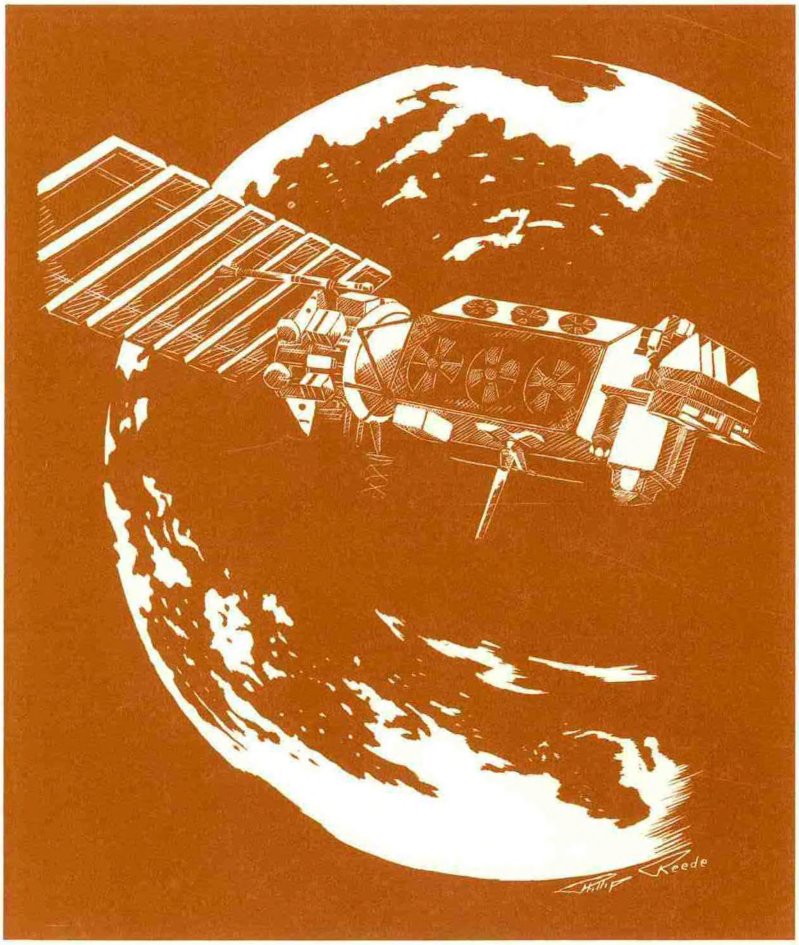
National Oceanic and Atmospheric Administration

Educator's Guide For Building and Operating Environmental Satellite Receiving Stations

Washington, D.C.

October 1991



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service

National Oceanic and Atmospheric Administration

The National Environmental Satellite, Data, and Information Service (NESDIS) manages the Nation's civil Earth-observing satellite systems, as well as global national data bases for meteorology, oceanography, geophysics, and solar-terrestrial sciences. From these sources, it develops and disseminates environmental data and information products critical to the protection of life and property, national defense, the national economy, energy development and distribution, global food supplies, and the development of natural resources.

This report is available from the National Technical Information Services (NTIS), U.S. Department of Commerce, Sills Bldg., 5285 Port Royal Road, Springfield, VA 22161 (prices on request for paper copies or microfiche, please refer to PB number when ordering) or by contacting Nancy Everson, NOAA/NESDIS, 5200 Auth Road, Washington, DC 20233 (when extra copies are available).

This publication is a reprint of the February 1989 edition of NOAA Technical Report NESDIS 44, Educator's Guide for Building and Operating Environmental Satellite Receiving Stations. The reprint is issued in connection with International Space Year -1992, one of several NOAA projects in education. This ISY reprint has been abbreviated from earlier editions to ensure as wide a distribution as possible to educators around the world.

ISY

INTERNATIONAL
SPACE YEAR 1992

National Oceanic and Atmospheric Administration

Educator's Guide For Building and Operating Environmental Satellite Receiving Stations

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FOREWARD

This publication has been prepared in keeping with National Oceanic and Atmospheric Administration's commitment to serve the public, and educators in particular, by providing for the widest possible dissemination of information based on its research and development activities.

The environmental/weather satellite program has its origins in the early days of the U.S. space program and is based on the cooperative efforts of the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA) and their predecessor agencies.

The information assembled here describes actual classroom experiences at the Chambersburg Area Senior High School in Pennsylvania. It represents a unique combination of aerospace research, technology and applications, providing actual experiences which will afford an insight into some of the most exciting activities of science and technology to come out of the space program. Hopefully, for many of the students, these activities may also provide a sampling of future careers.

In the preparation of this publication, NOAA's technical staffs, the faculty of the Chambersburg Area Senior High School, and representatives of NASA are acknowledged. In particular, the early efforts of Elva R. Bailey, R. Joe Summers, and Robert W. Popham proved instrumental in the development of the framework for the application of satellite technology in education. Cover page artwork was prepared by Phillip Reede, an art student at Chambersburg.

Since this publication is designed to serve as an instructor's manual for the construction of electronic equipment, brand names are cited in an attempt to help identify and locate items from readily available sources. However, this information is not to be construed as an advertisement or an endorsement of such items or their manufacturers.

Teachers and educators requiring additional information on the application of environmental satellite data in education should contact:

NOAA Educational Affairs
1825 Connecticut Ave., N.W.
Suite 627
Washington, D.C. 20235

(202) 606-4380
(202) 606-4425 (fax)

NOAA will publish a Directory of Resources for Earth Observation in Education in conjunction with International Space Year - 1992. The Directory will provide up-to-date information on educators using environmental satellite data, vendors supplying hardware and software to build satellite receiving stations, a bibliography of literature and curriculum materials relating to satellites and education, a glossary of satellite terminology, and a calender of events for satellite educators. To obtain a copy of the Directory call or write to the above address after March, 1992.

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I. INTRODUCTION

Satellites provide us with a unique and long-sought opportunity to look at Earth from space. These spacecraft now enable us to observe and measure the many forces of nature which converge on our planet. For the first time, mankind can begin to observe the global nature of the environmental factors which interact to form the complex systems we call Earth. From the unique vantage point of space, sophisticated environmental/ weather satellites bring us information about cloud formations and movements, precipitation amounts, temperatures, frost warnings, ocean currents, sea surface temperatures, air and water pollutants, drought and floods, severe weather conditions, vegetation, insect infestations, ozone contents of the atmosphere, volcano eruptions, and other factors that affect our daily lives. They have also provided us with less tangible aesthetic values which help shape attitudes about the environment of this planet. This new global attitude is, perhaps, just as important as the hard data that the satellites provide.

Much of this information is transmitted from these satellites via direct readout to ground stations where it can be displayed and analyzed. These Direct Readout Services were pioneered 28 years ago by the first weather satellites and have been expanded and operated in the United States by the National Oceanic and Atmospheric Administration (NOAA). The most popular of these services are the Automatic Picture Transmissions (APT) of the US polar orbiting satellites and WEFAX transmitted by the US Geostationary Operational Environmental Satellites (GOES). Other countries have launched, and are now operating, weather satellites with direct readout capabilities. These include the Soviet Union, Japan, the European Space Agency, and China.

Thousands of direct readout stations have been purchased or built to receive the direct readout transmissions from these satellites. In addition to government and military agencies, private industries, ham radio operators, and a variety of individuals are operating ground stations. Perhaps the fastest growing use of this free data is within the educational community. Many teachers with students at all levels within educational institutions have also discovered the benefits of these satellites. Innovative teachers are using real time data to teach a variety of curriculum materials including the sciences, electronics, engineering, computer sciences, social studies, geography and art. Exposure to this exciting world of Earth remote sensing can help retain students, motivate them toward higher education, and expand career possibilities to areas unheard of a few years ago. This publication is designed to provide teachers with the basic information needed to operate a direct readout ground station so that they can introduce students to this new technology. With a direct readout ground station, every classroom can have access to millions of dollars of high tech equipment every day.

II. AUTOMATIC PICTURE TRANSMISSION AND WEFAX DIRECT READOUT

AN OVERVIEW

Satellite pictures received from the very early weather satellites were analyzed by U.S. Weather Bureau meteorologists, and the results, in the form of hand drawn "nephanalyses" (cloud depiction charts) were transmitted to major forecast centers throughout the United States and overseas. These charts, sent by conventional landline or radio facsimile circuits, often reached these centers too late to be of any practical value in forecasting the weather. The Automatic Picture Transmission system (APT) was developed to help alleviate this problem by making it possible for forecast centers in any part of the world to receive satellite images in "real time" whenever an APT equipped satellite passed within radio range of the ground station. APT images were designed with a format so that they could be received and reproduced by relatively inexpensive ground station equipment.

The first APT system was pioneered on TIROS-VIII (Television Infrared Observational Satellite), launched in December 1963. TIROS VIII was one of the early polar orbiting weather satellites. Several U.S. weather offices were equipped to receive transmissions from this satellite, and plans for building relatively simple, low cost ground receiving stations were widely distributed to foreign meteorological services. By 1965, radio amateurs (hams) were designing stations for home reception and publishing design information in popular electronic magazines. Activity and interest in receiving direct readout transmissions by members of the academic community also developed. This was, in part, due to a series of articles by Professor H.R. Crane which appeared in 1968 and 1969 issues of the Physics Teacher journal.

Today, polar orbiting satellites launched by the United States continue to transmit images of the Earth via APT. These have been joined by Russian METEOR satellites with transmission systems similar to the APT on the current United States polar orbiting satellites. This is fortunate because a ground station capable of receiving the U.S. polar orbiting satellites can also receive images from these satellites.

APT FROM THE UNITED STATES TIROS SERIES SATELLITES

APT from the polar orbiting satellites have traditionally been on radio frequencies between 137 and 138 MHz FM. At the present time two United States satellites maintain polar orbits and transmit APT on 137.50 MHz and 137.62 MHz. The Russian polar orbiting satellites vary but have used 137.30 and 137.85 MHz on a regular basis. The FM signal from the satellites contains a subcarrier, the video image itself, as a 2400 Hz tone which is amplitude modulated (AM) to correspond to the light and dark areas of the Earth as seen by the detecting instrument on the satellite. The louder portion of this tone represents the lighter portions of the image while the lower volumes represents the darkest areas of the image. Intermediate volumes form the shades of the grey scale needed to produce the complete image. This, then, is an analog type of data transmission.

On the latest TIROS-N series United States satellites the APT images are produced by the primary scanning instrument called the Advanced Very High Resolution Radiometer (AVHRR). This instrument is designed to detect five channels of radiant energy reflected from the surface of the Earth ranging from the visible spectrum, the near-infrared, and infrared spectra. Data from all of these channels are transmitted directly by high resolution digital format at high speed transmissions known as High Resolution Picture Transmission (HRPT). HRPT ground stations usually cost $100,000 or more.

The analog APT signal is derived from the original digital data and multiplexed so that two of the five channels appear in the APT format. This is accomplished on the satellite by using every third scan line of the digital HRPT data, produced at 360 lines per minute, to amplitude modulate a 2400 Hz tone. The scan rate of the APT signal is, therefore, 120 lines per minute (2 lines per second). The two images that appear in the APT are selected from ground control and, during daylight passes, usually consist of the visual channel and one of the infrared channels. At night two infrared images are usually found in the APT. Therefore, the final product from APT consists of two images, side by side, representing the same view of the Earth in two different spectral bands. (See Plate II-1)

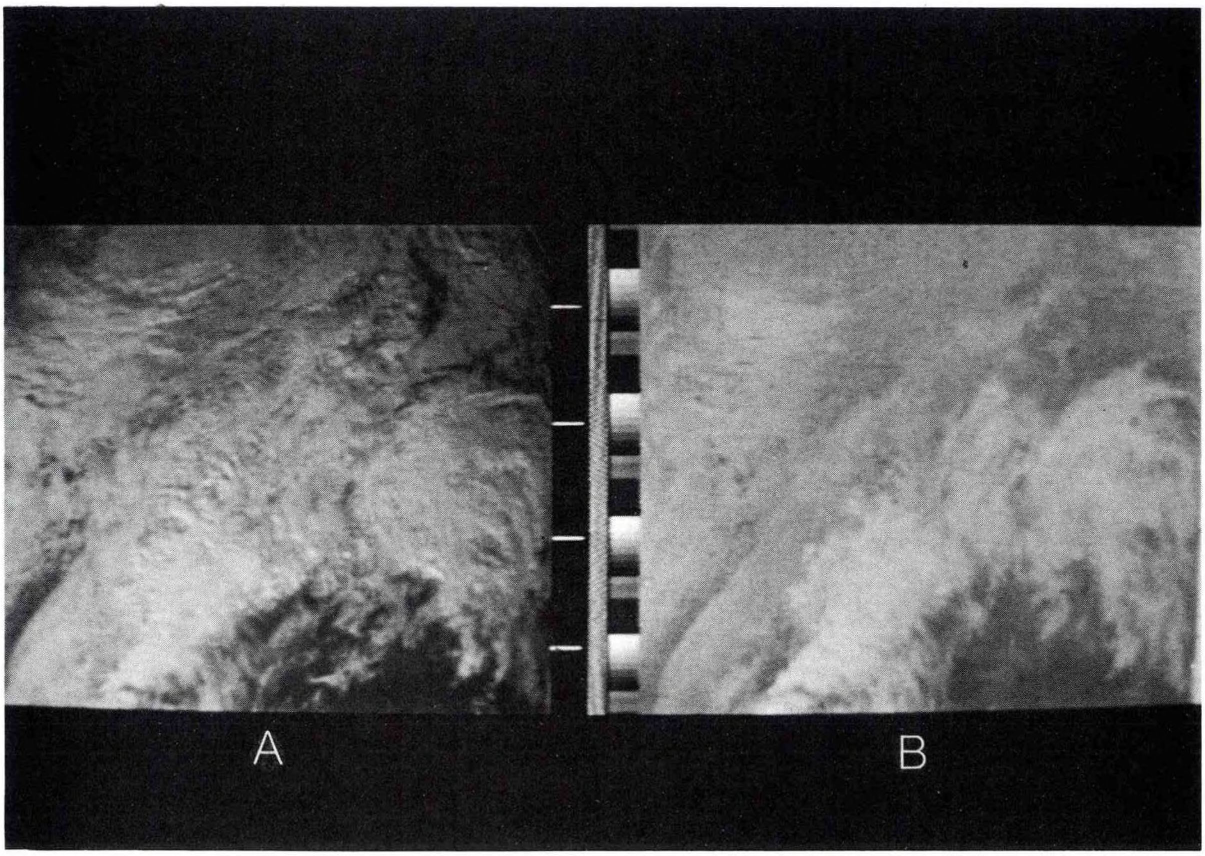


PLATE: II-1. APT Image Containing Visual Channel (A) and Infrared Channel 4 (B) Data

The APT signal is transmitted continuously from the satellites. This results in a strip of image as long as the transmission is received at the ground station and as wide as the scanning instrument is designed to operate at a particular altitude. Radio reception of the APT signal, however, is limited to "line of sight" from the ground station and can only be received when the polar orbiting satellite is above the horizon of a particular location. This is determined by both the altitude of the satellite and its particular path during the orbit across the ground station's reception range. The present U.S. and Russian satellites operate at altitudes between 810 and 880 km (488 and 544 miles). At these altitudes the maximum time of signal reception during an overhead pass is about 14 minutes. During this time a ground station can receive a strip of picture about 5800 km (3600 miles) long.

WEFAX FROM THE GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITES (GOES):

WEFAX (weather facsimile) is a direct readout service provided by the GOES satellites. WEFAX data consists of retransmissions of processed images produced by the primary imager on the GOES satellites as well as other meteorological data and images produced by the polar orbiting satellites. The format of the WEFAX signal is similar to the APT and was designed to be received and reproduced, with some modification, by low cost ground stations capable of receiving APT.

WEFAX was first tested on a geostationary Applications Technology Satellite (ATS-1) and later incorporated into the GOES satellites in 1975. The data format, using a 2400 Hz amplitude modulated subcarrier, was retained so that ground stations with display systems designed to reproduce APT could be used to also reproduce WEFAX. The radio frequency and rate of data transmission were, however, changed to 1691.0 MHz and 240 lines per minute. Therefore, APT ground stations require some modifications to receive and reproduce WEFAX. These modifications usually consist of the addition of a parabolic antenna and a downconverter which can convert the 1691 MHz frequency to 137.5 MHz. The signal can then be detected by the same radio used to receive APT. The image display system must also be modified to reproduce a 240 line per minute scan rate to recreate the image. Generally, when cost is a factor in building a ground station, an APT station is installed first and the additional components for GOES WEFAX are added later.

The addition of WEFAX to a ground station can greatly expand the applications that are possible in classroom use. This is because of the large amount and variety of data that can be obtained. In the current WEFAX schedule over 100 images can be received in a 24 hour period. These consist of scheduled data transmissions of quadrants of the full Earth disk and equatorial regions in visible and infrared spectra, composite images from the polar orbiting satellites, weather charts, ice charts, and operational messages.

III. THE SATELLITES: POLAR ORBITING AND GEOSTATIONARY

THE TIROS-N SERIES POLAR ORBITING SATELLITES:

The TIROS-N satellites, the third generation of United States operational environmental polar orbiting satellites, represent the current spacecraft available for receiving direct readout data. The basic operational concept of this series is to maintain two satellites in polar orbit at all times. One will maintain an orbit so that it will pass over the ground station, traveling from north to south (descending node) during the morning. The second satellite will pass from south to north (ascending node) during the afternoon. Each of these satellites will also pass over approximately 12 hours later traveling in the opposite direction. More detailed information on the orbital parameters and tracking can be found in Section VII of this publication.

SATELLITE	LAUNCH DATE	OPERATIONAL PERIOD
TIROS-N	Oct. 13, 1978	October 19,'78-January 30,'80
NOAA-6	June 27, 1979	June 27,'79-March 5,'83 and July 3,'84-November 16,'86
NOAA-B	Failed to achieve orbit	
NOAA-7	June 23, 1981	August 24,'81-June 12,'84
NOAA-8	March 28, 1983	May 3,'83-June 12,'84 and July 1,'85-October 31,'85
NOAA-9	Dec. 12, 1984	Placed in standby September 16,'91
NOAA-10	Sept. 17, 1986	Placed in standby September 16,'91
NOAA-11	Sept. 24, 1988	In service
NOAA-12	May 14, 1991	In service

TABLE III-1. Launch and Operational History of the TIROS-N Series Satellites

TIROS-N, the prototype spacecraft of this series, was launched on October 13, 1978 and remained operational until January 30, 1980. The next satellites of this series were designated by letters (A,B,C, etc.) until achieving orbit at which time the letters are replaced as numbers. The first was designated NOAA-6 (NOAA-A). Table III-1 lists the current launch and operational history of the TIROS-N satellites.

All of the TIROS satellites have been designed to carry an array of instruments to sample a variety of environmental/meteorological parameters on a global scale. Much of this data is contained in the information transmitted from the satellites in real time on specific radio frequencies and form an important NOAA/NESDIS function known as the Direct Readout Service.

Although the primary goal of this publication is to provide information on reception, image display, and use of the Automatic Picture Transmission (APT) direct readout products, it may be of interest to review all of the major missions of the TIROS satellites so that users of these satellites can get a better overall view of the instrumentation and products that are generated continuously.

SPACECRAFT:	Total Weight - 1,009 Kg (2,200 pounds) Excludes expendables)
PAYLOAD:	386 Kg (850 pounds)
SPACECRAFT SIZE:	3.71 meters in length (165 inches) 1.88 meters in diameter (74 inches)
SOLAR ARRAY:	2.37 meters X 4.91 meters - 11.6 square meters (125 square feet)
POWER REQUIREMENT:	Full Operation - 475 watts
COMMUNICATIONS:	Command Link - 148.56 MHz Beacon - 136.77 and 137.77 MHz S-Band - 1698.0, 1702.5 and 1707 MHz APT - 137.50 and 137.62 MHz DCS - (uplink) 401.65 MHz SAR - 1544.5 MHz SAR - (uplink) 121.5, 243.0 and 406 MHz
DATA PROCESSING:	All digital, APT translated to analog
ORBIT:	833, 870 Km nominal, sun synchronous
LAUNCH VEHICLE:	Atlas E/F
LIFETIME:	2 years planned

TABLE III-2. Summary of TIROS-N/NOAA E-J Satellites

Table III-2 contains a summary of general information concerning the latest, NOAA E-J, satellites. (A.Schwalb, 1987:NESS Technical Memorandum:NESS 116) It is interesting to note that not all functions of the current satellites involve meteorological applications. These latest satellites, known as the Advanced TIROS-N type, also carry a search and rescue instrument which is designed to aid in the location of emergency radio signals from downed aircraft and ships in distress. More information on this particular activity is available from:

James T. Bailey
SARSAT Project Manager
NOAA/NESDIS E/SP3
Washington, D.C. 20233

Figure III-1 is a diagram of a typical TIROS-N satellite showing the primary instruments and radio transmission hardware.

Advanced TIROS — N

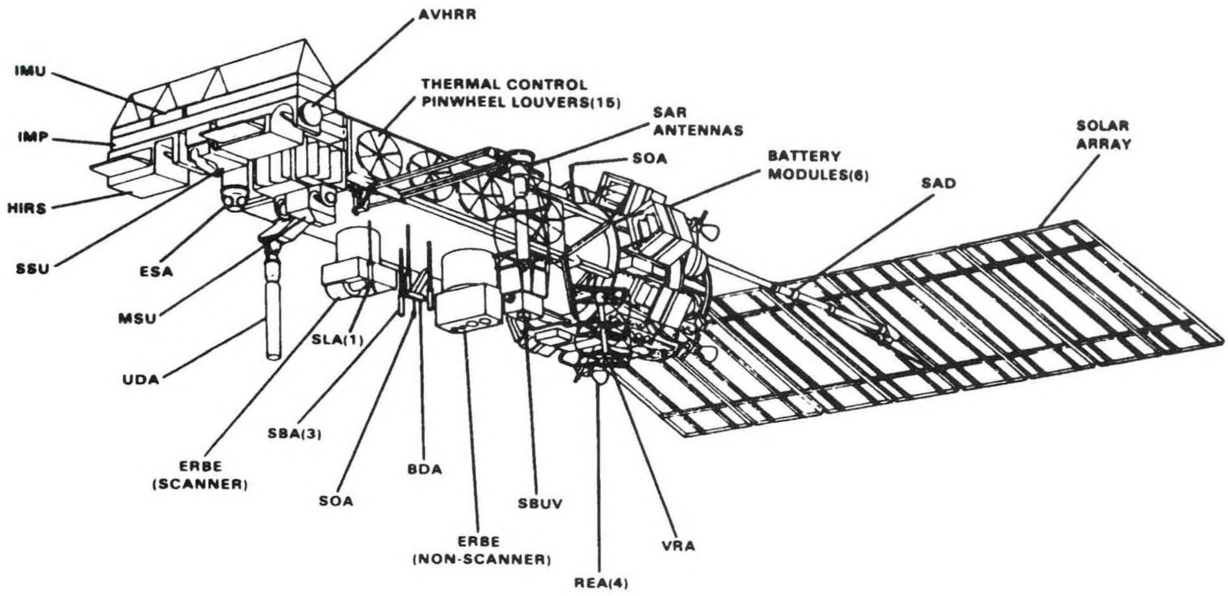


FIGURE III-1. Design of Typical Advanced TIROS-N Polar Orbiting Satellite

Major sensor systems include:

TOVS: TIROS Operational Vertical Sounder
AVHRR: Advanced High Resolution Radiometer
SEM: Space Environmental Monitor
DCS: Data Collection System
SAR: Search and Rescue System

PRIMARY SENSORS:

1. TIROS Operational Vertical Sounder (TOVS)
   This instrument is a three part system to:
   a. Measure the temperature profile of the Earth's atmosphere from the surface to 10 millibars
   b. Measure the water vapor content of the Earth's atmosphere
   c. Measure the total ozone content of the Earth's atmosphere
   d. Measure the CO2 content of the atmosphere
   e. Measure the Oxygen content of the atmosphere

2. Advanced Very High Resolution Radiometer (AVHRR)

   This is a five channel radiometer sensitive to visual and infrared spectra that provides the primary imaging system for both the High Resolution Picture Transmissions (HRPT) and the Automatic Picture Transmission (APT) images that are transmitted by the spacecraft.

3. Space Environment Monitor (SEM)

   This instrument is designed to detect radiation at various energy levels in space.

4. Data Collection System (DCS)

   This French supplied system is designed to collect data from Earth based environmental monitoring platforms. These platforms are placed in locations, some very remote, to measure various environmental parameters. This data is relayed to the satellite and then to ground stations. If the platform is moving, DCS can determine its position.

5. Solar Backscatter Ultraviolet Radiometer (SBUV)

   This instrument measures the vertical distribution and total ozone in the Earth's atmosphere. These data are used for continuous monitoring of ozone distribution to estimate long term trends. SBUV is carried on spacecraft in afternoon orbits.

6. Search and Rescue (SAR)

   This system is designed to detect the radio signals transmitted by emergency beacon locators that are carried on ships and aircraft. The Doppler shift of these transmissions, as detected on the satellite, can be used to determine the location of the emergency transmitter. This information is forwarded to the proper authorities to aid rescue efforts.

7. Earth Radiation Budget Experiment (ERBE)

Data gathered by this instrument package is used to study the average radiation budget of the Earth and determine the energy transport gradient from the equator to the poles. Studies of this type are used to better understand the Earth's climate.

THE UNITED STATES GEOSTATIONARY SATELLITES: Geostationary Operational Environmental Satellites (GOES)

Satellites in geostationary orbits, 22,500 miles (35,800 km) above the equator, maintain their apparent positions relative to points on the Earth's surface. This is because the period of the satellite orbit is equal to the Earth's rotation period and they are located at 0 degrees latitude. This type of orbit is particularly advantageous for meteorological/environmental remote sensing because the same areas of the Earth can be viewed continuously. Also, because of their high altitude, large areas of the Earth can be seen by the same satellite. A two satellite system can cover almost all of North America and South America from the Pacific to the Atlantic. When operational, these satellites are usually referred to as GOES-East and GOES-West. Due to periodic satellite failures and replacement schedules there are changes in exact satellite locations and operational schedules from time to time. Because of this, no details on this information will be given here. For the most current information on the GOES satellites it is advisable to contact the WEFAX coordinator at the address given in this section. This office also provides periodic WEFAX Memoranda which are mailed to GOES WEFAX users.

The first prototype satellite of this type was developed with NASA funding and launched on May 17, 1974. The designation, SMS-1 for Synchronous Meterological Satellite, was used by NASA. SMS-2 was launched on February 6, 1975. The first NOAA funded geostationary satellite, GOES-1, was launched in October of 1975. This current series of geostationary satellites will continue through GOES-7. A new series of GOES satellites, now referred to as GOES I-M, is planned for the 1990's. Information on GOES I-M is available from NOAA.

The current GOES series satellites were designed to conduct four major missions:

1. Earth imaging and data collection
2. Space environment monitoring
3. Data collection
4. WEFAX transmissions

The primary meteorological instrument on the GOES satellites is the Visible and Infrared Spin-Scan Radiometer (VISSR) Atmospheric Sounder (VAS). The VAS instrument can produce full Earth disk images every 30 minutes, 24 hours a day, in visible and infrared spectra. This schedule can be changed to produce smaller sectors of the Earth during the development of severe storms at shorter time intervals. The primary data from this instrument is used to estimate temperatures of cloud tops, determine sea surface temperatures, estimate precipitation, detect formation and movement of weather systems, predict severe weather outbreaks, and for a variety of other applications and research involving the Earth's surface and atmosphere.

The Space Environment Monitor collects data involving solar activity that is exhibited as high energy particles, solar X-rays and magnetic flux. Data from the SEM is valuable in providing information concerning high altitude and space radiation, solar activity, and radio wave propagation.

The Data Collection System

Equipment on the GOES satellites allows direct relay from remote reading platforms located on the Earth's surface. These platforms contain remote sensors and automatic data transmission equipment that allow information to be sent directly to the satellite from remote sites on the oceans, on land, and in the air where continuous data collection would be difficult or impossible. The environmental parameters that can be monitored are quite varied from these platforms. Data such as river heights, precipitation, earthquakes, ocean currents and temperatures, water pH, wind speed and direction, and barometric pressures are examples of the data sensed by these remote platforms. The data from these platforms are received by radio equipment on the GOES satellites and then relayed to ground stations for decoding and distribution to the operators of the remote platforms. More information is available from NOAA on this system.

The VISSR, SEM and DCS data are transmitted from the GOES satellites as high speed digital transmissions. This data is quite complex and, at this time, requires expensive ground station equipment to receive and reproduce. Some progress in receiving this data directly with less costly ground station equipment has been made.

Figure III-2 shows a diagram of a typical GOES satellite currently in operation. GOES I-M will have a different design but will perform similar functions.

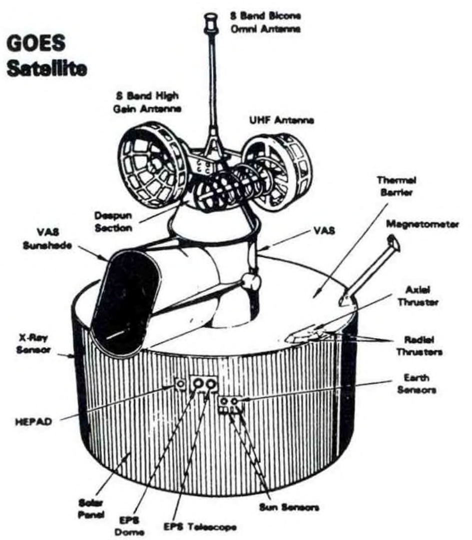


FIGURE III-2. Typical GOES Satellite

Major systems include:

VISSR: Visible-Infrared Spin-Scan Radiometer
VAS: Atmospheric Sounder
SEM: Space Environment Monitor
DCS: Data Collection System

GOES WEFAX

The Weather Facsimile (WEFAX) images transmitted by the GOES satellites is of most interest to operators of low cost ground stations. WEFAX transmissions contain images and charts transmitted via a 2400 Hz format similar to the polar orbiting APT data. This is important because an image display system that can reproduce APT signals can be adapted to display WEFAX images from the GOES satellites. There are, however, some significant differences between APT and WEFAX:

- WEFAX images are formatted in a 240 line/minute transmission rate instead of the 120 line/minute transmissions from the polar orbiting satellites

- WEFAX transmissions contain images of large sectors of the Earth that are transmitted on a predetermined 24 hour schedule. Table III-3 shows a sample portion of a WEFAX transmission schedule of GOES East. Because this schedule is changed from time to time, information on the most current schedule should be obtained from either of the following sources:

  WEFAX Coordinator, Data Collection and Direct Broadcast Branch
  U.S. Department of Commerce
  NOAA/NESDIS
  Washington, D.C. 20233

  NOAA Satellite Electronic Bulletin Board
  (Call 301-763-8447 for details)

TIME OF TRANSMISSION (Z)	PRODUCTS
1115	TBUS NOAA-9
1120	OPERATIONAL MESSAGE
1250	GOES-E 1200Z NE/SE QUADS IR
1320	GOES-E 1200Z NW/SW QUADS IR
1335	GOES-W 1245Z NW/SW QUADS IR
1350	GOES-E 1200Z TROPICAL W/E IR
1405	GOES-W 1245Z NE/SE QUADS IR
1420	SIG WEATHER PROG FL250-600
1425	SIG WEATHER PROG FL250-600
1430	RESERVED (TBUS)
1435	GOES-W 1245Z W/E TROPICAL IR
1450	NOAA-9 10E-80W NH/SH POLAR NIR
1535	GOES-E 1500Z NE/SE QUADS IR
1550	GOES-E 1500Z NW/SW Quads IR

TABLE III-3. Sample Portion of GOES EAST WEFAX Transmission Schedule (1100 to 1600 Universal Time (Z))

IV. BASIC GROUND STATION SYSTEM

Installing a ground station to receive and reproduce weather satellite images and data can generally be done in two ways. Today, a number of companies sell complete ground stations which, when properly installed, will provide all of the equipment necessary to receive satellite images. The cost of some of these pre-built units are now within the budget constraints of modern school systems. Another alternative, particularly when cost is a factor, is that a station can be assembled from components obtained through surplus equipment, purchase of some components and some student built hardware. The advantage of this second choice is that there can be a cost reduction and students can participate with "hands on" activities that result in a more complete understanding of the station hardware and technical operation. This was the approach first used at the Chambersburg Area Senior High School, Chambersburg PA and APT images were received at a cost of less than $500.00. Later, a geostationary system was installed to receive GOES WEFAX, and, over time, other equipment was added. This growth has resulted in a rather sophisticated station with both GOES WEFAX and polar orbiting capabilities and a state of the art computer display and image analysis system available for student use.

A generalized diagram of the components of a direct readout ground station to receive GOES WEFAX and polar orbiting APT is shown in Figure IV-1. These components are typical of many satellite ground stations currently in operation and are based on the design of the one operated at Chambersburg.

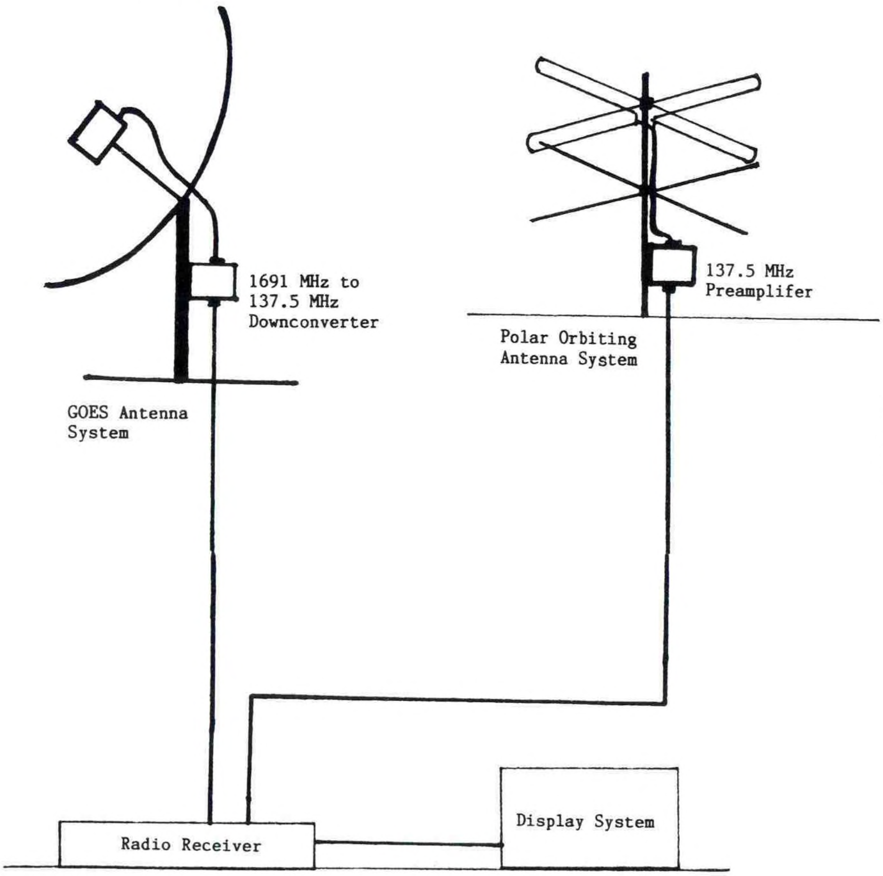


Figure IV-1. Generalized Components of a Direct Readout Ground Station

Two different antenna systems have been used successfully at the Chambersburg ground station for polar orbiting reception of APT. One is directional and requires tracking of the moving satellite and the second type, shown in Figure IV-1, is omnidirectional and less expensive but will give a slightly reduced reception range. Both of these are discussed in section V of this publication.

At the antenna, the signal is processed by a small preamplifier which serves to reduce unwanted noise and then is passed to the radio through a transmission line. The radio receiver used in most ground stations is a crystal controlled FM receiver with good sensitivity capable of detecting radio frequencies between 137 and 138 MHz. Since each satellite operates at slightly different frequencies, a specific crystal is needed for each satellite that is to be accessed. Some of the more modern radios now have synthesized frequency capabilities and do not require a crystal for each satellite.

The radio receives the FM signal and detects the 2400 Hz amplitude modulated subcarrier which is the satellite image. At this point, if this 2400 Hz tone is inserted into an appropriate display reproduction system the satellite image can be viewed. Some stations also have a stereo tape recorder so that the transmission can be recorded and played back later to make other copies of the image or to be archived for later reference.

A number of display systems are discussed in this publication. Until recently, the most popular way to display the satellite image has been with electrostatic facsimile machines which produce a paper copy of the image. With recent advances in computer analog to digital techniques and improved graphics, computer displays are rapidly becoming the display system of choice in most satellite ground stations.

To receive the WEFAX transmissions from the geostationary satellites, additional components are necessary. WEFAX is transmitted on a microwave frequency of 1691.0 MHz. To receive these satellites, a different antenna is required. Most stations use a parabolic or "dish" antenna which receives and reflects the signal into a "feed horn" located at the focal point of the parabolic reflector. Located in this feed horn is a small whip antenna which detects the signal and passes it from the antenna. In order to use the same radio receiver, a downconverter is used to convert the 1691.0 MHz signal to 137.5 MHz. Since signal loss at 1691.0 is fairly great in transmission lines, this downconverter is usually located near the antenna. From this point the downconverted signal can be carried through conventional shielded cable to the location of the radio. Since the signal is now at a frequency of 137.5 MHz and WEFAX also carries a 2400 Hz subcarrier, the radio will operate as it did to receive the APT transmissions from the polar orbiting satellites. This tone can then be fed to a display system and reproduced in a manner similar to the APT signals. The major difference here is that the display system should be able to reproduce images transmitted at 240 lines per minute.

Plates IV-1 to IV-4 are photographs of typical images received via direct readout of APT and WEFAX using the ground station described here. The Russian METEOR image was reproduced on a K550 fax machine described in section IX of this publication. All other Plates shown were taken from a monitor screen using an IBM computer display system developed by a commercial vendor of hardware and software for environmental satellite stations. The monitor screen was photographed with a 35mm single lens reflex camera. Exposures were made at 1/4 second with f stops between f2.8 and f4.0 depending on the brightness of the individual images. Slow shutter speeds, 1/8 second or less, are necessary to eliminate dark bars across the picture that occur due to monitor sync rates.

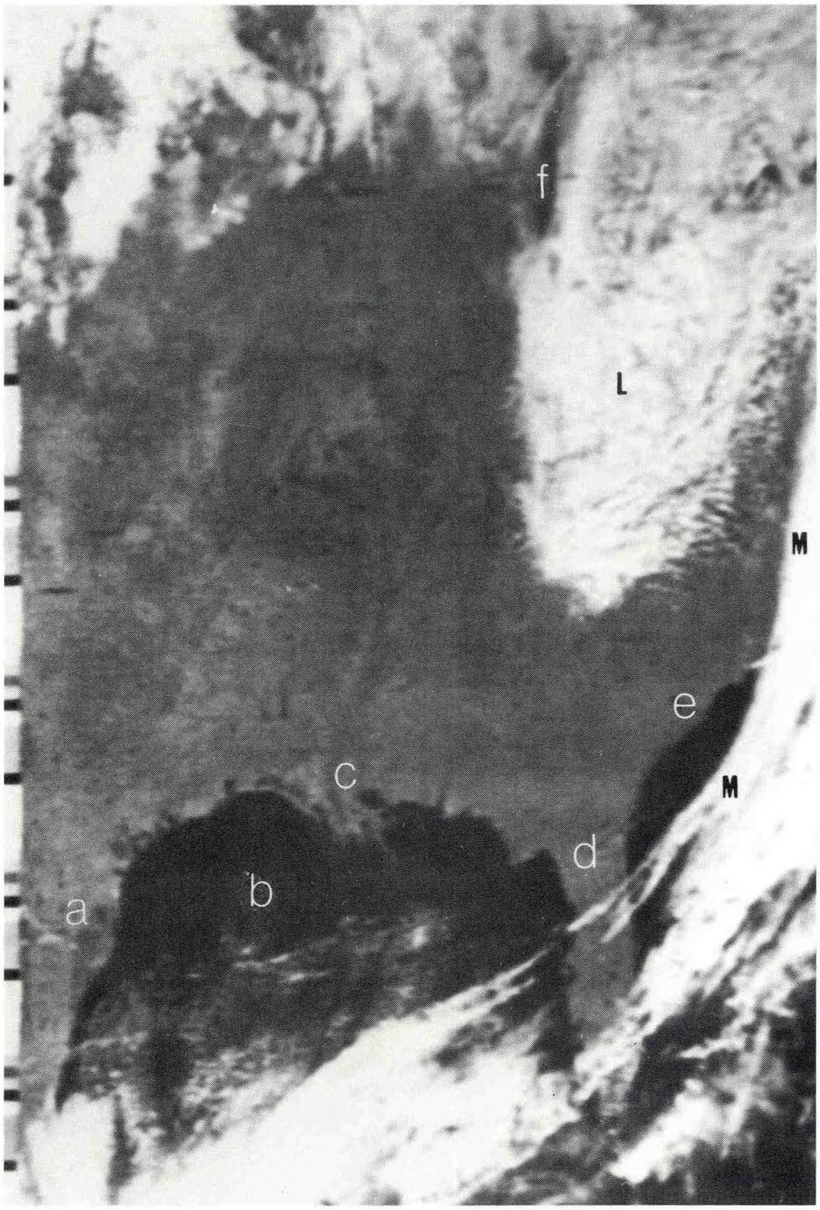


PLATE IV-1. NOAA-11 Visual Channel APT

PLATE IV-1. NOAA-11 Visual Channel APT.

Typical APT Visual Image from NOAA-11, December, 1988. This NOAA-11 pass shows a large area of central United States from Canada (top) to Mexico (a). The Gulf of Mexico (b), Mississippi River delta (c), Florida (d), the southeast coast (e), and a portion of Lake Michigan (f) can be seen. Meteorological features include a mass of clouds around a low pressure system (L) with a trailing cold front (M).

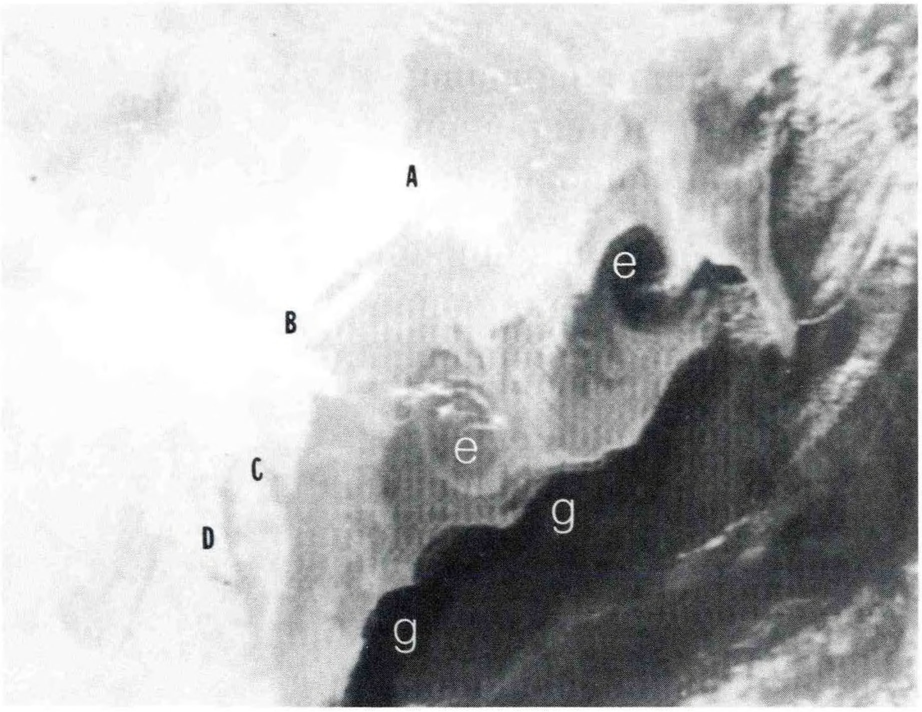


PLATE IV-2. NOAA-10 Channel 4 Infrared Image

PLATE IV-2. NOAA-10 Channel 4 Infrared Image, November, 1988.

The area covered by this image includes the northeast coastal region of the United States from near Nova Scotia (top) southward to Cape Cod (A), Long Island (B), the Delaware Bay (C), and the Chesapeake Bay (D). A large, mainly cloud free, area of the Atlantic Ocean can be seen east of the coastline. Infrared images show temperatures of the radiating surfaces with lighter shades showing colder surfaces and darker areas showing warmer surfaces. Cloud free satellite passes over this portion of the Atlantic provide spectacular views of the sea surface temperatures with the interaction of the warm meandering Gulf Stream (g) intruding into the colder shelf and slope waters of this area. Two large eddies (e) can be seen east of New Jersey and of Long Island. Infrared images of sea surface temperatures provide valuable information that can be used for cargo ship navigation, sailing, and the location of areas for sport and commercial fishing.

PLATE IV-3. Russian Meteor Satellite Visual Image, February, 1979.

This Russian Meteor Series satellite APT photograph shows a portion of the east coast of the United States and Canada. Most of the land area is covered with snow. Lake Superior (A), Lake Huron (B), and Lake Erie (C) are ice covered. Ice can be seen in the northern regions of Lake Ontario (D). The Chesapeake Bay (E) and the Delaware Bay (F) stand out well because of snow cover on the ground in these areas. The large dark area (G) is the Adirondack Mountain area in New York State that is visible because the pine forests block the snow cover on the ground. The large cloud formation in the bottom portion of this photograph is typical in winter when cold air moves over the warmer Atlantic waters.

PLATE IV-4. GOES-East, Northwest Sector Infrared Image, September, 1988.

This photograph shows a typical GOES image of the major portion of the United Sates. The characteristic comma shaped cloud formation shows the location of a low pressure system in Mississippi with clouds extending northward through the eastern states. GOES infrared images contain computer generated political boundaries and longitude and latitude lines so that geographic features can be accurately located.

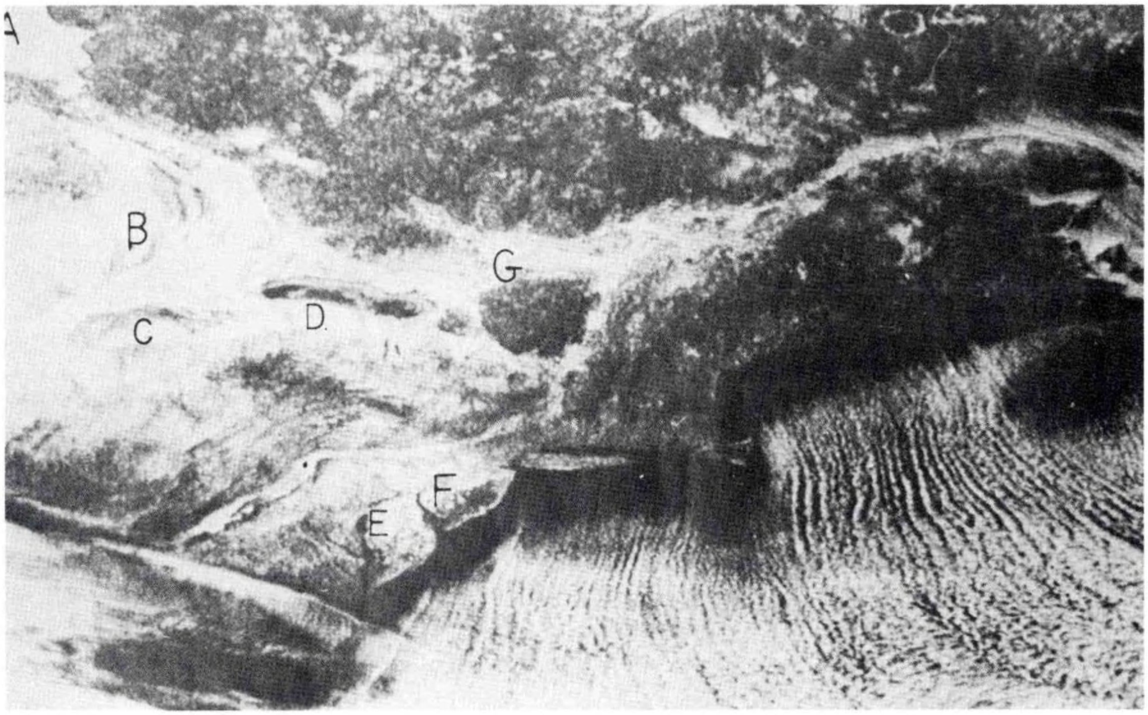


PLATE IV-3. Russian Meteor Series Satellite Visual Image

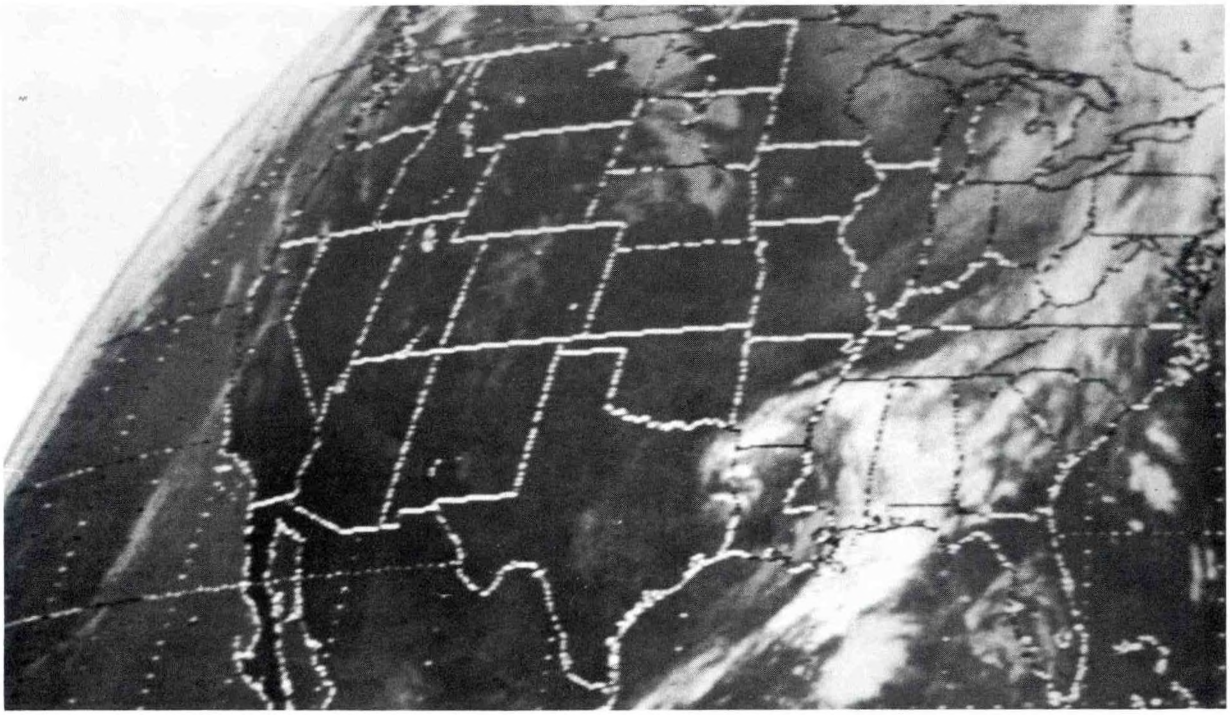


PLATE IV-4. GOES East Northwest Sector Infrared Image

V. ANTENNA SYSTEMS FOR APT AND WEFAX

A number of antennas are commercially produced that can be used for weather satellite reception. It is more practical, however, from an economic and instructional standpoint to construct this part of the APT direct readout station at the school. Antennas adequate for receiving pictures via APT do not have to be expensive or difficult to construct. Many high school industrial shops have the tools and equipment necessary for the construction requirements. Many students have the skills to do the work. With any efficient antenna, however, correct design and construction are necessary. Three design considerations are of primary importance:

1. The physical size of the antenna components is determined by the frequency of the transmissions it is intended to receive. In most VHF antenna designs, the driven elements or radiating elements are designed at 1/4 or 1/2 wavelengths.

2. The antenna design should fit the type of rf signal polarization it is to receive.

3. The antenna needs to produce sufficient signal gain to produce noise-free reception whenever it is used with an appropriate radio receiver.

At the present time the United States TIROS-N series satellites are transmitting APT at 137.5 MHz and 137.62 MHz, and the Russian Meteors at 137.3 MHz FM and 137.85 MHz with a transmitter power output of about 5 watts. The rf signal is circularly polarized on the U.S. spacecraft and assumed to be the same on the Russian Meteors.

Considering the frequencies, signal strength, and polarization factors of the transmissions, a number of antenna designs can accomplish adequate reception when used in conjunction with a properly designed radio receiver. Information is available in numerous publications which give details on construction of antennas for receiving radio signals from space. In these publications the helical antenna, the turnstile antenna, and the crossed yagi appear most often.

The crossed yagi directional antenna has been the popular choice of many "amateur constructed" APT stations. The crossed yagi described in this publication is currently in use at the Chambersburg Senior High School. (See Plate V-1) It functions well for APT reception, is relatively inexpensive, and is not difficult to construct. All materials needed should be easily obtained locally.

The crossed yagi is a directional, beam-type antenna comprised of a number of elements similar to a multi-element TV antenna. The major exception is that the elements are arranged at right angles to each other. This crossed element design eliminates fading of the circular polarized rf signal transmitted by the satellites. Because it is a directional beam design and in order to get maximum signal gain, the antenna must be pointed toward the satellite. This presents an additional problem.

Polar orbiting satellites are NOT stationary. They travel in paths that are generally either north to south (descending nodes) or south to north (ascending nodes). Following or tracking of the satellite by the antenna is therefore necessary. In the design given here, such tracking is accomplished by using two TV-type direction motors. One controls the elevation (angle above the horizon) of the antenna and the other controls the azimuth (compass direction) so that the satellite can be tracked at

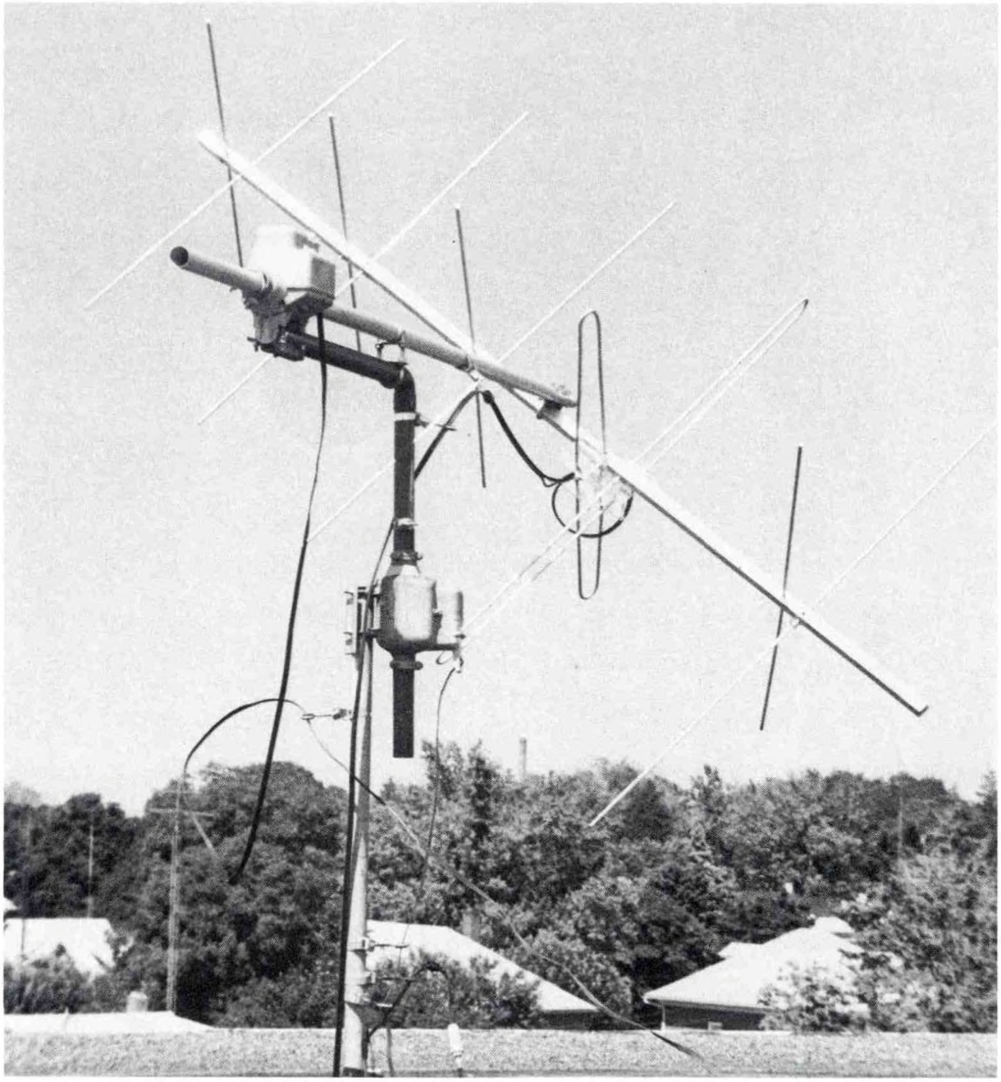


PLATE V-1. Crossed Yagi Directional Antenna for APT Reception

any elevation angle and direction as it passes within range of the receiving station. The beam width of this antenna is about +/– 20 degrees which gives it sufficient width so that pinpoint accuracy is not necessary.

ANTENNA CONSTRUCTION

Figure V-1a gives the spacing, arrangement, and physical dimensions of the one set of elements of the antenna pictured in Plate V-1. An identical set of elements with the same dimensions and spacing are then arranged at right angles to the first set but located 5.1 cm (2 inches) behind them. This forms the crossed arrangement necessary for proper reception of circular polarized rf signals.

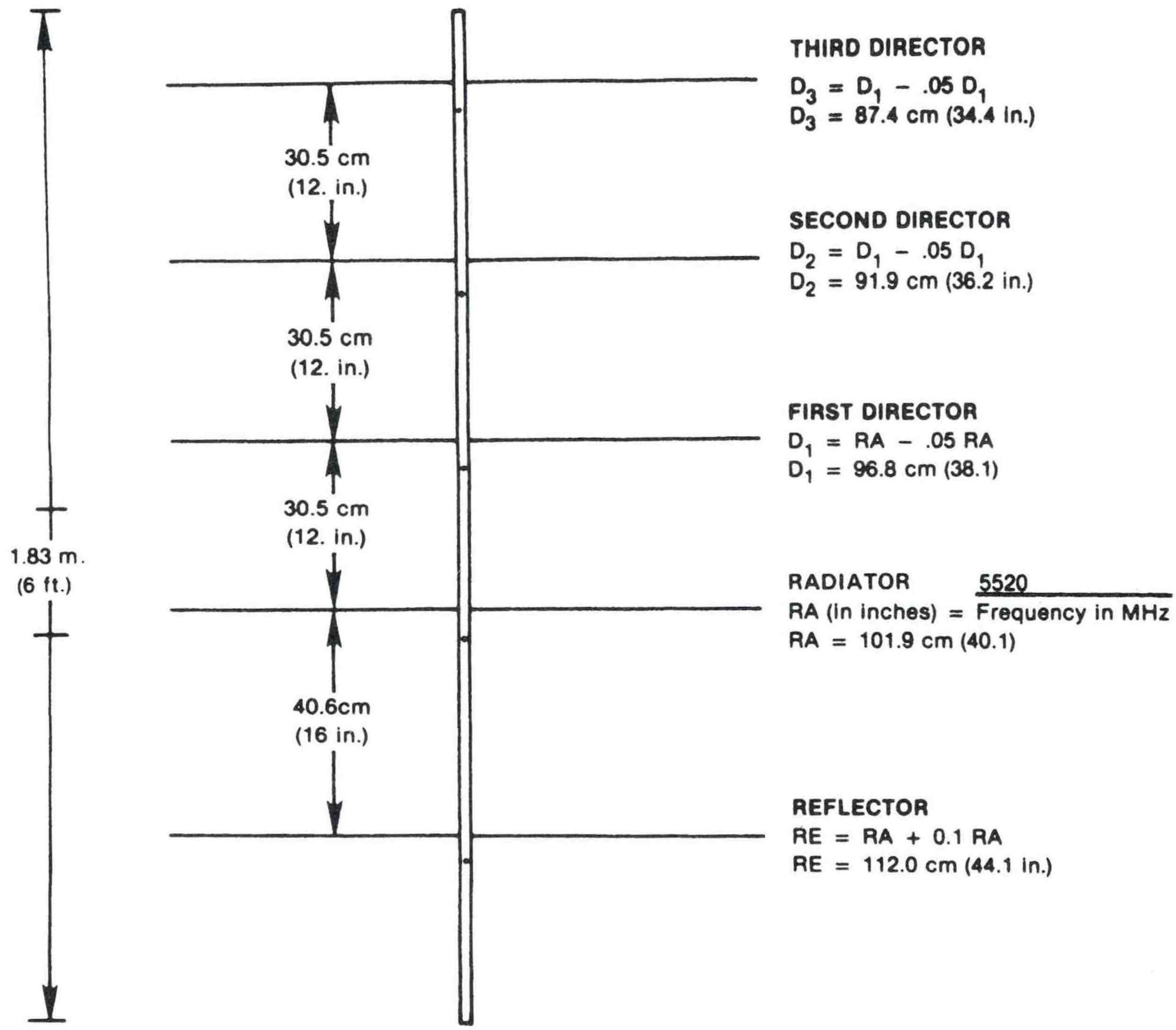


FIGURE V-1a. Spacing, Arrangement and Dimensions of One Set of Elements of a Crossed Yagi Antenna Used for APT Reception

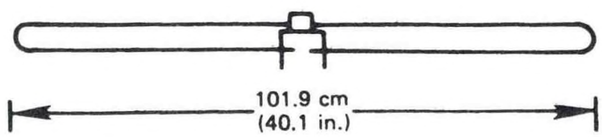


FIGURE V-1b. Design of One of the Radiators Shown in Figure V-1a.

The main beam which supports the elements is made from a piece of 2.5 cm (1 inch) square aluminum tubing, 1.83 meters (six feet) long. The elements are cut from 9.5 mm (three-eighths inch) diameter aluminum rods. These elements consist of three crossed sets of directors (D1, D2, D3). A pair of folded dipoles form the driven elements or radiators (RA) and a pair of reflectors (RE) are positioned behind the radiators. The length and spacing of all of these elements are dependent on the frequency that the antenna is designed to receive. All measurements given in Figure V-1a were calculated for a frequency of 137.5 MHz by formulas published in the ARRL Handbook for this type of antenna. The folded dipole radiators are similar to a design suggested in the Weather Satellite Handbook, available through Ralph Taggert, 602 S. Jefferson, Mason, MI 48854.

The first stage of construction requires measuring the correct spacing for the elements along the square beam. The first set of directors (D3) should be located about 12.7 cm (5 inches) from the end of the beam. The remaining element spacings should be drilled through both walls of the square beam. These holes should be as close to perpendicular as possible and centered on the flat surface. Another complete set of measurements and holes, following the same spacing as the first, should be marked and drilled. These, however, should be set 5.08 cm (two inches) behind the first and at RIGHT ANGLES to the first series. If possible, a drill press should be used. If the holes are correctly made, the aluminum rods should fit snugly.

The directors (D1, D2, D3) and reflectors (RE) offer no special problems. The aluminum rods forming these elements can be cut and pushed through the holes in the square beam so that they extend through the square equidistant on either side of the beam. There are a number of ways that these can be held in this position permanently. The simplest of these is to notch or crimp the rods on either side of the beam as close to the beam as possible using a large screwdriver and hammer. This will deform the rod enough so that it will not pass through the holes. Care should be exercised so that the rods are not bent!

The pair of radiators (RA) require a little more attention and care. The final design for one of the sets should look like the diagram in Figure V-1b. This requires two rods 2.08 meters (82.1 inches) long and positioned through the holes marked "RA" in Figure V-1a. These should be, one at a time, positioned so that they are centered and have equal extension on both sides of the square beam. The rods should then be crimped so that they retain their position. This rod is then bent 180 degrees at a point 50.9 cm (20.05 inches) from the center of the beam on both ends. A 3.8 cm (1.5 inch) wooden dowel can be held at this point and the rod bent around the dowel. Spacing between the two parallel portions of the dipole should be as close to 5.08 cm (two inches) as possible.

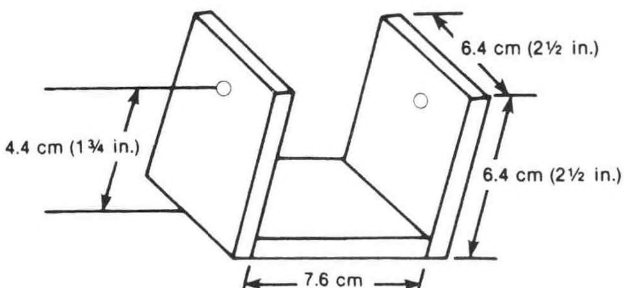


FIGURE V-2. Plastic Insulators for Supporting Open Ends of the Folded Dipoles (Two Needed)

The open ends of this folded dipole are held in position by a plastic holder shown in Figure V-2. This plastic insulator should be constructed from 6.4 mm (.25 inch) plastic sheet with 9.5mm (3/8 inch) holes that will accept the open ends of the folded dipole. The ends of the dipoles should be slid into the plastic holder first. Then the insulator should be drilled and mounted with metal screws on the flat portion of the beam. The second folded dipole, set at right angles to the first, is positioned in the same way. The final arrangement is shown in Plate V-2.

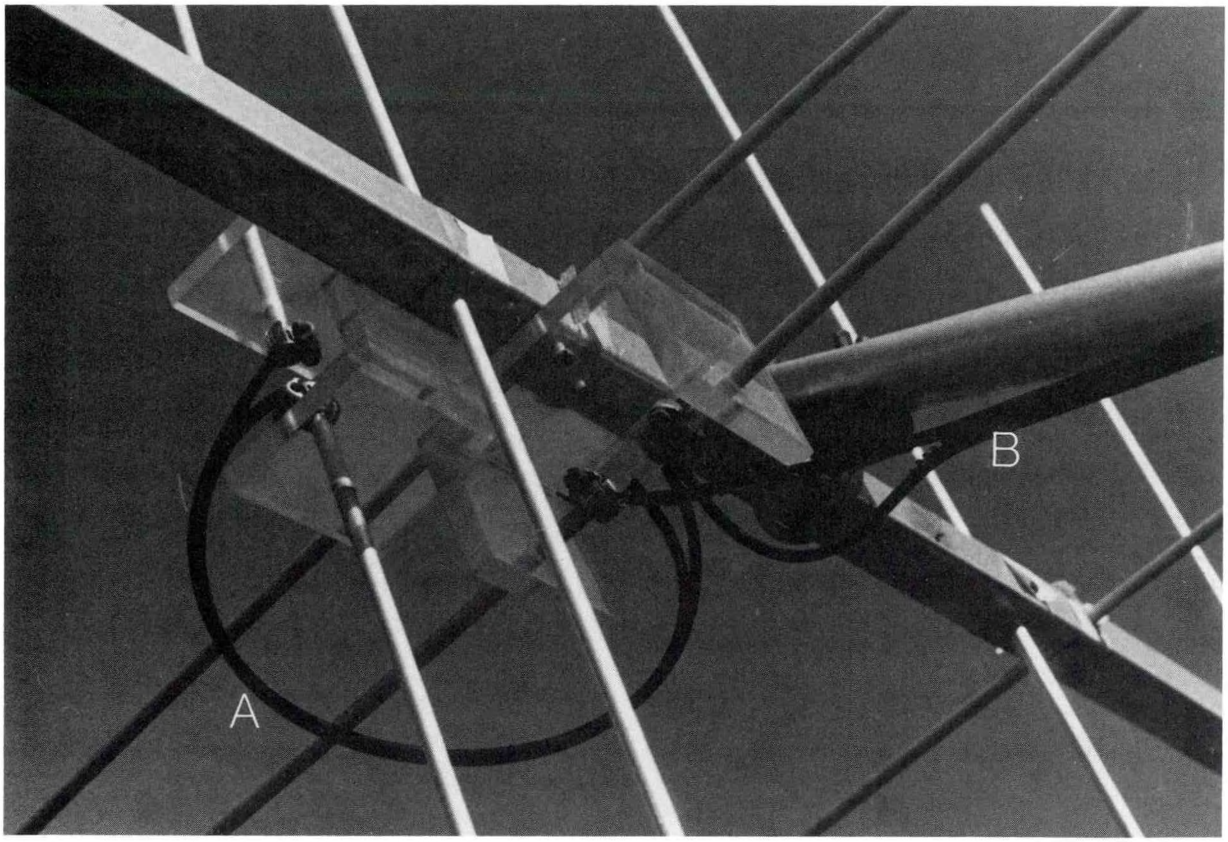
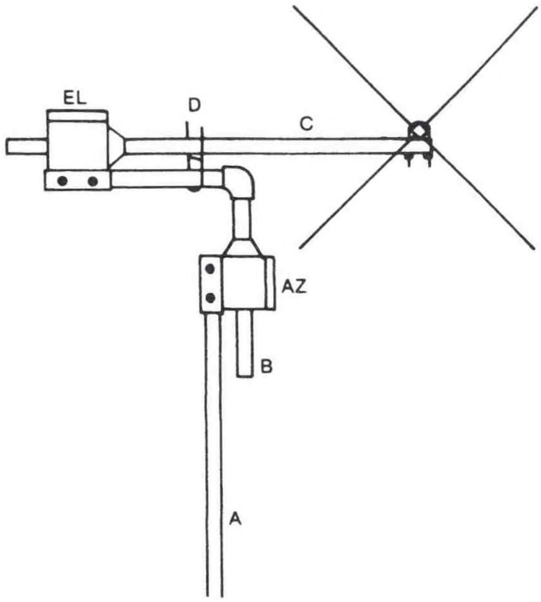


PLATE V-2. Plastic Holders Supporting Folded Dipoles

ANTENNA MOUNTING

The location of the antenna should be given careful consideration. If at all possible, it should be placed so that a clear view of the horizon is available in all directions. Consideration should also be given to a location where repairs and adjustments can easily be made. Long lead-in wires should be avoided. Generally, a flat roof of the school near the room where the electronic components are located would be best.

There are a number of mounting designs which allow azimuth and elevation antenna tracking of satellites. The design shown in Figure V-3 is one example that works well.



A - 1.52 m (5 foot) section of mast pipe
B - Two, 0.61 m (2 foot) sections of mast pipe connected by a 90° elbow
C - 1.22 m (4 foot) section of mast or aluminum pipe
D - Support U-bolt
EL - Elevation motor
AZ - Azimuth motor

FIGURE V-3. Antenna Mounting Design

Steel pipe 3.2 cm (1.25 inch) diameter was used for all mounting supports. It can be found at most plumbing supply houses or electronic stores which sell antennas. Sections of this pipe can often be found around the school at no cost. Also, a careful search may produce the antenna motors and control boxes at little or no cost.

Section A in Figure V-3 is approximately 1.52 m (five feet) long and is permanently mounted on the roof. Standard antenna mounting brackets can be used, but the method of mounting will vary with local conditions. An antenna motor (TV-type) is bolted to the top of section A. This motor serves as the azimuth (compass direction) motor. Section B is made from two, 0.61 m (two foot) sections of pipe connected by a 90 degree elbow. One end of Section B is mounted into the azimuth motor. A second antenna motor is then bolted to the other end of Section B. This motor will support the antenna and turn it through various degrees of elevation.

A third, 1.22 m (four foot) section of pipe (C), is mounted through the elevation motor. The antenna is mounted with U-bolts to the other end of Section C. (See Plate V-3.) The antenna should be attached at its center of balance. This pipe (C) can then be slid through the antenna motor until the weight of the antenna and the weight of the elevation motor counterbalance each other. A U-bolt with a supporting plate (D), is attached to C to support the weight of the antenna to take the stress off the bearings of the elevation motor. (See Plate V-4.)

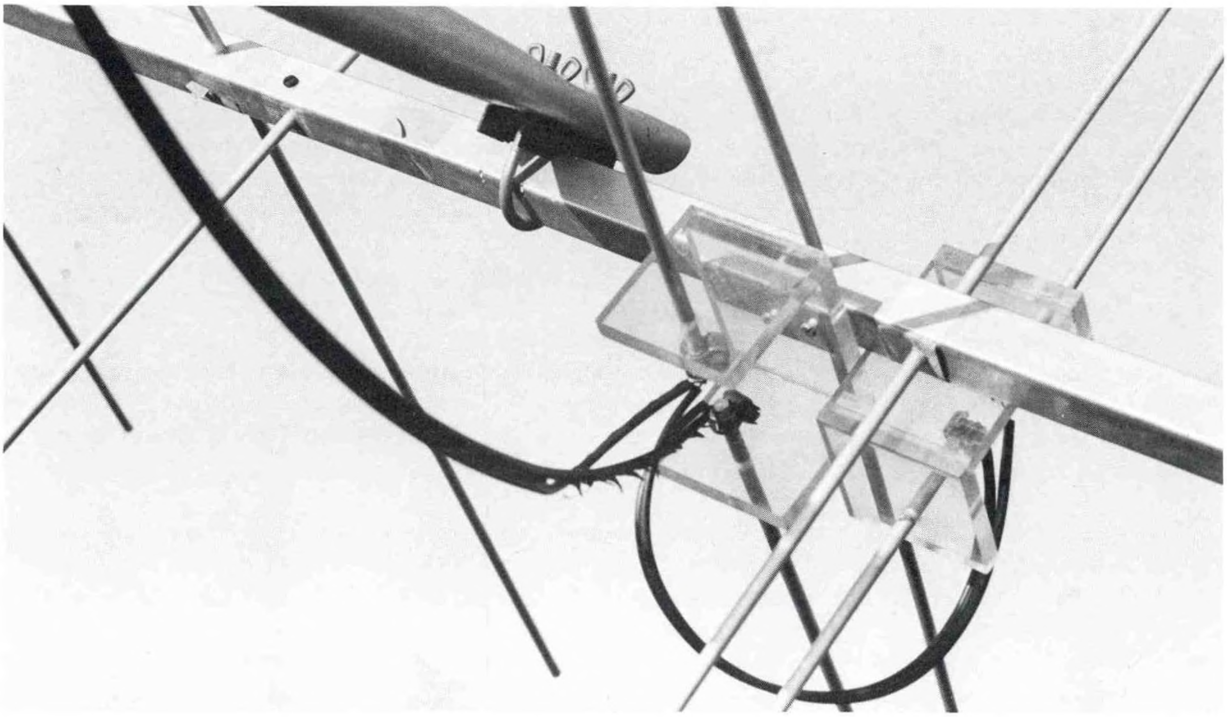


PLATE V-3. Antenna Details

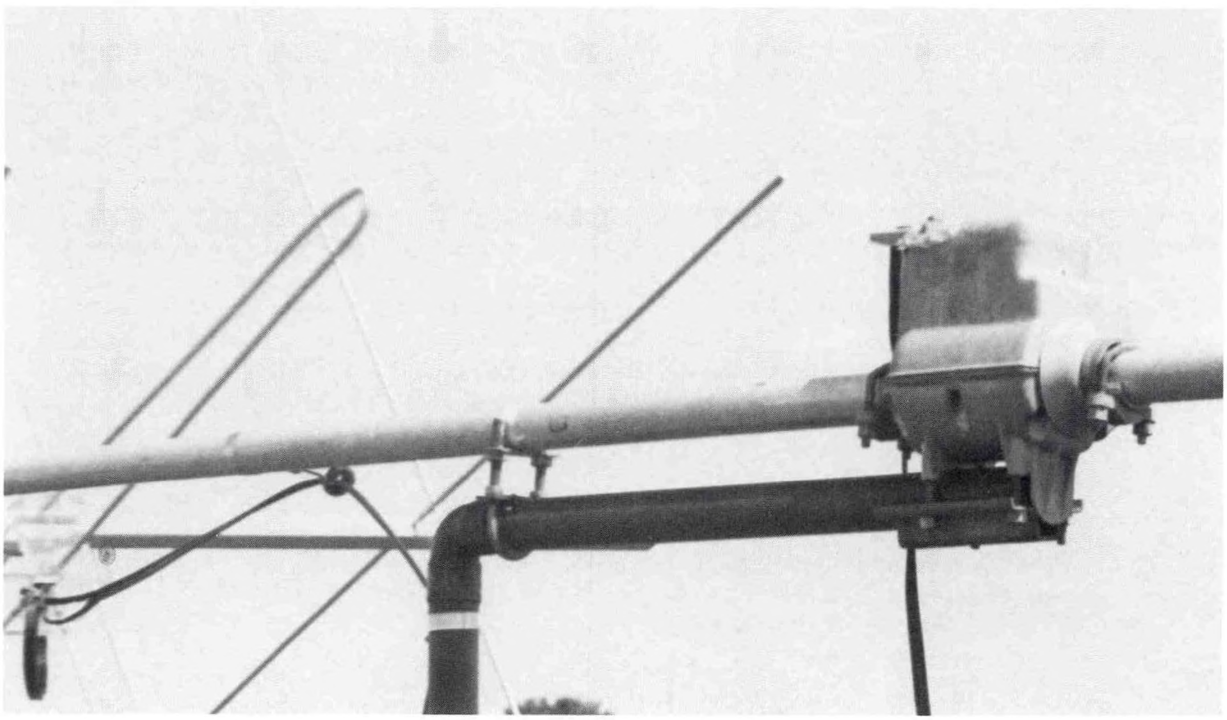


PLATE V-4. U-Bolt Support for Antenna

CALIBRATION OF MOTORS AND CONTROL BOXES

After mounting is completed, motor control wires should be run from each motor to separate control boxes. It is important to allow enough slack in the wires and wire standoffs, to permit the antenna to move freely in all directions. It is then necessary to calibrate the antenna azimuth and elevation directions so that the control indicators will give accurate representations of antenna directions.

To adjust the elevation of the antenna, rotate the control indicators of the elevation control box to the NORTH position. At the antenna, loosen the motor bolts of Section C and rotate the antenna by hand until it points directly overhead and then retighten the bolts. NORTH on the control box will then represent 90 degrees of elevation. Whenever the contol indicator is moved to the EAST position, the antenna should be level and pointing at the horizon. EAST will then be 0 degrees of elevation. A scale from 0 degrees to 90 degrees can be made and placed on the control box face between east and north which will give the operator the degrees to which the antenna is elevated.

The calibration for the azimuth (compass direction) is accomplished in a similar manner. First, the elevation control should should be positioned to 0 degrees (EAST). Then the azimuth control box should be rotated to the NORTH position and the antenna should be positioned, pointing north, on the roof. Whenever the bolts of the azimuth motor are retightened, the compass directions of the control should be a true indication of the antenna's azimuth through 360 degrees. With this arrangement, it is possible to track any polar-orbiting satellite through all the compass directions and elevations.

OMNIDIRECTIONAL ANTENNAS FOR APT RECEPTION

Omnidirectional antennas can also be used for APT reception. These can be purchased or built and offer an alternative antenna system which works well for APT. In theory, these antennas will receive APT from polar orbiting satellites in all directions above the ground station and, therefore, do not require the more complex tracking guidance needed by high-gain directional antennas. The disadvantage of these antennas is that they offer little, if any, signal gain and this will result in a reduced area of coverage compared to the higher signal gain offered by directional antennas. The main advantages are the convenience of not having to track the direction of the satellite and less cost for construction.

The Weather Satellite Handbook, by Ralph Taggart, presents a design for an omnidirectional antenna which is simple and inexpensive to construct while offering good APT reception. The design of this antenna is similar to a typical commercial FM antenna with a pair of crossed, folded dipole elements, that can be found in many radio stores. In fact, these antennas can be modified to receive APT at a very reasonable cost and with little effort. At the Chambersburg ground station a commercial FM antenna, shown in Plate V-5, was purchased for about $15.00 and adapted for APT with the following modifications:

1. The physical length of the folded dipoles was reduced by trimming the longer FM element tubing to 40.3 inches to provide an approximate 1/4 wavelength match for the 137.5 mHz center frequency of the satellite APT. (See A and A' in Plate V-5)

2. Two reflectors, 44.1 inches in length and made from 1/4 inch diameter aluminum tubing, were inserted parallel to and 17 inches below the folded dipoles. (See B and B' in Plate V-5) These reflectors create a broad beam antenna that, when pointed up, allows a wide angle of antenna reception with no need for directional orientation with the satellite as it passes over the ground station. Therefore, no directional tracking is necessary.

This antenna, with a preamplifer described in the next section, has been used successfully to receive both the NOAA and Russian polar orbiting satellites.

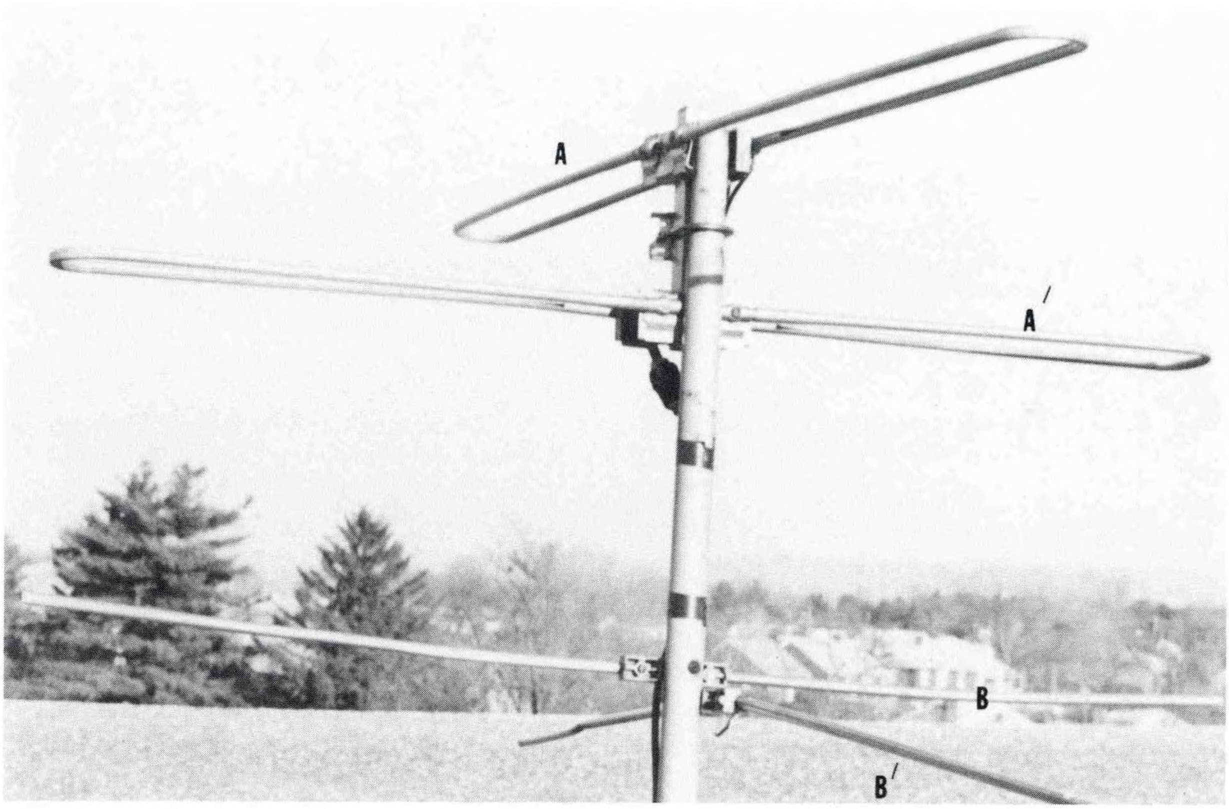
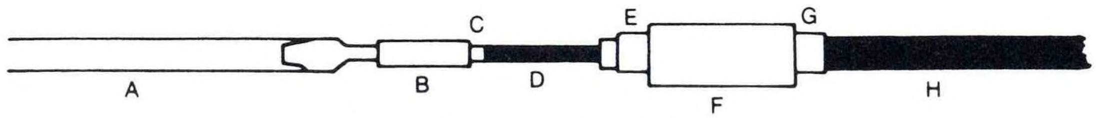


PLATE: V-5. Modified FM Antenna for Omnidirectional APT Reception

THE TRANSMISSION SYSTEM

The components of the transmission system which carries the rf signal from the antenna to the radio receiver are shown in Figure V-4. Proper construction of this portion of the direct readout station is important to insure that radio frequency signal losses do not exceed acceptable limits.



A - 300 ohm TV lead-in, 1.52 m (five foot) section
B - 300 ohm to 75 ohm matching transformer
C - F59 connector
D - RG58U, short section 30.5 cm (approx. 12 inches)
E - PL 259 connector
F - Vanguard Lab Preamplifier (Model 102W)
G - PL 259 connector
H - RG8U coaxial cable to radio receiver

FIGURE V-4. Components of the Transmission System

At the antenna, the open ends of one of the radiators are connected by a 54.6 cm (21.5 inch) length of 300 ohm TV lead-in wire to the open ends of the second radiator. (See part A of Plate V-2.) To insure good electrical contact, 1.3 cm (one-half inch) automobile hose clamps are used to hold the stripped ends of the TV lead-in wire in contact with the aluminum rods. Other methods can be used as long as electrical contact is insured.

A second 1.52 m (five foot) section of this 300 ohm wire is attached by the hose clamps to the ends of one of the folded dipole radiators. (See part B of Plate V-2.) This section is used to carry the signal from the antenna radiators and should be supported by TV stand-offs with enough slack allowed so that the antenna is free to move in all directions of azimuth and elevation.

To avoid excessive losses of signal from the antenna to the radio receiver, low loss 50 ohm RG-8U coaxial cable must be used for the transmission line leading through the building to the receiver. Also, most receivers will require a 50 ohm impedance match between the antenna and the receiver.

For a better impedance match between the 300 ohm TV line and the 50 ohm RG-8U, a 300 to 75 ohm matching transformer has been inserted between the 1.52 m (five foot) section of TV line and the RG-8U cable. This type of transformer was used because it is inexpensive and easily available in most TV appliance stores. Of course, a 300 to 50 ohm transformer would offer a better match and this type should be used if available.

Since high quality, noise-free signals from the satellite are the desired goal of a direct readout station, it is recommended that a preamplifier be incorporated into the transmission system. At the Chambersburg High School station, a preamplifier manufactured by Vanguard Labs (Model 102W) is used. The latest model (102WG2) contains improved low noise transistors. These new preamplifiers offer less that 2 db noise for about 17 db gain and can be ordered pretuned to 137.5 MHz which is the center of the frequencies of interest. The bandwidth is sufficient to cover all the APT frequencies. Purchase of this component will add about $60.00 to the cost of the station, but it will give a noticeable improvement to the quality of the APT signal.

The preamplifier, if used, should be placed in the 50 ohm RG-8U line close to the antenna. The Vanguard preamplifier is weatherproof and can be placed in exposed locations. To insert the preamplifier, the RG-8U cable should be cut and two male PL 259 connectors placed on the open ends. These in turn will be mated to the input and output female connectors on the preamplifier.

This preamplifier has provision for powering the electrical components through the coaxial line rather than running a separate power line to the preamplifier. The Vanguard comes with instructions and components to provide +12 volts to the center conductor of the RG-8U cable at the radio receiver. Some radios can be obtained with these power components already in place. All connector plugs in the transmission line should be installed carefully so that good electrical contacts are made. Any connectors exposed to the weather should be weather protected with some type of sealant so that water cannot enter the connectors or cable and cause electrical shorting. If this does happen, serious signal loss will occur.

ANTENNA SYSTEMS FOR GOES WEFAX

To receive WEFAX from GOES at 1691.0 MHz requires a different antenna system from the ones described for receiving APT from the polar orbiting satellites. The two primary reasons for this are the relatively lower signal strength received from geostationary satellites 22,500 miles above the Earth and the considerably higher frequency of the FM radio signal used to transmit the WEFAX data.

The most common approach to these problems has been to use a parabolic or "dish" reflector to collect and concentrate the weak signals into a smaller receiving area referred to as a "feed horn" that is placed at the focal point of the reflector. The amount of signal gain at the feed horn area is proportional to the size of the collecting area of the dish. This, and the use of electronic low noise preamplification of the signal, make it possible to receive noise free WEFAX transmissions. This same approach has been used with the popular Earth Stations that are used to receive satellite television from the geostationary television satellites that have proliferated in recent years. These television satellites, however, transmit signals that are quite different from the WEFAX of the weather satellites in both frequency and format. The feed horn construction and electronics are different but the parabolic reflectors are the same and can be modified for WEFAX reception if available.

An excellent treatment of this type of antennal design can be found in the article "Be A Weather Genius-Eavesdrop on GOES" by Ralph Taggert, published in the November 1978 issue of 73 Magazine for Radio Amateurs. This article also contains information on the use of 1691.0 to 137.5 MHz downconverters to bring the WEFAX signal to a frequency range that is usable by the standard APT radio receivers.

The photograph in Plate V-6 shows a surplus microwave antenna that was modified to receive GOES WEFAX at the Chambersburg ground station. A nine foot diameter dish is used to collect and focus the WEFAX signal into a feed horn (a) located at the focal point of the reflector. This feed horn was built from a 3 pound coffee can, as detailed in Taggart's article, and contains a small 3.7 cm brass probe mounted 5.9 cm from the back of the can on a Type N connector. The open end of the can is positioned at the focal point of the dish with the open end pointed toward the center of the dish. A short length of low loss RG-142/U cable (b) carries the 1691.0 MHz signal from the feed horn to the downconverter (c) that is placed in a weatherproof box. After the signal is converted to the 137.5 MHz frequency a longer length of less expensive coaxial cable (d) can be used to bring the WEFAX signal to the ground station radio.

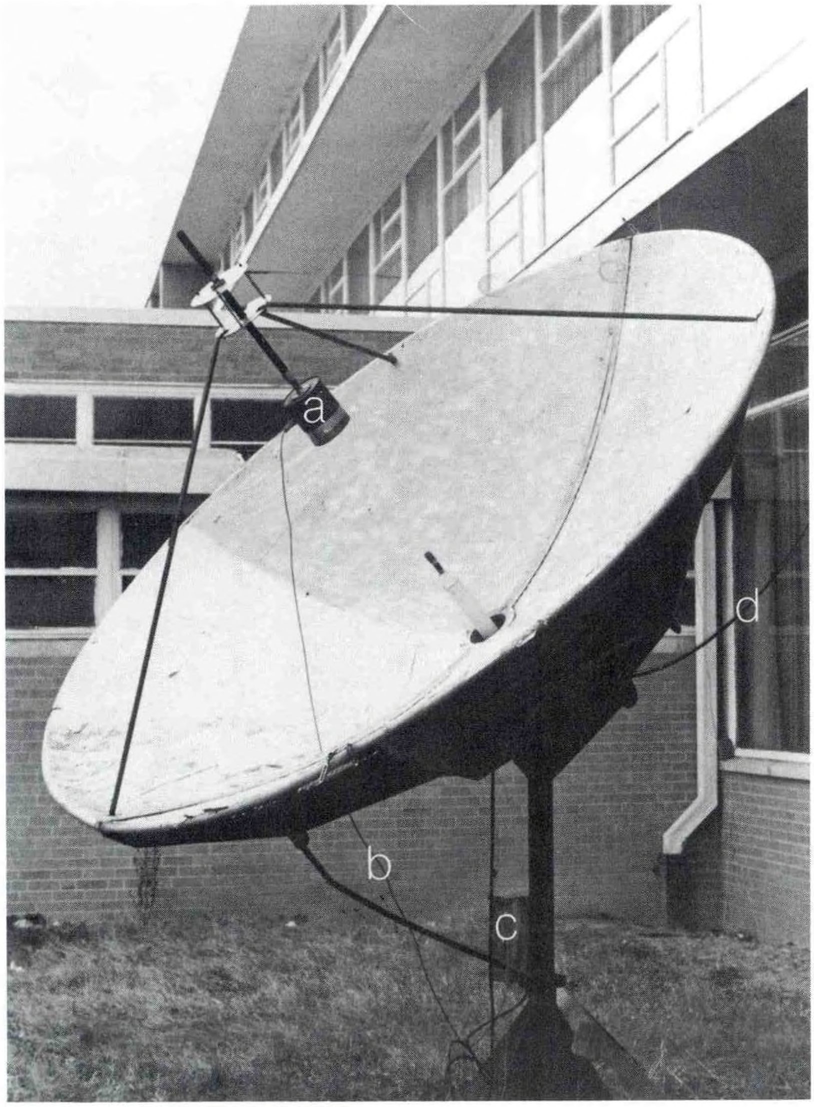


PLATE: V-6. GOES WEFAX Antenna

This antenna system and a down converter have been used successfully for 7 years to receive GOES WEFAX. Many of these have more advanced low noise electronics which make it possible to use smaller dish antennas which are easier to mount and have less wind resistance. A partial list of vendors of these systems can be found in the appendix.

VI. RADIO RECEIVERS FOR SATELLITE DIRECT READOUT

Radio receivers for direct readout stations are similar to the many FM "high band," solid state receivers with crystal controlled frequencies that are available today. In fact, many of these receivers could be modified for direct readout service. Basically, any receiver must meet certain minimum requirements for adequate video reception. These requirements are set by the nature of the APT signal transmitted from the satellite. The APT transmission parameters for the United States TIROS-N and Russian Meteor series satellites are given in Table VI-1.

PARAMETERS	TIROS-N SERIES	METEOR SERIES
Frequency	137.5 and 137.62 MHz	137.3 and 137.85 MHz
Carrier Modulation	analog AM/FM	analog AM/FM
Transmit Power	5 watts	5 watts
Antenna Polarization	right hand circular	circular
Carrier Deviation	+/– 17 kHz	+/– 15 kHz

TABLE VI-1. APT Transmission Parameters of the Polar Orbiting Satellites

There are four factors of primary importance in a direct readout station receiver:

1. The frequency of the APT signal
2. The type of rf signal modulation
3. The bandwidth of the transmitted signal
4. The sensitivity of the receiver

The "satellite band" for the APT from polar orbiting satellites is between 137 and 138 MHz. This is a narrow section of frequencies located between commercial aircraft allocations and the 2 meter amateur radio band. Presently, NOAA-9 and -11 are transmitting at 137.62 MHz. NOAA-12, launched in May 1991 is broadcasting at a frequency of 137.50 MHz. The Russian satellites are using frequencies of 137.3 MHz and 137.85 MHz. Future TIROS-N series satellites are planned with APT at the same frequencies. All these satellites are transmitting with Frequency Modulation (FM). Based on these transmitting frequencies, it will be necessary to obtain an FM receiver that is capable of operating through this range of radio frequencies.

The most practical approach for a direct readout station is to use a radio receiver that has crystal controlled tuning. Using this type of receiver, after the crystals of the proper frequency are placed in the radio, no further tuning should be necessary; and the radio will be on frequency for proper reception. Also, many radios of this type will accommodate a number of crystals of different frequencies with a switch for frequency selection.

Crystals of the proper type can be purchased from a number of manufacturers. Many of these advertise in popular radio magazines, and some have toll free telephone numbers for placing orders. The crystals for the APT frequencies will probably not be in stock, and there will be a few weeks before they will be available after the order is placed. The type and model of the receiver should be included with the order.

The bandwidth of the APT receiver is also an important factor in receiving good video products from the weather satellites. In receivers the bandwidth is established by a filter in the IF (intermediate frequency) stage. To reproduce good APT pictures, the bandwidth must be wide enough to pass the entire signal or distortion and loss of picture resolution will occur. Excessive bandwidth, however, will introduce excessive noise into the signal. The APT signal bandwidth is influenced by two factors, the satellite transmission deviation and the doppler effect, which cause a frequency shift as the rapidly moving satellite approaches and passes the ground station. The signal deviation of the TIROS series transmission is +/- 17 kHz. It is +/- 15 kHz for the Meteor series. The doppler frequency shift for these satellites is about +/- 4.5 kHz during an overhead pass, where the effect will be most severe. Using these parameters, for ideal APT signal reception, the bandwidth of the receiver should be about 40 kHz (+/- 20 kHz). However, receivers with bandwidth of 30 kHz (+/– 15 kHz), give adequate results. Most commercial high band receivers on the market have more narrow bandwidths and modification of this portion of the receiver would be necessary.

The sensitivity of the receiver is of prime importance in APT signal reception. Since noise-free signals produce the best satellite pictures, it is essential that the noise level be kept at a minimum. Sensitivity refers to the ability of the receiver to detect weak signals through the noise level of the receiving system which includes antenna and internal thermal noise of the receiver. Generally, this is referred to as the signal to noise ratio—where the signal strength is given in microvolts and the noise in db (decibels). A good receiver for APT direct readout stations will have a sensitivity of about 0.2 to 0.3 microvolts for 20 db of quieting. However, with the addition of a low noise preamplifier, receivers with less sensitivity, on the order of 0.6 microvlts, can produce noise-free signals when used with the antenna and transmission systems described in this publication.

In most cases, acquiring a receiver for the APT direct readout station will be influenced by cost. Since the basic requirements of frequency, bandwidth, and sensitivity are not unreasonable; a radio adequate for receiving APT should not introduce cost factors out of line with school budgets. Generally, there are three practical ways of obtaining radio receivers:

1. Purchase a new receiver of the proper sensitivity, frequency and bandwidth
2. Modify a surplus (used) high band receiver
3. Obtain a government surplus receiver of the proper type

At the Chambersburg Senior High School direct readout station, the first two of these suggestions have been used. During the initial assembly of the station, a used, Regency TMR-1H, single channel (one receive crystal) monitor was modified for APT reception. This radio was originally designed to receive FM signals at frequencies between 148 and 174 MHz and has a sensitivity of 0.6 microvolts. The original bandwidth was +/– 7 kHz. Both the bandwidth and receiver frequency were modified to conform to APT reception requirements. The total cost, including purchase, modification, and two crystals, was less than $75.00. Whenever this receiver was used with the antenna system and preamplifier, good results were obtained.

There are also solid state receivers that are either designed specifically for or meet the requirements for APT reception that can be purchased new. At Chambersburg, a Vanguard Labs FMR 260-PL receiver was purchased and has given excellent service. It has space for eleven crystals (with manual selection), a sensitivity of 0.3 microvolts for 20 db quieting, and can be ordered with a 30 kHz bandwidth. The newest model from this company (WEPIX 2000 B) is now priced at $349.95 (includes shipping). Further information on this receiver can be obtained from:

Vanguard Electronic Labs
196-23 Jamaica Avenue
Hollis, NY 11423

GOVERNMENT SURPLUS RECEIVERS

Another approach to obtaining a receiver for an APT station is a search of government surplus sources available to educational institutions. Most schools have some access to surplus outlets. There are, however, some disadvantages to obtaining a radio receiver through these sources; surplus receivers will not always be available and they will only be on an "as is" basis. The distinct advantage here, however, is that if a receiver is available, it will probably be at an extremely reasonable price. Therefore, if cost is a major concern, this source should be not overlooked.

POWER SUPPLIES

Most receivers discussed here will operate on either 120 volts AC or 12 volts DC. The Vanguard Labs FMR 260-PL operates only on 12 volts DC. In all cases, it is recommended that a good 12 volt DC power source be used. Many receivers, when operated on 115 volts AC, will have internal AC hum that will interfere with the quality of picture that is reproduced. This interference will appear as vertical lines through the picture causing poor results in the final product. Batteries will also suffice for DC supplies but are not as convenient to use.

VII. LOCATING AND TRACKING POLAR ORBITING SATELLITES

In order to obtain high quality APT video using direct reception, accurate information concerning locations, movements and times that the satellites can be received must be available. This is necessary because signal reception is possible only while the satellites are above that ground station horizon. Although all polar orbiting satellites have basic orbital characteristics in common, each spacecraft is unique in its orbital parameters and needs to be tracked individually. The data necessary to locate and track the meteorological satellites is generally not difficult to obtain and sources of this information are provided in this section. The generation of future orbits of a given satellite can be easily calculated and, if a directional antenna is used, determining the azimuth and elevation of the satellite as it passes over the ground station is not difficult after the basic orbital patterns are understood.

Figure VII-1 shows a typical orbital path of a NOAA-TIROS series satellite. A polar orbit, in strict terms, would carry the satellite directly over the north and south poles with an inclination of 90 degrees to the equator. Both the TIROS series and Russian Meteor series satellites have orbits that pass within 10 degrees of the geographic poles and have slight inclinations relative to the equator. The advantage of a polar orbit is that the satellite will have the best routine coverage for all areas of the Earth's surface during a 24 hour time frame. In addition, all of the TIROS series satellites are inserted into sun-synchronous orbits which will place the spacecraft in a relatively constant relationship to the sun so that the ascending node (northbound equator crossing) will remain at a constant solar time. This permits images and other meteorological data to be received by direct broadcast at about the same local time each day.

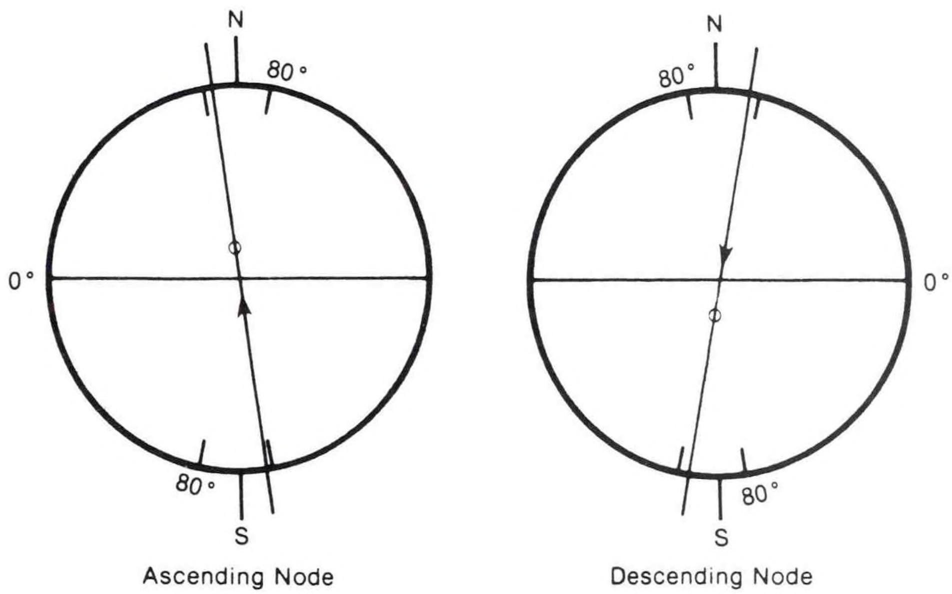


FIGURE: VII-1. Typical Orbital Path of NOAA/TIROS Series Satellites

The time required to complete one orbit is referred to as the NODAL PERIOD of that satellite. For polar orbiting satellites this is measured from the time it crosses the equator (0 degrees latitude) moving northward (ASCENDING NODE) until the next northbound equator crossing. The southbound equator crossing is called the DESCENDING NODE of that orbit. During the time of one orbit (NODAL PERIOD) the Earth is rotating at 0.25 degrees per minute. This causes the next equator crossing to be farther west than the previous one. The amount of Earth rotation between two successive equator crossings, given in degrees of longitude at the equator, is known as the satellite INCREMENT. This increment can be calculated as follows:

INCREMENT = NODAL PERIOD (in minutes) x 0.25 degrees

If a satellite's PERIOD, INCREMENT, and the time and longitude of an equator crossing are known, it is not difficult to predict future orbits for that satellite for days or months in advance. This can be done by simply adding increments and the times of orbits to get the next longitude of an equator crossing and the time this will occur. This is, however, a time consuming task if each orbit is calculated and recorded by hand. A more convenient approach is to use a computer and a simple orbit prediction program to do these calculations. Students with some knowledge of computer programming can develop and run programs for a variety of computers that will accurately predict future orbits of any polar orbiting satellite. These programs can take various approaches from simple listings of equator crossing longitudes and times to more complex programs that give local station times, orbital numbers, antenna tracking data for azimuth and elevation and a variety of other information.

```
10   CLEAR : TEXT : HOME
20   PRINT "POLAR ORBITING SATELLITE PREDICT"
30   PRINT "NUMBER OF MONTH?"
40   INPUT M
50   PRINT "DAY OF REFERENCE CROSSING?"
60   INPUT D
70   PRINT "LONG. OF ASCENDING NODE (DEGREES)"
80   INPUT E
90   PRINT "HOUR OF REFERENCE CROSSING? (USE 24 HOUR CLOCK)"
100  INPUT T
110  PRINT "MINUTE AND DECIMAL OF REFERENCE CROSSING?"
120  INPUT X
130  PRINT "ORBITAL INCREMENT BETWEEN ORBITS?"
140  INPUT W
150  PRINT "NODAL (ORBITAL) PERIOD?  NOTE: ENTER ONLY MINUTES IN EXCESS OF 60."
160  INPUT F
170  PRINT "SATELLITE NAME AND FREQUENCY?"
180  INPUT A$
190  PRINT A$
200  PRINT
210  PRINT "DATE          TIME        LONGITUDE"
220  PRINT
230  PRINT
240  REM
250  H = 1:I = W
260  LET Y = F
270  LET 2 = Q + 1
280  LET B = E + I
290  IF B > = 360 THEN B = B - 360
300  LET S = T + H
310  LET R = X + Y
320  IF R > = 60 THEN 340
330  IF R < = 60 THEN 360
340  LET S = S + 1
350  LET R = R - 60
360  IF S > 24 THEN 370
370  GOSUB 480
380  R = INT (R * 1000 + .5) / 1000
390  B = INT (B * 1000 + .5) / 1000
391  HTAB 15
392  PRINT S;
393  PRINT ":";
394  PRINT R:
395  HTAB 33
396  PRINT B
410  LET T = S
420  LET X = R
430  LET E = B
440  LET Q = Z
450  IF D< = 28 THEN 240
460  IF D> = 30 THEN 470
470  IF D> = 28 THEN 520
480  IF S> = 24 THEN D = D + 1
490  IF S > = 24 THEN PRINT : PRINT M"/"D: PRINT A$"
500  IF S > = 24 THEN S = S - 24
510  RETURN
520  IF M = 1 THEN 640
530  IF M = 2 THEN 690
540  IF M = 3 THEN 640
550  IF M = 4 THEN 720
560  IF M = 5 THEN 640
570  IF M = 6 THEN 720
580  IF M = 7 THEN 640
590  IF M = 8 THEN 640
600  IF M = 9 THEN 720
610  IF M = 10 THEN 640
620  IF M = 11 THEN 720
630  IF M = 12 THEN 640
640  IF D < = 31 THEN 240
650  IF D = 31 THEN 660
660  D = 1
670  M = M + 1
680  IF M = 13 THEN M = M - 12
690  M = M + 1
700  D = 1
710  GOTO 760
720  IF D < = 30 THEN 240
730  IF D = 30 THEN 740
740  D = 1
750  M = M + 1
760  END
```

TABLE VII-1. Basic Computer Program for Orbit Prediction

Table VII-1 lists an example Basic computer program written for an Apple PC that will calculate the future equator crossings for polar orbiting satellites if accurate data are available for one reference orbit. The following reference orbit input data are required to operate this program:

1. Month
2. Day
3. Longitude of the north bound equator crossing (Ascending Node)
4. Hour of the reference orbit equator crossing
5. The minute and decimal minute of the equator crossing
6. The Orbital Increment of the satellite
7. The time, in minutes, of the orbital period (Nodal Period) of the satellite

This data is available from the NOAA Satellite Electronic Bulletin Board (EBB). The EBB provides ready access to current operational information on various satellites and related topics of interest. Details on this information service are available from NOAA's Data Collection and Direct Broadcast Office, World Weather Building, Room 806, Washington, D.C 20233.

The computed equator crossing locations and times provided by this program, when used in conjunction with a tracking map shown in this publication, are all the information needed to accurately determine when a polar orbiting satellite will pass within reception range of a given ground station.

The following is an example of the reference Orbital Data provided in the **PREDICT DATA** provided by NOAA:

NOAA ORBITAL PREDICTIONS FOR 01 MAY 1988

	NOAA-9	**NOAA-10**
ORBIT #	17430	8408
EQ. CROSSING TIME	0010.71Z	0055.08Z
LONG. ASC. NODE (DEG)	125.7W	79.43W
NODAL PERIOD	102.0710 min	101.2855 min
FREQUENCY	137.62 MHz	137.50 MHz
INC. BET. ORBITS	25.52 deg	25.32 deg

NOTE: EQ. CROSSING is given in Greenwich Mean Time (GMT) in hours, minutes and decimals of minutes. 0055.08Z = 0 hours (24 hour clock) 55.08 minutes.

LONGITUDE OF ASCENDING NODE is the longitude where the satellite will cross the equator (northbound at 0 degrees latitude) during the reference orbit.

NODAL PERIOD is the time in minutes for one complete orbit from northbound equator crossing until the next northbound crossing. (101.2855 = 1 hour 41.2855 minutes)

FREQUENCY is the FM radio frequency on which the APT images are being transmitted by this satellite in megahertz.

INCREMENT BETWEEN ORBITS is given in degrees of Earth rotation during one orbit of the satellite. (NODAL PERIOD x .25 degrees/minute of Earth rotation = INCREMENT BETWEEN ORBITS in degrees)

Using the NOAA-10 reference orbit given here for the May 1988 predict, the input data for the computer program would be as follows:

Number of Month?	Input: **5**
Day of Reference Orbit?	Input: **1**
Long. of Ascending Node?	Input: **79.43** ***Note:** All longitudes are given using a 360 degree equator
Hour of Reference Crossing?	Input: **00**
Minute and Decimal of Reference Crossing?	Input: **55.08** ***Note:** The time references given are in GMT or Universal Time using a 24 hour clock
Orbital Increment Between Orbits?	Input: **25.32**
Nodal (Orbital) Period?	Input: **41.2855** ***Note:** The program has been written to assume orbits longer than 60 minutes. Therefore, the input should be Nodal Period(101.2588 -60 minutes= 41.2855) in this example.
Satellite Name and Frequency?	Input: **NOAA-10 137.50 MHz**

Table VII-2 gives a short example printout of the orbits for NOAA-10 using these inputs and the Basic program shown in Table VII-1.

```
POLAR ORBITTING SATELLITE PREDICT
NUMBER OF MONTH?
?5
DAY OF REFERENCE CROSSING?
?1
LONG. OF ASCENDING NODE (DEGREES)
?79.43
HOUR OF REFERENCE CROSSING?  (USE 24 HOUR CLOCK)
?00
MINUTE AND DECIMAL OF REFERENCE CROSSING?
?55.08
ORBITAL INCREMENT BETWEEN ORBITS?
?25.32
NODAL (ORBITAL) PERIOD?  NOTE: ENTER ONLY MINUTES IN EXCESS OF 60.
?41.2855
SATELLITE NAME AND FREQUENCY?
?NOAA-10  137.50
NOAA-10  137.50
```

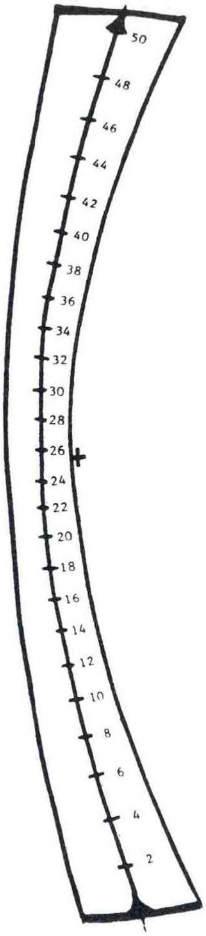
DATE	TIME	LONGITUDE
	2:36.366	104.75
	4:17.651	130.07
	5:58.937	155.39
	7:40.223	180.71
	9:21.509	206.03
	11:2.794	231.35
	12:44.079	256.67
	14:25.364	281.99
	16:6.649	307.31
	17:47.935	332.63
	19:29.22	357.95
	21:10.505	23.27
	22:51.79	48.59
5/2		
NOAA-10 137.50		
	0:33.076	73.91
	2:14.361	99.23
	3:55.646	124.55
	5:36.931	149.87
	7:18.216	149.87
	7:18.216	175.19
	8:59.502	200.51
	10:40.788	225.83
	12:22.074	251.15
	14:3.359	276.47
	15:44.644	301.79
	17:25.929	327.11
	19:7.214	327.11
	19:7.214	352.43
	20:48.499	352.43
	20:48.499	17.75
	22:29.785	43.07
5/3		
NOAA-10 137.50		
	0:11.07	68.39
	1:52.356	93.71
	3:33.642	119.03
	5?14.928	144.35
	6:56.214	169.67
	8:37.5	194.99
	10:18.785	220.31
	12:.07	245.63
	13:41.355	270.95
	15:22.641	296.27
	17:3.926	321.59
	18:45.211	346.91
	20:26.496	12.23
	22:7.781	37.55
	23:49.067	62.87

TABLE VII-2. Example Printout of NOAA-10 Orbits

Table VII-3 contains the location in degrees of longitude and latitude of a typical NOAA-TIROS series polar orbiting satellite (NOAA-10) for every two minutes during one orbit. These locations are known as the suborbital points. These points change during each orbit, but the orbital track traced over the Earth's surface does not appreciably change during any orbit of these satellites. If these points are plotted on a polar projection map, they form a track as shown in Figure VII-2. If this track is copied on a transparent film and placed on the polar map shown in Figure VII-3 so that this sheet can be rotated about the north pole (X on Figure VII-2), a simple but effective satellite tracking system is formed. By placing the arrow at any ASCENDING equator crossing longitude, the path that the satellite will follow across the northern hemisphere during that orbit can clearly be seen. Each two minute mark on figure VII-2 represents two minutes of travel **after the time of the equator crossing.**

TIME (In Minutes)Satellite		Location in Degrees
0	4.4 South	39.9 East
2	2.7 North	38.4 E
4	9.7 N	36.8 E
6	16.8 N	35.2 E
8	23.8 N	33.4 E
10	30.8 N	31.6 E
12	37.8 N	29.5 E
14	44.8 N	27.1 E
16	51.7 N	24.2 E
18	58.6 N	20.4 E
20	65.3 N	15.0 E
22	71.7 N	6.4 E
24	77.5 N	10.0 West
26	81.2 N	44.3 W
28	80.0 N	88.6 W
30	75.1 N	113.5 W
34	62.3 N	132.4 W
36	55.5 N	137.0 W
38	48.6 N	140.3 W
40	41.6 N	143.0 W
42	34.6 N	145.2 W
44	27.5 N	147.2 W
46	20.5 N	149.0 W
48	13.4 N	150.7 W
50	6.3 N	152.3 W
52	0.8 South	153.8 W

TABLE VII-3. Sub-Orbital Points for NOAA-10 Orbit 9427:Ascending Node



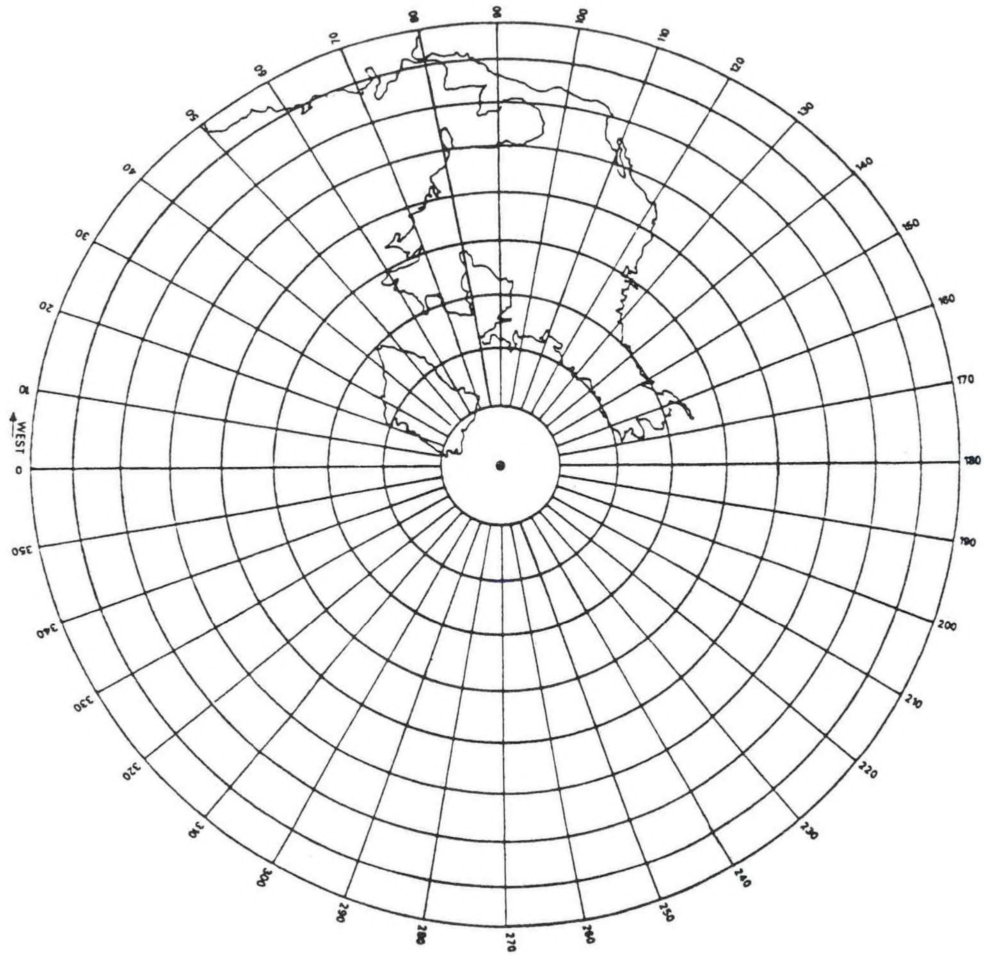


FIGURE: VII-2. Typical Orbital Track of NOAA/TIROS Series Satellites

FIGURE: VII-3. Northern Hemisphere Map

Also, the lines on either side of the center track represents the approximate video coverage that can be expected while the APT is being received at the ground station.

Reception of the 137-138 MHz APT signal from the satellites is essentially "line of sight" which means that the satellite must move above the ground station horizon before APT images can be received. This is a function of the altitude of the orbit. Since the NOAA TIROS series and Russian Meteor series satellites have planned orbital altitudes between 833 and 900 kilometers, a ground station can expect to receive APT signals if these satellites pass through a circular area with a radius of about 3100 kilometers with the ground station at the center. This area will vary somewhat with the exact altitude of a given satellite but can be used for routine work. More exact calculations can be made using the TIROS-N Series Direct Readout Services User's Guide available from NOAA's Data Collection and Direct Broadcast Office, World Weather Building, Room 806, Washington, DC 20233.

Figure VII-4 is a diagram of the ground station area of reception based on the general orbital parameters of the TIROS polar orbiting satellites and is drawn for a ground station located at approximately 40 degrees north latitude. This diagram, when drawn to scale around the ground station location on the polar map shown in Figure VII-3, will provide information on time of reception, azimuth, elevation, area of image coverage and the length of time the APT signal can be expected during any satellite pass. The outermost circle represents the approximate receiving range of the ground station (radius=3100 kilometers). A satellite passing through this circle can be received with a tracking antenna set at the proper azimuth and 0 degrees of elevation. The inner circles marked 2,4,6, and 8 represent the approximate antenna elevations X10, in degrees, needed to receive a clear signal as the satellite track intersects these circles. The azimuth and elevations obtained from this diagram are approximate but will be generally within the tolerances of most directional tracking antennas. Omnidirectional antennas do not require tracking but will generally give less area of coverage because of lower signal gain in one particular direction.

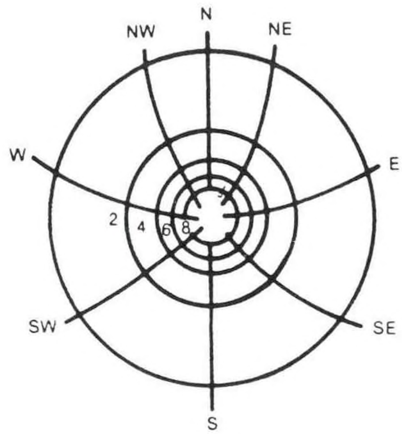


FIGURE VII-4. Satellite Receiving Area Drawn for Ground Station Located at 40 Degrees North Latitude

Figure VII-5 shows the tracking materials discussed here arranged for a ground station located at the Chambersburg Area Senior High School, Chambersburg, Pennsylvania. (39.9N / 77.7W) The satellite track positioned for this example shows an ascending node of approximately 63 degrees west longitude which is a typical afternoon orbit for a TIROS series satellite. The actual ascending longitude and time for this orbit would be obtained from the orbital predict data. Table VII-4 gives the tracking procedure for this particular satellite pass.

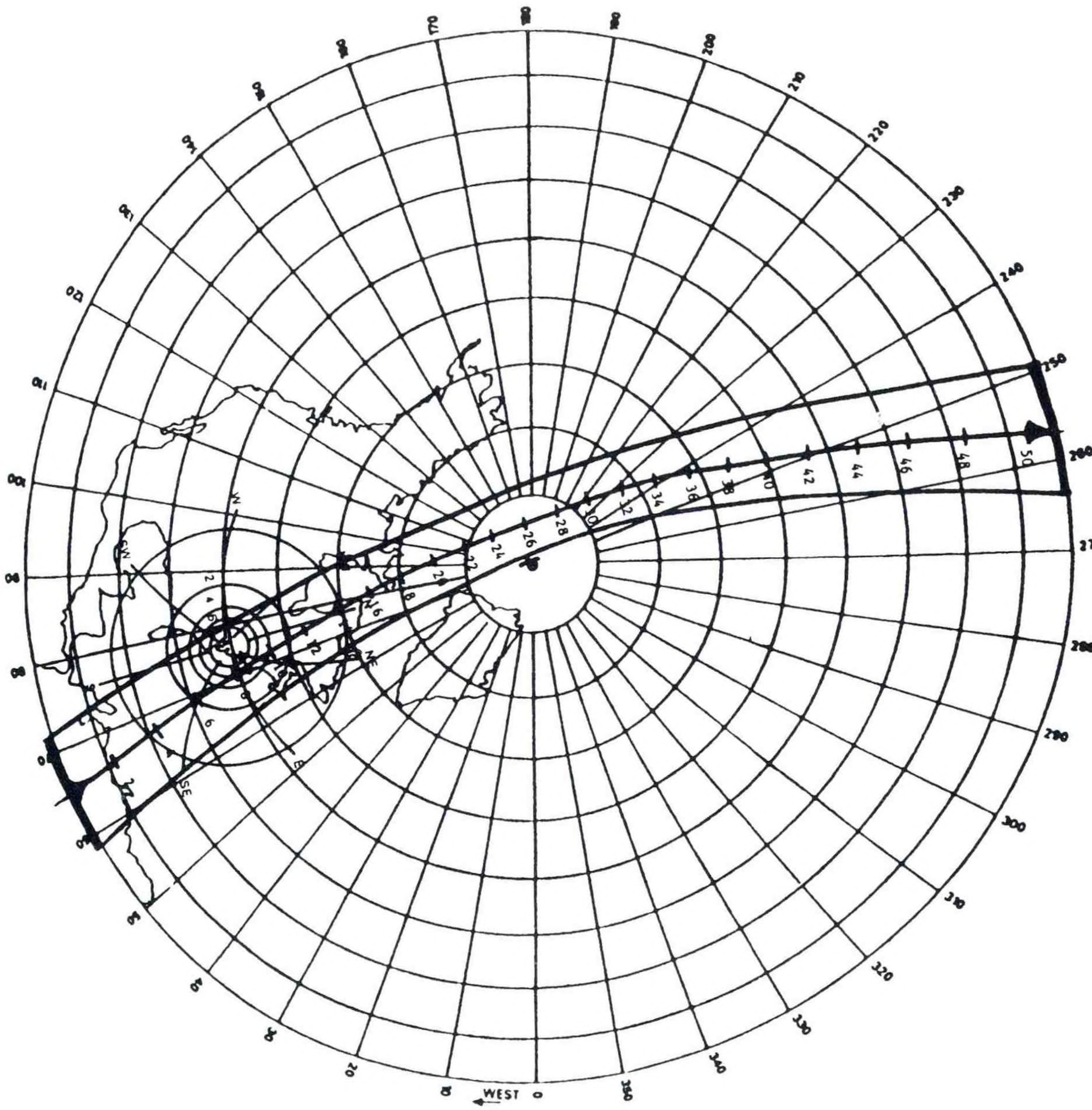


FIGURE VII-5. Tracking Materials Arranged for a NOAA Satellite Pass with an Ascending Node of 63 Degrees West

TIME	ANTENNA AZ AND EL	OBSERVATIONS DURING PASS
	AZIMUTH-ELEVATION	
0	EQUATOR CROSSING	No Signal
+ 4 min	S/SE 0 Degrees EL	APT Signal Received
+ 5	S/SE 10	Haiti and Cuba
+ 6	SE 20	Florida
+ 7	E/SE 40	
+8	E 60	East Coast of US
+9	N/NE 60	
+10	NE 40	Over Long Island
+11	N/NE 20	Great Lakes visible
+12	N 10	
+13	N 10	
+14	N 0	Hudson's Bay visible
+15	N 0	Loss of Signal

TABLE VII-4. Antenna Tracking Procedure for an Ascending Equator Crossing of 63 Degrees West as Shown in Figure VII-5.

VIII. RECORDING SATELLITE SIGNALS

Satellite images can be produced on most display systems as the signal is being received (real time). An audio tape recorder can be used to save these transmissions for later analysis or to archive data of special interest. Most tape recorders, however, do not have enough accuracy in motor speed to assure proper synchronization of the image on play back. This can be overcome if a stereo tape recorder is used and a synchronization reference, such as a 2400 Hz tone, is recorded on one of the audio channels while the satellite transmission is being recorded on the other channel. Then, on play back, the display system can use this reference to track slight changes in the motor speed and adjust the synchronization so that the satellite image will be properly aligned to produce a coherent image. An example of how this is done using a FAX machine to display the image is presented in section IX. Most computer display systems are designed with internal image synchronization and can also use recorded satellite transmission.

The specifications required of the tape recorder to be used in the APT and WEFAX station can be found in many commercially available models. The high school's audio-visual department could be a source of a tape recorder for the APT and WEFAX station.

The use of a tape recorder with extreme variations in motor speed during replay will cause the picture to drift or to have wave-like variations from border to border even when using a synchronization tone on the second channel. For this reason, the tape recorder must have a reasonably constant motor speed. The specifications that measure the amount of variation from a constant speed is called "wow and flutter" and is expressed in percentage values. Recorders with a wow and flutter around .3% will work well with APT and WEFAX if a sync tone is used.

Tape recorders with the required specifications for use in the APT and WEFAX station are available in both cassette and open reel formats. The cassette format offers the advantages of ease of operation, convenient storage and cataloging of tapes, and a more compact size.

The open reel format is a bit more clumsy to operate and requires a little more shelf space than the cassette. Many open reel recorders provide a choice of tape drive speeds. A two speed recorder will give the option of 3-3/4 ips (inches per second) and 7-1/2 ips. A three speed model will add 1-7/8 ips or 15 ips to these choices. The speed choices will allow the original 120 lines per minute transmission to be reproduced in a different format. For example, if a 2400 Hz motor synchronizing tone is recorded at 7-1/2 ips and replayed at 3-3/4 ips, a 1200 Hz tone will be produced driving the FAX or other display system at half the speed.

It is useful to have separate level controls for both record and playback on each channel. Some recorders have level controls which affect record only and provide replay at a fixed volume. Volume control on the playback is most useful for matching levels with the display inputs. Level meters are also useful in giving the station's operator a visual reference for duplicating or improving results.

A tape recorder which has the required specifications of constant tape drive speed, level controls, and meters will normally have excellent specifications in terms of frequency response. However, the video signals of the APT and WEFAX are constant frequencies in the middle range of the audible spectrum. The wide frequency response of most of today's high fidelity tape decks generously supersedes the requirements of the APT and WEFAX system. A high fidelity feature which may have some bearing on the performance or quality of the pictures is that of reproducing accurate dynamic levels since the APT and WEFAX video signal produces light and dark areas of the photograph corresponding to soft and loud variations in the level of the tone.

Most tape recorders will provide the user with the ability to monitor the tape while it is being recorded. This is accomplished by the placement of a separate playback head immediately beside the recording head and "playing" the tape a fraction of a second after it has been recorded. This monitor signal can be fed directly to the display system and an image can be produced in real time while the satellite is passing over the station. The recorded tape is not affected by the monitoring and additional images can be made by rewinding the tape to the point of the beginning of the transmission and replaying the recorded signal and synchronizing tones into the display system.

The APT signal from the NOAA operated TIROS Series satellites carries two images multiplexed from two different spectra, usually visible and infrared during daytime passes. These two pictures can be reproduced side by side on most display systems. When this is done the volume setting which is suitable for the visual image may cause the IR image to be too light or, if a volume setting is used to view the IR image the visual image may be too dark. The use of tape recorded passes will enable both images to be reproduced properly by using two separate replays of the tape and adjusting the volume accordingly.

Most standard audio tapes available today can be used to record satellite transmissions. A higher quality tape is most satisfactory if it is erased and reused a number of times. However, if a large number of passes are recorded on tape for printing at a later time, a less expensive tape will be adequate.

IX. REPRODUCING SATELLITE IMAGES

Obtaining or building the components necessary to reproduce pictures from APT and WEFAX video for a direct readout station may present the greatest problems and perhaps, the largest expense. At the present time there are four practical ways of displaying the weather satellite pictures received via direct readout:

1. CRT (Cathode Ray Tube) monitors
2. Photographic drum recorders
3. Electrostatic recorders
4. Computer display systems

The first two of these will probably require some construction of the necessary components. Methods of construction are available in the literature, and proper construction should provide good results. Electrostatic printers (FAX machines) are more adaptable for classroom use. Unfortunately, these are impractical to build and purchase of new ones will almost certainly exceed school budgets. Some electrostatic recorders are, however, available as surplus items; but they may require some modification before they can be used to reproduce satellite images. In the past several years, there has been a rapid growth in computer technology of analog to digital and graphic display systems. At the same time, costs of this computer hardware is becoming less. Companies and individual users of direct readout have applied these technologies to serve as interactive satellite image display systems. Therefore, computers are rapidly becoming the most popular display systems for APT and WEFAX satellite images.

CRT DISPLAYS OF APT

With modification, it is possible to adapt an oscilloscope with its cathode ray tube (CRT) into an APT facsimile display device for weather satellite video. The printing process involves tracing, line by line, the demodulated APT signal across the tube at the proper rate of speed and line deflection. In this way, a picture is “painted” across the screen in a way similar to television picture reproduction, but at a much slower rate than a standard television picture. The maximum APT signal produces a bright trace while the minimum signals produce various shades of gray. This tracing occurs at a relatively slow rate, 120 lines per minute, so the entire screen is not lighted at the same time. Therefore, it is not practical to view the screen directly. Instead, a time-lapse photograph of the screen must be taken while the signal is being fed into the display unit. Almost instant pictures can be viewed with the use of a Polaroid camera or negatives can be made with the standard camera and prints can be produced at a later time. In either case, the final product is a photograph of the CRT containing the satellite video.

PHOTOGRAPHIC FACSIMILE USING DRUM RECORDERS

High quality APT picture reproduction can be accomplished using rotating drum facsimile machines. This method of picture display is largely mechanical. Generally, a sheet of photosensitive paper (photographic enlargement paper) is wrapped around a drum which is rotated by a motor. A light source with a fine point focus is then moved along the rotating drum, causing fine lines to be drawn across the photographic paper. By modulating the light source with the APT or WEFAX signal from the satellite, the video signal is transformed into variations of brightness. This is turn causes variations of exposure on the light sensitive paper. After the photographic paper has been exposed, it must be developed by standard darkroom techniques to produce a photographic record of the satellite video transmission.

In order to produce satellite pictures by this method, accurate design considerations of the mechanical equipment must be undertaken. The drum motor, the light source drive, and the modulated signal must all be properly synchronized. Also, the light source drive must move along the rotating drum smoothly and the brightness of the light source must be matched to the sensitivity of the photographic paper to assure proper exposure. There must also be electronic components to process the satellite video signal for proper modulation of the light source.

In spite of the care needed in their construction, some amateur-built ground stations use drum facsimile for APT display with very high quality results. References found in the bibliography contain detailed information on the construction of these facsimile recorders.

There are some disadvantages of using this method of image reproduction in the classroom. First, at least some of the procedure requires darkroom facilities, which, for convenience, would need to be close to the other components of the direct readout station. Also, real-time printing is not as practical as other display methods discussed here. Most stations using drum recorders tape-record the satellite video and then reproduce the picture from this recording. The entire process of tape recording the satellite signal, exposing the photographic paper on the drum recorder, and then processing the photographic paper may require more time than is allowed in student schedules. Therefore, it may be difficult for students to participate in the entire process.

ELECTROSTATIC RECORDERS

Electrostatic facsimile recorders have been used for a number of years to reproduce facsimile transmitted to news facilities throughout the world. These pictures transmitted most often by telephone line in the form of an amplitude modulated tone in a line by line sequence which the recorder can reproduce as a photograph, chart, or printed material on electrosensitive paper.

The electrosensitive paper is moved with a constant speed between a steel writing blade on one side of the paper and a rotating helix wire on the other side of the paper. With this arrangement, the paper touches the blade and the helix wire at only a single point at any one time. If an electrical current is passed through the paper at this point, a chemical action occurs causing a coloration of the electrosensitive paper. The amount of coloration is directly related to the amount of current flow. In electrostatic recorders, this current is determined in other associated electronic circuits by the amplitude variations of the incoming signal. The rotation of the helix and the movement of the paper causes the point of contact to move across the paper creating a series of horizontal lines forming various shades of coloration corresponding to changes in the amplitude of the signal. In this way a photograph is built, line by line.

In all types of satellite video display devices, the scan rate must match the line rate-per-minute of the signal being reproduced. Therefore, the helix speed (RPM) must accurately match the satellite line transmission rate. Since the polar orbiting TIROS-N and Meteor series weather satellites are transmitting video at 120 lines-per-minute, picture reproduction requires a helix rotation of 120 RPM. To reproduce full sized WEFAX images, 240 lines-per-minute is required. Very slight variations in helix speed will cause the video display to drift across the paper. Greater variations will result in complete picture loss. Exact multiples of transmission rate (i.e. 240 lines-per-minute) reproduced at this 120 lines-per-minute helix rate will result in two pictures side by side.

In electrostatic recorders the helix speed is accurately controlled by an internally produced frequency standard. This frequency is usually established by a tuning fork or crystal-controlled oscillator and amplified. The resulting voltage is fed to a helix drive motor which turns the helix at a rate determined by the frequency. The D-611-P recorder was originally designed with a 1000 Hz frequency standard to drive the helix motor at 100 RPM. A newer version of the D-611-P, the K-550 facsimile recorder uses a 50 Hz frequency to drive the helix at 100 RPM. It is possible to modify these recorders to run at the desired 120 RPM rate. Other recorders, such as the Unifax I, already include a 120 lines-per-minute rate and should not require modification to reproduce the 120 lines-per-minute APT video.

While it is critical that the printing rate match the line rate of the incoming satellite signal, it is also important that the start of each scan line fall at or near the edge of the paper. If this phasing is not done, it is possible that the edge of the picture will fall somewhere toward the center of the paper with a portion of the picture on either side. The satellite video includes synchronization pulses for picture phasing. Portions of the electronic circuitry described in the references for CRT and photographic drum recorders include phasing mechanisms for the APT video. Electrostatic recorders also have picture phasing circuits. Sometimes, the phasing sequences required are not the same as contained in the satellite video. There is, however, a simple method to overcome this problem. The on/off toggle switch on the external frequency generator can be used to briefly interrupt the helix. The operator can then momentarily switch the helix off and then on to move the picture across the paper until proper alignment is accomplished. This method, of course, requires that the operator be able to see the picture as it is being printed. An additional modification is sometimes necessary in electrostatic recorders designed to pass input signal frequencies other than the 2400 Hz video carrier transmitted by the TIROS-N and Meteor satellites.

CRT, photographic drum recorders and electrostatic recorders all offer certain advantages and disadvantages when used to display weather satellite video. However, electrostatic recorders offer several advantages for instruction and classroom use:

1. The recorders are generally easy to operate and require a minimum of instruction for successful operation.

2. Electrosensitive paper is the least expensive material for picture reproduction.

3. The operator gets immediate results without the need for photographic processing or darkroom facilities.

4. Students can view real-time displays which aid in satellite tracking.

5. Where student scheduling limits time, photographs can be studied immediately after reception.

6. These recorders offer the same flexibility as the other methods of image display in that the signal can be tape recorded and additional photographs can be reproduced immediately after the satellite passes.

AVAILABILITY OF ELECTROSTATIC RECORDERS

Electrostatic recorders suitable for video reproduction of weather satellite APT should be available in either new or surplus condition from a number of sources. A few may be available through government surplus channels or, with luck, one may be located locally at low cost or perhaps at no cost to the school. Local newspaper offices and amateur radio operators should not be overlooked. Some recorders that do not have a printing rate of 120 lines-per-minute will need modification. Also, some adjustments may be needed for the recorder to respond properly to the 2400 Hz satellite carrier. These changes in most cases should not be difficult and any components necessary should be inexpensive.

MODIFICATION OF THE K-550 ELECTROSTATIC RECORDER FOR WEATHER SATELLITE APT REPRODUCTION

The K-550 recorder is designed to reproduce facsimile at a rate of 100 lines per minute. The helix speed is determined by an internally derived frequency standard established by a 3.2 MHz crystal controlled oscillator circuit and a series of integrated circuits which divide the 3.2 MHz frequency down to a 50 Hz square wave. This 50 Hz signal is then amplified by the motor amplifier circuit. All of these components are located on a printed circuit board PC 1443 "E". The amplified signal from this board is then fed to a pair of capacitors and diodes that rectify the 50 Hz pulses and drive the helix motor (MO 1) at a rate of 1500 RPM. The helix motor, through a gear arrangement, turns the helix at 100 RPM. A diagram of these components is shown in Figure IX-1.

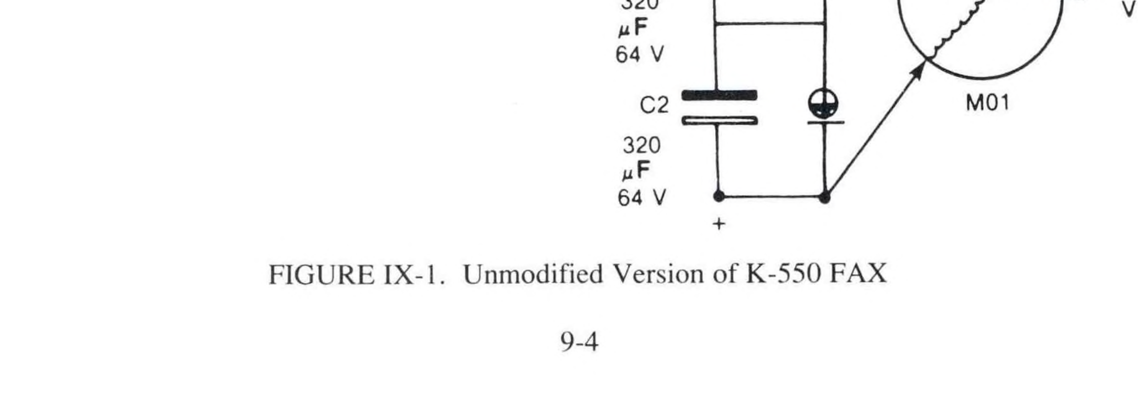


FIGURE IX-1. Unmodified Version of K-550 FAX

The modification of the motor speed for reproducing APT facsimile at 120 lines per minute requires two easy and inexpensive changes. The first of these requires a change of the internal frequency standard from 3.2 MHz to 3.84 MHz in the crystal controlled oscillator circuit. This new frequency of 3.84 MHz, when divided by the same integrated circuits, will produce a 60 Hz square wave which will increase the helix motor speed to 1800 RPM. Then, through the existing gear arrangement, the helix will turn at 120 RPM. This change of frequency can be accomplished by removing the original 3.2 MHz crystal on printed cicuit board PC 1443 "E" and replacing it with a 3.84 MHz (3840.0 KHz) crystal. (Specifications: 3.84 MHz, +/– .005%, 30 pF - available from: Sentry Manufacturing Co., Crystal Park, Chickasha, Oklahoma 73018, Phone order toll free: 1-800-654-8850.)

Because of the frequency change from 50 to 60 Hz, the electrolytic capacitors C1 and C2 (320 uF, 64 V) shown in Figure IX-1 will no longer function properly to drive the helix motor at the desired 1800 RPM rate. Based on the formula for inductive and capacitive reactance:

$$f = \frac{1}{2\pi \sqrt{LC}}$$

f = frequency
L = inductance in henrys
C = capacitance in farads
π = 3.14

Resonance at 60 Hz requires that the capacitors C1 and C2 be replaced by capacitors of 220 uF values. The original 320 uF capacitors are located below a plate accessible from the back of the K-550. These should be removed and replaced by two 220 uF capacitors of similar voltage. (50 volt capacitors have been used successfully.) The two original diodes in this circuit can be retained and used with this modification. Care should be taken to assure the same circuit configuration is maintained with respect to capacitor polarity and diode direction. Also, the incoming line carrying the 60 Hz signal from PC 1443 must be replaced in the same position or the motor direction will be reversed.

These changes, shown in Figure IX-2, should now produce an exact 1800 RPM motor speed with the resultant helix speed of 120 RPM. Any slight variations from the vertical picture reproduction can be adjusted by the variable capacitor CV 1 on PC 1443.

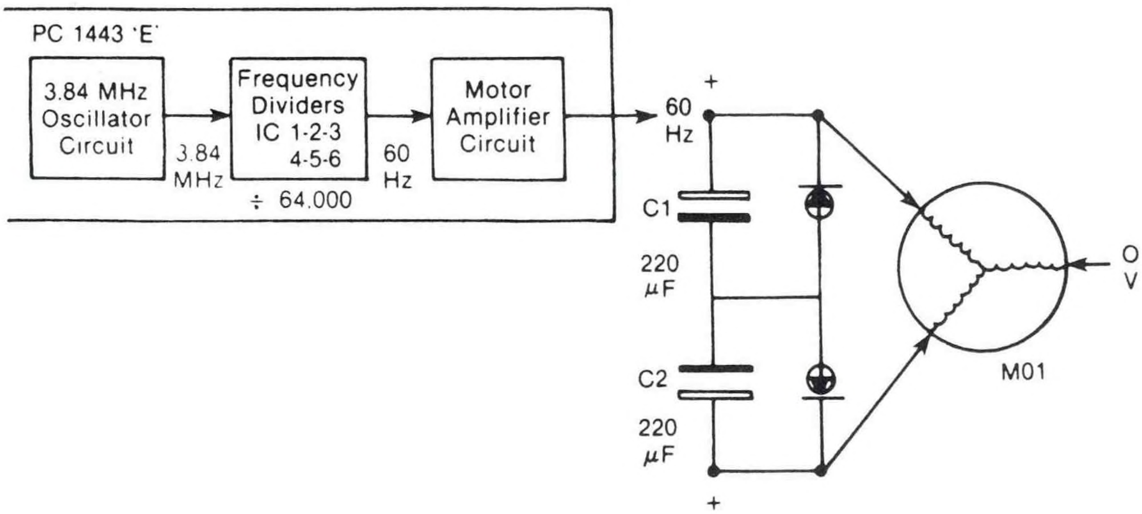


FIGURE: IX-2. Modified Version of K-550 FAX

MODIFICATION OF K-550 FOR USE WITH STEREO TAPE RECORDER

After completion of the modification for 120 lines per minute operation, weather satellite APT can be reproduced without further changes. However, if this electrostatic recorder is to be used with the stereo tape recorder, changes will be necessary to allow the 60 Hz sync signal to be recorded and to be played back. This will allow for slight variations in the tape speed.

Since it is possible to change the frequency of the K-550 internal frequency standard, it is not necessary to construct a frequency generator. Instead, the 60 Hz frequency can be obtained from the K-550 and tape recorded on one channel of a stereo tape unit. This signal can then be reinserted on playback to drive the helix motor. It also can be used while recording which allows picture reproduction in real time. Refer to Figure IX-3 for the following changes:

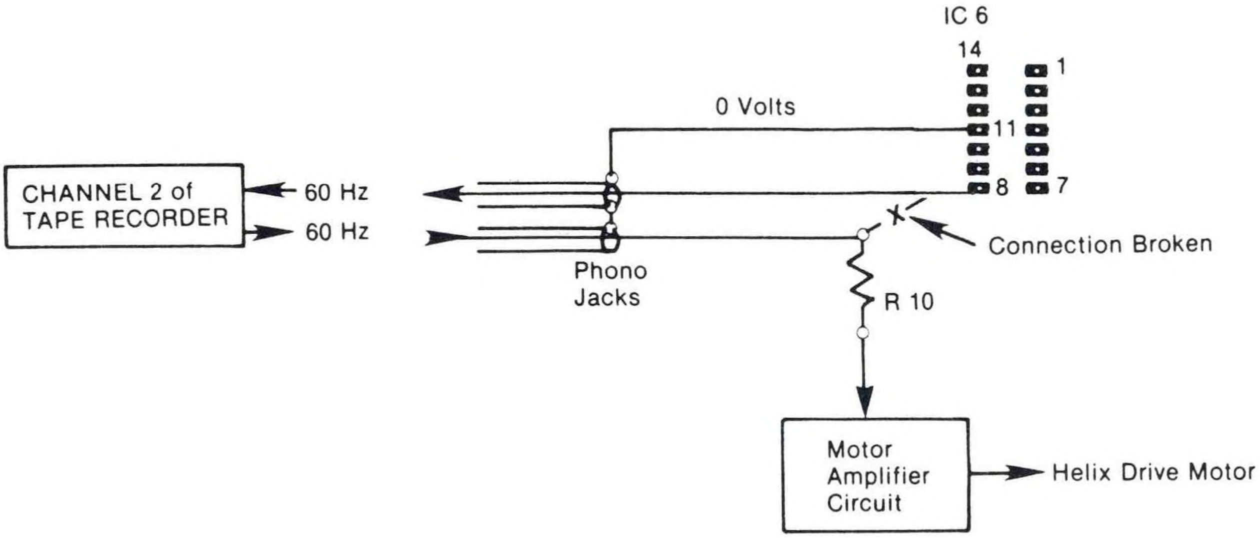


FIGURE IX-3: Diagram of the Foil Side of PC 1443 Showing Modifications to Record and Replay Sync Signal

1. Disconnect the short solder link between PIN 8 of IC 6 and resistor R 10. If a soldering iron is being used, do not overheat this area. This will break the connection between the output of the Frequency Divider Circuit and the input to the Motor Amplifier Circuit.

2. Solder a wire to PIN 8 of IC 6 to carry to 60 Hz signal to a phono jack outside the K-550.

3. Solder a second wire to the input point of R 10 and to a second phone jack. This will form the input to the Motor Amplifier Circuit from the tape recorder.

4. Connect a ground wire between both phono jacks and from this point to a 0 volt point on the printed circuit board such as PIN 11 of IC 6.

5. Standard connector cables can be used to link the phono jacks that are installed to the stereo tape recorder.

NOTE: The output voltage from the tape recorder to the Motor Amplifier stage should be 4 volts. If the output voltage is low, the helix motor will not operate. In this case, a small DC powered audio amplifier will be needed. Also, higher voltages at this point, should be avoided.

Figure IX-4 is a diagram showing the connections between the APT radio receiver, stereo tape recorder and the K-550 electrostatic recorder. Due to impedance mismatches between the radio receiver and the tape recorder and between the tape recorder and the 600 ohm video input to the K-550, small audio line matching transformers or other matching components may need to be added to these lines.

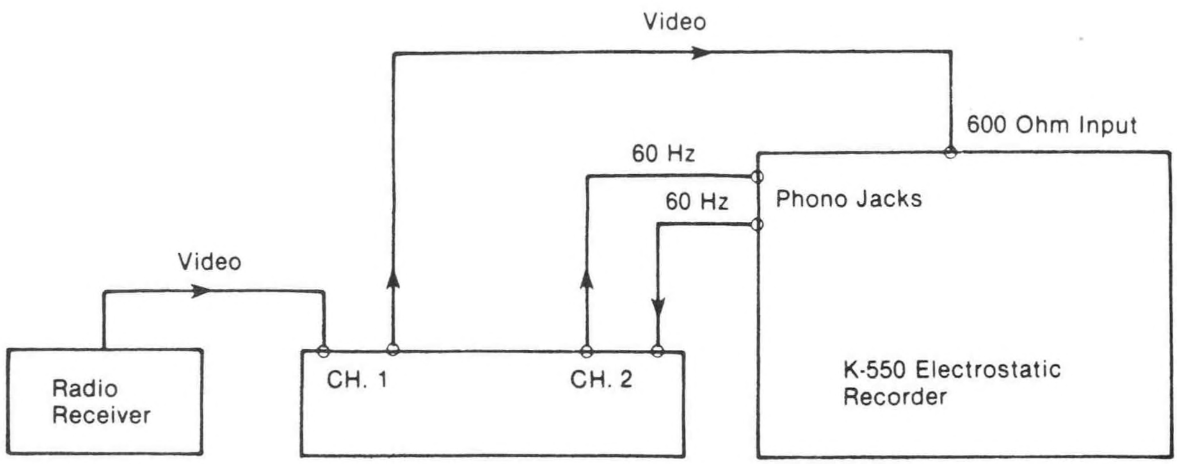


FIGURE: IX-4. Diagram Showing the Connections Between APT Radio Receiver, Stereo Tape Recorder and the K-550 FAX

OPERATION OF THE K-550 ELECTROSTATIC RECORDER

Because the K-550 was designed for facsimile via telephone line, the automatic sequencing is determined by a series of events at the transmission site. These sequences are not the same as contained by the satellite APT. When the unit is turned on, it remains in a "stand-by" condition. At this time, the helix motor is not running. When a "white" signal (Maximum signal) is detected at the input terminals, relays apply power to the motor circuits and the motor begins to run. Whenever the "white" signal is interrupted for 5 milliseconds or more, the helix gears are activated and the printing begins. When the signal is terminated for about 5 seconds, the machine returns to the stand-by condition.

Since the satellite video does not present a solid "white" signal, the K-550 will not activate with the satellite signal alone. It is possible, however, to activate the proper relays manually by using the test switch Si located on printed circuit board 1477 "D". Under standard operating conditions, this switch is set to NORMAL. When this switch is turned to WHITE, the helix motor will activate. If the switch is then returned to the NORMAL position with the satellite APT signal present, the printing process will begin and continue throughout the satellite pass as long as sufficient video signal from the satellite is present. Loss of this signal will terminate the printing and the machine will return to the stand-by state. Other methods may be possible.

COMPUTER IMAGE DISPLAY SYSTEMS

Computer display systems are now the most common method of displaying weather satellite images. Improved high resolution graphics hardware, increased computer speed and memory, high quality software programs with sophisticated image analysis processes are now available at costs that were unavailable only a few years ago. Because of the great variety of computer systems now available or under development, only a general discussion of this subject is possible here. When purchasing a computer system it is advisable to do some careful research and balance features that are offered against cost.

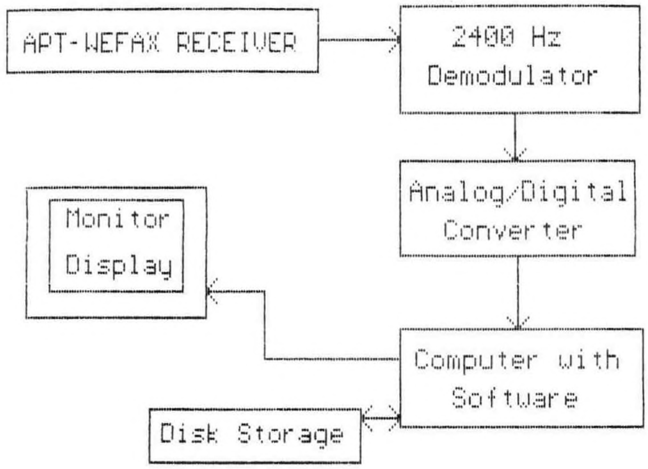


FIGURE IX-5. Generalized Diagram for the Hardware Components for Computer Display of Analog APT and WEFAX

The diagram in FIGURE IX-5 shows a generalized view of the hardware components that are found in most computer graphic APT and WEFAX display systems. At the ground station radio receiver, the satellite transmissions are detected as a 2400 Hz amplitude modulated (AM) signal transmitted at either 120 or 240 lines per minute from the TIROS or GOES satellites. At this point the image exists as an analog representation of the original image created by the satellite's imaging instrumentation. The varying amplitude can be measured as a varying voltage having a discrete voltage range. The 2400 Hz tone, referred to as the video subcarrier, carries the image as a function of its amplitude. Two electronic processes must be accomplished before this analog image can be managed within a computer system:

1. The 2400 Hz subcarrier must be removed and only the amplitude variations of this carrier, which is the actual image, allowed to pass. This process is known as demodulation and is necessary so that the 2400 Hz, which in itself contains no information, does not become a part of the finished image.

2. The demodulated video, in the form of a varying voltage, must be changed into relative digital values so that this data can be handled in the digital domain of the computer. This step in the process can be accomplished by an analog to digital converter (A/D) which is built to detect a voltage at a given instant and represent that reading as a digit. In 8- bit computer systems this will be a value between 0 and 255. This digit can then be stored in computer memory and the next conversion made. Each of these digital values then becomes a discrete element of the image and is referred to as a pixel

or picture element. It is important to note that the speed or frequency of the sampling process will influence resolution of the image and the relative width of each scan line but is limited by the resolution of the original data.

Two additional steps are needed in order to display these digital pixels as a coherent image on the computer video monitor. Both of these require software programs written specifically for the computer and graphic display hardware that is available.

1. Each digital picture element must be assigned a specific intensity or brightness proportional to the original amplitude of the image. In black and white displays this can be used to form a linear gray scale or, in instances where enhancement of a certain portion of the image is desirable, other intensities can be used. Color enhancement can be accomplished by assigning specific colors to ranges of digital values.

2. The picture segments, or scan lines, must be precisely aligned to form a final coherent image. This requires that the beginning of each scan line can be recognized by the software and positioned in the proper location on the monitor screen. Hard copy of the images can be made by photographing the monitor screen or by special graphic printing programs. There are two approaches to obtaining a satellite computer display system. Designing and building a computer display system is a demanding but excellent project for students who have some basic knowledge in computer programming and a basic knowledge of the nature of the satellite imagery. If a computer with graphics capabilities is already available, the only additional hardware necessary is a 2400 Hz demodulator and an analog to digital converter. Commercially built 2400 Hz demodulators may be difficult to obtain but construction of this piece of electronic equipment should not be difficult or expensive. Local radio amateurs or electronic experimenters can be good information resources for this project. A variety of commercial analog to digital converters are available from a number of sources. Information on these are available at most computer stores.

Software development will require time and effort. However, this process can be used as an excellent example of a practical research and development project for students that will involve numerous learning experiences.

Purchasing a commercial satellite computer display system is another alternative. If a computer is already available the cost of the additional hardware and software may not exceed the costs of other display systems discussed in this section. The computer systems now available have been designed for a variety of computers and have many different features. A partial list of vendors is provided in the appendix of this publication. When possible, it is advisable to examine the products that are now available before selection is made. Some features that can be expected from these commercial systems are:

1. Both APT and WEFAX capabilities
2. Color enhancement of images
3. Ease of image storage and retrieval
4. Zoom features
5. Image animation
6. Automatic start and stop features
7. Image enhancement
8. Automatic image storage
9. Automatic TIROS IR temperature calibration

The various methods of image display discussed in this section produce images that are good and can be used to study a variety of parameters of the Earth and its atmosphere. They do, however, all produce hard copy of photographs that allow little in the way of image manipulation to bring out specific features or to produce color enhancements. Because of the ways that digital images can be processed, computer display systems can add a new dimension to the use of satellite imagery in the classroom. The flexibility in image analysis can introduce students to the latest technology in this field and offer a number of student projects and learning experiences with real scientific value. Some examples of studies that are possible using these enhancement features are:

1. Studies of cloud top temperatures from IR images
2. Identification of snow fields and frost areas
3. Sea and lake surface temperature studies
4. Cloud areas most likely to produce precipitation
5. Determination of relative ground temperatures from IR images
6. Identification of fog areas
7. Determination of cloud cover percentages over specific areas
8. Development of animated image sequences to view storm and/or cloud movements

X. ADVANCED APPLICATIONS

APT and WEFAX images provide data for a wide range of studies of the Earth and its atmosphere. Since the imaging instruments on the TIROS and GOES satellites can sample various sections of the electromagnetic spectrum, visible and infrared products are available to ground stations discussed in this publication. The visible images are routinely used to obtain information on cloud cover, location and movement of storms, ice and snow cover, hydrologic data and land features. Infrared images, produced by sampling thermal radiations, provide information used to estimate precipitation, determine storm strength, measure soil moisture, provide for frost warnings, and measure sea and lake surface temperatures.

The application presented in this section is an example of how data from infrared images can more fully be used for student research and classroom teaching. The temperature calibration techniques for APT images provide basic information needed to obtain accurate temperature measurements using the infrared images transmitted by the TIROS satellites. The use of these techniques can expand the scope of studies possible with APT data.

DIGITAL TEMPERATURE CALIBRATION TECHNIQUES FOR TIROS APT INFRARED IMAGES

The analog Automatic Picture Transmission (APT) produced by the NOAA polar orbiting satellites is processed AVHRR data containing two images and corresponding calibration and telemetry data. The two images are selected by ground command for the APT from five possible spectral ranges available from the Advanced Very High Resolution Radiometer (AVHRR) imaging instrument. These are:

a. Channel 1 : .58 - .68 uM (Visible)
b. Channel 2 : .725 - 1.1 uM (Near Infrared)
c. Channel 3 : 3.55 - 3.93 uM (Thermal Infrared)
d. Channel 4 : 10.3 - 11.3 uM (Thermal Infrared)
e. Channel 5 : 11.5 - 12.5 uM (Thermal Infrared)

The APT format is shown in Figure X-1 . Each video line is 0.5 seconds in length, containing two equal segments. Each 0.25 second segment contains:

1. A specific sync pulse
2. Space data with 1 minute timing inserts
3. Earth scan imagery from a selected AVHRR spectral channel
4. A telemetry frame segment

During daylight passes the APT usually contains video from the AVHRR visible channel 1 and infrared channel 4. The space data and telemetry frames, located vertically along either side of the

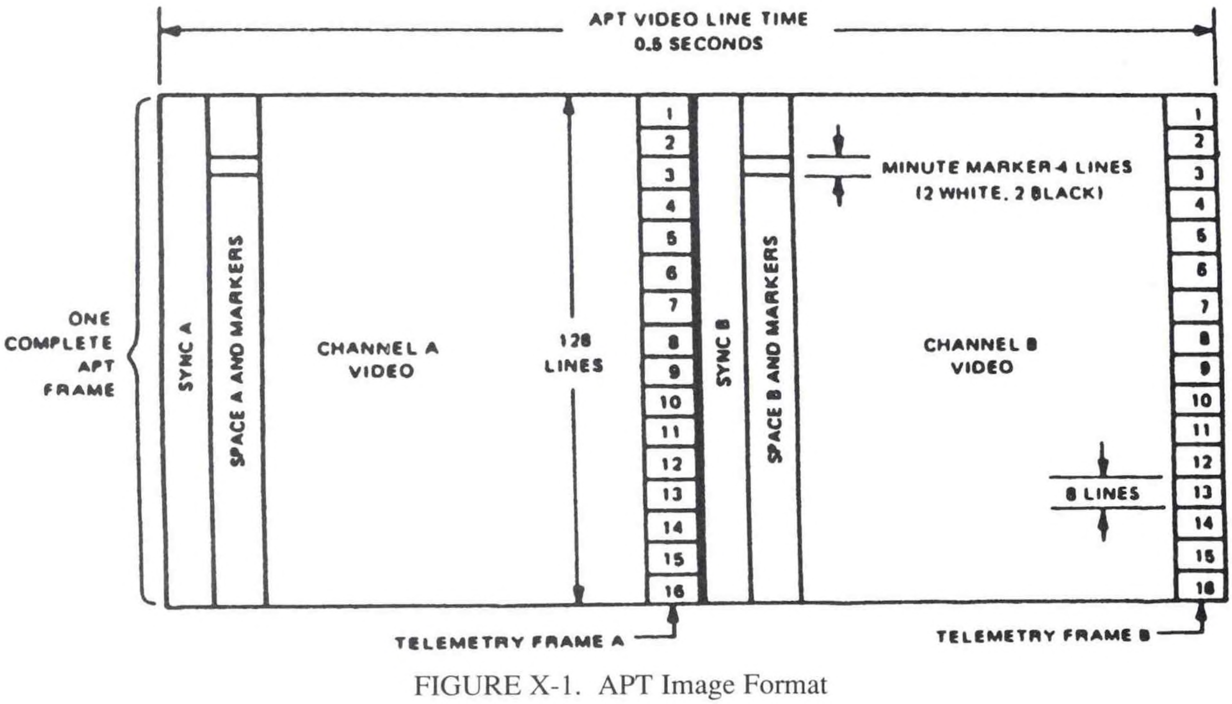


FIGURE X-1. APT Image Format

image, both contain information that pertains to that particular AVHRR channel.

The telemetry information is often overlooked by APT users. This is unfortunate because this contains data that can be used to obtain accurate temperature measurements from the thermal infrared images. The use of this data can greatly expand the applications possible for low cost APT stations. Temperature measurements from noise free signals can be made with an accuracy of +/– 2 degrees C using microcomputer techniques now available at many low cost ground stations.

In order to better understand the techniques of APT temperature calibration it is helpful to review the origin of the APT signal produced by the Advanced Very High Resolution Radiometer instruments on the NOAA polar orbiting satellites.

ADVANCED VERY HIGH RESOLUTION RADIOMETER

The AVHRR is the principal Earth imaging instrument operating on the TIROS-N satellites. It is designed to scan with a mirror, rotating at 360 rpm, perpendicular to the direction of the satellite flight. With each rotation of the mirror, data from deep space, an Earth scan, and a warmed black body radiator, which is a part of the instrument housing, are obtained. The radiant energy collected by the mirror is passed through a telescope and then through five separate optical sub-assemblies to each of five spectral "windows". Each of these detectors has been designed with sensitivity to radiant energy within specific spectral regions of the visible, near-infrared, and infrared spectrum. The three thermal infrared detectors are mounted on a passively cooled mounting called the "patch". This mounting is maintained at a temperature of about 105 degrees Kelvin to assure the proper operation of these infrared detectors.

The analog information from each of the detectors is converted to 10 bit digital samples via an analog to digital converter controlled by a high data rate processor called the Manipulated Information Rate Processor (MIRP). This digital data is then processed by the MIRP to produce separate data streams that are transmitted by the satellite to ground stations. These data transmissions are:

1. High Resolution Picture Transmission (HRPT) - Real time 1.1 kilometer resolution digital images containing all five spectral channels and telemetry data transmitted as high speed digital transmissions

2. Global Area Coverage (GAC) - Tape recorded digital images that are produced over various regions of the Earth and then are transmitted, on command, to ground stations during the satellite pass

3. Automatic Picture Transmission (APT) - Continuous real time analog transmissions of processed AVHRR data on radio frequencies of 137.5 or 137.62 MHz

APT FROM AVHRR DATA

The analog APT system was designed to produce real time video that can be received and the images reproduced by low cost satellite ground stations. This data stream is produced by the MIRP by amplitude modulating a 2400 Hz subcarrier with the 8 most significant bits of the 10 bit digital AVHRR data. This results in an analog signal with the amplitude varying as a function of the original AVHRR digital image and data. Two of the five possible AVHRR spectral channels are multiplexed so that channel A APT data is obtained from one spectral channel of the first AVHRR scan line and channel B from another spectral channel contained in the second AVHRR scan line. The third AVHRR scan line is omitted from the APT before the process is repeated. The two spectral channels are determined by ground command. This processing results in the APT containing 1/3 of the data from the AVHRR 360 scan lines/minute. The resolution of the APT is, therefore, proportionally reduced and is received at the ground station at a rate of 120 lines per minute of video. During the APT formatting, the MIRP also inserts appropriate calibration and telemetry data for each of the selected images being transmitted. This results in an APT video format as shown in Figure X-1.

APT ANALOG TO DIGITAL TECHNIQUES

NOAA technical manuals NESS 107: Data Extraction and Calibration of TIROS-N/NOAA Radiometers (Lauritson, et al.,1979) and APT Information note 78-5 (Nelson, 1978) describe APT calibration techniques. The NOAA Polar Orbiter Users Guide (Kidwell, 1986) also contains supporting information on AVHRR/APT data produced by the NOAA-6 through NOAA-10 polar orbiting satellites. These publications, however, do not give specific methods for the determination of the values within the calibration telemetry wedges. These values must be determined before temperature calibrations are attempted. In the original APT telemetry wedge values are determined by the amplitude of the analog signal and can be measured as voltage levels. This information constitutes a very short duration (10.817 milliseconds per image) of the 0.5 scan line which makes them difficult to detect and measure without specialized electronic instrumentation often not available to APT users. However, the development of PC based display systems using analog to digital conversion of the APT signal has made it possible to read these telemetry wedges as digital values from the image files. It has been shown that digitized APT offers good-quality quantitative measurements when statistically compared to AVHRR transmission products. (Wannamaker, 1984)

Most PC based image display systems currently use the same basic techniques. That is: they demodulate the signal to remove the 2400 HZ subcarrier, digitize the demodulated signal with an analog to digital converter which reads the voltage changes in a digital format, assigns a user determined color of gray level to the digital values, and display these as pixel elements of the original APT image on a monitor screen. (See Figure IX-5) The analog to digital conversion done in this process creates an accurate voltage measurement of the APT signal transmitted by the satellite. Basically, this process reverses the original processing done by the MIRP on the spacecraft and reproduces the original 8-bit values used to establish the amplitude modulation of the 2400 Hz carrier. Theoretically, if all systems were error free, the ground station will have recovered the exact digital values of the AVHRR. In practice, the transmission and reception process may add some non-linearity to the signal. This can be corrected by analysis of the values in the telemetry frame.

Although the hardware and software vary considerably from system to system, most software systems allow these digital images to be stored on diskette as a digital file. In a 8-bit digital system these will be values of 0-255 in an array which is used to create the image on the monitor screen.

If this array contains the IR image from the AVHRR thermal channels 3, 4, or 5 and the corresponding telemetry frames, the user can, with simple software, easily print out portions of the file containing the telemetry information and find the values of the wedges that are needed for the temperature calibrations. The same software can be used to print the digital values found in portions of the IR image. These, then, can be related directly to the original known values of the data transmitted by the NOAA spacecraft. This will provide the necessary information to complete temperature calibrations for the APT telemetry and to determine temperatures from the digital image.

THE APT TELEMETRY FRAME

The key to temperature calibration of APT infrared channels is in the understanding of the data contained within the space and telemetry frames and the ability to measure these values. Table X-1 shows the telemetry frame format used in the current NOAA polar orbiting satellites. One complete frame contains 16 individual wedges each of which is composed of eight successive video lines. (One frame = 16 wedges x 8 lines = 128 lines/frame) These frames are continuously repeated during the satellite orbit so that a number of complete frames are available at the ground station during one satellite pass. Only one frame is needed for the calibration process. It should be noted that within a telemetry frame the first 15 wedges are identical in both images of the APT format. Only wedges 15 and 16 will be different in channel A and B.

WEDGES 1-8:

	APT ANALOG VOLTAGE	DIGITAL VALUE
1	0.757 V MI = 10.6%	31
2	1.538 V MI = 21.5%	63
3	2.319 V MI = 32.4%	95
4	3.101 V MI = 43.4%	127
5	3.881 V MI = 54.2%	159
6	4.663 V MI = 65.2%	191
7	5.444 V MI = 76.0%	223
8	6.225 V MI = 87.0%	255
9	ZERO MODULATION	0
10	THERM TEMP PRT #1	
11	THERM TEMP PRT #2	
12	THERM TEMP PRT #3	
13	THERM TEMP PRT #4	
14	PATCH TEMP	
15	BACK SCAN	
16	CHANNEL IDENT	

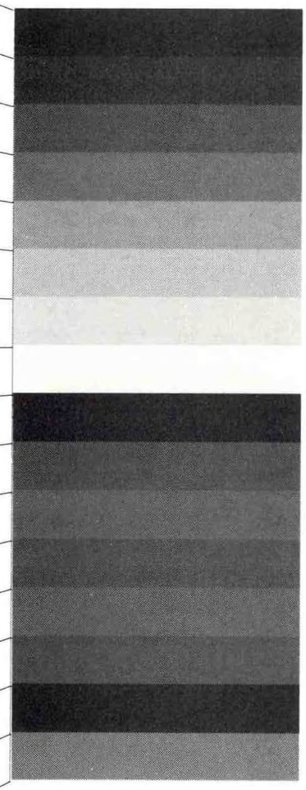


TABLE: X-1. Telemetry Frame Format Used in TIROS-N Series Satellite APT

The first eight wedges within one telemetry frame are produced by modulating the 2400 Hz APT subcarrier with 8 linear, 8-bit outputs, from the MIRP on the satellite. The digital values used to modulate each wedge are given in Table X-1 as " Digital Value". The resulting analog signal received at the ground station , is referred to as a "Modulation Index", and, in the analog domain, will exist as a voltage level for each wedge. A ground station using a black and white display system will see these eight wedges as a gray scale grading from dark gray to near white. MI=10.6% to 87.0%) The graph in Figure X-2 shows the relationship between the gray levels and the original 8-bit AVHRR output of the MIRP. This linear scale forms the standard APT signal output to which all telemetry data in the remaining wedges can be compared.

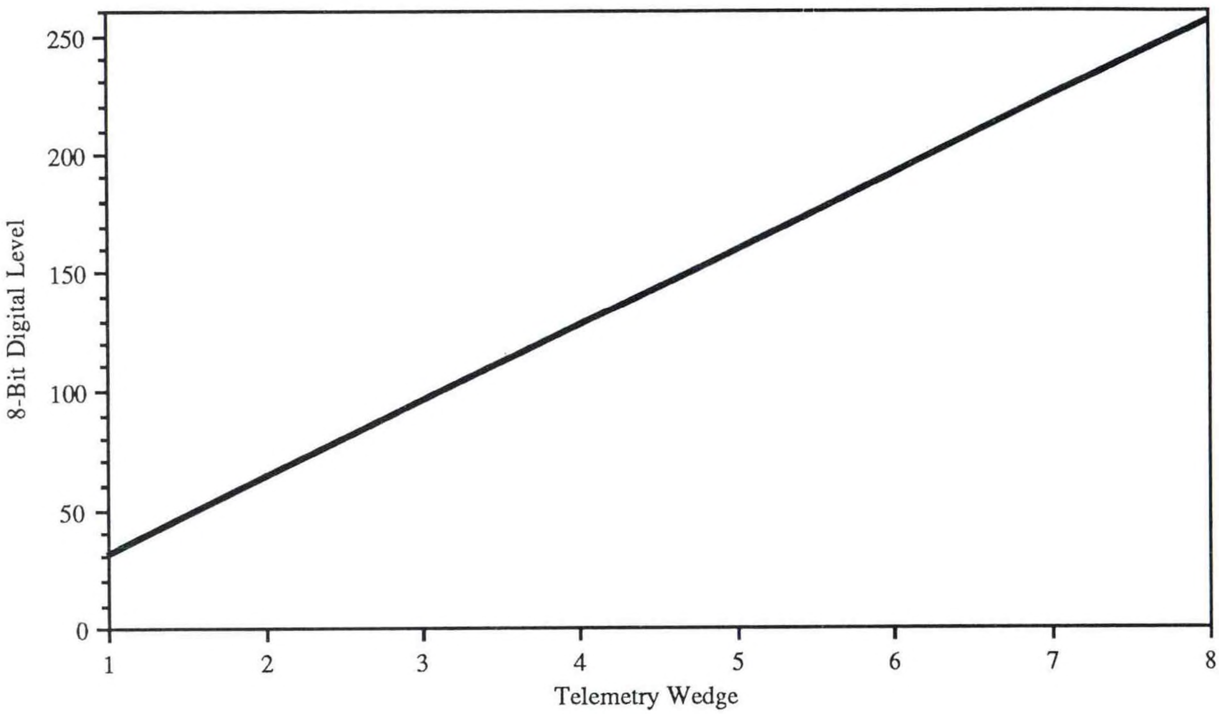


FIGURE X-2. Analog/Digital Telemetry Wedge Relationship

WEDGE 9: Zero Modulation

The zero modulation wedge contains no signal modulation and represents a base signal level reference. In a black and white display system this wedge will appear black and will have a voltage level of 0 and a 8-bit AVHRR equivalent value of 0.

WEDGE 10-13 (Thermal Temperatures 1-4)

During the operation of the AVHRR imaging, the scanner periodically "views" a warmed black body radiator held at approximately 20°C to detect the thermal radiance of that temperature. This "back scan" produces a telemetry response shown in wedge 15. The telemetry in wedges 10-13 provide the data necessary to determine the actual in-flight temperature of this black body radiator. Four Platinium Resistance Thermometers (PRT's) are mounted on this radiator. The output of each thermometer is monitored as a digital value which then is used to modulate this portion of the APT signal. Temperatures across this heated segment may vary slightly due to differences in temperatures on the satellite. The best estimate of the black body temperature will be obtained from an average of the values contained in wedges 10-13.

The equation to convert voltage of the PRT levels to degrees Kelvin is:

Kelvin Degrees = .206(8-bit value) + 276.943

The graph in Figure X-3 shows the digital to temperature relationship.

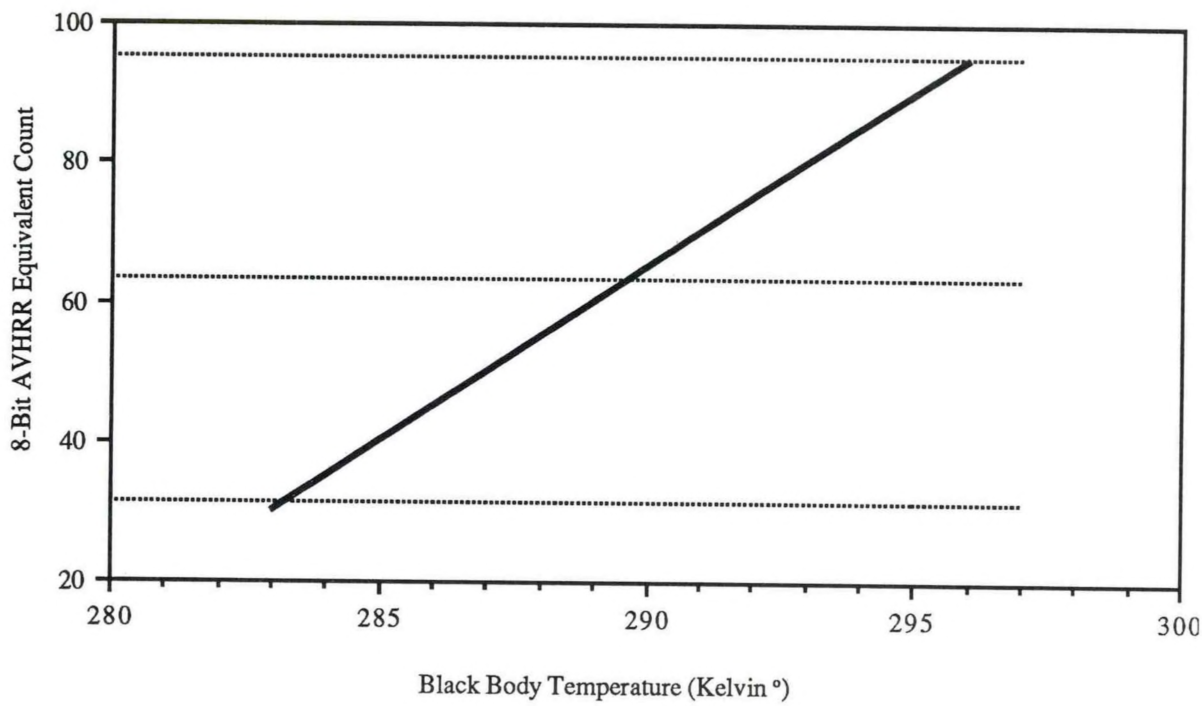


FIGURE X-3. Digital Black Body Temperature Relationship

WEDGE 14: PATCH TEMPERATURE

The patch temperature is a measurement of the temperature of a portion of the AVHRR thermal infrared window mounting that is passively cooled to a temperature of approximately 105° Kelvin.

This temperature is monitored but does not play a direct role in the calibration process discussed here. The equation for converting this value to Kelvin temperature is:

K= .124(8-bit AVHRR) + 90.113

WEDGE 15: Back Scan

The back scan is the telemetry value produced when the AVHRR instrument detects the radiance from the black body radiator. This value will vary with each thermal IR channel (AVHRR channels 3,4,5) and with slight variations in the temperature of the black body. The response of the AVHRR "look" at the black body is first measured as a digital value which is then used to modulate this portion of the APT signal. Since the value of this data is a measure of the radiance of the black body temperature, which is known from wedges 10-13, this data can be used for in-flight calibration of the spectral channel used to produce the APT IR image. This is done by plotting the measured thermal temperature value against the AVHRR 8-bit value of the back scan to form one point of a temperature calibration curve. A second point can be obtained from the space data described later.

WEDGE 16: Channel Identification

The channel identification wedge contains information to identify which of the 5 AVHRR channels is being used to produce the APT image. This is done by modulating this portion of the APT signal with a value equal to one of the first 5 gray wedges in the telemetry frame. Therefore, if wedge 16 contains a value equal to wedge 4, AVHRR channel 4 is producing the image seen in the APT video of that channel.

SPACE DATA

Immediately following the sync pulse for each image (See Figure X-1), the APT video line contains space data. This is a continuous bar that is overwritten with two lines which mark 60 second intervals during the flight of the satellite. The signal level of this data is equal to a value detected by the AVHRR as it views deep space within the spectral range of the IR channel that is presently operational. For temperature calibration purposes this value is considered to have zero radiance for each of the thermal AVHRR channels. This value can then be used to establish a second point for the temperature calibration curve.

DIGITAL APT IR TEMPERATURE TECHNIQUES

Table X-2 shows a print out of the digital values taken from one 16 wedge telemetry frame of channel 4 IR APT data received from a NOAA-10 pass during September 1988 using the ground station located at the Chambersburg Area Senior High School. NOTE: The IR channel identification can be done by observing the digital value of wedge 16 and comparing it with the first 8 telemetry wedges. In this example, wedge 16 matches wedge 4 indicating channel 4 IR is being transmitted via the APT. A small segment of space data is also included. In this example, the analog APT was digitized using an IBM interfacing system developed by GTI Electronics and Softworks, Inc. of Allentown, Pennsylvania. The image was received, digitized and stored as a digital text file using the GTI system. One noise free telemetry frame and segment of space data was then selected from this image file and printed.

WEDGE #1	31	31	30	30	31	30	30	30
	31	30	30	31	31	29	29	30
	31	32	31	31	32	33	30	29
	30	30	31	31	29	30	31	29
	30	30	31	31	30	30	31	31
	30	30	29	30	31	30	29	30
	32	32	31	30	31	30	29	29
	31	31	30	30	30	30	31	31
WEDGE #2	59	59	59	58	58	57	57	58
	58	58	59	58	58	58	58	59
	59	59	58	58	58	56	58	59
	58	58	58	59	57	57	57	58
	59	59	59	59	57	57	57	57
	59	58	57	57	60	60	58	57
	57	57	58	58	58	57	59	58
	57	57	59	58	56	57	58	59
WEDGE #3	84	84	85	84	83	83	86	87
	86	86	87	86	85	85	86	86
	84	84	84	83	82	84	86	85
	85	84	84	85	83	84	86	85
	86	85	86	86	85	85	86	86
	84	84	84	83	83	84	85	86
	83	83	83	85	84	84	86	86
	85	85	86	86	84	84	86	86
WEDGE #4	112	112	110	109	110	110	110	110
	113	113	111	111	113	113	111	111
	112	111	109	110	111	112	111	110
	113	112	110	109	111	111	110	110
	114	114	111	111	113	112	110	110
	112	112	110	111	114	113	111	111
	113	113	111	112	114	113	111	111
	111	111	110	110	112	111	110	111
WEDGE #5	136	137	137	138	137	137	137	136
	138	138	136	136	137	138	135	135
	138	137	137	138	139	139	136	137
	137	136	138	138	137	138	139	139
	135	135	136	137	137	136	137	138
	137	137	139	139	137	136	137	138
	135	135	137	138	136	136	138	138
	134	135	138	138	136	137	139	138
WEDGE #6	161	162	165	165	162	161	164	165
	161	162	165	165	162	162	164	164
	165	164	162	162	164	163	161	162
	161	162	165	164	162	162	164	163
	162	162	165	164	161	161	164	164
	162	163	165	165	163	163	164	164
	163	163	164	163	162	163	162	163
	163	163	164	164	162	163	163	163
WEDGE #7	188	189	189	188	187	188	189	188
	190	191	190	188	188	189	188	187
	188	190	190	189	189	190	189	188
	187	186	189	190	187	188	191	192
	188	188	191	191	187	187	190	191
	190	192	188	187	190	190	187	188
	191	191	188	188	190	190	187	187
	191	192	188	188	190	191	188	188
WEDGE #8	217	217	214	213	216	216	212	212
	217	218	213	212	215	215	213	214
	217	216	212	213	216	216	212	212
	217	216	211	212	215	215	212	213
	216	217	213	213	216	215	212	213
	213	213	215	214	213	215	218	216
	214	214	215	214	213	215	216	215
	215	215	213	214	216	215	213	214

WEDGE #9	3	3	3	4	4	5	4	4
	5	6	5	5	4	5	4	3
	4	5	5	5	5	4	3	3
	3	3	3	4	4	4	5	5
	5	5	4	5	5	5	4	4
	3	3	3	4	4	4	4	4
	3	3	3	4	3	3	4	4
	6	5	5	5	4	4	4	4
WEDGE #10	95	96	94	94	97	96	95	95
	95	95	97	96	94	93	96	96
	95	95	95	95	94	94	96	96
	94	95	97	96	95	95	96	96
	93	94	96	96	95	95	96	96
	95	94	94	95	93	95	96	95
	96	96	95	94	94	95	95	95
	94	94	95	95	96	96	96	96
WEDGE #11	95	94	93	94	95	96	95	94
	93	94	96	97	95	95	96	96
	94	95	94	94	96	97	95	94
	95	95	95	94	95	94	94	94
	95	95	93	94	96	96	94	94
	94	95	95	95	96	95	94	94
	95	95	94	95	97	96	94	94
	95	96	93	93	95	95	93	94
WEDGE #12	96	95	93	94	95	95	94	94
	95	94	93	94	97	96	94	93
	93	94	97	96	94	94	94	95
	94	94	95	95	94	94	94	94
	94	95	94	94	94	94	94	95
	95	94	93	94	95	95	94	95
	93	94	95	95	95	94	95	95
	93	93	95	95	94	94	94	95
WEDGE #13	93	94	95	95	94	93	94	95
	94	93	94	95	94	94	95	95
	93	93	94	95	95	95	95	94
	93	93	94	94	94	94	95	95
	95	95	92	93	96	95	93	93
	96	95	93	92	95	95	93	94
	93	93	96	96	93	93	95	95
	93	94	97	95	93	94	95	95
WEDGE #14	89	88	90	90	89	89	90	89
	88	89	91	90	88	89	90	89
	88	88	89	90	89	90	90	90
	89	89	90	90	89	90	90	90
	89	89	90	89	88	88	90	90
	89	90	90	89	89	90	89	89
	90	89	88	90	91	90	90	89
	89	89	90	90	90	90	90	89
WEDGE #15	61	61	61	60	61	61	60	61
	61	61	60	61	61	62	61	61
	61	62	62	61	62	61	61	61
	62	61	60	60	62	62	60	60
	61	62	61	61	61	61	60	60
	62	62	61	60	62	62	61	60
	63	62	61	61	61	61	61	60
	61	62	62	62	61	62	62	62
WEDGE #16	110	111	113	112	110	111	114	113
	112	112	111	112	112	112	111	111
	113	113	110	111	114	113	111	111
	113	113	111	110	113	113	111	111
	112	113	112	112	112	112	111	111
	113	112	111	111	113	112	111	111
	112	111	112	112	112	111	111	112
	113	111	111	112	113	112	111	111

SPACE DATA	211	211	206	206	211	210	208	209	211	211	206	206
	211	212	207	207	211	211	208	208	211	211	206	206
	211	211	206	207	211	210	208	208	210	211	207	207
	211	209	205	207	212	212	208	209	212	211	206	206

TABLE X-2. Digital Value Printout From One 16 Wedge APT Telemetry Frame

Since a variety of factors cause variation of the digital values within the data, an average was taken as the best estimate for each wedge and the space data. These averages, with their standard deviations to show the amount of variation within the data, are shown in Table X-3.

WEDGE NUMBER	MEAN DIGITAL VALUE	STANDARD DEVIATION
1	30.39	0.865
2	57.98	0.899
3	84.77	1.178
4	111.31	1.310
5	137.03	1.221
6	163.08	1.276
7	188.95	1.516
8	214.42	1.753
9	4.09	0.830
10	95.14	0.960
11	94.71	0.990
12	94.30	0.890
13	94.17	1.090
14	89.37	0.760
15	61.17	0.720
16	111.78	0.970
SPACE	209.80	2.189

TABLE X-3. Statistical Analysis of APT Digital Telemetry Frame

To calibrate the digital values received at the ground station to real temperatures a relationship must first be established between these station counts (SC) and the original AVHRR 8-bit linear values used by the spacecraft electronics to establish the analog APT signal. This can be done using standard statistical techniques of correlation and regression analysis. Determining the correlation between the APT station counts and the original AVHRR digital values will show how well the station counts will reflect the AVHRR counts and regression analysis will provide the necessary equation that can give the best estimate of the AVHRR data based on the station counts. Both of these analyses are not difficult but they do require rather laborious calculations. A number of pocket calculators perform these mathematical processes and a variety of statistical software packages for microcomputers are available to do both correlation and regression analysis. Additional information concerning these techniques can be found in any basic statistics book.

CALIBRATION STEPS

STEP 1

To determine if there is a statistically significant correlation between the station count data shown in Table X-3 and the standard AVHRR 8-bit digital values the following equation for correlation can be used:

$$r = \frac{n \cdot \Sigma XY - \Sigma X \; \Sigma Y}{\sqrt{[n \cdot \Sigma X^2 - (\Sigma X)^2] \; [n \cdot \Sigma Y \; - (\Sigma Y)^2]}}$$

Where X = AVHRR values
and Y = Station count averages in Table X-3

X	Y
31	30.39
63	57.98
95	84.77
127	111.31
159	137.03
191	163.08
223	188.95
255	214.42

$$r = \frac{[\,8\,(176532.4)\,] - [\,(1144)\,(987.93)\,]}{\sqrt{[\,8\,(206600-1309723.93)][8\,(150911.4-976005.68)]}}$$

r = .99

When using 8 pairs of data, r values between .66 and 1.0 are considered to be significantly correlated within a 95% confidence level. The correlation value (r=.99) in this example indicates that the station counts and the AVHRR data are significantly correlated and will be good predictors of the original AVHRR values established on the spacecraft.

STEP 2

If the relationship between the station counts and the AVHRR values show significant linear correlation, an equation to estimate the AVHRR counts from the station counts can be calculated by regression analysis using the following equation:

$$Y = BX + A$$

Where Y = Station Counts
X = AVHRR Counts

$$\text{and } B = \frac{n \cdot \Sigma XY - \Sigma X \cdot \Sigma Y}{n \cdot \Sigma X^2 - (\Sigma X)^2}$$

$$A = \frac{\Sigma Y - B \cdot \Sigma X}{n}$$

In this example:

$$B= \frac{[8\ (176533.35)] - [\ (1144)\ (987.93)\ ]}{[8\ (206600)] - (1308736)\ ]}$$

B= .8198

and

$$A= \frac{987.93 - [\ (.8198)\ (1144)\ ]}{8}$$

A= 6.25

Therefore, from Y=BX + A, the best estimate of AVHRR data from the station counts is:

Y=.8198 X + 6.25

or $$\frac{X=Y-6.25}{.8198}$$

or $$\frac{\text{AVHRR} = \text{Station Counts}-6.25}{.8198}$$

STEP 3

To establish a digital to temperature conversion scale on the graph in Figure X-4, three telemetry values must be established from the data contained in the telemetry frames and space data:

1. The data reported in telemetry wedges 10,11,12, and 13 that monitor the temperature of the black body radiator

2. The AVHRR digital equivalent of the back scan data in wedge 15

3. The AVHRR digital equivalent value contained in the space data

BLACK BODY TEMPERATURE:

The actual temperature of the black body can be determined by averaging the station counts in wedges 10 through 13 to get the best estimate of this data. This average station count value can then be converted to the AVHRR equivalent using the regression equation in step 2. This AVHRR count can then be converted to degrees Kelvin using the equation:

Black Body Temperature= .206(AVHRR count) + 276.943

In this example:

Average station counts (wedges 10-13)= 94.58

AVHRR equivalent value= 107.74

Temperature= .206(107.74) + 276.943

Temperature (K) = 299.14

BACK SCAN DATA:

The back scan data contained in wedge 15 must also be converted to an AVHRR equivalent value using the regression equation from step 2. In this example:

Back scan station count average= 61.17

AVHRR equivalent= 66.99

The average temperature of the Black Body radiator as reported by the four Platium Resistance Thermometers (299.14° K) and the digital response of the Advanced High Resolution Radiometer when it views the Black Body (66.99) form one point of the temperature calibration curve on the graph in Figure X-4. This is done by plotting the digital value of the back scan (X axis) against the temperature of the black body (299.14° K) on the Y axis.

SPACE DATA:

A second point is plotted using the space data. In this example the average station count of the space data was 209.8 as seen in Table X-2. Using the regression equation from step 2, the AVHRR equivalent value is calculated to be 248.41. The bottom line on this graph represents a nominal radiance of zero, corresponding to a theoretical temperature of 0 degrees Kelvin. When these two values, 248.41 plotted on the X axis and 0° K on the Y axis, they form a second point of the calibration curve in Figure X-4. A line drawn through these two points represents a calibrated linear correlation between the instrument observed radiance and the digital station counts. At this point, the digital values of the IR image can be converted to temperatures using the regression equation that was determined in step 2 and the calibration graph Figure X-4.

NOTE: This process requires that the original signal level, during the analog to digital conversion, not exceed the 255 digital level. This will drive the near white (cold temperatures) digital values to saturation and would result in a loss of this data and an inaccurate calibration of all of the image data. This can be controlled by establishing the proper volume of the radio receiver when the satellite signal is acquired and digitized.

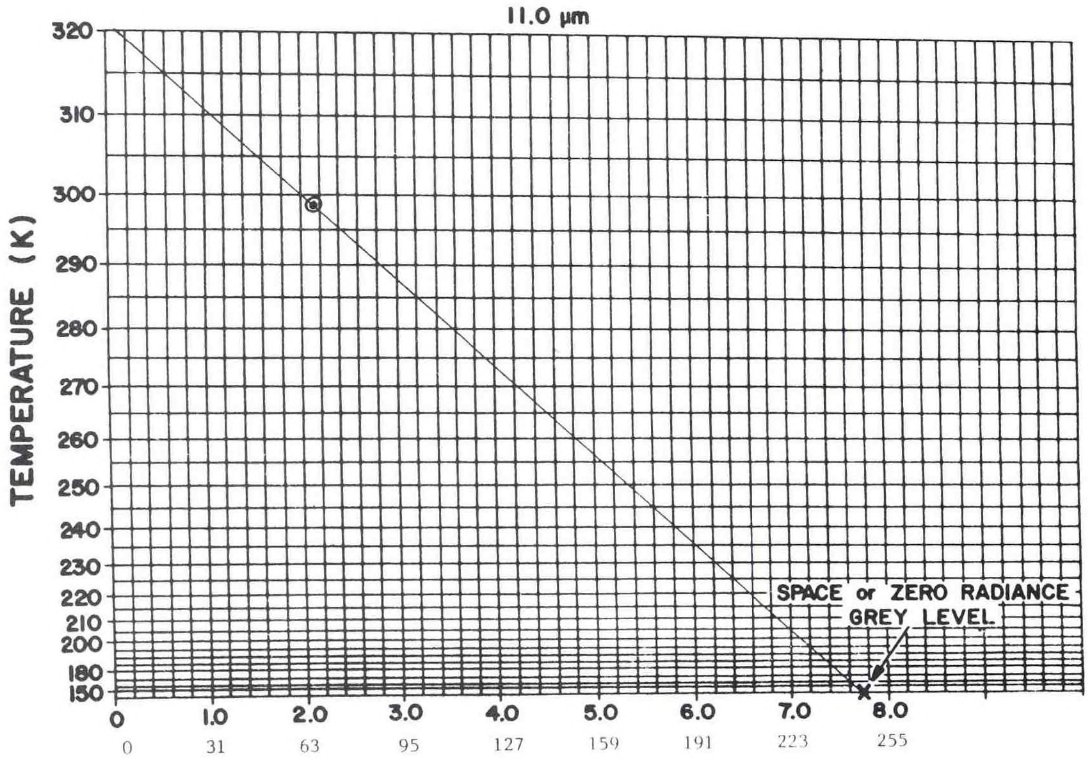


FIGURE: X-4. Calibrated Digital to Temperature Relationship of APT Channel 4 Infrared Image

XI GLOSSARY

amplitude modulation AM— the strength (amplitude) of a signal is varied (modulated) to correspond to the information to be transmitted. As applied to APT, an audible tone of 2400 Hz is amplitude modulated, with maximum signal corresponding to light areas of the photograph, the minimum levels black, and intermediate strengths the various shades of gray.

analog a system of transmitting and receiving information in which one value (i.e. voltage, current, resistance, or, in the APT system, the volume level of the video tone) can be directly compared to the information (in the APT system, the white, black, and gray values in the photograph.

APT Automatic Picture Transmission—one function of weather satellites which transmits earth scan photographs to direct readout stations in real time in an analog video format. Transmission consists of an amplitude modulated audible tone which can be converted to photographs when fed to an appropriate line-printing device.

ascending node the portion of a polar orbiting satellite's orbit which passes over the earth from south to north

azimuth compass direction

AVHRR (Advanced Very High Resolution Radiometer)— A five channel scanning radiometer on the TIROS series satellites sensitive in the visible, near infrared and infrared spectral regions. TIROS Automatic Picture Transmissions are derived from this instrument.

bandwidth in FM, radio frequency signal bandwidth is the amount of deviation of the signal.

carrier in radio, an rf frequency capable of being modulated with some type of information.

circularly polarized rf radio frequency transmissions where the wave energy is divided equally between a vertically polarized and a horizontally polarized component.

db decibel—the unit of measuring the intensity of a sound expressed as a ratio to a reference level. The decibel is also used to measure relative strengths of antenna and amplified signals and always refers to a ratio or difference between two values.

descending node the portion of a polar orbiting satellite's orbit which passes over the earth from north to south digital — a system of transmitting and receiving information in which the source is periodically sampled, analyzed, and converted or coded into numerical values. These numerical values are then transmitted and must be decoded at the receiver's end. Digital transmissions typically use the binary coding used by electronic computers and require rather expensive hardware to decode. Many satellite transmissions use digital formats because noise will not interfere with the quality of the end product and therefore, clear and higher resolution photography is possible.

Doppler shift — Doppler effect—the shift in frequency of a radiated signal due to relative motion between the transmitting source and receiving position.

elevation — angle above the horizon

facsimile (FAX) — a process where graphic or photographic information is transmitted or recorded by electronic means.

frequency modulation — FM—the frequency of a transmission signal is varied (modulated) from a given center frequency to correspond to the information to be transmitted. As applied to APT, the radio signal from the satellite is broadcast on an FM band of the radio spectrum, requiring an FM radio receiver for proper reception.

Hertz—MHz—KHz — Hertz is the unit of measuring the frequency of any radiated signal. One Hertz equals one cycle per second. Radio frequencies are expressed in the decimal multiples of Megahertz (1,000,000 cycles) and Kilohertz (1,000 cycles).

IC — integrated circuit—a solid state electronic circuit which consists of several micro components constructed to perform a special function

ips — inches per second—unit of measuring tape transport speeds in tape recorders. From slowest to fastest, the usual tape speeds available are 1-7/8, 3-3/4, 7-1/2, and 15 ips.

kilometer — metric unit of distance equal to 3,280.8 feet or .621 miles.

Meteor — the Soviet Union's series of polar orbiting weather satellites. The Meteor satellites transmit photographs in a system compatible with the NOAA and TIROS satellites.

MHz — Megahertz—see Hertz.

NASA — National Aeronautics and Space Administration.

nautical mile — a unit of distance equal to 1/60 of a degree or about 6,076 feet.

NESDIS	National Environment Satellite Data and Information Service, a component of NOAA.
NOAA	National Oceanic and Atmospheric Administration.
ohm	the unit of electrical resistance.
printed circuit	a fiber card on which integrated circuits and other electronic components can be mounted. Connections between the components are etched in the correct circuit patterns.
signal to noise ratio	how much a signal stands out above the receiver noise. Usually given in microvolts per db of quieting.
Sun-synchronous	describes the orbit of a satellite which provides consistent lighting of the earth scan view. The satellite passes the equator and each latitude at the same time each day. For example, a satellite's sun-synchronous orbit would cross the equator twelve times a day, each time at 3:00 P.M. local time. The orbital plan of a sun-synchronous orbit must also precess (rotate) approximately one degree each day to keep pace with the earth's surface.
TIROS	Television Infrared Observation Satellite
yagi	a type of receiving antenna which has several rod elements mounted on a beam. Its directional pattern of sensitivity and ease of construction make it ideal for APT direct readout stations.

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