National Oceanic and Atmospheric Administration

User's Guide for Building and Operating Environmental Satellite Receiving Stations

Updated: February 2009

U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration

National Environmental Satellite, Data, and Information Service

FORWARD

This is an update of the *User's Guide for Building and Operating Environmental Satellite Receiving Stations,* which was published in document form in July of 1997. There have been several changes in the technology and availability of receiving equipment as well as changes to the NOAA operated satellites since the previous publication. This has made a new User's Guide necessary to maintain the National Oceanic and Atmospheric Administration's commitment to serve the public by providing for the widest possible dissemination of information based on its research and development activities.

The previous version of this User's Guide was a major update of NOAA Technical Report 44, *Educator's Guide for Building and Operating Environmental Satellite Receiving Stations,* originally published in 1989, and reprinted in 1992.

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.

A portion of this publication is devoted to examining inexpensive methods of directly accessing environmental satellite data. This discussion cites particular items of equipment by brand name in an attempt to identify examples of readily available items. This information should not be construed to imply that these are the only sources of such items, nor an advertisement or endorsement of such items or their manufacturers. Sources for a more complete list of suppliers are cited elsewhere in this publication.

Readers of this publication requiring additional information on the application of environmental satellite data can consult Appendix B for several useful resources.

TABLE OF CONTENTS

CHAPTER **PAGE**

LIST OF FIGURES - TABLES

FIGURES: **PAGE**

TABLES: **PAGE**

I. INTRODUCTION

Satellites provide us with a unique and long-sought after 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. Mankind can now 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, ocean currents, sea surface temperatures, air and water pollutants, drought and floods, severe weather conditions, vegetation, insect infestations, ozone content 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 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 more than 45 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) and High Resolution Picture Transmission (HRPT) of the U.S. Polar Orbiting Environmental Satellites (POES) and Low-Rate Information Transmission (LRIT) and GOES Variable (GVAR) data transmitted by the U.S. Geostationary Operational Environmental Satellites (GOES).

Thousands of direct readout stations have been purchased or built to receive the direct readout transmissions from these satellites. Government and military agencies, private industries, and a variety of private individuals including ham radio operators, students and faculty are operating ground stations. Perhaps the fastest growing use of this data is within the educational community. Many teachers with students at all levels within educational institutions have 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 a broad spectrum of potential users with the basic information needed to establish and operate a direct readout ground station and understand the imagery provided by Earth-orbiting weather satellites.

II. DIRECT READOUT TRANSMISSIONS FROM METEOROLOGICAL SATELLITES

Overview

In the early 60's satellite pictures received from the 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 land line or radio facsimile circuits, often reached these centers too late to be of any practical value in forecasting the weather. The weather satellite direct broadcasting system, or more commonly called direct readout service, was developed to overcome this problem. Remotely sensed meteorological data are transmitted directly from polar orbiting or geostationary satellites in "real time" to forecasting centers and ground stations within signal range of the satellite. The weather satellite images were designed with a format that could be received and reproduced by relatively inexpensive ground station equipment, and the data is transmitted free of charge to anyone with the appropriate receiving and display equipment.

The Direct Readout Services are an integral component of both the Polar Operational Environmental Satellites (POES) system, and the Geostationary Operational Environmental Satellites (GOES). Each of these satellite platforms can provide a high resolution and lower resolution image data product. Direct Readout Services include Automatic Picture Transmission (APT), High Resolution Picture Transmission (HRPT), and Direct Sounder Broadcasts (DSB) from the POES satellites, and Low-Rate Information Transmission (LRIT)), and GOES Variable Format (GVAR) data from the GOES satellites. Today, the majority of the world's users of weather satellite imagery acquire them through the use of these direct readout systems. Over 120 countries and approximately 8,000 known (and an estimated several thousand more unknown) ground stations rely on these daily transmissions of meteorological data.

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. Interest and activity 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 issues of the *Physics Teacher Journal* during 1968 and 1969.

Today, polar orbiting satellites launched by the United States continue to transmit images of the Earth via APT and HRPT. These have been joined by Chinese Feng Yun spacecraft, with similar transmission systems. This is fortunate because a ground station capable of receiving data from the U.S. polar orbiting satellites can also receive images from satellites of other countries as well.

APT From The TIROS Series Satellites

APT services and subsystems were initially designed to broadcast direct readout satellite imagery to low-cost ground receiving equipment. By 1990, more than 5000 stations, were receiving APT data from U.S. and Russian satellites. A basic ground station consists of a low-cost steerable directional antenna or fixed omni-directional antenna, a VHF receiver, and a display device such as a personal computer. APT data can be acquired whenever a NOAA POES satellite passes within range of a ground station (at least four times in a 24 hour period). The number of satellite overpasses depends on the latitude of the station; high latitude stations can receive far more than four passes a day.

On the POES Advanced-TIROS-N series of 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 from the surface of the Earth ranging from the visible spectrum, the near-infrared, and infrared spectra. Data from these channels are transmitted directly in a high speed digital format known as High Resolution Picture Transmission (HRPT).

The analog APT signal is derived from the original digital data and is multiplexed so that only two of the original 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 Figure II-1)

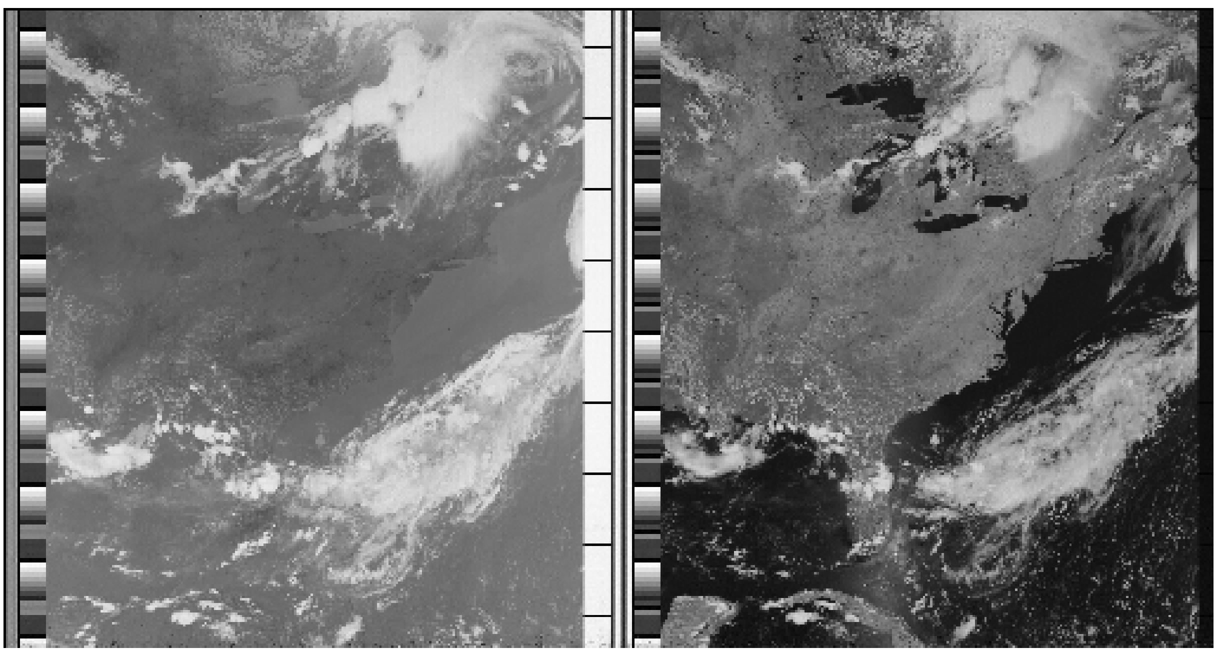


Figure II-1 APT Image Containing Infrared (left) and Visible (right) Channel Data

The APT signal is transmitted continuously from the satellites. This results in an image strip that continues as long as the transmission is received at the ground station. Radio reception of the APT signal, however, is limited to "line of sight" from the ground station and therefore it can only be received when the polar orbiting satellite is above the horizon of a user's ground station. This is determined by both the altitude of the satellite and its particular path across the ground station's reception range. The U.S. and Chinese polar orbiting satellites operate at altitudes between 810 and 1,200 km (488 and 744 miles). At these altitudes the maximum time of signal reception during an overhead pass is about 16 minutes. During this time a ground station can receive a picture strip equivalent to about 5,800 km (3,600 miles) along the satellite path.

NOAA plans to continue APT support throughout the current series of satellites and NOAA N' is yet to be launched. Based on the typical life expectancy of these satellites, APT should be available on at least one NOAA satellite until about 2015. APT will not be provided on future U.S. satellites, all data from the next generation NPOESS satellites will be digital services and will require different ground station equipment.

High Resolution Picture Transmission From The TIROS Series Satellites

The AVHRR instrument on the NOAA Advanced-TIROS polar orbiting satellites provides the High Resolution Picture Transmission (HRPT) digital imagery which is the original data from which the APT pictures are derived. Since the APT imagery is derived from the HRPT data, and both are received real time directly from the satellite, the area of coverage is essentially the same for the two data types. HRPT consists of six channels of data in the visible, near infrared and infrared spectrum, the data are digitized to 10-bit precision, transmitted at 360 lines per minute (LPM) at 665 kilobits per second (kbps). The HRPT data stream also includes non-imagery data from other instruments on board the spacecraft. Due to the higher resolution of the HRPT imagery (l .1km in the visible band), and the additional spectral channels of information, direct readout users often prefer this data stream over the analog APT, particularly where quantitative analysis is involved.

Several vendors provide HRPT systems as individual components or as an integrated ground station. Features available include automated satellite tracking, geopolitical gridding, longitude/latitude registration, temperature calibration, and scheduled ingest of data. HRPT ground stations previously cost $100,000 or more, but technological advances have brought this price range down to under $10,000, making it feasible for some amateur direct readout users to install an HRPT ground station. Figures II-2 and II-3 are examples of processed HRPT images.

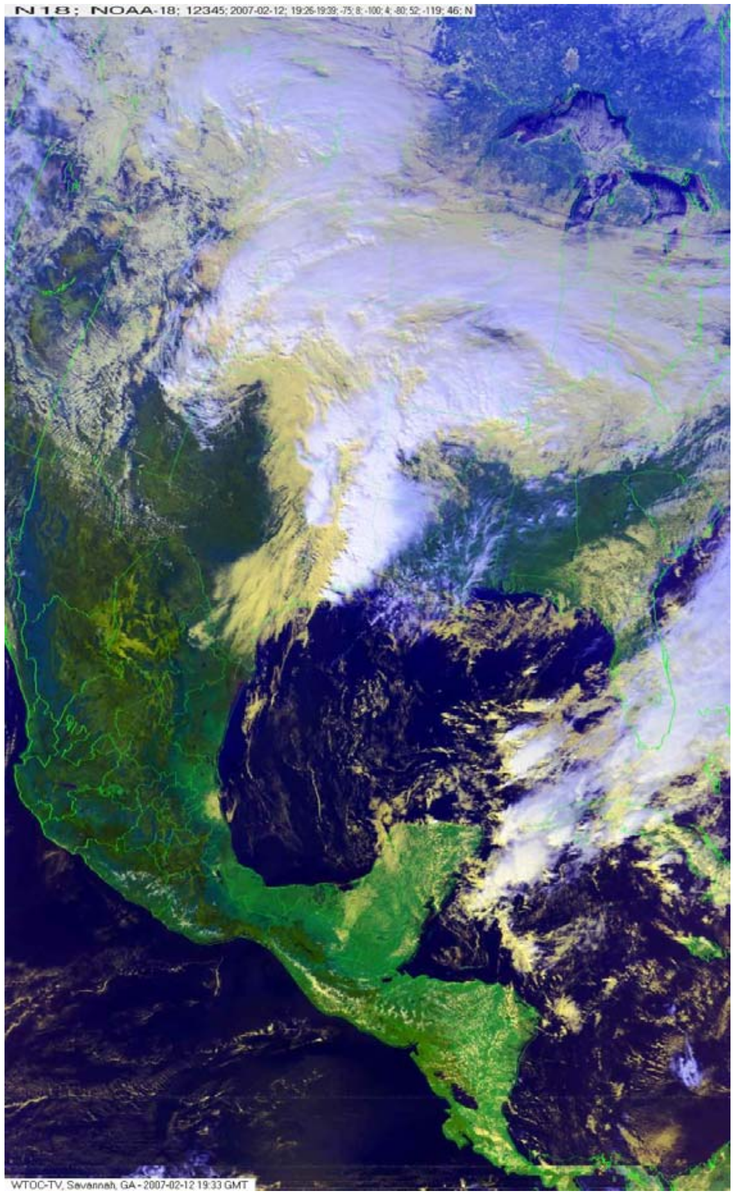


Figure II-2 Color Enhanced HRPT Visible Image of Central America, Mexico and the U.S.

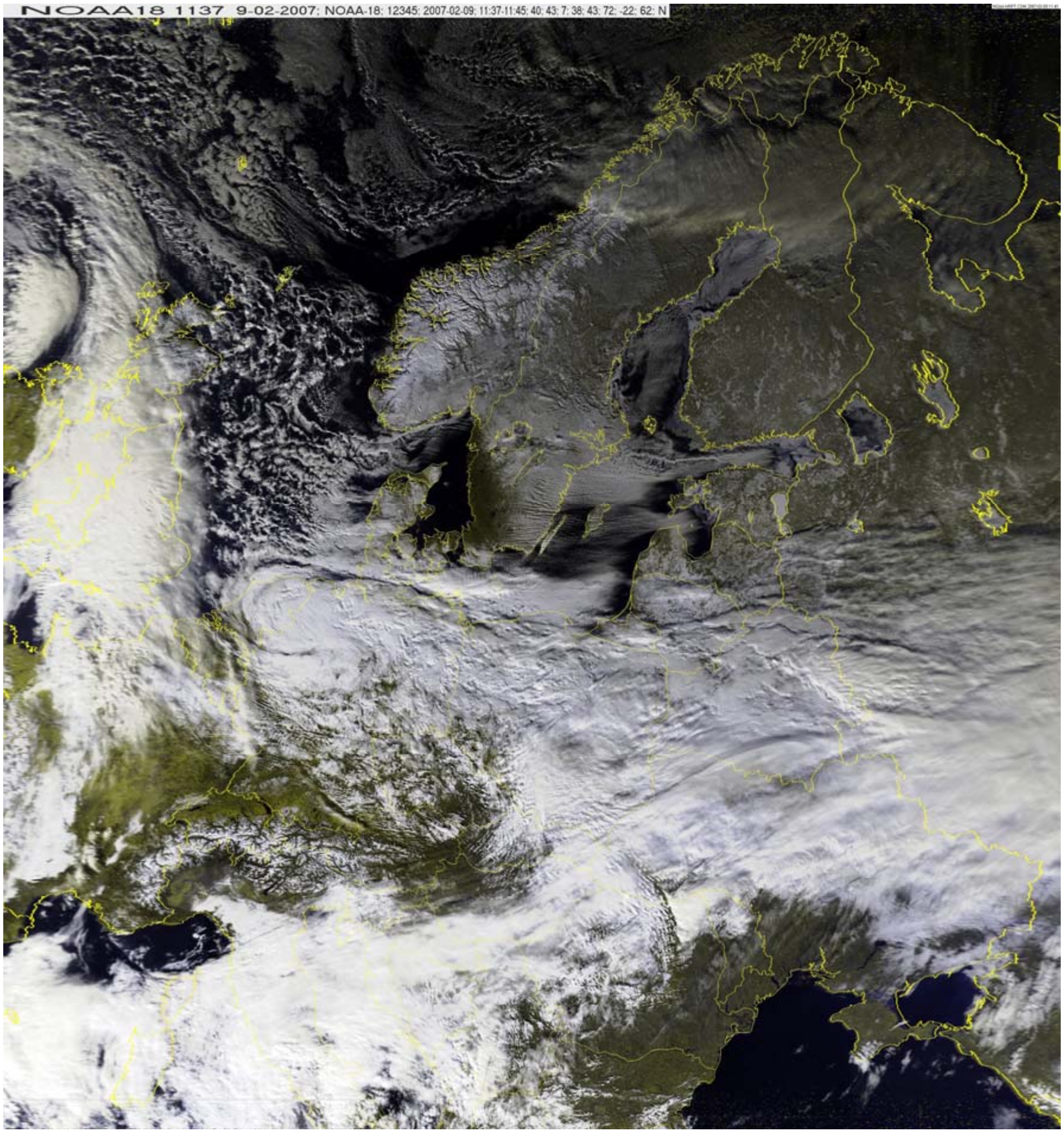


Figure II-3 NOAA 18 HRPT Visible Image of Europe with Geopolitical Gridding

High Resolution Imagery From The Geostationary Satellites

The GOES-East and GOES-West satellites provide a rich source of multispectral imager and sounder data that can be applied to a multitude of meteorological and earth sciences investigations. The Imager and Sounder on the GOES satellites scan various regions of the earth scene and generate a raw data stream that is transmitted to a NOAA Command and Data Acquisition ground station. The raw data is then processed on the ground to become the GOES VARiable (GVAR) processed instrument data. This data is then retransmitted in near real time to the spacecraft where it is relayed to direct data users. Figures II-4 and II-5 are examples of GOES GVAR Imagery. The GVAR format is used primarily to transmit high resolution (1 km. visible, 4 km. infrared) meteorological data and instrument data. This digital data is transmitted at 2.11 Mbps at a frequency of 1685.7 MHz. A significant advantage of direct data reception of geostationary data is that a tracking antenna is not required and imagery data is available nearly continuously throughout the day and night. Although the cost for a basic GVAR ground station is out of the reach of many amateur direct readout users, many professional meteorologists, commercial, and military users are benefiting from this high resolution imagery and sounder data. A complete, basic GVAR reception system can be purchased for approximately $10,000.

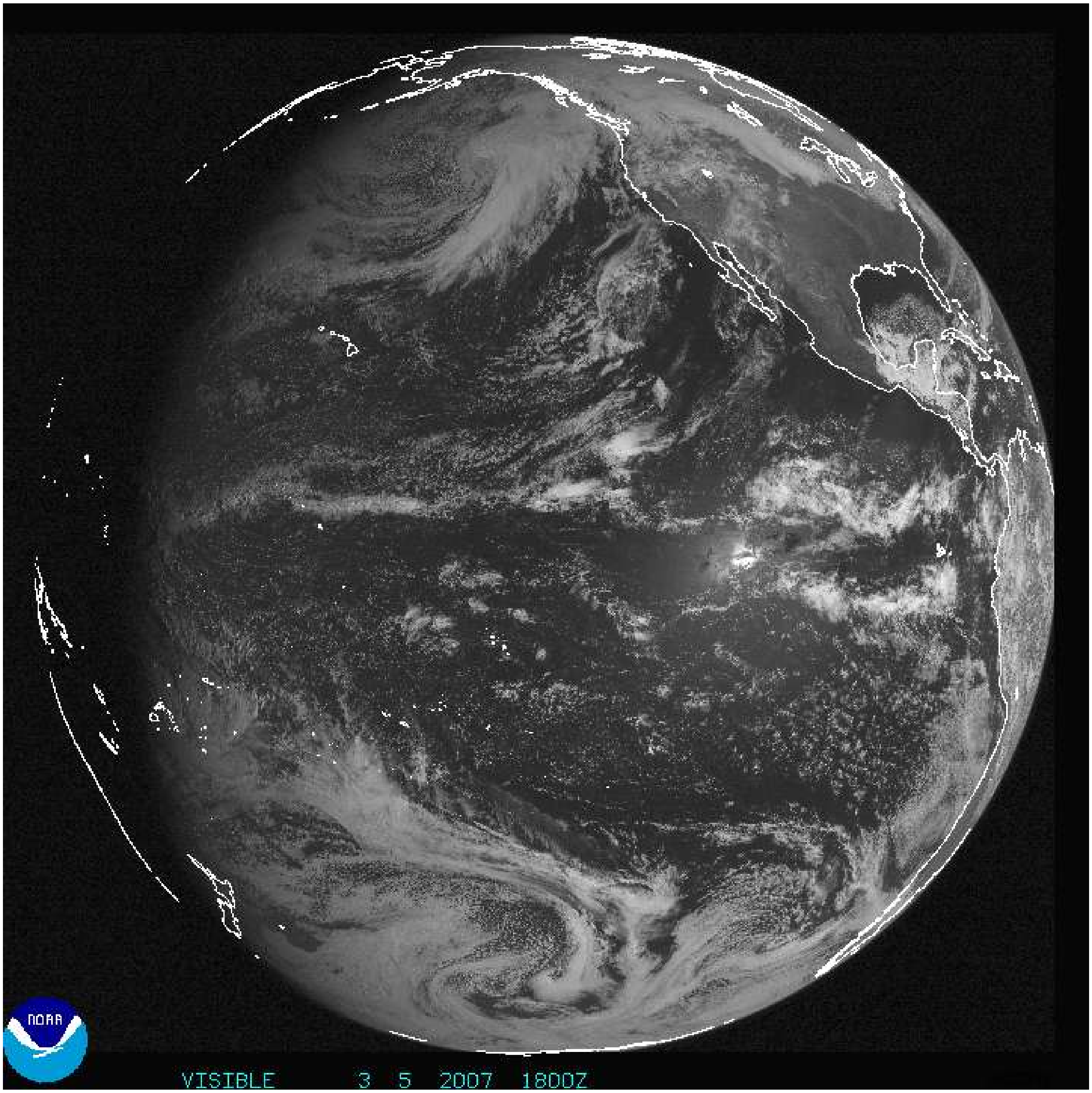


Figure II-4 GOES West Full Disk, Visible Channel Image

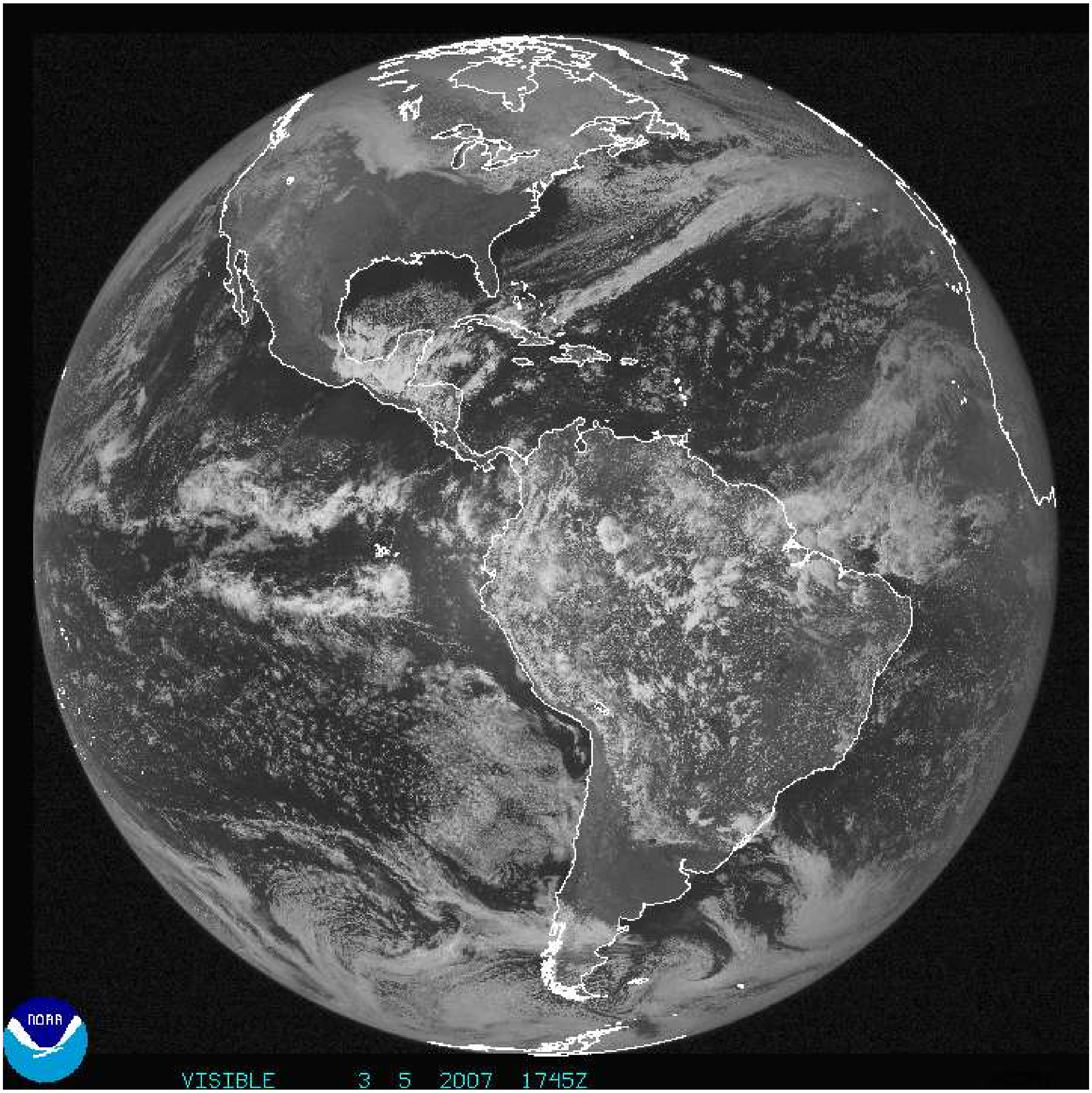


Figure II-5 GOES East Full Disk, Visible Channel Image

LRIT From The Geostationary Operational Environmental Satellites (GOES)

From 1975 until 2005 the GOES East and West spacecraft served as a communication relay for a low rate analog direct data service known as WEFAX. This service included data products from multiple sources including the host GOES spacecraft, POES images, European and Japanese Geostationary Images and other processed data. In 2005, NOAA completed a transition from the analog WEFAX format to the Low-Rate Information Transmission (LRIT) digital service. The Coordination Group for Meteorological Satellites (CGMS) began developing LRIT standards in the1990's in response to the recommendation of the World Meteorological Organization (WMO). The CGMS Global Specification provides the standard that is supported by all operational geostationary meteorological satellites to be flown by the United States, European agencies, Japan, China, and Russia. NOAA and other world meteorological agencies have developed subsequent system specifications, designs, and implementations of their specific LRIT systems. The LRIT system is an S-Band (1691MHz) broadcast of low rate digital data (64 kbps through 256 kbps) using CCSDS formatting. This service is available 24 hours a day from both GOES East and GOES West. Products available include GOES images, EMWIN forecasts and emergency weather information , DCS, text messages, and more. The LRIT system provides NOAA the opportunity to transmit more data, of various types, and with more flexibility than the WEFAX system allowed. Figure II-6 is a GOES-East full disk image as viewed on the LRIT user station.

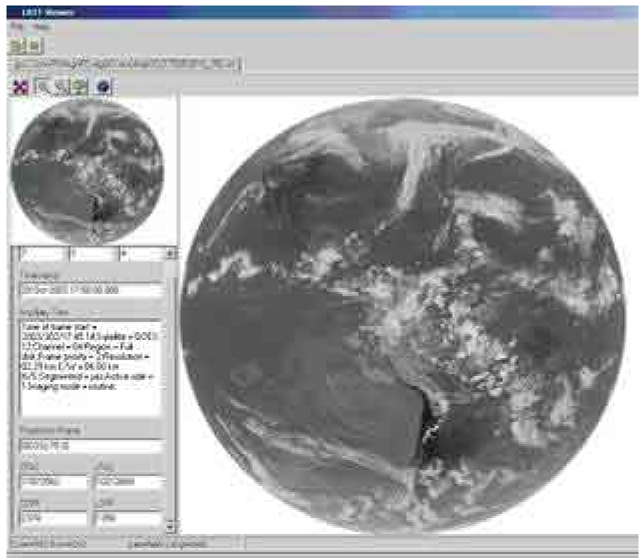


Figure II-6 GOES-East Full Disk Image Viewed Using LRIT

III. THE SATELLITES: POLAR ORBITING AND GEOSTATIONARY

The United States maintains two civil and one military program to provide meteorological imagery and data from spacecraft in polar and geostationary orbits around the Earth. The civil programs are managed by the National Oceanic and Atmospheric Administration (NOAA) and the military program is managed by the Department of Defense. The National Environmental Satellite, Data, and Information Service (NESDIS) is a unit of NOAA and is responsible for operating the civilian weather satellites (GOES and POES), distributing the satellite data and imagery, archiving the data, and planning for future systems. NESDIS also controls the Department of Defense constellation of polar orbiting weather satellites called Defense Meteorological Satellite Program (DMSP), which is similar to the civilian POES program.

Geostationary orbits are ones in which the satellite is always in the same position with respect to the rotating Earth. By orbiting at the same rate as the Earth, and in the same direction, the satellite appears to be stationary (synchronous with respect to the rotation of the Earth). This is achieved by placing the spacecraft into an orbit at an altitude of 35,790 kilometers (22,240 miles) above the Equator, this produces an orbital period equal to the period of the rotation of the Earth (about 23 hours 56 minutes). With this high altitude and near stationary position, a satellite can provide continuous coverage over a wide-area. The U.S. typically operates a constellation of two geostationary satellites, one at 135 degrees West longitude (GOES-West), and another at 75 degrees West longitude (GOES-East).

Figure III-1 shows the global coverage area for a constellation of geostationary satellites operated by the United States (GOES East and GOES West), European Space Agency (METEOSAT), India, (INSAT), China (FY-2), and Japan (MTSAT).

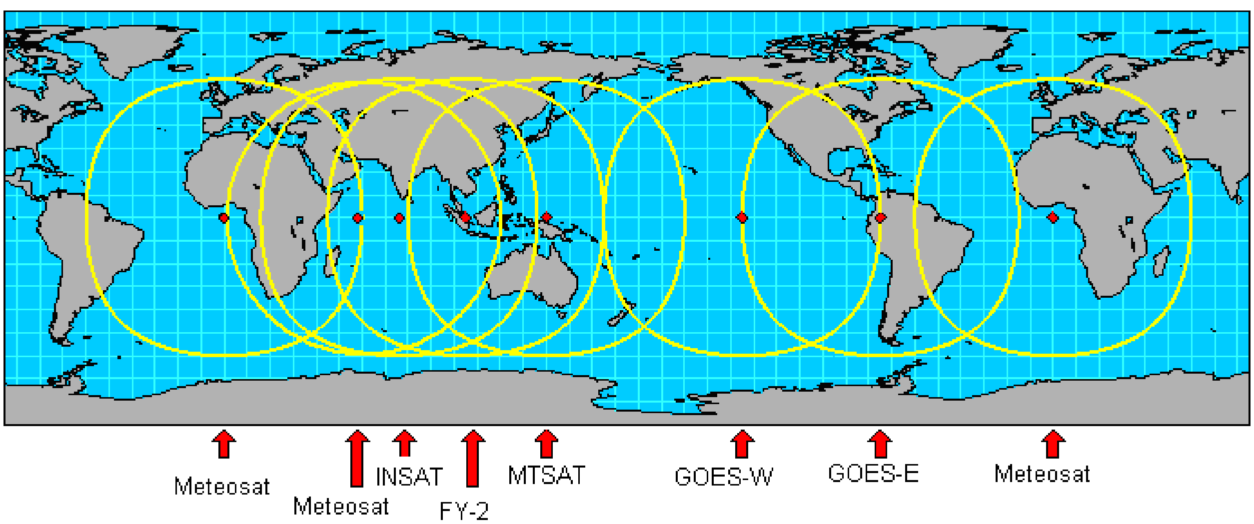


Figure III-1 Worldwide Geostationary Satellite Coverage

Polar orbiting weather satellites (POES and DMSP) provide a local view of the Earth but move in relation to the Earth to provide full global coverage every 12 hours. These satellites orbit around the poles of the Earth approximately every 101 minutes at an inclination to the Equator of 98 degrees (a true polar orbit has an inclination of 90 degrees). The satellites are launched into a sun-synchronous orbit which places the spacecraft in a relatively constant relationship to the sun so that the northbound portion of the orbit and the southbound portion remain at near constant solar time, this provides similar illumination orbit-to-orbit and throughout the year. To achieve a sun-synchronous orbit, the orbital plane of the satellite must rotate (precess) approximately one degree per day to keep pace with the Earth's orbit around the sun. Figure III-2 shows the orbital characteristics of a polar orbiting satellite. The satellite continues to orbit in nearly the same plane throughout the day while the Earth rotates beneath it. The result is a different ground path on subsequent orbits resulting in total coverage of the Earth twice per day.

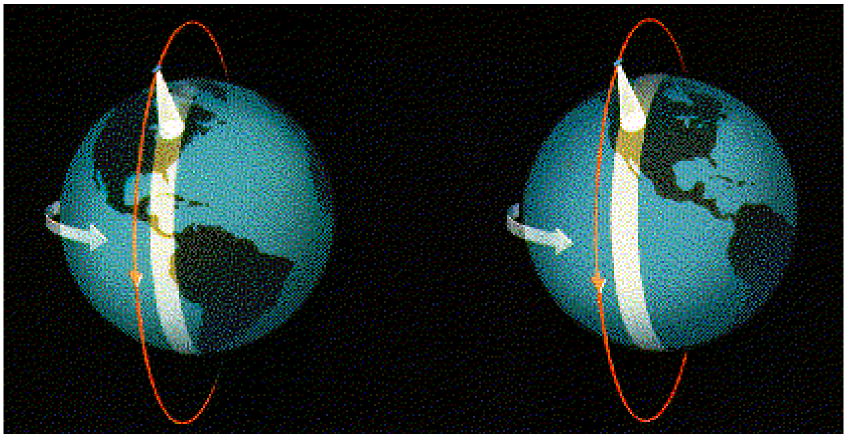


Figure III-2 Polar Orbit

Figure III-3 shows the satellite coverage of the Earth's surface for a single orbit and illustrates the offset caused by the Earth’s rotation.

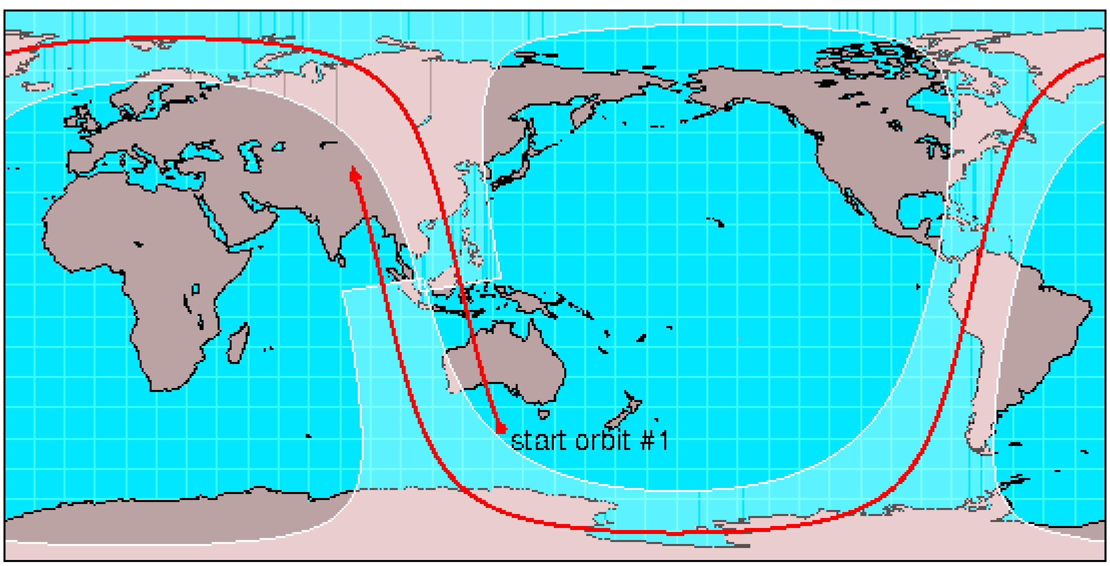


Figure III-3 Polar Orbit Ground Track

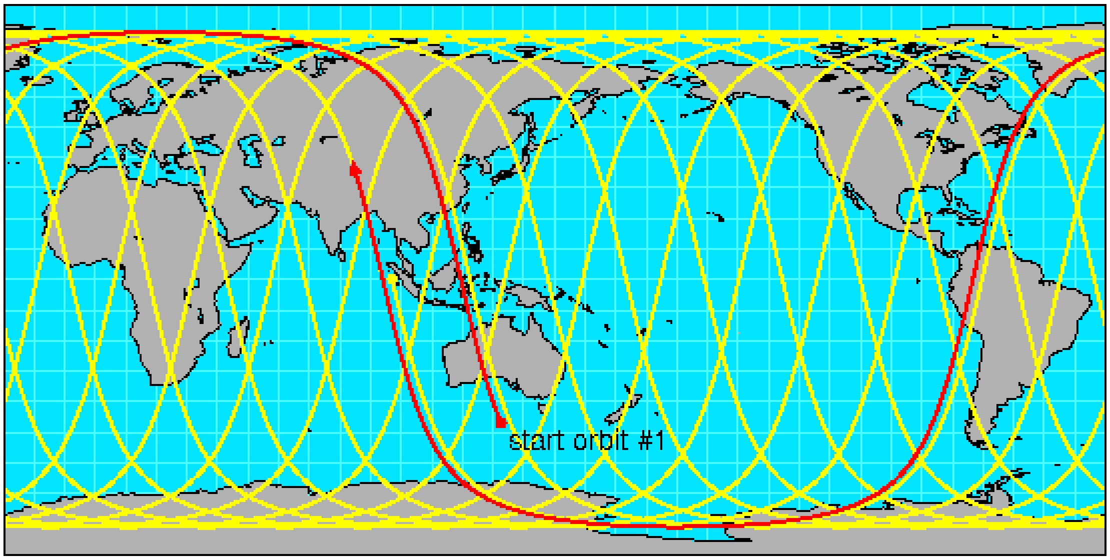


Figure III-4 Polar Orbit Ground Track for 24 Hours (14 orbits)

Figure III-4 shows the orbital track from the previous figure, but with 14 additional orbits drawn in yellow. This figure gives a good indication of the daily coverage of a single satellite in sun-synchronous orbit. Note that the satellite does not make an integer number of orbits in a single day, so that there is a slight offset in the orbital tracks after 14 orbits. This means that although the equatorial crossing time in terms of the local solar time is constant, the clock time for the satellite overpass at a fixed location will vary from day to day, as will the distance and azimuth to the satellite.

POES and GOES Satellites: Why Two Systems?

Figure III-5 illustrates the geometric differences between the orbits of a Low Earth Orbiting (LEO) polar satellite and a Geostationary (GEO) satellite. Each of these orbits provide specific advantages. The LEO polar orbiting satellites provide high resolution images of all the Earth's surface at least twice per day; however since the swath imaged by a single orbit is limited, these data do not allow continuous tracking of developing weather patterns especially in the tropical and temperate regions. Geostationary satellites on the other hand provide continuous coverage of one side of the Earth allowing them to track regional weather patterns. One disadvantage of the GEO orbit is that resolution at the Earth limb is limited; this impacts coverage in the polar regions. Also since the spacecraft observe only one side of the Earth, approximately five spacecraft are required to provide global coverage.

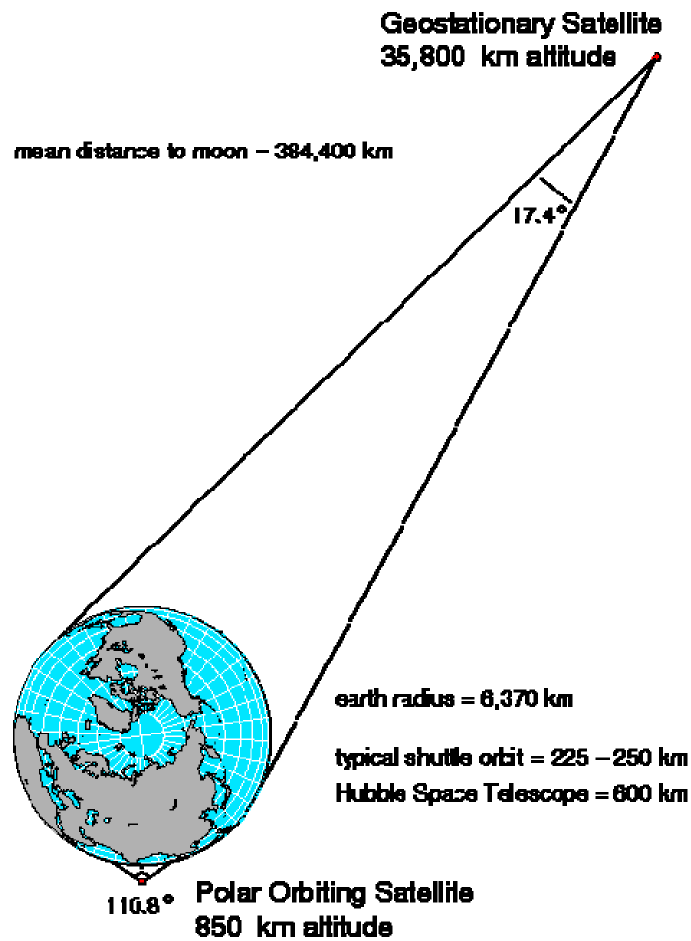


Figure III-5 Comparison of Geostationary and Polar Orbit Geometries

Figure III –5 shows the true relative distances from the Earth of geostationary and polar orbiting satellites. From geostationary altitude, the entire Earth disk only subtends an angle of 17.4 degrees. A typical polar orbiting meteorological satellite, at an altitude of about 850 km, sees a relatively small portion of the globe at any one time. For example, the Advanced Very High Resolution Radiometer or AVHRR scans a swath that is 110.8 degrees in width, corresponding to a surface distance of roughly 3000 km. As seen at this scale, the Earth's atmosphere, most of which is limited to altitudes below 30 km, is only slightly thicker than the width of the lines used to draw the illustration.

NOAA Polar-orbiting Operational Environmental Satellite (POES)

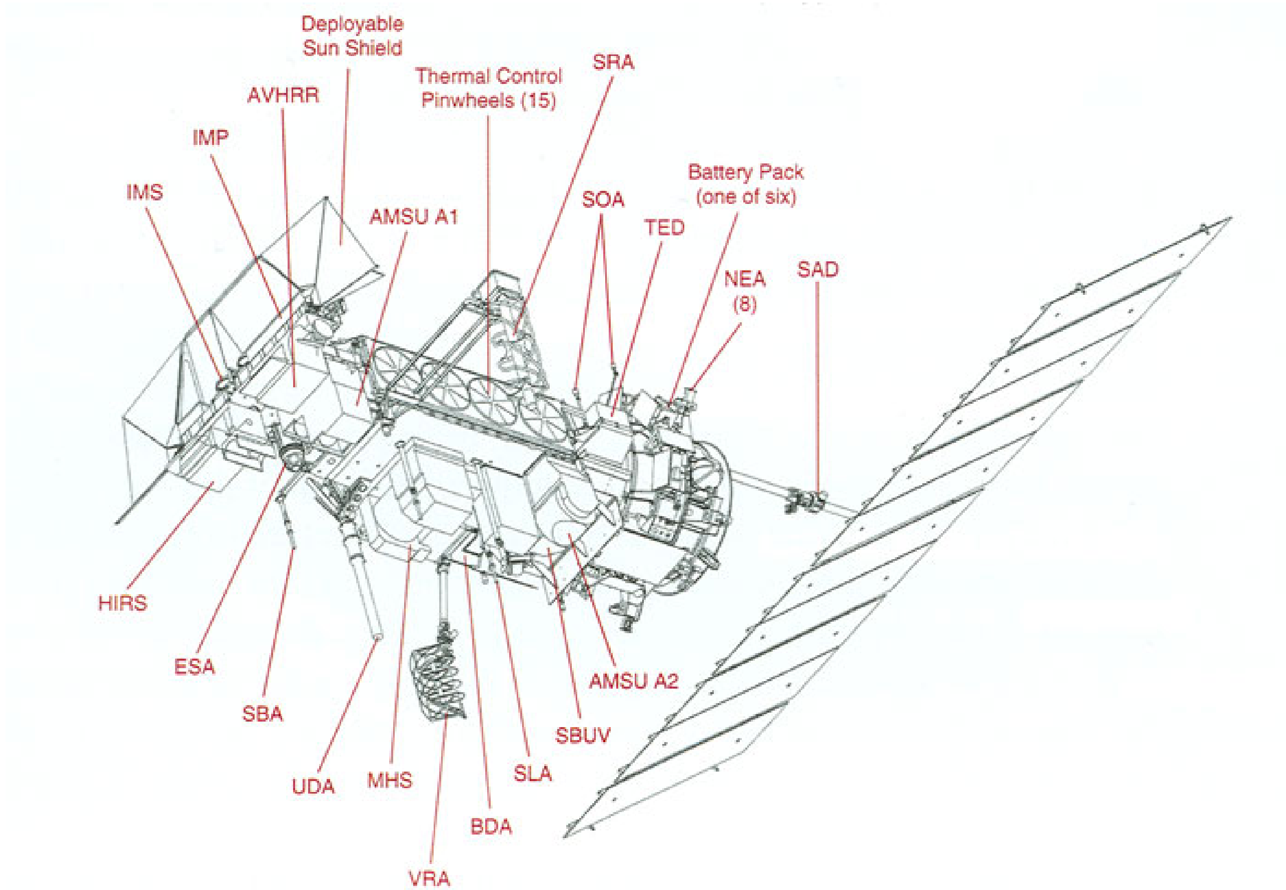
Because of the polar orbiting nature of the POES satellites, they are able to collect global data on a daily basis for a variety of land, ocean, and atmospheric applications. Data from these satellites supports a broad range of environmental monitoring applications including weather analysis and forecasting, climate research and prediction, ocean dynamics research, volcanic eruption monitoring, forest fire detection, global vegetation analysis, and many other applications. The instruments on the POES spacecraft perform the following functions:

1. Environmental monitoring for imaging and measuring the Earth's atmosphere, its surface and cloud cover, including Earth radiation, atmospheric ozone, aerosol distribution, sea surface temperature, and vertical temperature and water profiles in the troposphere and stratosphere.
2. Measurement of proton and electron flux at orbit altitude.
3. Data collection from remote platforms. These platforms consist mainly of drifting and moored buoys, subsurface floats, remote weather stations that serve meteorological and oceanographic applications, fishing vessels for fishing resource management, and tracking animals for biological and species protection purposes. The platforms relay data such as atmospheric pressure, sea surface temperature and salinity, surface and subsurface ocean currents, sea and river levels, vessel positions, and animal temperature and activity.
4. Search and Rescue beacon reception and relay for the Search and Rescue Satellite Aided Tracking (SARSAT) system. This international system, called COSPAS-SARSAT, transmits the location of emergency beacons from ships, aircraft and people in distress to SARSAT ground stations. The program, in place since 1982, has resulted in the rescue of over 20,000 people.
5. Passive microwave measurements for the generation of temperature, moisture, surface, and hydrological products in cloudy regions where visible and infrared (IR) instruments have decreased capability.

The POES instruments include: the Advanced Very High Resolution Radiometer (AVHRR), the High Resolution Infrared Radiation Sounder/4 (HIRS/4), the Advanced Microwave Sounding Units (AMSU-A1 and -A2), the Microwave Humidity Sounder (MHS), and the Solar Backscatter Ultraviolet Radiometer (SBUV/2), the Data Collection System (DCS), the Search and Rescue Repeater (SARR), the Search and Rescue Processor (SARP), and the Space Environment Monitor (SEM).

Figures III-6 and III-7 illustrate the POES Spacecraft and Instrument configuration.

More extensive information about POES spacecraft, their history, and current operational status are available via web sites referenced in Appendix B.



LEGEND
NOAA-N spacecraft on-orbit configuration
AMSU Advanced Microwave Sounding Unit
AVHRR Advanced Very High Resolution Radiometer
BDA Beacon Dipole Antenna
*DCS Data Collection System
ESA Earth Sensor Assembly
HIRS High Resolution Infrared Radiation Sounder
IMP Instrument Mounting Platform
IMS Inertial Measurement System
*MEPED Medium Energy Proton/Electron Detector
MHS Microwave Humidity Sounder
NEA Nitrogen Engine Assembly
SAD Solar Array Drive
*SAR Search and Rescue
SBA S-Band Antenna
SBUV Solar Backscatter Ultraviolet Radiometer
SLA Search and Rescue Transmitting Antenna (L-Band)
SOA S-Band Omni Antenna (2 of 6 shown)
SRA Search-and-Rescue Receiving Antenna
TED Total Energy Detector
UDA Ultra High Frequency Data Collection System Antenna
VRA Very High Frequency Real-time Antenna
*Not shown in this view

Figure III-6 POES Instruments and Spacecraft Components

Figure III-7 Artist View of NOAA-N on-Orbit Configuration

The United States Defense Meteorological Satellite Program

NOAA also operates a series of polar orbiting weather satellites for the United States Department of Defense called Defense Meteorological Satellite Program (DMSP). This is a parallel but currently a separate program from POES and provides high resolution weather imagery and other data to military commanders around the world

The DMSP program originated in the mid-1960s with well-defined military objectives, including the capability to provide daily cloud-cover information, worldwide. DMSP was used for the tactical support of U.S. forces in Vietnam in the late 1960's and into the 1970's and is today used by most of the Armed Forces of the United States on a daily basis. The primary missions of DMSP are to provide:

a. Global weather data, both visible and infrared (at a nominal resolution of 2.7 km.)
b. Tactical weather data (at a nominal fine-mode resolution of 0.55 km.)
c. Low-light visible data
d. Oceanographic and solar-geophysical information

The DMSP spacecraft fly in a sun-synchronous circular orbit of 833 km. and have an orbital period of 101 minutes, with an inclination of 98.7 degrees to the Equator. Normally, two satellites comprise the constellation, traditionally with one early morning earth terminator orbit and one midmorning orbit. The DMSP operates in the direct readout mode similar to the NOAA POES.

Some of the DMSP instruments include:

1. Operational Linescan System (OLS) - The primary sensor instrument for DMSP. OLS provides high resolution (0.55 km.) daytime visible imagery, and slightly lower resolution imagery in the Infrared spectrum. This instrument provides highly-detailed information about cloud tops and synoptic weather patterns. The OLS has a unique capability to detect low levels of visible-near infrared (VNIR) radiance at night. With the OLS "VIS" band data it is possible to detect clouds illuminated by moonlight, and lights from cities, towns, industrial sites, gas flares, and ephemeral events such as fires and lightning illuminated clouds.

2. Special Sensor Microwave Imager Sounder (SSM/IS) - This instrument measures 24 channels of microwave radiation from the Earth's atmosphere and surface. It provides vertical water vapor and temperature profiles and information about ocean surface wind speed, rain rate, sea ice, snow water content, and soil moisture content.

3. Special Sensor Ultraviolet Limb Imager (SSULI) – This instrument measures UV radiation in the 80-170 nm range (FUV/EUV), and provides global electron density and neutral density profiles of the upper atmosphere. It also provides atmospheric temperature and composition.

4. Special Sensor Ultra-violet Spectrographic Imager (SSUSI) - This instrument makes FUV (115-180 nm, 430-630 nm) spectrographic observations of the airglow and aurora, and visible photometric measurements of the aurora and nightglow. This provides a best estimate of electron density profiles, plasma transition zones, auroral boundaries, and energy deposition rates into auroral latitudes.

5. Space Environmental Sensors - A series of instruments that provides data on the geophysical environment of the upper atmosphere and ionosphere, including the charged particle activity and magnetic fields around the spacecraft, the Earth's aurora, and characterization of solar storms that may interfere with military communications around the globe.

Due to the classified nature of the DMSP imagery and other data products, the DMSP downlink data is encrypted, and thus the direct readout system is not available to nonmilitary users. However, data from the low light sensors, auroral imagery, and OLS hurricane imagery have been released to the public domain through the National Geophysical Data Center (NGDC) of NOAA. Figure III-6 is an example of the nighttime low light detection capability of the DMSP satellites it shows light bands from aurora and lights from Eastern U.S. cities.

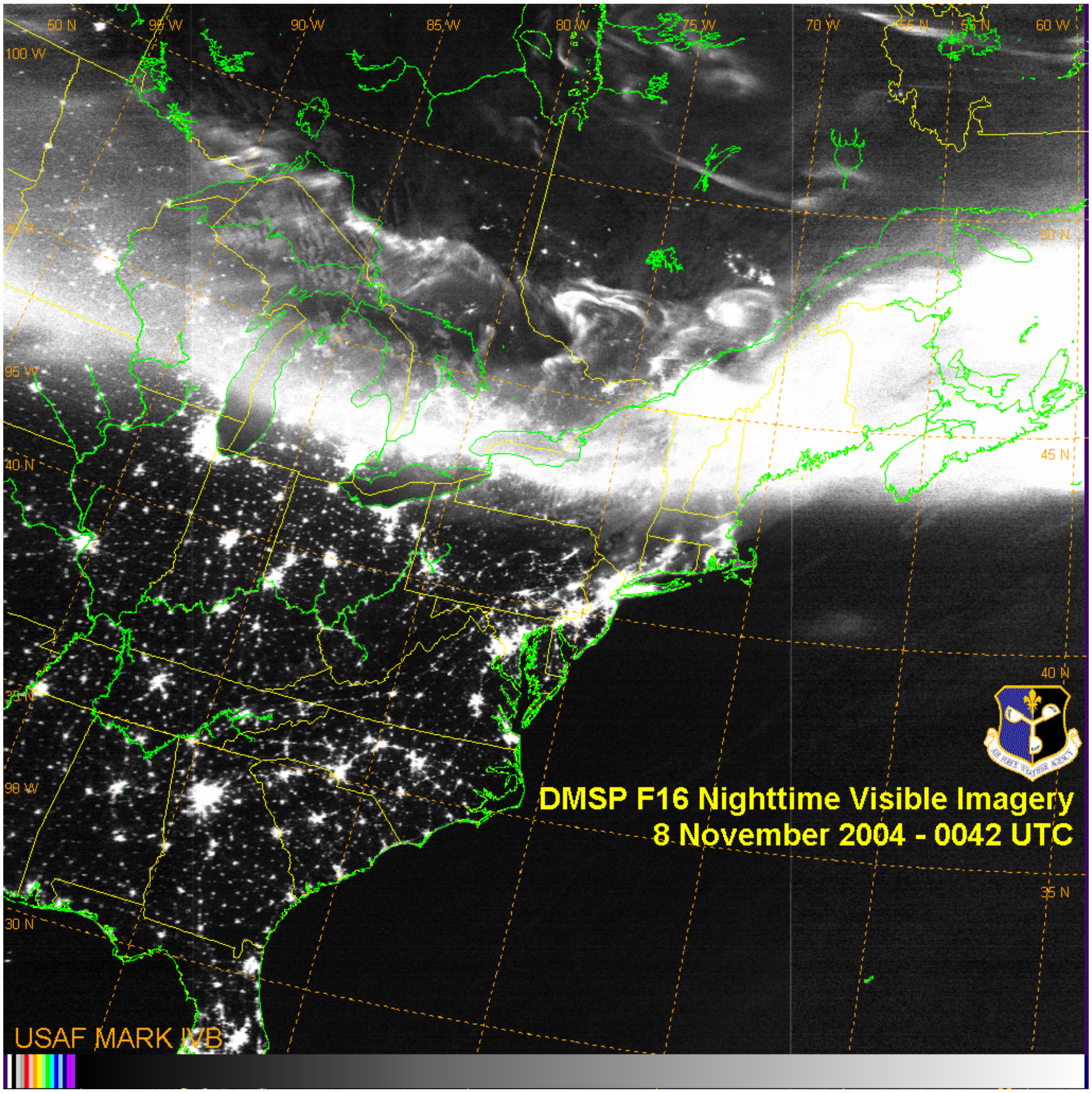


Figure III-8 Visible DMSP Satellite Image Utilizing the OLS Instrument

POLAR ORBITING WEATHER SATELLITES OF OTHER COUNTRIES

In addition to the United States, the People's Republic of China, and a consortium of European nations, own and operate polar orbiting weather satellite systems. Some of these satellites employ direct readout systems that are compatible with the U.S. POES direct readout data products, and thus may be received by the appropriately equipped ground stations.

Chinese Polar Weather Satellites

The People's Republic of China meteorological satellite program consists of both polar orbiting and a geostationary satellites. China's polar orbiting satellites have a direct readout capability fully compatible with the NOAA POES.

Feng Yun (FY-1D) was launched on May 15, 2002 it carries a 10 channel scanning radiometer. Chinese meteorological satellites provide a CHRPT direct broadcast service similar to POES HRPT data. The Chinese are developing their next generation of polar orbiting satellites which are designated Feng Yun -3.

European Polar Weather Satellites

The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) ,a consortium of twenty European nations, launched their first polar orbiting meteorological satellite, METOP-A in October 2006. This satellite carries a suite of advanced sensors, and is in an orbit similar to the U.S. POES satellites, EUMETSAT and NOAA have formed an Initial Joint Polar Orbiting Satellite System (IJPS) and will be sharing data between systems. EUMETSAT will operate METOP satellites in a morning orbit while the POES satellites will operate in an afternoon orbit. The METOP satellites have direct readout transmission services, providing AHRPT similar to POES HRPT. The APT service is not provided, LRPT (Low Rate Picture Transmission) is provided for users of lower resolution data. The LRPT service is digital rather than analog, requiring modification of APT receiving stations.

THE UNITED STATES GOES GEOSTATIONARY SATELLITES

As discussed in the beginning of this chapter, satellites in geostationary orbits maintain a fixed position relative to points on the Earth's surface. 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, therefore a two-satellite system can cover almost all of North America and South America from the Pacific to the Atlantic. The geostationary satellites operated by NOAA are usually referred to as GOES-East and GOES-West. GOES-East is positioned at 75 degrees West longitude, and GOES-West is positioned at 135 degrees West longitude.

The first prototype Synchronous Meteorological Satellite (SMS-1) was developed by NASA and was launched on May 17, 1974. The first NOAA funded geostationary operational satellite, GOES-1, was launched in October of 1975. The GOES series of spacecraft have been providing environmental monitoring since this time using spacecraft and sensors with ever increasing capabilities. An updated version of the early spacecraft was first launched in September 1980, and consisted of the GOES D-G (GOES 4-7) satellites. The next series of GOES satellites, referred to as GOES I-M, began with the launch of GOES-8 in April 1994. Further technological advances are included in the GOES N-P series; the first of this series (GOES-13) was launched in May 2006. Future GOES series (GOES-R) are in the planning process. Figures III-9 and III-10 are illustrations of GOES I-M and GOES N-P series satellites.

Figure III-9 Artist's Rendition of a GOES I-M Series Satellite on Orbit

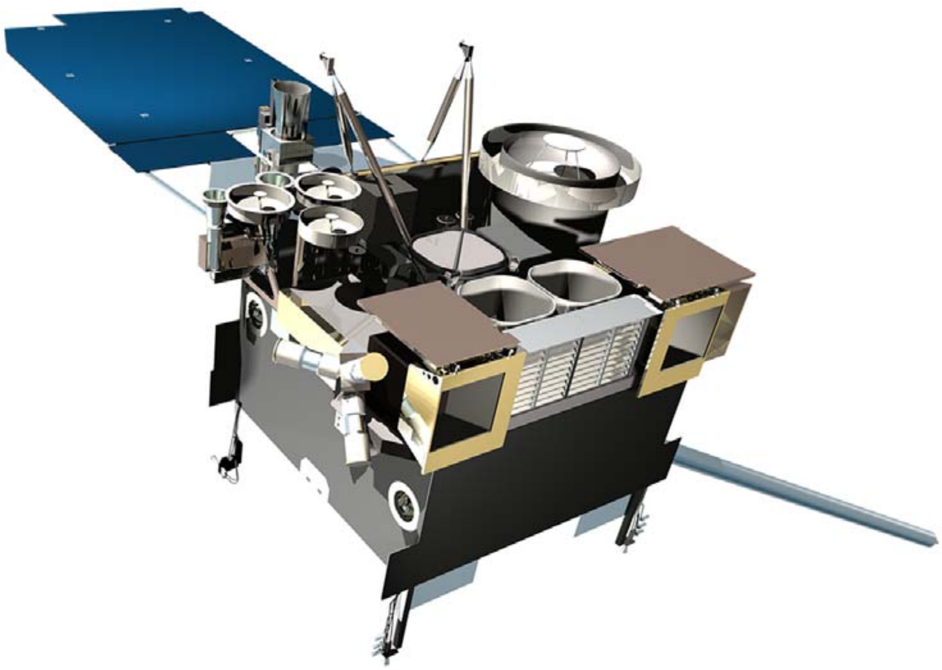


Figure III-10 GOES N-P Series Spacecraft with Earth Facing Panel at the Top of the View

GOES Spacecraft

Early GOES D-H spacecraft were spin-stabilized platform, consisting of a cylinder covered with solar panels, containing the instrumentation and antennas. The spacecraft spun at 100 rpm with the spin axis oriented parallel to the Earth's surface. The gyroscopic effect of the spin improved the stability of the satellite, making it easier to design a scanning instrument to take stable imagery of the Earth.

The GOES I-M spacecraft are the first three-axis stabilized geostationary weather satellites. With a three-axis stabilized attitude control system, the satellite body remains stationary relative to the desired pointing axis. The stationary platform provided by the GOES I-M allows spacecraft instruments to remain Earth pointing and supports simultaneous imaging and sounding using independent instruments.

The GOES satellites are designed to provide the nearly continuous and repetitive observations needed to predict, observe, and track severe weather. Instruments on the spacecraft observe the Earth's cloud cover, snow and ice cover, surface and cloud top temperatures, vertical distributions of atmospheric temperatures and humidity, and other environmental data. GOES also measures and images solar X-rays, collects and relays data from environmental remote platforms, and broadcasts instrument data to ground stations within the satellite communications "footprint"

The complement of instruments in the GOES payload section includes:

- Five-channel Imager (4 IR and 1 visible)
- Nineteen-channel Sounder (18 IR and 1 visible)
- Data Collection System
- Search and Rescue
- Solar X-Ray Imager
- Space Environment Monitor (SEM) instrument suite consisting of
    - High Energy Proton, Electron, and Alpha Particle Detectors
    - X-Ray Sensor
    - Magnetometer

The primary meteorological instruments on the GOES spacecraft are the 5-channel Imager and 19-channel Sounder. The Imager has a pair of servo motors that precisely move the instrument optics to produce an image. A scan line is produced by moving the optics in an East-to-West direction. At the end of the scan line, another motor slightly changes the optics elevation in a North-to-South direction, and the next scan line is swept in a West-to East direction. This process is repeated to produce the required image. The Imager can be commanded to scan various sized regions of the Earth, these range from a full Earth disk image once every 26 minutes, to a small area scan of severe storm activity as frequently as once per minute. The instrument resolution is 1 km in the visible range and 4 km. or 8 km in the infrared ranges.

The Sounder operates in a manner similar to the Imager, with one motor controlling the East-West and one controlling the North-South movement of the instrument optics. The instrument can produce sounding data over a 3000 by 3000 km. Region every 42 minutes. As with the Imager, the Sounder can be directed to scan smaller sectors, as needed.

The GOES Imager and Sounder data are used to produce a large number of primary or derived data products. These include:

Basic day/night cloud imagery
Winds derived from cloud motions at several levels
Sea surface temperature data
Albedo and infrared radiation flux to space, important for climate monitoring
Detection and monitoring of natural and manmade forest fires and smoke plume monitoring
Precipitation estimates
Vertical temperature and moisture profiles

These data products enable users to accurately monitor severe storms, determine wind speed and direction, and when combined with data from Earth based sensors, produce improved short-term weather forecasting and analysis.

The Data Collection System (DCS) equipment on the GOES satellites allow direct relay from remote reading platforms located on the Earth's surface. These platforms contain 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 the NOAA/NESDIS DCS Coordinator on this system (see Appendix B).

GOES also provides instantaneous relay functions for the SARSAT (Search and Rescue Satellite) system. A dedicated search and rescue transponder on GOES spacecraft is designed to detect emergency distress signals originating from Earth-based sources (ships at sea, planes, etc.). These unique identification signals are relayed to a search and rescue ground terminal, the information is validated and then routed to the appropriate Rescue Coordination Center where it is used to perform effective search and rescue operations.

The Space Environment Monitor (SEM) instrument suite 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.

GOES Direct Broadcast Services

There are two types of direct readout services provided by GOES satellites, GVAR and Low Rate Information Transfer (LRIT). Both of these data products can be received by a ground station within the "footprint" of the satellite signal. The GVAR data is the high resolution (1 km. visible, 4 km. infrared, 8 km. water vapor) Imager data and the Sounder data, and is transmitted at the S-band frequency of 1685.7 MHz. The data is transmitted to the ground station at 2.11 Mbps. This GVAR data is not generally received by the standard "amateur" ground station.

The Low Rate Information Transfer (LRIT) images and information transmitted by the GOES satellites are of most interest to operators of lower cost ground stations. The LRIT is a digital transmission that replaced the previous WEFAX which was similar to the POES APT analog format. Major ground station modifications are required to convert from the analog WEFAX to the digital LRIT service. The LRIT service uses the GOES spacecraft as a transponder to transmit low-resolution imagery sectors, Emergency Managers Weather Information (EMWIN) forecasts and notices, DCS data, and administrative messages to the direct data user. The LRIT format allows a great deal of flexibility in products transmitted, and additional processed data and information may be provided in the future.

A significant portion of the LRIT transmissions are imagery from the host GOES spacecraft, these are generated on a 24 hour schedule. The image sequence involves breaking up the Earth disc into major geographical regions. For GOES East, the routine sequence of images consists of a Northern Hemisphere extended, Continental US, and Southern Hemisphere image repeated on a half hour basis throughout the day. This sequence is interrupted for a full disk image every 3 hours. LRIT transmissions include visible and infrared images, grids outlining the political and geographic boundaries and longitude and latitude references assist in navigation of the imagery. LRIT data also includes a limited set of images from the alternate GOES spacecraft, this extends the image coverage beyond that of the host satellite.

GEOSTATIONARY WEATHER SATELLITES OF OTHER COUNTRIES

In addition to the United States; geostationary meteorological satellites are operated by Japan, China, India and a European consortium. Due to the geostationary nature of these satellites direct data reception is limited to the geographic region covered by the satellite; however cooperation between international meteorological organizations allows images from other nation's satellites to be provided in WEFAX or LRIT format to direct data users. Images from these satellites can also be found on various web sites

European Geostationary Satellites

The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) a consortium of twenty European nations operates a series of geostationary weather satellites called METEOSAT (METEOrological SATellite). EUMETSAT currently operates satellites at two orbital locations; the 0^o longitude location serves as the primary satellite servicing Europe, the second location at 57.5^oE longitude provides coverage for the Indian Ocean. The EUMETSAT satellites provide LRIT direct data services to European users.

Meteosat-7 provides data in three wavelength channels for visible, infra-red and water vapor images. Meteosat-7 served as the prime European satellite until it was moved to 57.5^oE longitude to provide coverage of the Indian Ocean. The first Meteosat Second Generation (MSG-1) series was launched in 2002 and entered into service with EUMETSAT as Meteosat-8; it serves as back-up at 0^o longitude. The MSG-2 satellite launched in December 2005, was renamed Meteosat-9, it is on station at 0^o longitude and serves as the prime operational meteorological satellite for Europe.

Indian Geostationary Satellites

The Indian Space Research Organization (ISRO) has operated a series of Indian National Satellite System (INSAT) geostationary satellites since 1983. The INSAT spacecraft are either communication satellites or multipurpose communications/meteorological satellites. Full disk Earth images as well as regional images from these satellites are available on the internet.

Chinese Geostationary Satellites

The first Chinese geostationary satellite Feng Yun -2A was launched in June 1997. The Feng Yun 2 series of satellites are spin stabilized with a VISSR-type instrument. FY-2 satellites can transmit S-VISSR high resolution digital data and WEFAX low resolution data. Feng Yun-2C was launched in October 2004 on a Long March-3A rocket from the Xichang Launching Centre. The satellite is located at longitude 105 degrees East. The satellite provides hourly full-disk images of the Earth in visible and infrared wavelengths.

Japanese Geostationary Satellites

The Japanese Geostationary Meteorological Satellite program launched (MTSAT-1R) on 26 February 2005. MTSAT-1R has an onboard sensor, which is called the Japanese Advanced Meteorological Imager (JAMI). JAMI obtains "full-disk" earth imagery, and observes earth surface conditions and cloud distributions as well as meteorological phenomena such as typhoons, depressions, and fronts. In addition, various meteorological parameters, such as sea surface temperature and winds from cloud motion are extracted from image data. MTSAT-1R has communication functions to disseminate image data and processed pictures. The original raw data of all channels are processed to normalized geostationary images, and are disseminated to the users of Medium-scale Data Utilization Stations (MDUS) with High Rate Information Transmission (HRIT). MTSAT 1R also provides weather facsimile (WEFAX) pictures and Low Rate Information Transmission (LRIT) image data to the users of Small-scale Data Utilization Stations (SDUS), according to the daily operation schedule.
Similar to U.S. GOES spacecraft, the MTSAT-1R also has a Data Collection System (DCS), communication function to relay in-situ meteorological data measured by Data Collection Platforms (DCP) equipped in buoys, ships, and aircraft. MTSAT-1R provides imagery for the Northern Hemisphere every thirty minutes, and full disk imagery every hour.

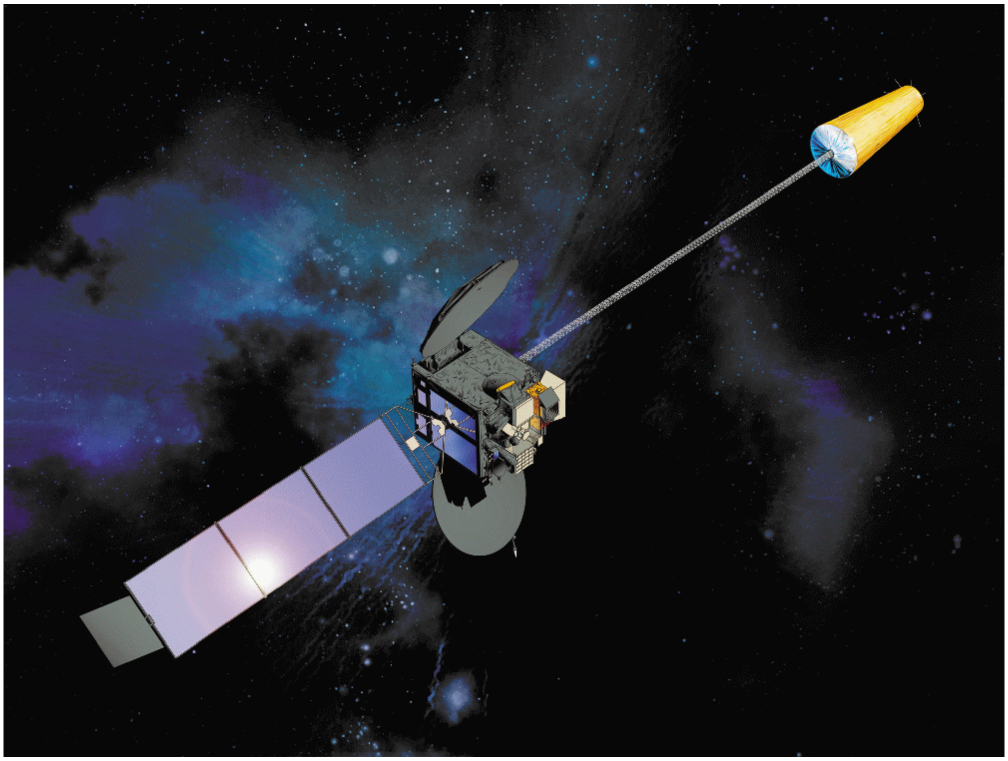


Figure III-11 MTSAT-1R

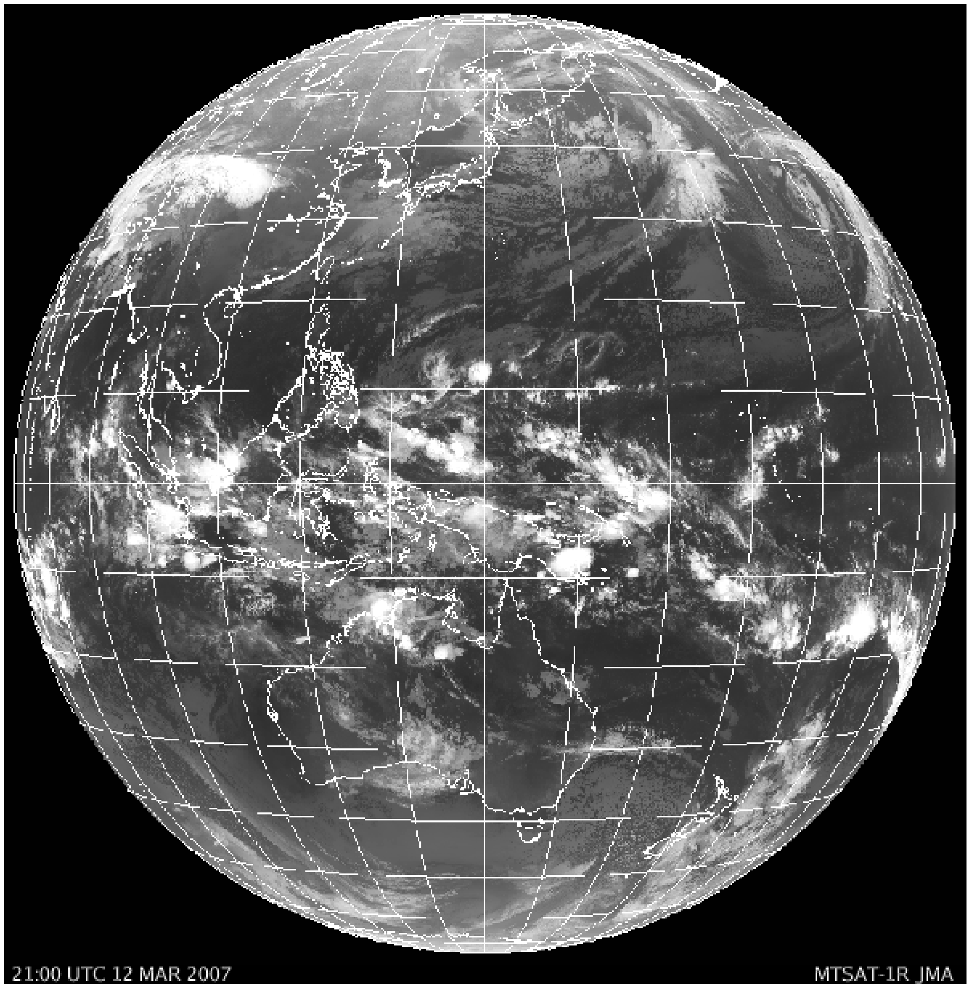


Figure III-12 Full Disk MTSAT-1R Infrared Image

IV. BASIC GROUND STATION SYSTEM

Technological advances in microelectronics and computer software applications over the past decades have made it rather simple to assemble and use a basic direct readout ground station. Early editions of this Guide discussed using surplus radio receivers to receive the satellite signals, and old photographic facsimile drum recorders to reproduce the APT or WEFAX imagery. Today one can purchase off-the-shelf, state of the art commercial products for the same cost as the older surplus equipment, and an inexpensive personal computer can perform most of the functions originally performed by additional hardware.

When planning the installation of a direct readout system, several issues must be considered:

- Do you purchase a complete "turn-key" system from a commercial source or,
- Do you purchase individual components (antenna, receiver, demodulator, software, etc.) and assemble a system yourself?
- Is the direct readout station primarily for low resolution regional imagery (APT), or do you require higher resolution or global capabilities (HRPT, GVAR and LRIT)?
- What are the financial considerations and limitations for assembling a complete direct readout system?

Most newcomers to weather-satellite imagery start by assembling a polar orbiter receiving station for the Automatic Picture Transmission imagery. Starting with a basic analog APT system allows the user to become familiar with satellite image reception techniques, receiving satellite radio telemetry from a fast-moving platform in space, learning the techniques of predicting satellite orbits and acquisition of signal timing, and analyzing weather patterns and temperature variations in the visible and infrared direct readout imagery. As one gains practical experience with satellite image reception, and as the application requirements change, one may migrate to the higher resolution digital LRIT, HRPT, and GVAR commercial systems.

A basic direct readout station typically contains the following components:

- Antenna
- Preamplifier
- Radio receiver
- Demodulator card to "decode" the satellite signal
- Display system to view the satellite imagery (typically a personal computer)
- A storage system (computer disk, tape) to store and archive the satellite imagery
- Computer software to manipulate the imagery (image enhancement)
- A method to predict when the satellite will be in view of the ground station

Each of these components will be described in further detail in the following chapters.

The more advanced direct readout systems (LRIT, HRPT, GVAR) utilize the same basic components, although the antenna, receiver design and demodulation system differ due to the nature of the radio frequencies required to transmit and demodulate the high speed digital imagery.

A generalized diagram of the components of a direct readout ground station to receive polar orbiting APT is shown in Figure IV-1. These components are typical of many satellite ground stations currently in operation for the U.S. POES satellites, as well as the Chinese Feng Yun satellites.

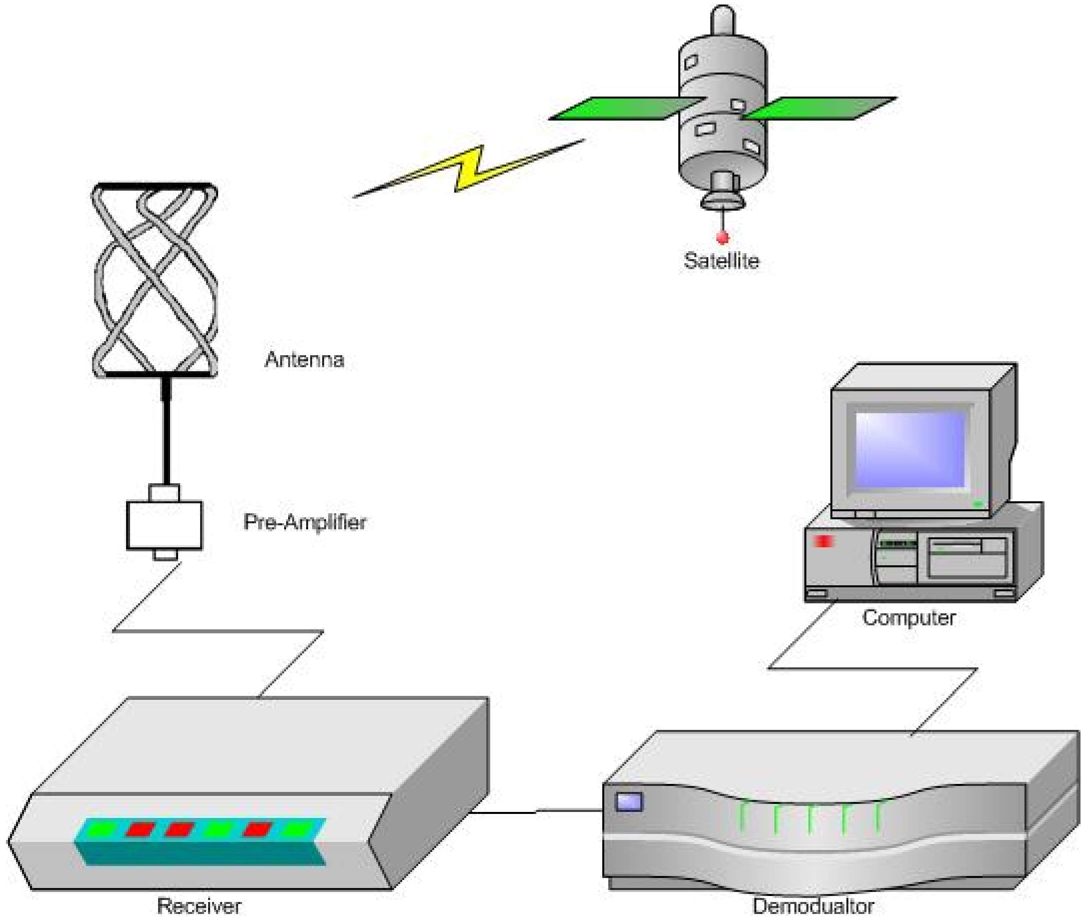


Figure IV-1 Typical Components Found in an APT Receiving Station

Several different types of antennas may be used for polar orbiting reception of APT imagery. One is directional and requires tracking of the moving satellite and the second type, shown in Figure IV-2, is omnidirectional and less expensive but will give a slightly reduced reception range. Both of these are discussed in Section V of this publication.

Figure IV-2 Omnidirectional "turnstile" Type Antenna for APT Reception

Near the antenna, the signal is processed by a small preamplifier which increases the strength of the desired frequencies and also filters out unwanted frequencies, the signal is then 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 modem radios 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 sub-carrier which carries 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 use a stereo tape recorder to record the 2400 Hz sub-carrier at this stage of the processing so that the transmission can be played back later.

The majority of display systems are based on personal computers that use specialized demodulator cards and software programs to ingest the audio signal from the satellite, convert it to a digital signal, display the image on the screen, and store the image to disk. Some direct data users use the sound card provided with most PCs to demodulate the subcarrier. Other software features on the PC may be used to schedule data ingest, digitally enhance images, add geographic gridding, or analyze the temperature variations in the infrared imagery.

Figure IV-3 is an APT image of the Eastern U.S. with thermal channel data on the left and visible channel on the right. This image was received at a direct readout station similar to the one described above. Figures IV-4 and IV-5 are enlarged Visible and Infrared portions of the same APT image, Figure IV-6 is a combination of the IR and visible images color enhanced using commercially available software.

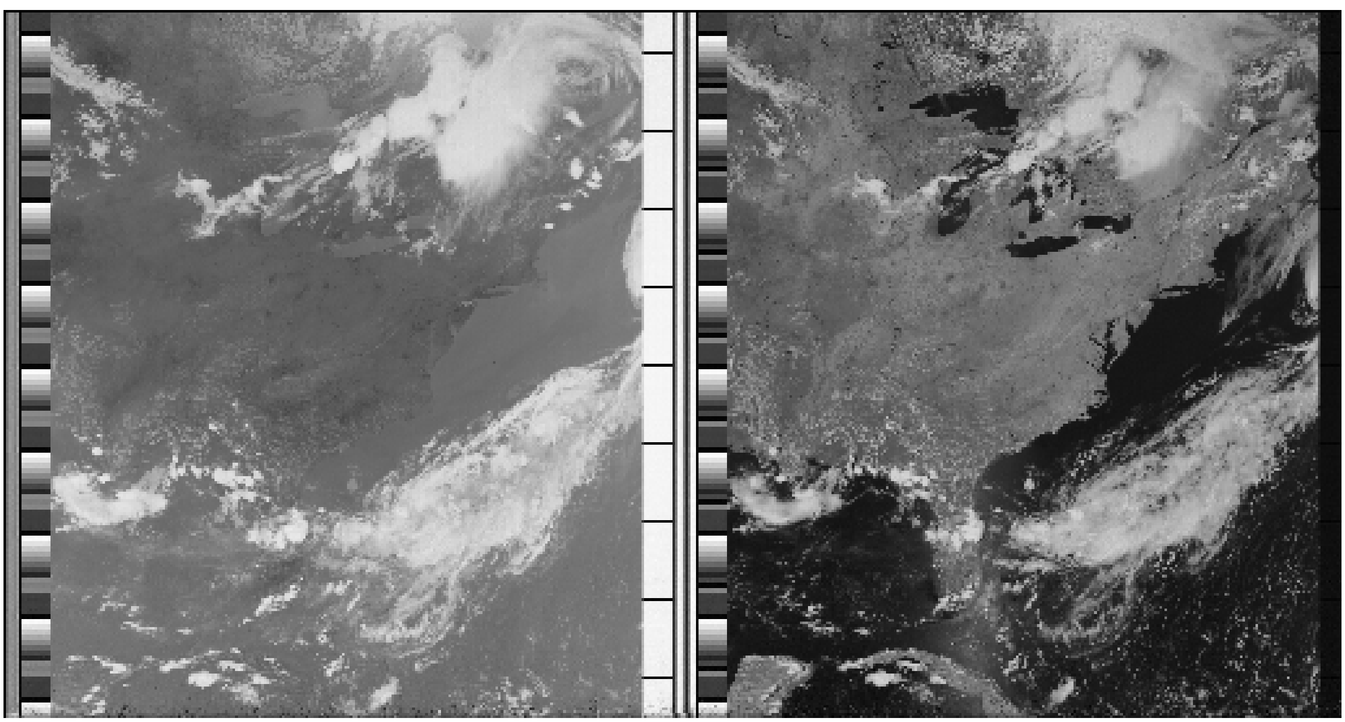


Figure IV-3 NOAA-17 APT Image

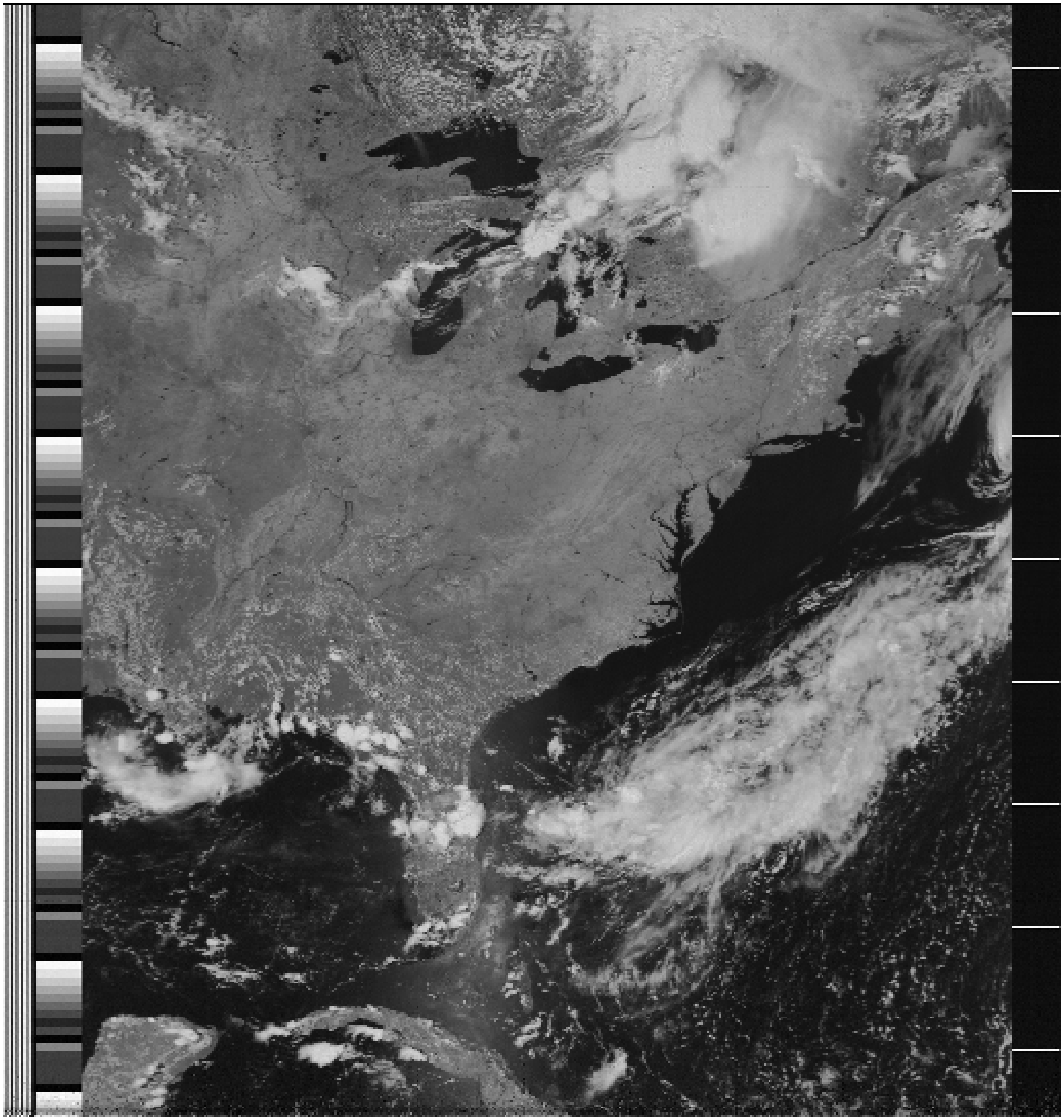


Figure IV-4 Visible Image Portion of Figure IV-3

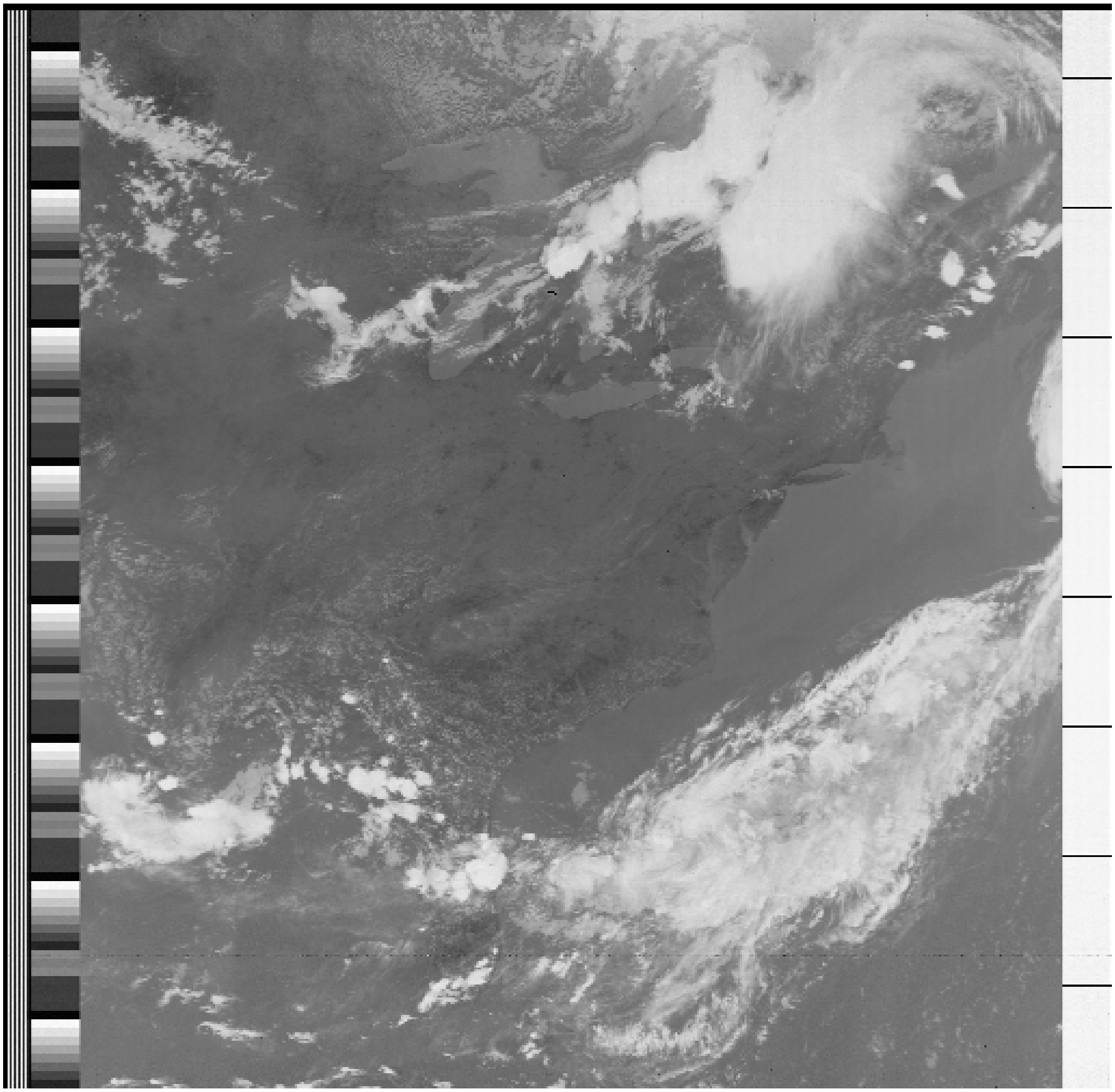


Figure IV-5 Infrared Image Portion of Figure IV-3

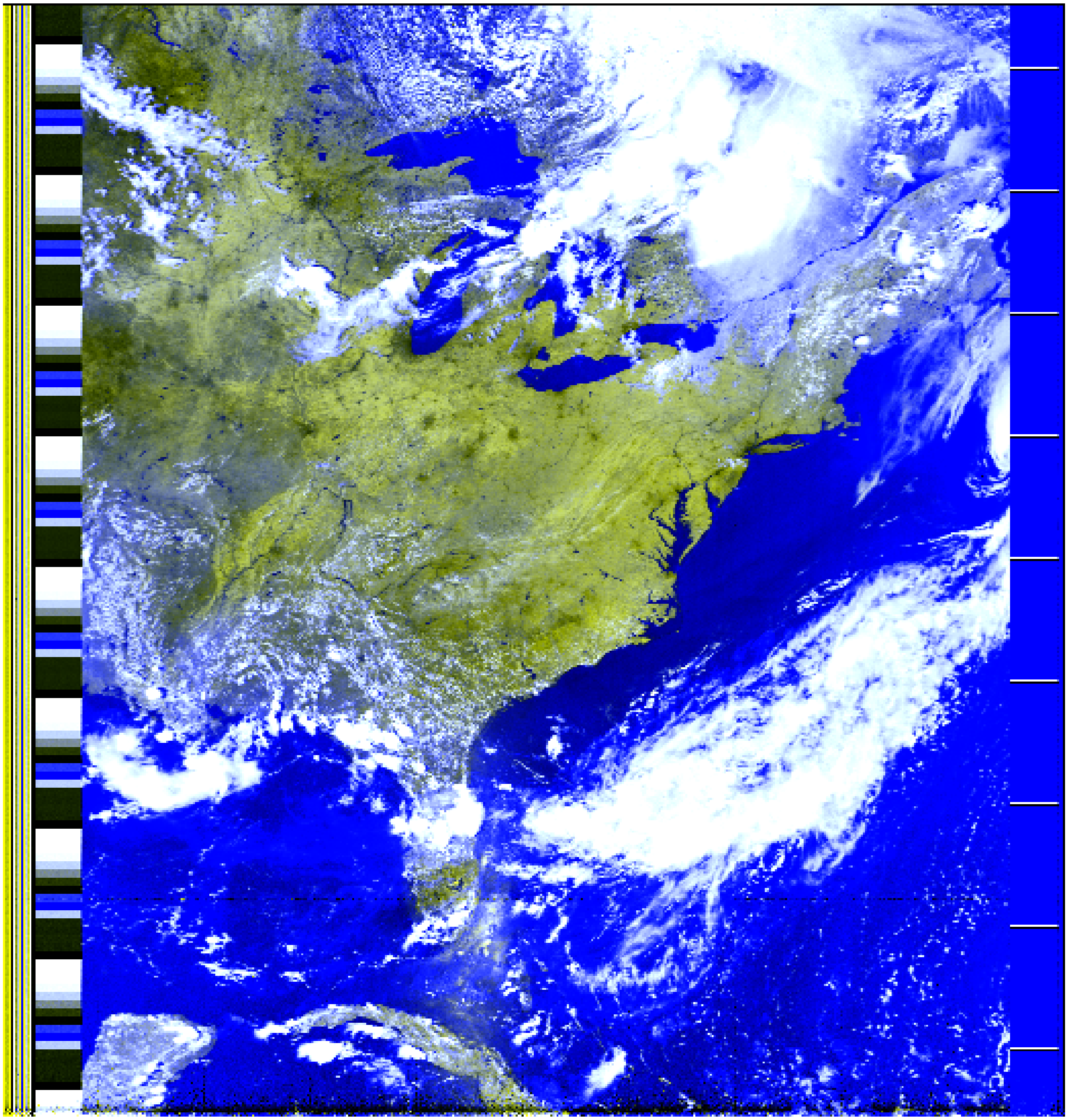


Figure IV-6 Color Enhanced APT Image with Infrared and Visible Channels Combined

DIRECT READOUT SENSORS AND IMAGE FORMATS

In order to gain an appreciation for the ground station equipment required to receive the polar orbiting direct readout imagery, it is helpful to have a basic understanding of the sensors on board these spacecraft, and how the images are created, formatted, and transmitted from the satellites to direct readout ground stations.

Polar Orbiting Environmental Satellite Direct Readout Sensors

The primary imaging sensor on the Advanced-TIROS satellites is the Advanced Very High Resolution Radiometer (AVHRR/3) instrument. The AVHRR is the latest in a long series of imaging instruments to be flown on the polar orbiting satellites. The original sensors provided by the early weather satellites were actually television-based systems using automatic (analog) picture transmissions. Since the TV vidicon tubes were very delicate and easily damaged by the rigors of space, they were replaced in later satellites by scanning radiometers.

The scanning radiometer is basically a system of various lenses, a motor-driven mirror system, and several solid state sensors sensitive to various wavelengths of the electromagnetic spectrum. The scanning radiometer builds up an image by scanning successive thin lines at right angles to the satellite's orbital track. The satellite motion along its orbital track causes the successive scan lines to form a contiguous, two-dimensional image. The system operates continuously, so an image of the Earth scene can be received for the full time the satellite is within range of the ground station.

The AVHRR scanning mirror rotates at 360 rpm, with each rotation of the mirror; data are collected from deep space, the Earth scene, and a warmed black body radiator. The scan across the Earth measures visible light and infrared wavelengths. Each infrared channel is effectively recalibrated on every revolution of the scanning mirror by providing the blackbody radiator and the deep space data as references. The spectral energy collected by the scanning mirror is passed to six separate detectors for the visible, near-infrared, and thermal infrared channels (See Table IV-1).

Channel	Spectral Range (μM)	Wavelength	Primary Uses
1	0.58-0.68	Visible	Daytime cloud/surface
			delineation, snow & ice
			melting
2	0.725-1.00	Near-infrared	Surface water delineation,
			sea surface temperature,
			vegetative indexing
3A	1.58-1.64	Near-infrared	Snow / Ice discrimination
3B	3.55-3.93	Thermal	Forest fire monitoring,
			nighttime cloud mapping,
			surface temperature
4	10.30-11.30	Thermal	Sea surface temperature,
			and night cloud mapping,
			soil moisture
5	11.50-12.50	Thermal	Sea surface temperature,
			and night cloud mapping

Table IV-1 AVHRR/3 Instrument Sensing Characteristics

The Channel 1 detectors are sensitive to visible light, and thus dependent entirely on sunlight reflected off the Earth. Illumination levels need to be quite high to obtain usable visible light images. Land/sea contrast is generally poor, particularly at higher latitudes. Channel 2 is reflected infrared energy. This channel is usually assumed to be the "visible" channel on APT transmissions. Land/sea boundaries are very clear and cloud detail is also very good. Channel 2 is the most used daytime channel for APT images. Channel 4 is the long wave infrared channel and is effective both day and night. It is the channel offering good land/sea and cloud contrast during the night and is the channel used for nighttime APT imagery. Channel 5 has very similar characteristics to Channel 4. Channel 3B can image the Earth by both reflected infrared and emitted infrared energy.

When energy falls on the AVHRR detectors, it generates a proportional electric current which is amplified and converted to digital information via an analog-to-digital converter. This digital information is what comprises the actual weather satellite imagery. The image is composed of 2048 picture elements (pixels) per line; the number of lines received at a station varies based on the length of time the spacecraft is above the horizon on that particular orbit. Each pixel transmitted has a resolution of 1.08 km. at the satellite nadir point (point on Earth immediately below the satellite sensor). However, as the image moves away from the nadir point, the pixels become progressively distorted, and resolution decreases to approximately 5 km.

This digital data from the AVHRR is processed to produce separate data streams that are transmitted by the satellite to the ground stations. These data transmissions are:

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

2. Global Area Coverage (GAC) - Recorded 4 km. digital images that are produced over all regions of the Earth and then are transmitted, on command, to NOAA command and control ground stations.

3. Local Area Coverage (LAC) – Full resolution HRPT data that are recorded over selected regions of the Earth and then are transmitted, on command, to NOAA command and control ground stations.

4. Automatic Picture Transmission (APT) - Continuous real time analog transmissions of 2 channels of processed, reduced resolution AVHRR data.

High Resolution Picture Transmission Data

The HRPT data format is digital, and is transmitted by the POES satellites at six lines per second (360 lines per minute). Each HRPT scan line is formatted as digital "words," with 11,090 words of information (each of these words is 10 binary digits (bits) long, providing 1024 levels of gray scale). Not all of the HRPT digital data is imagery. Data from the TIROS Operational Vertical Sounder (TOVS), the Space Environment Monitor, the Data Collection System, and the spacecraft telemetry are also transmitted.

Since the HRPT imagery is transmitted as a digital signal (665 kilobits per second, split phased encoded, phase modulated), at radio frequencies of 1698 MHz, 1707 MHz, or (standby) 1702.5 MHz, fairly sophisticated ground receiving equipment is required to receive the radio signal, demodulate the signal, and display it on a personal computer. Until recently, an HRPT receiving ground station was not economically feasible for most amateur users of POES direct readout imagery. The requirements for an HRPT ground station will be covered in the chapter on Advanced Direct Readout Systems.

Automatic Picture Transmission Data Format

The analog APT system was designed to produce real-time video images that can be received and reproduced by low cost satellite ground stations. This data stream is produced by amplitude modulating a 2400 Hz sub-carrier 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 data. Two of the six 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 and are not selectable by the user. 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, appropriate calibration and telemetry data for each of the selected images is inserted into the transmission. This results in an APT video format as shown in Figures IV-6 and IV-7.

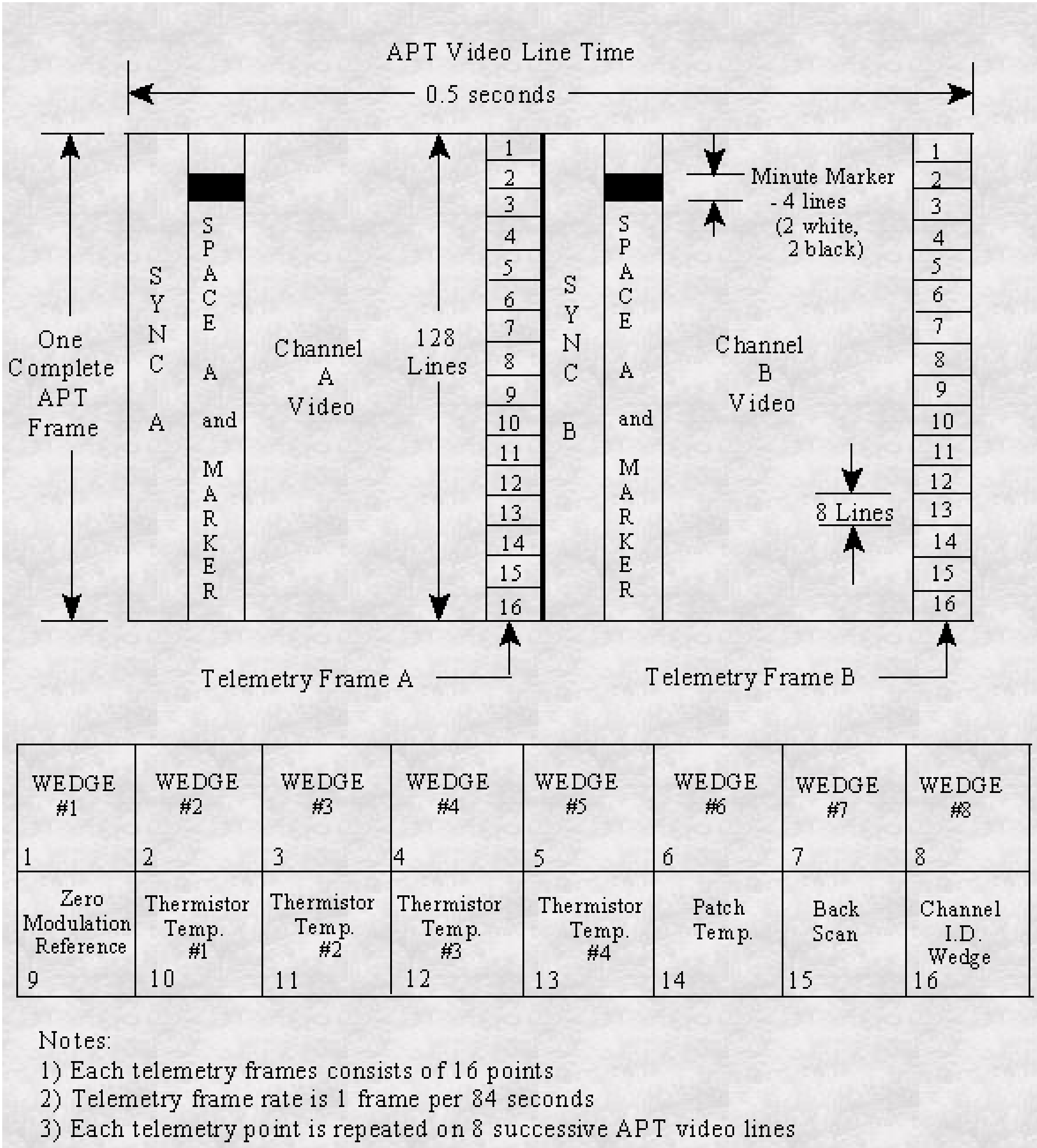


Figure IV-7 APT Frame Format

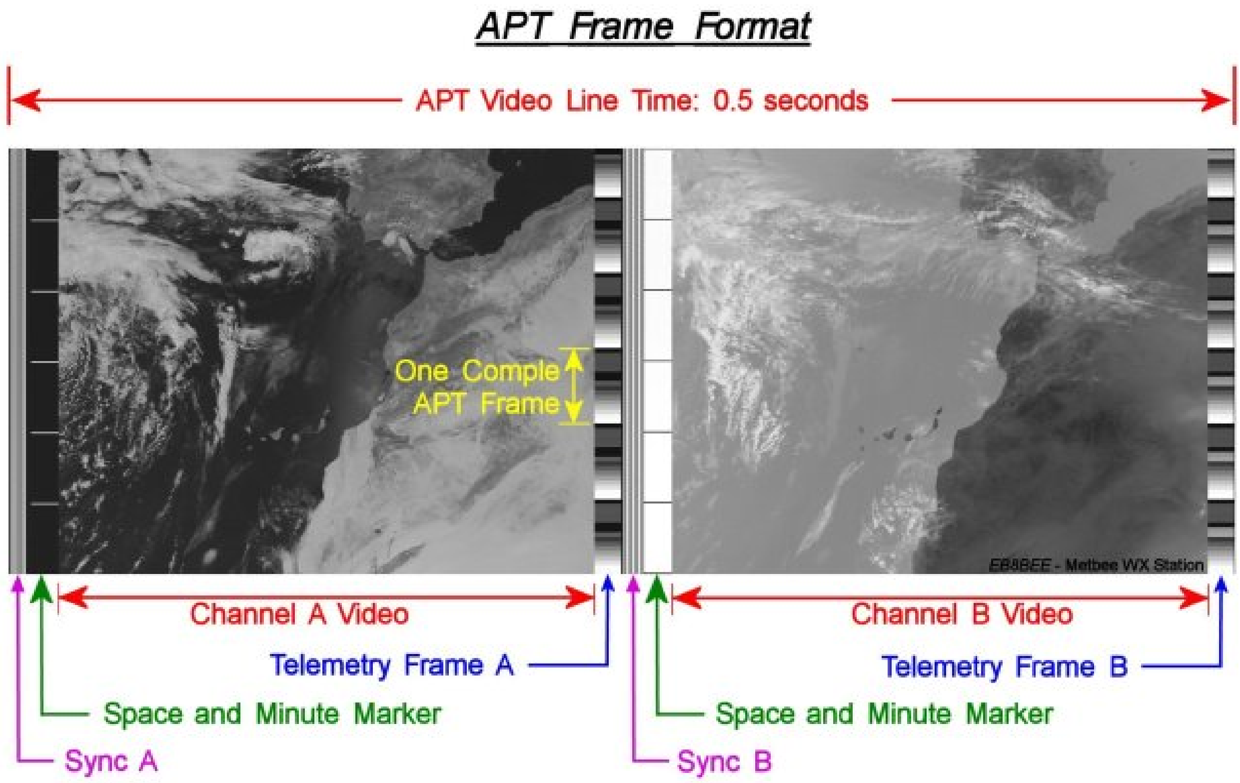


Figure IV-8 APT Frame Format Image

As can be seen in Figures IV-6 and IV-7 each APT 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 channel
4. A telemetry frame segment

Each 500 ms line of image data contains 250 ms of IR data, and 250 ms of visible light data. While the majority of each 250 ms interval consists of Earth scan data, the sync pulse, space data with 1 minute timing inserts, and telemetry frames are also of interest to the direct readout user. The following paragraphs describe these elements.

IR Sync Sequence - Each IR scan line begins with a 832 Hz square wave sync sequence where the sub-carrier swings between white and black for seven cycles. Receiving equipment can detect this 832 Hz sync to detect the IR component of the image. This train of pulses appears in the IR image as a series of fine vertical black and white bars. This IR sync and the visible sync make up the distinctive "tick-tock" sound on the received APT audio signal.

IR Pre-Earth Scan - Prior to scanning the Earth, the IR sensor briefly scans empty space. The IR data format represents cold as white in the image, and therefore space data appears as a white strip down the edge of the IR image. Once each minute, the spacecraft clock inserts minute markers into this pre-Earth scan portion of the image. These minute markers appear as thin, black horizontal lines across the white pre-Earth scan. The black markers provide a 60 second time reference in the image.

IR Earth Scan - The majority of the 250 ms IR scan is the scan of the Earth's surface. Warm objects appear black or shades of gray, with cold objects appearing white or lighter shades of gray.

IR Telemetry - At the end of the IR line is a zone dedicated to telemetry information. This data is coded as step-like changes in brightness, resulting in a strip down the right side of the IR image made up of gray scale step "wedges." This information is used for calibrating temperature data in the image.

Visible Sync Sequence - The visible image follows the IR scan data. The visible scan begins with a seven-pulse sync sequence similar to the IR sync, except it is a 1040 Hz rate so that the receiving equipment can discriminate between the IR and visible sync pulses. The visible sync pulses appear as narrower vertical black and white stripes down the left side of the image as contrasted to the IR sync pulses.

Visible Pre-Earth Scan - The scan of deep space in visible light produces a black stripe down the side of the visible image. The 60 second clock data appears as white horizontal lines across the vertical black strip.

Visible Light Earth Scan - The majority of the 250 ms visible light interval is taken up by the Earth scan data. This is a scan using reflected light from the Earth's surface, oceans, and clouds. Clouds appear in varying shades of white, water as black, and land features various shades of gray.

Visible Light Telemetry - The visible scan line ends with a telemetry window similar, but not identical, to the IR telemetry wedges.

During daytime passes, the APT format shows the visible data and IR data. During nighttime passes, the ground control stations may command the satellite to insert data from another IR channel to replace the visible channel, as the visible channel data would appear all black during a nighttime pass. The two IR channels would sample slightly different spectral bands, and thus would appear different from each other.

Further details of the APT format are available on-line via the NOAA KLM users guide which is available on web sites referenced in Appendix B.

Geostationary Satellite Sensors

The GOES satellites have independent Imager and Sounder instruments that operate simultaneously, they independently scan different portions of the earth scene. Raw data output from these instruments is received at a NOAA Command and Data Acquisition (CDA) ground station, where it is demodulated, processed, and output in the GVAR format by the Sensor Processing System at the CDA. After processing the data, the calibrated, earth-located, GVAR data is retransmitted back up to the GOES satellite, which in turn, retransmits it to the direct readout stations on the ground.

The GOES satellites carry a five-channel (four infrared and one visible) Imager and a 19 channel (18 infrared and one visible) Sounder. Imager channels 1, 2, 4, and 5 correspond approximately to the Advanced TIROS AVHRR channels 1, 3, 4, and 5. GOES Imager channel 3 is centered on 6.75 µM.

GVAR (Goes VARiable) Data Format

The GVAR data is digital data, transmitted to the direct readout ground stations at 2.11 Mbps. Resolution is 1 km. for the visible channel, 4 km. for three of the infrared channels, and 8 km. for the water vapor channel. The majority of the amateur direct readout community utilize the NOAA POES APT imagery, due to ground station complexity and cost constraints, a smaller portion of the direct readout population is currently receiving the high resolution GVAR image products. However, costs for GVAR readout stations have fallen over the past few years and the increasing number of users of these data now include small commercial enterprises, educational institutions and a few amateurs.

Ground stations configured to receive LRIT, HRPT and GVAR digital data will be described in the chapter entitled "Advanced Direct Readout Systems."

V. ANTENNA SYSTEMS FOR APT

Antenna systems for weather satellite reception consist of two primary elements, the antenna and the transmission system. Several design factors will determine how well an antenna system will function and thus will impact the overall quality of the weather satellite imagery. The three design considerations of primary importance include:

1. The physical size of the antenna components is determined by the frequency of the transmissions it is intended to receive. In most Very High Frequency (VHF) antenna designs, the driven elements or radiating elements are designed for 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 provide sufficient signal gain to produce noise-free reception whenever it is used with an appropriate radio receiver.

Several key definitions are required to fully understand the design and function of antenna systems. These include gain, beamwidth, and polarization:

Gain - The *gain* of an antenna is the measure of how much the antenna increases the level of the signal relative to some reference point. This reference point is usually a simple dipole antenna. Gain is based on a logarithmic scale, and the units of gain measured in decibels (dB). Since this is a logarithmic scale, a gain of 3 dB indicates a doubling of the signal level. The gain of the antenna will assist in overcoming signal losses in the cable transmission system and result in better overall image quality. However, higher gain usually means a decrease in the beamwidth of the antenna. External preamplifier circuitry can be used in conjunction with the antenna to increase the overall gain and signal strength presented to the radio receiver.

Beamwidth - *Beamwidth* is a measure of the width of the antenna pattern. The wider the antenna pattern, the more signals it will receive from different directions. Generally, the wider the beamwidth or pattern, the lower the gain of the antenna. Thus, a trade off exists for gain and beamwidth. A high-gain antenna must be pointed very accurately due to the narrower beamwidth. For polar orbiting weather satellites, this means that some method of tracking or pointing the antenna will be required.This is usually accomplished with a postioner mounted just below the antenna that can turn the antenna both in azimuth and elevation in order to track the movements of the satellite.

Antennas that are "omnidirectional," or receive signals from many directions, generally have very low gain, but have the advantage of not requiring a method of tracking of the satellite. One special type of omnidirectional antenna is called a quadrifilar design, and receives signals well from all directions.

Polarization - *Polarization* is a function of the orientation of the radio waves in space to that of the transmitting and receiving antenna. Ideally, the receiving antenna should be oriented in space to match the orientation of the transmitted signal, thus maximizing the signal strength. The most common types of antenna polarization include linear (horizontal, vertical) and circular polarization. TV and FM radio stations usually have horizontally polarized transmitting antennas, and thus TV antennas are designed to have the elements mounted horizontally to the ground. Police radios and cellular phones typically use vertical polarization, and thus the receiving whip antennas are mounted vertically on the automobile. Satellites, particularly polar orbiting platforms, commonly use antennas with circular polarization. This is due to the fact that satellites are in constant motion, and linearly polarized signals would be constantly changing polarization (and hence signal strength) with respect to linearly polarized ground station antennas. Circularly polarized antennas on both the spacecraft and on the ground provide a more stable received signal strength. A linearly polarized ground antenna can be used for the POES satellites, but significant signal loss would occur due to cross-polarization from the transmitting to the receiving antennas. Geostationary satellites do not move in relation to a ground station, so linear polarized antennas may be used at both the spacecraft and ground station.

The RF signal is right-hand circularly polarized on U.S. spacecraft and varies between left and right-hand circularity on the Russian and Chinese satellites.

VHF Antenna Systems for APT Imagery

Considering the frequencies, signal strength, and polarization factors of the transmissions, a number of antenna designs can accomplish adequate APT reception when used in conjunction with a good preamplifier and a properly designed radio receiver. These designs include both omnidirectional antennas and higher-gain beam antennas. With the advent of modern electronics; antenna construction remains as one of the few areas that amateurs can build hardware to yield significant savings and performance equivalent to commercially available antennas. There are numerous amateur webs sites with detailed instructions to construct antennas that are suitable for APT reception.

Omnidirectional antennas:

Turnstile Reflector - The turnstile reflector (see Figure IV-2) antenna is one of the simplest and least expensive antennas to use for APT weather satellite imagery. It is omnidirectional, theoretically receiving the satellite signal from all directions, is easy to mount, and does 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 can result in a reduced area of coverage compared to the higher signal gain offered by directional antennas. Due to the design and placement of the antenna elements in a turnstile, the satellite signal is often received better in one direction than others. This can create some loss of signal strength and a "fading" of the received APT transmission. Fading often results in noise bursts or "sparklies" in the APT video image.

Quadrifilar Helix Antennas - A quadrifilar helix antenna is a special type of omnidirectional antenna that provides a much better "radiation pattern" compared to turnstile reflectors, and does not suffer from the loss of signal strength exhibited in simple turnstile antennas. The quadrifilar helix usually consists of four 1/2-turn helices equally spaced around the circumference of a common cylinder. The radiation pattern is omnidirectional in the plane perpendicular to its main axis. Radiation of the signal is nearly circularly polarized over the entire hemisphere irradiated. This makes it almost ideal for receiving signals from polar orbiting weather satellites. Well designed quadrifilar helix antennas often exhibit inherent gain from 3 dB to 5 dB. A low physical profile combined with high performance makes the quadrifilar antenna an excellent antenna for APT reception in the home. Its small diameter also allows it to be enclosed in a waterproof housing or made from corrosion resistant materials.

Figure V-1 shows two quadrifilar helix antennas designed for 137 MHz APT reception. One antenna is commercially available; it is constructed of stainless steel specifically for marine use. The second antenna is a simple home built design. Instructions for home built Quadrifilar antennas designed for APT reception can be located on various web sites.

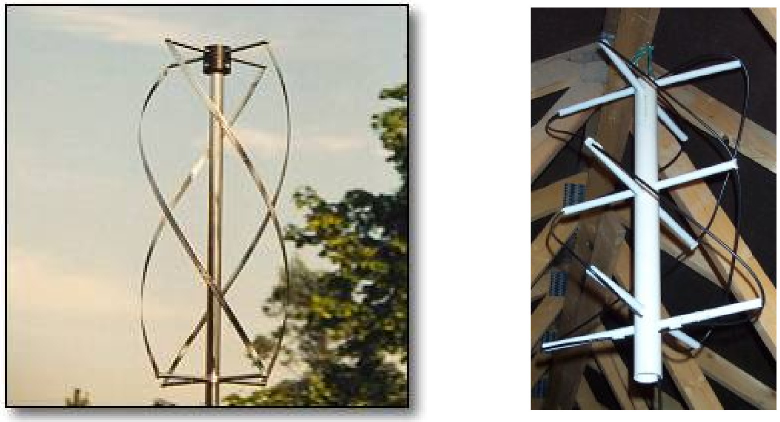


Figure V-1 Quadrifilar Helix Antennas

Pricing differences and performance at low reception elevations are the factors which separate the turnstile and quadrifilar antennas. The quadrifilar antenna will provide virtually noise free reception once the satellite reaches an elevation of 5 to 10 degrees above the horizon. The turnstile will provide slightly less performance at lower elevations levels, but is usually much less expensive to purchase than the quadrifilar design.

The simple omnidirectional antenna shown in Figure V-2 can be constructed by modifying a commercial FM antenna with a pair of crossed, folded dipole elements. These antennas can be found in many stores and on web sites selling television and radio antennas. Such antennas are low cost, and are made of thin wall aluminum tubing that can be cut to modified dimensions quite easily. Similar antennas designed specifically for APT can also be purchased commercially.

The antenna in Figure V-2 was modified as follows:

1. The length of the folded dipoles (A and A') was reduced by trimming the longer FM element tubing to 103 cm (40.3 inches) to provide an approximate 1/4 wavelength match for the 137.5 MHz center frequency of the APT transmission.

2. Two reflectors (B and B') at right angles to each other were made from 6.4 mm (1/4 inch) diameter aluminum tubing, cut to 113 cm (44.1 inch) length. These were mounted 43.6 cm (17 inches) below and parallel to the folded dipoles. These reflectors create a broad beam antenna that, when pointed vertically, allows a wide angle of antenna reception with no need for pointing toward the satellite as it passes over the ground station.

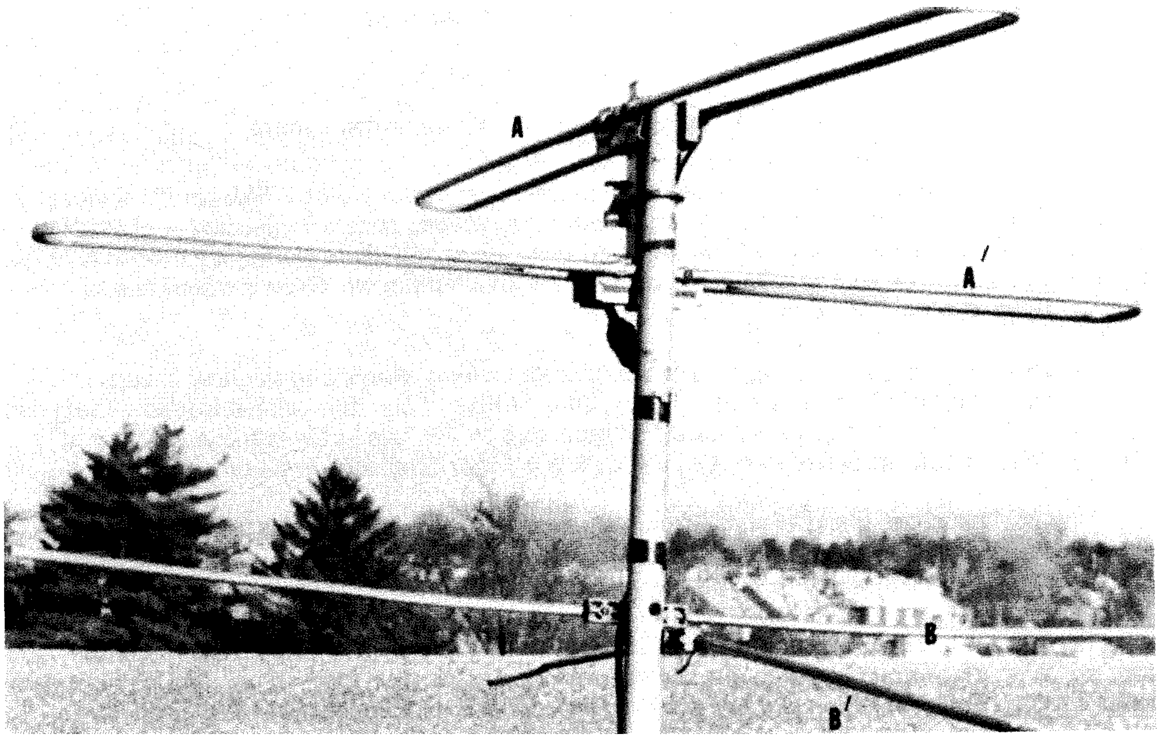


Figure V-2 Modified FM Antenna for Omnidirectional APT Reception

Directional Antennas:

Directional antennas offer much higher gain and signal to noise ratios compared to simple onmidirectional antennas. Such directional antennas have very sharp radiation patterns, and therefore require accurate tracking of the satellite to take advantage of the gain provided by the antenna system. This tracking requirement presents an additional complexity to the receiving station both in construction and operation since the satellites must be actively tracked from horizon to horizon. Directional antennas can be positioned using TV type rotors mounted in an Azimuth / Elevation configuration or using commercially available or home built antenna positioners controlled by a PC.

Crossed Yagi -The crossed yagi directional antenna has been a popular choice for many amateur constructed APT stations. This design functions well for APT reception, is relatively inexpensive, and can be purchased commercially or constructed without much difficulty. The crossed yagi antenna consists of a number of elements similar to a multi-element TV antenna. The major difference 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. Figure V-3 illustrates a commercially available crossed Yagi antenna (without satellite tracking positioners).

Figure V-3 Commercial Crossed Yagi Antenna

The Transmission System

The components of the transmission system which carries the RF signal from the antenna to the radio receiver are a critical part of the satellite station. Proper construction of this portion of the direct readout station is important to ensure that radio frequency signal losses do not exceed acceptable limits. Excessive cable lengths and improper cable selection can result in significant attenuation of the signal

To avoid excessive loss of signal from the antenna to the radio receiver, low loss 50 ohm RG8U coaxial cable should be used for the transmission line leading through the building to the receiver. Most receivers require a 50 ohm impedance match between the antenna cable and the receiver and therefore support direct connection of a 50 ohm cable.

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 (i.e. "Coax-Seal") so that water cannot enter the connectors or cable and cause electrical shorting. If this does happen, serious signal loss will occur.

Modified FM antennas and some home built antennas are designed to connect to 300 ohm TV lead-in wire. For a better impedance match between the 300 ohm TV line and the 50 ohm RG-8U, a matching transformer or balun should be inserted between the TV line and the RG-8U cable.

For stations with relatively short feed cable lengths a pre-amplifier may not be required to achieve high quality, noise-free signals from the satellite. However longer feed lengths may require that a preamplifier be incorporated into the transmission system. These preamplifiers offer less than 0.5 dB noise for about 20 dB gain and can be ordered pre-tuned 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. Most commercial preamplifiers are weatherproof, and can be placed in exposed locations. Many preamplifiers have provisions for powering the electrical components through the coaxial line rather than running a separate power line to the preamplifier, they have components to provide +12 volts to the center conductor of the RG-8U cable at the radio receiver end. Some receivers have their own internal pre-amp power supply; these supplies typically have current limiting to prevent damage if shorted. Figure V-4 shows a commercially available pre-amp which includes band pass filtering and is designed specifically for APT reception.

Figure V-4 Commercial Pre-Amplifier

VI. RADIO RECEIVERS FOR SATELLITE DIRECT READOUT

One of the key components of a direct readout station is the radio receiver. The type of radio receiver used for the satellite downlink will determine the ultimate quality and resolution of the APT imagery. Radio receivers for direct readout stations are similar to the many FM "high band," solid state receivers used to receive police and fire department transmissions, and NOAA weather radio broadcasts. 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 polar orbiting weather satellites of the United States are given in Table VI-l.

Parameters	U.S. POES
Frequency	137.50, 137.62, 137.1, 137.9125 MHz
Carrier Modulation	Analog AM/FM
Transmit Power	5 Watts
Antenna Polarization	Right Hand Circular
Carrier Deviation	+/- 17 KHz

TABLE VI-1 APT Transmission Parameters for POES Satellites

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

- The frequency of the transmitted APT signal
- The type of RF signal modulation
- The bandwidth of the transmitted signal
- The sensitivity of the receiver
- The selectivity 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. All the satellites are transmitting APT with Frequency Modulation (FM) with an underlying sub-carrier that is amplitude modulated. 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 (and least expensive) 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 and distributors. Many of these advertise in popular radio magazines, and have on-line shopping or 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.

Newer radio receivers have a built-in frequency synthesizer. Crystals are not required. The frequency is simply punched in via a keyboard on the radio or through the use of tuning switches. One advantage of a synthesized receiver is that no additional crystals are required if the frequencies for APT reception are changed. Many newer radios also have the capability to automatically scan a set of frequencies for active signals, allowing for automatic reception of APT imagery from multiple satellites at different times of the day.

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. Too narrow an IF bandwidth and the blacks and whites in the imagery will be clipped. 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). A signal received on a typical police-type scanner with a +/- 7.5 KHz (15 KHz bandwidth) will be very distorted and produce poor imagery. It is possible to modify these receivers by changing out the original IF bandwidth filter with one closer to 30-40 KHz deviation and receive adequate imagery from both the POES and Russian satellites.

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 microvolts, 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 most personal budgets. Generally, there are three practical ways of obtaining radio receivers:

1. Purchase a commercial receiver specifically designed for APT
2. Modify a scanner receiver for the correct bandwidth
3. Modify a surplus high-band commercial receiver

COMMERCIAL RECEIVERS

The simplest, most effective approach is to purchase a commercial weather satellite receiver. There are several vendors who market crystal-controlled and fully synthesized receivers optimized for the 137 MHz weather satellite band. References to commercial vendors are discussed at the back of this publication. One such vendor is Hamtronics, Inc. An example of their crystal controlled receivers is the R139 which is shown in Figure VI-1, and is typical of such APT receivers.

Figure VI-1 Crystal Controlled Receiver

The R139 Weather Satellite receiver is a low cost, crystal controlled receiver featuring high sensitivity (0.2 microvolts typical) and selectivity for the 137 MHz band. This receiver uses special wideband filters for 38 KHz IF modulation acceptance and low video distortion from the U.S. POES spacecraft. The unit can automatically scan up to five channels, and lock on to any one active satellite frequency. The scan circuit contains a tape recorder control to allow automatic and unattended search and recording of satellite signals. The R139 can be purchased *fully* assembled or in a kit form.

There are several sources for commercial, frequency synthesized general coverage broadband receivers. They are available with interfaces allowing them to be directly controlled by a personal computer. These high-end commercial units cover both the VHF APT weather satellite band, as well as the WEFAX, GVAR, and HRPT S-band frequencies of 1.6 and 1.7 GHz. These receivers are very flexible and can be fully programmable either in manual mode or via a PC. Due to the bandwidth requirements of APT a modification kit may be needed to change the IF bandwidth in FM narrow-band mode to 40 KHz. Most of these receivers are in the $ 500 to $1000 price range, but they provide many features allowing reception of several different direct readout data products, and other radio services.

SCANNERS

One economical approach to obtaining a weather satellite receiver is to modify a new or used police or utility band scanner. Several different types of scanners exist in the used marketplace, including crystal controlled scanners, programmable scanners for public service bands, and the wider-coverage commercial scanners.

Crystal-controlled VHF scanners covering the 144-174 MHz band are fairly common. These are generally the easiest to convert by those familiar with hobby electronics. Crystals for the 137 MHz band can be ordered, an IF filter of 30-40 KHz bandwidth can be installed, and with a slight amount of re-tuning, the modifications should provide adequate signal quality for APT imagery. A good preamplifier is recommended as the front-end sensitivity of these earlier model scanners was generally poor.

Programmable scanners made by Radio Shack, Uniden, and other manufacturers are also prime candidates for low cost APT receivers. Many of these scanners already cover the 137 MHz frequency range. It is simply a matter of punching in the correct frequency with the keypad and modifying the IF filter. One brand of scanner, manufactured by Uniden, simply requires the 10.7 MHz IF ceramic filter to be removed, and replaced with a 0.01 microfarad capacitor to bring the IF bandwidth to 40 KHz. This procedure normally takes less than thirty minutes and can provide good performance for a APT receiver. Once again, a good preamplifier, preferably mounted at the antenna, is recommended for higher gain and sensitivity.

SURPLUS HIGH BAND RECEIVERS

Many police and fire departments have been retiring the commercial FM units designed primarily for the VHF frequency ranges, in favor of the newer 900 MHz cellular or trunked radio systems. These surplus units are of high quality, and could be converted to the 137 MHz frequency with minimal effort. Often these units may be obtained at very low cost or even free for schools. Typically the IF frequency filters need to be changed for 30-40 KHz, and some retuning of the front-end circuitry required for peak performance at 137 MHz. Local ham radio operators can often assist with conversion of these units.

PREAMPLIFIERS

Due to the fairly low signal strength from the POES satellites, receiving stations generally require a high quality preamplifier. The preamp should have a reasonable amount of gain and a relatively low noise figure. Gain specifies how much signal is amplified, and the noise figure is a measurement that specifies the amount of noise the amplifier adds to the original satellite signal. A noise figure of 1 dB and a gain of 15 to 20 dB are more than adequate for APT reception.

The general rule on preamplifier gain is to use only enough gain to set the system noise figure and overcome the loss in the coaxial cable that connects the preamp to the receiver. Any excess gain contributes to receiver inter-modulation problems. Inter-modulation (also called intermod) is a common problem for receiving stations located in larger cities. Intermod is created in the receiver due to excessive preamplifier gain. If you hear aircraft radios or ham radios coming through the satellite receiver, then intermod is usually the problem.

Typically, signal losses in a 100-foot run of RG-8 coax can be as much as 50%, depending on the frequency of the received signal. Preamplifiers help boost the initial signal strength prior to traveling down the coax line to the receiver. Modern preamplifiers use either JFET or Gallium Arsenide JFET transistors. These units provide high gain (20 dB typical) with low noise figures (0.8 dB). Normally the preamps are manufactured in a small metal enclosure with either PL259 or N connectors at both ends for the attachment of coax cable to the antenna and the receiver.

Preamplifiers mounted at the antenna will require both power and waterproofing. Either a separate +12 volt line may be run externally to the preamplifier, or, the coax feed line can carry both the DC power and the RF signals. Many modern weather satellite radios can provide the + 12 volts to the preamp directly from the radio through the coax lines. Weatherproofing can be provided with rubber gasket seals around the metal housing and antenna connectors. Commercial preamplifiers can be purchased for around $60, and can be provided in weatherproof metal enclosures for in-line mounting close to the antenna.

RECORDING SATELLITE SIGNALS FROM WEATHER SATELLITES

With advances in PC memory capacity and disk storage space, most users will store satellite imagery directly on their PC in a digital format. This readily provides for image processing, enhancement and display. However since the APT sub-carrier at 2400 Hz is in the middle of the audio range, this signal can also be recorded and reproduced using a tape recorder.

Many audio tape recorders 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. The use of a tape recorder with large 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. Recorders with a wow and flutter around 0.3% will work well with APT if a sync tone is used.

Users report that digital audio tape (DAT) recorders provide a good platform to record APT signals with little or no distortion in the video image. Users have also had good results using video recorders, since these usually have excellent wow and flutter specifications.

VII. DEMODULATION AND DISPLAY OF APT IMAGERY

The next major component of the direct readout station is that of demodulation and display of the imagery. Once the signal is received from the POES satellites, the audio tones must be converted or demodulated to represent varying levels of visible and infrared energy as processed by the satellite radiometer. Computer display systems are 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 available, only a general discussion of this subject is possible in this publication. However, some computer features that are required for satellite direct readout are examined, which can guide the user in selecting a computer that will meet their needs.

The diagram in Figure IV-1 shows a generalized view of the hardware components that are found in most personal computer APT systems. At the ground station radio receiver, the satellite transmissions are detected as a 2400 Hz amplitude modulated (AM) signal transmitted at 120 lines per minute from the POES 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 sub-carrier, 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 sub-carrier 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 binary 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 also 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.

Purchasing a commercial satellite computer display system is probably the most viable alternative in setting up a direct readout station. If a computer is already available, the cost of the additional hardware and software is normally not prohibitive. The commercial direct readout systems now available have been designed for a variety of computers and have many different features. A partial list of vendors is available from the resources listed in the Appendices. Some features that can be expected from these commercial systems are:

1. Capture and display of U.S. POES satellite data.
2. Automated image ingest and storage in various graphic file formats
3. Color enhancement of images
4. Multi-spectral (IR and visible) image processing and enhancement
5. Automatic IR channel temperature calibration
6. Zoom and pan features
7. Built-in satellite prediction and tracking routines
8. Scheduling features for unattended satellite image capture
9. Automatic longitude/latitude and geopolitical gridding
10. Some of the systems provide an input jack for a Global Positioning Satellite (GPS) receiver to input the station's exact location, altitude and precise local time directly to the satellite receiving system

Since APT data transmissions have been available for over 40 years, many of the commercially available systems were developed for earlier versions of personal computers. With this in mind, the system requirements for APT reception are quite modest by today's standards for memory capacity, speed and disk storage. Since these requirements are so modest a personal computer configuration meeting these requirements may be readily available as a second hand or surplus machine.

As an illustration, the following is the recommended minimum configuration for a commercial system in use by NOAA to receive and process APT data; this software also runs on more current hardware and operating systems:

- IBM PC compatible with 80486 processor (Pentium II recommended)
- Microsoft Windows 95/98/NT
- 16 MB of random access memory
- 20 MB free hard disk space
- Super VGA type display with at least 800 x 600 pixels and 256 or more colors
- Spare serial port

The exact configurations of commercial APT systems will vary depending on the computer type and features offered. In some cases both the demodulator and receiver are combined on an internal PC card, and for some both the receiver and demodulator are external units. In a system that has an external receiver and demodulator, cables must be installed between the receiver, the audio input jack of the demodulator, and the demodulator output to the computer. Following the physical installation of the receiver / demodulator to the personal computer, cables are connected from the receiver to the APT preamplifier and antenna.

SETTING UP AND USING DIRECT READOUT SOFTWARE

APT software programs generally have four or five main functions. These would include:

1. Initial Configuration and System Setup
2. Satellite Image Capture and Scheduling
3. Satellite Prediction and Tracking
4. Viewing and Enhancement of Satellite Imagery
5. Image Animation

After some initial configuration and testing, the user has a choice of capturing new satellite images, displaying and enhancing images already in memory or stored on the hard drive, creating weather animations from a series of stored images (typically only used for geostationary satellite images), or predicting when a particular satellite will be in view of the ground station.

l. Initial Configuration and System Setup

A software installation program will properly configure the software for the type of demodulator card, APT image reception, and printer configurations. Most vendors provide a software installation routine to assist the user with setting the correct interrupt levels and addresses unique to the personal computer and the specific type of computer operating system. Following installation of the demodulator card and software, an internal test routine may be run to validate proper installation of the hardware and configuration options.

One of the first items to customize in most direct readout software programs is to tell the program your geographic location and local time information. This data is used to help predict when the polar orbiting satellite will be in view of your station, and also to setup 24 hour scheduling of APT imagery. Normally the program will ask for the following information:

- Latitude

- Longitude

- Height above sea level

- Time offset from Universal Time Coordinate (Greenwich) time

The latitude, longitude, and height above sea level can be obtained from a good quality atlas, local pilots, airports, or municipal government offices. The latitude and longitude values entered should be accurate to at least one arc minute or 0.0167 decimal degrees. Height should be accurate to the nearest 305 meters (1000 feet). UTC time offset is based on your local time zone. The UTC offset for Eastern Standard Time would be -5 hours, for Central Standard Time -6 hours, etc. All four data points can usually be obtained by calling the local flight control center at the local airport. Alternatively, a GPS receiver may be used to directly input this data.

2. Satellite Image Capture and Scheduling

APT direct readout software needs to know which satellite will be transmitting the imagery so that it can be properly formatted and displayed, or to animate several frames of APT images. For systems that have built in receiver control, this will also set the correct frequency for the satellite transmissions. Most APT software uses the concept of a configuration file to define what is expected from specified satellites.

Several of the weather satellites differ in their characteristics. Polar Orbiting satellites use several different VHF frequencies to transmit the APT information, including 137.40 MHz, 137.50 MHz, 137.62 MHz, 137.85 MHz, and 137.795 MHz The image formats used by U.S. and Russian satellites are very different: U.S. satellites send two side-by-side images simultaneously, while the Russian satellites send one visible or infrared image only. U.S. satellite image information is synchronized (phase-locked) to the radio signal frequency, while most Russian satellites are not synchronized. When utilized, phase-locking allows image registration control during reception, which assures that the image is precisely aligned vertically, without any sideways skew or bowing of the images. Finally, satellites alternate between ascending passes (south to north movement) and descending passes (north to south movements).

In order to properly receive and display images, the software must know which satellite will be transmitting the imagery. For example, data will not be received if the desired satellite is transmitting an image on 137.5 MHz, but the software has configured the receiver to 137.62 MHz. Furthermore, once the receiver is set to the correct frequency, the image will not be displayed properly if the satellite type is set to Meteor when attempting to receive a U.S. NOAA satellite. With the software set to a satellite type of Meteor, the adapter card will listen for the 256 Hz tone burst that defines the image edge of a Meteor satellite, but the NOAA satellite uses a 832 Hz tone burst. Since the expected tone burst will not be received, the image will not start.

Thus, a configuration file will help determine which satellite profile needs to be implemented. A list is normally displayed of the various weather satellites capture modes, including: NOAA POES, Meteor, Feng Yun, METEOSAT, GMS and, possibly OKEAN.

Often the capture program will allow the user to specify the image sampling rate, which will define the image resolution. The APT images are sent as individual scan lines. Many direct readout adapter cards have the ability to vary the number of samples that are taken and stored from each line of image information. When the sample rate matches the resolution of the images being transmitted, then the maximum image resolution is captured, and no increase in the image quality will be gained by setting the sample rate to a higher value. The cost for the increased resolution is that the stored file size increases with higher resolutions. An image capture at 4,800 samples per second will be 33 percent larger than one captured at 3,200 samples per second. So, the file size is a tradeoff for increased resolution.

The sampling rate also affects image symmetry. For example, increasing the sample rate will increase the resolution of an individual scan line, but since the number of scan lines is fixed by the transmission format, the image symmetry will change. Optimally square pixels are obtained in NOAA APT image transmissions by using the 4096 sample per second rate. Increasing or decreasing the sample rate will change the resolution at the expense of the image symmetry.

The image capture routine will typically allow setup up of specific directories to store the captured satellite images. The software may also support several different graphics file types for the received images (i.e., GIF, JPEG, TIF, PCX, BMP, etc.).

The image capture routine also requires a method to correct for Doppler shift. Since the polar orbiters spend virtually all of their time moving from or toward the ground station receiver, the frequency as seen by the stationary receiver is shifted (the Doppler effect). If the receiver does not correct for the amount of shift, the image will bow as is shown in Figure VII-1. This is due to the fact that Doppler shift slightly adds to, or subtracts from, the 2400 Hz sub-carrier being transmitted by the satellite. If the receiver uses a fixed oscillator as a reference frequency, the Doppler shift changes the start and stop for each scan line in relation to the fixed oscillator. Use of a Phased Lock Loop (PLL) circuit in the APT demodulator can correct the Doppler shift problem. By setting the PLL clock, the hardware locks onto, and tracks the received frequency instead of a fixed oscillator. The PLL therefore tracks the amount of Doppler shift and compensates for it. The use of the PLL allows true vertically aligned images in spite of the Doppler shift present on the satellite signal.

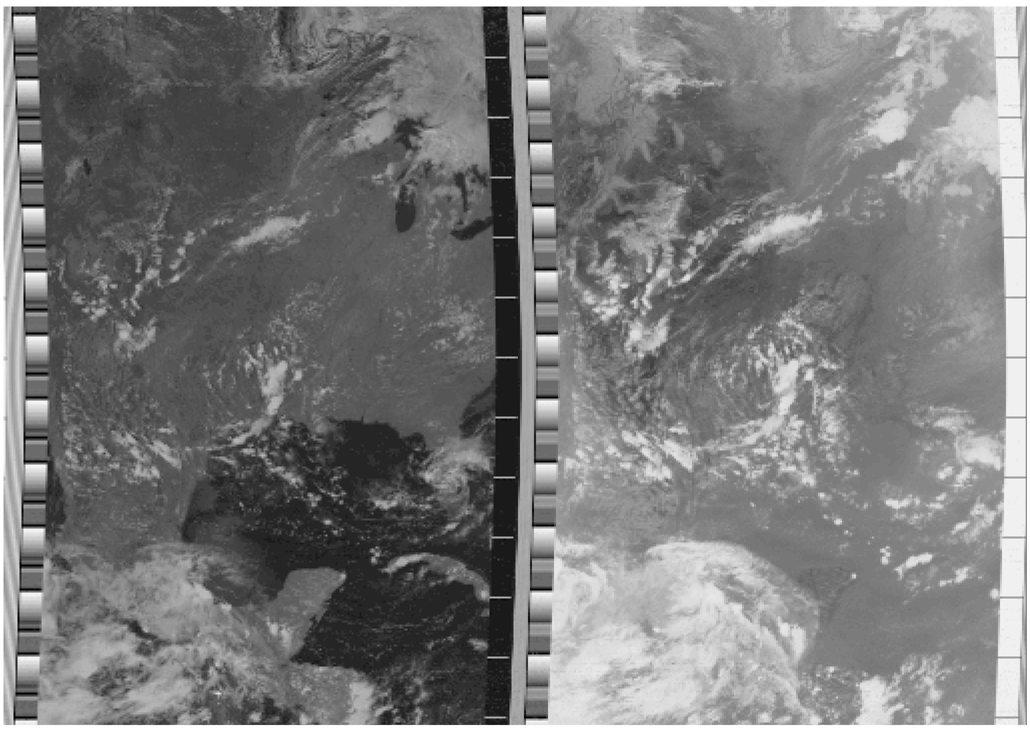


Figure VII-1 Doppler Shift "bowing"

The software program may also allow the user to establish time slots when images will be automatically received and stored to the hard drive. This allows unattended reception of images for later use or analysis at a more convenient time. Most scheduler routines work on a 24-hour format. The schedule will wait until the scheduled time before capturing the image for the scheduled duration. For polar orbiting satellites, normally you set each event in the scheduler to start one minute before the image is transmitted and the stop time to one minute after transmission is predicted to end.

3. Satellite Prediction and Tracking

Several of the APT direct readout systems include a "Predict" function which provides satellite prediction, tracking, and APT data capture in a single, integrated program format. Use of the standard "SGP4" satellite orbital prediction model is common. This is a mathematical model intended to track and acquire data from polar orbiting satellites. The SGP4 prediction model is accurate for all low altitude satellites such as the NOAA POES and Russian Meteors. Although the satellites can be entered which are not strictly covered by the SGP4 model, such as geosynchronous satellites, the accuracy of the predicted position is decreased since deep space perturbations are not accounted for. Further discussion on predicting when the satellite will be in view and orbital mechanics will be covered in the chapter on "Satellite Tracking and Prediction."

Three items are critical to the proper tracking of satellites during image capture:

Accurate time - Probably more important than any other item, the PC clock should be accurate to within two seconds. Time is especially critical if images are to be ground located (map grid lines added) based on time of reception. There are shareware programs available from on-line bulletin boards and Internet sites that allow the computer to be synchronized with the National Institute of Standards and Technology (NIST) or the U.S. Naval Observatory. These programs can readily set the PC clock to an accuracy of 0.5 second or better. The NIST provides time synchronization via radio, internet, and dial-up modem. Alternatively, a GPS receiver may be used to set the PC clock.

Accurate Ephemeris - The ephemeris data need to be updated at least every two weeks. This is actually radar observation data gathered by the U.S. Air Force and is the information used by the satellite prediction program to determine when a satellite will be in view of the ground station. Ephemeris data (otherwise known as Keplerian elements) may be obtained from many bulletin boards and the Internet. Some sources are in the Appendices.

Accurate Ground Station Location Information - the latitude, longitude, and height above sea level entered during the initial setup of the APT program will be used by the satellite prediction routines in determining acquisition of signal and loss of signal times for the satellites. Some software packages support GPS receiver updates of ground station location; this is especially helpful for marine and mobile systems.

A separate satellite prediction/tracking program may also be used for those APT systems that do not include an integrated satellite prediction function. Such programs are available as "shareware" and "freeware." Use of a multitasking operating systems such as Windows allow both the APT capture program and satellite tracking routine to be run concurrently.

4. Viewing and Enhancement of Satellite Imagery

The ultimate goal of direct readout is the actual viewing and manipulation of the satellite imagery. APT programs often provide extensive image processing functions such as zoom, rotate, contrast, brightness, false coloring, sharpen, smooth, noise filter equalize, NOAA enhancement curves, and even 3-D effects of the IR imagery are possible. The ability to place map grid lines and a temperature calibration of the NOAA imagery are other features often integrated into the programs and can add to the information value extracted from the image. Once image enhancement has been performed on the original image, the new image may be saved under a different filename to compare and contrast with the original data.

When temperature differences in transmitted infrared images are small, it becomes difficult for the human eye to recognize significant cloud and surface features present in the images. The information may be present, but the observer cannot discern the features. Such phenomena include convective weather features, haze, fog, ocean current boundaries, and terrain features. Image enhancement, through the use of enhancement curves, increases the contrast between targeted features and the background, which serves to make the features more apparent. These curves also serve as a convenient way to identify several different types of features within the images. Satellite images may also be colorized, by changing the palettes used for the image. Such false-coloring can often assist with accentuating cloud tops, rotation in hurricanes, and sea surface temperatures.

A map overlay function is another useful feature of direct readout programs. The polar orbiting weather satellites do not transmit images with map overlays as is done on the GOES GVAR direct readout. The lack of map overlays can create difficulties identifying land and water features in images covered with clouds, since no reference point can be found in the image. APT software often overcomes this limitation with the ability to create map overlays (longitude, latitude, and geopolitical boundaries) for NOAA polar orbiting weather satellites.

Figure VII-2 shows a NOAA 17 APT thermal image with geopolitical gridding applied and a user created enhancement curve. This curve was selected to enhance variations in ground temperature which reveals warmer temperatures in urban areas. The info window shows the surface temperature at a selected curser location (Chicago) to be 88 ^{o}F, it also calculates the latitude, longitude, and heading and distance from user selected location to the curser position.

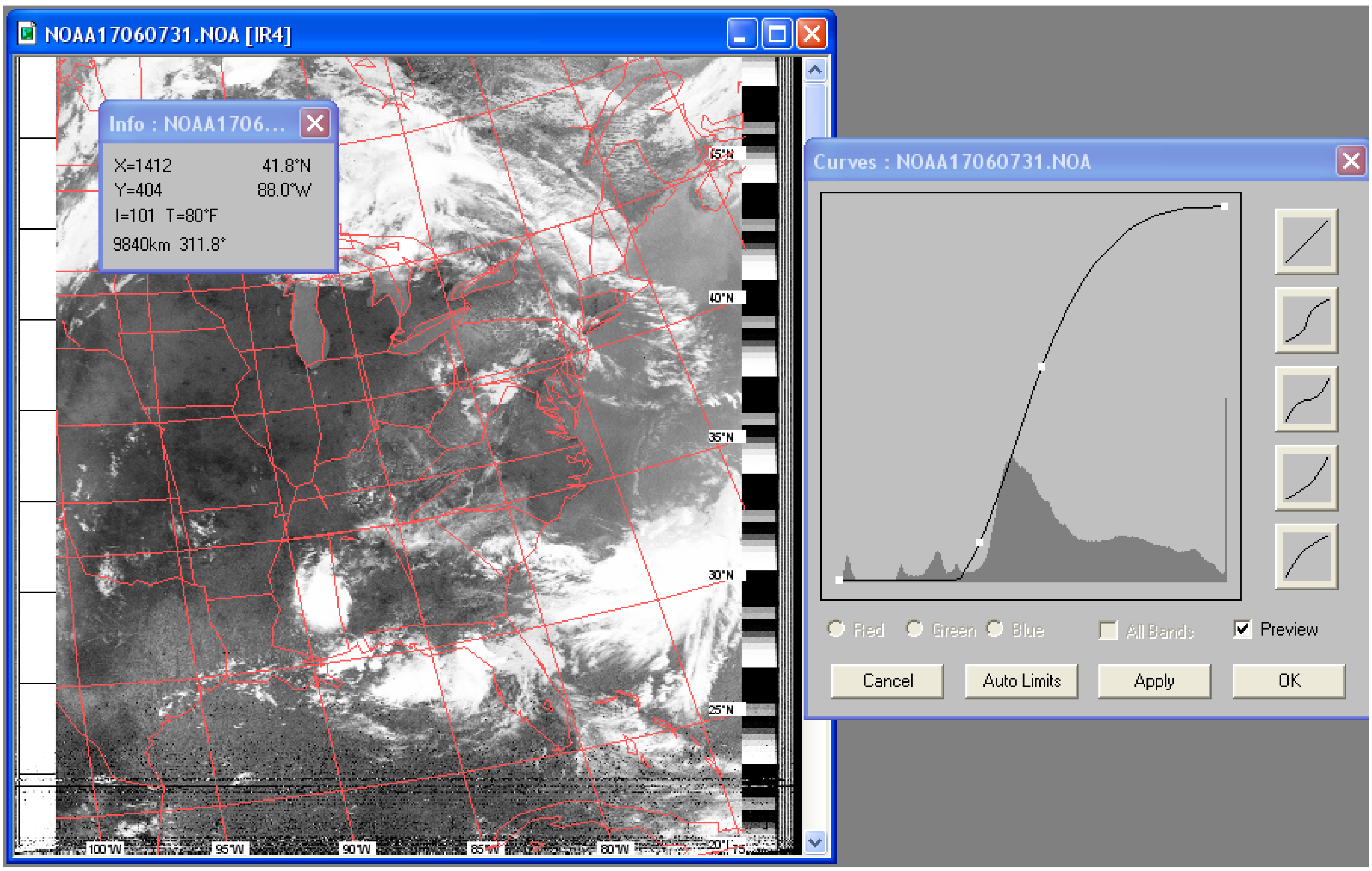


Figure VII-2 NOAA 17 Thermal APT Image Showing Software Enhancement Tools

5. Image Animation

An image animation function can be used to display a sequence of captured images. This feature is especially useful for geostationary images but it can also be applied to polar orbiting images. Individual frames of images are usually stored in a special subdirectory based on a specified capture schedule. The number of frames to be animated and speed of the animation sequence is entered in the program, and the images are displayed in a continuous loop on the computer screen. The animation capability is very useful for tracking hurricanes, weather fronts, and even changes in sea surface temperatures and can help in understanding to the physical processes taking place.

Shareware Direct Readout Software

Over the years direct readout enthusiasts have written their own image capture and display software, and designed some simple demodulator circuits that can be built by the electronics hobbyist for less than $50. The software has been freely distributed as "shareware," and these programs can be downloaded from the Internet. Some of these programs have not been updated to be compatible with current hardware.

VIII. ADVANCED DIRECT READOUT SYSTEMS

The popularity of APT direct readout systems grew over the years due to the ability of the user community to receive real-time weather satellite imagery on a daily basis with low cost and easy to maintain receiving equipment, while not being charged for either the service or the data products. The more advanced direct readout systems (HRPT and GVAR) had, until recently, been both very expensive to procure and complicated to operate. The cost of an HRPT ground station could easily exceed $100,000 with similar costs for the GOES GVAR systems.

In the late 1980's amateur radio operators and APT imaging enthusiasts were experimenting with HRPT receiving systems of their own design. Amateur radio operators have always been at the forefront of designing and building their own systems, and advanced direct readout imaging stations were no exception. Thanks to the efforts of these experimenters basic schematics and components for HRPT ground stations were available in kit form by 1990, and several amateur weather satellite enthusiasts finally had access to the high resolution imagery from NOAA POES. Similar "amateur" development occurred for the earlier GOES VAS data products (and later GOES GVAR). These advanced direct readout systems were based on personal computer technologies, and utilized the high resolution graphics capabilities and fast microprocessors necessary to receive, display, and store digital imagery.

Inevitably, these amateur designs were expanded and enhanced by several commercial manufacturers, and HRPT and GVAR / LRIT ground stations may now be either purchased commercially or assembled from component parts for approximately $10,000. Although this represents a significant expenditure, it is an order of magnitude less cost than the $100,000 to $250,000 commercial systems available just a few years ago. Since some of the ground station components of an APT system may be utilized for HRPT and GVAR / LRIT (personal computer, disk storage, tracking antennas), it is actually possible to configure an HRPT or GVAR / LRIT station for approximately $8,000.

This chapter will review the basic components of HRPT and GVAR / LRIT direct readout stations..

Parabolic Dish Antennas

Due to the higher frequencies and higher data rates for HRPT, GVAR and LRIT parabolic dish antennas are required to receive these data types. A parabolic or "dish" reflector collects and concentrates the weak signals into a smaller receiving area referred to as a "feed horn" that is placed at the focal point of the reflector. This, and the use of electronic low noise pre-amplification of the signal, make it possible to receive noise free transmissions. This same approach has been used with C-band satellite dishes that receive satellite television from geostationary television satellites. The television satellites, however, transmit signals that are quite different from weather satellites in both frequency and format. The feed horn construction and electronics are different but the parabolic reflectors are similar and can be modified for weather satellite reception if available.

The diameter of the antenna dish determines the overall gain of the antenna however here are trade offs between gain, beam width, and physical structure / tracking systems. A 2-3 foot dish is small and easy to handle, but offers minimal gain and a very wide beam width which is susceptible to interference from signals of other satellites. Larger dishes provide high gain but have a very narrow beam width; if the dish is not aimed accurately the satellite may move out of the antenna pattern causing loss of signal. Table VIII-1 illustrates the Gain versus diameter of parabolic dish antennas.

Dish Diameter	Gain (dBi)
2 feet (0.6 meters)	18
4 feet (1.2 meters)	24
6 feet (1.8 meters)	27.5
10 feet (3.0 meters)	32

Table VIII-1 Parabolic Dish Antenna Diameter Versus Gain

POES High Resolution Picture Transmission Direct Readout

By way of review, the AVHRR instrument is the primary imaging system flown on the NOAA POES satellites. This instrument provides the raw data for the High Resolution Picture Transmission (HRPT) and Automatic Picture Transmission (APT), Global Area Coverage (GAC), and Local Area Coverage (LAC) modes of operation. The LAC and GAC services use onboard tape recorders (or digital solid state recorders) to store the digital information for selected portions of the satellite's orbit. This recorded data is transmitted to NOAA ground stations in the United States for processing, and is re-broadcast via other services around the world. Most direct readout users would not be able to receive and process these recorded transmissions

The AVHRR instrument has a resolution of 1.1 km providing 10 bit data in five separate spectral bands. Table IV-1 summarized the spectral range and primary uses of the five sensors. Contrasted with the 4 km, 8 bit data and 2 spectral bands for the APT transmissions, HRPT, with its 5 data channels and 10 bits of data represents about a 10-fold advantage in the amount of information that may be analyzed when compared to APT data. This is very important to meteorologists and other professionals who need the most accurate information available for analysis.

Table VIII-2 reviews the parameters for the AVHRR HRPT digital transmissions from the NOAA POES satellites.

Transmit Frequencies	1698,1707,1702.5 MHz
Antenna Polarization	Right-hand Circular, Left-hand Circular based on transmitter in use
RF Carrier Modulation	Digital, Split Phase, Phase Modulated
Bandwidth	3 MHz
Lines per Frame	6 per second (360 lines per minute)
Digital Words per line	11090
Word Rate	66,540 per second (665.4 kbps)
Number of bits	665,400 per second
Words per Channel	2048 per line
Spectral channels	Five Channel l 0.58-0.68 uM Channel 2 0.72-1.1 uM Channel 3A/3B 3.55-3.93 / 3.55-3.93 uM Channel 4 10.3-11.3 uM Channel 5 11.5-12.5 uM

Table VIII-2 Characteristics of the POES HRPT Digital Transmissions

The question arises as to what additional ground station equipment is required to receive and display HRPT images. Although the basic requirements appear similar to those required for APT ground stations, the high data rate and digital nature of the transmissions require some specialized circuitry. A basic HRPT ground station would consist of the following elements:

1. Four-foot (or larger) parabolic dish
2. Antenna positioner and control hardware including azimuth and elevation rotators
3. Feedhorn and quadrature combiner
4. Low noise amplifier
5. Wide band receiver
6. Down converter circuitry
7. Phase-locked loop demodulator
8. Bit-synchronization board
9. Personal Computer
10. Software for image ingest, processing, and display

Figure VIII-1 Illustrates most of these elements. There are common features / functions required in all digital ground systems however there are many variations in ground system configuration based on the hardware utilized. Earlier ground stations tended to have separate functions performed in separate hardware, however with more advanced microcircuit technology and the advent of high speed digital signal processing many of the functions required to process digital data from a meteorological satellite are now included in a single chassis or on a single computer card. Therefore, while the general functions of a ground station may be common, the hardware available to individual users will affect the ground station configuration significantly.

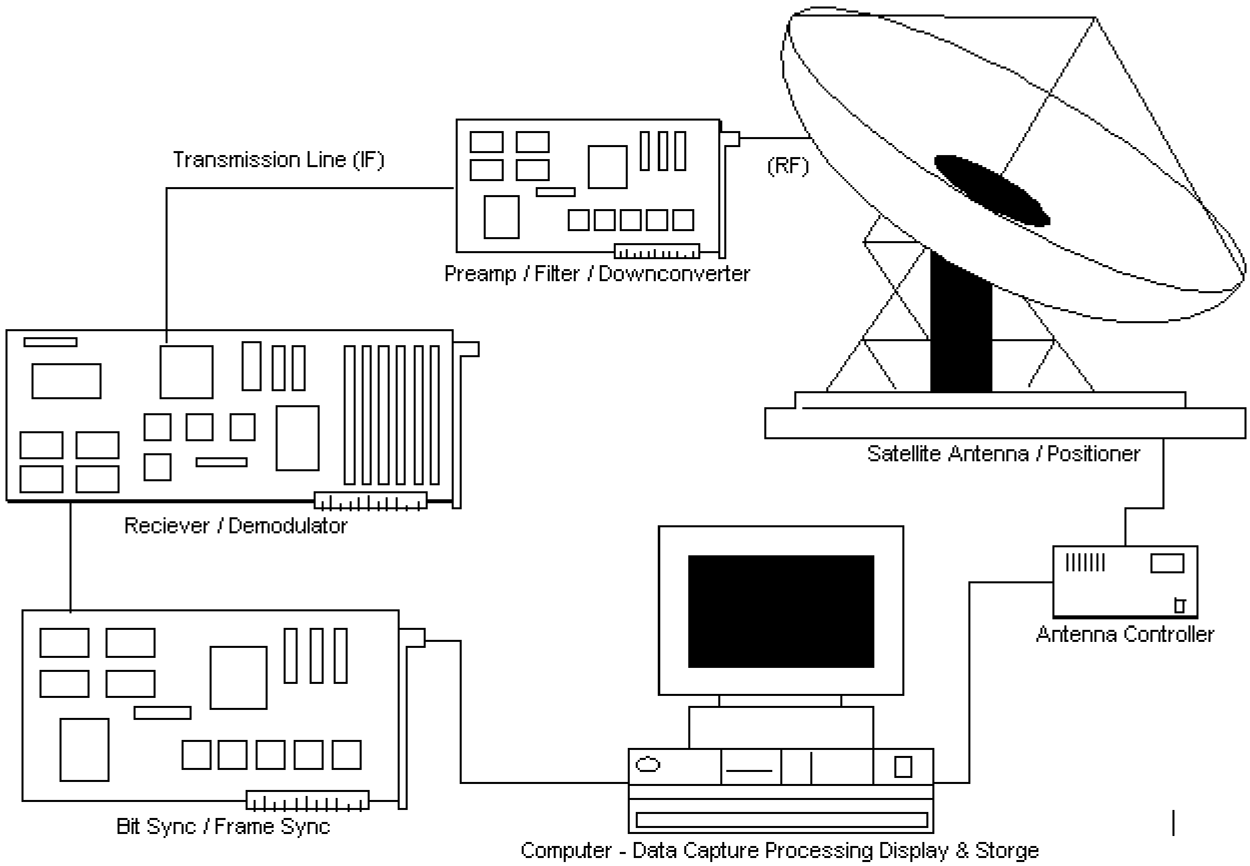


Figure VIII-1 A General Functional Diagram of a Digital Ground Station

Basic HRPT Station Design

Antenna **-** The HRPT signal is transmitted at 1698 and 1707 MHz, with backup at 1702.5 MHZ. At these frequencies the beam width is very narrow and proper tracking of the satellite is essential. Most HRPT systems employ a parabolic dish. Experience has shown that a four-foot dish (1.2 meters) provides adequate gain (around 24 dB) while still providing a manageable platform for tracking. Some experimenters have utilized a six-foot "loop yagi" antenna design, but stability of the antenna during tracking can lead to signal fades and loss of signal synchronization and lock. Parabolic dishes are available commercially at moderate cost. From a durability, accuracy, and maintenance perspective, they are a very good investment.

Feedhorn and Combiner **-** The feedhorn can be around 17 cm. long and 12 cm in diameter, centered at the focus of the parabolic dish. Two quarter-wave monopole probes, each about 4 cm. long, need to be placed 90 degrees apart about 4.5 cm. from the back of the feedhorn. Circular polarization may be obtained by feeding one pole 90 degrees out of phase with respect to the other. This is the quadrature combiner.

Low-Noise Preamplifier **-** A low noise preamplifier is a must for good quality HRPT images. The LNA noise figure should be 0.8 dB or lower. This corresponds to a noise temperature of 59 degrees Kelvin. The gain should be at least 30 dB.

Down converter - The HRPT signal at 1698 to 1707 MHz is often converted to a more transportable signal in the VHF frequency range. A down converter circuit is used to perform this conversion. Frequencies of 128 to 145 MHz are often used as the output of the down converter. Good quality down converters use 6 pole filters to prevent out of band interference to the HRPT receiving system.

Demodulation - The demodulation section is essentially an amplifier-filter that raises the signal level and establishes the final system band pass for the phase demodulation. A phased-lock loop (PLL) demodulator circuit is used.

Bit and Frame Synchronization - A bit synchronizer is required to extract the data clock. Frame synchronization and decommutation is accomplished with another circuit to complete the telemetry and image data extraction. This document does not attempt to provide the specific frame synchronization and decommutation schemes required to extract useable information from the HRPT data stream. This information is readily available on NOAA web sites referenced in Appendix B. Commercial software with compatible hardware are available for this purpose as are various shareware sources.

Personal Computer - The personal computer needs to have enough power to handle the 665 kbps data rate and substantial storage for the hundreds of megabytes of AVHRR data. Today's personal computers are more than sufficient for this purpose. A minimum disk storage should be two gigabytes with 16 megabytes of RAM. The same computer used for APT reception may be utilized for HRPT if there is enough disk storage and slots for the HRPT data and circuitry.

GOES GVAR High Resolution Direct Readout

The NOAA GOES series of satellites have two primary instruments, the Imager and Sounder. The Imager is the instrument most people are familiar with, as it produces the views from space we most often see. The Imager is a five-channel imaging radiometer that can sense reflected and radiant energy. Table VIII-3 summarizes the characteristics of the 5 channels that comprise the Imager data.

Channel	Wavelength Range µm	Resolution at nadir	Meteorological use
1	0.55-0.75	1 km	Visible cloud cover
2	3.80-4.00	4 km	IR nighttime cloud cover
3	6.50-7.00	8 km	Water vapor detection
4	10.20 - 11.20	4 km	Surface temperature, clouds
5	11.50 -12.50	4 km	Sea surface temperature, water vapor

Table VIII-3 GOES I-M Imager Sensor Summary

The GOES GVAR high resolution direct readout transmission and transmissions are different in nature than the POES HRPT transmission. On the POES spacecraft, radiances detected by the AVHRR instrument are processed on board the spacecraft and then transmitted directly to the direct readout user on the ground as the spacecraft flies overhead. With the GOES spacecraft, the 5 channel, 10-bit Imager raw data is down-linked to the NOAA CDA station at Wallops Island, Virginia at a rate of 2.62 Mbps. Here it is processed and formatted into the GVAR format, then sent back up to the GOES satellite at a rate of 2.111 Mbps to a relay transmitter. This relay transmitter provides the GOES GVAR transmission service (called the processed data relay or PDR) that is received by users. The GVAR data stream contains the data from both the Imager and Sounder instruments as well as calibration and spacecraft navigation data, spacecraft telemetry and miscellaneous products. Similarly the LRIT data does not originate directly on board the satellite; it is provided by various data sources and is relayed to the CDA station where it is transmitted to the GOES spacecraft for relay to data users.

Table VIII-4 is an overview of the characteristics of the GVAR and LRIT data transmission from the U.S. GOES satellites.

	GVAR	LRIT
Transmit Frequency	1685.70 MHz	1691.00 MHz
Antenna Polarization	Linear	Linear
RF Carrier Modulation	Digital, Biphase, Shift Keyed (BPSK)	PCM/NRZ-L/BPSK
Bandwidth	6 MHz	293 Ksamples.sec
Lines per Scan	8	N/A
Number of Digital Words	Variable	N/A
Words per image	Variable	N/A
Data Rate	2,111,360 bits per second	128 Kbps
Spectral channels	Five	N/A

Table VIII-4 Characteristics of GVAR and LRIT Digital Transmissions

It should be noted that the number of words making a complete line (or E-W swath), or a complete GOES GVAR image is variable. How the Imager instrument aboard the GOES operates to make an image is substantially different from the AHVRR operation aboard the POES. The AVHRR scans continuously using a mirror rotating at a constant 360 rpm. An image is essentially unlimited in the direction along the satellite track over the Earth's surface and is constrained by a fixed, consistent scan width in a cross-track direction. With GOES, the Imager scanning mirror can be moved in an East-West direction and North-South direction by variable amounts depending on how large or small an area of the Earth is being imaged. This results in a variable number of Imager data words being transmitted, followed by a variable number of Sounder data words (depending on how many are available for transmission) which comprise the total GVAR data structure.

Basic GVAR / LRIT Station Design

In the simplest form, the basic components of a GVAR / LRIT station are very similar to an HRPT receiving station. The data stream is captured using a parabolic antenna, collected at a feed horn, passed through a preamplifier and down converted, demodulated, after which bit and frame synchronization occurs. The exact specifications of each component are different to accommodate the different transmission frequencies, bandwidth, data rates, etc. Hardware complexity is also significantly reduced because active antenna tracking is not required due to the geostationary orbit.

Antenna - The GVAR and LRIT transmission are also in the S-band, at 1685.7 and 1691.0 MHZ. Parabolic dishes are required, GVAR reception requires a minimum 3 m (10-foot) diameter required for acceptable results, and a somewhat larger size of 3.6 m (12-foot) diameter is preferred. LRIT with its lower data rate should provide acceptable reception with a 1.8 m (6 foot) dish. Once the antenna is aimed at a geostationary satellite; it can be locked in position and does not have to be actively steered as is the case with HRPT.

Feedhorn - The feedhorn assembly is not as complex as HRPT, as the polarization of the GVAR / LRIT signal is linear and is not changing with respect to the ground station as the satellite moves as is the case with HRPT. The feedhorn is aligned once to maximize the linearly polarized signal from the GOES transmitter and then fixed in place.

Low Noise Preamplifier - A preamplifier for a GVAR / LRIT receiving system is essentially the same as would be used in an HRPT system.

Down converter - The GVAR / LRIT signals transmitted at 1685.7 / 1691.0 MHZ are converted to a signal in the VHF frequency range. The converted output signal is usually at or about 70 MHZ and fully filtered to prevent out of band interference.

Demodulation - The demodulation technique is nearly the same in GVAR and HRPT. LRIT includes more complex encoding and bit error correction techniques that increase the complexity of the signal processing. These include randomization, Viterbi convolutional encoding to reduce bit errors in transmission, Reed Solomon encoding to perform bit error correction, and data compression.

Bit and Frame Synchronization - While there are different bit frame patterns in GVAR, LRIT, and HRPT, the technique for frame processing is nearly the same. This document does not attempt to provide the specific frame synchronization and decommutation schemes required to extract useable information from the LRIT or GVAR data streams. This information is readily available on NOAA web sites referenced in Appendix B. Commercial software with compatible hardware are available for this purpose as are various shareware sources.

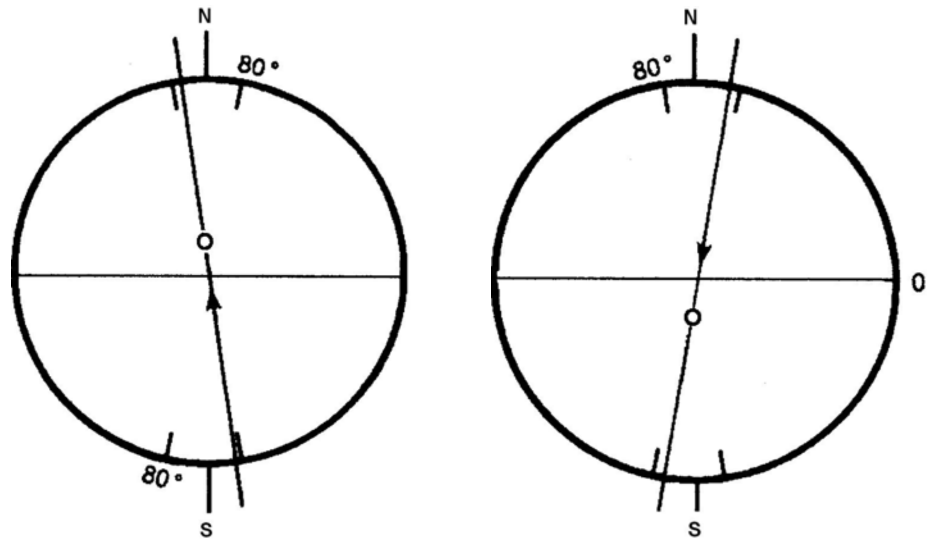
Personal Computer - Because 5 channels of HRPT data are received only for a short period of time (the length of a pass over the station), while GVAR and LRIT are available nearly continuously; the disk storage and memory requirements for GVAR or LRIT are greater. A full disk scan of GVAR data requires approximately 350 megabytes of storage. Also, because of the larger file sizes typical with GVAR images, animation of imagery usually requires 32 MB (or greater) of RAM.

In spite of the somewhat greater hardware requirements for a GVAR ground receiving station, the advantage of GVAR and LRIT over HRPT is the 24-hour availability of the data. HRPT is only available at certain times of the day when a polar orbiting satellite is within view of the receiving station. Each user has to balance the costs involved, the type of data needed, and application of the data when choosing whether HRPT or GVAR / LRIT would be more appropriate

IX. SATELLITE PREDICTION AND TRACKING

In order to obtain 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's 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 meteorological satellites is not difficult to obtain. NOAA provides a TBUS report daily for each of its spacecraft; and two line element files that define the satellite's orbit are also available. Sources of this information are provided in Appendix B. These reports provide the detailed orbit information needed to automatically track the spacecraft using a narrow beam-width dish antenna. These inputs can also be used by analysis software to properly geo-locate the data received. The TBUS reports include two minute sub-point latitude, longitude and altitude information for a single orbit that can be used manually to predict data acquisition times for APT direct data users with omni-directional antennas. If a directional antenna is used this will also allow the user to determine the azimuth and elevation of the satellite as it passes over the ground station. With a single orbit's information, the generation of future orbits of a given satellite can be also be easily calculated. Numerous software programs are available to perform these functions to a great accuracy, and most users will want to use these tools however, the paragraphs that follow serve to illustrate that the basic concepts of predicting satellite passes are straight forward, and can be performed using simple mathematics and mechanical tools.

Figure IX- I shows a typical orbital path of a NOAA-POES 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. Most polar orbiting meteorological 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 POES 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.



Ascending Pass **Descending Pass**

Figure IX-1 A Typical Orbital Path of a POES / TIROS Series Satellite

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 NODAL PERIOD, 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 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 or a spreadsheet to do these calculations. Any user 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.

Table IX-1 displays an example spreadsheet that calculates the future equator crossings for polar orbiting satellites using the method described above. The following reference orbit input data are all that is required:

1. Time of equator crossing (Month, Day, Year, Hour, Minutes, Seconds)
2. Longitude of the north bound equator crossing (Ascending Node)
3. The time, in minutes, of the orbital period (Nodal Period) of the satellite

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

Satellite ID	Time of Equator Crossing	East Longitude of Equator Crossing (decimal degrees)	Satellite Orbital Period (minutes)	
NOAA18	5/5/07 23:48	207.3265	102.10748	
Date	**Time of Equator Crossing**	**East Longitude of Equator Crossing**	**Satellite Orbital period (decimal days)**	**Satellite Orbital Increment (degrees Long.)**
May 5, 2007	23:48:47	207.3265	0.0709	25.52687
May 6, 2007	1:30:53	181.7996		
May 6, 2007	3:13:00	156.2728		
May 6, 2007	4:55:06	130.7459		
May 6, 2007	6:37:13	105.2190		
May 6, 2007	8:19:19	79.6922		
May 6, 2007	10:01:26	54.1653		
May 6, 2007	11:43:32	28.6384		
May 6, 2007	13:25:38	3.1115		
May 6, 2007	15:07:45	337.5847		
May 6, 2007	16:49:51	312.0578		
May 6, 2007	18:31:58	286.5309		
May 6, 2007	20:14:04	261.0041		
May 6, 2007	21:56:11	235.4772		
May 6, 2007	23:38:17	209.9503		
May 7, 2007	1:20:24	184.4235		
May 7, 2007	3:02:30	158.8966		
May 7, 2007	4:44:37	133.3697		
May 7, 2007	6:26:43	107.8428		
May 7, 2007	8:08:49	82.3160		
May 7, 2007	9:50:56	56.7891		
May 7, 2007	11:33:02	31.2622		
May 7, 2007	13:15:09	5.7354		

Table IX-1 A Spreadsheet for Simple Orbit Prediction

Time (Minutes) since Ascending	Latitude	Longitude
0	4.4 S	39.9 E
2	2.7 N	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	37.8N	29.5E
14	44.8 N	27.1 E
16	51.7 N	24.2 E
18	58.6N	20.4E
20	65.3 N	15.0 E
22	71.7 N	6.4 E
24	77.5 N	10.0 W
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 S	153.8 W

Table IX-2 Latitude and longitude of a NOAA Satellite sub-points, at Two-Minute Intervals

Table IX-2 contains the location in degrees of longitude and latitude of a typical NOAA POES polar orbiting satellite for every two minutes during the Northern half of one orbit, these locations are known as the orbital sub-points. This information is calculated by NOAA for each operational satellite and is included (in a different format) in the daily TBUS reports. These specific points change for each orbit, but the shape of the orbital track traced over the Earth's surface is the same for any orbit of these satellites. If these points are plotted on a polar projection map, they form a track as shown in Figure IX-2. If this track is copied on a transparent film and placed on the polar map shown in Figure IX-3 so that this sheet can be rotated about the north pole on Figure IX-3, 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 IX-2 represents two minutes of travel *after the time of the ascending equator crossing,* the swath width on the diagram represents the image swath for the POES AVHRR.

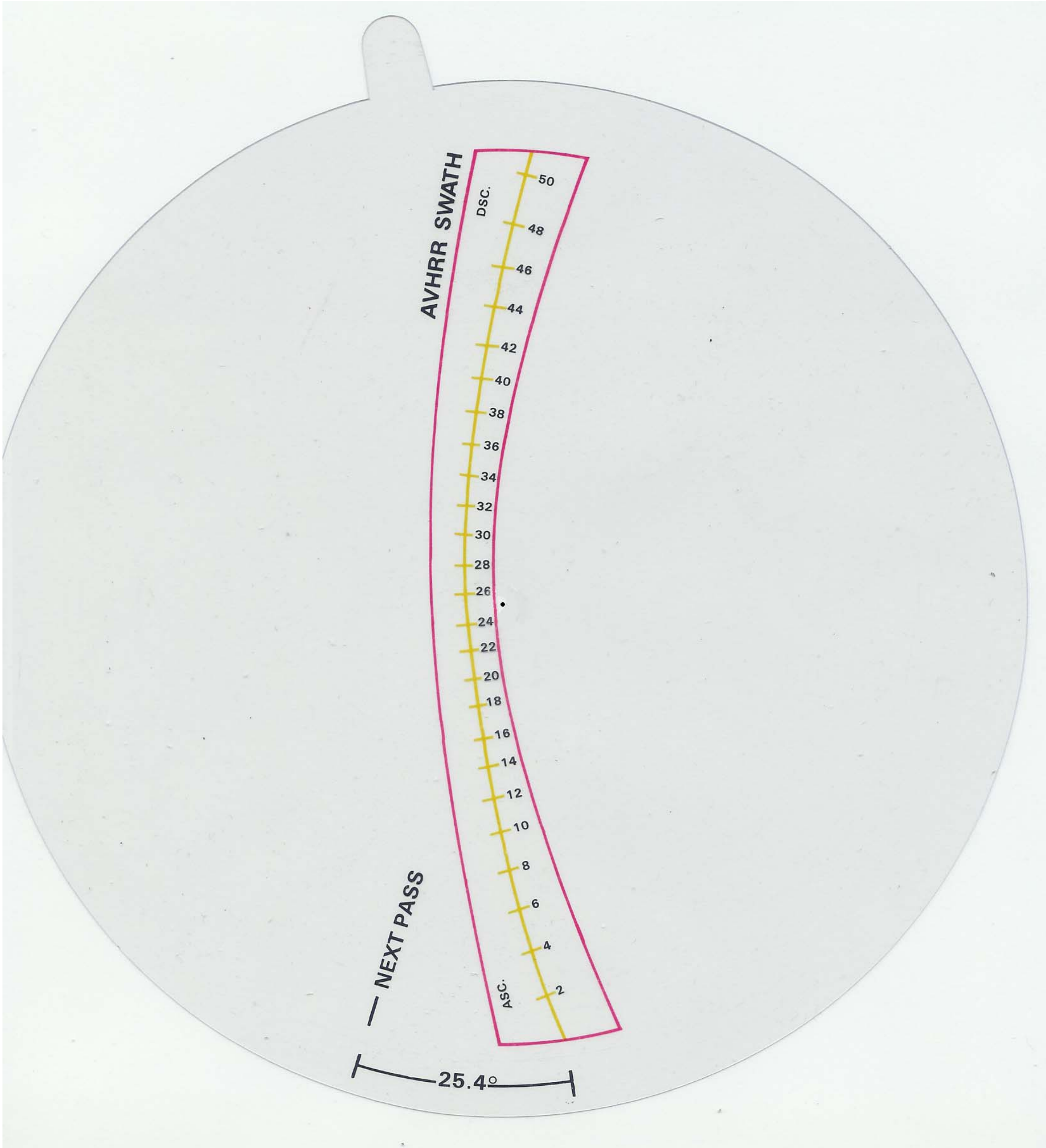


Figure IX-2 Typical POES Orbital Track Plotted at 2-Minute Intervals

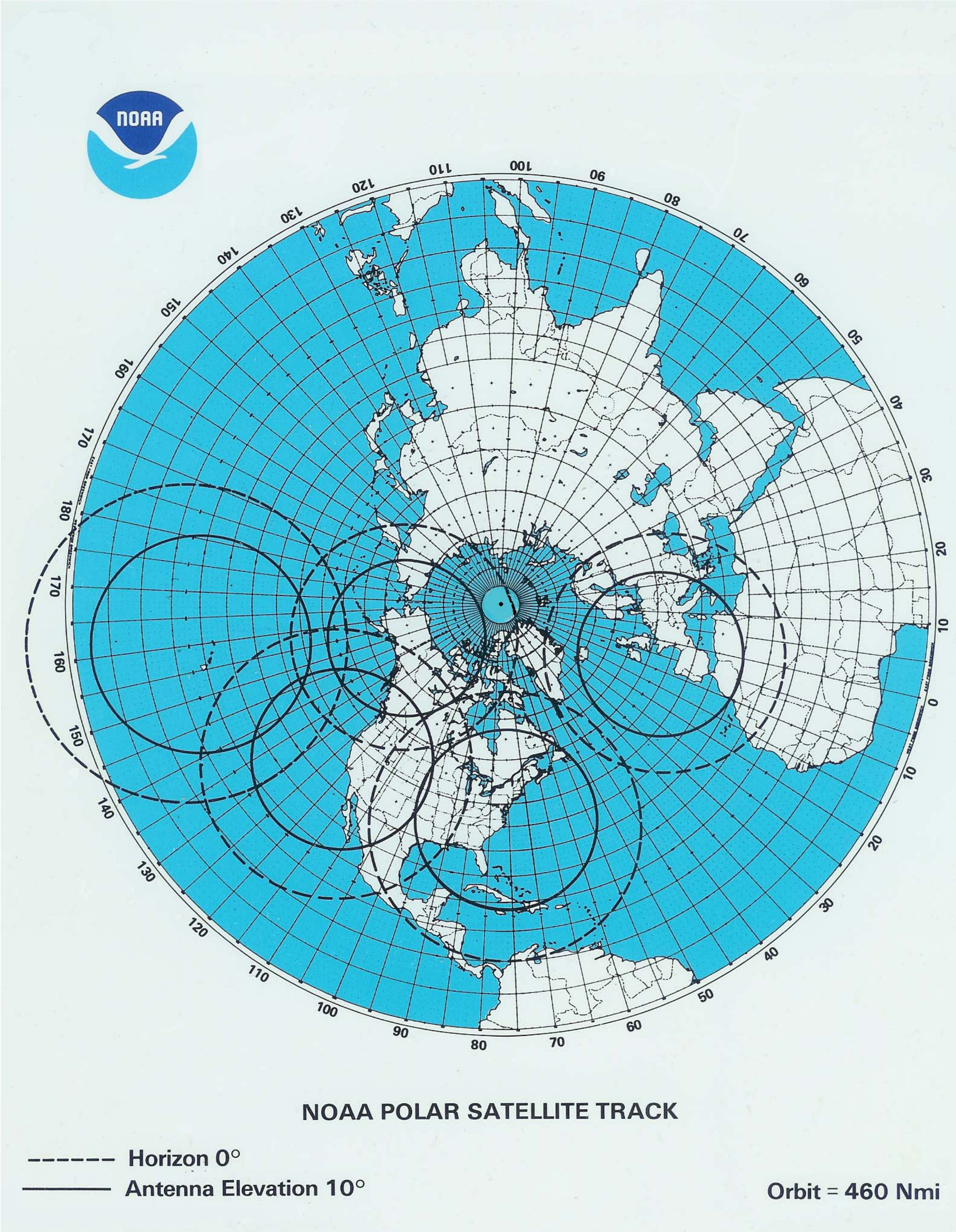


Figure IX-3 Northern Hemisphere Orbital Track Plotting Map

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 POES satellites have 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 3,100 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.

Figure IX-3 includes the “station circles” for five different ground stations used during various phases of a POES satellite mission. The outer circles represent a zero degree elevation, this is the idealized receiving range of the ground station (radius=3,100 kilometers). A satellite passing through this circle can be received with a tracking antenna set at the proper azimuth and 0 degrees of elevation. In reality all stations have physical limitations due to local geography that affect reception at very low elevations, for this reason the inner circles are included, they represent an elevation of 10 degrees above an idealized horizon. The five stations displayed vary in latitude from 20 degrees North to 65 degrees North, and as can be seen from the diagram the station circle plots vary in size for each station and are not truly circular, this is due the polar projection of this map. If these station circles were displayed on a spherical globe they would all be of the same size and would be circular. The station circles illustrated can be used as a template for direct data stations at similar latitudes by tracing them onto a clear sheet and placing the template at the station’s location.

When the ground track overlay of Figure IX-2 is combined with the map of Figure IX-3 and the time and longitude of ascending node, these materials can be used to 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. There are many sophisticated personal computer based tracking programs available that provide more advanced capabilities than the materials in this chapter, but this exercise gives one an appreciation of the methodology.

X. THE FUTURE OF DIRECT READOUT SYSTEMS

During the next ten to twenty years; there will be new series of both polar orbiting and geostationary meteorological satellites launched by the United States, the European consortium (EUMETSAT), Japan and China. These satellites will carry improved versions of current instruments or entirely new instruments. The general trend is towards sensing in additional areas of the electromagnetic spectrum with multi-spectral instruments providing higher resolution data at higher data transmission rates. At the same time, the world's meteorological organizations are moving towards more international cooperation with further integration of systems and sharing of environmental data. As part of this process NOAA is participating in the Global Earth Observation System of Systems (GEOSS). With GEOSS, additional data sources will be available to the direct data user. These factors combined will result in vastly increased amounts of data being transmitted from satellites, at higher transmission rates, and with further use of data compression techniques to transmit the data within available bandwidth. During this time, there will also be the continued transition from analog transmissions (as presently used for APT) to all digital transmission services. The following paragraphs discuss some of these future plans.

LRPT / APT

The analog APT direct data service will be replaced with a Low Resolution Picture Transmission (LRPT) format on future NOAA spacecraft. LRPT is an all digital data service, which is not compatible with APT receive systems. The LRPT digital transmission will be similar to the present-day digital HRPT transmission from NOAA satellites. However, LRPT image data will be compressed, and the data will be packetized into a CCSDS (Consultative Committee for Space Data Systems) format. Hardware / software will be required to perform demodulation, bit synchronization, frame synchronization and processing the stream of packetized data units to the computer. Computer software will also be required to decode, sort and decompress the data the user wants to display. The first opportunity for direct data users to receive LRPT data was to be the METOP-A satellite, however as of this writing the service will not be used operationally on METOP-A due to an electrical interference problem on the spacecraft.

While an LRPT receiving system is more complex than APT, this complexity will be offset by the advantages of more useful data. The number of channels will be increased from the present two, to three. Spatial resolution will be increased from the present average of 4 km to 1 km. With the digital format the radiance of each pixel is specifically quantified, eliminating analog to digital conversion errors at the ground station. The LRPT data stream will also include data from other spacecraft instruments which will contain information about the vertical and horizontal temperature and moisture structure of the atmosphere. References relating to the LRPT format can be found in Appendix B.

NOAA will continue to provide the analog APT system on its satellites through NOAA-N'. According to present schedules, NOAA-N' would likely reach the end of its design life around 2013, however historically these satellites have performed well beyond their design life, and it is quite possible that APT will be available until 2017. Prior to that, NOAA will launch the first of the National Polar Orbiting Satellite System (NPOESS) satellites. NPOESS is a program that combines the civilian NOAA POES satellite mission with the Department of Defense DMSP mission into a single, integrated system. NPOESS spacecraft will carry digital LRPT systems.

There will a considerable period of overlap when both analog APT and digital LRPT will be available to users. METOP and POES satellites will continue to be in orbit simultaneously, and there will also be a period of time when METOP, POES, and NPOESS satellites will be operating simultaneously. This overlap will allow APT users to transition their ground stations to LRPT.

MCUT

Recognizing that digital ground station costs are higher than current analog APT and previous WEFAX systems, and that the digital signals do not lend themselves to modification of readily available consumer equipment, NOAA has funded the development of prototype Multi-Constellation User Terminals (MCUT). These terminals are designed to serve as a demonstration of technologies that can reduce the costs of manufacturing satellite receive systems. The cost reductions are achieved by using Application Specific Integrated Circuits (ASIC) -based receiver technology which was developed for wireless applications and is available at low cost without the software development needs of other digital approaches. This technology allows the reception and processing of UHF/VHF, L and S-Band meteorological services using a single receiver. MCUT has also developed common antenna hardware for reception of L and S band services. These designs may be made available to manufacturers for further development and production, and it is hoped that this can further reduce costs to the direct data user.

GEONETCast

The United States along with 57 other nations have agreed to develop a Global Earth Observation System of Systems (GEOSS) to meet the need for timely, high quality, long-term global information as a basis for sound decision making and to enhance delivery of benefits to society. The GEOSS goal is to enhance access to environmental data in nine societal benefit areas (agriculture, weather, water resources, energy, health, climate, biodiversity, disaster mitigation, and ecosystems).

GEONETCast is a data distribution system within the GEOSS by which environmental data and products from data providers are transmitted to users through a global network of communications satellites using a multicast, broadband capability. This general dissemination capability, manifested through a small number of regional but interconnected GEONETCast systems, may be especially useful in parts of the world where high speed land lines and/or internet are not available, or in regions where terrestrial communication lines have been disrupted by disasters. GEONETCast is currently deployed in Europe as EUMETCast, in Asia as Fenyuncast and in the Americas the U.S. is developing the GEONETCast Americas portion of the GEONETCast system.

GEOSS data that will be disseminated through GEONETCast Americas will include processed value-added products and may include diverse raw data. The products may include environmental data or products from any observing data platforms including operational or research-based, *in situ* or remote sensing systems such as satellites (polar or geostationary), ground-based, or airborne platforms. Other non-observational environmental information will also be disseminated such as text-based environmental data or products, e.g., climate assessments, fisheries announcements, or earthquake advisories that support GEOSS.

The GEONETCast Americas broadcast service will be based on DVB-S technology similar to that used in satellite television. It will be received on the ground by relatively low-cost user receiver stations with commercial off-the-shelf components to the maximum extent possible. These receive stations are intended to be relatively affordable with a projected cost of just a few thousand dollars or less. The stations will include an appropriately-sized dish antenna (initially a 2.4 meter dish) and a standard personal computer and components necessary to decode the incoming satellite signal and create the data files on the station's hard disk. Standards and specifications for these components will be developed and published by NOAA for use by potential users and commercial vendors. Receiver station hardware, software and instructions will be available from commercial vendors to decode the signal, select the data types of interest to the user, translate the signal into data files in their original format, and distribute the incoming data products into appropriate product category folders on the receiver station.

Additional information regarding GEONETCast can be found on a NOAA sponsored web site identified in Appendix B.

CLASS

When the first version of this document was written, world wide network access was in its infancy. At the present time users with a high speed connection have nearly immediate access to multiple types of environmental data from numerous sources world wide. While this is not specifically direct data which is the topic of this document, for many users, this approach may satisfy their needs and may be more cost effective than establishing a ground station. A key development by NOAA in this area is the Comprehensive Large Array-data Stewardship System (CLASS). CLASS is a web-based data archive and distribution system for NOAA's environmental data. It is NOAA's premier online facility for the distribution of NOAA and U.S. Department of Defense (DoD) operational environmental satellite data (GOES, POES, and DMSP) and derived data products. CLASS is evolving to support additional satellite data streams, such as MetOp, EOS/MODIS, NPP, and NPOESS, and NOAA's in situ environmental sensors, such as NEXRAD, USCRN, COOP/NERON, and oceanographic sensors and buoys, plus geophysical and solar environmental data. CLASS is in a major 10-year growth program, adding new data sets and functionality to support a broader user base. A link to NOAA's CLASS can be found in Appendix B.

GOES-R

NOAA and NASA are currently in the conceptual design phase of the next generation of GOES spacecraft, the first of these spacecraft will be GOES-R. New instruments will be flown on these spacecraft providing expanded monitoring of the space environment, solar activity, and earth scene. The new imaging system will provide multi-spectral capabilities with higher image resolutions and faster image rates requiring much faster data rates. Many of the present day direct data services will continue to be provided from this new series however some data formats will change. Current plans are to continue the transmission of EMWIN, DCS, and LRIT, although the LRIT data rate will most likely be increased to 256 Kbps making it a HRIT. Current information regarding the GOES R project can be found on websites identified in Appendix B.

XI. ADVANCED APPLICATIONS

APT images provide data for a wide range of studies of the Earth and its atmosphere. Since the imaging instruments on the TIROS satellites can sample various sections of the electromagnetic spectrum, visible and infrared products are available to direct data ground stations. 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 process presented in this section is an example of the steps required to derive quantitative data from APT infrared images to support more detailed analysis. Unfortunately the analog nature of APT transmission requires additional steps to correct the received digital values to their original digital values. 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 possibilities for using 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 for the APT are selected by ground command from six possible spectral ranges available from the Advanced Very High Resolution Radiometer (AVHRR) imaging instrument. These are:

Channel l:	0.58 – 0.68μm	Visible
Channel 2:	0.325 – 1.10μm	Near Infrared
Channel 3A:	1.58 – 1.64μm	Thermal Infrared
Channel 3B:	3.55 – 3.93 μm	Thermal Infrared
Channel 4:	10.30 – 11.30 μm	Thermal Infrared
Channel 5:	11.50 – 12.50 μm	Thermal Infrared

Table X1-1 APT Channels

The APT format is shown in Figure IV-7. 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 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 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 a relay optics assembly where it is split into six spectral "windows" and passed to six separate detector assemblies. 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, previously discussed, are: High Resolution Picture Transmission (HRPT) - real time 1. 1 kilometer resolution digital images containing all five spectral channels, and Automatic Picture Transmission (APT) - continuous real time analog transmissions of processed AVHRR data.

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 sub-carrier 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 six 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 IV-7.

APT ANALOG TO DIGITAL TECHNIQUES

One must begin by determining the calibration and telemetry values within the calibration telemetry wedges. These values must be determined before temperature calibrations are attempted. In the 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 segment (10.817 milliseconds) of the 0.5 second scan line which makes it 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.

Most PC based image display systems use the same basic techniques. That is, they demodulate the signal to remove the 2400 HZ sub-carrier, digitize the demodulated signal with an analog to digital converter which reads the voltage changes in a digital format, assigns a user determined gray level to the digital value, and displays these as pixel elements of the original APT image on a monitor screen. (See Figure IV-3 and IV - 4). 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. If all systems were error free, the ground station could recover the exact digital values of the AVHRR however in practice, the transmission and reception process add some non-linearity and offset in the received digital values. These errors can be corrected by analysis of the values in the APT telemetry frame.

Although the hardware and software vary considerably from system to system, most software systems allow these digital images to be stored as a digital file. In an 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 XI-2 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 14 wedges are identical in both images of the APT format. Only wedges 15 and 16 will be different in channel A and B.

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. 4.663V MI = 65.2%	191
7. 5.444 V MI=76.0%	223
8. 6.225V MI = 76.0%	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	

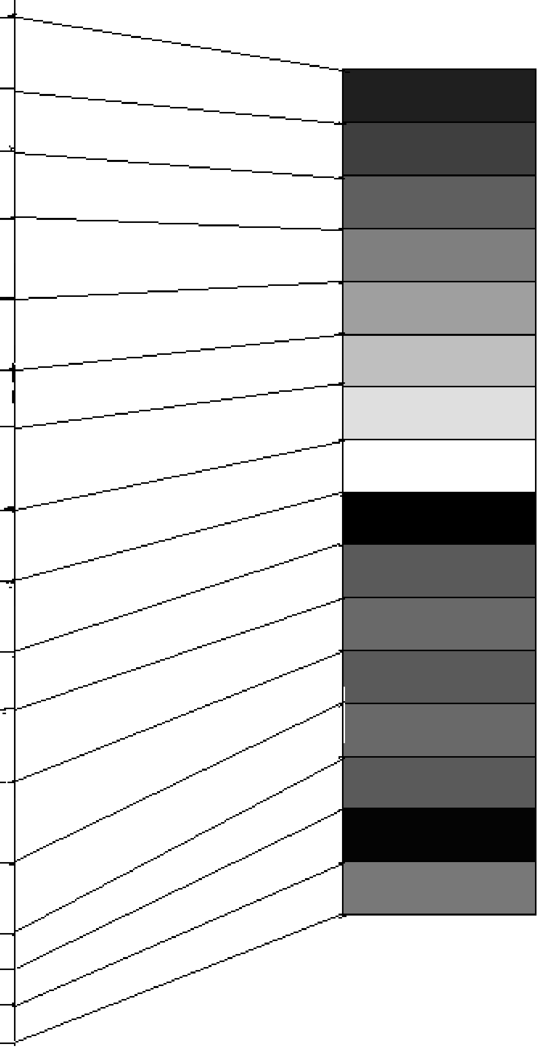


Table XI-2 Telemetry Frame Format Used in TIROS-N Series Satellite APT

WEDGE 1-8: Calibration Values

The first eight wedges within one telemetry frame are produced by modulating the 2400 Hz APT sub-carrier with 8 linear, 8-bit outputs, from the MIRP on the satellite. The digital values used to modulate each wedge are given in Table XI-2 as "Digital Value." The resulting analog signal received at the ground station is referred to as a "Modulation Index" (MI), 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 shading from dark gray to near white (MI=10.6% to 87.0%). The graph in Figure XI-1 shows the relationship between these 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.

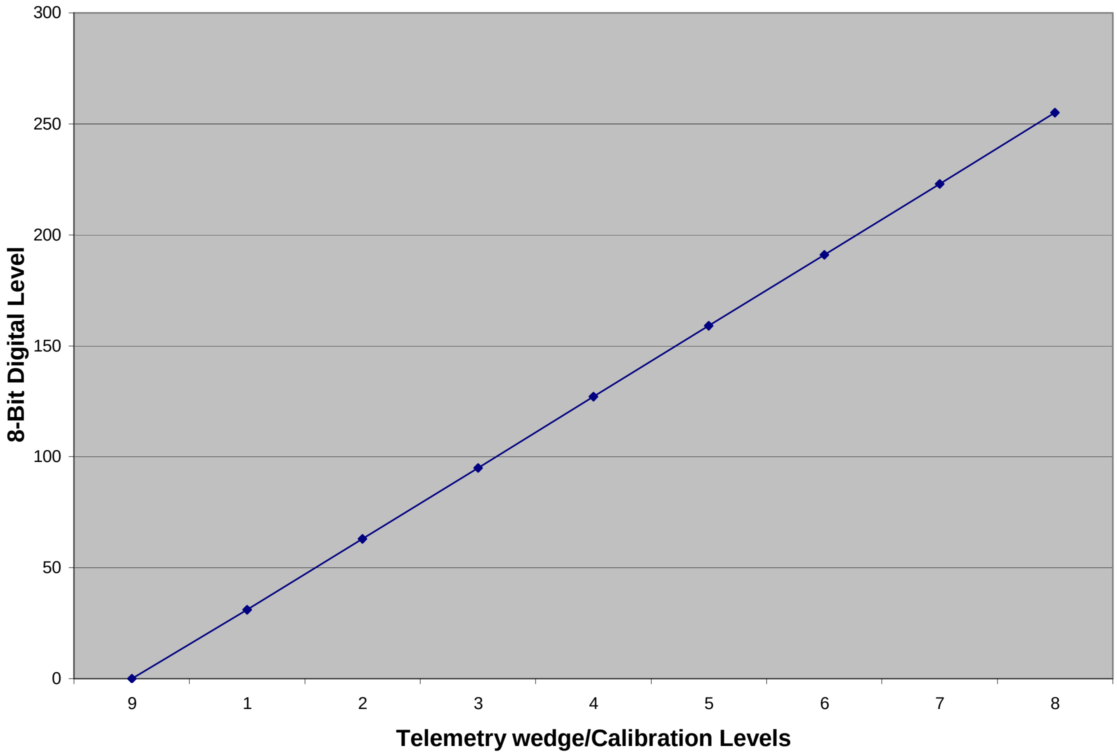


Figure XI-1 Analog/Digital Telemetry Wedge Relationship

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 an 8-bit AVHRR equivalent value of 0.

WEDGE 10-13: Black Body Temperatures 1-4

During the operation of the AVHRR imaging, the scanner periodically "views" a warmed black body radiator held at approximately 20°C (293°K) to detect the thermal radiance of that temperature. This "back scan" radiance 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 Platinum 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 the PRT levels to degrees Kelvin is provided in Appendix D of the NOAA KLM Users Guide (see Appendix B of this document for the web site) is:

$$T_{PRT} = d_0 + d_1 C_{PRT} + d_2 C_{PRT}^2 + d_3 C_{PRT}^3 + d_4 C_{PRT}^4$$

Where T_{PRT} is the PRT temperature in degrees Kelvin d_0, d_1, d_2, d_3, d_4 are the calibration coefficients provided by NOAA and C_{PRT} is the digital count. The users guide provides different calibration coefficients for each PRT on each spacecraft, however the coefficients are for 10 bit HRPT telemetry versus 8 bit APT telemetry. The easiest approach to accommodate this is to add the two least significant bits to the 8 bit data to fill it to a 10 bit quantity before applying the values to the equation above. This has the effect of multiplying the 8 bit APT counts by 4. For NOAA-17 the PRT1 coefficients are:

d_0 = 276.628
d_1 = 0.05098 (10 bit coefficient)
d_2 = 1.371 E -06 (10 bit coefficient)
d_2, d_3 = 0

Figure XI-2 shows a representative example of this equation with the counts multiplied by 4 before they are applied to the equation. The horizontal lines are markers for the APT calibration levels in telemetry wedges 1, 2, and 3.

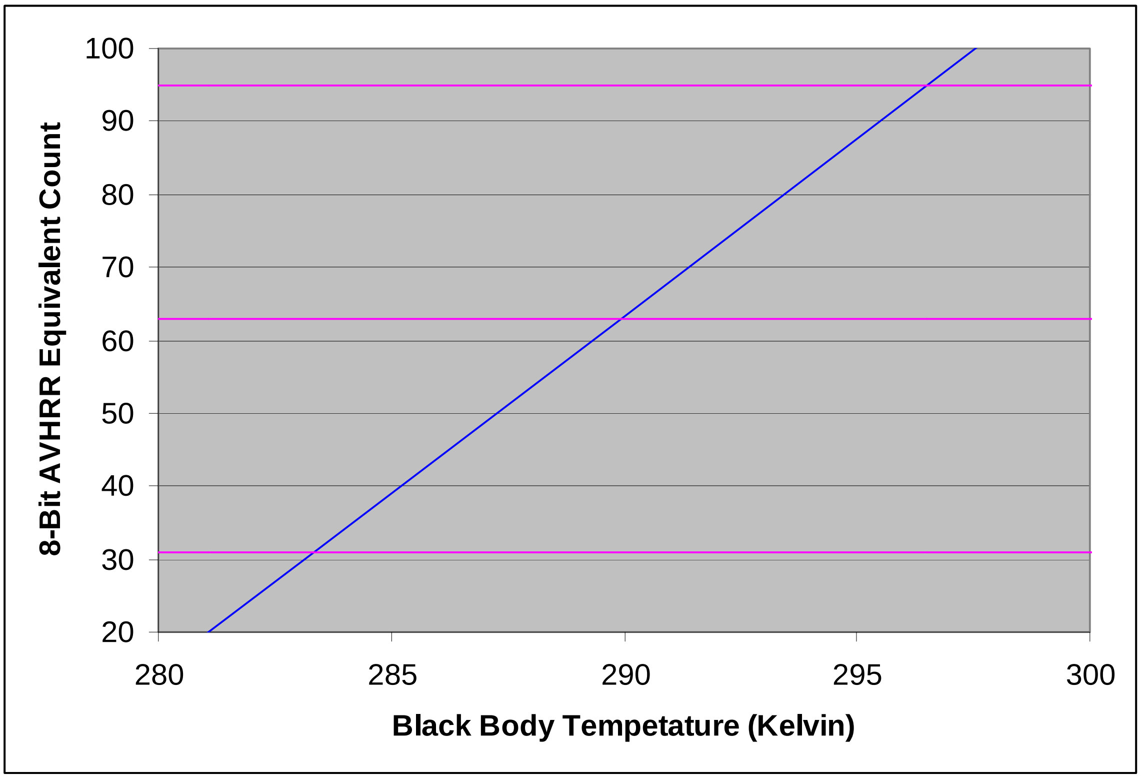


Figure XI-2. Digital Black Body to Temperature Relationship

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 observes and 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, and the black body is at a known temperature (from wedges 10-13), this data can be used as a single point for in-flight calibration of the infrared spectral channel.

WEDGE 16: Channel Identification

The AVHRR channel identification wedge contains information to identify which of the 6 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 6 gray calibration wedges in the telemetry frame. Table XI-3 illustrates how this is interpreted on current POES spacecraft which provide both a channel 3A and 3B.

Channel in use	Equivalent Wedge
1	1
2	2
3A	3
3B	6
4	4
5	5

Table XI-3 Wedge 16 AVHRR Channel Indicator

Space Data

Immediately following the sync pulse for each image (See Figure IV-7), 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. For temperature calibration purposes this value is considered to have zero radiance for each of the thermal AVHRR channels. This value can therefore be used to establish a second point for the temperature calibration.

WEDGE #1	31	31	30	30	31	30	30	30	WEDGE #9	3	3	3	4	4	5	4	4
	31	30	30	31	31	29	29	30		5	6	5	5	4	5	4	3
	31	32	31	31	32	33	30	29		4	5	5	5	5	4	3	3
	30	30	31	31	29	30	31	29		3	3	3	4	4	4	5	5
	30	30	31	31	30	30	31	31		5	5	4	5	5	5	4	4
	30	30	29	30	31	30	29	30		3	3	3	4	4	4	4	4
	32	32	31	30	31	30	29	29		3	3	3	4	3	3	4	4
	31	31	30	30	30	30	31	31		6	5	5	5	4	4	4	4
WEDGE #2	59	59	59	58	58	57	57	58	WEDGE #10	95	96	94	94	97	96	95	95
	58	58	59	58	58	58	58	59		95	95	97	96	94	93	96	96
	59	59	58	58	58	56	58	59		95	95	95	95	94	94	96	96
	58	58	58	59	57	57	57	58		94	95	97	96	95	95	96	96
	59	59	59	59	57	57	57	57		93	94	96	96	95	95	96	96
	59	58	57	57	60	60	58	57		95	94	94	95	93	95	96	95
	57	57	5S	58	58	57	59	58		96	96	95	94	94	95	95	95
	57	57	59	58	56	57	58	59		94	94	95	95	96	96	96	96
WEDGE #3	84	84	85	84	83	83	86	87	WEDGE #11	95	94	93	94	95	96	95	94
	86	86	87	86	85	85	86	86		93	94	96	97	95	95	96	96
	84	84	84	83	82	84	86	85		94	95	94	94	96	97	95	94
	85	84	84	85	83	84	86	85		95	95	95	94	95	94	94	94
	86	85	86	86	85	85	86	86		95	95	93	94	96	96	94	94
	84	84	84	83	83	84	85	86		94	95	95	95	96	95	94	94
	83	83	83	85	84	84	86	86		95	95	94	95	97	96	94	94
	85	85	86	86	84	84	86	86		95	96	93	93	95	95	93	94
WEDGE #4	112	112	110	109	110	110	110	110	WEDGE #12	96	95	93	94	95	95	94	94
	113	113	ill	Ill	113	113	Ill	111		95	94	93	94	97	96	94	93
	112	Ill	109	110	ill	112	111	110		93	94	97	96	94	94	94	95
	113	112	110	109	Ill	Ill	110	110		94	94	95	95	94	94	94	94
	114	114	Ill	ill	113	112	110	110		94	95	94	94	94	94	94	95
	112	112	110	111	114	113	111	111		95	94	93	94	95	95	94	95
	113	113	Ill	112,	114	113	Ill	111		93	94	95	95	95	94	95	95
	111	ill	110	110	112	111	110	Ill		93	93	95	95	94	94	94	95
WEDGE #5	136	137	137	138	137	137	137	136	WEDGE #13	93	94	95	95	94	93	94	95
	138	138	136	136	137	138	135	135		94	93	94	95	94	94	95	95
	138	137	137	138	139	139	136	137		93	93	94	95	95	95	95	94
	137	136	138	138	137	138	139	139		93	93	94	94	94	94	95	95
	135	135	136	137	137	136	137	138		95	95	92	93	96	95	93	93
	137	137	139	139	137	136	137	138		96	95	93	92	95	95	93	94
	135	135	137	138	136	136	138	138		93	93	96	96	93	93	95	95
	134	135	138	138	136	137	139	138		93	94	97	95	93	94	95	95
WEDGE #6	161	162	165	165	162	161	164	165	WEDGE #14	89	88	90	90	89	89	90	89
	161	162	165	165	162	162	164	164		88	89	91	90	88	89	90	89
	165	164	162	162	164	163	161	162		88	88	89	90	89	90	90	90
	161	162	165	164	162	162	164	163		89	89	90	90	89	90	90	90
	162	162	165	164	161	161	164	164		89	89	90	89	88	88	90	90
	162	163	165	165	163	163	164	164		89	90	90	89	89	90	89	89
	163	163	164	163	162	163	162	163		90	89	88	90	91	90	90	89
	163	163	164	164	162	163	163	163		89	89	90	90	90	90	90	89
WEDGE #7	188	189	189	188	187	188	189	188	WEDGE #15	61	61	61	60	61	61	60	61
	190	191	190	188	188	189	188	187		61	61	60	61	61	62	61	61
	188	190	190	189	189	190	189	188		61	62	62	61	62	61	61	61
	187	186	189	190	187	188	191	192		62	61	60	60	62	62	60	60
	188	188	191	191	187	187	190	191		61	62	61	61	61	61	60	60
	190	192	188	187	190	190	187	188		62	62	61	60	62	62	61	60
	191	191	188	188	190	190	187	187		63	62	61	61	61	61	61	60
	191	192	188	188	190	191	188	188		61	62	62	62	61	62	62	62
WEDGE #8	217	217	214	213	216	216	212	212	WEDGE #16	110	Ill	113	112	110	Ill	114	113
	217	218	213	212	215	215	213	214		112	112	ill	112	112	112	ill	111
	217	216	212	213	216	216	212	212		113	113	110	111	114	113	111	ill
	217	216	211	212	215	215	212	213		113	113	111	110	113	113	ill	ill
	216	217	213	213	216	215	212	213		112	113	112	112	112	112	ill	111
	213	213	215	214	213	215	218	216		113	112	ill	Ill	113	112	111	ill
	214	214	215	214	213	215	216	215		112	111	112	112	112	111	ill	112
	215	215	213	214	216	215	213	214		113	ill	111	112	113	112	ill	ill
				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 X1-4 Digital Value Printout from one 16 Wedge Telemetry Frame

DIGITAL APT NORMALIZATION TECHNIQUES

Table XI-4 shows a printout of the digital values taken from one 16-wedge telemetry frame of channel 4 IR APT data. 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. The source data for this table is an APT image that was received, digitized and stored as a digital text file. One noise-free telemetry frame and segment of space data were then selected from this image file and printed.

Since a variety of factors cause variation of the digital values within the APT 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 XI-5.

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 XI-5 Statistical Analysis of an APT Digital Telemetry Frame

The first step to calibrate APT data is to utilize the first nine calibration wedges to normalize the received digital values to those transmitted by the satellite. A relationship must first be established between the received 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 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. Fortunately, a number of pocket calculators perform these mathematical processes and a variety of statistical software packages for PCs are available to do both correlation and regression analysis. Additional information concerning these techniques can be found in any basic statistics book.

NOTE: The calibration process requires that the original signal level, during the analog to digital conversion, not exceed the 255 digital level. This would 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.

Normalization

Step 1

To determine if there is a statistically significant correlation between the station count data shown in Table XI-5 and the standard AVHRR 8-bit digital values the following equation for correlation can be used:

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

Where X = AVHRR values and Y= Station count averages from Table XI-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

$$r = \frac{[8 (176532.4)] - [(1144) (987.93)]}{\sqrt{[8 (206600) - 1308736] [8 (150911.4) - 976005.68]}}$$

$$r = .99$$

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,

and X= AVHRR Counts

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

In this example:

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

$$B = 0.8198$$

and

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

$$A = 6.25$$

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

$$Y = .8198\ X + 6.25$$

Or, $X = \frac{Y - 6.25}{0.8198}$ or, $\text{AVHRR Counts} = \frac{\text{Station Counts} - 6.25}{0.8198}$

TEMPERATURE CALIBRATION

Using the prior steps the received APT data can be converted to equivalent AVHRR counts, however, several additional steps are required to arrive at calibrated temperature values derived from the Earth scene counts. Following is a quick overview of the steps required:

1. Calculate the temperature of each of the three black body temperature PRT sensors as discussed earlier in this chapter, and average these to provide a black body temperature.
2. Calculate the black body radiance at this temperature
3. Utilize the black body and space radiances and counts to compute a linear representation of the Earth scene radiance.
4. Calculate a non-linear correction and add it to the linear representation to provide Earth radiance values
5. Convert the Earth scene radiances into equivalent black body temperatures.

This process is presented in detail in the KLM Users Guide section 7.1.2.4 which is available on-line. This section of the KLM Users Guide is written for HRPT users, however the same techniques apply to APT users with the exception that APT counts should be multiplied by four to arrive at an HRPT equivalent (10 bit) input value. The calculations described can be a daunting task to perform by hand, however once the equations have been entered into a spreadsheet or programmed into a PC the process can be run quickly. An APT user applying these techniques needs to determine an approach that best suits their needs. Some alternatives are to have software perform separate calculations for each pixel in a scene or to generate a software look up table with a cross reference between earth scene counts and temperature for given satellite pass.   Table XI-6 is a lookup table generated using a spreadsheet to perform the equations provided in the KLM Users Guide. The inputs to the equations are the black body and space scene data in Table XI-5 and the calibration values for the NOAA-18 AVHRR provided in the KLM Users Guide.

8-bit Earth Station Counts	Ce 8-bit AVHRR Counts	10 Bit Equivalent	Nlin Earth Radiance Linear Approx.	Ncorr Radiance Correction	Ne Corrected Earth Radiance	Te Un-Corr. Earth Temp Deg K	Te Corrected Earth Temp Deg K
55	59.466	237.863	115.358	0.016	115.374	301.761	301.745
56	60.686	242.742	114.577	0.008	114.586	301.300	301.283
57	61.905	247.621	113.797	0.001	113.798	300.837	300.819
58	63.125	252.501	113.016	-0.005	113.011	300.373	300.355
59	64.345	257.380	112.235	-0.011	112.224	299.907	299.888
60	65.565	262.259	111.454	-0.016	111.438	299.440	299.421
61	66.785	267.138	110.673	-0.020	110.653	298.971	298.951
62	68.004	272.018	109.892	-0.024	109.868	298.501	298.480
63	69.224	276.897	109.111	-0.027	109.084	298.030	298.008
64	70.444	281.776	108.330	-0.029	108.301	297.556	297.534
65	71.664	286.655	107.549	-0.031	107.518	297.082	297.059
66	72.884	291.535	106.768	-0.032	106.736	296.605	296.582
67	74.103	296.414	105.987	-0.033	105.955	296.127	296.103
68	75.323	301.293	105.206	-0.032	105.174	295.648	295.623
69	76.543	306.172	104.425	-0.032	104.394	295.166	295.141
70	77.763	311.051	103.644	-0.030	103.614	294.684	294.657
71	78.983	315.931	102.863	-0.028	102.835	294.199	294.172
72	80.202	320.810	102.083	-0.026	102.057	293.713	293.685
73	81.422	325.689	101.302	-0.022	101.279	293.225	293.196
74	82.642	330.568	100.521	-0.018	100.502	292.735	292.706
75	83.862	335.448	99.740	-0.014	99.726	292.243	292.213
76	85.082	340.327	98.959	-0.008	98.950	291.750	291.719
77	86.302	345.206	98.178	-0.003	98.175	291.254	291.223
78	87.521	350.085	97.397	0.004	97.401	290.757	290.726
79	88.741	354.965	96.616	0.011	96.627	290.258	290.226
80	89.961	359.844	95.835	0.019	95.854	289.757	289.724
81	91.181	364.723	95.054	0.027	95.081	289.255	289.221
82	92.401	369.602	94.273	0.036	94.310	288.750	288.715
83	93.620	374.482	93.492	0.046	93.538	288.243	288.208
84	94.840	379.361	92.711	0.056	92.768	287.734	287.698
85	96.060	384.240	91.930	0.067	91.998	287.223	287.187
86	97.280	389.119	91.149	0.079	91.228	286.710	286.673
87	98.500	393.999	90.369	0.091	90.460	286.195	286.157
88	99.719	398.878	89.588	0.104	89.692	285.678	285.639
89	100.939	403.757	88.807	0.118	88.924	285.159	285.119
90	102.159	408.636	88.026	0.132	88.158	284.637	284.597
91	103.379	413.515	87.245	0.147	87.391	284.114	284.073
92	104.599	418.395	86.464	0.162	86.626	283.588	283.546

93	105.818	423.274	85.683	0.178	85.861	283.059	283.017
94	107.038	428.153	84.902	0.195	85.097	282.529	282.486
95	108.258	433.032	84.121	0.212	84.333	281.996	281.952
96	109.478	437.912	83.340	0.230	83.570	281.460	281.416
97	110.698	442.791	82.559	0.249	82.808	280.922	280.877
98	111.918	447.670	81.778	0.268	82.046	280.382	280.336
99	113.137	452.549	80.997	0.288	81.285	279.839	279.792
100	114.357	457.429	80.216	0.309	80.525	279.294	279.246
101	115.577	462.308	79.435	0.330	79.765	278.746	278.697
102	116.797	467.187	78.655	0.352	79.006	278.195	278.146
103	118.017	472.066	77.874	0.374	78.248	277.642	277.592
104	119.236	476.946	77.093	0.397	77.490	277.085	277.035
105	120.456	481.825	76.312	0.421	76.733	276.527	276.475
106	121.676	486.704	75.531	0.445	75.976	275.965	275.913
107	122.896	491.583	74.750	0.470	75.220	275.400	275.347
108	124.116	496.463	73.969	0.496	74.465	274.833	274.779
109	125.335	501.342	73.188	0.522	73.710	274.262	274.208
110	126.555	506.221	72.407	0.549	72.956	273.689	273.633
111	127.775	511.100	71.626	0.577	72.203	273.112	273.056
112	128.995	515.980	70.845	0.605	71.450	272.532	272.475
113	130.215	520.859	70.064	0.634	70.698	271.949	271.891
114	131.434	525.738	69.283	0.663	69.947	271.363	271.304
115	132.654	530.617	68.502	0.693	69.196	270.774	270.714
116	133.874	535.496	67.721	0.724	68.446	270.181	270.120
117	135.094	540.376	66.941	0.756	67.696	269.584	269.523
118	136.314	545.255	66.160	0.788	66.947	268.985	268.923
119	137.534	550.134	65.379	0.820	66.199	268.381	268.318
120	138.753	555.013	64.598	0.854	65.451	267.774	267.711
121	139.973	559.893	63.817	0.888	64.704	267.163	267.099
122	141.193	564.772	63.036	0.922	63.958	266.549	266.484
123	142.413	569.651	62.255	0.957	63.212	265.931	265.864
124	143.633	574.530	61.474	0.993	62.467	265.308	265.241
125	144.852	579.410	60.693	1.030	61.723	264.682	264.614
126	146.072	584.289	59.912	1.067	60.979	264.051	263.983
127	147.292	589.168	59.131	1.105	60.236	263.417	263.347
128	148.512	594.047	58.350	1.143	59.493	262.778	262.707
129	149.732	598.927	57.569	1.182	58.752	262.135	262.063
130	150.951	603.806	56.788	1.222	58.010	261.487	261.414
131	152.171	608.685	56.007	1.262	57.270	260.835	260.761
132	153.391	613.564	55.227	1.303	56.530	260.178	260.103
133	154.611	618.444	54.446	1.345	55.790	259.516	259.441
134	155.831	623.323	53.665	1.387	55.052	258.849	258.773

Table XI-6 Look-Up table for Earth Scene Temperature Derived from Table XI-4 Data

APPENDIX A. GLOSSARY

albedo	Same as reflectivity. Expressed as the percent of visible radiation reflected from a surface.
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.
apogee	The point in a satellite's orbit farthest from the Earth.
APT	Automatic Picture Transmission. A function of polar orbiting weather satellites which transmits earth scan imagery 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 an image when fed to an appropriate display device.
argument of perigee	Number of degrees from the ascending node where perigee occurs.
ascending node	Intersection of a satellite's orbital plane with the Earth's equatorial plane.
AVHRR	Advanced Very High Resolution Radiometer. Sensor on board POES and METOP satellites which senses passive radiation emitted from Earth and its atmosphere.
azimuth	Angle measured in the horizontal plane from true North.
bandwidth	In FM, radio frequency signal bandwidth is the amount of deviation of the signal.
blackbody	A perfect radiator and absorber of electromagnetic energy. A blackbody has an emissivity of 1, and its NOAA IR channel temperature will be equivalent to its actual temperature.
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 (db)	Decibel - the unit 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 Pass	The portion of a polar orbiting satellite's orbit which passes over the earth from north to south
DMSP	Defense Meteorological Satellite Program
Doppler effect	If an electromagnetic source moves relative to an observer, there is a shift in the observed frequency. If the source is receding from the observer, the observed frequency will appear to decrease.
dropout	The loss of data from one or more scan lines.
eccentricity	Description of the shape of a satellite's orbit. A circular orbit has an eccentricity of 0.0, the closer to 1.0 the eccentricity, the more elliptical an orbit is. Most meteorological satellite orbits have an eccentricity less than 0.01, essentially circular.
ecliptic	The great circle around the sky on which the sun appears to move through the year as the earth revolves around it. The ecliptic plane is the plane of the earth's orbit around the sun. The orbit's of the other planets also lie close to this plane.
elevation	Angle above the horizon
emissivity	The ratio of energy emitted by a material to that which would be emitted by a blackbody at the same temperature.
EMWIN	Emergency Managers Weather Information. A direct data service providing users with weather forecasts, warnings and other information.
epoch	Year, Month, Day of orbital elements.
equatorial plane	An imaginary plane through the center of the Earth and the Earth's equator.
facsimile (FAX)	A process where graphic or photographic information is transmitted or recorded by electronic means.
Field of View	Essentially the synthesis of the IFOV from the scanning process of the radiometer.
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 reception.
GAC	Global Area Coverage. Recorded HRPT data at low resolution (4 km).
GEONETCast	

An international environmental data distribution system providing worldwide distribution of data, and processed products via communications satellite

geostationary orbit — An orbit whose period equals the rotation period of the Earth and whose orbital inclination is approximately zero degrees. Geosynchronous satellites are placed in orbit at 35,800 km altitude above earths equator.

GMS — Geostationary Meteorological Satellite. Specifically, a Japanese satellite.

GMT — Greenwich Mean Time, also known as Zulu time or UTC (Coordinated Universal Time), it is the local time at Greenwich Observatory, England (0 degrees longitude).

GOES — Geostationary Operational Environmental Satellite. Specifically, a United States satellite.

GVAR — GOES VARiable. The processed instrument data format for GOES.

Hertz-MHz-KHz — Hertz is the unit of measuring the frequency. 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).

HIRS — High Resolution Infrared Radiation Sounder, a TIROS instrument.

HRIT — High-Rate Information Transmission, a digital direct data service providing imagery and processed data

HRPT — High Resolution Picture Transmission. A telemetry from the NOAA TIROS-N satellites.

IFOV — Instantaneous Field of View. The solid angle through which a detector is sensitive to radiation. It forms one limit to the resolution of an imaging system.

inclination — The angle between the orbit plane and the Earth's equatorial plane, measured counter-clockwise. A zero inclination orbit would mean the satellite is orbiting directly over the equator, an inclination of 90 degrees is a perfectly polar orbit.

IR — Infrared

Kbps — Kilobits per second

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

LAC — Local Area Coverage, HRPT data recorded at high resolution (1.1 km).

LRIT — Low-Rate Information Transmission, a digital direct data service providing imagery and processed data and information via GOES and other international geostationary environmental satellites

mean anomaly — Represents the angular distance from the perigee point to the satellites mean position. Measured in degrees along the orbital plane in the direction of motion.

mean motion — Number of complete revolutions the satellite makes in one day.

Mbps	Megabits per second.
Meteor	The Soviet Union's series of polar orbiting weather satellites. The Meteor satellites transmit imagery in a system compatible with the NOAA TIROS satellites.
METEOSAT	Meteorological Satellite. Specifically, a European satellite. Megahertz-see Hertz.
MSU	Microwave Sounding Unit, a TIROS instrument.
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
Nadir	The point on the ground vertically beneath the satellite.
NESDIS	National Environmental Satellite Data and Information Service, a component of NOAA.
OLS	Operational Line Scanner, a DMSP satellite instrument.
orbital elements	A collection of quantities that, together, describe the size, shape, and orientation of an orbit.
PDUS	Primary Data User Stations consisting of mainly a ground station and an image processing system. Refers to those stations receiving data directly from the satellite (such as GVAR data) versus preprocessed data.
perigee	The point in a satellite's orbit where it is closest to the Earth.
POES	Polar Operational Environmental Satellite
polar orbit	An orbit whose path crosses near the earths poles.
reflectivity	Same as albedo. Expressed as the percent of visible radiation reflected from a surface.
Retrograde	Satellite orbit motion which is opposite to the Earth's direction of rotation, also defined as an orbit with an inclination greater than 90 degrees
right-ascension-of-ascending-node	The angular distance from the vernal equinox measured eastward in the equatorial plane to the point of intersection of the orbit plane where the satellite crosses the equatorial plane on the ascending node.
SAR	Search And Rescue
SBUV	Solar Backscattered Ultraviolet system. A TIROS instrument.
SEM	Space Environment Monitor. An instrument found aboard both TIROS and GOES satellites.

shimmer — An effect produced by the movement of masses of air with differing refractive indices. Shimmer results in the blurring of remote sensed images, and is the ultimate limiting factor over the resolution.

SDUS — Secondary Data User Station. A ground receiving station capable of receiving preprocessed satellite imagery (and other imagery), typically referring to WEFAX user stations.

SSM/I — Special Sensor Microwave Imager. A DMSP satellite instrument.

SSM/TI — Special Sensor Microwave Temperature sounder on board the DMSP satellites

SSM/T2 — Special Sensor Microwave water vapor profiler on board the DMSP satellites.

SST — Sea Surface Temperature.

SSU — Stratospheric Sounding Unit. A TIROS instrument.

Sun - synchronous — Describes the orbit of a satellite whose orbital plane remains at a fixed angle with respect to the sun. This provides consistent lighting of the earth scene and causes the satellite to pass the equator and each latitude at the same local time each orbit. The orbital plan of a sun-synchronous orbit must also precess (rotate) approximately one degree each day to keep pace with the earth's orbital rate around the sun.

TIROS — Television Infrared Operational System. A series of polar orbiting meteorological satellites operated by NOAA. Only early satellites used television as the imaging instrument; however the TIROS name remains as the satellite series name.

TOVS — TIROS Operational Vertical Sounder. A suite of instruments aboard TIROS comprised of the HIRS, MSU and SSU.

VISSR — Visible Infrared Spin-Scan Radiometer. The primary imaging instrument aboard the GOES satellites through GOES-7.

WEFAX — Weather Facsimile. An analog data transmission service from the GOES satellites. This service has been replaced by the LRIT digital service.

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.

APPENDIX B. INFORMATION RESOURCES

The NOAASIS web site (http://noaasis.noaa.gov/NOAASIS/ is operated by NOAA/NESDIS Direct Services Division, and contains extensive information related to the NOAA TIROS and GOES satellites. The NOAASIS web site also contains links to sources of information for other meteorological/environmental satellites and related areas of interest to satellite direct readout users.

Current information about POES satellite status can be located at http://www.oso.noaa.gov/

The NOAA KLM Users Guide and other POES documents can be located at http://www2.ncdc.noaa.gov

Orbital elements for tracking meteorological satellites, in the form of two-line elements (TLEs), monthly predictions and/or TBUS messages can be found on the following Internet sites:

> NOAASIS web site, http://noaasis.noaa.gov/NOAASIS/ml/navigation.html
>
> Celestrak, http://celestrak.com/index.asp This site also has information on the contents and decoding of the TLE messages.

A list of manufacturers and suppliers of complete weather satellite receiving systems and components is available. This "Manufacturers List" can be requested from address (1) below, or can be found on the NOAASIS web site http://noaasis.noaa.gov/NOAASIS/ml/manulst.html

NOAA's Comprehensive Large Array-data Stewardship System (CLASS) is a web-based data archive and distribution system for NOAA's environmental data it can be located at http://www.osd.noaa.gov/class/

GVAR Data Format http://noaasis.noaa.gov/NOAASIS/ml/nesdis82.html

LRIT Data format http://noaasis.noaa.gov/LRIT/

LRPT Format http://www.wmo.int/pages/prog/sat/documents/pdf_cgms_04-LRPT-HRPT.pdf

HRPT Data Format http://www2.ncdc.noaa.gov/docs/klm/html/c4/sec4-1.htm

GEONETCast Americas http://geonetcastamericas.noaa.gov

GOES-R Project http://osd.goes.noaa.gov/

Addresses

(1)
Direct Readout Program Manager
NOAA/NESDIS Satellite Services Division
NSOF Room 1660
4231 Suitland Road
Suitland, MD.
20746
Telephone: 301-817-4523

FAX: 301-817-3904

E-mail : satinfo@nesdis.noaa.gov

(2)
Direct Broadcast Program Manager
NOAA/NESDIS Satellite Services Division
NSOF Room 1659
4231 Suitland Road
Suitland, MD.
20746
Telephone: 301-817-4521

FAX: 301-817-3904

For information about the Search And Rescue program utilizing the NOAA GOES and TIROS satellites, contact:

(3)
SARSAT Coordinator
NOAA/NESDIS Satellite Services Division
NSOF Room ????
4231 Suitland Road
Suitland, MD.
20746
Telephone: 301-817-3846

FAX: 301-817-3904

For information about, and requirements to use the GOES Data Collection System (DCS) contact:

(4)
DCS Coordinator
NOAA/NESDIS Satellite Services Division
NSOF Room 1663
4231 Suitland Road
Suitland, MD
20746
Telephone: 301-817-4558

FAX: 301-817-3904

E-mail : goes.dcs@noaa.gov <mailto:dcs@noaa.gov>

(5)
SARSAT Coordinator
NOAA/NESDIS Satellite Services Division
NSOF Room 1426
4231 Suitland Road
Suitland, MD.
20746
Telephone: 301-817-3846

FAX: 301-817-3904

The following internet sites provide information about non-U.S. meteorological satellite agencies and their spacecraft:

Information about the European METEOSAT and METOP satellites, and their operations can be found on the EUMETSAT web site, http://www.eumetsat.int/Home/index.htm

Information about the Japan Meteorological Agency and MTSAT spacecraft can be found at http://www.jma.go.jp/jma/jma-eng/satellite/

Information about the Indian Space Research Organization and INSAT spacecraft can be found at http://www.isro.org/

The following internet sites are suggested as places to find more information about getting started in satellite direct readout activities and general information about meteorological/environmental satellites:

www.amsat.org/amsat/keps/kepmodel.html

www. rig. org. uk

www.drig.com

http://www.nasa.gov/

http://www.wmo.ch

At least one journal is devoted exclusively to weather satellite reception, and aimed at nonscientific and amateur readers. Contact them for subscription information.:

Remote Imaging Group Journal
PO Box 142
Rickmansworth WD3 4RQ
United Kingdom
(or web site www.rig.org.uk)

APPENDIX C. GROUND STATION USER'S SURVEY

The National Environmental Satellite, Data, and Information Service (NESDIS) manages the United States' civil Earth-observing satellite systems. In an effort to better serve the user community of NOAA-operated and other environmental satellites, NESDIS maintains a "users list" of all known environmental satellite readout stations throughout the world.

The users list is one way NESDIS has of keeping the user community informed of changes to satellite operations, establishing how direct readout data is being used, and planning future satellite capabilities and programs. NESDIS also provides limited information about satellite station location and type of data received only, to the World Meteorological Organization (WMO).

When establishing a new satellite receiving station, or modifying or relocating an established station, NESDIS requests the station operator's cooperation by completing the questionnaire (or a copy) on the following page, and returning to NESDIS.

Your response is voluntary and all information is handled in accordance with the United States Privacy Act.

The completed questionnaire can be mailed to the following postal address:

Direct Readout Program Manager
NOAA/NESDIS Satellite Services Division
NSOF Room 1660
4231 Suitland Road
Suitland, MD.
20746
Telephone: 301-817-4523

FAX: 301-817-3904

E-Mail: nesdis.osdpd.dsd.info@noaa.gov <mailto:satinfo@nesdis.noaa.gov>

An on-line version of the survey is also available for completion at the NOAASIS web site.

NOAA Satellite Ground Station Customer Questionnaire

OMB Authorization #0648-0227 expires 31 May 2008

This survey is for any organization or person operating a ground station who receives data from NOAA meteorological and environmental satellites.

NOAA, the operator of Geostationary Operational Environmental Satellites (GOES) and Polar Orbiting Environmental Satellites (POES), maintains a voluntary list of known meteorological satellite receiving stations throughout the world. NOAA will make significant changes to its satellite systems over the next few years and this user list enables NOAA to keep its satellite user community informed.

This survey is designed to help NOAA provide the best service to you. It also assists us in planning and evaluating changes to the next generation of NOAA satellites and in providing limited information to the global meteorological community through the World Meteorological Organization (WMO).

If you have not completed a similar survey for NOAA during the past 12 months or would like to update your previously submitted information, please complete this short survey. We are specifically interested in responses from all users throughout the world who receive meteorological data from NOAA satellites.

All respondents are advised that any information you submit will be treated in accordance with the U.S. Freedom of Information Act. We do not disclose any of your personal information that would constitute an invasion of your personal privacy.

NOAA provides a limited amount of information about the type of station you operate and satellite data you receive to the WMO. NOAA does not provide personal information about you to the WMO.

Thank you for taking the time to complete this survey. Please answer all questions that apply to you and your reception equipment.

*Please Note: * Indicates a Required Field*

1. *Select one user category that best describes your activity:
   A Amateur
   B Commercial /Business
   C Equipment or Software manufacture, (also see below)
   D Government meteorological organization
   E Other civil government
   F Military
   G High School, Technical School or Elem. School
   H Television or Radio Broadcast Station
   I University or College
   J Other Category____

If You've selected 1C, Equipment or Software manufacture, please select products/services that you make:

____ APT ____ AHRPT ____Software

___LRPT _____LRIT ____Image interpretation services

__HRPT _ __GOES GVAR _ __Complete 'turn-key ' installations

2. *What data types do you receive?
Please select all products or services below that apply

___ APT ____ AHRPT ____EMWIN

_ __LRPT _ _____LRIT ____Do not know or Not Applicable

_ __HRPT ______GOES GVAR

3. What is the location of your receiving station antenna?

Please use DD:MM:SS format; i.e 32 degrees, 34 minutes, 3 seconds N would be 32:34:03 N or DD.dddd decimal format; i.e 32.5675 degrees N would be 32.5675 N)

LATITUDE*_________________North/ South

LONGITUDE*_______________West / East

ELEVATION ________________feet / meters

______Not Applicable (no antenna but receive data via the internet, cable, etc.)

4. User Information *Please Note: * Indicates a Required Field)*

Name (Last, First) *____

Title ____

Organization ____

Division ____

Country *____

Street Address*____

City/Town *____

State/Province*____

Postal /Zip Code*______________________________________

Telephone ____

Fax ____

Email Address*____

Describe your data application (what do you use it for?)____________

____

____

____

____

http://directreadoutsurvey.noaa.gov/user/survey_form.jsp?lang=en&Referer

If you have any questions about this survey or any aspect of the NOAA satellite program, please contact the Data Services Team at the above address or facsimile number.