.8 \text{ dB}) \qquad (24)$$

$$A_L = 0.9 \text{ dB}$$

Now, a realistic assumption can be made. If the transmission line loss is 0.9 dB, then the power amplifier and the transmitter must combine to produce approximately 13.5 dBW to establish communications with AO-13. If this is split evenly, then each must produce 6.75 dB. Terrestrial transmitters operating in the 435 MHz range typically produce from 7 - 17 dBW of power [2]. Typical power amplifiers can produce gains from 6 - 12 dB [1, 2].

Closer inspection of this analysis indicates that if the transmitting antenna is optimized to produce the 20.8 dB gain, the transmission lines induce only 0.9 dB of attenuation, then a power amplifier is not required for this system. A typical transmitter should be able to establish satellite communications on mode B with AO-13.

Now, the transmitter is investigated. As mentioned, terrestrial transmitters operating in the 435 MHz range typically produce from 7 - 17 dBW of gain [17]. If the transmitter gain is fixed at 17 dBW, then Equation (25) indicates the other components must produce gains of approximately

$$33.4 \text{ dBW} - 17 \text{ dBW} = 16.4 \text{ dB} \tag{25}$$

to establish communications. As in the previous example, the transmission line will induce roughly 0.9 dB of attenuation. This causes the power amplifier and the transmitting antenna to produce 17.3 dB to create the link. If the transmitting antenna produces gains more than 17.3 dB, the power amplifier is not required.

In summary, the transmitting signal power can be produced by optimizing one or more of the components. In the previous examples, the antenna and the transmitter were individually optimized. The result is that a system can be built with only the transmitting antenna, a transmission line, and a transmitter, is an antenna with a gain of more than 20 dB is used. Using the analysis of the previous paragraphs, an assumed uplink EIRP may computed by using the typical values of the individual components. These are shown in Equation (26)

$$P_{ant} * P_{xmsn} * P_{pwramp} * P_{xmtr} = P_{Typ} \tag{26}$$

where P_{ant} = Typical value of the transmitting antenna (36 - 120 W)

P_{xmsn} = Typical value of the transmission line attenuation (1.5 W/100')

P_{pwramp} = Typical value of the power amplifier (4 -16 W)

P_{xmtr} = Typical value of the transmitter (5 - 50 W)

P_{Typ} = Typical EIRP for the transmitting system

(36W * 4 W * 5 W)/1.5 W = 720 W EIRP

As a comparison, the recommended uplink EIRP from an earth station to the AO-13 satellite in mode B operation is 21.5 dBW. The computed typical value of 720 W EIRP (28 dBW) compares well with this recommendation.

3.4.2 Earth Station Transmitting Equipment Characteristics

The satellites employ receivers in the range of 145 MHz to 1.2 GHz [1, 2]. The receiving antennas on the satellites use linear, RHC, and LHC polarities. Also, the satellites use both linear and digital transponders. Furthermore, multiple methods of modulation such as RTTY, CW, SSB, FSK, and PSK are used in the receiving systems of the satellites [1, 2]. Therefore, the transmitting system must produce signal power levels such as those discussed in the previous section, employ antennas capable of switching polarities and that have gains of at least 17.3 dB, and be capable of multiple modulation methods.

3.5 Earth Station Target Tracking Characteristics

The earth-orbiting targets of interest have different orbits. These orbits vary from circular to highly elliptical to Molniya orbits [1, 2, 5, 14, 15]. Appendix B documents the various orbits for the satellites. Additionally, each satellite has an orbital period and other orbital mechanics unique to itself.

Tracking earth-orbiting satellites presents specific requirements for an earth station. To track the satellite in real-time or near real-time operations, several parameters must be known for the satellite. These parameters include the current altitude above earth, the velocity, the operating mode used by the satellite at its present position in time, and the satellite azimuth and elevation relative to the tracking earth station. To obtain the required information and actively track a satellite, in real-time operations, some method of automatically tracking the satellite is required. This may be a computer-based program and associated equipment that has the historical orbital parameters stored in memory or an established graphical analysis method with the appropriate equipment.

To track the earth-orbiting satellites, ARRL, AMSAT, and other amateur radio operators employ rotational devices for the receiving antenna systems [1, 2]. These rotational devices are commonly referred to as antenna rotors. One common type of antenna rotor permits both azimuthal and elevation antenna pointing and, therefore, satellite tracking capabilities. The requirement specified by the varying satellite orbits are for some type of rotor that can rotate the receiving and transmitting antenna continuously to follow the varied orbital paths. This dictated the rotor selected for the earth station had to be able to provide complete azimuthal coverage and horizon to horizon elevation control for medium and large size directional satellite antennas. Also, the rotational unit had to permit manual and automatic control to provide real-time manipulation of the antenna system.

To augment the rotational devices, some type of computer-based software program is required. The software program must be capable of storing the current altitude above earth, the velocity, the operating mode used by the satellite at its present position in time, and the satellite's azimuth and elevation relative to the tracking earth station for each target. Additionally, the tracking program must be capable of displaying this information to the user in a real-time scenario for accurate tracking and subsequent satellite communications.

3.6 Summary

This chapter provides background information on communication systems, data types, amateur satellites, earth stations, and the signal power levels for amateur satellites. This information has been used to specify the requirements for an actual earth station. Table 3.6 summarizes the earth station requirements. The requirements listed in Table 3.6 cover the equipment required for the station as well as the operating characteristics of the required equipment. These serve as the minimum earth station requirements. These requirements will be used to select the actual components for the earth station.

Table 3.6 Requirements for the AFIT Earth Station

Parameter	Specifications
Receiving Antennas	Switchable between polarities (RHC and LHC); Gain ≥ 15 dBic @ 436 MHz; Gain ≥ 13 dBic @ 145 MHz
145 MHz Preamplifier	Gain ≥ 15 dB @ 145 MHz
435 MHz Preamplifier	Gain ≥ 15 dB @ 435 MHz
Transmission Lines	Loss ≤ 6 dB/100' @ 435 MHz and ≤ 3 dB/100' @ 145 MHz
Receiver	Coverage of 144 - 148 MHz and 430 - 450 MHz for both terrestrial and satellite operations; Capable of multiple modulation methods such as SSB and FM for terrestrial communications; Packet data operation required
Transmitting Antennas	Switchable between polarities (RHC and LHC); Gain ≥ 15 dBic @ 436 MHz and Gain ≥ 13 dBic @ 145 MHz
Power Amplifier	Gain ≥ 15 dB; Min output power ≥ 150 W
Transmitter	Coverage of 144 - 148 MHz and 432 - 436 MHz for both terrestrial and satellite operations; Capable of multiple modulation methods such as SSB and FM for terrestrial communications; Packet data operation must be supported; min 12 W output signal power
Modem	Capable of FSK and PSK modulation methods
Tracking Devices	Complete azimuthal coverage and horizon-to-horizon elevation coverage
Tracking Software	Capable of displaying real-time data on each target

Chapter IV Satisfying the Earth Station Requirements

4.1 Overview

The previous chapter investigated the requirements for an amateur radio earth station by examining the requirements dictated by the selected targets of interest. This chapter discusses how these requirements for an amateur radio earth station are met. To satisfy these requirements, it was necessary to conduct research into the current capabilities of each required component and select typical devices to fulfill the station needs. The following sections document this process.

4.2 Determining Earth Station Equipment

The requirements are specified in Table 3.6. Each requirement is discussed in the appropriate section of this chapter.

4.2.1 Earth Station Receiver

From the operating characteristics of the target satellites, it was determined that the earth station receiver must be capable of operating between 145 - 148 MHz and 434 - 436 MHz. The receiver must be designed to provide SSB modulation methods and data communications as a minimum. The receiver selected for the satellite earth station is as important as the transmitter. To communicate effectively, a station must be able to acquire as well as transmit signals.

For low-earth-orbiting (LEO) satellite communications, the receiver should have some degree of built-in signal tracking capability such as an automatic frequency control (AFC) system. Due to the Doppler effect, the actual frequency of the recieved signal may differ from the frequency being transmitted. To avoid the necessity of selecting an additional component for the earth station, the requirement for a receiver with AFC capability was given serious consideration.

There are a variety of receivers ranging from analog tuning single band receivers to digital tuning multi-band receivers. For employment in the AFIT earth station, special emphasis was placed on the ability of the receiver to acquire signals in the 145 MHz and 435 MHz frequency ranges (these cover the mode B and mode J operating requirements). The Icom IC-970A multi-band transceiver was selected for the AFIT earth station. It meets or exceeds the basic criteria established in Chapter 3 for an earth station receiver. It provides coverage of the 145 MHz and 435 MHz ranges, is capable of SSB modulation methods, and can be interfaced to external TNCs and modems for packet data operation. Table 4.1 provides a summary of the various characteristics of the IC-970A transceiver.

Table 4.1 IC-970A Characteristics

Parameter	**Value**
Frequency Coverage	140.1 - 150.0 MHz & 430.0 - 450.0 MHz
Modes	SSB (A3J), FM(F3), CW(A1)
Antenna Impedance	50 Ohms (unbalanced)
Transmitter Output Power	3.5 - 25 W (All mode)
Transmitter Modulation System	SSB - balanced modulation FM - frequency modulation

4.2.2 Earth Station Transmission Lines

The requirement is for transmission lines that permit losses of ≤ 6 dB/100' @ 435 MHz and ≤ 3 dB/100' @ 145 MHz. For an earth station, the transmission lines are a major consideration and must be selected with great care. Because satellite communications use the VHF and higher frequencies, the power loss characteristic and the impedance were major considerations. The transmission line should be selected to transfer the RF energy with a minimum of attenuation where the heat and radiation losses can be minimized.

When meeting these requirements for transmission lines for the AFIT earth station, the electrical characteristics and specifications of different cables were investigated. Specifically, RG-213/U and RG-8/U cables were selected for the earth station. Table 4.2 lists the typical losses for coaxial cables [1].

Table 4.2 Approximate Coaxial Cable Attenuation Values

Power Loss per Hundred Feet (dB)

Cable Type	**146 MHz (2m Band)**	**435 Mhz (70 cm Band)**
RG-58A	6.5	12
RG-58A/U	4.5	8.0
RG-8/M Foam	3.2	7.2
RG-8/U & RG-213/U	3.1	5.9
RG-8 Foam	2.1	3.7
RG-17	1.0	2.3
0.5" Hardline	1.0	1.8
0.75" Hardline	0.8	1.6
0.875" Hardline	0.7	1.3

Research by the ARRL indicates the values from Table 4.2 are for new cable that is free of imperfections. Table 4.2 indicates hardline cable provides the least amount of loss for the 146 MHz and 435 MHz frequencies. Hardline cable would produce less transmission line losses than the RG-8/U or RG-213/U cables. However, hardline was not selected due to the vastly higher cost compared to RG-8/U and RG-213/U cabling. Hardline cable (0.5") costs approximately $5.50 per linear foot. On the other hand, the RG-8/U cable costs about $0.25 per foot. Likewise, RG-213/U costs about $0.36 per foot.

Coaxial cable becomes more susceptible to power losses as it ages. Therefore, these signal power loss approximations will have to be reevaluated as the system ages. For instance, the sun's ultraviolet radiation changes the polymers in the outer jacket of the coaxial cable, making the jacket more brittle as the cable ages. If the cable is then physcially disturbed, it will crack and allow water to seep into the conductor area. The water changes the distributed constants of the cable so that the permittivity of the insulator (or through corrosion) the conductivity of the outer braid conductor, diminishes. The AFIT earth station incorporates several coaxial cables into the system. The basic requirement is for a loss $\leq$ 6 dB/100' @ 435 MHz and $\leq$ 3 dB/100' @ 145 MHz. Table 4.2 suggests the RG-213/U and RG-8/U coaxial cables (as well as other types of cables) meet or exceed this requirement.

The RG-213/U and RG-8/U cables provide acceptable power loss levels at the 145 MHz (~ 5.5 dB) and 435 MHz (~ 10.4 dB) frequencies. The RG-8/U cable was available locally from commercial suppliers. The RG-213/U cable used in the earth station installation was excess cable from previous AFIT projects.

4.2.3 Earth Station Preamplifier

The earth station requirements include a preamplifier that provides a gain $\geq$ 15 dB @ 145 MHz and has a noise figure $\leq$ 3 dB. Similarly, a requirement exists for a preamplifier that provides a gain ≥ 15 dB @ 435 MHz and has a noise figure ≤ 3 dB. The following paragraphs discuss how these requirements were met.

Analysis shown in Section 3.6 indicates roughly -154.62 dBW of signal power will be delivered to the earth station receiver from AO-13 in mode B operation. This analysis was performed by combining the published transmitting EIRP for AO-13 in mode B with computed free space path losses for a typical mode B downlink. Then, the receiving system was modelled to establish the requirements for the earth station. After modelling the receiving system, the results suggest a preamplifier with a gain of approximately 15 dB in the 145 MHz range would provide better performance for the AFIT earth station. The selected preamplifier is the AG-25 from the ICOM Company. The manufacturer specifications suggest the AG-25 has a gain of 20 dB [18]. The AG-25 provides the high gain and low noise figure desired for the receiving system. The noise figure for the AG-25 is roughly 2.5 dB [18]. The ICOM AG-35 preamplifier was selected for the 435 MHz link. The AG-35 has a gain of approximately 20 dB and provides a noise figure of approximately 3 dB [18].

4.2.4 Earth Station Receiving and Transmitting Antennas

The earth station is required to use either a signal antenna that can provide reception on both the 145 Mhz and 435 MHz ranges or two distinct antennas covering a single frequnecy range each. In an earth station, it is recommended that there be at least two distinct system antennas - a transmitting antenna and a receiving antenna [1, 2, 5, 19]. By using a simple switching arrangement, this may be a single physical antenna in reality. However, for optimum performance and practical considerations, two separate antennas are employed in the AFIT earth station.

One of the receiving antennas is required to have a gain greater than 15 dBic in the 435 MHz band and be switchable between RHC and LHC polarities. Additionally, a receiving antenna that provides a gain greater than 13 dBic in the 145 MHz band and is switchable between RHC and LHC polarities is required. The transmitting antennas must provide the same performance characteristics as the receiving antennas.

There are numerous kinds of antennas, just as there are diverse kinds of transceivers. Among the various antennas are diploes, loop, biconical, cylindrical, linear arrays, reflector-type, slot, horn, lens, long wire, polyrod, rhombic, and phased arrays.

In satellite communications, the choice of transmitting and receiving antennas must include the specific frequency bands of interest. Also, the geometry of the particular satellite orbit will affect the selection of a particular antenna [3]. For instance, for geo-stationary orbits, statistical studies have proven the high power, large reflector antennas such as parabolic reflectors provide better results than Yagi-Uda or other wire-type antennas in most cases [3]. For the instances where the amateur satellites use elliptical orbits, where tracking the satellite's motion is a factor, the helical or Yagi-Uda antennas with their relatively wide beamwidth (25 to 40 degrees) will provide accurate continuous tracking of a low-earth orbiting satellite [1].

For the AFIT earth station, bayed (side-by-side)crossed-Yagi antennas were obtained. More properly called Yagi-Uda arrays, this type of antenna is relatively inexpensive to purchase and provides flexibility of use and reasonably good gain for frequencies up to 900 MHz [9]. Figure 4.1 illustrates the bayed Yagi-Uda array.

The KLM brand Model 435-40CX antenna was selected to cover the 435 MHz band for the AFIT earth station. This choice was based upon the selection criteria established in Chapter 3. The KLM 435-40CX antenna is designed to be a high gain, circularly polarized antenna [17]. The manufacturer, Mirage Communications Equipment, designed this antenna to improve satellite reception of Mode B and Mode L [1].

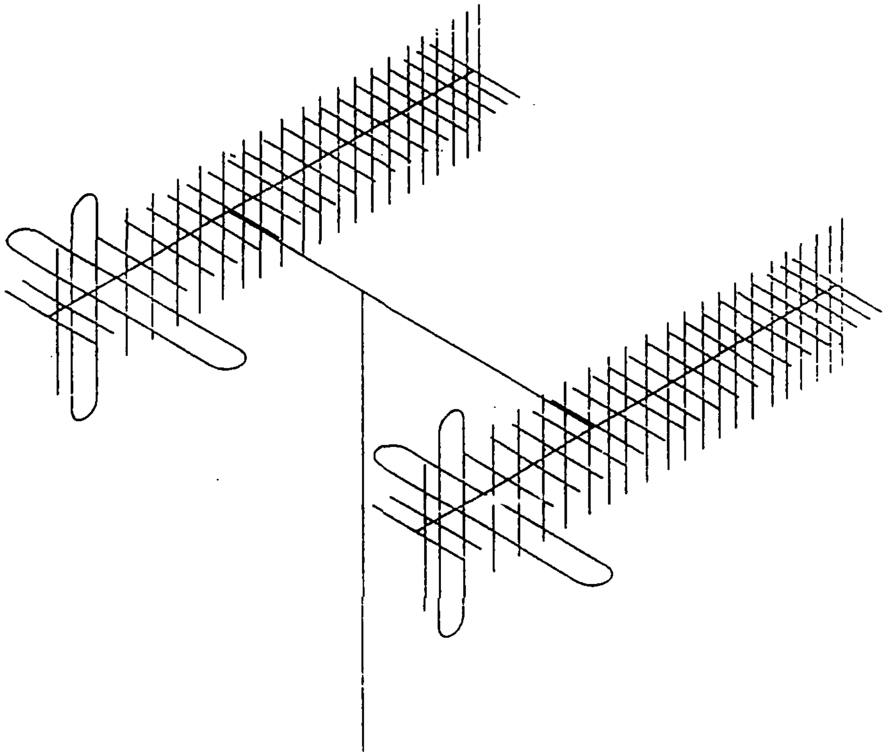


Figure 4.1 Bayed Yagi-Uda Array

Articles published by AMSAT indicate the wide bandwidth and high gain make the KLM 435-40CX antenna a good choice for Amateur Radio Service satellite reception [1, 2]. Also, the KLM 435-40CX antenna is suitable for terrestrial communications in the 435 MHz region. Table 4.3 contains the manufacturer's electrical specifications for the KLM 435-40CX. These specifications indicate the requirements for a system antenna in the 435 MHz range has been fulfilled.

Table 4.3 KLM 435-40CX Electrical Specifications

Electrical Specification	Remarks
Spec. Freq. Range	420-440 MHz
Useable Freq. Range	410-450 MHz
Polarity	Circular (switchable between right and left hand using CS-2 switcher
Gain	15.2 dBc @ 436 MHz
Beamwidth	25 degrees
Front-To-Back Ratio	20 dB min.
Front-To-Side Ratio	25 dB typical
Elipticity	3 dB max.
Input Impedance	50 ohms (unbalanced)
VSWR	1.5 : 1 max. between 432 - 436 MHz
Power Handling	250 watts max. with CS-2

Another antenna selected for use in the AFIT Earth Station is the Mirage Model KLM 2M-22C antenna. The 2M-22C antenna is a high gain, circularly polarized 2-meter antenna designed specifically for satellite and terrestrial communications. Mirage Communications Equipment Company elected to manufacture this antenna for use in communicating via the OSCAR satellites, specifically the OSCAR-10. The manufacturer felt communication with the OSCAR-10 satellite required improved 2-meter downlink receive gain [17]. According to the manufacturer's measurements, this antenna offers approximately 2 dB more gain than previous antennas such as the 2M-14C antenna. Table 4.4 provides the electrical specifications for the KLM 2M-22C.

Table 4.4 KLM 2M-22C Electrical Specifications

Electrical Specification	Remarks
Specified Bandwidth	144-146 MHz
Useable Bandwidth	144-148 MHz
Gain	13 dBc
Front to Back Ratio	20 dB
Front to Side Ratio	25 dB
Beamwidth	34 degrees
Input Impedance	50 ohms (unbalanced)
VSWR	Better than 1.5 : 1 between 144 - 148 MHz
Power Handling	2 kW PEP, derate to 600 watts when used with CS-3 switcher

After analyzing the manufacturer specifications and comparing them to the requirements, note that both antennas fulfill the requirements for station receiving and transmitting antennas. The KLM 435-40CX provides the 420 - 440 MHz coverage and the KLM 2M-22C provides the 144 - 146 MHz coverage. These antennas serve as both receiving and transmitting antennas. The antennas characteristics indicate the gain (13 dB for 145 MHz and 15 dB for 435 MHz) and polarization switching capabilities required for the earth station have been met with these antennas.

4.2.5 Earth Station Transmitter

The requirement established in Chapter 3 is for a transmitter capable of SSB and packet data communications that can operate in the 145 MHz and 435 MHz bands. The transmitter should produce an output signal power of about 12 W. Also, the transmitter must be able to be interfaced to a modem and TNC devices to handle other modulation methods such as FSK and PSK for packet radio communications between amateur satellites and the earth station.

Some of the transmitter characteristics of importance are discussed in the following paragraphs. The characteristics discussed here are not, of course, the entire selection set for the transmitter, but represent the most significant characteristics of an earth station transmitter that can satisfy the given requirement.

Initially, an important characteristic is that a transmitter must operate in one of the specific radio frequency bands, or modes, used for the satellite communications [6]. The ICOM IC-970A transceiver, selected for use in the AFIT Earth station, is capable of operating in the 140-150 MHZ (2 meter) band and the 430-450 MHZ (70 cm) band [20].

After choosing the correct transmitting bands, the power output from the transmitter must be determined. One significant factor here; the actual power output requirement to communicate with a satellite is the EIRP off the end of the transmitting antenna. For mode B operation to AO-13, the transmitting system must be capable of producing the recommended 720 W EIRP (28 dBW) [1, 2, 5]. As a comparison, for mode JD operations with FO-20, the recommended uplink EIRP is 100 W [1, 2]. The transmitter must be capable of producing much of this uplink signal power. Computations and research compare favorably to suggest approximately 20 W supplied to an antenna with a typical gain of 10 dB will satisfy the FO-20 mode JD requirements. However, for mode B with AO-13, approximately 72 W will be required for the transmitting antenna or a combination of the transmitter and another device such as a power amplifer must combine to provide 72 W to a 10 dB transmitting antenna. The ICOM IC-970A was selected for the AFIT earth station. It is a low power transmitter providing only between 5 - 35 W of output power. Therefore, for mode B operation a power amplifier is required.

Another characteristic of the transmitter to be considered is the modulation capability. To communicate with a mode J satellite, the transmitter must be able to provide various modulation techniques or be able to interface to devices that can produce the required modulation. The requirement is to be able to provide SSB and packet data capabilities [6]. The ICOM model IC-970A transceiver can generate SSB signals [20]. The transceiver can be interfaced to modems and TNC devices to permit PSK modulation techniques, but requires these additional interfacing components, such as a PSK modem and the TNC to communicate to satellites employing mode J [20]. The transmitter used in the AFIT station, the IC-970A, can be interfaced to numerous modems in use today, such as the Pac-Comm PSK-1 modem.

4.2.6 Earth Station Power Amplifier

The earth station requirement for a power amplifier is to provide a gain greater than 15 dB and to have a minimum output power greater than 140 W. The ICOM IC-970A is a low power transceiver capable of only 5 - 35 W output power [20]. To increase this output power, a power amplifier capable of producing up to 160 W output power using a 10 W input, was selected for the station. The power amplifier must be installed at the input of the transmitting antenna to increase the transmit power from about 25 W to the minimum recomended level of 21.5 dBW for mode B to AO-13 and 25 dBW for mode J required for establishing communications between the earth station and the orbiting AO-13 satellite [21].

4.2.7 Modem, Communications Software, and Interface Equipment

A modem capable of handling FSK and PSK modulation to permit packet data communications is required for the earth station. Because the earth station was designed for multiple modes of operation (B, and J) to permit digital communications, a modem, terminal node controller (TNC), computer interfaces, and tracking software were required to perform satellite communications.

Specifically, the Pac-Comm Model PSK-1 modem with the separate Model Tiny-2 TNC packet controllers were used to interface the IC-970A and the 80386-based computer. This permits two-way communications between the earth station and the selected amateur satellites.

In the design of the AFIT Earth station, each piece of equipment had to fulfill the overall objective of establishing digital and analog communications between the station and the satellites. The selected modem provides complete coverage of the OSCAR satellites and permits terrestrial packet communications.

In the AFIT earth station, the operator uses an Intel 80386-based computer to input data for transmission to an orbiting satellite. The communications software, Procomm Plus, is loaded on the computer. Information is keyed into this program, passed to the Pac-Comm TNC and then to the Pac-Comm PSK-1 modem. From there, it is processed and sent to the ICOM-970A transmitter. From the ICOM-970A transmitter, the digital information is broadcast to a selected target satellite. The AFSK can be handled by the Pac-Comm TNC or by the combination of the TNC and PSK-1 modem.

On the receiving side of the earth station, incoming digital signals are captured by the receiving antenna, amplified by a preamplifier, and passed to the receiver. The receiver forwards the demodulated signal tones to the Pac-Comm modem. The modem converts the tones to binary electrical data and passes them to the TNC. The TNC "depacketizes" the data and relays the information to the Procomm software that is active on the computer. At this point, the operator should be able to read the information in an acceptable intelligent form such as ASCII text.

In the AFIT earth station, a separate Pac-Comm TNC is used to provide multiple capabilities to the station. In reality, the Pac-Comm PSK-1 modem has a built-in TNC. However, a specific requirement for the AFIT earth station was to permit both satellite and terrestrial communications. The terrestrial communications capability was used to establish the operability of the system components. The separate Pac-Comm TNC provides the terrestrial capability for the station. Figure 4.2 shows the mode J station block diagram.

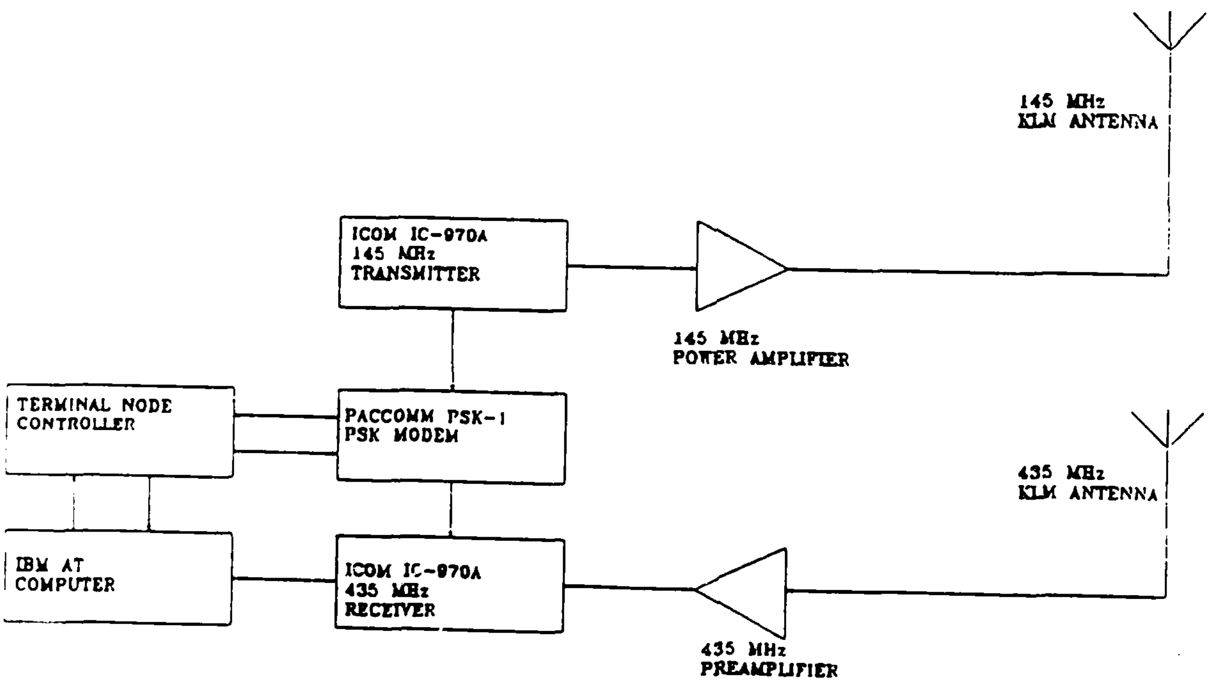


Figure 4.2 Mode JD Station Block Diagram

The computer interfaces and communication software are important to this station. Figure 4.3 illustrates the physical connections of the different pieces of equipment in the laboratory. Each component dictated unique interfaces to other components. Thc actual connections between the computer, the Pac-Comm TNC, and the Pac-Comm PSK-1 modem are made through the use of a generic A/B serial switch box. The cabling is standard RS-232C cabling from the switch box to the computer. There are two connections; one from port A on the box to the COM1 connector of the computer; the other from port B on the switch box to COM2 of the computer. When desired, the user can switch between the desired coputer communications ports.

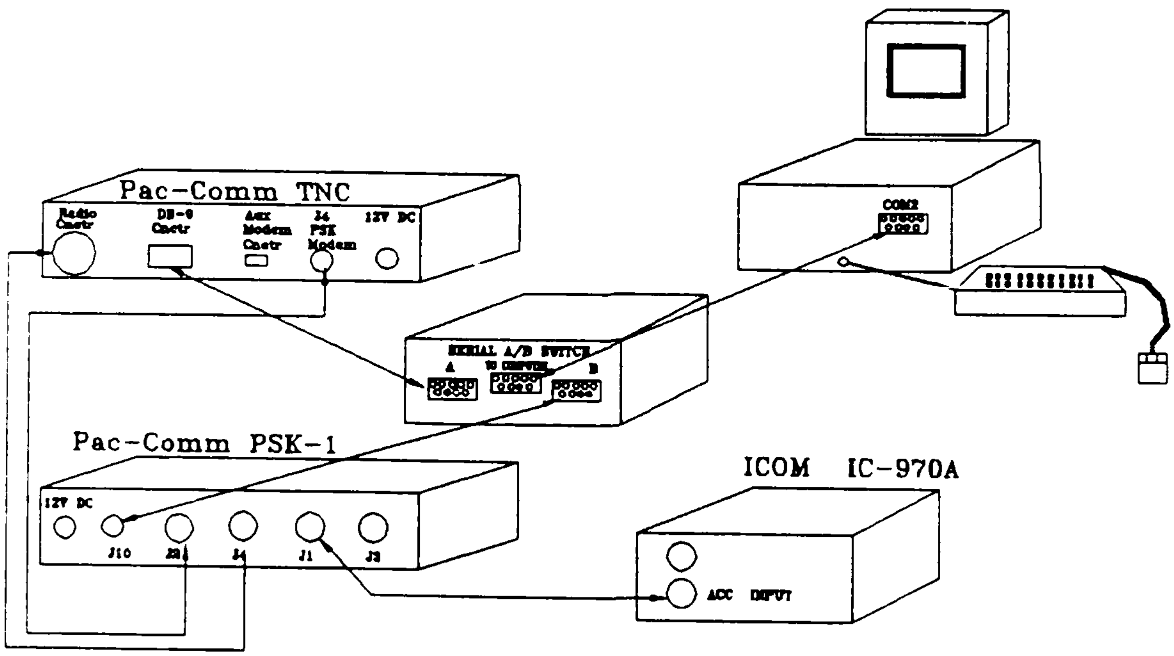


Figure 4.3 Connections Between Station Components in the Laboratory

As is shown in Figure 4.3, port A permits communication between the TNC and the computer. Port B provides communications between the PSK-1 modem and the computer. The Pac-Comm PSK-1 and the Tiny-2 TNC fulfill the requirements to permit AFSK and PSK modulation methods for packet data communications.

4.2.8 Additional Station Support Equipment

Some additional equipment is required to satisfy the earth station requirements completely. For instance, antenna rotational devices (rotor), a rotor controller, and satellite tracking software complete the requirements for the earth station. These are discussed in the following sections.

4.2.8.1 Antenna Rotor and Controller

The AFIT earth station is required to be able to rotate the antennas continuously to follow the low and high orbit amateur satellites. This requirement dictated that the rotor selected for the station had to be able to provide complete azimuthal coverage and horizon to horizon elevation control for medium and large size directional satellite antennas. Also, the unit had to be able to permit both manual and computer control.

The Yaesu brand Models G-5400 and G-5600 rotors and controllers exceeded all requirements for this station. This equipment provides the complete azimuthal and the elevation control required [22]. The rotor motors may be integrated into one unit or used as separate azimuth and elevation motors. For the purpose of this project, the units were combined and mounted as a single unit on top of the tower located on the roof of the AFIT Graduate School of Engineering Building.

The controller unit has dual analog meters for azimuth and elevation indication. There are direction controls for azimuth, showing compass direction and degrees. Additionally, there are elevation switches for 0 to 180 degree control. Finally, the controller has mating jacks for remote control by either a microcomputer or other display controller.

4.2.8.2 Satellite Tracking Software

The earth station is required to provide real-time or near real-time tracking operations. To fulfill this requirement, satellite tracking software is needed to provide the operators with the requisite data in order to know where the system antennas must point during communications sessions. One way to keep track of the details of a satellite orbit, present operating characterisitics, and expected times of access is to employ satellite tracking software. The tracking software chosen for this station, InstantTrack, is discussed below.

The satellite tracking software used in the AFIT earth station is the InstantTrack program written by Franklin Antonio [23]. This software provides a graphical interface to the various parameters of a particular satellite. The InstantTrack software can provide amateur radio operators with the data necessary to track several earth-orbiting satellites simultaneously element sets available commercially. Also, it will orient the appropriate antenna toward the satellite in real time using the azimuth, elevation, current operating mode of the satellite, and other orbital parameters [23].

Additionally, this program allows users to obtain precise access times for communications providing both AOS and LOS for each satellite from the current tracking facility. The InstantTrack software meets the earth station's satellite tracking requirements.

4.3 Summary

This chapter discussed how the earth station requirements were met and what was selected to meet the requirements. Table 4.5 lists the selected equipment for the AFIT earth station.

Table 4.5 Selected Equipment for the AFIT Earth Station

Component	**Name/Function**
Receiver	ICOM IC-970A. 145 MHz; 435 MHz; 1.2 GHz receiver.
Transmission Lines	RG-213/U and RG-8/U coaxial cable.
Preamplifier	AG-25 and AG-35 preamplifiers. AG-25 for 145 Mhz and AG-35 for 435 MHz.
System Antennas	KLM 435-40CX and KLM 2M-22C. KLM 435 CX for 420 - 440 MHz. KLM 2M-22C for 144 - 146 MHz.
Transmitter	ICOM IC-970A. 145 - 435 MHz transmitter.
Power Amplifier	Johnson PA. 10 W to 160 W power amplification.
Modem, Communications Software, and Interface Equipment	Pac-Comm PSK-1, Tiny-2 TNC, Procomm Plus, Serial Switch Box. PSK-1 permits packet data communications. TNC transmits/receives packet data. Procomm Plus permits communcations between the computer and the modem/TNC. Switch box permits user switching between devices.
Antenna Rotor and Controller	Yaseu G-5400B rotor and controller. Permits system antenna pointing.
Satellite Tracking Software	InstantTrack. Provides users real-time target information to include antenna pointing data.

Chapter V Station Build and Testing

5.1 Overview

This chapter presents a discussion of the actual installation, configuration, and testing of the selected earth station equipment. The material in this chapter is presented in terms of major components. Much of the installation and testing occurred at the same time. Therefore, an overview of the equipment configuration is given. Next, the installation procedures as presented. Then, the test results from component tests are presented. The focus of the component testing was to verify proper operation of each module. Once each component was tested, the completed station was tested.

5.2 Equipment Installation and Testing

Figure 4.3 illustrated the physical configuration of the AFIT earth station. Details of each component in the AFIT earth station are presented throughout this chapter.

5.2.1 Tower Installation

Initial preparations for the station construction began with the installation of a 30' tower on the roof of the AFIT Graduate School of Engineering Building. The tower was attached to an I-beam and braced using universal clamps.

It was determined that a 30' tower was required due to the physical length of the selected system antennas. The KLM-2M-22C has a boom length of 19'1". In order to provide full elevation coverage, the tower had to be tall enough to permit the antenna to rotate fully. The tower sections were 10' each. One section of tower was not sufficient to mount the antennas and permit full rotation. Therefore, three sections of tower (totalling 30') were used.

5.2.2 Yaesu G-5400B Rotor Installation

Next, the Yaesu G-5400B antenna azimuth-elevation rotator (rotor) and controller components were tested in the laboratory. To test the components, the controller was attached to the G-5400B rotor in the laboratory as shown in the installation instructions for the Yaesu products [20].

The controller was powered on and the azimuthal and elevation controls were engaged. The meter lamps on the controller unit illuminated. The analog indicator armature moved to the center of the azimuth meter (0 degrees) and to the center of the elevation meter (90 degrees).

Next, the elevation Up switch was pressed. The elevation rotor began to turn as the meter analog indicator swept to the right. The Up switch was released and the elevation rotor ceased movement. This test was repeated for elevation sweeping in the opposite direction.

The azimuth Left switch was tested by depressing the switch. The azimuthal rotor began to move in a counter-clockwise manner. The switch was released and the rotor stopped movement. The test was repeated for the Right switch and proper operation was verified in the laboratory, before the device was installed on the tower.

5.2.3 Cabling Installation, Termination, and Testing

The selected transmission lines are the RG-213/U and RG-8/U coaxial cables. It was decided to run sufficient cable for both the current earth station requirements and for future station needs. Therefore, a total of four (two RG-213/U and two RG-8/U cables) coaxial cables (roughly 176' in length for each cable) and one rotor power control cable were run from the Communications/Radar Laboratory to the roof of the AFIT Graduate School of

Engineering. These serve as the transmission lines from the IC-970A to the system antennas.

Two of the transmission lines (one RG-213/U and one RG-8/U cable) had approximately 15' sections cut from them (leaving the sections from the laboratory to the preamplifiers at lengths of about 161'.) Presently, there is one 161' section of RG-213/U cable from the IC-970A 435 MHz jack to the AG-35 preamplifier. Then, a 15' section is installed at the AG-35 preamplifier and runs to the KLM 435-40CX system antenna. From the 145 MHz output of the IC-970A, a 161' section of RG-8/U runs to the AG-25 preamplifier. From the AG-25, a section of approximately 15' of the RG-8/U runs to the KLM 2M-22C system antenna is installed.

The transmission lines and power cable run from the northwest corner of the laboratcry up into the tiled ceiling, down the central hallway of the second floor, across the ceiling of the Motion Control Laboratory (Room 242), and then, up into the capped venting of the roof above the Computer Simulation Laboratory (Room 240).

This cabling installation is not the optimum path, but was dictated by necessity. It was necessary to install the cables, in order for the earth station research to begin. However, the Communications/Radar Laboratory (Room 225) does not permit direct access to the roof of the AFIT Graduate School of Engineering. Therefore, a viable route had to be found to run the cables from the earth station equipment to the system antennas on the roof. Future corrective actions for the cabling are presented in the recommendation portion of this thesis.

All three sections of RG-213/U cables were terminated at each end with N-type connectors. The three sections of RG-8/U cables were terminated with PL-259 (UHF) terminators. The rotor power cables were terminated at each end with the ring-tongue style connectors provided with the product [22]. The rotor power connectors were connected to the screw-down clamps on the rotor and rotor controller.

At the one end, the rotor power cables were attached to the Yaesu G-5400B rotor. The rotor is located at the top of the antenna tower. At the other end, the rotor power cables were attached to the rotor controller unit. Cable signal power attenuation was measured by using a Bird Wattmeter. Figure 5.1 illustrates the process used to measure the cable attenuation.

The Bird Wattmeter was inserted between the transmitter and the beginning of the first RG-213/U cable. A 50 Ω dummy load Wattmeter was placed at the end of the cable. The IC-970A transmitter was powered on for normal operation at the actual uplink frequency of 435 MHz. An initial reading was taken at the end of the transmitter. This value was recorded as P_A. Then, the wattmeter was removed. The cable was reconnected to the transmitter. The 50 Ω dummy load was removed and the wattmeter was fixed to the end of the cable. At this time, the power level at the end of the cable was determined. This value was recorded as P_S.

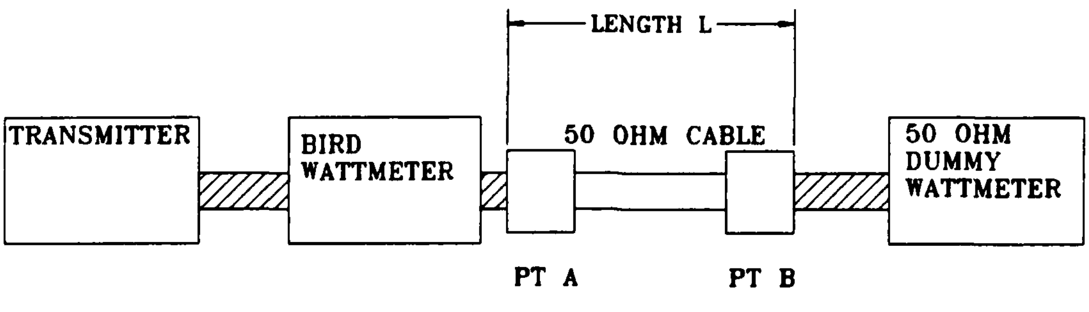


Figure 5.1 Cable Attenuation Measurement

The process was repeated three times to verify the actual output powers. Then, the process was repeated for the remaining cables. The cable attenuation was found by using Equation (27) [1].

$$\text{Cable Attenuation - } A_L \text{ (dB)} = 10 \log(P_A/P_S) \tag{27}$$

Therefore, attenuation for the total run of cable (approximately 176') is shown to be:

$$\text{Attenuation per 100' - } A_T \text{ (dB)} = (100/176)\,(A_L)$$

where A_T = attenuation per 100' at 435 MHz

A_L = measured attenuation

The power measured in the forward direction at the output of the transmitter was 13 W. The reflected power was 0.5 W. This indicates that 12.5 W is the output power for the cable attenuation measurements. A power reading was taken at the input of the KLM 2M-22C system antenna. The value obtained at that point was 1.0 W. Therefore, 12.5 - 1.0 = 11.5 W loss across the cable. Using these values, the measured cable attenuation was found to be 10.97 dB across the length of the 176' cable. Theoretical cable losses estimated in Chapter 3 suggested a loss of 10.38 dB at a frequency of 435 MHz. Therefore, the measured value compares well with the expected value.

5.2.4 Transmitter and Receiver Installation and Testing

The ICOM IC-970A multi-band transceiver was selected to perform the transmitter and receiver functions for the earth station. Also, an ICOM IC-R9000 was obtained as an extra station receiver used to verify the operation of the station, but is not used in the earth station for satellite communications at present. These tests were performed in conjunction with the cable testing and system antenna checkouts.

A series of preliminary tests were performed to verify the proper operation of the transceiver before its installation into the earth station. These tests included initial visual inspection of the casing, internal boards, and the external connectors. Next, the transceiver was connected to the AC main supply and powered up. A whip antenna was connected to the antenna connector and the receiver tuned to a local repeater frequency. Each of the receiver functions and controls were tested for proper operation per the manufacturer's recommendations [20].

The whip antenna was removed and a Bird dummy load/Wattmeter was connected to the antenna connector. The transmitter functions were tested per the manufacturer's recommendations [20]. The power output levels were measured and compared against the manufacturer's specifications. Relatively low power levels for satellite communications work were obtained. The output signal power at 435 MHz was approximately 12.5 W. The manufacturer's specifications indicate the IC-970A can produce from 5 - 35 W of output signal power. For the satellite packet data communications, the transmitter should be able to produce at least 20 W (preferably more) of output signal power. The computed link budget values obtained during the requirements analysis suggest a power amplifier is needed to provide approximately 15 dB gain to the transmitting system. This practical power measurement reinforced the previous conclusions that a power amplifier was required to satisfy the thesis requirement of permitting satellite data communications.

5.2.5 System Antennas Installation and Testing

The KLM 435-40CX was built first. Initially, the three boom sections were mated together. Total boom length is 175.5". Mating the sections of the boom required only a few minutes work. Next, the driven element assemblies were constructed. Folded dipoles were used as the driven elements. The coaxial cable labelled as #1 was fixed to the feed point of the vertical driven element. The cable labelled #2 was mated to the horizontal driven element. Figure 5.2 illustrates the actual configuration of the driven elements (folded dipoles), the parasitic elements, and the CS-2 switcher with respect to the boom sections.

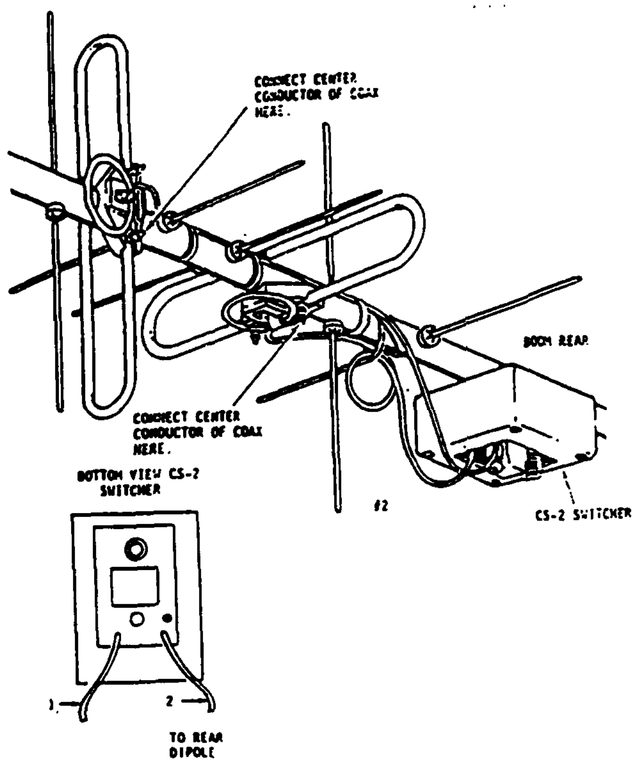


Figure 5.2 KLM 435-40CX Antenna

Next, the two driven element insulators were connected to the boom. The CS-2 switcher was mounted at the rear of the boom parallel with the rear reflector. The RG-303 teflon-silver-plated coaxial cables were attached to the CS-2 and the dipole feed points. Afterwards, the two folded dipole driven elements were attached to the insulators and the CS-

2 switcher. The reflector and director elements were installed at this time. To facilitate the installation of these elements, the manufacturer color-coded the elements. These elements were aligned to within 1/32" tolerances. Anything larger than 1/32" would result in minor pattern anomalies resulting in slightly reduced forward gain and slightly increased sidelobe response.

The antenna creates a field all around the antenna and not merely in front of the plane of the elements. Any metal mass located within proximity of this field will disturb the gain, VSWR, pattern, and ellipticity of this antenna [2, 9]. Therefore, one must be careful to minimize the effects of any metallic object in the proximity of driven elements, reflectors, and directors. This includes the feedlines, the mast, and the boom sections.

Assembling the other system antenna, the KLM 2M-22C, provided interesting challenges and problems not encountered with the KLM 435-40CX antenna. Initially, the five boom sections of the 2M-22C satellite antenna were mated together. During the build phase, the antenna components were grouped according to function. The total length of the boom is 241". The insulators, folded dipole sections, the balun feedlines, and PC board were attached to the boom sections. The PC board was attached to the vertical dipole studs and then the coaxial balun leads were attached to the feedpoint lugs.

Next, the folded dipole type of driven elements were assembled. The vertical dipole was mounted on the boom first. The element was placed towards the rear of the boom. The vertical dipole insulator mounting block faced toward the front of the boom. Afterwards, the horizontal dipole was mounted in a similar fashion.

The PC board was mated to the vertical dipole and the coaxial balun leads were secured. Then, the SO-239 case was attached to the boom. Once these components were mated, it was time to mount the parasitic elements.

The rod element insulator arrangement was a trivial, yet important part of the antenna build. The elements were separated into vertical and horizontal element groups. The vertical elements were installed first. Then, the horizontal elements were installed. Once all elements were installed, close attention was given to the critical step of centering each element to within 1/32" tolerances. Each element was centered and reinspected three times. After all elements were centered, the button insulators and push nuts were mated to the elements to fix them into place.

The SO-239 connectors and case were mounted on the rear boom section to avoid metal mass interference problems with the radiating elements of the antenna. The initial configuration of this antenna was to be right hand circularly (RHC) polarized. Therefore, the center lead of the SO-239 was fed to the right feedpoint of the horizontal dipole (when viewed from the rear of the boom).

Next, the parasitic elements were attached to the respective portions of the boom. The longest elements served as the reflector of the antenna. After mating all the elements to the boom sections, the antenna elements were trimmed to within 1/32" tolerance to provide the maximum gain and VSWR. To properly trim these antennas, the elements had to be centered on the boom sections within 1/32".

A DAIWA RF reflectometer (a VSWR bridge) was borrowed from the University of Dayton. The reflectometer was installed between the antenna input connector and the feedline from the transmitter. A reflectometer is able only to compare the output impedance to the input impedance. The transmission line impedance is 50 ohms. The transmission line used to test this system has to be a minimum of several wavelengths. This ensures a valid measurement. If short stubs of transmission line are used, the system impedance is not firmly established and the measurements may or may not be valid [2].

The DAIWA RF reflectometer displays an analog measurement for the tests. The meter reading displays only the resultant VSWR value. The KLM 2M-22C and the KLM 435-40CX antennas were both tested. The reflectometer produced VSWR values of about 1.1 at 145 MHz, 1.125 at 146 MHz and approximately 1.15 at 147 MHz for the KLM 2M-22C. The antenna manufacturer provided a typical VSWR curve for comparison to the VSWR measured in the laboratory and in actual configuration. The Mirage literature indicates the VSWR should be about 1.07 at 145 MHz, 1.09 at 146 MHz and 1.1 at 147 MHz [20]. The antennas were rotated through their pointing ranges while observing the reflectometer for changes greater than 0.1 in VSWR reading. None were observed.

Figure 5.3 shows the completed KLM 2M-22C configuration. Figure 5.3 also shows the physical configuration of the driven elements, parasitic elements, and the SO-239 to the boom sections. For the KLM 435-40CX, values of 1.2 at 435 MHz and 1.3 at 436 MHz were obtained. However, no VSWR values were specified in the product literature for the KLM 435-40CX antenna.

The Mirage/KLM 2M-22C 2 meter antenna was used as the transmitting antenna for some of the satellites and as a receiving antenna in other cases. Due to small power levels on the order of picowatts for the amateur satellites, close attention to the actual mating of the various elements was required to maximize the gain of the antenna. The specifics of the antennas are given in Chapter 4. The reader is referred to Chapter 4 to review the electrical specifications of the different antennas.

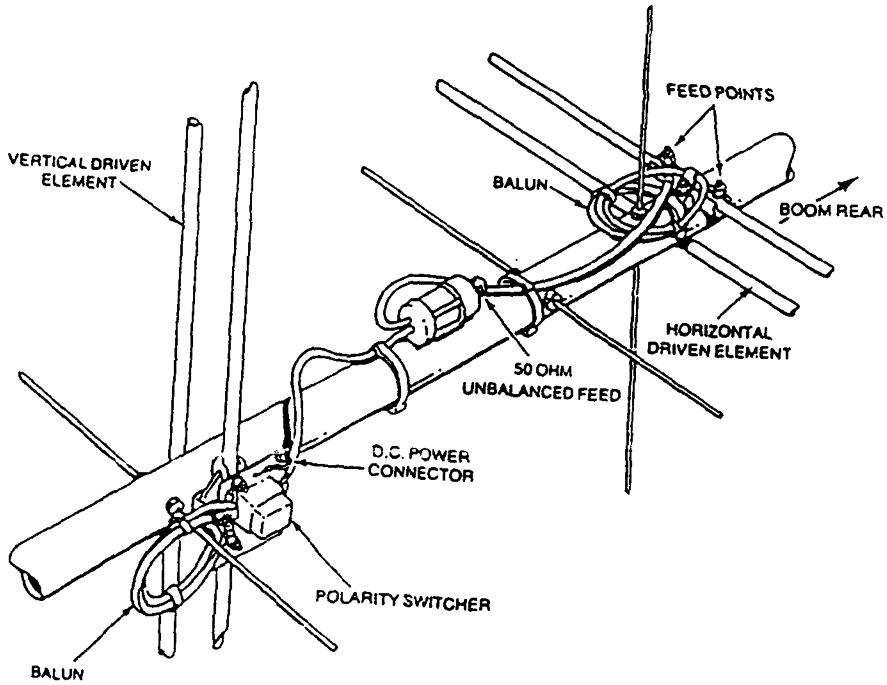


Figure 5.3 KLM 2M-22C Configuration

The antennas were built in the AFIT Communications/Radar Laboratory. It was necessary to disassemble the antenna into two portions for transport to the roof of the building. This was accomplished at a later time in the project. Once both antennas were built, they were disassembled into transportable sections and carried to the roof. On the roof, they were reassembled, rechecked for proper element centering, and mounted on the mast of the antenna tower.

The actual antenna mounting required several days to get the antennas into the proper positions for best system performance. Upon initial antenna mounting, the various coaxial and power cables were attached to the proper devices. Each cable had been coded with cable ties to indicate its function.

Upon initial power-on testing to the rotor, it was discovered that the antennas were improperly mounted on the mast. The antennas would sweep from approximately 8 degrees below the horizontal to about 10 degrees from vertical (80 degrees elevation). This problem was corrected after several antenna fittings.

A problem in the physical construction of the rotor still exists. On some of the rotors, the rotor gear teeth are not truly evenly spaced, causing an end-to-end travel error of the antenna. This fact is documented by the manufacturer [20]. Using a level and a protractor, the pointing error deviations were estimated to be greater than the ± 4% suggested by the associated documentation. In actuality, the deviation measured graphically is roughly ± 8%. This deviation does not cause the antennas to exceed the 3 dB beamwidths and thus cuase inconsistent performance.

Once the deviation was noticed and documented for further research, preliminary antenna pointing tests were run. These tests involved attaching the power cables to the rotor and the external rotor power box sealed to prevent weather damage to the elements. Then, the antennas were swept the full range of the controller. The azimuthal rotor controller was swept from left to right. A pocket compass was used to estimate the validity of the antenna pointing. Therefore, the pointing error can not be provided with any detail. Once the azimuthal pointing tests were complete, the elevation controller was engaged and the antennas were swept from 0 degrees to 180 degrees.

After the antenna pointing tests were concluded, satellite tracking tests were conducted for the AO-13, WO-18, and LU-19 satellites. At times, the AO-13 satellite remains in view for several hours and provided an excellent opportunity to tweak the antenna alignments. Tracking tests with the other two spacecraft was more challenging. Initially, the tracking software was not installed. Computer printouts of the expected passover times, ranges, Doppler shifts, operating modes, and other orbital parameters were reviewed prior to each test. This information was used to estimate the closest time period for the target satellites. Appendix C provides details of the proper use of the tracking software and sample data sets for some of the earth-orbiting amateur satellites used by the earth station.

During the initial tests, the station was unable to track these fast moving satellites until the operator became familiar with the Doppler effect on digital data. The operator manually switched the antenna azimuth and elevation pointing angles by depressing the appropriate levers of the rotor controller in response to the changing real-time tracking data provided by the InstantTrack computer program. Simultaneously, the station operator was tuning the ICOM IC-970A receiver to acquire the actual digital data on the receiver and thus at the computer terminal. Because, the operator was attempting to perform manually numerous duties at the same time, many data recovery errors were made during initial checkout trials of the antenna and rotor components. These errors were minimized after considerable practice with the system.

5.2.6 Preamplifier Installation and Testing

Two preamplifiers were installed in accordance with the earth station requirements. These were the AG-25 144 - 146 MHz (2 meter) and the AG-35 435 - 438 MHz (70 cm) preamplifiers. Both were installed because of the need to be able to receive on either band. During the actual communications testing, however, only one preamplifier was in operation at a time.

The preamplifiers were tested in the laboratory before installation next to the receiving antennas on the top of the tower. The preamplifiers were placed in line between the receiver and the respective system antennas and measurements on the IC-970A S-meter were noted.

During the initial testing, it was discovered that the 435 - 438 MHz preamplifier (AG-35) had problems in receiving the low end of the band. At frequencies below 435 MHz (434.65 MHz for example), the preamplifier actually functioned as an attenuator. The S-meter readings and audio quality of the signals were degraded with the AG-35 in-line. With the AG-35 removed from the arrangement, the S-meter produced higher readings.

Likewise, above 439 MHz, the AG-35 preamplifier attenuated incoming signals. Similarly, the 144 - 146 MHz preamplifier (AG-25) attenuated signals at frequencies of 145 MHz and below. Above 146.5 MHz, the AG-25 attenuated the signals. Again, the IC-970A S-meter was used to note the system response with the AG-25 in-line and out-of-line.

Because the AO-13 frequencies for mode B operation are from 145.825 - 145.975 MHz for AO-13 and from 435.715 - 436.005 MHz for mode J. For AO-16 (437.026 - 437.051 MHz), DO-17 (145.824 MHz), WO-18 (437.075 - 437.102 MHz), and LU-19 (437.125 - 437.153 MHz) the mode J frequencies of interest range from 435.0 - 437.6 MHz. The AG-35 preamplifier was well suited for this range. The AG-25 did not hinder data collection from any of the target satellites.

Due to the Doppler effect and the slight variations in actual received frequencies, the attenuation problem permitted losses of signal for some of the satellites. Further discussion of this phenomena is found in the results portion of this document.

Once the preamplifiers were tested in the laboratory, they were installed next to the appropriate receiving antenna. The 144 - 146 MHz preamplifier was mounted on the tower and the 435 - 438 MHz preamplifier was mounted directly below the 144 - 146 MHz preamplifier. The preamplifiers were attached to the tower using standard U-bolts and cables were run from the antenna elements to the preamplifiers. The preamplifiers are mounted about 3' below the receiving antennas. Initially, short sections of cable (approximately 8' in length) were used to connect the preamplifiers to the antennas. However, when the antenna swept to the extreme limits of rotation, the cable sections became tight and appeared to pull the preamplifier away from the tower. Therefore, longer sections of cable (about 15' in length) were used.

This extra cable length reduced connector stress caused by cable movement when the antenna is rotated. Any length much shorter might create a fatigue failure at the preamplifier's connector or cause some type of system disturbance.

Once the preamplifiers were installed, the transmitting and receiving systems were retested. For these tests, AO-13 was used as the target satellite. It remained in view of the station for almost five hours, whereas the other satellites were only in view for about 15 minutes each. The S-meter on the IC-970A was used to note the signal levels. The preamplifier performance for both the AG-25 and AG-35 was satisfactory when the signals were within the specified ranges for each. Once the receiver was moved outside of the permissible frequency range (up to 149 MHz for example), the S-meter readings were reduced. In most cases, no received signal power was indicated by the S-meter, even when SSB signals were detected by the operator's ear.

5.2.7 Modem, TNC, and Interface Equipment

The earth station required a modem, TNC, computer interface equipment, and associated hardware and software to permit packet data communications. The following paragraphs discuss the installation and testing of these components.

The final installation and integration of the Pac-Comm PSK-1 modem and separate Pac-Comm TNC required probably the most time and effort during the integration portion of this thesis. This was due, in part, to the numerous manufacturing and documentation problems found with the modem and the subsequent alterations performed on the modem [15, 16].

The modem was installed into the system for testing early on into the project. However, it failed to operate properly. Repeated calls to the manufacturer finally resulted in the admission that the model purchased for the system had a known defect [24]. During fabrication, data lines on the modules system board were routed incorrectly. Additionally, one op-amp and one connector plug were inserted backwards into the board. Furthermore, the documentation sent with the modem had several typographical errors. Therefore, modifications to the modem board were required as well as changes to the accompanying documentation.

At first, the emphasis was on correcting the problems with the Pac-Comm modem. The TNC was installed into the system and the ICOM IC-970A was used to acquire terrestrial packet data. After a few false starts and a quick tutorial in the world of terrestrial packet communications, several successful collections were made of packet data. Samples of these collections are discussed in the results portion of this thesis and complete copies of the data can be found in Appendix E of this document.

During the terrestrial testing of the system with only the TNC, communications were successful and communications software parameters were tweaked to provide better data collection services for the system. For example, the Procomm software setup was altered to permit the incoming data to be written to ASCII files for future reference. Then, attention was focused on correcting the problems with the PSK-1 modem and integrating it into the system successfully.

The first task was to repair the board mistakes. Therefore, the field effect transistor (FET) Q2, a type VN10, was turned around on the board so that the FET would function properly. There was some concern about whether the FET was destroyed or not. Fortunately, it survived. As shipped, the drain of the FET was connected to the source solder point and vice versa. The FET was turned around, and installed properly. However, other alterations were still required.

Next, the traces between the FET and a capacitor needed to be cut and a jumper soldered directly between the J4 connector and the capacitor. Additionally, during the fabrication of the board, two leads of the J4 connector had been soldered together. It was necessary to cut and separate the two pads.

Once these modifications to the PSK-1 modem were performed, the TNC needed altering. On the TNC, jumpers were removed from the JP10 and JP11 pads. Then, a jumper was placed on JP26 to activate this pad. These were the only modifications to the TNC. This permitted the TNC to operate as a separate TNC or permit the PSK-1 internal TNC to operate when it was connected in the system. These settings can be overridden through either software controls or hardware switches on the front of the PSK-1.

Also, the cables between the modem and the transceiver required alterations. The documentation was incorrect for the cabling between the modem and the ICOM IC-970A transceiver. The cabling was repatched to the proper pins. Figure 5.4 shows the current (and proper) pinout arrangements for all the cabling between the devices.

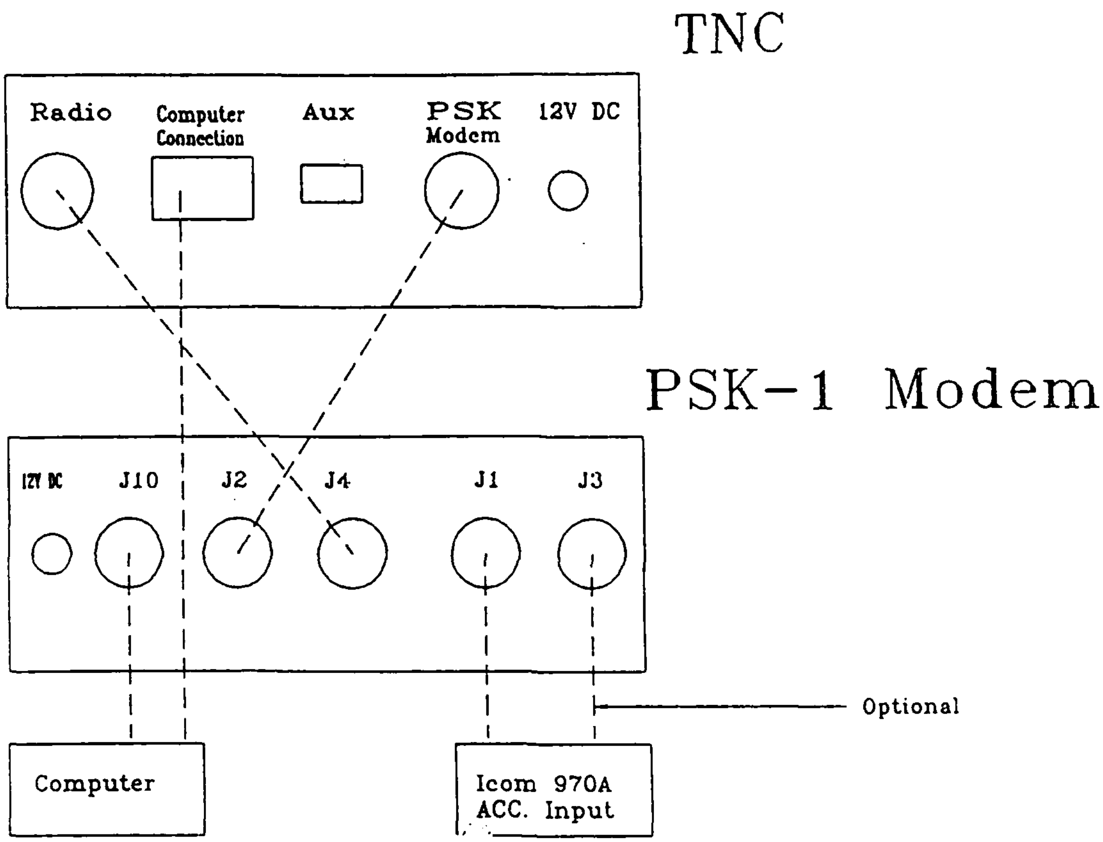


Figure 5.4 PSK-1 Modem and ICOM IC-970A Cabling

Installing the computer required moving it from one location in the laboratory to another. Once the Intel 80286-based computer was positioned, connections were made between the COM1: and COM2: serial ports on the computer, an A/B serial switch box, the PSK-1 modem, and the TNC.

Once everything was connected, the system was retested to ensure proper operation of the system. The Procomm Plus communications software program was installed on the 80286-based computer to permit communications between the PSK-1 modem, the TNC, and the computer. The proper port and line settings were established. These are COM1: serial port, no parity, eight data bits, and one stop bit.

Once these communications parameters were set, the various components were powered on. Initially, the A/B switch box was switched to permit communications between the TNC and the computer. At the time of boot-up of the TNC, it downloads a datastream of the commands and settings stored in its EEPROM. These settings can be modified somewhat through the computer. The EEPROM data is shown in Figure 5.5.

```
PacComm TNC-NB96 Packet Controller
AX.25 Level 2 Version 2.0
Features:
KISS
PERSONAL MESSAGE SYSTEM V 3.0
Release P1.1.6D4  Feburary 10, 1992 - 32K RAM
Checksum $07
Cmd:
```

Figure 5.5 PacComm TNC Message System

When TNC to computer connections are established, the switch box can be set to permit communications between the computer, the PSK-1 modem, and the transceiver. A description of these commands is found in the product literature [12, 13]. Once the commands were passed to the computer, it was necessary to ensure the automatic "connect" feature was turned on. Also, the reception of the data from the TNC ensures there is proper communications link between the two devices. It serves as a self-check every time the system is booted.

After the TNC to computer communications are established, the A/B switch is turned to position B to enable data links between the computer and the PSK-1 modem. Figure 5.6 is a sample of the data passed from the PSK-1 modem's EEPROM to the computer:

```
cmd:***********************************************
 * Press CONTROL-C or ESCAPE for configuration menus *
***********************************************
*     P a c C o m m  P S K   M o d e m        *
*    PSK Firmware version 2.10  CSUM: 2A05    *
*  (C) 1990 Digital Signal Sys, 1991 PacComm  *
***********************************************
<1> Mode:         Manchester (Satellite)
<2> Modem:        Out-of-Line (TNC's modem)
<3> Joint/Split: Joint (VHF RX, VHF TX)
<4> AFC:   LSB (Tone freq decreases with decreasing RX freq)
<5> Mic-Click Sense:   Active-Low
<6> Clicks-per-Step:   One
<7> Maximum Step Rate: 2  per second
<8> DCD Output Sense:  Active-Low
<9> RS232 Speed:       9600 8N1
<A> Help:
    Enter Function # or CONTROL-C or ESCAPE to exit...
```

Figure 5.6 PSK Firmware Message System

At this point, option number 1 was selected to reset the mode of operation. The PSK-1 paged into a different menu. Then, PSK (terrestrial) operation was selected to perform system checkouts via terrestrial communications. Once this is complete, then the PSK-1 modem is reset via this menu system to enable satellite communications. Figure 5.7 shows the menu that permits changes from satellite to terrestrial commuications.

The system was reset to terrestrial communications and tested on a known amateur packet data radio terrestrial communications link. The test involved attempting to collect packet data from known amateur radio stations. Four different sets of data were collected during the initial terrestrial data collection tests. These files are available from the author upon request. Attempts to transmit to terrestrial radio stations failed initially due to the problems documented with the Pac-Comm equipment. However, these problems were resolved and transmissions to local DARA BBS radio stations and to WA3ULL (the Callsign of Dr. Mark Mehalic) using terrestrial packet frequencies were successful between 19 - 20 April 1993.

```
***********************************************
*     P a c C o m m  P S K   M o d e m        *
*    PSK Firmware version 2.10  CSUM: 2A05     *
*  (C) 1990 Digital Signal Sys, 1991 PacComm  *
***********************************************
    Mode:                      Manchester (Satellite)
<1> Manchester (Satellite)
<2> PSK (Terrestrial)
<3> 400bps Telemetry
    Enter NEW Selection # or CONTROL-C or ESCAPE ...
```

Figure 5.7 PSK Menu Selection For Terrestrial and Satellite Communications

Numerous packet data sets as well as SSB contacts were collected from March 1993 to January 1994 from the amateur satellites (in mode J operation) and terrestrial radio stations. These data sets are stored in Appendix F. Repeated attempts to transmit to the OSCAR satellites failed. The suggested EIRP uplink to FO-20 is 100 W [1]. Without the use of a power amplifier, the earth station delivered only 17 W EIRP from the transmitting antenna at 145 MHz. Using a borrowed power amplifier capable of up to 160 W output signal amplification from the University of Dayton, the signal power delivered to the transmitting antenna was approximately 25.5 W producing over 500 W EIRP.

With the power amplifier installed, repeated attempts to connect (transmit) to FO-20, AO-13, and AO-16 failed. The earth station would timeout on every attempt. However, the operation of the earth station modem, TNC, and computer interface equipment was verified through the reception of packetized data from the amateur satellites and from terrestrial packet stations. Additionally, the full duplex communications using packet data between the earth station and other earth stations verifies the operation of the system. The requirement for the earth station is to provide both terrestrial and satellite communications for SSB and packet data communications. The terrestrial links are full duplex for both SSB and packetized data communications. The earth station to amateur satellite links are receive only, half duplex links when using packetized data (mode J operations) and two way, full duplex links for SSB. The failure of the transmit link to the satellites was due to operator inexperience. The operator left the uplink in PSK operation. The uplink should have been AFSK.

5.2.8 InstantTrack Tracking Software Installation

Three different tracking programs were investigated and evaluated for this project. These included TrakSat III, InstantTrack, and the Orbit tracking programs. The InstantTrack software was readily available from a local amateur radio club and was obtained within 24 hours. InstantTrack was loaded on the 80386-based computer located next to the supply cabinet in the Communications/Radar Laboratory. By installing the tracking software on this computer, this freed the 80286-based computer to perform the packet data communications between the earth station and the orbiting platform.

Once the software was installed, the time and date were updated to reflect the current data. Then, the program was started. A few tests were performed to verify the operation of each module. Basically, this entailed trying to execute each different menu option from the main menu of the program. The main menu options are shown in Figure 5.8. The complete menu listings and an elementary users guide is found in Appendix C of this thesis. The command IT at the C:\instant> command prompt began the program. Once the program was launched, the main menu appeared.

```
08/28/92  20:01:07 UTC
                         InstantTrack V1.00b
                              Main Menu

1.   Realtime Track 1 Satellite (Text Screen)
2.   Realtime Track 1 Satellite (Map Screen)
3.   Satellite Position Table (Ephemeris)
4.   Satellite Visibility Schedule
5.   Update Satellite Elements
6.   Update Station Elements
7.   Multiple Satellite Co-visibility
8.   Update Time (NBS via modem)
9.   TSR Status
?.   Help
Q.   Quit
Select:
```

	RS-10/11	RS-12/13	AO-10	AO-13	AO-21	UO-22
Azim	155.983	344.084	149.539	319.980	178.424	23.502
Elev	-63.961	-5.547	58.163	22.891	-58.810	-27.983

Figure 5.8 InstantTrack Main Menu

From the main menu, each succeeding menu was tested by simply inputting the first letter of the desired selection. For most of this project, the Satellite Visibility Schedule, Multiple Satellite Co-visibility, and Realtime Track 1 Satellite (Map Screen) were most helpful.

These menus provided real-time tracking data, which was used to update the positions of the tracking antennas. In the Realtime Track 1 Satellite (Map Screen) menu, a graphical representation of the ground track was shown on the display. At the same time, at the bottom of the display, the current tracking earth station, the azimuthal, elevation, range, Doppler, and offpointing data were supplied. Additionally, the current latitude, longitude, altitude, phase, operating mode, and approximate ground sub-point were shown. Figure 5.9 presents this data.

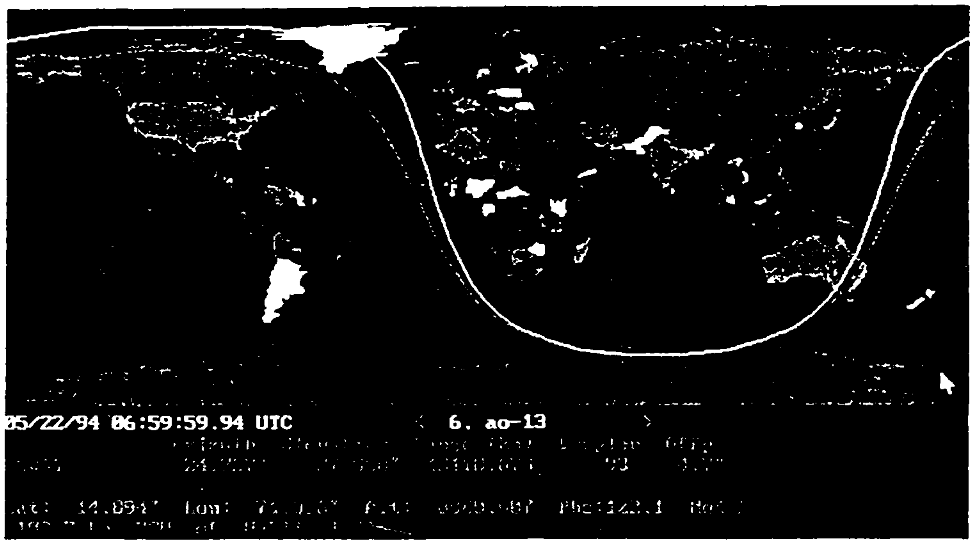


Figure 5.9 InstantTrack Realtime Track 1 Satellite (Map Screen) Display

Once the desired data was obtained, the rotor controller was used to manually rotate the antennas to the desired pointing angles. Then, the receiver was tuned to the different frequencies for the satellites of interest. Doppler shifts and other fluctuations were accounted for and after several tests of the system, successful results were obtained. These are documented in the results portion of this thesis. At this point, several display shots were captured to the printer and the computer for incorporation into a training manual for the system.

5.2.9 System-Level Testing

The completed system was used to perform terrestrial communications - SSB and packet data. During March, April, and May 1993, several terrestrial SSB and packet data communications occurred. Most of these are documented by collected packet data found in

Appendix E. Some were taped on standard voice grade audio tape. These tapes are available from the author upon request.

Once satisfactory terrestrial communications were established, i.e., SSB and packet data collections verified the operation of the system, the earth station was used to perform satellite communications. Initially, the test was to receive and decode packet data from an amateur satellite. Then, the earth station would be used to try to transmit packet data to the amateur satellite. Over a ten day period in April - May 1993, numerous attempts were performed. The initial test included only the transmitter, the transmission line, and the transmitting antenna. However, no transmission links from the AFIT earth station to an orbiting amateur satellite were successful. The theoretical computations had indicated the earth station needed to produce signal power levels of approximately 100 W to communicate with the amateur satellites. However, the transmitting system provided only about 1.0 W to the transmitting antenna. The transmitting antenna concentrated this to approximately 33 W EIRP. This was insufficient (without the use of a power amplifier) to communicate to the amateur satellites.

An RF power amplifier was obtained on loan from the University of Dayton. This power amplifier increased the output signal levels to about 26.20 W at the output of the power amplifier. At the input to the transmitting antenna, the power levels were recorded as 25.50 W. All measurements were performed by the Bird Wattmeter.

The increase in output signal power to the transmitting antenna permitted approximately 834.37 W to be transmitted from the end of the transmitting antenna. For Mode B operation, the uplink is about 435 MHz. The KLM 435-40CX antenna produces a gain of 15.20 dB. This is a multiplication factor of about 33, resulting in a signal output power of about 800 W EIRP. Therefore, the 834.4 W signal output power level arises.

Over a period of three days, SSB contacts with two different earth stations were completed. These are documented by the QSL card affixed to Appendix F and the earth station QSL Record Log stored in the Communications/Radar Laboratory. Additionally, the other stations recorded the events in their log books.

Once the SSB communications were established to AO-13 in mode B operation, attempts were repeated to transmit packet data to FO-20, AO-13, and AO-16 over a three day period. All attempts failed. At the end of the three day period, the power amplifier was returned to the University of Dayton.

The most likely possibility is the inexperience of the station operator. This was the first attempt by the station operator to connect to earth-orbiting satellites using packet data. The operator spent a considerable amount of time tuning the transmitter to the desired frequencies and not enough time ensuring accurate pointing angles for the tracking antennas or that the equipment was properly setup. Some of the target satellites use an AFSK uplink and a PSK downlink. The modem was left in PSK operation for all tests. Also, the satellites are only within view of the earth station for 10 -15 minutes each. The satellites passed out of view after only two to three attempts to contact each.

Other possibilities for the failure to establish communications include a saturation of the orbiting platform by more experienced and more powerful earth stations. As discussed previously, many of the amateur satellites have a finite amount of power to distribute to the system users. The more users working on a particular satellite, the less power each receives on the downlink side of the link. Also, at some point, the satellite can not accept any additional users.

One additional possibility is the initial misalignment of the system antennas. During testing of the system antennas, it was discovered the antennas had moved from their initial positions and were not balanced on the mast. This problem was corrected during the latter part of May 1993.

The end result is that the earth station can communicate on terrestrial links using both SSB and packet data. Also, the earth station can receive mode B and mode J communications from the targets of interest. The limiting factor is the inability to transmit packet data to the amateur satellites.

5.3 Test Results

Several tests were conducted during the installation and system checkout phase of this thesis. These tests were documented in the preceding section. Where possible, the results were included in the preceding discussion. In general, the individual tests produced some type of results that verified the individual components being tests were capable of performing their assigned task.

There is one notable exception. The transmitting system does not produce sufficient transmitting power to permit transmissions (SSB or packet data) to amateur satellites. A power amplifier is required to permit these operations.

Because configuration testing indicated anomalies with the alignment of the system antennas, these were repositioned in the latter part of May 1993. The misalignment of the antenna pointing could have affected the attempts to communicate to the amateur satellites via packet data transmissions. The SSB communications were affected, but not as severely because the AO-13 remained in view of the AFIT earth station for several hours versus a few minutes for the satellites using mode J. This was due to the orbit of AO-13 providing longer overhead passes. The longer overhead passes required less antenna pointing corrections for AO-13 than for the other satellites.

Configuration tests indicated one other anomaly. The receiving equipment (IC-970A) displayed receiving frequencies for different satellites about 10 - 15 Hz off from other amateur radio stations (N8EHA and W8BIFM).

5.4 Intercept Data

The following sections present a listing of the data intercepts collected from the different targets of interest for this thesis. The actual data collected from the targets does not contain as much useful information for this thesis as does the intercept parameters. Therefore, the discussion presents the intercept versus the actual data collected.

Appendix E documents the actual data intercepts for many of the target intercepts. Table 5.1 provides a listing of the data intercepts for the period between March 1993 and January 1994. From Table 5.1, it can be seen that the earth station has collected SSB and packet data from amateur radio service satellites and terrestrial radio stations using packet data. This fulfills the mode B and mode JD requirements for the thesis.

Table 5.1 Data Intercept Log - Terrestrial

Date/Time	Activity	Initial Frequency (MHz)
28/Mar/93 1850-1857	Terrestrial packet from W8BI	145.03
28/Mar/93 1858-1942	Terrestrial packet from W8BI	145.01
28/Mar/93	Failed attempt to connect to AFIT Digipeater	
28/Mar/93 1842-1943	Terrestrial packet from W8BI	144.91
2/Apr/93 1142-1150	Terrestrial packet from W8BI	145.01
2/Apr/93 1155-1200	Terrestrial packet from W8BI	145.93
18/Apr/93 1257-1303	Terrestrial packet from W8BI	145.027
19/Apr/93 1900-1905	Terrestrial packet from W8BI	145.9
20/Apr/93 1900-1903	Terrestrial packet from WA3ULL	145.01
23/Apr/93 2120-2130	Terrestrial packet from W8BI	145.07
26/Apr/93 2110-2200	Terrestrial packet from WA3ULL	145.01
27/Apr/93 1036-1044	Terrestrial packet from W8BI	145.07

Table 5.2 Data Intercept Log - Satellite

Date/Time	Activity	Initial Frequency (MHz)
29/Apr/93 1942-1955	Terrestrial packet from W8BI. Satellite packet from WO-18 & LU-19	W8BI - 145.73 WO-18 - 437.110 LU-19 - 437.132
2/May/92 1300-1800	Satellite packet from AO-13, DO-17, WO-18, LU-19 & AO-16	AO-13 - 437.051 DO-17 - 145.824 WO-18 - 437.1082 LU-19 - 437.1332 AO-16 - 437.051
9/May/92 1302-1314	Satellite packet from WO-18 & LU-19	WO-18 - 437.1117 LU-19 - 437.1335
14/May/92 1343-1400	Mode B contact on AO-13	145.85
16/May/92 1300-1320	Satellite packet from WO-18 & LU-19	WO-18 - 437.1118 LU-19 - 437.1335
23/May/92 1039-1745	Satellite packet from AO-16, WO-18. LU-19 & FO-20. Mode B AO-13 contact with W8BIFM	AO-16 - 437.060 WO-18 - 437.1133 LU-19 - 437.1295 FO-20 - 435.9191 AO-13 - 145.853
4/Jan/94 2100-2200	Satellite packet from AO-16, WO-18, & LU-19	AO-16 - 437.026 WO-18 - 437.0751 LU-19 - 437.154

During the intial intercepts between March 28 and April 2, 1993, several corrections to the earth station equipment were performed. Among these were the corrections to the Pac-Comm PSK-1 systems board. Once the repairs were performed, the data collection resumed on April 18, 1993. Packet data was collected terrestrially until April 29, 1993. On April 29, 1993, the intial satellite packet data was intercepted. From April 29 to May 14, 1993, packet data was collected from AO-13, AO-16, DO-17, WO-18, LU-19, and FO-20.

On May 14, 1993, the intial SSB full duplex contact was made via the AO-13 patform in mode B operation. This contact ws between N8VAT and W8BIFM. This contact is verified by the QSO card shown in Appendix E. On May 23, 1993 , full duplex SSB contact was repeated for the thesis advisor and documented in the earth station Contact Log stored in the Communications/Radar laboratory. Finally, on January 4, 1994, the earth station was used to revalidate the proper operation for packet data operations.

5.5 Summary

This chapter discussed the actual installation, configuration, and testing of individual components and the completed AFIT earth station. As the completed station tests show, the earth station is capable of transmitting and receiving SSB and packet data on a terrestrial link. On satellite links, SSB and packet data can be received. However, additional equipment (more specifically, a power amplifier) may be required for packet data transmissions to amateur satellites. Also, retesting of the antenna pointing system may produce satisfactory transmit results. Finally, this chapter documented the intercepts for terrestrial and satellite packet and SSB (mode JD and mode B) operations.

Chapter VI Conclusions and Recommendations

This chapter provides a summary of this thesis effort, and makes recommendations for further research into amateur radio earth station design and analysis.

6.1 Summary

This thesis involved detailed research into amateur radio earth stations, packet data communications, satellites and orbital mechanics, and many other areas. The focus of the thesis was to design, analyze, and build a functional mode B and mode JD earth station as a training tool for future Air Force engineers. The earth station was designed. Along the way, each system component was analyzed individually and then collectively. Also, a working terrestrial radio station was developed first. Then, the operational radio station became an earth station by virtue of satellite packet data collections and SSB (mode B) contacts with other earth stations. The earth station is capable of communicating with other terrestrial stations in two-way operation. In the satellite communications, the earth station has proven two-way mode B operation. In mode J operation, only the reception of digital data has been accomplished from the earth-orbiting satellites. Due to operator error, this was not demonstrated.

6.2 Conclusions

The design and analysis of a mode B and mode JD earth station is a complicated task. The multitude of equipment that must be interfaced, the complexities of overcoming weak received signal power levels on the order of picowatts, the actual integration of the transceiver to the packet data devices, and the accuracy levels required for precise real-time tracking of the low earth-orbiting amateur satellites each contribute to the intricacies of the design and analysis of a multi-mode earth station.

The approach to the solution of the problems presented in this thesis is only one method of solving this problem. The approach used in this thesis worked well for this system build. The final result, an operational earth station, verifies this conclusion.

The completed earth station has met the requirements developed earlier in this thesis. Multiple modulation methods and signal types can be collected from this station.

6.3 Recommendations

The following paragraphs present some topics for future research and development in support of the design and analysis of an earth station.

1. Add a power amplifier that provides at least 160 W of output signal power to improve satellite communications.
2. Investigate the implementation of a computer controlled, automatic satellite tracking system to provide real-time, accurate tracking of multiple earth-orbiting satellites.
3. Integrate the ICOM IC-R9000 into the earth station to permit multiple signal reception from multiple satellites simultaneously.
4. Design, build, and integrate L-band system antennas. These antennas can be used to integrate the L-band stage into the ICOM IC-970A and further enhance the earth station.
5. Investigate means to reduce the transmission line losses. One method is to work with the Civil Engineering offices to provide direct access to the antennas on the roof of the Engineering Building. Another possible way to reduce the

transmission line losses is to relocate the earth station. A third method is to replace the existing coaxial cable with hardline cabling.

In summary, the earth station permits SSB and packet data communications to other radio stations. However, the packet data communications are two-way only for the terrestrial radio stations. The earth station requires additional equipment in the form of power amplifiers to provide the two-way packet data communications between the earth station and OSCAR platforms.

Appendix A. Terms

Term	Definition
Acquisition of Signal	The term given to the time at which an earth station begins to receive radio frequency signals from an orbiting satellite.
Apogee	Maximum orbital point
AX.25	Amateur packet-radio link layer protocol.
Azimuth	The angle measured in the horizontal plane with respect to 0 degrees (north).
Beacon	In a satellite, an RF signal transmitted to a receiving station indicating activity/status of the channel or system.
Beacon Station	The name given to an amateur radio station transmitting signals for the purpose of experimental observations of propagation and related activities.
Bulletin Board Service	A computer service allowing computer users to exchange information with other users having similar interests. The amateur radio satellites serve as a type of orbiting BBS at no cost to the users.
Callsign	Alphanumeric designator for an operator of a radio station.
Coaxial	Type of transmission line.
Doppler Shift	The phenomenon where a time rate change in the length of the path between a source and observation point induces a change in the observed frequency of a wave in a communications system.
Downlink	Term used to describe the RF link beginning at a spacecraft and terminating at an earth station.
Eccentricity	One parameter describing the actual shape of an elliptical orbit.

Elevation	Angle measured above the horizontal plane.
Fiber Optic	Type of transmission line.
Flying Mailbox	Nickname for amateur satellites providing messaging services.
Geo-stationary	Satellite orbit which `appears' to keep a satellite fixed above a given equatorial point.
Loss of Signal	Time at which an earth station loses RF signals from a satellite.
Mark	Positive value indicating presence of data between nulls called Spaces in early communication systems.
Mode	Pair of operating frequencies denoting the uplink and downlink frequencies for a given amateur satellite.
Modem	Modulator-demodulator. A device to
Molniya	Originally a series of Soviet satellites with a unique, elliptical orbit. Term commonly used to describe other highly elliptical satellite orbits.
N-type	Type of cable connector.
Noise Figure	The ratio of the total noise power to the input noise power (in decibels) given the input termination is at 290K.
Orbital Elements	A group of six numbers, defined at a precise time (epoch), that describe the size, shape, and orientation of a satellite orbit completely.
Packet Radio	A method of communications (digital) that employs short bursts of data. The short bursts of data contain addressing, control, and error-checking information in each transmission.
Perigee	Minimum orbital point for a satellite.
PL-type	Type of cable connector.

Rotor	Device to rotate azimuth and/or elevation antennas towards a target of interest (usually a satellite).
RS-232C	A standard physical-level interface between terminals and modems using 25-pin connectors.
Selectivity	The measure of the ability for a circuit to discern and separate the desired signal from those at other frequencies.
Sensitivity	The degree of response of a control unit to a change in the incoming signal. Also the measure of a receiver to detect weak signals.
Space	Null between data values called Marks in early communications.
Stability	The measure of performance for a transmitter or receiver to remain on frequency without drifting to another frequency.
Telemetry	RF signals transitted from a source to a monitoring site that indicate the status or performance of active systems.
Terminal Node Controller	A device that assembles and disassembles packets of data.
Twisted Pair	Type of transmission line.
Uplink	Term used to describe the RF link beginning at an earth station and terminating at a spacecraft.
Yagi-Uda	Type of wire antenna used for satelliteand terrestrial communications.

Appendix B. Satellite Characteristics

B.1 Overview

This appendix presents background information on the amateur satellites chosen as targets of interest for this thesis. The data contained in this appendix is derived from numerous publications, books, and private conversations with other amateur radio station operators [1, 2, 5, 11, 14]. The material contained in this appendix is not comprehensive by any means. Rather, these details are intended to provide the necessary information an operator of the AFIT earth station would require during a typical communications session.

B.2 UoSAT-OSCAR 11 (UO-11)

UO-11 is the oldest of the UO series of satellites that remains in orbit about the earth. The satellite was built by students and faculty at the University of Surrey, England as an educational and research satellite [1, 11]. This satellite provides only downlink services.

B.2.1 Orbital Parameters

Table B.1 Orbital Parameters for UO-11

Orbit Type	Period	Apogee Altitude	Perigee Altitude	Maximum Access Distance
low-altitude, circular, sun-synchronous orbit.	98.3 min.	688 km	670 km	2846 km

B.2.2 Power Levels

The transmitting peak power is approximately 1 W [1].

B.2.3 Signal Information

The UO-11 satellite does not employ any open-access transponders. It does have an experiment on-board that was used to design the transponders currently employed with the Pacsat (AO-16) [1].

B.2.3.1 Beacons

There are three beacons on UO-11. The beacon data is presented in Table B.2.

Table B.2 UO-11 Beacon Information

Beacon No.	Frequency (MHz)	Power Output	MODULATION METHOD	Maximum Doppler
1	145.826	400 mW	NBFM (AFSK) ± 5 KHZ	3.6 kHz
2	435.025	600 mW	NBFM (AFSK) ± 5 KHZ	10.5 kHz
3	2401.500	500 mW	NBFM (AFSK) ± 10KHZ	12.0 kHz

B.2.3.2 Modulation Methods Employed

The modulation method employed is a narrow band frequency modulation (NBFM) AFSK method with PSK option available.

B.2.4 Antenna Systems

The UO-11 spacecraft has a linearly polarized monopole mounted on top and two circularly polarized SHF helical antennas located on the bottom of the satellite.

B.2.5 Remarks

This research satellite carries many experimental packages that were used to provide design information for follow-on satellites. Among the experiments on-board UO-11 are the digital communications experiment that was used to obtain data for futre packet radio protocols, impact detectors for space dust and particle damage, a CCD camera, and a wave correlator experiment used to investigate wave types that cause electrons to be accelerated into the auroral beam [1].

B.3 AMSAT-OSCAR 13 (AO-13)

The AO-13 satellite was launched on 15 June 1988. This is a popular satellite for the amateur radio enthusiasts due to its 50 W of transmitting peak power and its Molniya orbit. The Molniya orbit keeps the spacecraft in view of north american earth stations for a relatively long period of time.

B.3.1 Orbital Parameters

Table B.3 provides the orbital parameters for the AO-13 satellite [1].

Table B.3 AO-13 Orbital Parameters

Orbit Type	Period	Apogee Altitude	Perigee Altitude	Max Access Distance
Molniya Orbit	11.44 Hrs	38074 km	734.9 km	9050 km

B.3.2 Power Levels

The peak transmitting power for AO-13 is 50 W [1]. Suggested uplink EIRP is presented for each transponder in Table B.4.

B.3.3 Transponder Information

The information presented in Table B.4 provides the basic information an earth station operator requires. Additional information, such as the translation equations are required as well. Equation (27) is the translation equation for the mode B downlink.

$$F_{downlink} = 581.398 - F_{up} \pm \text{Doppler} \tag{27}$$

where F_{dwnlnk} = Downlink frequency in MHz

F_{up} = Uplink frequency in MHz

Equation (28) shows the translation equation for the mode J downlink.

$$F_{dwnlnk} = 580.413 - F_{up} \pm \text{Doppler} \qquad (28)$$

where F_{dwnlnk} = Downlink frequency in MHz

F_{up} = Uplink frequency in MHz

Equation (29) shows the translation equation for the mode L downlink.

$$F_{dwnlnk} = 1705.356 - F_{up} \pm \text{Doppler} \qquad (29)$$

where F_{dwnlnk} = Downlink frequency in MHz

F_{up} = Uplink frequency in MHz

Equation (30) shows the translation equation for the mode S downlink.

$$F_{dwnlnk} = 1965.109 + F_{up} \pm \text{Doppler} \qquad (30)$$

where F_{dwnlnk} = Downlink frequency in MHz

F_{up} = Uplink frequency in MHz

Table B.4 AO-13 Transponder Information

Trans #	Type	Modulation	Mode	Uplink (MHz)	Downlink (MHz)	Suggested Uplink EIRP
1	Linear, Inverting	CW/SSB	B	435.420-435.570	145.825-145.975	500 W
2	Linear, Inverting	CW/SSB Packet	J	144.425-144.475	435.990-435.940	800 W
3	Hard-Limiting, Non-Inverting	CW/SSB	L	1269.33-1269.62	435.715-436.005	4 - 8 kW
4	Hard-Limiting, Non-Inverting	CW/SSB	S	435.602-435.638	2400.711-2400.747	500 W

B.3.4 Beacon Information

There are four beacons of interest on AO-13. These are listed in Table B.5 [1].

Table B.5 Beacon Frequencies for AO-13

Beacon	Frequency (MHz)	Max. Doppler (kHz at perigee)
B General	145.812	2.6
B Engineering	145.985	2.6
JL General	435.652	7.6
S General	2400.664	41.9

The beacon schedule for AO-13 is listed below. This beacon can be heard plainly. It transmits at approximately 1 W [14].

B.3.4 Modulation Methods Employed

AO-13 employs CW, RTTY, PSK, SSB, and packet data communications.

B.3.5 Antenna Systems

Table B.6 lists important information on the AO-13 antenna systems [1, 17].

Table B.6 AO-13 Antennas for 145 MHz and 435 MHz.

Antenna Frequency Band	Type	Gain (dB)	Polarization
145 MHz	ZL special, three phased two-element beams	6.0 dBic	RHC
145 MHz	Monopole	-2.0 dBi	Linear
435 MHz	3 phased dipoles over ground	9.5 dBic	RHC
435 MHz	Monopole	-2.0 dBi	Linear

B.4 UoSAT-OSCAR (UO-14)

UO-14 was built by the same design group at the University of Surrey, England that built UO-11 [1, 11].

B.4.1 Orbital Parameters

Table B.7 provides useful information on UO-14 orbital parameters [1].

Table B.7 UO-14 Orbital Parameters

Orbit Type	Period	Apogee Altitude	Average Altitude	Maximum Access Distance
Low-altitude, circular, sun-synchronous, near polar	100.8 min	805 km	794 km	3038 km

B.4.2 Power Levels

The transmitting peak power is 10 W [1].

B.4.1 Signal Information

The transponder, beacon, and modulation method used by UO-14 are in the following sections.

B.4.3.1 Transponder Information

UO-14 was the first amateur satellite to employ an open-access transponder. There is a single uplink and a single downlink frequency for this transponder. However, the downlink can be in either 1200 bps AFSK (NBFM) or in 9600 bps FSK (FM) [1, 11]. Table B.8 provides the transponder data.

Table B.8 UO-14 Transponder Data

Data Rate	Modulation	Uplink (MHz)	Downlink (MHz)
1200 bps	AFSK (NBFM)	N/A	435.070
9600 bps	FSK (FM)	145.975	435.070

B.4.3.2 Beacons

The beacon signal on UO-14 is heard on 435.070 MHz and uses 1200 bps AFSK (FM) or 9600 bps FSK. It has a maximum Doppler of 10.3 kHz [1, 11].

B.4.3 Antenna Systems

There is a 145 MHz monopole and a 435 MHz turnstile on the bottom of the spacecraft.

B.5 UoSAT-OSCAR (UO-15)

The UO-15 spacecraft was intended to include a CCD video camera to provide images of the Earth during its orbit. However, this payload ceased operating a short time after it was launched.

B.6 Pacsat-OSCAR (AO-16)

The AO-16 satellite is referred to as the Pacsat. The AO-16, DO-17, WO-18, and LU-19 satellites were launched at the same time from Kourour, French Guiana on February 22, 1990 [1, 2, 11, 14].

B.6.1 Orbital Parameters

Table B.9 presents the AO-16 orbital information. This information is very similar to the DO-17, WO-18, and LU-19 spacecraft.

Table B.9 AO-16 Orbital Parameters

Orbit Type	Period	Apogee Altitude	Average Altitude	Maximum Access Distance
Low-altitude, circular, sun-synchronous, near polar	100.8 min	800 km	793.7 km	3038 km

B.6.2 Power Levels

AO-16 has a transmitting signal power strength of 4 W on he 435 MHz band. Also, it has a 1 W output signal power on 2.4 GHz [1].

B.6.3 Signal Information

AO-16 provides packet data services. Many amateur radio operators refer to this satellite as the pacsat, because it functions like a flying mailbox.

B.6.3.1 Transponder Information

The AO-16 transponder data is presented in Table B.10.

Table B.10 AO-16 Transponder Information.

Trans #	Modulation/Signal Type	Mode	Uplink (MHz)	Downlink (MHz)	Connect Address
1	AFSK (FM) 1200 bps AX.25 Manchester	J	145.900, 145.920, 145.960	N/A	Pacsat-1
2	PSK 1200 bps (SSB) AX.25 BPSK	J		437.02625	Pacsat-1
3	Raised Cosine 1200 BPS (SSB) AX.25 BPSK	J		437.05130	Pacsat-1
4	1200 BPS AX.25 BPSK	S		2401.1428	Pacsat-1

B.6.4 Antenna Systems

The 2.4 GHz antenna is a bifilar, helix. The 145 MHz receiving antenna is a stub antenna. It is linearly polarized. The 435 Mhz transmit antenna is a canted turnstile that has four radiating elements. This antenna is mounted on the bottom of the satellite [1, 11].

B.7 DOVE-OSCAR 17 (DO-17)

DO-17 is a digital orbiting voice encoder. It uses PT2PAZ as its callsign. It is an educational satellite and was intended to interest school children in amateur radio. It provides only a downlink signal. However, unlike the AO-16 platform, this satellite can be heard by using only a standard terrestrial FM packet mode for the 145 MHz band.

B.7.1 Orbital Parameters

Table B.11 shows the DO-17 orbital data.

Table B.11 DO-17 Orbital Data

Orbit Type	Period	Apogee Altitude	Average Altitude	Maximum Access Distance
Low-altitude, circular, sun-synchronous, near polar	100.8 min	800 km	793.4 km	3038 km

B.7.2 Power Levels

DO-17 transmits 4 W on 145 MHz and 1 W on the 2.4 GHz bands [1, 11].

B.7.3 Signal Information

Table B.12 shows the DO-17 downlink beacons information.

Table B.12 DO-17 Beacon Data

Modulation /Signal Type	Mode	Downlink (MHz)	Callsign
1200 bps AFSK (FM) AX.25	J	145.82516	PT2PAZ
1200 bps AFSK (FM) AX.25	J	145.82438	PT2PAZ
1200 bps BPSK	S	2401.2205	PT2PAZ

B.7.4 Antenna Systems

DO-17 has a linearly polarized 145 Mhz canted turnstile antenna mounted on the bottom of the satellite. DO-17 also has a 2.4 GHz circularly polarized bifilar helix antenna.

B.8 Webersat-OSCAR 18 (WO-18)

The WO-18 satellite is intended to provide imaging data to the Weber State University group that designed and built the satellite. The imagery collected by the satellite is stored on-board and downlinked in a format compatible to amateur satellite packet radio techniques [1].

B.8.1 Orbital Parameters

The WO-18 orbit is nearly identical to AO-16, DO-17, and LU-19. The Wo-18 information is shown in Table B.13.

Table B.13 WO-18 Orbital Parameters

Orbit Type	Period	Apogee Altitude	Average Altitude	Maximum Access Distance
Low-altitude, circular, sun-synchronous, near polar	100.7 min	805 km	793.4 km	3038 km

B.8.2 Power Levels

In modes J and L, WO-18 transmits approximately 4 W of signal power [1, 11].

B.8.3 Signal Information

WO-18 has a pacsat transponder on-board. However, the primary goal is imagery store-and-forwarding.

B.8.3.1 Transponder Information

Table B.14 shows the WO-18 transponder information.

Table B.14 WO-18 Transponder Parameters

Modulation\ Signal Types	Mode	Uplink (MHz)	Downlink (MHz)
Nominal 1200 bps BPSK AX.25 (SSB)	J	144.300 - 144.500	437.07510
Raised Cosine 1200 bps BPSK AX.25 (SSB)	J	144.300 - 144.500	437.12580
ATV NTSC (AM-TV)	L	1265.000	

B.8.4 Antenna Systems

WO-18 has a bifilar helix 2.4 GHz antenna. The 145 MHz receiving antenna is a linearly polarized stub antenna. The 435 Mhz transmit antenna is a canted turnstile with four radiating elements and is mounted on the bottom of the satellite [1, 11]. Also, WO-18 has a 1.2 GHz, 1/4-wavelenth stub antenna used to receive ATV transmissions from the earth.

B.9 Lusat-OSCAR 19 (LU-19)

This satellite is more similar to AO-16, than to either DO-17 or WO-18. This is another store-and-forward satellite intended for amateur radio purposes.

B.9.1 Orbital Parameters

Table B.15 presents the orbital information for LU-19.

B.9.2 Power Levels

LU-19 transmits approximately 4 W on 437.15355 and 437.12580 MHz. It transmits approximately 0.8 W for the CW telemetry on 437.125 MHz [1, 11].

Table B.15 LU-19 Orbital Information

Orbit Type	Period	Apogee Altitude	Average Altitude	Maximum Access Distance
Low-altitude, circular, sun-synchronous, near polar	100.7 min	805 km	793.1 km	3038 km

B.9.3 Signal Information

The LU-19 satellite provides packet radio (mode J) services.

B.9.3.1 Transponder Information

Table B.16 LU-19 Transponder Information

Modulation/ Signal Type	Mode	Uplink (MHz)	Downlink (MHz)	Connect Address
1200 bps AFSK (FM) AX.25 Manchester	J	145.840, 145.860, 145.900		Lusat-1
Nominal 1200 bps BPSK AX.25	J		437.15355	

B.9.3.2 Beacons

LU-19 has two beacons. The first is a raised cosine operating at 1200 bps BPSK (SSB) AX>25. The second passes CW telemetry data at approximately 0.8 W [1, 11].

B.9.4 Antenna Systems

LU-19 has a 145 MHz receiving antenna that is a linearly polarized stub antenna. The 435 Mhz transmit antenna is a canted turnstile with four radiating elements and is mounted on the bottom of the satellite [1, 11].

B.10 Fuji-OSCAR 20 (FO-20)

The FO-20 satellite has both a linear, non-inverting transponder and a digital transponder. However, the linear transponder is not active often. The callsign for FO-20 is 8J1JBS.

B.10.1 Orbital Parameters

The FO-20 orbital parameters are shown in Table B.17.

B.17 FO-20 Orbital Parameters

Orbit Type	Period	Apogee Altitude	Average Altitude	Maximum Access Distance
Low-altitude, elliptical, non- sun-synchronous	112.23 min	1745 km	1328 km	4257 km

B.10.2 Power Levels

FO-20 transmits approximately 2 W peak envelope power on mode JA and 1W RMS on mode JD [1].

B.10.3 Signal Information

There are both a linear and a digital transponder. The linear is not active often. The digital transponder information is presented in Table B.18

B.10.3.1 Transponder Information

The uplink in mode JD must be Manchester encoded FM. The protocol is AX.25, level 2, version 2. The data rate is 1200 bps. The downlink is 1200-baud BPSK [1]. Equation (31) provides the translation equation for mode JA operation.

$$F_{dwnlnk} = 581.800 - F_{up} \pm \text{Doppler} \tag{31}$$

where F_{dwnlnk} = Downlink frequency in MHz

F_{up} = Uplink frequency in MHz

Table B.18 FO-20 Transponder Information

Transp. No	Mode	Uplink (MHz)	Downlink (MHz)	Suggested Uplink EIRP	Bandwidth	Max. Doppler
1	JA	145.900 - 146.00	435.800 - 435.900	100 W	100 kHz	6.7 kHz
2	JD	145.850, 145.870, 145.890, 145.910	435.910	100 W	N/A	N/A

B.10.3.2 Beacons

FO has a beacon on 435.975 MHz. It uses CW or PSK modulation. The output power for the beacon is approximately 60 mW. The maximum Doppler is 10.1 kHz. Another beacon is on 435.910 MHz for the digital transponder downlink. The modulation is PSK and it has a 1 W output power. The maximum Doppler is 10.1 kHz.

B.10.4 Antenna Systems

FO-20 has a 145 MHz turnstile antenna located on the bottom of the satellite. The 435 MHz transmitting antenna is used for both modes JA and JD. It is a canted turnstile located on top of the satellite.

B.11 Summary

This appendix provides useful information for the amateur radio operator just beginning to work with amateur satellites. This is not a comprehensive spacecraft analysis. For additional information, please contact either the AMSAT or ARRL area coordinators.

Appendix C. InstantTrack

C.1 Overview

The purpose of this guide is to permit novice users a step by step process in using the InstantTrack software. This guide may be used as a means of obtaining the current orbital parameters for a given satellite. The guide does not attempt to provide detailed descriptions of every function of the software program. For complete details, the reader is referred to the manual written by Franklin Antonio [23].

C.2 Introduction to InstantTrack

InstantTrack is a useful tool for tracking a number of earth-orbiting satellites. Also, it allows users to have the computer pass antenna pointing parameters to a rotator, if the rotator is equipped to permit such operation. Finally, the InstantTrack software provides radio station operators the ability to estimate pass-over windows for their favorite targets.

C.3 Starting InstantTrack

The InstantTrack software is installed on the computer system next to the storage cabinet in the Communications /Radar Laboratory. Start the InstantTrack software by powering on the computer system that is located next to the gray storage cabinet. The InstantTrack software is installed on both the C-drive of the computer in the C:\IT> subdirectory. Log to the C:\IT> subdirectory and type IT to begin the program.

C.4 The Main Menu

Once the InstantTrack program initializes, the main menu appears and data for the most commonly tracked satellites can be seen at the bottom of the main menu. The AO-13 satellite has been included in this set of targets. The current azimuth and elevation for the

AO-13 satellite are listed on the bottom of the screen. This information can be input to the rotator manually or automatically via the computer. Figure C.1 depicts the main menu of the InstantTrack program.

```
08/28/92  20:01:07 UTC
                              InstantTrack V1.00b
                                   Main Menu

     1.   Realtime Track 1 Satellite (Text Screen)
     2.   Realtime Track 1 Satellite (Map Screen)
     3.   Satellite Position Table (Ephemeris)
     4.   Satellite Visibility Schedule
     5.   Update Satellite Elements
     6.   Update Station Elements
     7.   Multiple Satellite Co-visibility
     8.   Update Time (NBS via modem)
     9.   TSR Status
     ?.   Help
     Q.   Quit
     Select:
```

	RS-10/11	RS-12/13	AO-10	AO-13	AO-21	UO-22
Azim	155.982	344.084	149.539	319.980	178.424	23.502
Elev	-63.961	-5.547	58.163	22.891	-58.810	-27.983

Figure C.1 Main Menu of the InstantTrack Program

C.5 Setting the Station Timezone and the Station Coordinates

The first thing an operator should do upon starting the InstantTrack software is to ensure the timezone and the operator's station coordinates are stored in the program properly. Presently, the timezone and the AFIT earth station coordinates are stored correctly in the program. If the computer system loses power or some other problem causes this data to get erased, these values can be reentered. To replace the timezone variable for the program, exit the program. At the command prompt, type in the data shown below.

SET TZ=EST5EDT

This command sets a DOS environment variable and enables the computer to provide accurate passover times for selected satellites. To update the operator station coordinates, select the Option #6 (Update Station Elements) from the main menu of the Instanttrack program. Press the Enter key and a station selection menu appears. This is a database file. this file can hold up to 50 station locations. The first record is reserved for the AFIT tracking earth station. The operator must select a station to edit. this will be station #1. The station edit screen appears. The current values for the station should appear at this time.

Use the up-arrow and down-arrow keys to select the line that requires changes. To input a new value for the station press the = (equal) key and input the new value. Then, press the Enter key to record the value in the database. Continue updating the station values as required. Once this is complete, press the Q key to exit the program. The Q key is the universal escape/cancel operation function for the InstantTrack program. The new station location values are stored in the program file IT.QTH.

C.7 The Realtime Tracking Screens

The InstantTrack program can provide additional information such as the current operating mode, distance from the earth station, and estimated doppler offset for the receiver. This information can be used to fine tune the earth station transmitter or receiver settings. This additional information is found in Realtime Track 1 Satellite Screens (either the text of map screens). To get this information in textual form, press the #1 from the main menu of InstantTrack. The program pages to a new menu. The operator is prompted to select a satellite. Type in the number corresponding to the desired satellite (#6 for AO-13) and press the Enter Key on the keyboard. The software will display a textual listing of orbital parameters for the AO-13 satellite.

The same information can be displayed in a graphical nature, by selecting option #2 from the main menu of InstantTrack. If the option #2 is selected from the main menu, the software will page to the same menu that prompts the user to select a satellite. Simply select the number corresponding to AO-13 (#6) and press the Enter Key. The graphical representation is now displayed.

If a printer is connected to the first line printer terminal port of the computer (LPT1:), the keyboard printscreen key will direct the current screen display to the printer. This is useful for obtaining printouts of the current satellite positions. Figure C.2 shows the RealTime Track 1 Satellite (Text) Screen.

```
05/20/94 19:44:25.53 UTC  <6. AO-13>
      Az        El      Range (Km) dR/dt  Doppler  Offp  Path Loss
N8VAT 247.719  48.743 38185.996  0.8625 -419     9.95  -167.4 dB

Lat.      Long.     Alt. (km)     Phase     Mode  Grid
20.6325   -119.2095  36805.687     101.5     B     DL00jp

995.9 km WSW of La Paz, Mexico

      X (km)    Y (km)     Z (km)     R.A.      Decl.           Tsky
Sat  23107.144 33156.628 15216.467 03:22:47  +165:57:31       338K
Obs  -28.717   4892.855  4078.180
```

Figure C.2 The Realtime Track 1 Satellite (Text Screen)

C.8 Other Main Menu Options

There are other menu selections that permit other displays of a target satellite. These options are self explanatory. For example, option #2, the RealTime track 1 Satellite (Map Screen) shows a graphical display of the above data. One other useful option from this main menu is the option #7. This provides a tabular listing of the satellites and annotates the expected passover times for the tracking earth station. This is useful when the operator wishes to track multiple satellites simultaneously and does not want to have to monitor multiple screens or multiple sheets of paper. Figure C.3 shows a sample of this display.

The modes are marked in capital letters. The expected passover times are marked by the asterik. The dashes represent no coverage of the AFIT earth station.

```
                                Satellite Schedule
Day: 04/26/93
Station: N8VAT
                                   Hour - edt
--------0  1  2  3  4  5  6  7  8  9  10 11 12 13 14 15 16 17 18 19 20 21 22 23
Sun     ---------------------*****************************************----------
Moon    *------------------------------*****************************************
rs-10/11-----------A----AA---AA---------------------A----A----AA----------------
rs-12/13-----------------------KK---KK----K---------------------KK---KK----K----
ao-10   ---BBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBB----------------------------------
ao-13   BBBBBBB-----------------BBBBBBBBBBBBBBBBBBSSJJBBBBBBBBBBB----BBBBBBBBBBB
ao-21   ----------BB---BB----B------------------------B----B----BB--------------
uo-11   -----------------------*---**---**----------------------*---**---**-----
uo-14   ---**------------------------------**---**---**-----------------*----**-
UO-15   **----*-------------------------**---**---**----------------------**---*
ao-16   ----*------------------------------**---**---**------------------*---**-
do-17   ---**------------------------------*----**---*-----------------------*--
wo-18   -**---*--------------------------*----*----*-----------------------*---*
lo-19   -**---**-------------------------*----**---**----------------------*----
fo-20   -**--------------**---**----**---**----------------------------**----**-
mir     *---*----*----*----*---------------------------------------*---**---**--
uo-22   *---**-------------------------*---**---**----------------------**---**-
ko-23   --**----**----*-------------------------------*----**----**----**----**-
MOS-1   *----*--------------------------**---**---**------------------*----**---
GOES 7  ************************************************************************
```

Figure C.3 Multiple Satellite Co-Visibility

C.9 Getting Help

InstantTrack has an on-line help which can be invoked by selecting option #? at the main menu. The station operator should refer to this, if problems arise. The remainder of the options for the software are not absolutely required to track amateur satellites. Experimentation with these options are left to the reader.

C.10 Summary

This guide serves as a stepping off point for beginning amateur satellite trackers. It is not intended to provide explicit details of the entire InstantTrack software program. This appendix provided information on starting the InstantTrack software, setting the earth station timezone, updating the earth station coordinates, and obtaining satellite tracking information from the program.

Appendix D. AFIT Earth Station User's Guide

D.1 Overview

The following information is intended as a users guide for the AFIT earth station. In Section D.2, information about the station components is presented. Section D.3 provides instruction on the proper use of the station equipment. Most of the earth station equipment is housed within the gray 6' movable rack located in the northwest corner of the laboratory.

D.2 The Equipment in the Earth Station

Figure D.1 illustrates the physical layout of the earth station components in the Communications/Radar Laboratory. Included in this figure are the IC-970A transceiver, the Pac-Comm PSK-1 modem, the Pac-Comm TNC, a serial two-port switch box, and the Intel 80386-based computer system.

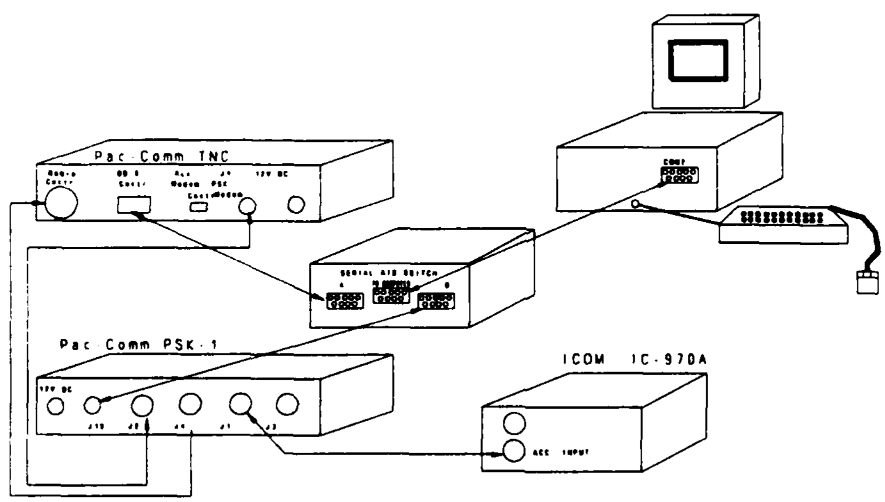


Figure D.1 Earth Station System Diagram

These components are discussed in the following paragraphs. For complete details on a particular component, please review the manufacturer's equipment instruction manual.

D.2.1 The Receivers

There are two receivers in the earth station. These are the ICOM IC-970A and the ICOM R-9000. The R-9000 is used for other purposes at this time. Therefore, the following discussion pertains to only the IC-970A.

The IC-970A is actually a dual-band transceiver. It can receive and transmit signals in the 144 MHz and the 430 MHz bands. The IC-970A can be operated either using VFO or direct keypad entry. The receiver can perform simultaneous reception on both bands. This is performed via a main and a sub band selection switch on the front panel of the receiver. The IC-970A actually has two separate, fully independent receivers. Each receiver can operate in a unique mode, squelch setting, and volume setting. The IC-970A permits SSB, CW, AM, and FM operation.

D.2.2 The Transmitter

As mentioned, the IC-970A is actually a transceiver. There are two transmitter modules within the IC-970A. These can be only operated one at a time. The IC-970A can transmit in the 144 MHz and 435 MHz bands. The modulation methods permitted are SSB, FM, and CW. The transmitter can be connected to packet data switching equipment through the use of either the accessory or the data external connections on the back panel of the transceiver.

D.2.3 The Computer System, Modem, TNC and Interface Equipment

The Intel 80386-based computer system is connected to the Pac-Comm PSK-1 modem and the Pac-Comm TNC via a serial two-port switch box. The computer has the Procomm Plus communications software loaded on the computer system to permit data communications between the earth station and other radio stations.

The Pac-Comm PSK-1 modem provides the capability to communicate with amateur satellites that operate use Manchester encoded AFSK uplinks and PSK downlinks. The PSK-1 is not required to communicate with either the DO-17 or the UoSAT satellites. The DO-17 spacecraft uses normal AFSK packet and synthesized voice as downlink signals. The UoSAT satellites employ standard 9600 baud FSK uplink and downlink signals. The PSK-1 modem is controlled by means of software commands input through the serial port (typically from a computer using a communications software program) of the modem or by the push buttons on the front panel of the modem.

The Pac-Comm terminal packet controller (the TNC) functions as an interface between the IC-970A radio and the computer. The TNC permits radio communications between the IC-970A and another radio station using similar equipment. The packet controller's audio signals are fed into the accessory connector on the back panel of the IC-970A. The packet controller output is adjusted to provide a proper modulation level. The audio for the receiver is collected from an external audio output or the speaker jack on the IC-970A. This audio is then fed into the packet controller. The TNC is controllable by means of software commands input from the computer system or by the push buttons on the rear of the TNC.

D.2.4 The Tracking Software

The tracking software is the InstantTrack software program. Appendix C provides an elementary users guide to this program. The function of the software is to provide realtime or near-realtime orbital data for the satellites of interest to the station operator. The software can display up to seven realtime satellite tracks at the same time. This software is loaded on the Intel 80386-based computer system and a second computer system located next to the storage cabinet in the laboratory.

The software program can be used to control an antenna rotator to provide automatic satellite tracking. Presently, another software program, the Kansas City Tracker program, is used to perform this function.

D.2.5 The Antenna Rotator and Rotator Controller

The rotator employed in this station is the Yaesu G-5400B. The G-5400B is mounted on top of the antenna tower on the roof of the AFIT Graduate School of Electrical Engineering. The rotator controller is located in the Communications/Radar Laboratory in the cabinet housing the earth station equipment. The rotator provides horizon-to-horizon elevation coverage and complete azimuthal coverage. The rotator can be either manually or automatically controlled. Presently, the rotator is computer controlled via the Kansas City Tracker software program for another research project.

D.2.6 System Cabling, Antennas, and Preamplifiers

The transmission lines used in the earth station are RG-213/U and RG-8/U cables. The KLM 435-40CX and the KLM 2M-22C antennas serve as both receive and transmit antennas for the earth station. The KLM 435-40CX operates on the 435 MHz band and the KLM 2M-22C operates on the 145 MHz band. The AG-25 and the AG-35 serve as the 145 MHz and 435 MHz preamplifiers (respectively) for the earth station. These are mounted on the antenna tower on the roof of the AFIT Graduate School of Electrical Engineering.

D.3 Getting Started

The following sections discuss the recommended steps to begin a communications session with another radio station. The initial setup provides common sense tips on ensuring satisfactory communications between radio stations. The remaining paragraphs provide information on the proper equipment operation.

D.3.1 Initial Setup

Begin by making sure the IC-970A and the audio speaker are plugged into the power strip located on the shelf in the 6" movable rack. This power strip must be plugged into a grounded 110V power source. Next, ensure all remaining earth station components, such as the TNC, the modem, the computer systems, and the rotator, are plugged into the nearest power sources and powered on. At this time, ensure the circuit breakers have been turned on. These are located on the wall of the lab, next to the earth station workbench. As a precaution, before the IC-970A is powered on, ensure the transmit/receive switch on the IC-970A is turned to the receive selection. The IC-970A may be turned on after this precaution is completed.

D.3.2 Selecting a Target

Now, the operator must decide on a target. The procedures for a terrestrial target differ from the satellite operating procedures. For the purpose of this manual, the target will be one of the amateur radio service satellites. For terrestrial operations, please refer to the IC-970A Instruction Manual.

Decide upon the actual satellite to be contacted. Many of the satellites have unique operating characteristics. However, all of the amateur satellites uplink within one frequency and downlink signals within a different frequency band. Select one of the amateur satellites. For this manual, the first target is AO-13. Now, obtain the operating characteristics for the AO-13 satellite from any of the ARRL or AMSAT publications. For convenience, the author has placed a copy of The Satellite Experimenter's Handbook in the Communication/Radar laboratory [5]. Obtain the uplink and downlink frequencies, the beacon frequencies, and the suggested minimum ERP for AO-13.

D.3.3 Locating the Target

Start the InstantTrack software on the computer located next to the gray storage cabinet. The InstantTrack software is installed on both the C-drive of the computer in the C:\IT> subdirectory. Log to the C:\IT> subdirectory and type IT to begin the program.

Once the InstantTrack program initializes, the main menu appears and data for the most commonly tracked satellites can be seen at the bottom of the main menu. The AO-13 satellite has been included in this set of targets. The current azimuth and elevation for the AO-13 satellite are listed on the bottom of the screen. This information can be input to the rotator manually or automatically via the computer.

For this guide, this information must be fed to the rotator manually. The operator must turn the antennas to point to the indicated azimuth and elevation by use of the lever switches on the G-5400B rotator controller. For example, if the AO-13 is located at an azimuth of 319.980 degrees and an elevation of 22.891 degrees, the operator should press the appropriate lever switch on the rotator controller until the analog dials point to these settings.

D.3.4 Selecting the Correct Equipment

At this time, the operating frequencies and AO-13 orbital parameters are known. The

InstantTrack program can provide additional information such as the current operating mode, distance from the earth station, and estimated doppler offset for the receiver. This information can be used to fine tune the earth station transmitter or receiver settings. This additional information is found in Realtime Track 1 Satellite Screens (either the text of map screens). To get this information in textual form, press the #1 from the main menu of InstantTrack. The program pages to a new menu. The operator is prompted to select a satellite. Type in the number corresponding to the desired satellite (#6 for AO-13) and press the Enter Key on the keyboard. The software will display a textual listing of orbital parameters for the AO-13 satellite.

The same information can be displayed in a graphical nature, by selecting option #2 from the main menu of InstantTrack. If the option #2 is selected from the main menu, the software will page to the same menu that prompts the user to select a satellite. Simply select the number corresponding to AO-13 (#6) and press the Enter Key. The graphical representation is now displayed.

Now, the earth station operator can tune the transceiver to the desired operating frequencies for AO-13. First, begin by becoming acquainted with the IC-970A. Figure D.2 is a diagram of the IC-970A front panel display. All of the switches, controls, and displays of the IC-970A are shown in Figure D.2. For complete details of each function, please refer to the ICOM IC-970A Instruction Manual [20].

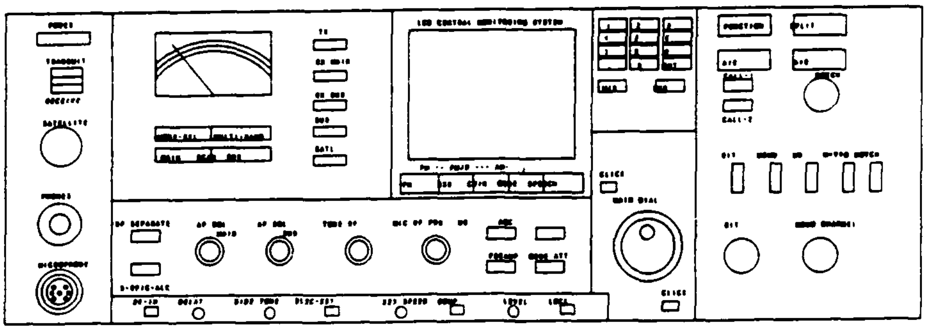


Figure D.2 ICOM IC-970A Front Panel

D.3.5 Receive First, Then Transmit

It is recommended for the operator to receive signals from a satellite, before trying to transmit to the satellite. Therefore, ensure the SATELLITE switch on the IC-970A is set to SATL to select the satellite operating mode. The AO-13 frequencies have been stored in the memory of the IC-970A in the MEMO-8 channel. To recall these settings, simply rotate the MEMO-CH switch (located on the lower right hand side of the transceiver) until the number 8 appears in the LCD Display along with the proper operating frequencies. For this example, it is assumed AO-13 is in mode B operation. Visually check to be sure the uplink modulation method is LSB and the downlink frequency is USB. If not, then press the SSB button until the proper modulation method appears for the MAIN and SUB bands.

The uplink frequency of 435.428 MHz and the downlink of 145.970 have been programmed into the IC-970A. The actual operating frequencies will differ from these values. At this time, the operator will set the downlink frequency by depressing the SUB button. Turn the MAIN dial until the current downlink frequency obtained from InstantTrack (for example

145.812 MHz - the general beacon frequency for AO-13) is displayed in the LCD monitoring area of the IC-970A. Figure D.3 shows a typical LCD display with the SUB band displayed at the top of the display and the MAIN band displayed in the lower right hand side. The memo channel is shown in the upper right hand side of the screen.

Now, ensure that the antenna rotator has been positioned to the current azimuth and elevation for the satellite. Fine tune this antenna pointing by listening for the beacon frequency of AO-13. The beacon has a high pitched hum sound and is easily discernable from background noise, CW, or SSB. The AO-13 general beacon is a strong signal and can be heard quite plainly. The beacon on AO-13 is transmitting at a constant output EIRP of 1 W [14]. The beacon schedule for AO-13 can be found in The Satellite Experimenter's Handbook [1]. The beacon changes between CW, PSK, and RTTY on a regular basis.

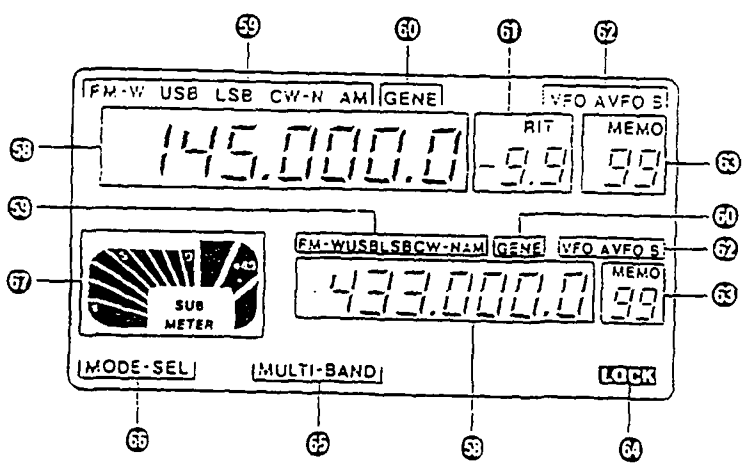


Figure D.3 LCD Display on IC-970A

Tune the receiver until the best reception of the beacon can be obtained. Remember, to monitor the orbital elevation and azimuthal values to ensure the antennas follow the satellite. Update the pointing angles as required. Depress the SUB button once more to activate the MAIN band of the transceiver. Turn the main dial to update the uplink frequency to match tha data obtained from InstantTrack. Once this value is entered, depress the SUB button again. The IC-970A is now ready to receive and transmit signals.

The operator is cautioned to continue receiving signals before transmitting to AO-13. Spend sufficient time to check the loading (volume of users on the satellite) before transmitting signals to the satellite. The satellite has a limited amount of receive and transmit power available. This power is divided up among the number of users on the satellite. If too many work the satellite, the signal power levels may become too low to permit continued communications. Likewise, if too much transmit signal power is directed towards the satellite, it may overload the satellite and prohibit anyone else from using the satellite.

Once receiving functions are verifed, perform a loop test to ensure the transmitter signal can reach the satellite. This test also checks to see, if a transceiver can receive the returned satellite signal. Perform this test wear[illegible] headphones to block out any background noise from the lab. The following discussion presents methods of computing the expected downlink frequency when an uplink frequency is known.

Each satellite that permits two way communications has a translation frequency formula. There is a formula for each transponder on an amateur satellite that permits two way communication. Use the translation frequency for AO-13 to predict the downlink frequency, when an uplink frequency is known. The translation frequency is available The Satellite Experimenter's Guide located in the Communications/Radar Laboratory [1]. For

AO-13 in mode B operation, the translation frequency is expressed by Equation (27) below.

$$F_{dwn} = 581.398 - F_{up} \pm F_{doppler} \quad (27)$$

Equation (28) is the translation frequency for mode J operation on AO-13.

$$F_{dwn} = 580.413 - F_{up} \pm F_{doppler} \quad (28)$$

Assume an uplink of 435.490 MHz has been selected and that InstantTrack indicates -0.1 MHz is the Doppler shift. Equation (29) computes the expected downlink frequency for mode B operation.

$$F_{dwn} = 581.398 \text{ MHz} - 435.490 \text{ MHz} - 0.01 \text{ MHz} = 145.898 \text{ MHz} \quad (29)$$

Start the test by depressing the PTT/Tx (transmit) button. Turn the main dial to put the SUB band frequency back to the current downlink frequency. Move the SATELLITE switch to N or R on the left hand side of the switch. N permits normal tracking, where the transceiver will track the operating frequencies in the same direction. Selecting the R setting instructs the IC-970A to track the frequencies in the opposite direction. At this time, speak into the microphone and transmit voice signals to AO-13. The operator may wish to call CQ, CQ AO-13, or something similar. Monitor the downlink signals from AO-13 on the SUB band. Remember there will be some amount of doppler shift involved in the downlink. The InstantTrack program provides this expected value. Use this value to tune the transmitting frequency, while maintaining a constant downlink frequency. Remember to keep a constant watch on the InstantTrack program and manually update the antennas position via the antenna rotator.

The previous instructions were given to verify that the earth station could communicate to the AO-13 satellite. If these tests were successful, then the operator can try to communicate with other stations at this time. Again, uplink the operator's voice on a known frequency and listen for it on the expected downlink frequency. When the communications session is completed, unplug the headphones and store them in the movable rack. Power off all equipment and inspect the area around the earth station. Ensure all components are returned to their original location. This completes the operators initial mode B operation.

D.4 Intercepting and Storing Data on the Computer System

To transmit and receive packet data signals using mode J from the AO-13 satellite, the process is similar to the mode B. However, a few additional steps are required. These are discussed in the following paragraphs.

First, ensure all earth station equipment is powered on. This time, ensure the computer system with the communications software, Procomm Plus, has been turned on. Log to the C:\PROCOMM> subdirectory and start the program by typing PCPLUS at the command prompt. Once the program begins, press ALT-Z to start the HELP screen of the program. The major functions are listed on this screen. Depress the ALT-F1 keys at the same time to create a log file of all activity during the current communications session. Make sure the proper communications ports and data rates are set. If these require changing, select the ALT-P keys together to enter the setup for the communications ports. Refer to the help documentation in the Procomm software for further assistance.

Once the computer is ready, set the switch box to port B. This enables communications between the PSK-1 and the computer. When the PSK-1 modem is powered on, it will download its current settings into the computer system. These will be displayed on the screen, if the communications link between the computer and the modem is set up properly. Turn on the PSK-1 modem. If the modem settings are not displayed, check the cables between the devices. If the settings are displayed on the screen, verify the current setting of the operating mode for the PSK-1 modem. The menu displayed on the computer screen lists the selections for the various menu screens for the modem. If the PSK-1 modem is switched to the terrestrial setting, press #1 and enter the mode selection screen. Select #1 to put the modem into satellite operation.

Once the modem is set up, switch the serial switch box to port A. This enables communications between the computer and the TNC. Turn the TNC on. The TNC should download its current settings to the computer. If this is successful, the values will be displayed on the computer screen. Start the InstantTrack software and obtain the current operating values for AO-13. Ensure AO-13 is operating in mode J at the present time. If the satellite is not employing mode J at the present time, choose a different mode or try the session during the scheduled mode J operation for AO-13. Use the InstantTrack program to print out a listing of the passover times for AO-13 and the expected operating mode.

Next, turn the SATELLITE switch on the IC-970A to SATL. Select the memo channel #8 for AO-13. This recalls some preset frequencies for the satellite. Select a new uplink frequency. Use Equation (28) to compute the expected downlink frequency. Input these values to the transceiver as in the mode B example. Ensure the uplink and downlink modulation methods are

Once the satellite receiver has been updated, begin by trying to receive signals from the satellite. The mode J data signals have a unique sound to them. To an unfamiliar operator, the data sounds may sound like the intermittent whining of a grinding machine. If the receiver detects packet data, and the system processes it, the data will be displayed on the computer screen where the PROCOMM software is active. If the log file has been enabled, all collected data will be stored in an ASCII text file on the hard drive of the computer for future reference.

If the packet data can not be received from the satellite, verify the antennas are pointing at the satellite. Remember to update the antenna pointing with the InstantTrack values on a continuous basis. If the reception is still not effective, begin an organized inspection of each link of the earth station. A common problem is not having the PSK-1 modem operating in a satellite mode. Other common problems are bad cable connections to the computer, switch box set to the wrong device, or antenna pointing problems.

Once packet data is received from the AO-13 satellite, begin to try to transmit (connect) to the satellite. To do this, use the keyboard of the Intel 80386-based computer and type in instructions on the screen. Please review the command instruction listing in the documentation for the Pac-Comm TNC and modem [12, 13]. To begin, type in the **MYcall XXXXX** command at the cmd: prompt. The XXXXX is the current operator's callsign. Once this is typed into the computer, press the Enter key and submit the instruction to the system. The computer display should reproduce the operator's instruction. This verifies the system is accepting instructions.

Now, type in the **Connect XXXXX** at the cmd: prompt. If the AO-13 receives the transmitted signal and establishes a connection with another radio station, the computer screen should display a message such as *** **CONNECTED TO XXXXX**, where XXXXX is the callsign of the responding earth station in the link. If the operator wishes to connect to another amateur satellite such as the FO-20 platform without having another earth station in the link, the returned callsign from FO-20 would be 8J1JBS. Other amateur satellite callsigns are listed in The Satellite Experimenter's Handbook [1].

Once a connection is made, the operator can communicate to the other earth station by typing in whatever data the operator wishes to transmit. The operator is reminded the duration of the communications link may be for only 10 -15 minutes. The operator needs to continue to monitor the antenna pointing and frequency deviations as well as maintain the conversation with the other earth station. Once the operator wishes to terminate the link, the operator can type in the instruction **Disconnect** and press the Enter Key.

D.5 Logging Your Intercepts and Contacts

Once the operator is finished with the communications link, all equipment returned to the original location, and all equipment is powered off, a final step is to log all intercepts. A station record book has been placed next to the IC-970A for the AFIT earth station.

D.7 Summary

The information included in this user's guide is intended to provide an operator sufficient information to use the AFIT earth station. An overview of the station equipment and standard operating procedures for mode B and mode J operation are included in this guide.

Appendix E. Sample Data Intercepts

E.1 Overview

This appendix provides samples of the data collected from the terrestrial and amateur satellite targets of interest. As mentioned in the thesis, the actual intercept data does not provide as much useful information for this thesis as did the intercept parameters. These intercept parameters, such as the actual frequencies copied during the intercept, the observed Doppler shift from the expected frequency, the azimuthal pointing angle, and the elevation pointing angle provided more useful information for this thesis.

E.2 Terrestrial Intercepts

The following data are samples from some of the terrestrial collections. The date of intercept and method of data storage are listed in Chapter 5 of this thesis.

Terrestrial Intercept Number 1 was collected on April 26, 1993. Figure E.1 illustrates a communication between two terrestrial stations. The link is between the AFIT radio station in Area B of WPAFB and Dr. Mehalic (WA3ULL) in Fairborn, Ohio.

```
*** CONNECTED to WA3ULL
Hello Dennis!
HI MARK ...KKKTurn your power up a little.\
IS THAT A LITTLE BETTER ...KKK
Let's go to 145.01
That's better.
SWITCHING NOW ...KKKOK
You there??
```

Figure E.1 Two Terrestrial Stations

Terrestrial Intercept Number 2 was collected on April 29, 1993. The link was between the AFIT radio station (N8VAT) and the DARAHH BBS (W8BI). This is shown in Figure E.2.

```
cmd:c w8bi*** CONNECTED to W8BI
 Hello and welcome to the W8BI mailbox!
================================================================
     This is the Dayton Amateur Radio Association P.B.B.S.
================================================================
I see that you have logged on before but not registered as a
user.Please do so soon. To whom should this message go?
WA3ULL Please enter a subject for your message.
FINALLY REGISTERED THIS SYSTEM FOR AFIT
MARK, THIS IS ANOTHER TEST OF THE TERRESTRIAL LOGIN AND
CONNECTIONCAPABILITY OF THIS SYSTEM.  I HAVE CAPTURED SOME
ADDITIONAL CW TONIGHTBUT WILL RETURN TOMORROW AND THIS WEEKEND TO
CONNECT TO SATELLITE PACKET.TALK TO YOU LATER. DENNIS Message
5406 has been stored!
```

Figure E.2 Sample Terrestrial Communication

E.3 Satellite Intercepts

The following data are sample from some of the amateur satellite intercepts. These samples are from mode J intercepts from the AO-16, DO-17, WO-18, and LU-19 satellites. The samples are representative samples for the entire data collection set. Figure E.3 shows Satellite Intercept Number 1. The intercept came from the FO-20 platform. The date of the intercept was May 23, 1993.

```
cmd: Mycall   N8VAT
cmd:8J1JBS>WB7QKK:NO.  DATE   UTC    FROM    TO      SUBJECT
8J1JBS>WB7QKK:0790 05/23 11:32  WW8T    WB7QKK  Mobile FM
Went to ham feast.Running 440 mhz. now. JAS>8J1JBS>TG9IKE:3BDR
ALL GREETINGS !
```

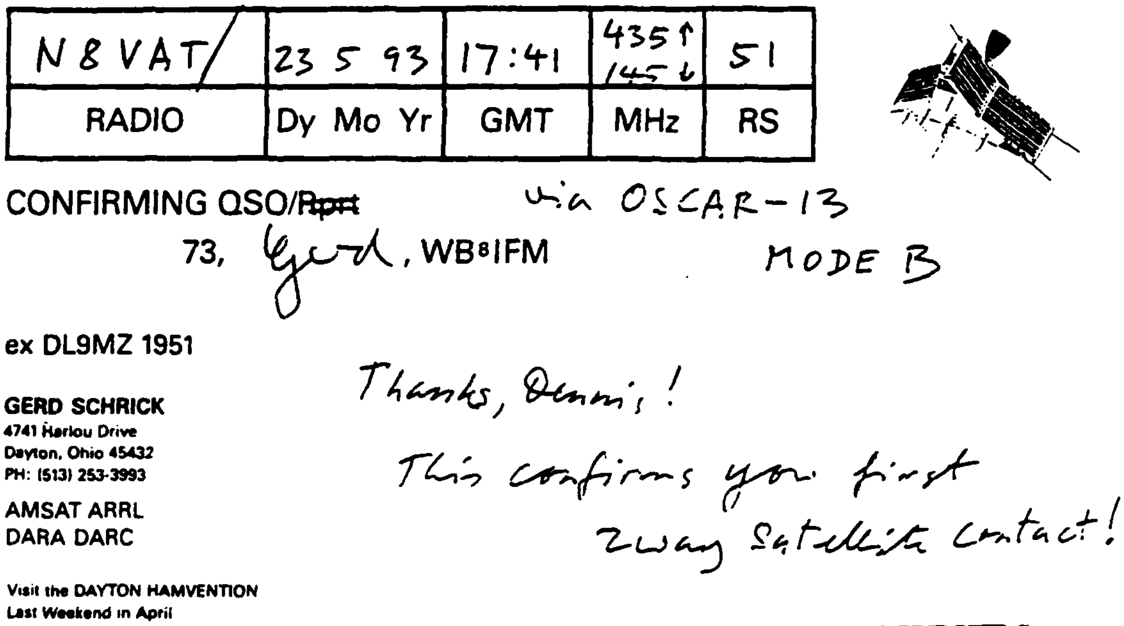
Figure E.3 Sample Satellite Intercept

Figure E.3 shows the parameters for the second sample satellite intercept.

23/May/93	Event	= AO-13 Mode B SSB Contact
	$Frequency_{down}$	= 145.9219
	$Frequency_{up}$	= 435.4773
	Azimuth	= 347 deg
	Elevation	= 72 deg
	Range	= 26,525 Km
	Time Period	= 13:43
	Remarks	= Contact with Gerd Schrick

Figure E.3 Satellite Intercept Parameters

Figure E.4 shows the card confirming a QSO with Mr. Gerd Schrick. This occurred on May 23, 1993 using the parameters shown in Figure E.3.



N8VAT/	23 5 93	17:41	435↑ 145↓	51
RADIO	Dy Mo Yr	GMT	MHz	RS

CONFIRMING QSO/~~Rpt~~ via OSCAR-13

73, Gerd, WB8IFM MODE B

ex DL9MZ 1951

Thanks, Dennis!

GERD SCHRICK
4741 Harlou Drive
Dayton, Ohio 45432
PH: (513) 253-3993

This confirms your first 2way Satellite contact!

AMSAT ARRL
DARA DARC

Visit the DAYTON HAMVENTION
Last Weekend in April

Figure E.4 Confirmation of QSO Between the AFIT Earth Station and WB8IFM

E.4 Summary

This appendix presents samples of the data intercepted from the terrestrial and earth-orbiting targets of interest. The remainder of the intercepted data is available from the author upon request.

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Vita

Mr. Dennis J. Hance was born on November 23, 1957. Mr. Hance enlisted in the United States Air Force in April 1980 and was assigned to the 6950th Electronic Security Group Berlin, Germany. He was selected for the Airman's Education and Commissioning Program in 1985 and he transferred to Wright State University in Dayton, Ohio to pursue a Bachelor of Science degree in electrical engineering. Mr. Hance graduated from Wright State in 1987 and was commissioned as a second lieutenant in the United States Air Force in 1988. Mr. Hance served at the National Security Agency from 1987 to 1991 when he was reassigned to the Air Force Institute of Technology to complete a Master of Science in Electrical Engineering degree with emphasis in communications and digital computer communications. He is married to Pamela Hance of Louisville, Kentucky and they have three children.

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This thesis focuses on the design, integration, and analysis of an amateur radio service mode B and mode JD satellite earth station. Preliminary designs were investigated to determine the optimum configuration for the earth station. Modern digital modems, cabling structures, an 80386-based computer system, satellite tracking software, transmission and reception antennas, preamplifiers, and sophisticated performance measurement technologies were integrated into a functioning earth station. Initially, component availability and station design dictated the selection and acquisition of the requisite station equipment. Integration of the transmitter, receiver preamplifiers, antennas, and computer equipment followed. Preliminary testing of the various components in the integration station occupied a significant amount of time. Emperical test tracking of different amateur and commerical satellites verified proper operation of the earth station. Results are discussed throughout this thesis.

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