Use of Satellites in Data Retransmission

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INTRODUCTION

During the early 1960's, experiments conducted with the Omega Position Location Equipment (OPLE) System and the United States National Aeronautics and Space Administration's (NASA) Applications Technology Satellite demonstrated the feasibility of relaying small quantities of data from a given location to a satellite and then to a central receiving site. Further experiments were conducted by NASA, all of which demonstrated the technical feasibility of such systems. However it was the launch of Landsat-1 (formerly ERTS-1) in 1972 that prompted the greatest interest in the potential user community.

Landsat-1 carried a Data Collection System that enabled many users in North America to conduct experiments with satellite retransmission of data using relatively inexpensive equipment. The system proved to be of particular interest to persons engaged in various hydrometeorological activities as it allowed data users to receive information from any location in the western hemisphere on a near "real time" basis. More recent developments indicate that it should be feasible to use satellite retransmission systems as a primary means of data collection, theoretically eliminating the need for on-site recording of data.

This paper discusses the current technology and speculates on developments through 1980, gives examples of results of various programs, and makes comparisons with conventional telemetry techniques.

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SATELLITE DATA RETRANSMISSION SYSTEMS

Satellite data retransmission systems such as Landsat consist of a Data Collection Platform (DCP) that can receive data from various sensors then transmit to a satellite on a certain schedule or upon interrogation, a satellite-carried transponder that receives data from a DCP then retransmits the data to earth, and a receiving antenna and ground data handling facility for processing and dissemination data.

Data Collection Platforms

A DCP consists of a small electronic unit (about 0.01 to 0.02 m^3 volume, 5 kg mass) and an antenna. DCPs have been supplied by several companies in the United States and one Canadian company; also units will be manufactured in other countries soon, therefore there are some differences even in those designed to operate with the same satellite. Units that are easily convertible for use in transmitting to two satellite systems have also been manufactured.

The DCP collects data such as water level or precipitation from sensors, encodes the data in the format required by the satellite system, and transmits the data along with an identification code to a satellite. All DCPs now in operation transmit at 400 to 403 MHz although some work is in progress on units that would operate at microwave frequencies (4-6 GHz). Figure 1 is a portion of the electromagnetic spectrum with some commonly used frequencies identified.

The length of the transmitted message and the rate at which it is transmitted are governed by the satellite system. Message lengths vary from 32 to over 1000 bits and rates from 100 bps to 2500 bps. In some cases, data must be in serial digital form for collection by the DCP but several manufacturers make provision for entry of parallel digital and analogue data as well. In the latter cases the message is organized into a series of 4, 8 or 12 bit words and the type of data entry is set by the user of the DCP.

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Some manufacturers make provision for a DCP memory in their units. The memory will hold about 700 to 800 bits of data and the contents may be transmitted in segments or all at once depending on the satellite being used.

More recent developments include the use of microprocessor controlled DCPs. This enables significant reductions in the number of components in the DCP as the microprocessor can handle such tasks as encoding of the data, insertion of the platform address, control of the memory, scanning of incoming data to generate alarm messages, and conversion of the DCP to operation with another satellite system. The result of this technology is decreased platform cost, increased reliability and increased versatility.

The housing of the DCP, its environmental specifications, and the antenna designs vary from manufacturer to manufacturer. Some DCPs have weatherproof enclosures, some are hermetically sealed; some units will operate at temperatures as low as -50°C and as high as +50°C and in 100% relative humidities. Antennas are small, some as small as 350 mm square and 3 mm thick. Power supply is about 12 VDC and power consumption 50 to 100 mW.

Transmissions from a DCP may be controlled in three ways: random, self timed and interrogated. In the random mode (used with low orbiting satellites) the DCP transmits its message at short intervals, of about 40 s to 200 s. The DCPs are designed so that the interval between transmissions drifts randomly with time, say ±10 to 15 s. In this way the possibility of two transmitting DCPs blocking each others signals for long periods of time is greatly reduced. The number of DCPs for a 5% jamming probability is a function of the satellite orbit, the message length, the rate at which the DCP transmits data, and the time between transmissions. Usually a single satellite channel can handle 500 to 1000 DCPs in view at one time without significant interference. In the self-timed mode the platform must transmit (to a geostationary satellite) during a precise assigned time slot, say 120 s every 3 hours. Finally, in the interrogated mode, the satellite initiates the transmission by sending a signal to the DCP. Of the three systems, the random mode transmission systems are cheapest to build and operate and interrogated are most expensive. However, use of an interrogated system is the only way that an operator of DCPs can obtain data at will.

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Spacecraft

At present two satellite data retransmission systems are in operation, others will be in use shortly and additional systems are under consideration. The transponder can be carried by a satellite in one of three kinds of orbit: low (900-1000 km) circular at various inclinations to the equator, geostationary (altitude 36.000 km), or highly elliptical. All orbits have advantages and disadvantages.

Low orbiting spacecraft tend to be less expensive to build and launch and, if inserted in a near polar orbit, global, though intermittant, coverage can be achieved with one satellite. As the DCPs used with such satellites are operated in a random mode, they tend to be less costly to construct. The DCPs are easy to install since it is not necessary to aim the antenna in a particular direction.

Geostationary satellites are more expensive to build and launch and only provide coverage of 2/3 of a hemisphere, however this coverage can be provided continuously, unlike that of a low orbiting satellite. The antenna used to receive data can be relatively inexpensive as no sophisticated mechanism is needed to track the satellite. There can be problems using a geostationary satellite in northern or mountainous areas as the required elevation angle of the DCP antenna for a "line-of-sight" to the spacecraft may be so low that the transmission is blocked. For example, at latitude 60^{o} the antenna elevation angle must be 22^{o} or less.

Satellites having highly elliptical orbits have not been used for data retransmission but it is possible that a system consisting of two such satellites in near polar orbits could provide nearly continuous global service, and yet be more cost effective than a geostationary satellite system.

Landsat

The Landsat spacecraft, launched July 23, 1972 and January 22, 1975, are in identical sun synchronous (near polar) orbits that are 9 days out of phase. The spacecraft circles the earth at an altitude of 900 km every 103 minutes and crosses the equator southbound at 09:42 local time. The satellites carry

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Multispectral Scanner (MSS) and Return Beam Vidicon (RBV) imaging systems and a Data Collection System. The Multispectral Scanner on Landsat-1 is still in use; the Data Collection System is operational but has been turned off since, because of the nature of the spacecraft orbits, it would not provide additional data.

The Landsat Data Collection system (Figure 2) can relay 64 bits of data from a DCP to a centrally located receiving antenna whenever the satellite is in mutual view of the DCP and the antenna. (The DCP transmits the data in a 38 ms burst every 180 s). Data may be retransmitted during the southbound passes of the satellite each morning and the northbound passes in the evening. Usually data are obtained on 3 or 4 orbits each day although in some parts of northern Canada data have been retransmitted as often as 8 times a day. The reason for this is that the satellite's orbital tracks tend to converge in the north (and south) polar regions. Usually 10 to 25 actual transmissions are received, some of which are only 180 s apart. NASA's Landsat program is considered to be experimental and, although users are permitted to run "quasi-operational" programs, there is no guarantee of continued availability of Landsat spacecraft. However, NASA is funding Landsat-C which could be launched in 1977.

GOES

The Geostationary Operational Environmental Satellite (GOES) system was developed by the United States as its contribution to a worldwide system of similar satellites. The GOES system will consist of two satellites stationed over the equator at 75° and 135° west longitude and an in-orbit spare mid-way between the two operating spacecraft as shown in Figure 3. The two NASA prototypes of the GOES spacecraft were launched on May 17, 1974 and February 6, 1975. SMS-1 (Synchronous Meteorological Satellite) is located at 75° and SMS-2 at 115° west longitude. A spare satellite, GOES-1, was launched on October 23, 1975 and two more satellites are under construction. The operator of the satellites is the National Environmental Satellite Service (NESS), National Oceanic and Atmospheric Administration (NOAA), U S Department of Commerce.

The GOES satellites are multi-purpose in nature, carrying a Visible and Infrared Spin-Scan Radiometer (VISSR), a Space Environmental Monitoring (SEM) System, and a weather facsimile (WEFAX) retransmission system in addition to a Data Collection System. The users of the GOES Data Collection System are assigned channels and time slots during which DCPs can transmit. Each satellite has 183 channels; 50 are for self-timed platforms, 100 for satellite interrogated platforms and 33 for the first international GARP project, an oceanographic project, in 1978. Each satellite can handle retransmitted data from over 10 000 DCPs. In fact, the satellite can generate 45 000 interrogation commands in a 24 hr period.

Other uhf Geostationary Satellites

As part of a global observing system, the European Space Agency (ESA), the Soviet Union and Japan will operate satellites similar to GOES at 0^{o}, 70^{o}E and 140^{o}E by 1978. The ESA satellite is known as Meteosat and the Japanese one as GMS (Geostationary Meteorological Satellite). These satellites (and the Soviet Union's) will carry the identical 33 international data retransmission channels as do the GOES satellites. In addition Meteosat will have 33 other channels and GMS will have 100 other channels for domestic use.

No commitments have been made by the countries involved in these programs to operate systems beyond the lifetime of the first successfully launched satellite. The data retransmission service provided could therefore terminate abruptly with the failure of the satellite transponder or the satellite itself.

Planning studies for a low capacity, geostationary, uhf communications satellite that would have data retransmission capability are underway in Canada. The main purpose of the system would be to meet communications needs that cannot be met by the Anik series of domestic communications satellites. Doubtless, other nations are also considering satellite programs that could provide data retransmission service on a multipurpose satellite.

Tiros-N

This satellite is the NASA prototype for a series of operational meteorological satellites; it is scheduled for launch on 1978. The system will consist of two operating satellites in different sun synchronous orbits; new units will be launched as the original ones fail. The satellites will carry an atmospheric sounder, a high resolution radiometer, a space environment monitor and a data collection system.

The data collection system is under development by the French Centre National d'Etudes Spatiales (Project Argos). The system will retransmit messages that can vary in length from 32 to 256 bits. These messages are transmitted randomly by the DCP at intervals of 40 s (80 s or longer can also be used) at a rate of 400 bps. The data will be recorded on board the satellite for play-back when the satellite is in view of a receiving antenna.

The TIROS-N series of spacecraft also will have the capability to compute the position of a DCP on the basis of the Doppler shift in the carrier frequency of the incoming data message. This will enable the tracking of a moving DCP such as one suspended from a meteorological balloon. Using this technique wind speeds may be determined to an accuracy of ±1.6 m/s.

Datasat Concept

All of the present data retransmission satellites and the ones that will be operational soon are multipurpose in nature. Because of this the satellite orbits are not necessarily the best from a data retransmission standpoint. Also, since the data retransmission transponder is a relatively small proportion of the overall satellite cost, some users have raised the question: if the transponder fails and the rest of the satellite remains operational, would a spare satellite be put into service? For this, and other reasons, there has been interest in NASA's Datasat concept.

Datasat, as part of the Applications Explorer Mission, would be a low cost satellite whose sole purpose is to provide a data retransmission service. A number of satellites in low polar orbits would provide frequent global coverage and could be launched by inexpensive launch systems such as Scout rockets or the Space Shuttle. DCPs used with the satellite would transmit in a random mode and therefore be inexpensive.

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Commercial Communications Satellites

All of the satellite systems discussed to this point operate with uhf uplinks however the feasibility of utilizing existing commercial communications satellites, such as Anik, that have microwave (6 GHz) uplinks is under investigation. Companies such as Telesat Canada and Comsat General have expressed interest in providing a data retransmission service. Factors that may prevent establishment of a service are that the DCPs for such systems could cost three times as much as the uhf DCPs. Also, the antennas for the microwave DCPs must be aimed at the satellites to high precision, such is not the case with uhf systems.

Data Reception and Distribution

As data are retransmitted virtually instantly from a remote DCP to a receiving antenna, it is essential that an effective system of distributing data be set up so that users can derive maximum benefit from the system. In the case of Landsat and GOES the user may obtain data within an hour of its transmittal by a DCP.

The Landsat data are received at NASA antennas in Goldstone, California and Greenbelt, Maryland then formated and transmitted by NASA landlines to a ground data handling centre at Greenbelt. (These NASA antennas also monitor the health of the spacecraft and command it.) The data are then sorted and sent to major users by dedicated telephone lines for further distribution. In addition, computer punch cards are prepared and these cards, together with a printout, are mailed to the users. The cards may then be used to produce a "hard copy" of the data for archival purposes.

The GOES data are received at the Wallops Flight Center in Virginia then sent by landline to NESS in Suitland, Maryland for sorting and distribution to users by landline. NESS also sends users a printout of the data by mail.

The Tiros-N data will be received by NESS at Wallops Flight Center or at Gilmore Creek, Alaska and could be disseminated from Suitland or from the Argos processing center in Toulouse, France.

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In addition to the data reception and distribution centres operated by agencies that operate spacecraft, some major users of data such as the US Geological Survey and the US Army Corps of Engineers have established their own antennas for reception of data. This tends to reduce the time taken for the user to obtain data and reduces the possibility of data loss due to landline problems.

RESULTS

The results of experimental satellite retransmission programs that have been conducted by the United States and Canada have been outstanding. A multitude of parameters have been retransmitted; data have been used for purposes ranging from reservoir operation to prediction of volcanic erruptions. In the field of hydrology the most frequently used parameter is water level while precipitation and air temperature are most frequently used in meteorological applications. Other hydrometeorological data that have been transmitted include water quality parameters such as temperature, pH, dissolved oxygen, conductivity and turbidity plus other data such as water velocity, presence/absence of river ice cover, snow water contant, wind speed and direction, relative humidity and atmospheric pressure. Housekeeping data such as battery voltages, water stage recorder operation check, and enclosure temperature have also been transmitted by DCPs.

Retransmitted hydrological data have been used for preparation of flow and flood forecasts and in operation of gauging stations. The forecasts are used in reservoir operation for flood control, hydroelectric power generation or irrigation. Data are also used in preparation of water level forecasts for navigation and for flood warning. Formerly, it was not economically feasible to obtain the required data on a real time basis by landline from some isolated locations.

The satellite retransmitted data can be used in operation of gauging stations in several ways. The incoming data can be monitored as a means of determining sensor performance. Thus if a malfunction is observed a special

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trip into a site can be made to carry out repairs. As the nature of the malfunction is known the appropriate parts can be carried into the site. Alternatively if sensor performance is all right and there is no need to visit the site to conduct other work, a visit can be postponed.

Transmittal of data concerning conditions at a gauging station such as cloud cover, wind speed and direction, presence/absence of ice cover on a stream provides valuable information so that a field party can plan trips into an area, particularly when aircraft are used.

Another fundamental use of satellite retransmission of data in addition to meeting real time data needs is that of using this technology as a primary means of data collection. The DCP memory units now available enable the user to collect several hundred bits of data each hour if the GOES spacecraft is used. Use of a memory equipped DCP with the Landsat system will produce about 100 bits of data each day. The retransmitted data can then be entered into existing computer programs for processing of hydrologic data and the permanent record computed in the same manner as data obtained from an on-site recorder.

The DCP memory could, therefore, enable a data collection agency to dispense with on-site recording of data and thereby reduce the cost of operating a data gathering network. Such a step would be dependent on having an absolute certainty of the long term availability of a suitable spacecraft with spares and several data handling and processing sites. Without these redundancies, the impact of a lengthy satellite or ground station failure on a national data gathering program could be catastrophic.

The DCPs have proved to be rugged and reliable pieces of equipment. They are very easy to interface with existing commercially available sensors and are easy to install. Typically two persons can install a DCP at a site where sensors are already in place in a few hours. In cases where an antenna mast was installed earlier, the DCP can be installed in less than an hour. Figure 4 shows a typical Water Survey of Canada hydrometric station with Landsat antenna and solar charger.

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COMPARISON WITH CONVENTIONAL TECHNIQUES

It is difficult to make rigorous comparisons of satellite retransmission systems for data collection with more conventional systems since satellite systems are relatively new and are still undergoing changes. Also, because of the multipurpose nature of the present spacecraft, the user of the data retransmission service is not called upon to contribute to the cost of the satellites; in the case of the conventional systems the user generally pays all costs. For the sake of comparison assume the availability of an operational uhf satellite system at no cost to the user, the purchase of local user terminals to receive and process data and the availability of self-timed standardized DCPs produced in large quantities.

Operating Considerations

Installation of a local user terminal permits the user of satellite retransmission systems to function in almost the same way as the operator of more conventional systems. The only real difference is that the user cannot interrogate sites at will to obtain data when a satellite system is used. An operational satellite system is not as subject to interruptions in service such as those that result when telephone lines or radio towers are destroyed by winds or floods. Also in the event of a power failure at the local user terminal, back-up data would be available from the agency operating the satellite system, or from other local user terminals.

Since DCPs are designed for multi-parameter inputs, it is a very simple matter to add additional data to the usual message that is transmitted. This is not always the case for some conventional telemetry systems. Also a DCP can be deployed quickly to meet data needs that may arise suddenly, for example, during a flood.

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Cost Considerations

If the assumptions stated earlier are used to develop cost figures for satellite retransmission, the result is as follows. Figures are expressed in United States dollars.

Local User Terminal

The cost of the receiving antenna and related equipment for a terminal is about $100 000 although this price could decrease as terminals become more standardized. Some equipment in a local user terminal would also be required in sophisticated conventional telemetry system control center.

DCPs

The present cost of a DCP is about $4000 although studies that have been conducted show that this cost could drop to less than $2000 for quantity production. The rapid developments in electronic technology tend to keep costs down. Also, developments in microprocessor technology will tend to reduce the chances of a DCP becoming obsolete because of satellite changes.

Other Equipment

In some cases an interface is needed between a DCP and a sensor. Depending on the sensor used, the interfacing cost could be significant. For example the interface between a water level sensor and DCP may cost $500 to $1200. Sensors having analogue or serial digital outputs usually do not require costly interface equipment.

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Some manufacturers of DCPs supply test boxes that enable the user to start operation of the unit and to monitor its performance. These test boxes cost about $1500. One test set is used with several DCPs.

Miscellaneous items such as batteries and solar chargers could cost about $200.

Operating Costs

The operating and maintenance cost of a DCP is very small; some units have been in operation for over 3 years without maintenance. Improvements in electronic technology and standardization should ensure even better performance.

The principal operating expenses would be those associated with the local user terminal. Persons would be needed to operate the terminal and maintenance could be $10 000 a year. These same kind of costs are encountered when operating some conventional telemetry systems.

In comparing the above costs to those associated with conventional telemetry, it should be noted that in parts of many countries conventional telemetry is simply not economically feasible. In any case conventional telemetry costs are very dependent on site conditions and location. Where it's customary to install telephone telemetry systems, generally it can be said that these systems are cheaper to install but more expensive to operate than satellite systems. Also there appears to be little possibility of these costs decreasing because of technological advances.

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Radio telemetry systems tend to be more expensive to install and to operate than satellite systems. The saving in using satellite retransmission is so great that the cost of a local user terminal can be defrayed even if only a relatively small number of sites are involved. As much of the expense of using radio systems is in the construction and maintenance of towers, it is not likely that system costs will decrease.

CONCLUSIONS

Satellite data retransmission programs using the capability of Landsat, and more recently, GOES satellites have demonstrated the feasibility of utilizing this technology for retransmitting hydrologic data from remote locations to data users. The equipment has proved to be accurate, reliable and relatively inexpensive.

Data relayed in this manner have been used for flow and flood forecasting and in the conduct of hydrometric field work. It's likely that the replacement of on-site recorders with satellite telemetry systems will prove cost effective.

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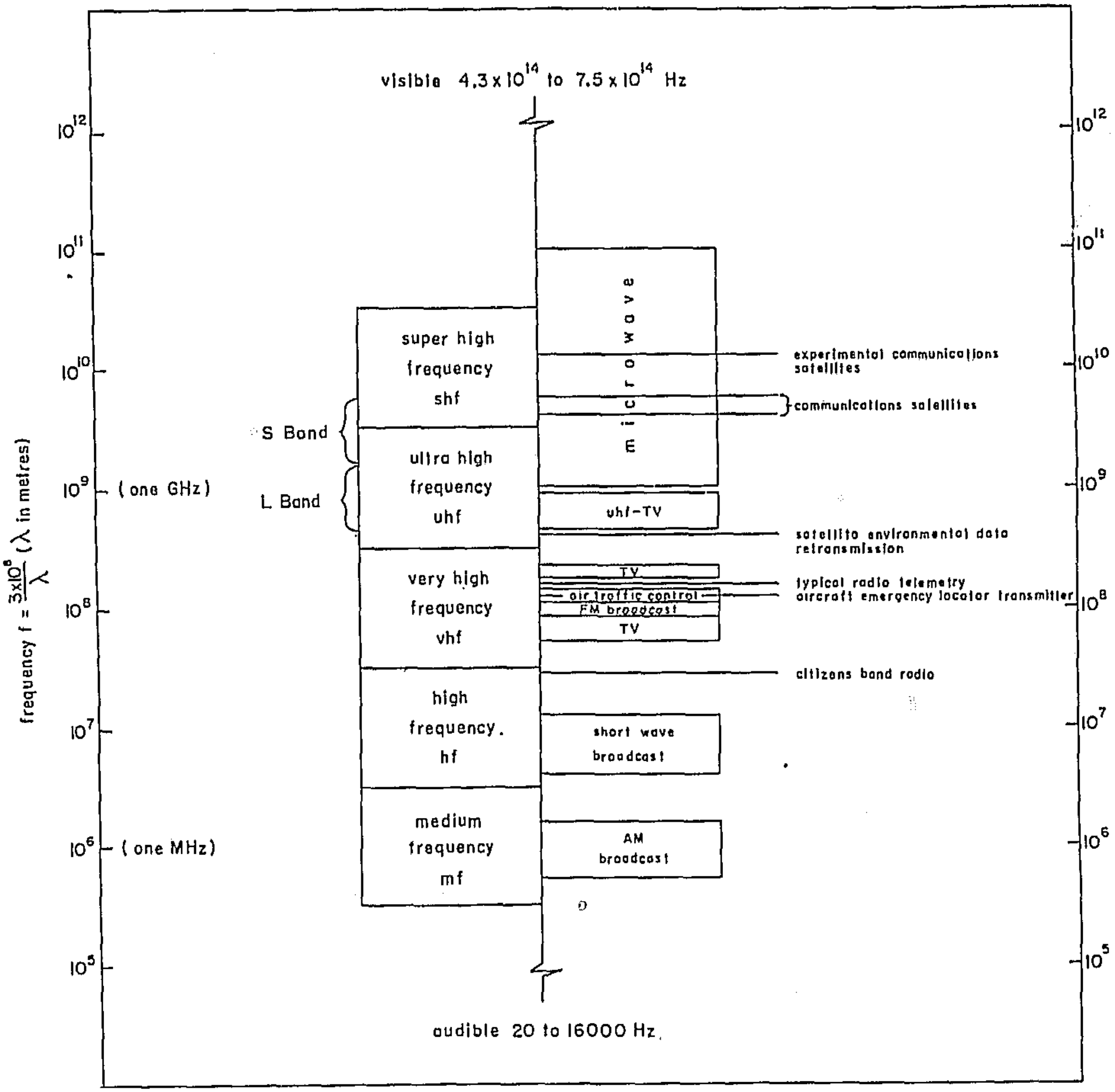
FIGURE I - PART OF THE ELECTROMAGNETIC SPECTRUM



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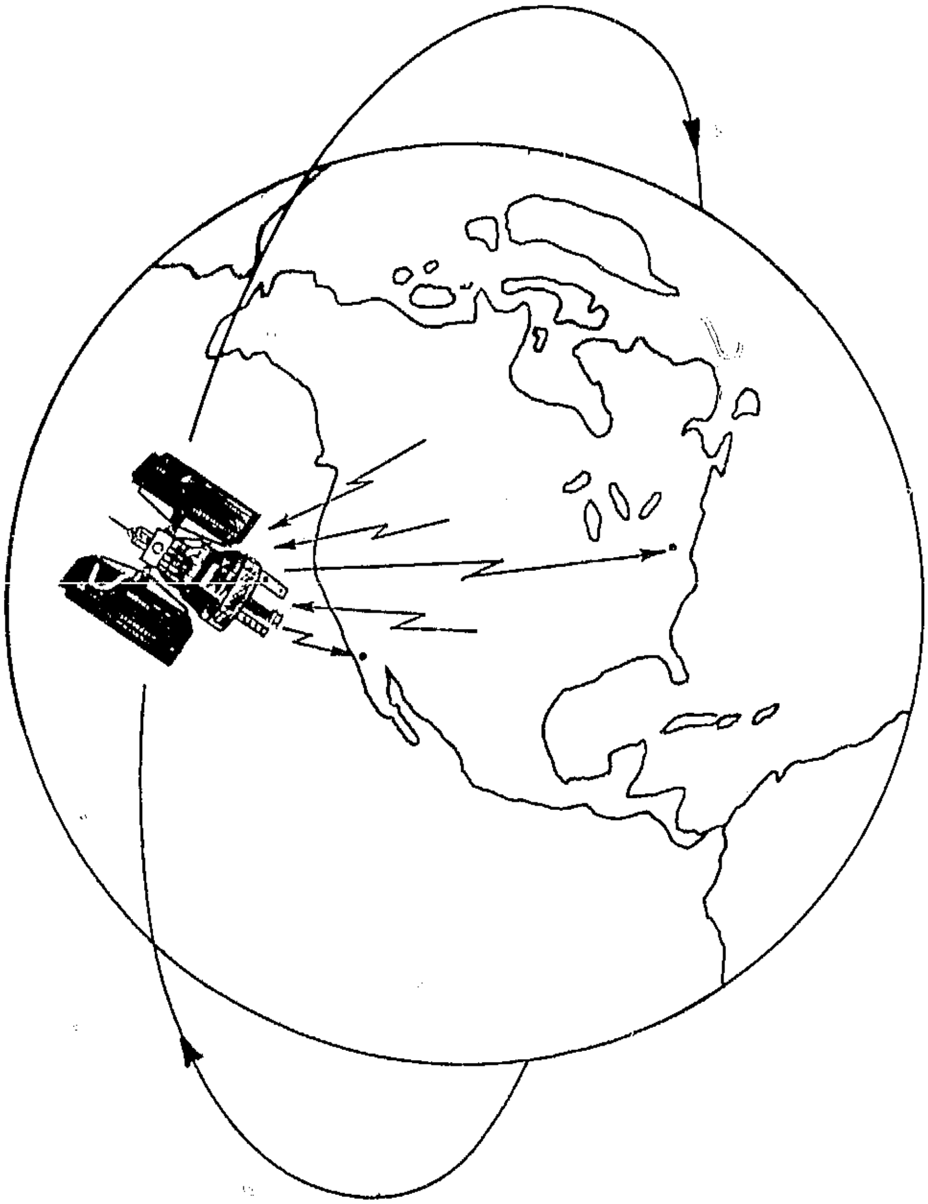

FIGURE 2 - LANDSAT DATA COLLECTION SYSTEM

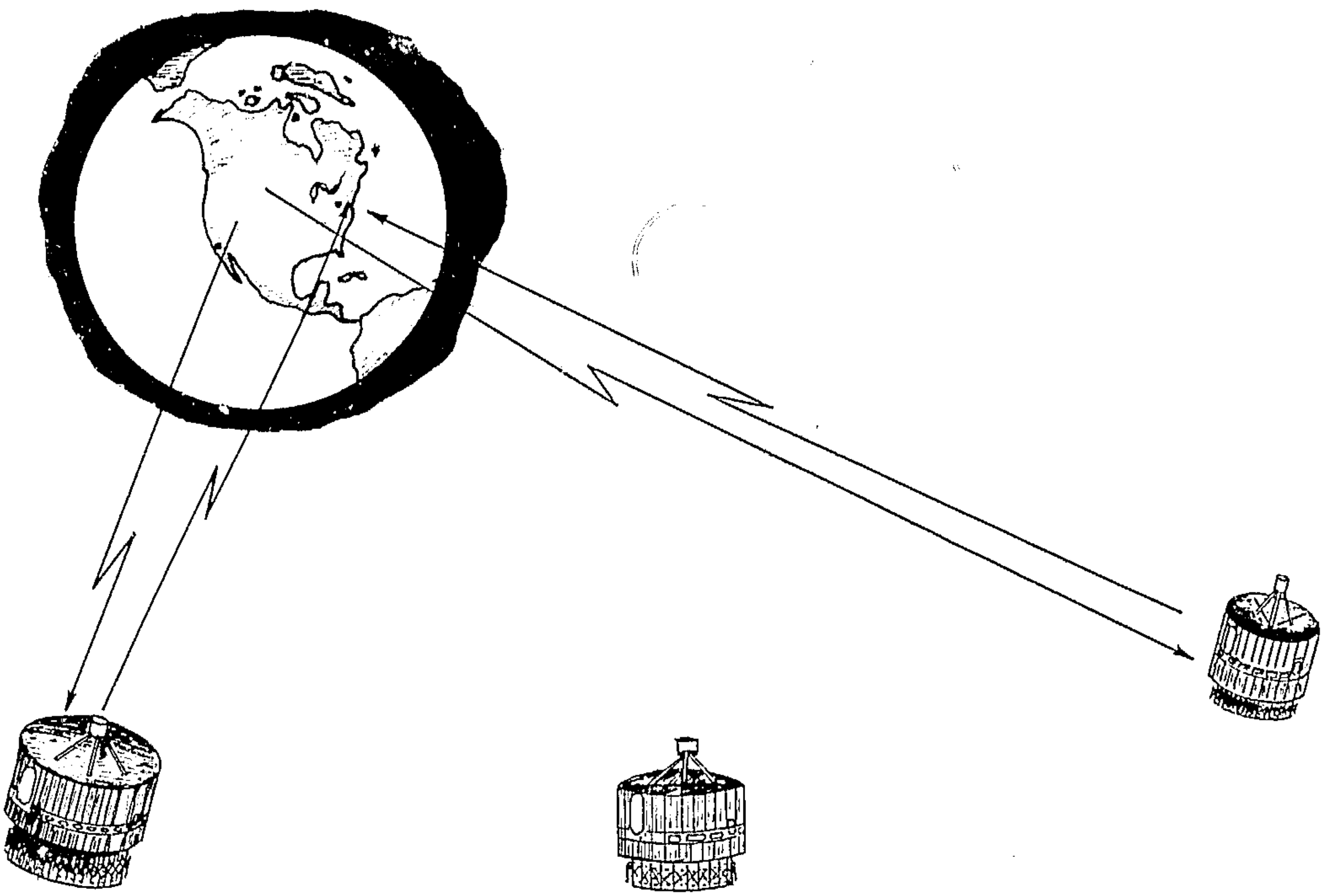

FIGURE 3 - GOES DATA COLLECTION SYSTEM

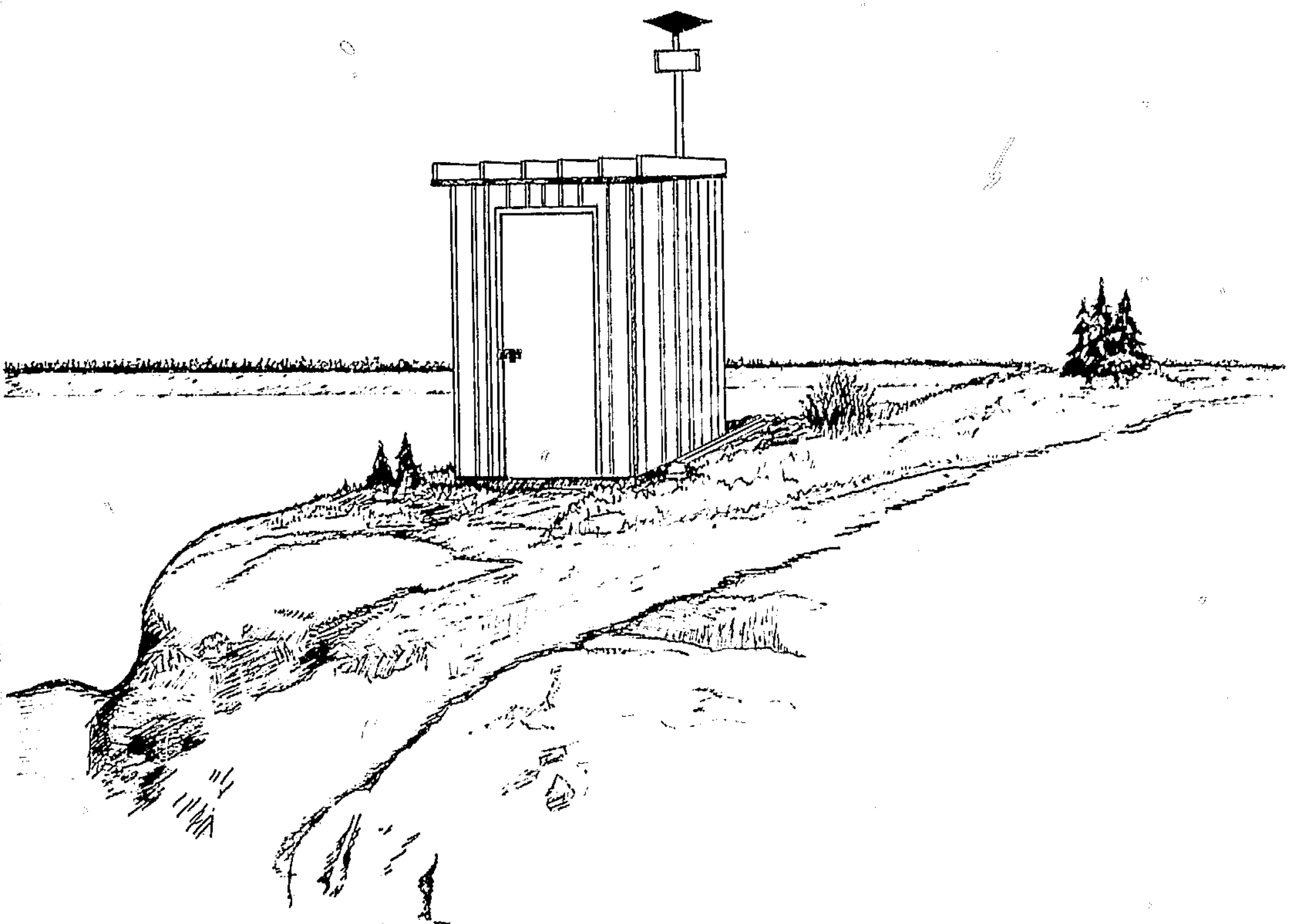

FIGURE 4 – TYPICAL DCP INSTALLATION