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NASA CR-130232

FINAL REPORT

DCS

A GLOBAL SATELLITE

ENVIRONMENTAL DATA COLLECTION SYSTEM STUDY

JANUARY 1973

PREPARED BY

SYSTEMS ENGINEERING DEPARTMENT
RADIATION
A DIVISION OF HARRIS-INTERTYPE CORPORATION
MELBOURNE, FLORIDA

PREPARED FOR

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND
UNDER CONTRACT NO. NAS5-21622

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APPENDICES

1.0 INTRODUCTION

This final report on the Add-on to Contract NAS 5-21622 presents the results of the Study of Data Collection Systems for A Global Satellite Environmental Data Collection System. The study has been performed by Radiation, a Division of Harris-Intertype Corporation, Melbourne, Florida during the period 28 June to 20 December 1972.

The general objective of this study has been to evaluate cost and technical feasibility of five medium orbiting and six geo-synchronous satellite data collection system (DCS) configurations with varying degrees of spacecraft and local user terminal (LUT) complexity. The goal of trading spacecraft and local user terminal complexity was to determine practical feasible systems with low cost local user terminals but yet with a reasonable overall system cost that would permit the broad worldwide utilization of a highly beneficial data collection system. A secondary objective was to study appropriate local user terminal data display techniques and to select those which would be most suitable for anticipated user requirements.

Because of the broad nature of this study and the relatively modest level of time and staffing, the study was by necessity a higher level system trade-off study with only enough effort on each configuration to determine relative costs and technical feasibility. The study was performed with a unique set of ground rules which will be reviewed in the next section and are essential in interpreting the conclusions of the study. The prime benefit of this study has been to provide parametric trade data on technical performance and relative system hardware cost. In essence, the study provides a shopping list of feasible systems to permit the selection of the most advantageous data collection system.

This report is divided into five major headings which provide the major study results. Supporting information on minicomputers and technical briefs on the selected hardware components are included in the appendices.

Section 2.0 presents a general summary of the study including a discussion of the objectives, ground rules, key study problems and the significant results. General system considerations including the user requirements and classes of users are discussed in section 3.0. The details and conclusions of the study of the five medium-orbiting or polar orbiting satellite DCS configurations are presented in section 4.0 with the study of the six geo-synchronous configurations presented in section 5.0.

2.0 STUDY SUMMARY

This study was fundamentally motivated by the desire to make the tremendous benefits of satellite relayed data from remotely deployed data collection platforms directly available to world wide users. The highly successful ERTS 1 data collection system has demonstrated the practical feasibility of using a polar or medium orbiting satellite to relay data received from remotely deployed un-synchronized burst transmission mode data monitoring platforms. In the ERTS 1 system, the data is received only at the Regional Collection Centers as shown in Figure 2.0-1, and thus, there is considerable delay and expense in providing the data to the various users. This study addresses the problem of providing the data from future satellite data collection systems directly to a low cost local user terminal in the users own facility.

The study takes a cursory look at a wide variety of system approaches which are not necessarily optimum to permit a comparison of the basic approaches. Both medium orbiting ERTS and EOS type satellite and geo-synchronous SMS and SEOS type satellite data collection systems were studied. The various medium orbiting satellite configurations were studied independently of the geo-synchronous satellite configurations with no study objective to compare the two types of satellite systems. Since many of the same ground rules, including the use of the ERTS data collection platforms, were applied to both studies, there is some basis of comparison, although none is included herein.

2.1 Scope of Study and Ground Rules

This study was broad in that it covered 11 different DCS configurations for both medium orbiting and geo-synchronous satellites and included S-Band, UHF and VHF downlink frequencies. Key ground rules included the use of the present ERTS data collection platform with no changes for the medium orbiting configurations and with only an antenna gain increase for the geo-synchronous configuration. The basic block diagram of the data collection systems considered by this study is shown in Figure 2.1-1. Details of the various configurations are found in sections 4.0 and 5.0. The key ingredient of all configurations is that the data comes directly from the satellite to a low cost local user terminal that can be place directly at the user's facility for near-real time data reception.

An understanding of the ground rules and cost estimate guidelines which constrained the study effort is necessary for proper interpretation of the results. These were established by NASA and Radiation to best focus the theme of the study while maintaining a reasonable expenditure. The study ground rules are self-explanatory and are listed as follows:

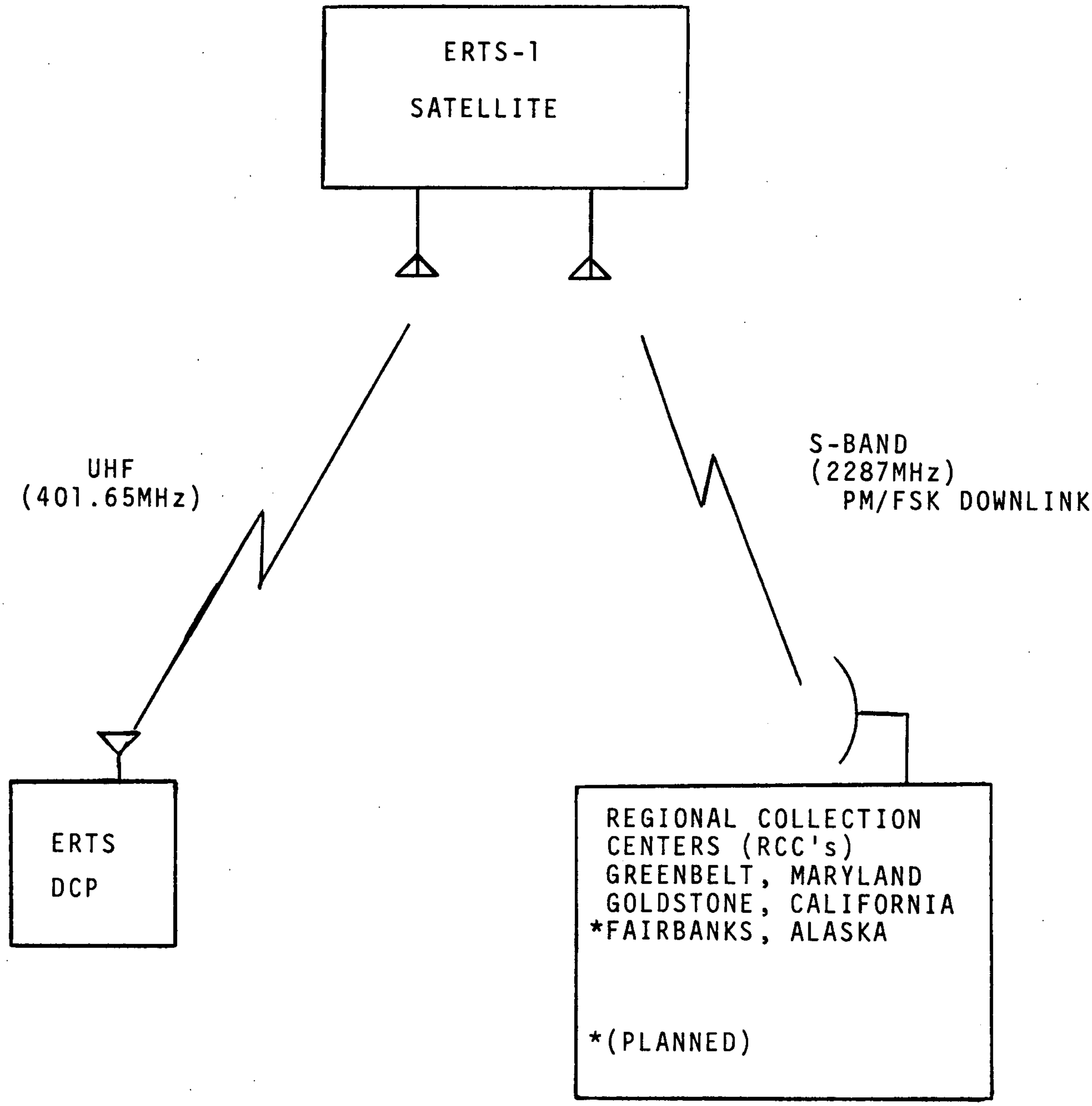


FIGURE 2.0-1 PRESENT DCS SYSTEM USING ERTS-1

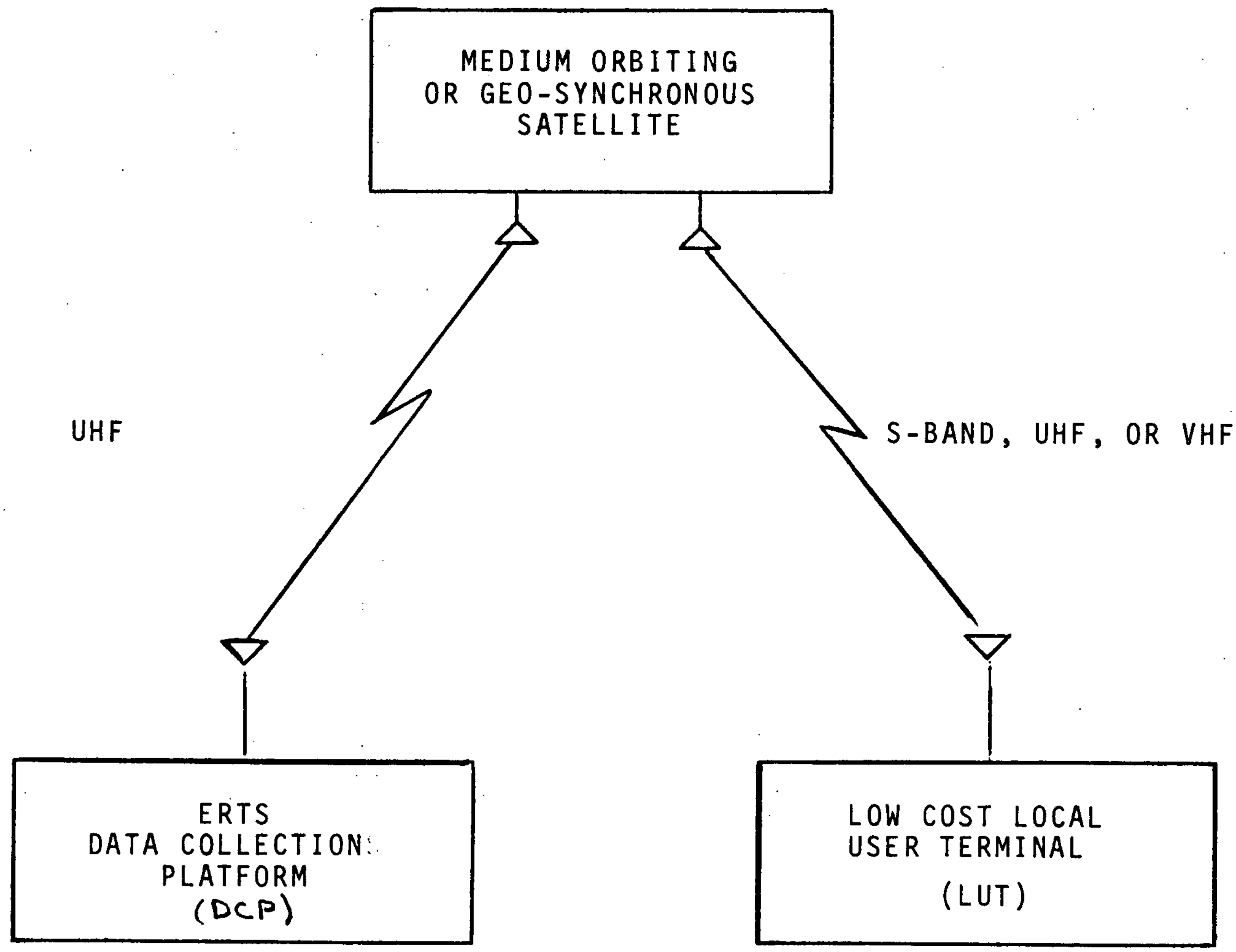


FIGURE 2.1-1

BASIC BLOCK DIAGRAM OF DCS CONFIGURATIONS INCLUDED IN THIS STUDY

DCS STUDY GROUND RULES - GENERAL

1) Minimize initial cost of LUT by trading satellite and LUT complexity.

2) Use off-the-shelf pre-qualified hardware whenever possible in satellite and LUT.

3) Assume that DCS satellite hardware will be independent of other systems and will be added on to either a medium orbiting or a geo-synchronous satellite.

4) If items such as antennas, etc. can be jointly used for other satellite missions, then the cost could be reduced accordingly at that time.

5) Don't worry about typing DCS system to an imagery system.

6) Only S-Band UHF, and VHF on downlink should be considered. Only UHF for uplink.

7) Assume no satellite S-Band, UHF, or VHF transmitters are available, thus use direct carrier modulation technique on downlink if possible.

8) This is a trade study and hence is not a study to optimize one particular configuration. All approaches should be considered equally.

9) On configurations having decoder in spacecraft or in high-capacity ground relay, assume confidence bits are desireable but not required to be transmitted to LUT.

10) Use 1972 prices on cost estimates but assume that system would be built in 1975. (NASA will incorporate correct inflation rate.)

11) LUTs may be mass produced or built one at a time, or both.

12) Minimize maintenance and logistics costs of LUTs since DCS system will be worldwide with many users overseas in underdeveloped nations.

13) If system design could also permit point-to-point message communication or command activated servo control for floodgates, etc., this would be an additional desireable feature, particularly overseas, and in remote areas in our hemisphere.

ADDITIONAL GROUND RULES FOR MEDIUM-ORBITING SATELLITE/LUT CONFIGURATIONS ONLY

14) No changes to present ERTS DCP.

15) Use an inexpensive receiver such as the Vanguard Labs VHF receiver in LUT VHF configuration.

ADDITIONAL GROUND RULES FOR GEO-SYNCHRONOUS SATELLITE/LUT CONFIGURATIONS ONLY

16) Use ERTS DCP's with only antenna changes.

17) The DCP antenna gain and beamwidth must be such that the antenna can be accurately pointed at the satellite with only a plumb bob and compass.

18) Assume that there would be three geo-synchronous satellites for worldwide coverage.

19) For hi-cap relay station approach assume that stations would be available and that DCS requirements could share existing antennas and receivers.

The many tables of cost estimates contained herein are based strictly on the following cost estimate guidelines and notes which must be kept in mind in comparing the various system approaches.

COST ESTIMATE GUIDELINES AND NOTES

- Estimates are for recurring hardware and test costs only.

- Non-recurring design and development costs are not included.

- Local user terminal hardware costs assume

  a) Quantity of 1 on off-the-shelf vendor supplied (OTS) items.

  b) Quantity $\geq$ 100 on new items but assembled one at a time. This quantity permits productizing various units so they can be manufactured at low cost.

  c) Recurring integration and test costs assuming manufacturing $\geq$ 100 are included; but no test procedures, documentation or drawings costs are included.

- Satellite hardware costs assume

  a) Quantity of 2 (1 flight item and 1 back-up) for medium orbiting satellite.

  b) Quantity of 6 (3 flight items and up to 3 back-ups) for geo-synchronous satellite.

- Cost estimates do not include G&A on vendor purchased items (G&A is approx 11% for most companies).

- Cost estimates include average manufacturing overhead loading on new items.

- Cost estimates do not include profit.

As the study developed, a number of important items were identified and addressed. These are summarized in Table 2.1-1 and will be discussed in the body of the report.

Table 2.1-1 Data Collection System Study Important Study Items

I. General

1) Establishing system design ground rules for "piggyback" satellite DCS configurations.

2) Estimating local user requirements and identifying general user classes.

II. Technical

1) Frequency uncertainties and bandwidths available at the possible frequencies.

2) Modulation choice.

3) Minicomputers vs. hardwired decoder for (1) decoding convolutional codes and (2) sync recognition and data deformatting.

4) Data display selection.

5) Finding low-cost off-the-shelf hardware to match technical requirements.

2.2 Study Results

2.2.1 General

The five medium orbiting satellite and local user terminal configurations which were studied included three S-band downlink configurations, one UHF downlink configuration, and one VHF downlink configuration. The S-band configurations included a receiver/translator and retransmit "bent-pipe" relay configuration similar to ERTS 1; an on-board processing configuration which included an FM demodulator, bit synchronizer, and convolutional decoder; and a third configuration similar to the preceding but with the convolutional decoder in the LUT. The UHF and VHF downlink configurations were both on-board processing configurations with FM demodulator, bit synchronizer and convolutional decoder in the satellite. All five configurations were found to be technically feasible with adequate gain margin with a satellite transmitter power of 5 watts.

The six geo-synchronous satellite and local user terminal systems which were studied included an S-band and a VHF downlink configuration similar to the planned SMS configuration which employs a high-capacity ground relay station and a double bent-pipe satellite relay. Four full on-board processing configurations with FM demodulator, bit synchronizer and convolutional decoder were also studied. These included a straight S-band downlink configuration, an S-band downlink with conversion to VHF at the LUT configuration and straight UHF and VHF downlink on-board processing configurations. All six configurations were shown to be technically feasible with adequate gain margin with a satellite transmitter power of 5 watts.

It must be emphasized that since the main objective of the study was to determine the technical feasibility and recurring cost of systems with varying degrees of complexity in the satellite and local user terminal, the various systems configurations presented herein are non-optimal. They are simply technically feasible, preliminary system designs using the best available off-the-shelf units and modifications of existing designs.

The system configurations which could be implemented either primarily or totally with off-the-shelf items, would obviously minimize non-recurring costs. These systems would also tend to minimize recurring costs since the actual manufacturing costs of the components had been amortized over a quantity of units. The systems requiring non off-the-shelf components require a considerable non-recurring cost to manufacture a quantity of one or two items. The recurring cost also tends to be high for a small quantity. To reduce the recurring cost to a reasonable level, it is necessary to assume that a sufficient quantity such as 100 or more units will eventually be built. With this kind of a ground rule, one can then assume a reasonable amount of additional non-recurring dollars would be expended to "productize the designs" with printed circuits and other labor and parts saving features to permit the units to be manufactured at a minimal recurring cost. The quantity of 100 ground rule for the local user terminals was utilized for the purposes of this study.

Since all of the data collection system configurations studied were shown to be technically feasible, the main study conclusions can be drawn from comparing the estimates of recurring costs for the individual satellite and local user terminal hardware configurations and for the combined system recurring cost.

2.2.2 Synopsis of Key Results and Conclusions

All five medium orbiting satellite DCS configurations and all six geo-synchronous satellite DCS configurations addressed in this trade study were shown to be technically feasible. In other words, with reasonable assumptions and hardware selections, the eleven data collection systems employing an ERTS data collection platform (with antenna modification only for geo-synchronous cases) transmitting to a satellite with retransmission to a local user terminal can perform at a bit error rate of less than or equal to 10^{-5}. The tradeoffs for the DCS systems for each type of satellite rests on cost, size, weight, power and other performance factors.

2.2.2.1 Medium Orbiting Satellite DCS Configurations

The recurring costs for a "piggyback" medium orbiting satellite DCS system with one backup hardware system and 100 local user terminals will be shown later in Table 4.4-1. In brief, they show a recurring cost advantage of about 2 to 1 in favor of the VHF configurations over the S-band configurations with the UHF configurations close to the VHF.

The VHF configurations require the least satellite electrical power, but the size and weight advantage of the simple S-band bent-pipe relay configuration (similar to the present ERTS-1 system) is considerable, and thus with the satellite cost penalties, the weighted overall recurring costs would be closer together. This would permit the final choice to rest on a variety of factors such as frequency availability, RF interference, non-recurring costs, the actual satellites to be used, and the total number of LUT's to be deployed. The cost differentials favoring VHF increase linearly with the number of LUT's and hence the latter item would be significant.

2.2.2.2 Geo-synchronous Satellite DCS Configurations

Since a minimum of three geo-synchronous satellites are required to give world-wide coverage, the recurring costs for a three satellite "piggyback" DCS system with three backup hardware systems and 100 local user terminals was computed for each of the six configurations and will be shown later in Table 5.4-1. They show a smaller recurring cost differential with the lowest recurring cost VHF systems showing only a 1% cost advantage over the lowest cost S-band system (the high-capacity ground relay system similar to SMS).

The VHF on-board processing configuration requires the least satellite electrical power, but has a considerable size and weight disadvantage relative to the S-band high capacity ground relay system; and thus, for the geo-synchronous case, the weighted overall recurring costs are very close. The gain and physical size of the satellite VHF and UHF antennas required for the geo-synchronous configurations (assuming 5 watt satellite transmitter) and their high non-recurring costs make these configurations less attractive. Obviously the antenna gain and size can be reduced by greatly increasing satellite electrical power which in turn increases the satellite cost. Thus the decision as to the correct choice for geo-synchronous DCS configurations must also rest on other factors such as frequency availability, RF interference, non-recurring costs, the actual satellites to be used, and the total number of LUT's anticipated.

3.0 GENERAL SYSTEM CONSIDERATIONS

This effort was intended to be primarily a system trade study. In performing the study, it was necessary to consider all facets of the total satellite, ground station, and user interaction. The general system considerations were thus a blend of user considerations and the technical system considerations involved in developing the various possible approaches for meeting the user needs.

User considerations included the basic desire for direct reception of data at low cost. Additional considerations included the quality, quantity, timeliness and display of the desired data.

The technical system considerations which influenced the various approaches included the "piggy back" ground rule for separate DCS hardware on-board the satellite, the possible downlink frequencies, and the availability of usable off-the-shelf hardware.

3.1 User Considerations

With the fundamental motivation for this study being the desire to provide data from a satellite data collection system directly to the user, the prime study emphasis was oriented towards the user. Unfortunately, a profile of the characteristics of the potential users has not been performed.

One of the first study problems addressed was, therefore, the problem of attempting to obtain information about potential users and to classify the types of users and their requirements. This was accomplished using information obtained from letter inquiries, personal visits, telephone discussions and a literature review.

3.1.1 Classes of Users and Requirements

The possible DCS users can probably be classified by the following four characteristics:

(1) Level of need for DCS data

(2) Economic situation

(3) Geographic situation

(4) Maintenance capability

Using the preceding, the possible DCS users were grouped into three classes as shown in Table 3.1.1-1.

No attempt was made to estimate the total number of potential DCS users or the distribution between the classes. Obviously, as the cost and complexity of the possible local user terminals decreases, the number of worldwide users particularly from the non-prosperous emerging nations would increase.

The requirements of the preceding three classes of potential DCS users were assumed to be as shown in Table 3.1.1-2 for the purposes of this study. These are further discussed in the following paragraphs.

3.1.2 Quantity, Timeliness, and Quality of Data

The quantity of data available from a satellite data collection system is determined by the number and type of data collection platforms utilized on the ground and the type of satellite. In accordance with the ground rules, this study considered only the ERTS data collection platforms which transmit 38 millisecond bursts of data every 3 minutes. The data format, as shown in Figure 3.1.2-1, permits one 8 bit word from each of 8 transducer channels per data burst.

Medium orbiting satellites are attractive economically because one satellite can provide nearly worldwide coverage. Using the ERTS 1 orbital parameters as shown in Table 3.1.2-1 as being typical of medium orbiting satellites, the satellite would pass approximately overhead only once every 12 hours. The pass would be visible for about ten minutes allowing three data bursts to be received. Assuming that adjacent passes (103 minutes apart) are also usable as per Figure 3.1.2-2 means that data is available approximately every 9 hours. See the final report from the "ERTS Direct Readout Ground Station Study" which preceded this study for a detailed discussion and set of curves of actual values.

The geo-synchronous satellites, with their fixed position in space (normally an altitude of 22,000 N. Miles), are attractive primarily because of their ability to provide continuous coverage of a portion of the earth's surface. Unfortunately, to provide a reasonable approximation of worldwide coverage requires a minimum of three strategically placed satellites as shown in Figure 3.1.2-3. The quantity of data available to a particular user is then determined only by the characteristics of the data collection platform transmission scheme and the number of data collection platforms that he has deployed.

Table 3.1.1-1

Possible DCS User Classes

DCS Users Can Probably Be Classified By
The Following Four Characteristics

	Class I Prosperous	Class II Non-Prosperous	Class III Research/Status
1) Level of Need For DCS Data	High	High	Low-moderate
Mission	Emergency warning, flood control, pollution control	Emergency warning, flood control, pollution control	Research, or non-critical status monitoring
Timeliness of Data	Near real time with frequent updates	Near real time with frequent updates	Delay acceptable with several updates/day
2) Economic Situation	Good	Non-properous	Moderate
3) Geographic Situation of LUT	Developed area	Undeveloped or semi developed area	Semi developed or developed area
4) Maintenance Capability	Good	Poor	Average

Table 3.1.1-2

Assumed DCS User Requirements

Class I User - Prosperous with prime need

1) Data Requirements

- Near real-time
- Frequent updates
- Quality, $P_B \leq 10^{-5}$

2) LUT Hardware Requirements

- Can afford and justify reasonably large initial cost
- High reliability
- Moderate maintenance costs
- Flexible or expandable capability for growth in number of DCP's
- Command capability to DCP's (some users only)

Class II User - Non-prosperous, but with prime need

1) Data Requirements - same as Class 1

2) LUT Hardware Requirements

- Must be low initial cost
- Low maintenance costs and maintainable by semi-skilled technicians
- Command capability to DCP's (some users only)

<u>Class III User</u> - Research/Routine Status Monitoring

1) Data Requirements

- Quality $P_B \leq 10^{-5}$

- Brief delays (several hours) with updates on the order of 2 to 4 times/day are acceptable

2) LUT Hardware Requirements

- Moderate initial cost and maintenance

- Flexibility (would use minicomp for data eval.)

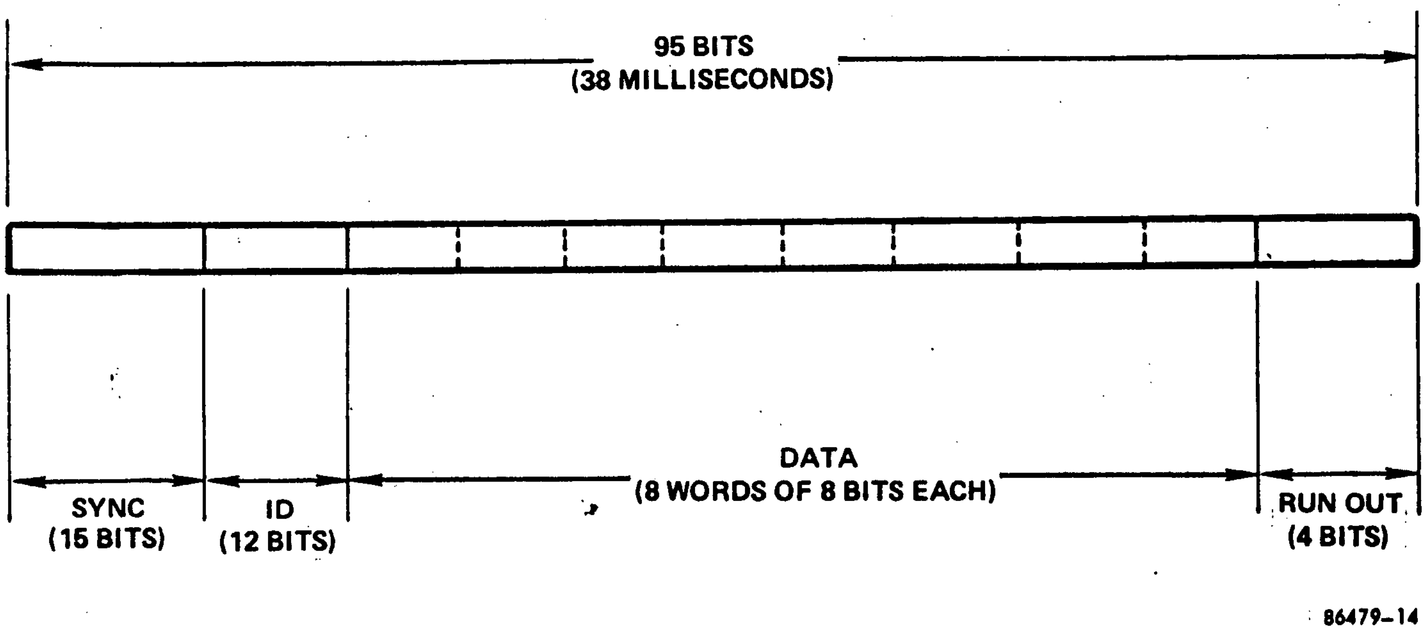


Figure 3.1.2-1. ERTS DCP Data Format (Before Encoding)

Table 3.1.2-1

Orbit Parameters for ERTS -1 *

Altitude	492.35 NM
Ellipticity	0 (circular)
Inclination	99.088 Deg.
Period	6,196 Sec. = 103.2 min
Time of Ascending Node	21:30
Coverage Cycle Duration	18 Days (251 Revs)
Distance Between Adjacent Ground Tracks	86.06 NM
Ground Velocity	3.5 NM/Sec

- Daily Sub-Satellite Swaths Sidelap by Approx. 10% (at Equator)
- Sub-Satellite Swaths Coincide by ± 10 Mi on Successive Coverage Cycles

* Source: "Earth Resources Technology Satellite (ERTS) System Design Review" 22, 23, 24 September 1970, General Electric.

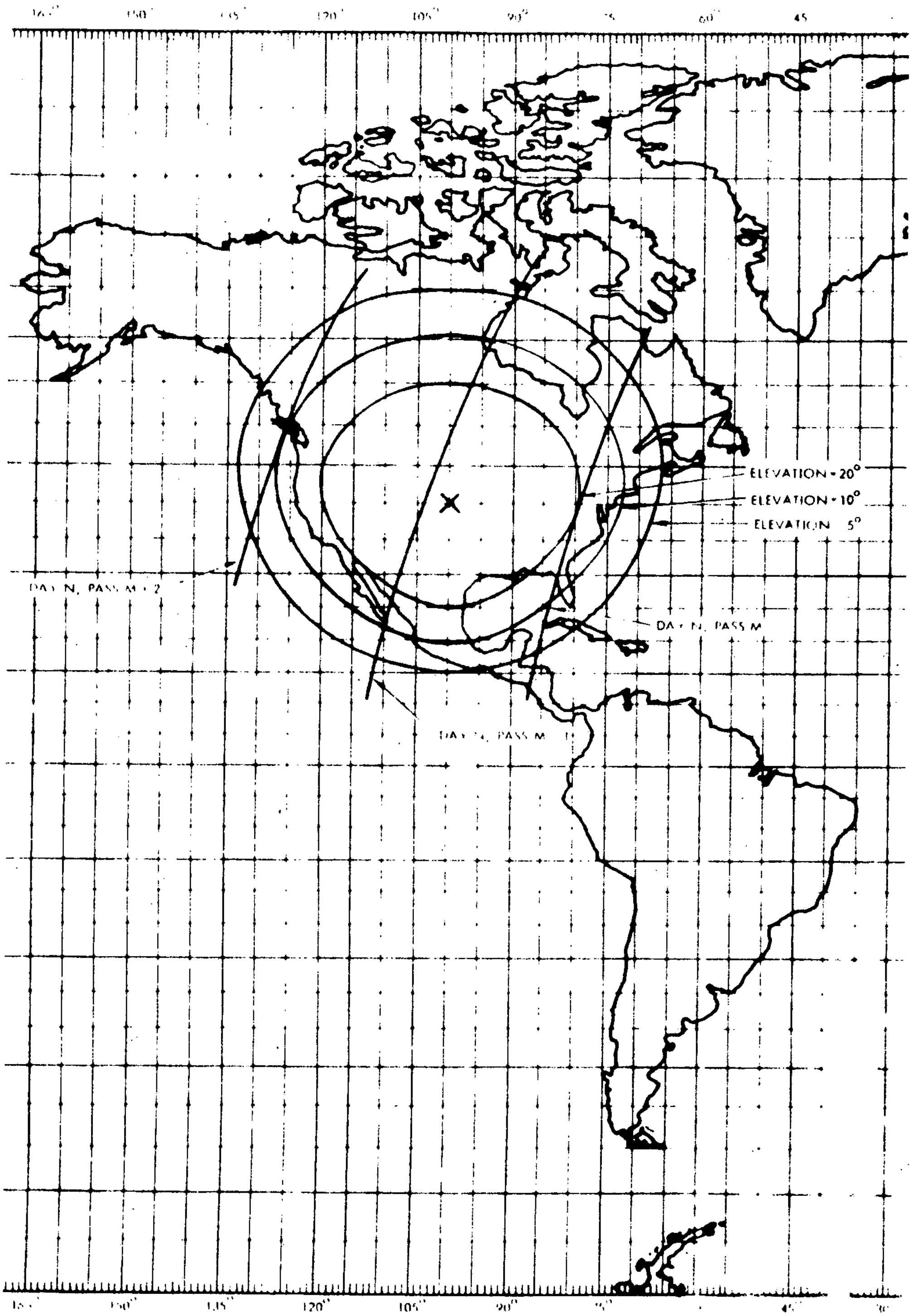


Figure 3.1.2-2. Satellite Coverage for Ground Station Elevation Angle Above 5°, 10°, and 20°

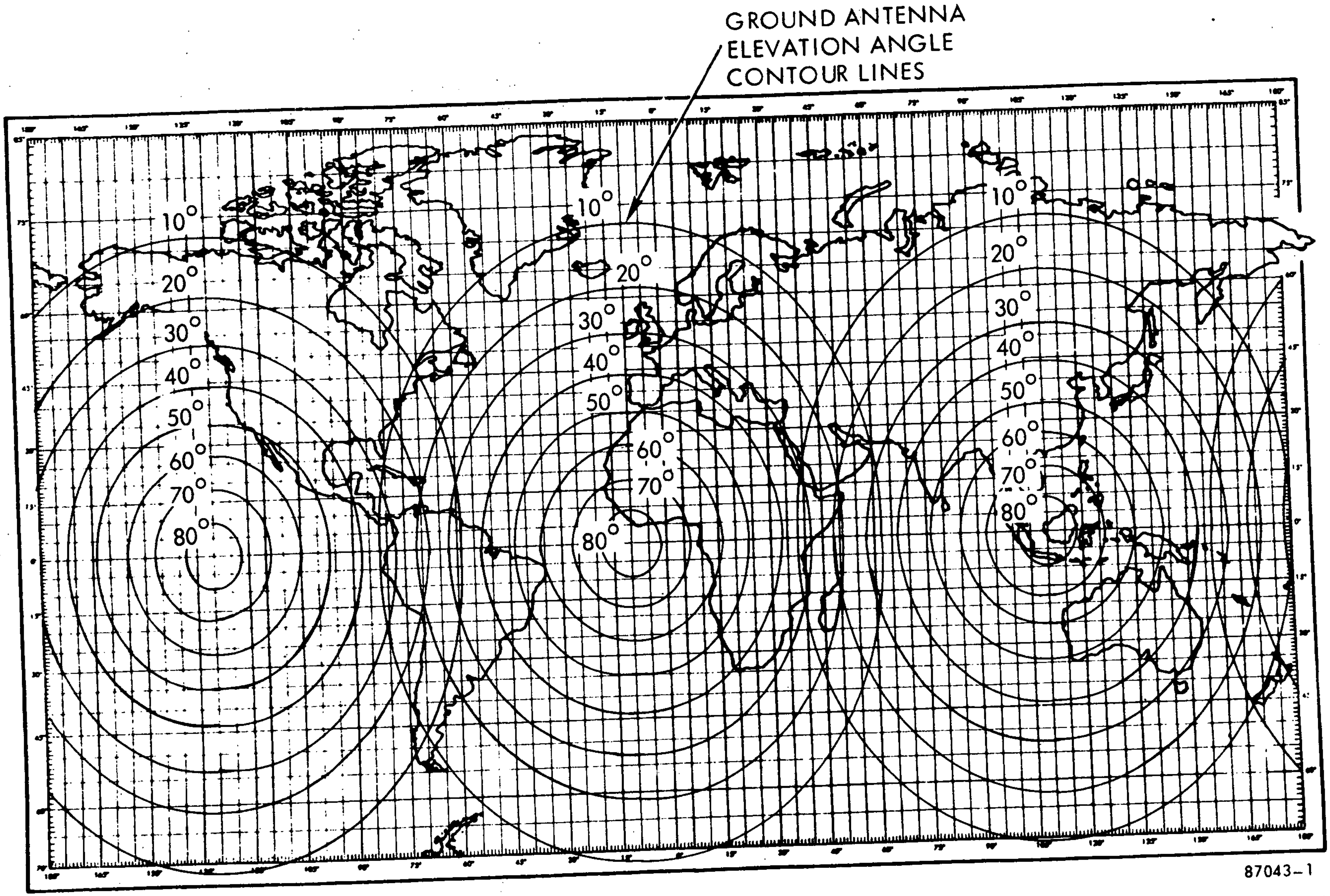


Figure 3.1.2-3 Possible Earth Coverage by Three Geo-Synchronous Satellites

As a ground rule for this study, the ERTS DCP, with only antenna modifications, was assumed. However, it may well be desirable to consider possible simple changes to the format, length, and frequency of the data bursts, as will be discussed in Section 5.1.2.

The timeliness of DCS data is a function of the type of satellite and the number of satellites in the medium orbiting case, and the time delays involved in satellite and local user terminal processing and display. For the medium orbiting satellite configurations, Table 3.1.2-2 shows the minimum number of properly spaced satellites aloft to give a certain period between passes (assumes both overhead and adjacent passes are usable).

The data in Table 3.1.2-2 was computed in the following manner. With a period of 103.2 minutes a medium orbiting satellite with trajectory identical to ERTS-1 will make nearly 14 orbits per day. When a southbound pass is approximately overhead LUT #1 it will then be seven orbits later before a northbound pass is approximately over LUT #1. Assuming adjacent passes are visible, the time between coverage is thus 5 x 103.2 min = 516 min. as indicated in Figure 3.1.2-4.

For two satellites aloft at 180^{o} intervals, the maximum period between coverage is then 206.4 minutes as indicated in Figure 3.1.2-4. For three satellites at 120^{o} intervals, the maximum period between coverage reduces to 103.2 minutes as also indicated in Figure 3.1.2-4.

The only satellite data processing delay would be in those configurations having an on-board convolutional encoder, but this delay would be negligible. In the local user terminal, a hardware decoder would have a similar delay. If a minicomputer were used for data decoding at the LUT, the delay is then a function of the number of DCP messages to be decoded and the speed of the computer and delays on the order of an hour might be typical. Once the user's DCP messages have been decoded, deformatting of the data for printout on a teletype printer would be performed even with a minicomputer (as opposed to a hardwired device) on the order of seconds.

The received data quality is a function of the performance of the entire digital data communication system. The bit error rate directly influences the cost of the system. For a low cost local user terminal, a bit error rate of $P_B \leq 10^{-5}$ (1 error per 100,000 bits) was felt to be a suitable baseline requirement for this study. Since all system designs resulted in some system gain margin above that which is necessary for $P_B \leq 10^{-5}$, the effective bit error rate should actually be less, providing at least one valid transmission per pass.

Table 3.1.2-2

Period Between Passes Versus
No. of Medium Orbiting Satellites

# of Satellites (103.2 Min. Period)	Max Period Between Passes
1	516 Min.
2	206 Min.
3	103 Min.

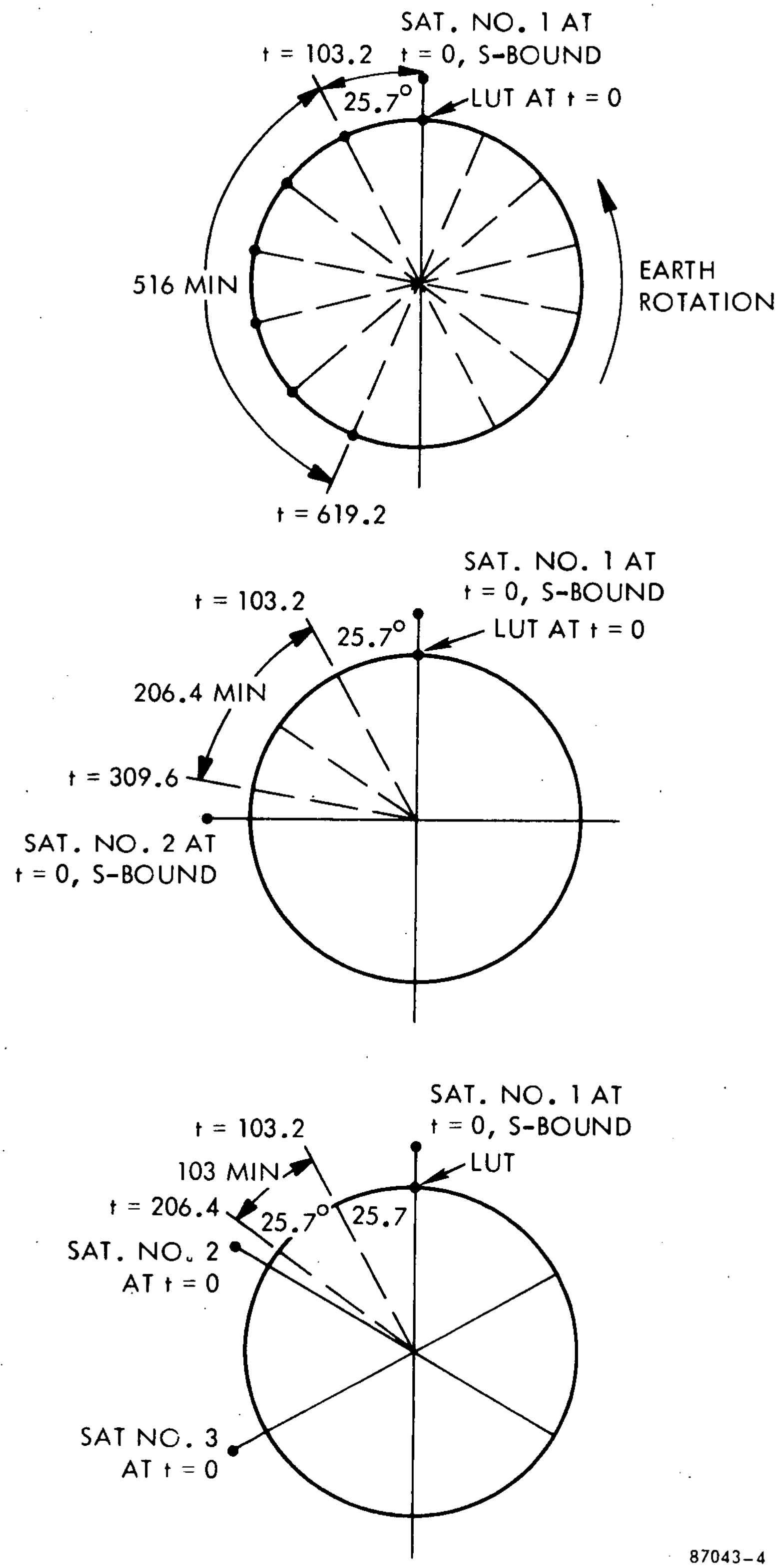


Figure 3.1.2-4 Computation of Maximum Time Between Coverage for 1, 2, and 3 Medium Orbiting Satellites Aloft

3.1.3 Flexibility and Data Display Considerations

The degree of flexibility in the selected design for the local user terminal will greatly enhance its value to a wide spectrum of users. The prime areas or functions that permit a flexible design are the data decoding and deformatting operations which can be performed by a hard-wired system or a minicomputer and the data display system.

The use of a minicomputer in the LUT is extremely attractive because of its inherent flexibility to perform additional functions between satellite passes or during periods when data is not required from a geo-synchronous satellite system. The minicomputer is essentially a modular device that can be expanded with additional I/O and memory capability as future needs change. Strong consideration was thus given to the use of a minicomputer for both the data decoding and deformatting operations. The trade-off data will be presented in later sections; but as will be shown in the selected configuration approaches, a minicomputer was selected to perform at least the deformatting operation and in some cases, the decoding operation.

The availability of a recorder for real time recording of the 2.5 Kbs data and clock would be desirable features that would permit considerable flexibility in the use of the LUT. A recorder suitable for quality stereo operation would be adequate for the purpose. Recorders are shown only as optional items in the LUT configurations because of their non-essential nature and the desire to reduce LUT cost.

The data display area in the LUT design was of prime concern. The advantages and disadvantages of three classes of possible display options are shown in Table 3.1.3-1. The computer controlled hard copy approach using either a teletype or line printer is by far the most attractive and flexible display technique for the various potential LUT users. It provides permanent hard copy with almost no operator attention with appropriate captions, comments or flags on data items of interest.

3.1.4 Reliability Considerations

When comparing relative merits of the various configurations, it is of course necessary to examine the effects of overall reliability for both the local terminal and the spacecraft. The reliability of the spacecraft equipment is of obvious importance, since failures cannot be repaired in flight. Reliability of local terminals is also important, since the ready usability of the terminal directly affects its efficiency. In other words, the use of poor equipment in order to minimize costs is not justified if the local terminal is frequently down for repairs during passes of the satellite. Therefore, while highly reliable (and therefore costly) equipment is

Table 3.1.3-1

POSSIBLE DISPLAY OPTIONS

NIXIE TUBES, LED'S, ETC.

ADVANTAGES	DISADVANTAGES
1. Low Cost in Final Display Device	1. Requires Refresh
2. Compact - Requires No Floor Space	2. No Hard Copy
	3. Requires Constant Observation
	4. Rapid Sequence of DCP Messages May Cause Lost Data
	5. Ability to Display Decimal Values Precludes Ability To Display Discretes and Vice Versa

GRAPH PLOTTER

ADVANTAGES	DISADVANTAGES
1. Provides Analog Display of Analog Sensors	1. Requires Separate Plotter Channel for Each DCP Word - One 8-Channel Plotter for Each DCP
2. Compacts Data from Several Hours Into Little Space	2. Inappropriate for Descrete or Threshold Sensors
3. Provides Continuity of Channel Data	3. Ambiguity of Data Between Data Points may be a Problem in Data Interpretation
	4. Control of Plotter Drive to Prevent Excessive Paper Consumption is Severe Problem

Table 3.1.3-1 (continued)

COMPUTER CONTROLLED HARD COPY

ADVANTAGES	DISADVANTAGES
1. Permanent Copy	1. High Initial Expense
2. Capable of Unattended Operation	2. Requires Software Programming for Flexibility
3. Data Processing Possible Prior to Readout	
4. Discrete, Threshold, Analog-Sample, or Alarm Data may be Processed Simultaneously	
5. Computer May Be Used for Purposes Other Than Display	
6. Secondary Output Media Available (Punched Paper Tape, e.g.) in Addition to Primary (Type-Out Copy)	

justifiable in a satellite but not in an inexpensive ground terminal, the use of unreliable equipment (although it may be very inexpensive) is not acceptable either.

Equipment specified and referenced in this document are within these guidelines. The equipment for use in the local terminals is of commercial quality, but does not use selected, high-reliability, expensive components.

3.1.4.1 Spacecraft Reliability Estimate

The most critical area in terms of reliability is of course the spacecraft. In order to elminate single-point failures, redundancy must be incorporated into each subsystem of the spacecraft relay system. Naturally, the most reliable system is also the simplest in terms of parts count and component complexity. In order to appreciate the relative reliability of each of the configurations, a preliminary reliability estimate has been performed for each system. The results presented here are provided only for comparative views of the various medium orbiting satellite configurations and should not be taken as precise figures of merit due to the estimating procedures used.

3.1.4.2 Summary of Results

The following list shows the rough reliability estimate for each configuration in terms of probability of success for a one year mission duration:

	Configuration	P_s (1 year)
1.	UHF Receiver, S-Band Transmitter	0.97
2.	UHF Receiver, FM Demodulator and Bit Sync, Decoder, S-Band Transmitter	0.87
3.	UHF Receiver, FM Demodulator and Bit Sync, S-Band Transmitter	0.90
4.	UHF Receiver, FM Demodulator and Bit Sync, Decoder, VHF Transmitter	0.87
5.	UHF Receiver, FM Demodulator and Bit Sync, Decoder, UHF Transmitter	0.87

3.1.4.3 Discussion of Analysis Procedure

The analysis assumed the reliability figures of 0.98 for the redundant UHF receivers and 0.99 for the redundant transmitters derived from previous ERTS analyses. The approximate number of integrated circuits in the demodulators and the decoder were then estimated by design personnel as follows:

FM Demodulator	215 I.C.'s
Bit Demodulator	130 I.C.'s
Decoder	170 I.C.'s

An average high reliability I.C. failure rate of 0.2×10^{-6} failures/hour was assumed based on previous information and GSFC I.C. screening procedures. The total active failure rate of each function was calculated and used in the standby redundant reliability model

$$R = e^{-\lambda T} + \frac{\lambda}{\lambda'} \left[e^{-\lambda T} - e^{-(\lambda + \lambda') T} \right]$$

In this model, T is the mission duration of one year (8760 hours), λ is the total active failure rate of the function, and λ' is the off-line failure rate of the standby function (assumed to be 0.1 of the active failure rate in accordance with past GSFC practice).

This procedure yielded the following results:

Function	Active Failure Rate	Reliability of Redundant Configuration
FM Demodulator	43×10^{-6}	0.95
Bit Sync	26×10^{-6}	0.98
Decoder	34×10^{-6}	0.96

The various functional reliability figures were then multiplied together as appropriate for the particular configuration to arrive at the system figures shown in paragraph 3.4.2.1.

3.1.5 Maintainability Considerations

3.1.5.1 General

Just as reliability is of prime consideration for the spacecraft equipment, maintainability is of importance in the local terminal equipment. Equipment selected for use should use readily available components, be packaged in such a manner to facilitate test, trouble-shooting, and repair, and should not require the use of expensive and sophisticated test equipment.

While the maintainability of spacecraft equipment is only of secondary value, it should not be completely ignored. Once the spacecraft is launched, it is of course inaccessible. Prior to launch, however, the system undergoes exhaustive test and checkout in order to verify its performance. Failures during this period should be repairable, so that manufacturing procedures such as complete encapsulation are not desirable.

3.1.5.2 Modularity of LUT

The local terminal equipment should be built of replaceable modules and subassemblies to the greatest extent practical. This would permit the repair of a unit in the least amount of time, minimizing the probability of lost data because a critical unit was inoperative during a satellite pass. This would require that a complement of spares be kept on hand at the local terminal, however, adding to the total initial system cost. Modular spares are generally more expensive then piece part spares, due in part to the duplication of components such as transistors, resistors, etc., used in more than one module. Even if modular spares were not maintained, piece part spares should be available. The difference in system cost is generally offset, however, by the increased overall reliability of the local terminal.

Inexpensive subsystem components need not be modular in construction, since it may be more practical merely to keep a spare unit available, or the failure rate may be sufficiently low to justify piece part spares.

3.2 Technical System Considerations

Since the actual configuration of future satellite systems is relatively undefined and with the requirement for a low cost local user terminal, the result was a ground rule to assume a separate "piggy back" satellite hardware data collection system. This ground rule led to an additional ground rule to use direct carrier modulation schemes where possible.

The present ERTS 1 subcarrier modulation scheme, for example, has 7db of modulation loss, and with only a 1 watt transmitter, the effective radiated power (ERP) is +25dbm. This, in turn, results in a 6' diameter minimum antenna size at S-Band which is too large for a low cost LUT system.

For the purposes of this study, a 5 watt satellite transmitter was felt to be a reasonable baseline for both the medium orbiting and geo-synchronous satellite configurations.

3.2.1 Frequency Selection Considerations

This study considered downlink configurations at S-Band, UHF, and VHF for both the medium orbiting and geo-synchronous satellite configurations. The following frequencies were used in the link analysis:

	Medium Orbiting	Geo-Synchronous
S-Band	2287 MHz	1690 MHz
UHF	465 MHz	465 MHz
VHF	136 MHz	136 MHz

The choice of frequencies for a given application is usually the most fundamental of system considerations. The efficiency of the satellite transmitter decreases sharply as the frequency increases (typically 35% at VHF and 16.5% at S-Band for the latest generation of transmitters). This directly influences the cost of the overall satellite system.

The higher frequencies have wider channel allocations and thus more bandwidth. But for present baseline ERTS DCP system with its 5.0kbps encoded data rate, bandwidth was not a major problem. At VHF, where the channel size is only 100kHz, we considered only on-board satellite processing configurations which reduce the frequency uncertainty to within the available bandwidth.

The higher frequencies have greater propagation path loss as indicated by the following free space path loss equation

$$L = +36.58 + 20 \log_{10} F + 20 \log_{10} R$$

where

F = freq in MHz

R = range in statute miles

However, since at higher frequencies such as S-Band, antenna size decreases with frequency and antenna gain increases with antenna size, the path loss for a given frequency is offset by the increased gain for a given antenna.

The effect of atmospheric attenuation as a function of frequency is negligible for frequencies below 3GHz and antenna elevation angles of 5 degrees. Atmospheric attenuation was thus neglected in this study.

The low frequencies, particularly VHF, may suffer from increased interference problems due to the wide spectrum of commercial usages. The effects of interference at VHF and UHF were not considered in this study, since local RFI conditions vary from one location to another.

3.2.2 Local User Terminal Antenna Considerations

Because of the fixed position relative to the earth of a geosynchronous satellite, the local user terminal antenna can be extremely low cost. It can be manually pointed towards the satellite with a plumb bob and compass and after adjusting for maximum received signal strength, it can be bolted down and left unattended.

The antenna receiving signals from a medium orbiting satellite, however, must be manually or automatically pointed at the satellite during each pass over the local user terminal. For most large satellite terminals for this type of satellite, the cost of the antenna system, including the antenna reflector, feed, pedestal, and servo drive for automatically pointing the antenna, are the largest part of the cost of the terminal. To minimize the cost of local user terminal systems, it was felt that a manually positioned system must be used as a baseline approach.

Manual antenna positioning systems such as the Scientific Atlanta Model 5405-30 and its control/readout units are readily available off-the-shelf. By manually controlling elevation and azimuth position inputs, the antenna is mechanically pointed to each set of input coordinates. Since a satellite pass lasts on the order of ten minutes or more, by observing the received signal strength on the terminal receiver during a pass, it would be physically possible to manually track the antenna across the prescribed path.

The tracking error involved in manually tracking a satellite is a function of the beam-width of the antenna, the response time of the mechanical positioner, and the skill of the operator. The beamwidth of an S-Band parabolic dish antenna increases as the diameter of the dish decreases as shown by the following table.

Table 3.2.2-1 S-Band Antenna Beamwidths

Antenna (2.2GHz)	S-Band Antenna Beamwidths
10' dish	3.20
6' dish	5.0
4' dish	7.8
3' dish	10^o

The dividing line between requiring a manual versus some form of an automatic tracking system is approximately the 6' dish. As will be shown in later sections, by using a 5 watt direct carrier modulated satellite transmitter, a 4' dish at S-Band can then be utilized. With the response times of the available off-the-shelf manual positioning systems, the error due to system response will be negligible. Tracking error with a manual system and a 4' dish should be less than 2db which can be tolerated in an effort to minimize costs.

For the VHF and UHF downlinks, which require on the order of 12db antenna gain, the beamwidth is on the order of 25 degrees or more. The manual positioning scheme would thus be even more feasible at the lower frequencies since the system would be much more tolerant to operator error.

If a user can afford the additional cost of an automatic antenna pointing scheme, this would undoubtably be a desirable option. There are two basic types of automatic schemes which are usually referred to as program track and auto track schemes.

A program tracking antenna system utilizes a stored set of discrete antenna position coordinates and simply inputs these commands at set time increments to drive the servo system and point the antenna. The program track system can use the same antenna and feed and possibly the same servo system as a manual system. A minicomputer or some other data input device, plus a servo interface unit would be required in addition to the manual system components. If a user already had a computer available, then a program track scheme probably has a lesser additional cost then the auto-tracking system.

An auto-tracking antenna system is a closed loop feedback control system that can track a downlink carrier and maintain the antenna pointing at the satellite to within 1db signal loss due to tracking accuracy. Auto-tracking antenna systems have the advantage over program track systems in that they effectively guarantee a certain level of tracking accuracy. The program track scheme, on the other hand, can only perform to the accuracy of the path and time information provided it.

A typical auto-tracking scheme uses either a conical scan or pseudo-monopulse antenna feed and servo system with the former usually being less expensive. A carrier tracking receiver with a tracking signal output is also required to implement the closed loop feedback control system. The system would only track the signal automatically after it had been initially manually positioned to intercept the signal. It would then automatically acquire the signal and track. In general, auto-track systems are more expensive to implement than program track systems.

Antenna support structures or pedestals can be designed in either Az-El (azimuth - elevation) or X-Y configurations. The former are the most common and generally lower in price. Unfortunately, the Az-El configurations generally have a small circular area directly overhead (known as the keyhole) in which they cannot point. For small beamwidth antennas, this would be a negligible problem, particularly since the DCP data is repeated at three-minute intervals. Therefore, if a DCP message were lost in the keyhole, it could be received at lower elevation angles three minutes before or three minutes after the satellite reaches the keyhole area. For this reason, the Az/El pedestal is recommended for use in this application because of its lower-cost advantages. Additionally, the X-Y pedestal is not as available commercially as the Az/El type.

3.2.3 Hardware Availability Considerations

Implementation of the basic configurations in this trade study was performed in accordance with the ground rule to use off-the-shelf hardware whenever possible. The system configurations are thus not custom designed optimal configurations tailored to the basic user need; but they are workable systems that permit a meaningful trade study.

The design of systems using a compilation of off-the-shelf components generally minimizes non-recurring costs but will not necessarily minimize the recurring system cost. Minimizing the recurring cost may require a custom design to provide only the features and performance required; and then an optimization of this design or key components of the design to permit low-cost quantity manufacturing.

4.0 MEDIUM-ORBITING SATELLITE DCS CONFIGURATIONS

This section presents the results of the study of five medium-orbiting satellite data collection system configurations. The study was performed in accordance with the ground rules of Section 2.0. The study assumed that the DCS system would be incorporated in a future ERTS or EOS type satellite.

The five medium-orbiting satellite DCS configurations studied include three S-Band downlinks, one VHF downlink, and one UHF downlink configuration. The system block diagrams are shown in Figures 4.0-1 through 4.0-5 for configurations 1 through 5 respectively.

The three S-Band downlink configurations include a bent-pipe system (configuration 1) similar to the present ERTS-1 which merely receives the UHF DCP signal and translates it to 1.024 MHz, used a subcarrier at S-Band, an on-board processing system (configuration 2) which demondulates and decodes the data in the satellite prior to re-transmission to the LUT, and an intermediate system (configuration 3) which demodulates but does not decode the data on the spacecraft. Since the emphasis in this study was on minimizing the local user terminal cost, the VHF and UHF downlink configurations both employ on-board satellite processing. A VHF bent-pipe relay configuration is not possible due to the downlink frequency uncertainty exceeding available VHF channel bandwidths.

4.1 System Analysis

The basic characteristics of a medium-orbiting satellite data relay system are well-known. The analyses performed within the scope of this study were directed at verifying technical feasibility of the proposed configurations. The efforts included computing frequency uncertainty and comparing modulation types for the downlinks, the up and down link analyses, and the comparison of hardwired computers versus minicomputers for decoding convolutional codes and for deformatting data at the LUT.

All configurations assume manual tracking of the satellite can be performed with minimal signal loss. Automatic tracking would be a desirable optional item for those users whose needs can justify the considerable additional expense, but this feature was excluded from the baseline LUT systems because of the low-cost ground rules.

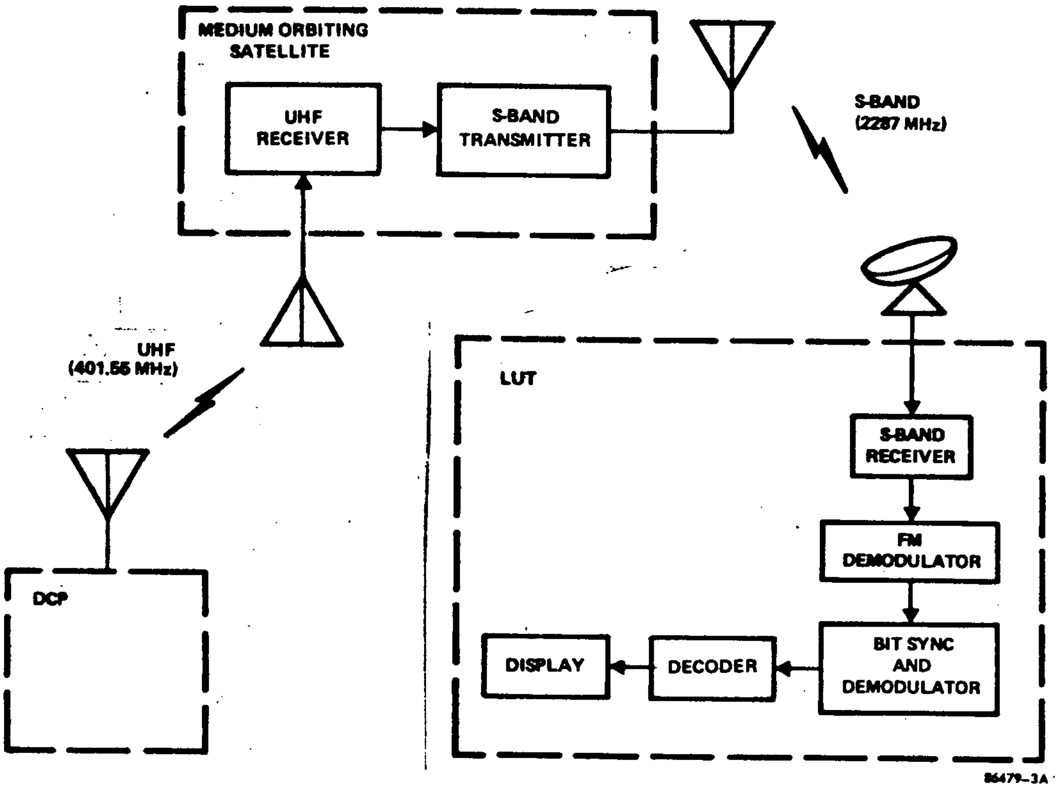


Figure 4.0-1. Medium-Orbiting Satellite Configuration 1 - Bent-Pipe Approach

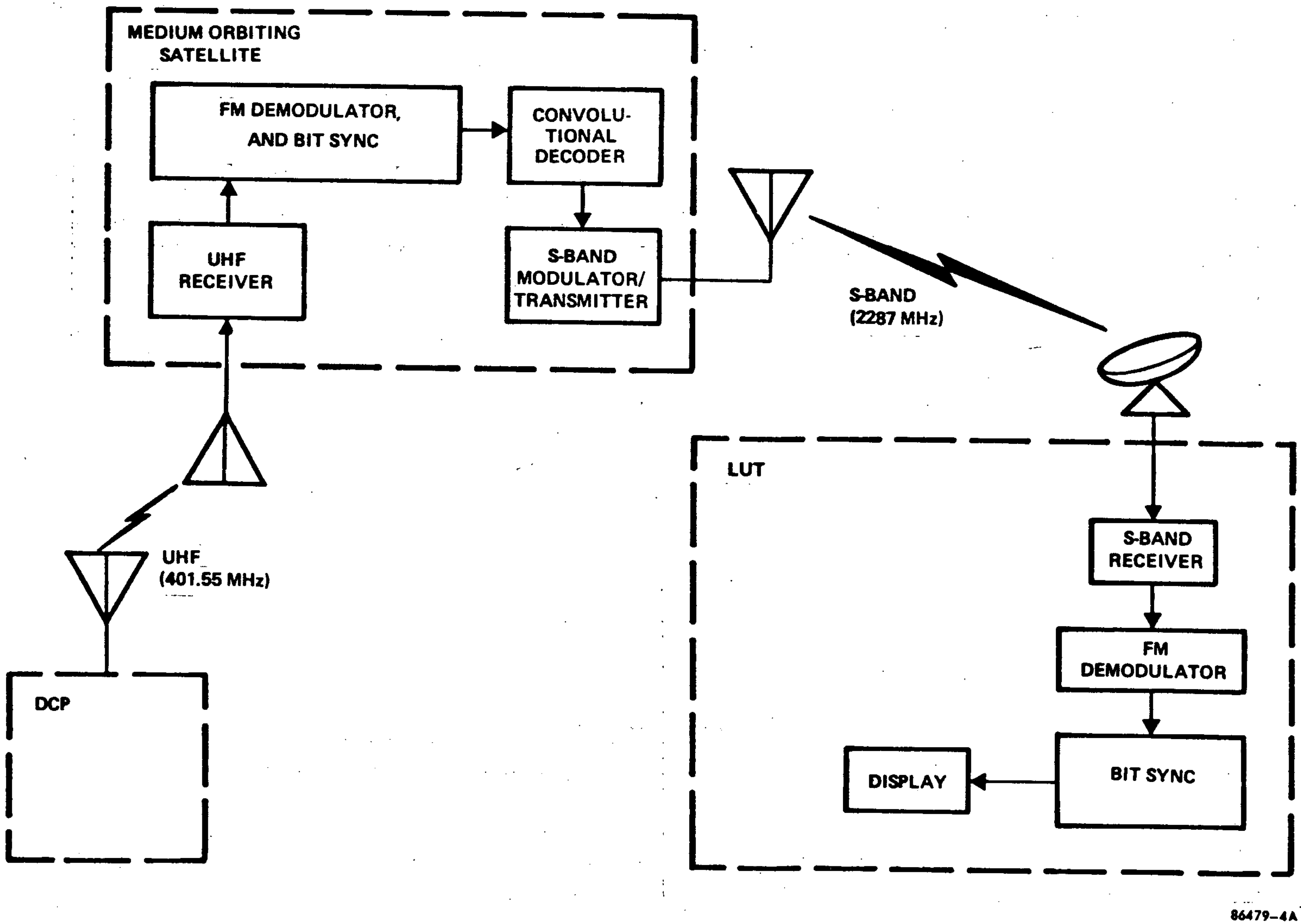


Figure 4.0-2. Medium Orbiting Satellite Configuration 2 - On-Board Processing, S-Band Downlink

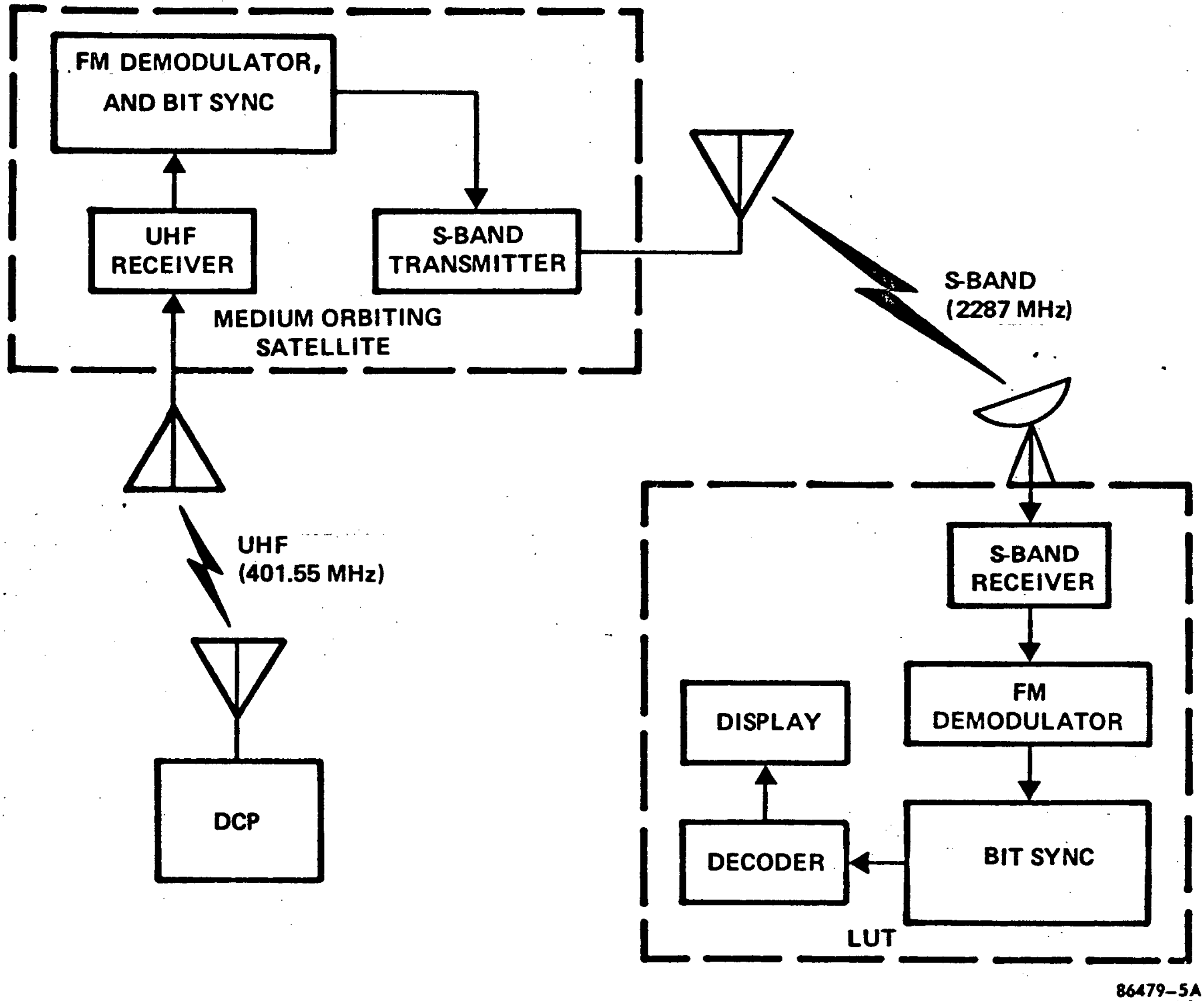


Figure 4.0-3. Configuration 3 - LUT Decodes, S-Band Downlink (Frequency Uncertainty Removed)

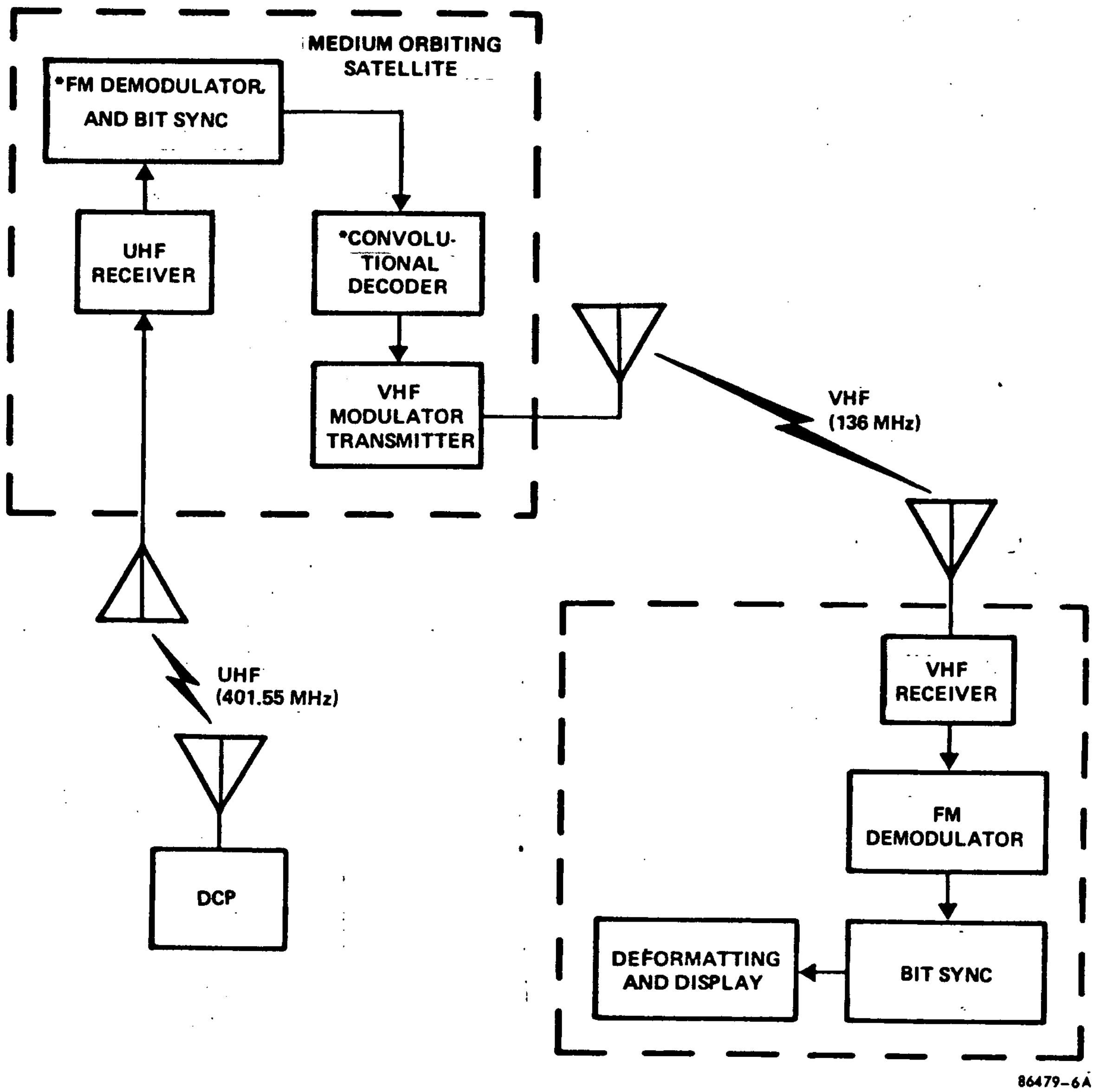


Figure 4.0-4. Medium Orbiting Satellite Configuration 4 - On-Board Processing VHF Downlink

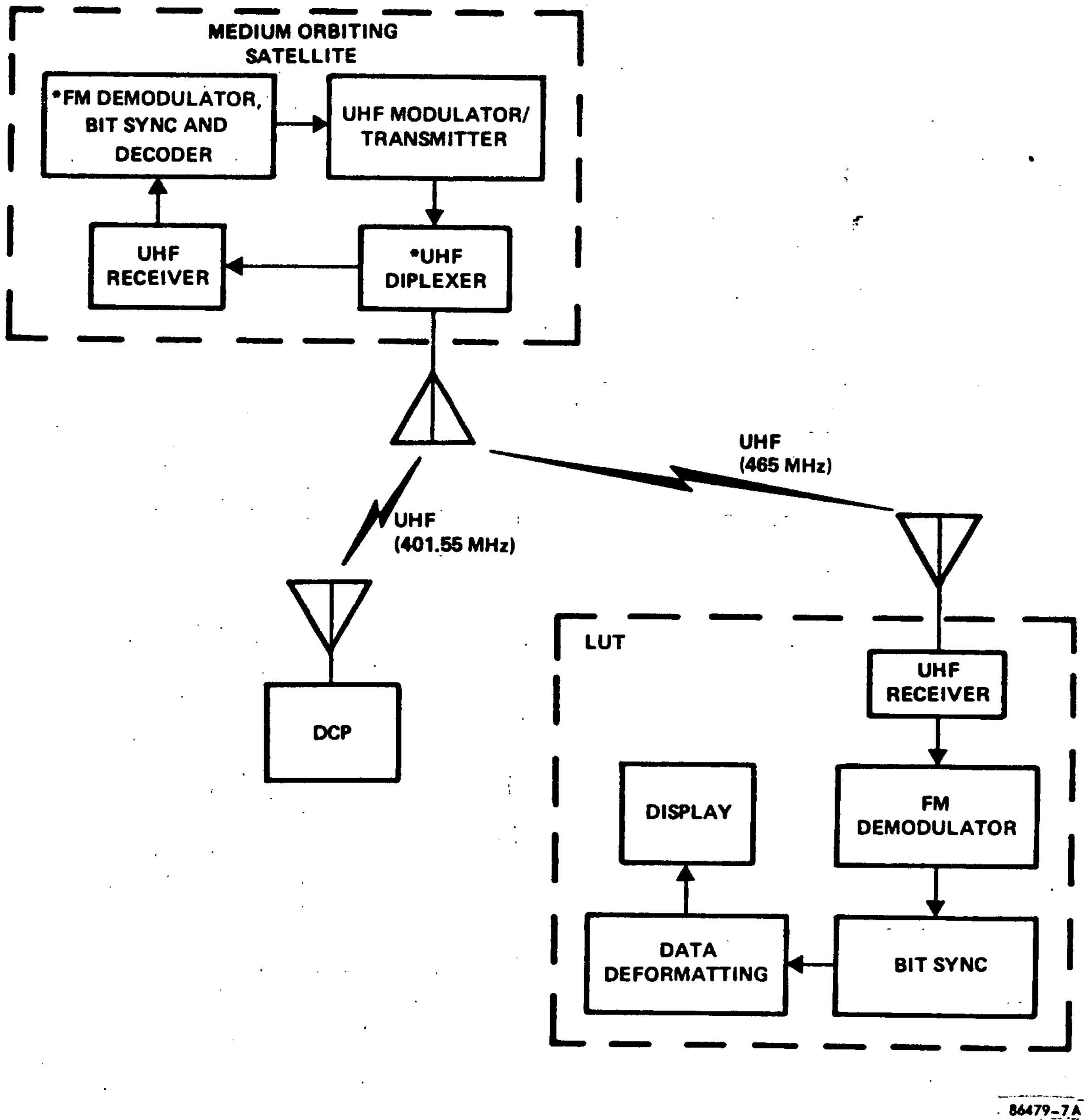


Figure 4.0-5. Medium-Orbiting Satellite Configuration 5, On-Board Processing, UHF Downlink

4.1.1 Discussion of Candidate System Alternatives

The bent-pipe relay, configuration 1, (similar to ERTS 1) requires the least amount of satellite hardware and hence maximizes rather than minimizes LUT complexity and cost. It was included as a baseline comparison system to help evaluate the relative overall system costs in relation to on-board processing systems. The bent-pipe relay system suffers from wide downlink frequency uncertainties and low system gain margins, but has to remain attractive for systems with a small number of LUT's because of the minimal satellite complexity, cost, size, weight and power requirements.

The S-Band downlink on-board processing system, configuration 2, demodulates and decodes the data on the spacecraft and thereby minimizes downlink frequency uncertainty, provides adequate gain margin even with non-coherent FSK modulation, and minimizes LUT complexity and cost relative to the other S-Band systems.

Configuration 3 which demodulates but does not decode the data on the spacecraft is simply included as a compromise approach to reduce both satellite cost relative to configuration 2 and LUT cost relative to configuration 1.

Since the cost of the LUT decreases with decreasing frequency, the VHF and UHF on-board processing configurations (configurations 4 and 5) appear even more attractive than the S-Band approach in terms of minimizing LUT cost. The lower frequencies of course have less propagation path loss which even permits the use of a VHF omni-directional antenna at the LUT if desired. But the lower frequencies do have considerably more RF interference from the multiplicity of commercial and other usages of the spectrum than does the less crowded S-Band spectrum. In terms of satellite costs the VHF and UHF frequencies are attractive because of the UHF uplink which permits the possible use of a diplexer and a single satellite antenna.

4.1.2 Spacecraft Options

The basic spacecraft system block diagrams were shown in Figures 4.0-1 through -5. The hardware configuration designs developed for this study will be presented in Section 4.2. The options that were considered in developing these design configurations included consideration of alternatives to the present ERTS-1 receiver with its 1.024 MHz output, the possibility of on-board data storage and reformatting, the transmission of confidence bits from the decoder, and use of direct versus subcarrier downlink modulation schemes.

The ERTS-1 UHF receiver without modification was selected for all five satellite configurations because of the cost involved in developing a new receiver. The disadvantage of this receiver results from the fact that when used with the FM demodulator unit the system has three stages of frequency conversion. A brief investigation of modifications to the receiver indicated that both performance and cost would benefit by leaving it alone and custom designing the FM demodulator unit to interface with it.

The option of on-board data storage and reformatting was briefly considered and felt to be unnecessary. If changes to the DCP data format are required, these should be obtained by modifying the ERTS DCP rather than doing it real-time in the spacecraft. The only real data reformatting required in the spacecraft with the present ERTS DCP is to re-insert the 15 bit preamble which is removed in the on-board demodulation process. This function could be done very easily in the decoder since the decoder temporarily stores and decodes one entire message at a time. In the case of Configuration 3 which has no on-board decoder the function would have to be incorporated after the bit demodulation in the FM Demodulator/Bit Sync Unit.

The transmission of confidence bits (which indicate bit decision reliability) from the decoder was considered. These are presently provided to users of the ERTS-1 DCS system. They essentially increase the bit rate by a factor of two in the present format and further increase the decoding requirements for a minicomputer decoder in the LUT. These were felt to be unnecessary for low-cost systems.

Sub-carrier remodulation techniques were considered for the on-board processing configurations and are discussed along with direct carrier modulation schemes in the following sub-section. Sub-carrier schemes for an independent DCS system that did not share a transmitter with some other spacecraft function were essentially felt to be too inefficient in terms of effective radiated power for the present schemes.

4.1.3 Modulation Choices

The current ERTS Data Collection Platform transmits a data message of 38 milliseconds duration with a repretition period of 180 seconds. This message is FSK modulated onto a 401.55 MHz carrier at a bit rate of 5 Kbps (after convolutional encoding). The uplink modulation choice of FSK is based on these particular parameters, derived from the requirement that at least one error-free message be processed from each DCP in every 12-hour period with the 500 n.m. circular-orbit ERTS satellite. However, the ERTS downlink system is not a dedicated carrier system, but utilizes a 1.024 MHz subcarrier phase modulated onto an

S-Band carrier. The 1.024 MHz subcarrier is obtained by downconverting the UHF uplink frequency to the subcarrier frequency without detecting the DCP data. The resulting downlink modulation for this system is PM/FSK with the modulation of the carrier frequency occurring only during that period when a DCP is actually transmitting.

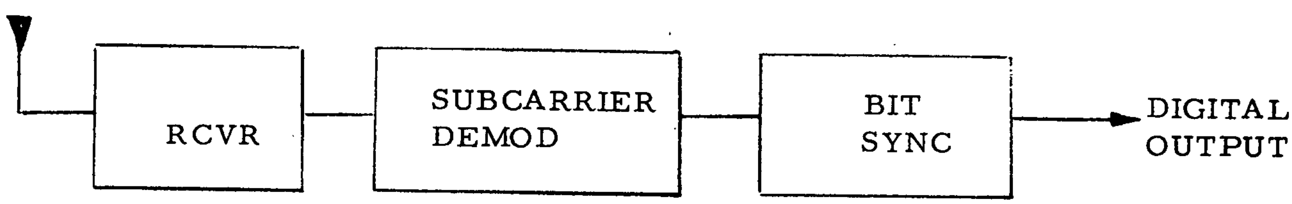
Such an approach is not necessarily optimum for all the configurations under study here. In order to determine a selected modulation scheme, it is necessary to examine several criteria for each configuration and to arrive at a modulation scheme best suited for each particular application.

4.1.3.1 Subcarrier Modulation

While outside the basic scope of this study, the use of common rf equipment in conjunction with other services (such as telemetry) is of interest. Accordingly, the derivation of required system performance using sub-carrier modulation can prove useful in an overall trade-off of system requirements to define a particular modulation scheme.

4.1.3.1.1 FM/FSK System Analysis

A system composed of DCP data FSK-modulated onto a subcarrier frequency which is then FM-modulated onto a carrier is a possible alternative. A possible receiver system such as that required at an LUT is shown in Figure 4.1.3-1.



F_{sc} = 1.024 MHz

B_{if} = 3.3 MHz

DEV = .6 MHz pk

BW_{sc} = 20 KHz

DEV = 11 KHz pk-pk

Bit Rate = 5 Kbps

Figure 4.1.3-1 FM/FSK RECEIVER SYSTEM

Parameter values shown in Figure 4.1.3-1 are compatible with those of the current ERTS receiving equipment where applicable. The IF bandwidth B_{if} is taken as the nearest off-the-shelf value to that desired as an application of Carson's Rule,

$$B_{if} = 2\,(\Delta f_c + f_m)$$

$$= 2\,(.6 + 1.024)\ \text{MHz}$$

$$= 3.248\ \text{MHz}$$

where the deviation ration (0.6) is an assumed value. The signal power out of the subcarrier discriminator is given by

$$S = (\overline{\Delta F})^2\,(1 - e^{-\rho})^2$$

where $\overline{\Delta F}$ is the mean value of the carrier deviation and ρ is the signal-to-noise ratio in the receiver IF. The noise power out of the discriminator is given by

$$N = \int_{f_1}^{f_2} \left[.3\,B_{if}\,e^{-1.2\rho}\left(1 - \frac{f}{B_{if}}\right) + \frac{(1 - e^{-\rho})^2}{\rho}\left(\frac{f^2}{B_{if}}\right)\right] df$$

$$= .3\,B_{if}\,B_{sc}\,e^{-1.2\rho}\left(\frac{B_{sc}}{1 - Bif}\right) + \frac{(1 - e^{-\rho})^2}{\rho}\left(\frac{f^2_{sc}\,Bsc}{B_{if}}\right) \qquad (2)$$

so that

$$S/N = \frac{(\overline{\Delta F})^2\,(1 - e^{-\rho})^2}{0.3B_{if}\,B_{sc}\,e^{-1.2\rho}\,(1 - \frac{B_{sc}}{B_{if}}) + \frac{(1-e^{-\rho})^2}{\rho}\left(\frac{fsc^2\,Bsc}{B_{if}}\right)} \qquad (3)$$

Figure 4.1.3-2 gives the solution to the equation for bit-rate bandwidths of 2.5 and 5.0 KHz.

For orthogonal FSK systems, the required $\frac{Eb}{No}$ (or $\frac{S}{N}$ in a bit rate bandwidth) is 13.2 db. From Fig. 3.2.3-2, the required ρ_{if} for the data rate of 2.5 KBPS is seen to be -3.7 db. For the IF bandwidth of 3.3 MHz, this corresponds to a signal-to-noise density of

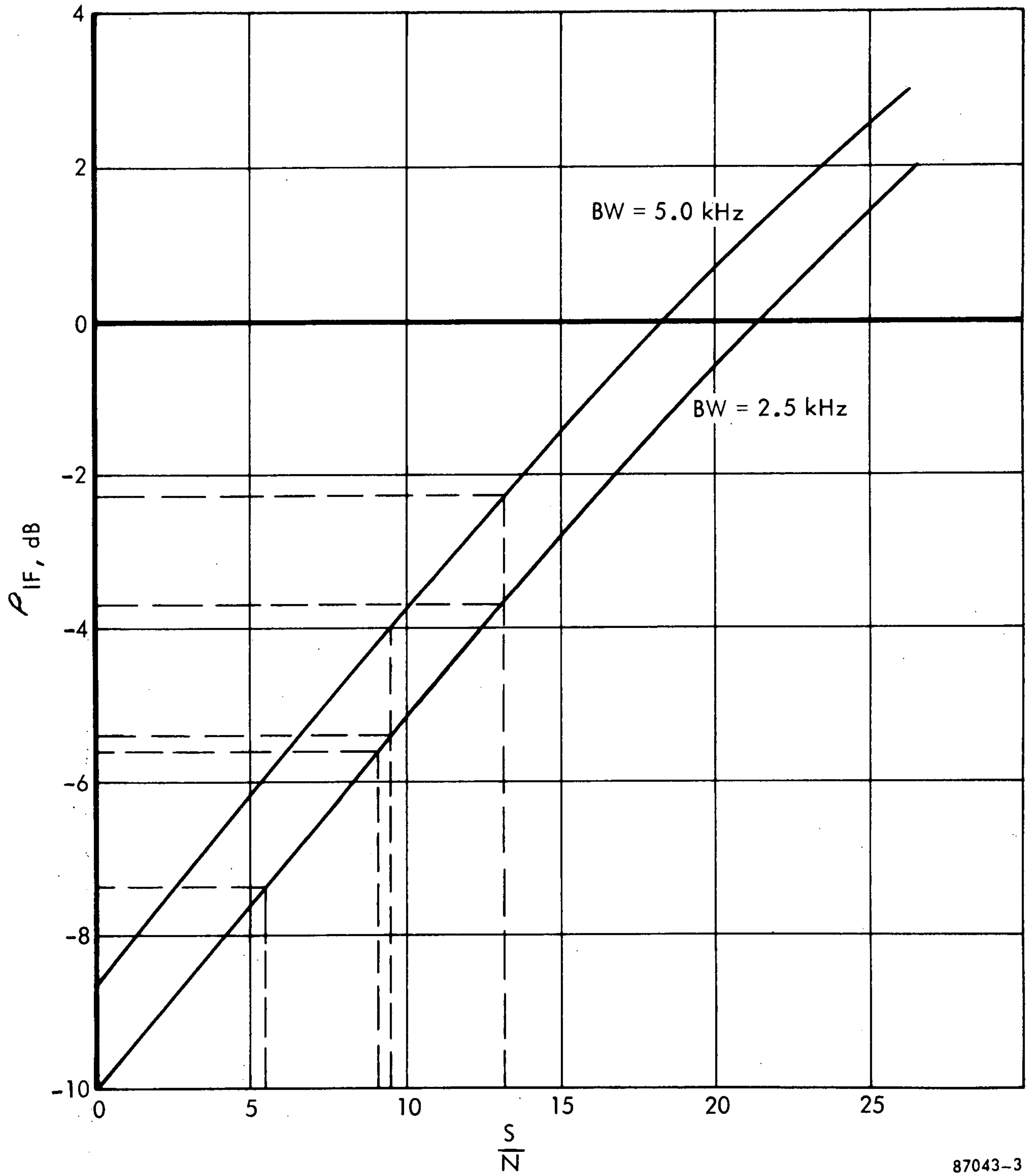


Figure 4.1.3-2 S/N vs ρ_{if} For FM Subcarrier Demodulation

$$\frac{C}{KT} = -3.7 + 10 \log (3.3 \times 10^6)$$

$$= -3.7 + 65.2$$

$$\frac{C}{KT} = 61.5 \text{ db-Hz} \quad \text{for uncoded data at 2.5 KBPS}$$

Coding gain derived through the use of a rate 1/2, constraint length 5 convolutional code can be about 4 db, requiring an Eb/No of 9.2 db or even less. These requirements correspond to an IF signal to noise ratio of -5.6 db, for a signal-to-noise density of

$$\frac{C}{KT} = -5.6 + 65.2$$

$$\frac{C}{KT} = 59.6 \text{ db-Hz} \quad \text{for coded data}$$

If the spacecraft decodes the DCP message in a manner similar to that now employed in the current ERTS system, it may be desirable to transmit confidence bits as well as data bits to the LUT. In this event, the effective data would be nearly equal to twice the DCP data rate, or 5 KBPS.

As can be seen from Figure 4.1.3-2, the IF signal-to-noise ratio required for an Eb/No of 13.2 db is -2.3 db, or

$$\frac{C}{KT} = -2.3 + 65.2$$

$$\frac{C}{KT} = 62.9 \text{ db-Hz} \quad \text{for 5 KBPS uncoded data}$$

The required values of $\frac{C}{KT}$ derived above for an FM/FSK system are valid for a particular set of system parameters data rate, subcarrier frequency, carrier deviation, and IF bandwidth. It must be pointed out that none of these parameters has necessarily been optimized for best performance.

Since subcarrier modulation is used in this analysis, there is a tacit assumption that the S-Band carrier is shared with one or more other services, such as housekeeping telemetry. Final system design would consider requirements of these services as well to select the best choice of system parameters (subcarrier frequency, deviation, etc.) for the best overall performance. Values used above and in other analyses following use parameters currently in use where applicable. In order to make the system performance comparison valid, however, the same parameters are used for each configuration under consideration.

4.1.3.1.2 PM/FSK System Analysis

An alternate method of subcarrier modulation is the PM/FSK approach, whereby the 1.024 MHz subcarrier signal is used to phase modulate an S-Band carrier. This technique promises improved performance over the FM/FSK approach, but at a higher cost in receiver hardware. A block diagram of a typical receiver system configuration is given in Figure 4.1.3-4.

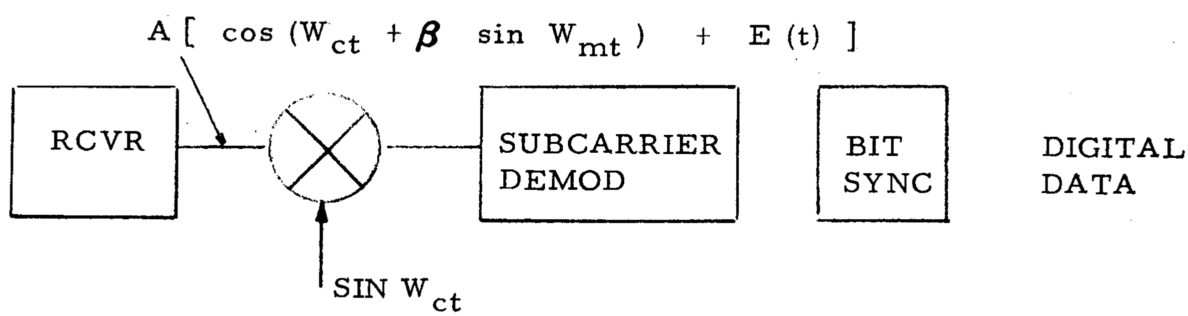


Figure 4.1.3-4 PM/FSK Receiver System Block Diagram

The signal out of the phase demodulator is given by

$$V(t) = A \sin W_{ct} \left[\cos (W_{ct} + \beta \sin W_{mt}) + X(t)\right]$$

$$= A \sin \beta \sin W_{mt} + X_s (t)$$

where $X_s(t)$ is the white gaussian noise in the receiver output, and $A \sin \beta \sin W_{mt}$ is the desired signal.

The signal power is then found to be

$$S = \frac{A^2 \beta^2}{2} \qquad (4)$$

and the noise power is

$$N = N_o B_{sc} = \frac{B_{sc}\ B_{if}}{B_{if}} \cdot N_o$$

$$N = \frac{B_{sc}}{B_{if}} \quad P_{nif} \qquad (5)$$

so that

$$\frac{S}{N} = \frac{\frac{A^2 \beta^2}{2}}{\frac{B_{sc}}{B_{if}} \quad P_{nif}}$$

$$\frac{S}{N} = \frac{\beta^2}{2} \quad \rho_{if} \left(\frac{B_{if}}{B_{sc}} \right) \qquad (6)$$

$$\frac{S}{N} = \frac{\beta^2}{2} \quad \frac{C}{KTB_{if}} \left(\frac{B_{if}}{B_{sc}} \right)$$

$$\frac{S}{N} = \left(\frac{\beta^2}{2} \right) \left(\frac{1}{B_{sc}} \right) \frac{C}{KT} \qquad (7)$$

or

$$\frac{C}{KT} = \left(\frac{2B_{sc}}{\beta^2} \right) \frac{S}{N} \qquad (8)$$

The solution to this equation yields the required signal-to-noise density ratio for a given required value of S/N.

If the subcarrier bandwidth is taken as the bit rate bandwidth, then the corresponding value of S/N is the required Eb/No.

Substitution of the system parameters into the above equation (8) yields

$$\frac{C}{KT} = \left(\frac{2 \times 2.5 \times 10^3}{(.6)^2}\right) \quad \left(\frac{Eb}{No}\right)$$

$$= 10 \log \left(\frac{5000}{.36}\right) \quad + 13.2 \text{ in db}$$

$$= 41.4 = 13.2$$

$$\frac{C}{KT} = 54.6 \text{ db-Hz} \qquad \text{with no coding gain.}$$

If coding gain is included, then the required value of Eb/No is decreased by about 4 db for the same bit error rate of 10^5. The required signal-to-noise density ratio is then

$$\frac{C}{KT} = 41.4 + 9.2$$

$$\frac{C}{KT} = 50.6 \text{ db-Hz} \qquad \text{with coding gain}$$

If the DCP data is decoded in the spacecraft and confidence bits are transmitted with data bits, the required C/KT is given by

$$\frac{C}{KT} = 10 \log \left(\frac{2 \times 5000}{.36}\right) \quad + 13.2$$

$$\frac{C}{KT} = 57.6 \text{ db-Hz} \qquad \text{for 5KBPS with no coding gain}$$

4.1.3.1.3 FM/PSK System Analysis

The derivation of the relationships given previously for frequency and phase modulation of the subcarrier onto the carrier signal is valid for whatever form of modulation is utilized to place the data message on the subcarrier. The resultant signal-to-noise ratio is that found at the input to the subcarrier demodulator. The required value of S/N for a given level of performance is a function of the data modulation scheme. For FSK modulation, the required value of E_b/N_o (and S/N in the bit rate bandwidth) is 13.2 dB. For PSK, the same level of performance - 10^{-5} BER - is obtained with a value of E_b/N_o of 9.6 dB.

With the same system parameters as those used in the solution to the equation for FM modulation (bandwidth, subcarrier frequency, deviation ratio, etc.), the system response given by Figure 4.1.3-2 applies here as well. For a required S/N of 9.6 dB, the necessary value of ρ_{IF} is seen to be -5.4 dB for a data rate of 2.5 KBPS. With the IF bandwidth of 3.3 MHz, this corresponds to a signal-to-noise density of

$$\frac{C}{KT} = -5.4 + 60 \log (3.3 \times 10^6)$$

$$\frac{C}{KT} = 59.8 \text{ dB-Hz for 2.5 KBPS with no coding gain}$$

For data transmission where the decoding process is performed at the LUT, the required value of E_b/N_o (and S/N in the bit rate bandwidth of 2.5 KHz) is reduced by about 4 dB to 5.6 dB for error rates of 10^{-5}. Again using Figure 4.1.3-2, the necessary signal-to-noise ratio in the receiver IF is found to be -7.3 dB, so that

$$\frac{C}{KT} = -7.3 + 10 \log (3.3 \times 10^6)$$

$$\frac{C}{KT} = 57.9 \text{ dB-Hz for 2.5 KBPS data with coding gain}$$

For the third FM/PSK configuration in which the spacecraft decodes the DCP message, then transmits the data with confidence bits, the bit rate is 5 KBPS with a required E_b/N_o of 9.6 dB for a BER of 10^{-5}. From Figure 4.1.3-2, the required ρ_{IF} is seen to be -4 dB, so that

$$\frac{C}{KT} = -4 + 10 \log (3.3 \times 10^6)$$

$$\frac{C}{KT} = 61.2 \text{ dB for 5 KBPS data}$$

4.1.3.1.4 PM/PSK System Analysis

As with the case of FM carrier modulation, the derivation of system performance when the subcarrier frequency is phase modulated onto the carrier is independent of the method by which the low bit rate baseband data is modulated onto the subcarrier. Therefore, the derivation of paragraph 4.1.3.1.2 resulting in Equation (8) is valid for PM/PSK as well as PM/FSK. Again using the same system parameters of subcarrier frequency, modulation index, etc., as was used with FSK systems, the required signal-to-noise density is given by

$$\frac{C}{KT} = \frac{2(B_{sc})}{\rho^2} \quad (S/N)$$

$$= \frac{2(2.5 \times 10^3)}{(.6)^2} \quad \left(\frac{S}{N}\right)$$

$$= 10 \log \left(\frac{5000}{.36}\right) + 9.6 \text{ in dB}$$

$$\frac{C}{KT} = 51 \text{ dB-Hz for 2.5 KBPS data without coding gain}$$

For data transmissions where the decoding process is performed at the local terminal, the downlink is protected from errors by a margin of at least 4 dB. The required E_b/N_o for a BER of 10^{-5} is 5.6 dB or less for PSK modulation. Using the same system parameters as before,

$$\frac{C}{KT} = 10 \log \left(\frac{5000}{.36}\right) + 5.6 \text{ in dB}$$

$$= 41.4 + 5.6$$

$$\frac{C}{KT} = 47 \text{ dB-Hz for 2.5 KBPS with coding gain}$$

For the configuration in which the spacecraft demodulates and decodes DCP data, then transmits the data message with confidence bits, the data rate is 5 KBPS and the corresponding value of C/KT is given by

$$\frac{C}{KT} = 10 \log \left(\frac{2 \times 5000}{.36}\right) + 9.6 \text{ in dB}$$

$$\frac{C}{KT} = 54 \text{ dB-Hz for 5 KBPS data}$$

4.1.3.2 Direct Carrier Modulation

For several of the configurations under study, the spacecraft (whether it be medium-orbiting or geo-synchronous) detects the DCP message into its digital structure. For the downlink, the spacecraft remodulates a carrier with digital data. It is possible that the downlink carrier, at S-Band, would be dedicated solely to the function of transmitting this data. If that is the case, then direct modulation of the carrier frequency is desireable instead of using intermediate subcarrier frequencies. There is then no requirement for a separate modulation in the spacecraft and a separate demodulator at the local terminal. (Of course, other functions such as telemetry will require a separate carrier frequency and transmitter).

4.1.3.2.1 S-Band FSK Modulation

The classic system design for FSK modulation is to implement a system with an "optimum" deviation ratio of 0.71 and an IF bandwidth equal to the bit rate. In this case, the narrow bandwidth results in an effective overlap of consecutive bits, with a consequent performance similar to coherent FSK systems. However, this approach is valid only as long as the frequency uncertainties are negligible compared to the bit rate of the modulation. For data rates as low as 5KBPS and final uncertainties of about 50 KHz, obviously, the "classic" approach is unsuitable.

In order to properly establish the optimum deviation ratio for a system with relatively large frequency uncertainties, a more rigorous analysis of FM discriminator systems is required. The deviation of the performance of such systems has been performed by McRae(1). In order to utilize this analysis, which determines the required signal-to-noise ratio in the receiver IF with various values of bit rate, deviation, and IF bandwidth, it is most convenient to assume specific parameters and perform an iterative process to determine the best system design. In this process, successively wider deviations are assumed, correspondingly wider bandwidths are selected, and required S/N is determined. From this result, the required C/KT is calculated. The results of this

(1) McRae, D.C. "Error Rates in Wideband FSK with Discriminator Demodulation", Radiation, Inc., Melbourne, Florida, 6 July 1966.

process are presented in Table 4.1.3-1 for data rates of 5KBPS, such as would be obtained if data were decoded in the spacecraft and confidence bits were transmitted to the LUT along with data bits.

Table 4.1.3-1

Direct Carrier FSK Modulation

S-Band

Bit Rate = 5.0 KBPS

CASE	DEV	BW_{IF}	$\frac{DEV}{BW}$	$\frac{B_{IF}}{\text{Bit Rate}}$	$\frac{S}{N}\Big\vert_{Pe = 10^{-5}}$	$\frac{C}{KT}$
1	11 KHz	75 KHz	.14	15	10 db	58.8 db-Hz
2	50 KHz	100 KHz	.50	20	4 db	54.0
3	100 KHz	150 KHz	.66	30	2 db	53.8
4	150 KHz	200 KHz	.75	40	.4 db	53.4
5	200 KHz	250 KHz	.08	50	-.5 db	53.5

As can be seen from Table 4.1.3-1, the best overall performance, measured by the minimum required C/KT, is obtained when the deviation is about 150KHz, or a deviation ratio of 30. Because most of the uncertainty in the carrier frequency is removed by the AFC circuits in the LUT receiver, the IF bandwidth must be only about 50KHz wider than the amount required due to the deviation. Therefore, in each of the cases in Table 4.1.3-1, the IF bandwidth is about 50KHz wider than the deviation.

The required C/KT for 5KBPS FSK modulation of the S-Band carrier is then 53.4 db-Hz.

If configuration 3 is employed, where the decoding function is performed at the LUT, the S-Band carrier could be modulated at 5KBPS, but a symbol error rate of 3×10^{-3} is sufficient to yield a bit error rate of 10^{-5}, due to the processing gain achieved with the decoder. Again, using the technique described above, Table 4.1.3-2 shows the iteration to yield the optimum system.

Table 4.1.3-2

S-Band Direct Carrier FSK Modulation
5KBPS, With Coding

Case	DEV	BW IF	$\frac{DEV}{BW}$	$\frac{B_{IF}}{\text{Bit Rate}}$	$\frac{S}{N}\Big\vert P_{e=10^{-5}}$	$\frac{C}{KT}$
1	25 KHz	75 KHz	.33	15	4.3 db	53.1 db-Hz
2	50 KHz	100 KHz	.5	20	7	52
3	100 KHz	150 KHz	.66	30	-.7	51.1
4	150 KHz	200 KHz	.75	40	-2	51.0
5	200 KHz	250 KHz	.8	50	-3	51.1

As can be seen from the table above, the same receiver system found to be optimum for the non-encoded configurations is also optimum for the case where the decoding process is performed at the LUT. This is, of course, not surprising, as the bit (symbol) rate is the same in both cases. However, the processing gain achieved by the decoder yields a required C/KT which is 2.4 db less than that required for the non-encoded configuration.

The system described above, using a 5KBPS downlink with no coding, would be employed if there were a desire to transmit to the LUT a confidence bit for each data bit. The confidence bit would be used to inform the local terminal of the relative assurance that the data bit decoded in the spacecraft was in fact valid data. This is similar to the technique currently employed by the Regional Collection Systems. Another possible concept exists, however. To reduce the complexity of the LUT data processing program, it may be desired to transmit decoded data only, without confidence bits, to the LUT. This system would then require a downlink data rate of only 2.5 KBPS. For this case, Table 4.1.3-3 shows the iterative process involved in arriving at the optimum system sensitivity.

Table 4.1.3-3

S-Band Direct Carrier FSK Modulation, 2.5KBPS

Case	DEV	BW_{IF}	$\frac{DEV}{BW}$	$\frac{BW}{\text{Bit Rate}}$	$\frac{S}{N} \Big\vert P_e = 10^{-5}$	$\frac{C}{KT}$
1	25 KHz	75 KHz	.33	33	4 db	52.7 db-Hz
2	50 KHz	100 KHz	.5	40	2	52.0
3	75 KHz	125 KHz	.6	50	.5	51.5
4	100 KHz	150 KHz	.666	60	0	51.8
5	125 KHz	175 KHz	.735	70	-.5	51.9

As can be seen from the table above, the optimum bandwidth for the receiver is 125 KHz with a deviation reduced to 75KHz from that of the other S-Band options (150KHz deviation). This, too, is not surprising. Since the data rate was reduced by half, it would be expected that the required deviation would reduce by the same proportion.

Since the S-Band receiver recommended for this application, the Scientific Atlanta 410 Telemetry Data Receiver, is available with a wide variety of plug-in IF filters, the same basic receiver could be used for any of the above applications with only a difference of IF filter bandwidth involved. For purposes of discussion, the bandwidth considered in the equipment descriptions will be 200KHz, even though the reduced bandwidth filter may actually be used if configuration 2 is selected for use with FSK modulation.

4.1.3.2.2 VHF FSK Modulation

One of the possible system frequencies under study is a 465 MHz downlink from the spacecraft to the LUT. For an FSK modulation scheme, the iterative process applied above may be used in this configuration as well. Table 4.1.3-4, below, presents the resulting data for 2.5KBPS data.

Table 4.1.3-4

UHF Direct Carrier FSK Modulation
2.5 KBPS

Case	DEV	BW_{IF}	$\frac{DEV}{BW}$	$\frac{BW}{\text{Bit Rate}}$	$\frac{S}{N} \mid P_e = 10^{-5}$	$\frac{C}{KT}$
1	25 KHz	60 KHz	.41	24	+4.5 db	52.3 db-Hz
2	40 KHz	75 KHz	.53	30	+3	51.8
3	70 KHz	100 KHz	.7	40	+1	51
4	120 KHz	150 KHz	.8	60	-1	50.8
5	250 KHz	300 KHz	.83	120	-3	51.8

As can be seen from this table, the optimum system requires a 150 KHz IF bandwidth in the LUT receiver. Using this bandwidth and the deviation of 125KHz for the 2.5KBPS data signal, a C/KT of 50.8 db is required for a bit error rate of 10^{-5}.

Because the UHF configuration is designed to minimize cost and complexity of the LUT, no other option need be considered for this case. The decoding process is performed on the spacecraft, and confidence bits are not required at the LUT.

4.1.3.2.3 VHF FSK Modulation

As was the case for the UHF downlink configuration, the major concern in examining a VHF downlink was to minimize the LUT costs as much as possible. In order to accomplish this goal, a compromise was made in the selection of a VHF receiver. Rather than a telemetry-quality receiver, a much more simple voice-quality receiver, such as that used in mobile vehicle applications was selected for examination. The drawback to this approach, however, lies in the fact that voice receivers are generally available with only a limited selection of IF bandwidths, so that the modulation parameters, such as deviation, must be selected to meet those limitations of hardware flexibility. Further, the AFC, metering, and other features common to telemetry receivers will not be found in the spartan voice-service receivers.

Because of doppler shifts, oscillator inaccuracies, and instabilities in both the spacecraft transmitter and local terminal receiver (none of which may be eliminated with AFC tracking loops which are not a part of the equipment), the bandwidth of the receiver must be considerably wider than the deviation. For data rates of 2.5KBPS and an available IF bandwidth of 30KHz, the largest deviation which may be accommodated is 10KHz. The required C/KT for these conditions is shown in Table 4.1.3-5.

Table 4.1.3-5

FSK Modulation for VHF Receiver

BW_{IF}	DEV	$\frac{DEV}{BW}$	$\frac{BW}{\text{Bit Rate}}$	$\frac{S}{N}$ $P_{e=10^{-5}}$	$\frac{C}{KT}$
30 KHz	10 KHz	.333	12	7.8 db	52.6 db-Hz

4.1.3.2.4 PSK Modulation

When split-phase PSK modulation of the carrier frequency is employed, the determination of required C/KT is more straight-forward than that for FSK system. In this case, the C/KT is computed using the bandwidth equal to the bit rate (2.5KHz). The required value of E_b/N_o (in the bit rate bandwidth) is 9.6 db for a $BER=10^{-5}$ when no coding gain advantage is available, and 5.6 db when maximum likelihood detection of the convolutional code is used. Implementation losses of about 2 db below theoretical may be assumed, resulting in actual required E_b/N_o values of about 11.6 db and 7.6 db, respectively. With the bit rate of 2.5 KHz, or 34 db-Hz, the required C/KT for PSK data is 45.6 db-Hz with no processing gain, and 41.6 db-Hz if processing gain is available. These values are independent of the carrier frequency in use. Actual IF bandwidths required do vary with carrier frequency and related uncertainties, but do not affect the system sensitivity computed above.

4.1.3.3 Summary of Required Sensitivities

Table 4.1.3-6 below, summarizes the required values of C/KT for each of the modulation schemes considered.

Table 4.1.3-6

Summary of System Sensitivity Requirements (C/KT)

	S-Band		UHF		VHF	
	Encoded	Unencoded	Encoded	Unencoded	Encoded	Unencoded
FM/FSK	59.6	61.5	*	*	*	*
FM/PSK	57.9	59.8	*	*	*	*
PM/FSK	50.6	54.6	*	*	*	*
PM/PSK	47.0	51.0	*	*	*	*
FSK	51.0	51.5	*	50.8	*	52.6
PSK	41.6	45.6	*	45.6	*	45.6

* - Not considered within scope of study.

Based on several factors, notably cost, link margin, and equipment complexity, recommendations are made for the most desirable selection of modulation scheme for each of the three frequency bands of interest.

4.1.3.4 Summary of Modulation Choices

Each of the configurations under study was examined separately and the selection of modulation was based solely on the configuration performance versus relative cost requirements. Tables 4.1.3-7 presents the results of these trade-offs. Further discussions and considerations in this report are based on these recommendations.

Table 4.1.3-7

Downlink Modulation Choices

Configuration	Modulation Scheme Preferred
1	PM/FSK
2	Direct PSK or FSK
3	" " "
4	" " "
5	" " "

4.1.4 Frequency Uncertainties

The IF bandwidth to be used by the receiver at the local terminal must be sufficiently wide to accommodate the data modulation scheme, but must also accommodate frequency uncertainties due to doppler shifts, transmitter accuracy and stability variations, and receiver accuracy and stability variations.

4.1.4.1 S-Band System

The accuracy and stability requirements for the spacecraft transmitter and receiver oscillators are assumed to be $\pm$ .003%. For the DCP data transmitter, this value is specified as $\pm$ .0025%.

The configuration 1 option is the only recommended system to use subcarrier modulation. The total uncertainty in the subcarrier frequency is given by:

$$\Delta F_{s/c} = \Delta F_{DCP} + \Delta F_{L.O.} + \Delta F_{doppler}$$

where the terms on the right side of the equation are DCP transmitter variations, spacecraft translator inaccuracies, and uplink doppler shifts, respectively. The doppler shift can be shown to be, for the system under consideration here, equal to 22 Hz per MHz of carrier frequency, as shown in Figure 4.1.4-1, taken from the "ERTS DIRECT READOUT GROUND STATION STUDY", Final Report, Contract NAS5-21622. Substitution of specified values in the above equation yield:

$$\Delta f_{s/c} = (\pm 2.5\times10^{-5})(401\times10^{6}) + (\pm 3\times10^{-5})(100\times10^{6}) + (\pm 22\times401)$$

$$= \pm 10\text{KHz} \pm 12\text{ KHz} \pm 8.8\text{ KHz}$$

$$= \pm 30\text{KHz or } \underline{60\text{ KHz}} \quad \text{Total uncertainty}$$

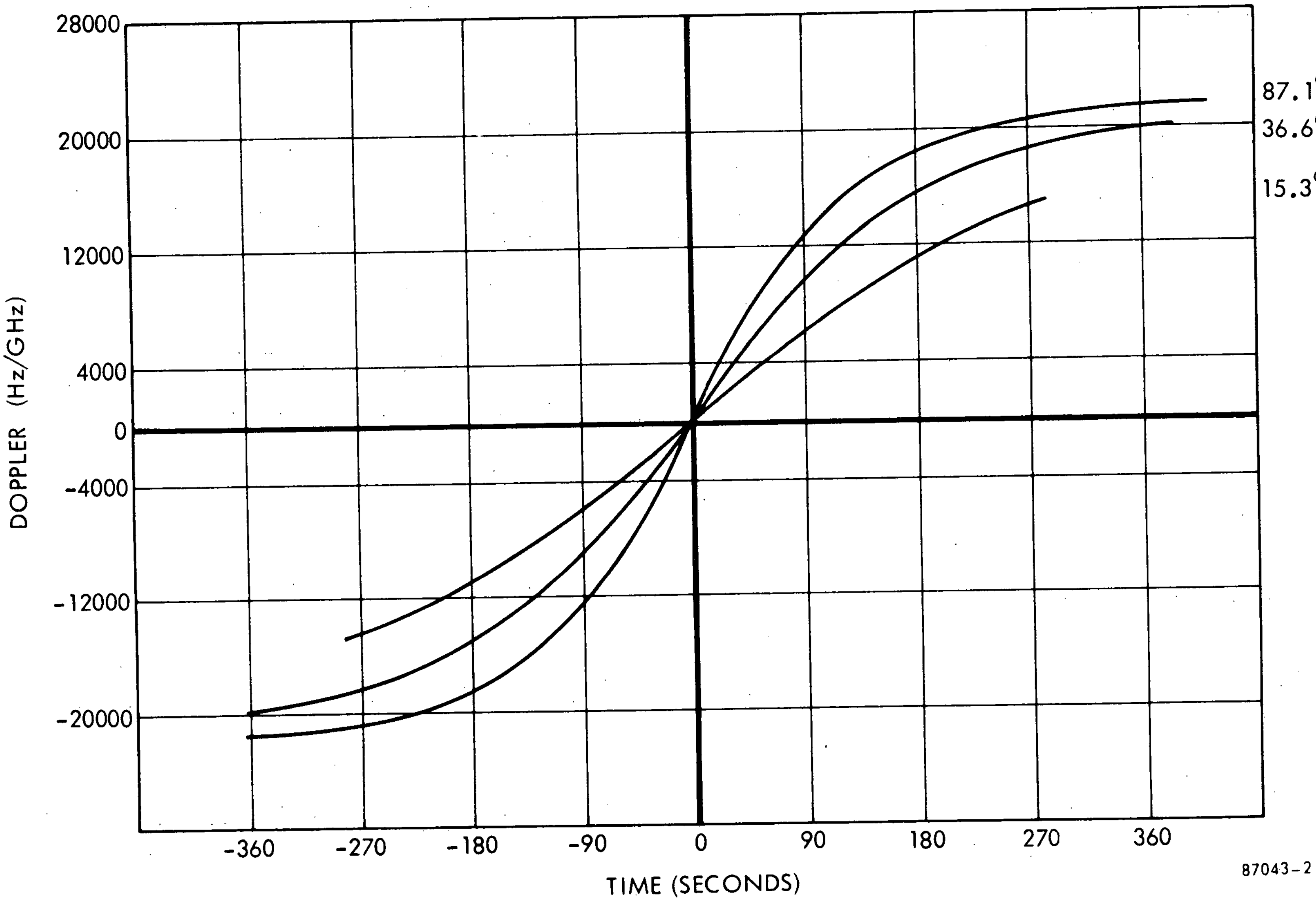


Figure 4.1.4-1 Normalized Doppler Shift for the ERTS Orbit

It is assumed that the uncertainties of the downlink doppler shift, receiver uncertainties, etc., have been removed from the system due to AFC loops or other schemes, so that the above reflects the actual uncertainty in the subcarrier frequency at the subcarrier demodulation. Note that no provisions for modulation bandwidth are included, so that the subcarrier demodulation overall bandwidth should actually be on the order of 100KHz. As will be shown in following sections, the noise bandwidth allowed by the link margin should not exceed 20KHz, so the subcarrier demodulator must be designed with a comb filter front end, consisting of six overlapping 20KHz filters to accommodate the broad uncertainty computer above.

For all S-Band configurations other than the first, direct carrier modulation is used. (The overall frequency uncertainty is not dependent on the presence or absence of a subcarrier, but the IF bandwidth required in the receiver is.) Calculation of the S-Band downlink uncertainty must include transmitter inaccuracies, doppler shift, and receiver inaccuracies. This is seen to be

$$\Delta F_{S\text{-}Band} = \Delta F_{XMTR} + \Delta F_{dopp} + \Delta F_{RCVR}$$

where the values for transmitter accuracy and doppler shift are as given above. The receiver is assumed to employ a temperature controlled crystal, so that its inaccuracies are on the order of $\pm .001\%$. Then the downlink uncertainties are given by

$$\begin{aligned}\Delta F_{S\text{-}Band} &= (3\text{x}10^{-5}+2287\text{x}10^{6})+(22\text{x}2287)+(1\text{x}10^{-5}+2287\text{x}10^{6}) \\ &= 68.7\text{KHz} + 50.7\text{KHz} + 22.9\text{KHz} \\ &= \pm 142.3\text{KHz}\end{aligned}$$

In order to remove most of the uncertainty, the S-Band receiver should have a search-and-lock feature which sweeps the IF bandwidth $\pm$250KHz about the center frequency. By this means, the noise bandwidth admitted to the receiver can be drastically reduced, improving the system margin accordingly. The IF bandwidth then need only be about 50KHz wider than that required for the modulation scheme. This margin would allow for reaction delays and other inaccuracies in the receiver AFC tracking loop.

4.1.4.2 UHF System

The UHF system under study employs direct carrier modulation at 465MHz. The contributions to the received frequency uncertainty are again due to the transmitter and receiver accuracy and stability and downlink doppler shifts. This is given by

$$\Delta F_{UHF} = \Delta F_{XMTR} + \Delta F_{RCVR} + \Delta F_{DOPP}$$

For the accepted specified values,

$$\Delta F_{UHF} = (3x10^{-5}x465x10^{6})+(1x10^{-5}x465x10^{6})+22x465$$

$$\Delta F_{UHF} = 14KHz + 4.65KHZ + 10.2KHz$$

$$= \pm 28.85KHz$$

or a total uncertainty of about 57KHz. A desirable feature in the UHF system, then would be an AFC tracking loop with the capability to acquire, lock on, and track the incoming carrier signal in order to reduce the overall noise bandwidth to nearly that required by the modulation scheme. As with the S-Band system, allowances must be made in the choice of IF bandwidth for the reaction delays and other inaccuracies of the UHF receiver tracking loop.

4.1.4.3 VHF System

In the VHF system, the frequency uncertainties are found to be of a nature identical to that for the UHF system. Direct carrier modulation is utilized and the only uncertainties encountered are those due to transmitter and receiver inaccuracy and instability, and doppler shift in the downlink. With the same specified parameters as given previously,

$$\Delta F_{UHF} = \Delta F_{XMTR} + \Delta F_{RCVR} + \Delta F_{DOPP}$$

$$= (3x10^{05}x136x10^{6})+(1x10^{-5}x136x10^{6})+(22x136)$$

$$= 4.08KHz + 1.36KHz + 3KHz$$

$$= \pm 8.5KHz$$

or a total uncertainty of about 17KHz. This is an amount which is small enough that expensive AFC tracking loops may not yield sufficient improvement to justify their use. For the VHF configuration then, the IF bandwidth should be made broad enough to accommodate both the modulation bandwidth and the downlink uncertainty. As shown by the link budgets, there is more than enough margin to accommodate this added bandwidth.

4.1.5 Link Analysis

A prediction of the link performance for this system requires that several assumptions be made at the outset. A five watt transmitter is assumed for the spacecraft, as well as a bifolium radiation pattern for the antenna which compensates for variations in range as a function of satellite elevation. The link calculations are made at a slant range of 1070 N.M. corresponding to a 20^{o} elevation at which the satellite antenna gain is assumed to be +3 dB. (At the zenith, the satellite altitude is 500 N.M. The corresponding free space loss is nearly 8 dB less than for the low elevation range, and the spacecraft antenna gain at this point is -3 dB, with an overall increase in link gain of +2 dB. Therefore, the low elevation case is the most conservative.) Other assumptions, such as tracking loss, are based on system concepts for the LUT configuration, such as the use of a manual tracking system. Equipment characteristics of bandwidth, gain, noise figure, etc., are taken from specifications of available equipment suited for this application.

4.1.5.1 Calculation of System Noise Temperature

The system noise temperature for all configurations may be derived from the block diagram given in Figure 4.2-1.

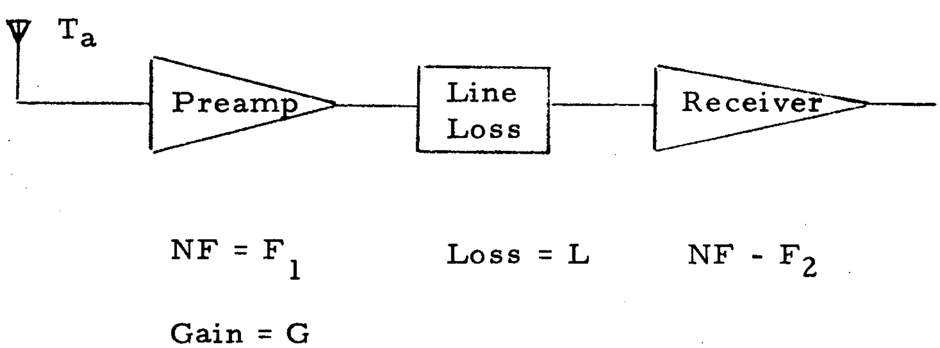


Figure 4.1.5-1 Receiver System Block Diagram

With a system configured as shown, the overall system noise temperature, T_s, is given by the equation

$$T_s = T_a + T_e \qquad (1)$$

where T_a = antenna noise temperature

T_e = receiver system noise temperature

The receiving system noise temperature, T_e, may be derived from the definition of noise figure,

$$T_e = (F_{eff} - 1)\ (290^{o}K) \qquad (2)$$

and

$$F_{eff} = F_1 + \frac{LF_2}{G}$$

The antenna noise temperature, T_a, is composed of contributions from galactic and atmospheric sources, and is found from the equation

$$T_a = T_G + T_A \qquad (3)$$

where $T_G = 100\ (\lambda)^{2.4}$

and λ = wavelength of carrier in meters.

$T_A \approx 50^{o}K$ at the minimum elevation angle of interest, 20^{o} above the horizon.

Substitutions of equations (2) and (3) into Equation (1) yields the result that

$$T_s = 100\ (\lambda)^{2.4} + 50 + (F_1 + \frac{LF_2}{G} - 1)\ (290) \qquad (4)$$

At the frequencies of interest, noise figures of 3 dB are achievable at VHF or UHF, and 4dB is available for S-Band frequencies of 2200-2300 MHz. Preamplifier gains of 20 dB are sufficient to minimize the effects of cable loss and receiver noise figures of 10 dB on the overall system noise temperatures. Line loss of 2.3 dB at VHF, 4.1 dB at UHF, and 3.2 dB at S-Band are assumed (100 feet of RG-213 at the lower frequencies and 7/8" Helix, at S-Band).

Substitution of the above values into Equation (4) and using frequencies of 136 MHz, 465 MHz, and 2200 MHz,

for VHF: $T_s = 100\ (2.21)^{2.4} + 50 + (2 + \frac{1.7x10}{100} - 1)\ (290)$

$= 670 + 50 + 388$

$T_s = 1058^{o}K$

for UHF: $$T_s = 100(.665)^{2.4} + 50 + (2 + \frac{2.56x10}{100} -1)(290)$$

$$= 35 + 50 + 648$$

$$= 733^oK$$

for S-Band: $$T_s = 100(.136)^{2.4} + 50 + (2.52 + \frac{2.09x10}{100} -1)(290)$$

$$= .84 + 50 + 501$$

$$T_s = 552^oK$$

4.1.5.2 Antenna Considerations

In order to minimize the cost of the LUT, one of the prime constraints that must be placed on the antenna system is that expensive autotrack or program tracking schemes should be avoided, and manual tracking systems be employed. However, if the manual tracking system is to be effective, the beamwidth of the antenna radiation pattern must be wide enough to permit significant errors in human control. The magnitude of this minimum required beamwidth is an arbitrary value, since the magnitude of the errors involved depend heavily on the skill of the operator. In any case, it is felt that a beamwidth of 5-10 degrees should be the minimum considered.

For S-Band applications, a beamwidth of 8 degrees corresponds to an antenna diameter of four feet, with a gain of 26.5 dB. Smaller antenna sizes could be considered, based on link calculations, with attendant larger beamwidths and lower gains. For example, an antenna diameter of two feet has a beamwidth of 15.5 degrees, but a gain of only 20 dB. For purposes of this analysis, the larger four foot dish will be assumed, since it is felt that a beamwidth of 8 degrees would be within the capabilities of most operators.

For VHF and UHF applications, broad beamwidths are inherent in any steerable system, due to the required small size of the antenna compared to the wavelength of the signal. Typical yagi arrays with gains of 9-10 dB are available with antenna beamwidths of 40 degrees or more at VHF, and 25 degrees or more at UHF. These antennas are multi-element arrays, and approach the limits of the mechanical capabilities of small, inexpensive tracking pedestals. Because the free space loss of VHF and UHF signals are as much as 25 dB less than that at S-Band, the lower gain is quite acceptable.

Just as it is desirable to maintain as large a beamwidth as practical to allow manual tracking of the satellite, it is also desirable to avoid excessively large beamwidths to minimize the effects of ground noise, RFI, etc. Again, this maximum permissable beamwidth is somewhat arbitrary. For the applications here, minimum elevation angles of 20 degrees are assumed, allowing beamwidths of 25-40 degrees without encountering excessive ground noise effects.

With these considerations, the VHF and UHF antenna assumed for this analysis has an elevation beamwidth of about 40 degrees and a gain of about 10 dB.

Link budgets for the three downlinks may now be computed and are presented in Tables 4.1.5-1 through 4.1.5-3. Table 4.1.5-4 presents a budget for the DCP-to-Spacecraft uplink for information purposes.

4.1.6 Link Summary

With the calculations for the three downlink budgets performed and the required C/KT values for all the possible modulation schemes selected, it is then possible to narrow the wide range of possible configurations to a most-desirable selection. Table 4.1.6-1 presents a summary of the selected modulation schemes for those configurations where the decoding process is performed in the spacecraft; Table 4.1.6-2 presents the choices where the decoding process is performed at the LUT. Table 4.1.6-3 summarizes the overall link margin for each configuration chosen, with the value of C/KT required for each configuration.

4.1.7 LUT Options and Assumptions

A general block diagram of the possible LUT configurations for the medium orbiting satellite DCS configurations is shown in Figure 4.1.7-1. With the assumptions that a low cost baseline LUT required a manually operated tracking system and did not require a recorder, the prime options are then the data decoding and deformatting operations and the data display operation.

4.1.7.1 Use of Minicomputer for Decoding Convolutional Codes

The decoding of convolutional encoded data using a minicomputer is an attractive alternative to using a hardwired maximum likelihood decoder due to the savings in hardware cost. Unfortunately, with a typical 1 microsecond cycle time minicomputer, the time required to decode a constraint length 5, 190 bit DCP message, is about 3 seconds.

TABLE 4.1.5-1

LINK BUDGET
FOR
MEDIUM-ORBITING SATELLITE
S-BAND (2287 MHz)
DOWNLINK

	DIRECT MODULATION	SUBCARRIER MODULATION
Transmitter Power	+ 37 dBm	+ 37
Losses (cable, etc.)	- 1 dBm	- 1
Antenna Gain	+ 3 dB	+ 3
ERP	+ 39 dBm	+ 39 dBm
Modulation Loss	---	- 7 dB
Free-Space Loss (1070 NM @ 20°EL)	- 165.6 dB	- 165.6
Tracking Loss (Manual)	- 2 dB	- 2
Polarization Loss	- .5 dB	- .5
Antenna Gain (4' dish)	24.1 dB	24.1
Received Signal Level	- 105.0 dBm	- 112.0 dBm
System Noise Temperature (513°K)	27.1 dB-°K	27.1
Boltzmann's Constant	- 198.6 dBm/Hz-°K	- 198.6
Noise Density	- 171.5 dBm	- 171.5
C/KT	66.5 dB	59.5dB

TABLE 4.1.5-2

LINK BUDGET
FOR
MEDIUM ORBITING SATELLITE

UHF (465 MHz) DOWNLINK

XMTR POWER	+ 37	dBm
LOSSESS	- 1	dB
GAIN	+ 3	dB
ERP	+ 39	dBm
FREE SPACE LOSS (1070 n.m. @ 20° EL)	-151.8	dB
TRACKING LOSS	- 2	dB
POLARIZATION LOSS	- .5	dB
ANTENNA GAIN	+ 12	dB
RECEIVED SIGNAL LEVEL	-103.3	dBm
NOISE TEMPERATURE (733° K)	+ 28.6	dB-$^{\circ}$K
BOLTZMANN'S CONSTANT	-198.6	dBm/Hz-$^{\circ}$K
KT	-170	dBm/Hz
C/KT	66.7	dB-Hz

TABLE 4.1.5-3

LINK BUDGET
FOR
MEDIUM-ORBITING SATELLITE
VHF (136 MHZ)
DOWNLINK

Transmitter Power	+ 37 dBm
Losses (cable, etc.)	- 1 dB
Antenna Gain	+ 3 dB
ERP	+ 39 dBm
Free-Space Loss (1070 NM @ 20°EL)	-141 dB
Tracking Loss (Manual)	- 2
Polarization Loss	- .5
Antenna Gain	12 dB
Received Signal Power	- 91.5 dBm
Noise Temperature (1150°K)	30.6 dB-$^{\circ}$K
Boltzmann's Constant	-198.6 dBm/Hz-$^{\circ}$K
Noise Density	-168 dBm
C/KT	76.5 dB

TABLE 4.1.5-4

LINK BUDGET FOR MEDIUM ORBITING SATELLITE UHF (401.55 MH_Z) DCP UPLINK

DCP POWER OUTPUT		+ 37 dBm
LINE LOSS		- 1 dB
ANTENNA GAIN		1.5 dB
ERP		+ 37.5 dBm
FREE SPACE LOSS	(1240 MN @ 15° EL)	-152 dB
RECEIVED SIGNAL POWER		-114.5 dBm
POLARIZATION LOSS		- .5 dB
ANTENNA GAIN		+ 3 dB
RECEIVER SIGNAL LEVEL		-112 dBm
SYSTEM NOISE TEMPERATURE	(Estimated)	750° K
SYSTEM NOISE DENSITY		-169.8 dBm-Hz
C/KT		57.8 dB-Hz
BANDWIDTH		44.8 dB (30 kHz)
S/N_{uplink}		13 dB
DECODER IMPROVEMENT		4 dB
$S/N \mid_{out}$		17 dB
S/N reqd $\mid_{Pe = 10^{-5}}$		12.6 dB
HARDWARE DEGRADATION		2 dB
MARGIN		2.4 dB

Table 4.1.6-1

Medium Orbiting Satellite

DCS Downlink Modulation Choices
For 2.5 Kbps Uncoded Data

	S-Band Downlink	VHF Downlink	UHF Downlink
First Choice	Direct FSK	Direct FSK	Direct FSK
C/KT Req.	51.5 db/Hz	52.5 db/Hz	50.8 db/Hz
GM	17.6 db	23.9 db	15.9 db
Reason for Choice	Lower Cost	Much Lower Cost	Much Lower Cost
Second Choice	Direct PSK	Direct PSK	Direct PSK
C/KT Req.	46 db/Hz	46 db/Hz	46 db/Hz
GM	23 db	30.5 db	20.7 db
Reason for Choice	High Gain Margin	High Gain Margin	High Gain Margin

Table 4.1.6-2

Medium Orbiting Satellite

DCS Downlink Modulation Choices
For 5.0 Kbps With Decoding At LUT

	S-Band Downlink
First Choice	Direct FSK
C/KT Req.	51 db/Hz
Gain Margin	18.1 db
Reason for Choice	Lower Cost
Second Choice	Direct PSK
C/KT Req.	45 db/Hz
Gain Margin	24.1 db
Reason for Choice	Highest Gain Margin

Table 4.1.6-3

Summary of Required C/KT and Downlink Gain Margins for Medium Orbiting Satellite DCS Configurations

Medium Orbiting Satellite		C/KT Required For BER $\leq$ 10-5	Gain Margin
Conf. 1:	S-Band Relay (Translate Frequency Use PM/FSK)	56.0 db/Hz	3.5 db
Conf. 2:	S-Band On-Board Processing S/C Demodulates and Decodes (Direct Carrier FSK)	51.5 db/Hz	17.6 db
Conf. 3:	S-Band S/C Demodulates, LUT decodes (Direct Carrier FSK)	51.0 db/Hz	18.1 db
Conf. 4:	VHF On-Board Processing (Direct Carrier FSK)	52.5 db/Hz	23.9 db
Conf. 4A:	VHF with Omni Antenna (Direct Carrier FSK)	52.5 db/Hz	11.9 db
Conf. 5:	UHF On-Board Processing (Direct Carrier FSK)	50.8 db/Hz	15.9 db

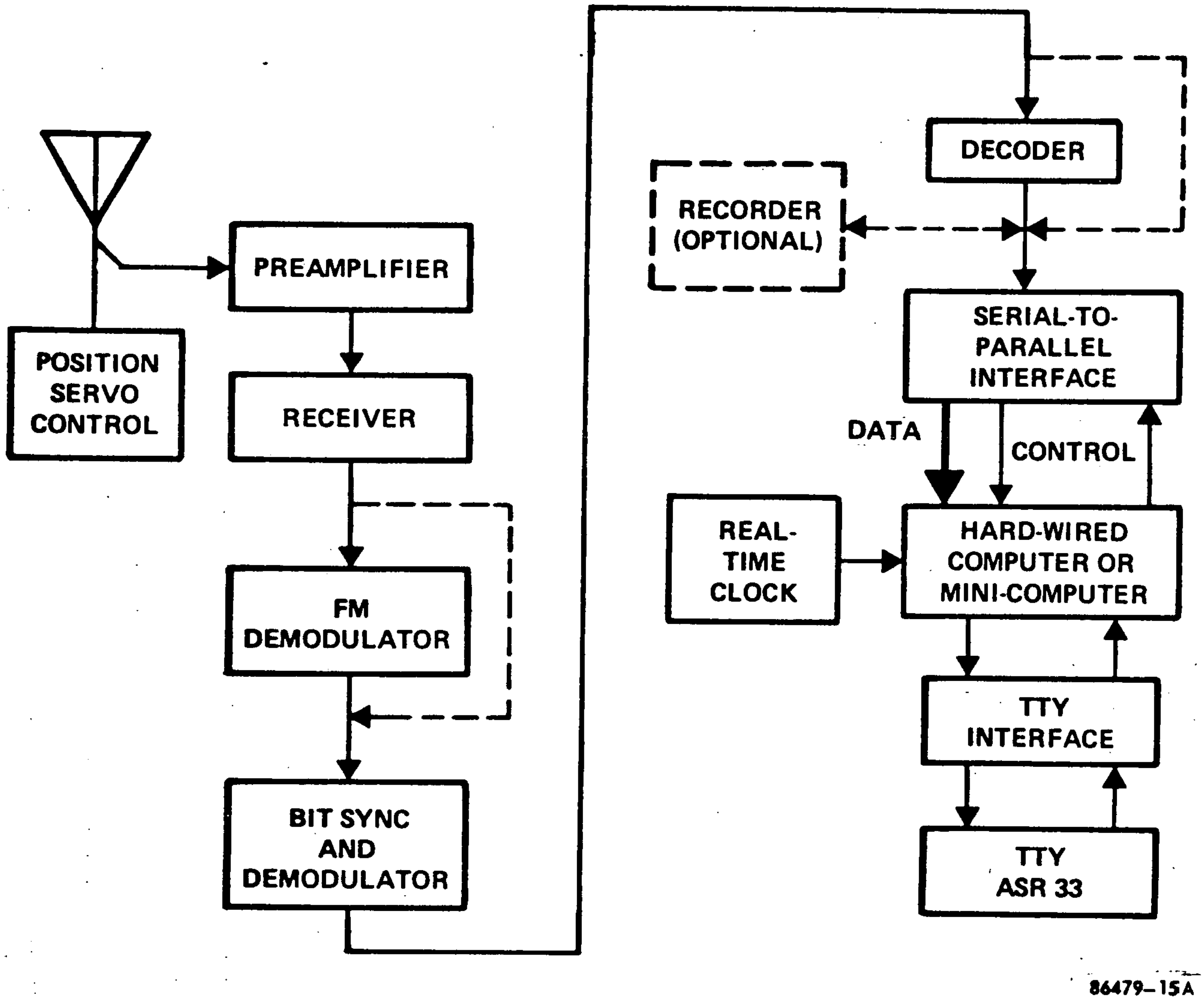


Figure 4.1.7-1. Medium-Orbiting Satellite

Since there will be many DCP's in the field of view with each transmitting every 3 seconds, the minicomputer cannot decode in real time and off line storage and processing must be used.

For non-real time decoding of data, the primary factor which affects the minicomputer approach is the total number of DCP's that are transmitting data through the satellite when it is in the field of view of a local user terminal. This number can be computed as follows:

- Length of medium orbiting satellite pass is about 10 minutes.
- Each transmits 3 times during a pass.
- The period between the end of a pass and the start of the next pass is about 90 minutes for ERTS 1 for example, permitting the computer to process off-line approximately 1800 messages, or data from up to 600 DCP's.

The amount of data storage required per pass for 600 DCP's is thus approximately 1,062,000 bits since each message contains 590 bits (190x3 soft decision DCP bits out of bit sync + 20 bit time code). A Potter DD-480 disk drive can store up to 640,000 bits and could thus handle up to 360 DCP's at the nominal cost of $1,000.

Although the minicomputer could be used with appropriate storage in an off-line decoding mode, the non-real time nature of the system and its time delay make the choice of a hardwired decoder versus minicomputer dependent upon the particular user and situation. The minicomputer for decoding the convolutional encoded data is thus shown as an option on some configurations, and the hardwired decoder, which is cost effective, (assuming a quantity of 100 or more would be built) is the specified choice on most LUT configurations used in this study.

4.1.7.2 Use of Minicomputer for Deformatting Data

A possible hardwired computer for recognition of a single DCP message and then deformatting is shown in Figure 4.1.7-2. Although relatively simple to design and assemble, the functions of a hardwired computer could easily be performed by a low-cost minicomputer. The trade-off is shown in Table 4.1.7-1 and shows that the breakpoint in recurring cost is five DCP's. Since most users would have at least this many DCP's deployed, the minicomputer was the selected option for data deformatting.

Tabel 4.1.7-1

Deformatting Options

Recurring

Limited Station		Flexible Station	
Fixed-Wire Computer	$900	Texas Instruments Model 960A computer with Teletype	$5,200
Card Cage, Wired	500	Interface Board to RCVR equipment	200
Model 33RO TTY	534	Additional cost per DCP	None
Additional Cost Per DCP	900	Total Cost per Station Up to 30 DCP's Deployed	$5,400
Total Cost per Station 5 DCP's Deployed	$5,534		

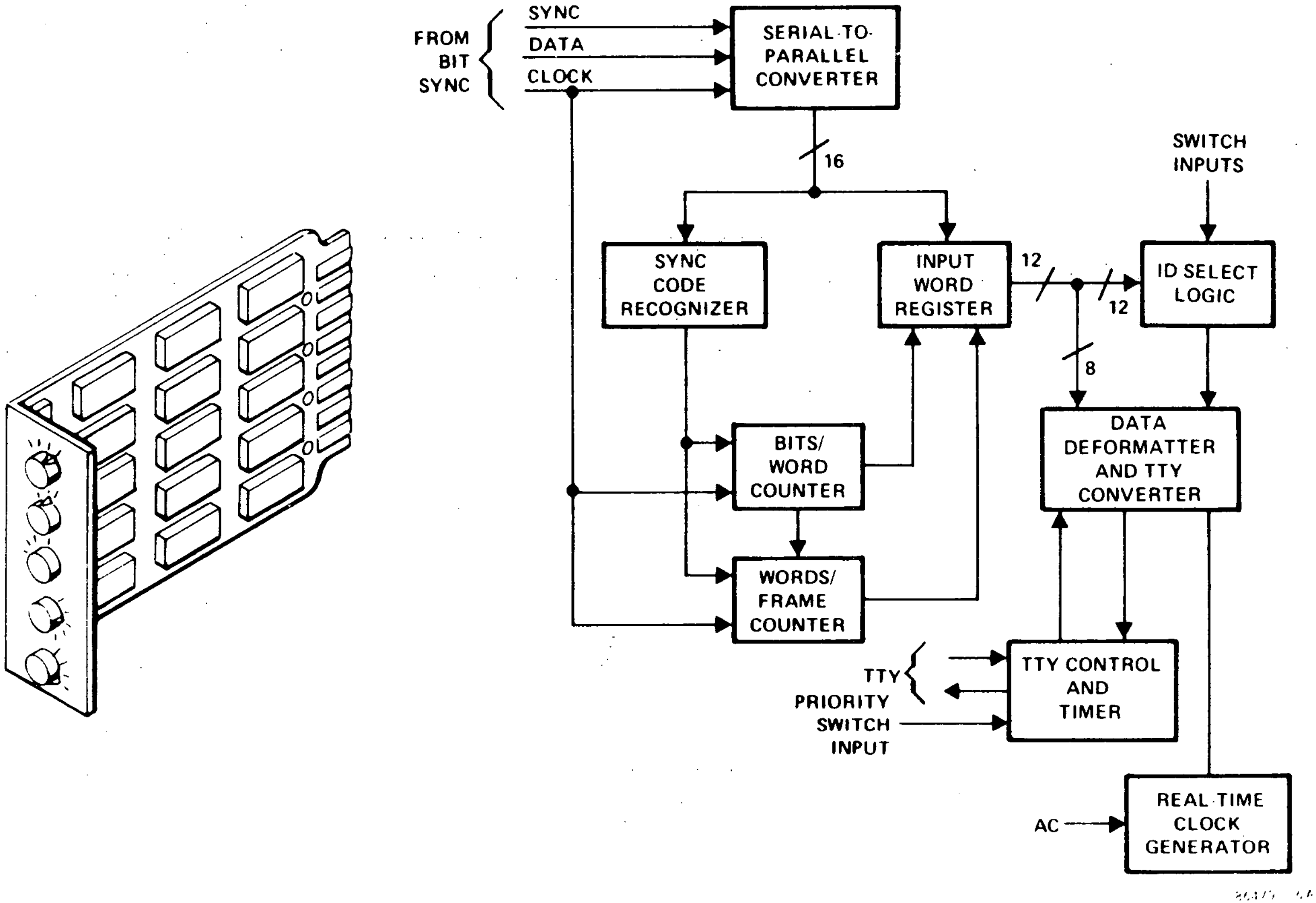


Figure 4.1.7.2. LUT Fixed-Wire Computer for Single DCP Recognition and Data Deformatting

4.1.7.3 Data Display Selection

With the selection of a minicomputer for at least the data deformatting operation, the choice of some form of computer controlled hard copy output in light of the considerations of Section 3.1.3, is a natural choice. The trade-off between the TI730 and ASR33 teletypes and a 336 line/minute line printer is shown in Table 4.1.7-2. The ASR33 teletype is thus the most cost effective approach for the average DCP user with up to 40 DCP's deployed.

Table 4.1.7-2
Computer Controlled Hard Copy
TTY/Line Printer Trade-Off

TTY #1 (TI 730)	
Speed:	30 cps
Characters/DCP: (including time code)	(Typical) 42
Time Per DCP:	1.5 seconds
DCP Capacity:	120
Price:	$2100 (with TI 960A Computer)

Line Printer	
Speed:	356 LPM
Characters/DCP:	N/A
Time per DCP:	170 seconds
DCP Capacity:	1000
Price:	$12,000 (including interface kit)

TTY #2 (ASR 33)	
Speed:	10 cps
Characters/DCP: (including time code)	(Typical) 42
Time per DCP:	4.5 seconds
DCP Capacity:	40
Price:	$1500 (including interface to computer)

4.2 Spacecraft Configurations

4.2.1 General Description

The spacecraft hardware selections for the five medium orbiting satellite DCS configurations are shown in the combined block diagram of Figure 4.2.1-1. Recurring costs plus size, weight and power requirements if any are shown. It should be emphasized that this discussion deals only with the "piggyback" DCS system; thus the other essential satellite components such as power supply, thermal control, etc., are not shown.

4.2.2 Detailed Component Discussion

Since many of the required spacecraft components are common to all or part of the five configurations, the components will be discussed individually rather than by configuration.

4.2.2.1 UHF Satellite Antenna - Modified Turnstile

The ERTS-1 UHF modified turnstile antenna for the DCP to satellite uplink was selected for all five medium orbiting configurations. The antenna is a low cost space qualified design with the following specifications:

Receive Frequency	401.55 MHz
Gain	8 db
Transmit Frequency	465.0 MHz
Gain	6 db
VSWR	1.5-1
Size	14 x 18 x 1"
Weight	1 lbs.

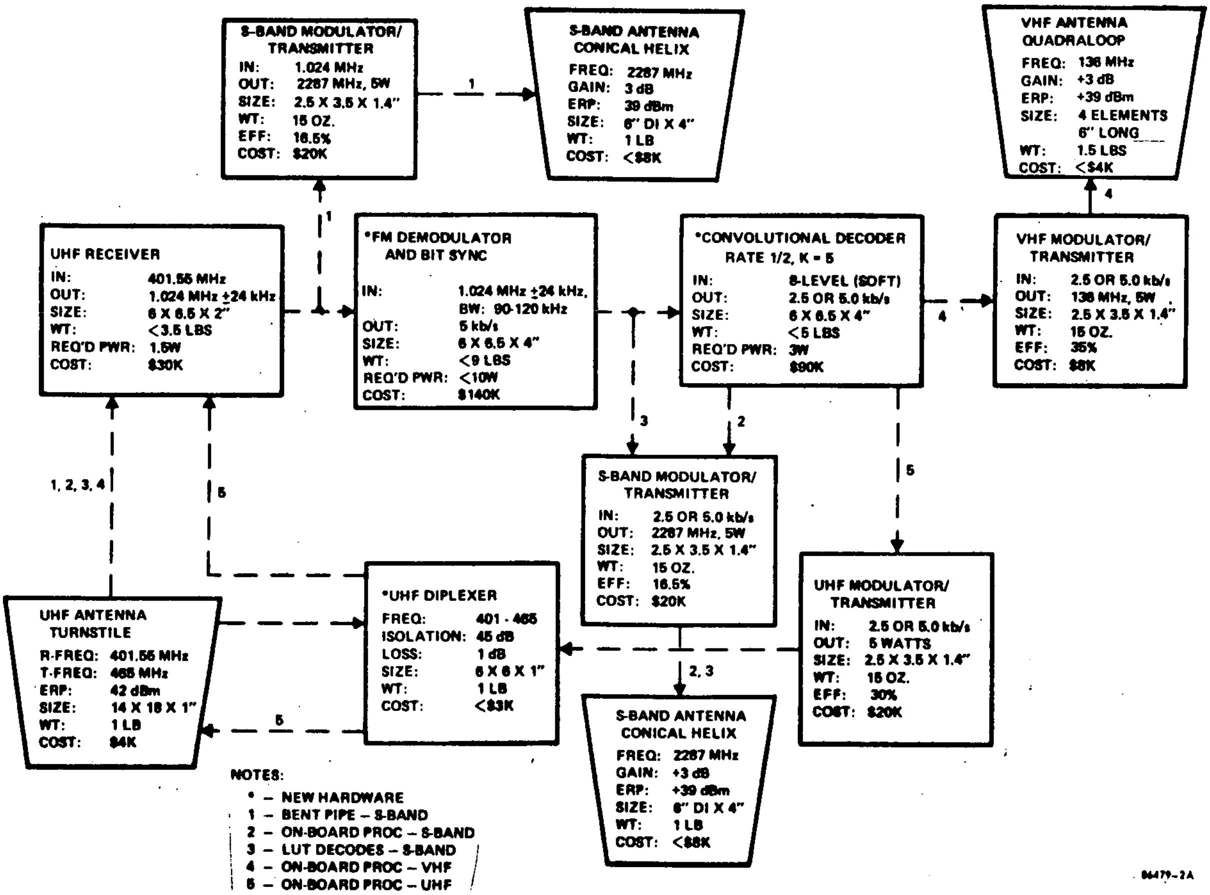


Figure 4.2.1-1. Medium-Orbiting Satellite DCS Configurations

4.2.2.2 UHF Receiver/Translator

The ERTS-1 UHF receiver/translator was also selected for all five medium-orbiting configurations because of its relative low cost and space qualified design. The unit receives the 401.55 MHz uplink signal and simply translates the signal to a 1.024 MHz IF center frequency. The unit has the following specifications:

Receiver Input Specifications

Center Frequency	401.55 MHz
3 db Bandwidth	90 KHz min
Attenuation at 401.7 MHz	30 db min
Attenuation between ± 250 KHz and ± 1.024 MHz	40 db min
Image Rejection	60 db min
Dynamic Range	-121 dbm to - 70 dbm
Input VSWR (50 ohm source)	2.0:1 max
Input Impedance	50 ohms
Noise Figure (at antenna input)	3.5 db max

Gain - Sufficient to provide limiting at output with no input signal

Receiver Output Specifications

Output Frequency (with 401.55 MHz in)	1.024 MHz
Output Level (open circuit)	2 volts p-p (± 10%)
Output Impedence	50 ohms

Input/Output Relationship - An increase in the input frequency shall result in an equal increase in the output frequency and vice versa.

Local Oscillator Accuracy & Stability

Short Term (any 100 ms period)	± 150 Hz rms max
Long Term (one year)	± 0.0015% max

Receiver Size, Weight and Power

Size	2 x 6 x 6.5"
Weight	3.5 lbs
Power Required (at 24.5V ± 2% dc)	1.5 watts max

4.2.2.3 S-Band Modulator/Transmitter

The new miniature space qualified 5 watt S-Band transmitters such as the Teledyne TR-2300 series are recommended. They offer a modulation choice of FM, PM, FSK or PSK and a reasonable efficiency, 16.5%, at 5 watt output. Brief specifications are as follows:

Transmit Frequency (S-Band)	2200 - 2300 MHz
RF Output Power	5 watt minimum
VSWR	1.5-1
Output Impedance	50 ohms
Carrier Stability (Per IRIG 106-69)	± .003%
Size	2.5 x 3.5 x 1.4"
Weight	15 oz.
Efficiency (at 5 watts out)	16.5%
Power required	31.8 watts

4.2.2.4 S-Band Antenna - Conical Helix

The ERTS-1 S-Band conical helix antenna was selected for the satellite to LUT downlink. The antenna has the following specifications:

Transmit Frequency	2287 MHz
Gain	+3 db
Hemispherical Radiation Pattern	
Size	6"0. x 4"
Weight	1 lb

4.2.2.5 FM Demodulator and Bit Sync

For the satellite on-board processing configurations an FM subcarrier demodulator and bit sync is required. This unit would perform the identical functions of the Radiation supplied FM Demodulator and Bit Synchronizer units presently being used in the ERTS DCS system at the Regional Collection Centers. The unit would reduce the frequency uncertainty of the 1.024 MHz subcarrier to 20 KHz, demodulate the subcarrier, acquire bit synchronization of the 5 Kbs rate 1/2 convolutional encoded data, and provide 8 level (soft) bit decisions. The package could be designed and built within a reasonable nonrecurring cost and would have the following general specifications:

FM Demodulator

Input (not including deviation)	1.024 MHz ± 24 KHz
Bandwidth (centered at 1.024 MHz)	90-120 KHz
Modulation: Carrier deviation	FSK, ± 5.5 KHz
Modulation Symbol Rate (Biphase Manchester II)	5.0 Kb/s
Level (Signal Plus Noise at 50 ohms)	-3 dbm ± 3 db
Carrier to Noise Ratio:	50 db-Hz min.
VSWR	1.5:1 max

Bit Synchronizer and Demodulator

Bit Sync Clock Acquisition		15 symbol periods max
Ambiguity Resolution by		19th symbol period
Jitter (In steady state cond)		4% max
BER After Ambiguity Resolution		
at 5 db SNR		3.4×10^{-2} max
Output Levels	Logical "1"	$\pm 3.5 \times \pm 1.0$v
	Logical "O"	$0.0V \pm 0.5V$
Output Impedance		93 ohms
Rise and Fall Times		1.0 uses max
Size		6 x 6.5 x 4"
Weight		9 lbs max
Required Power		10 watts max

4.2.2.6 Convolutional Decoder

For the on-board decoding configurations a space qualified, miniaturized version of the Radiation ERTS Regional Collection Center convolution decoder would be required. The decoder would decode 95 data bit or 180 code bit bursts of rate 1/2, constraint length 5, convolutionally encoded data received at a 5.0Kb/s code rate (8-level soft decisions on each code symbol give a 15.0 Kb/s input symbol rate). The decoded output bit rate would be 2.5 Kb/s without confidence bits. Confidence bits are presently provided by the RCC decoder and increase the output data rate to about 5.0 Kb/s. These are felt to be unnecessary for a low-cost local user terminal system.

Specifications on a rate 1/2, constraint length 5 convolutional decoder would be as follows:

Input Code Rate	5.0 Kb/s
Input Symbol Rate (8-level soft)	15.0 Kb/s
Logic "O"	0.0 $\pm$ 0.5 volts
Logic "1"	+ 3.5 $\pm$ 1.0 volts
Impedence	93 ohms nom.
Clock	5 KHz
Decoding Accuracy	
Prob of Missed Message	5 x 10^{-2} max
Message Error Rate	10^{-3} max
Output Rate	2.5 Kb/s
Output Format	
Preamble (Reinserted by Decoder)	15 bits
ID	12 bits
Data	64 bits
Size	6 x 6.5 x 4"
Weight	5 lbs max
Required Power	3 watts max

4.2.2.7 VHF and UHF Modulator/Transmitters

The Teledyne TR-2300 series of miniature 5 watt space qualified transmitters are also available at optional VHF and UHF frequencies. They offer a choice of modulation - FM, PM, FSK, or PSK - and have the following specifications:

Transmit Freq. (VHF)	Optional Choice
(UHF)	Optional Choice
RF Output Power	5 watts
VSWR	1.5:1
Output Impedance	50 ohms
Carrier Stability (Per IRIG 106-69)	$\pm$.003%
Size	2.5 x 3.5 x 1.4"
Weight	15 ozs.
Efficiency (at 5 watts out)	
VHF	35%
UHF	30%
Power Required (at 5 watts out)	
VHF	14.3 watts
UHF	16.7 watts

4.2.2.8 UHF Diplexer

A UHF diplexer with the exact frequency range required is not readily available in space qualified form. Modifications of existing resonant cavity lumped element designs for a 401-465 MHz frequency range would be a simple task. Brief specifications for such a unit are as follows:

Receive Frequency	401 MHz
Transmit Frequency	465 MHz
Isolation	45 db
Loss	1 db
Size	6 x 6 x 1"
Weight	1 lb

4.2.2.9 VHF Antenna - Quadraloop

A VHF quadraloop antenna is presently used on ERTS-1 and would be satisfactory for configuration 4 of this study. Brief specifications are as follows:

Frequency	136 MHz
Gain	+ 3 db
Size	Four 6" elements on a ring
Weight	15 ozs.

4.2.3 Satellite Hardware Cost Estimates

The cost estimate guidelines were discussed in Section 2.1. The cost estimates presented in this section are for recurring hardware and testing only. The satellite hardware costs assume a minimum quantity of two systems, one flight item and one backup, would be built. The recurring cost estimates including system integration and test for the five medium orbiting satellite configuration are shown in the following two tables, 4.2.3-1 and -2. The items which are not available off-the-shelf or with negligible non-recurring cost are marked with an asterisk.

4.2.4 Size, Weight, and Power Considerations

For satellite systems the size, weight, and power requirements of on-board electronic systems are critical to the overall cost of a deployed satellite system. There is a tradeoff between the amount of non-recurring dollars required to minimize the size, weight and power requirements of a given system and the additional cost of deploying reasonably well designed but non-optimized satellite hardware. The scope of this study did not permit any efforts to minimize size, weight, and power for each of the systems.

The systems shown in Figure 4.2.1-1 are a low-cost compilation of space qualified components and new items with reasonable designs and hence reasonable costs. Using these items with the best size, weight, and power requirements available resulted in the values shown in the summary Table 4.2.4-1 for the five medium orbiting satellite DCS configurations.

Table 4.2.3-1

Summary of Satellite Hardware Recurring Costs
Medium Orbiting Satellite
S-Band Options, Configuration 1, 2, 3

Equipment Required	Config. 1 Bent Pipe Relay	Config. 2 On Brd Proc	Config. 3 LUT Decodes
UHF Antenna (Turnstile)	$ 4K	$ 4K	$ 4K
UHF Recvr/Transl	30K	30K	30K
S-Band Transmitter (2287 MHz, 5 Watts)	20K	20K	20K
S-Band Antenna (Conical Helix)	8K	8K	8K
FM Demod & Bit Sync		140K	140K
Conv. Decoder (Rate 1/2, K = 5)		90K	
Subtotal Hardware	$ 62K	$ 292K	$ 202K
Integration and Test	100K	200K	170K
Total	$162K	$492K	$372K

Table 4.2.3-2
Summary of Satellite Hardware Recurring Costs
Medium Orbiting Satellite
VHF & UHF Downlink Options, Configuration 4 & 5

Equipment Required	Config. 4 On-Brd Proc VHF Downlink	Config. 5 On-Brd Proc UHF Downlink
UHF Antenna (Turnstile)	$ 4K	$ 4K
* UHF Diplexer		3K
UHF Recvr/Transl.	30K	30K
* FM Demod & Bit Sync	140K	140K
* Conv. Decoder (Rate 1/2, K = 5)	90K	90K
VHF Mod/Xmitter	8K	
VHF Antenna (Quadraloop)	4K	
UHF Mod/Xmitter		20K
Subtotal Hardware	$276K	$287K
Integration & Test	200K	200K
Total	$476K	$487K

Table 4.2.4-1

Summary - Satellite Component Size, Weight and Power
Medium Orbiting Satellite DCS Configurations

Component Summary	Configurations #1 Bent-Pipe S-Band	#2 On-Brd Proc S-Band	#3 LUT Decodes S-Band	#4 On-Brd Proc VHF	#5 On-Brd Proc UHF
No. of Items	4	6	5	6	6
Total Internal Volume (cu. in.)	90	402	246	390	436
Total Weight (ozs.)	103	327	247	325	327
Total Power (watts)	31.8	44.8	41.8	28.8	31.1

4.2.5 Summary of Satellite Hardware Trades for Medium Orbiting Satellite DCS Systems

As could be expected the satellite hardware configuration with the least recurring cost is the receiver/translator-and-retransmit "bent pipe" relay system of Configuration 1. This system would also have the lowest nonrecurring cost since there are no new items required. Because of its relative simplicity, configuration 1 has the least size and weight but requires slightly more power (31.8 watts) than the VHF configuration 4 (28.8 watts) due to the lower transmitter efficiencies at S-Band.

The next lowest cost satellite hardware configuration is configuration 3, the S-Band on-board processing system without decoder, which essentially reflects the high initial recurring cost of one or two space qualified maximum likelihood convolutional decoders. Configurations 2, 4, and 5, the S-Band, UHF and VHF configurations with on-board processing including decoding were about the same in terms of recurring cost, size and weight with the only appreciable difference being in the higher power requirements for the S-Band transmitter.

4.3 Local User Terminal Configurations

4.3.1 General Description

A block diagram for the local user terminal of each configuration considered is presented in Figures 4.3.1-1 through 4.3.1-5. Each of these is described separately below.

4.3.1.1 Configuration 1 - "Bent-Pipe" Relay

Figure 4.3.1-1 illustrates the required LUT configuration when the satellite is designed much the same as the current ERTS equipment. The satellite receives the DCP UHF uplink signal, translates its frequency to 1.024 MHz, and uses this resulting signal as a subcarrier to modulate an S-Band downlink carrier.

The S-Band signal from the satellite is received by the medium-gain parabolic antenna and amplified by the preamplifier prior to delivery to the receiver input cable. The antenna is of broad enough beamwidth (10^{o}) that manual tracking of the satellite is feasible. The antenna positioner is collocated with the receiver, and the servo controls manipulated in such a manner as to maintain a maximum signal strength indication on the receiver. This technique of manually tracking a satellite is awkward but practical for installations where the user's budget cannot afford expensive autotracking antenna systems.

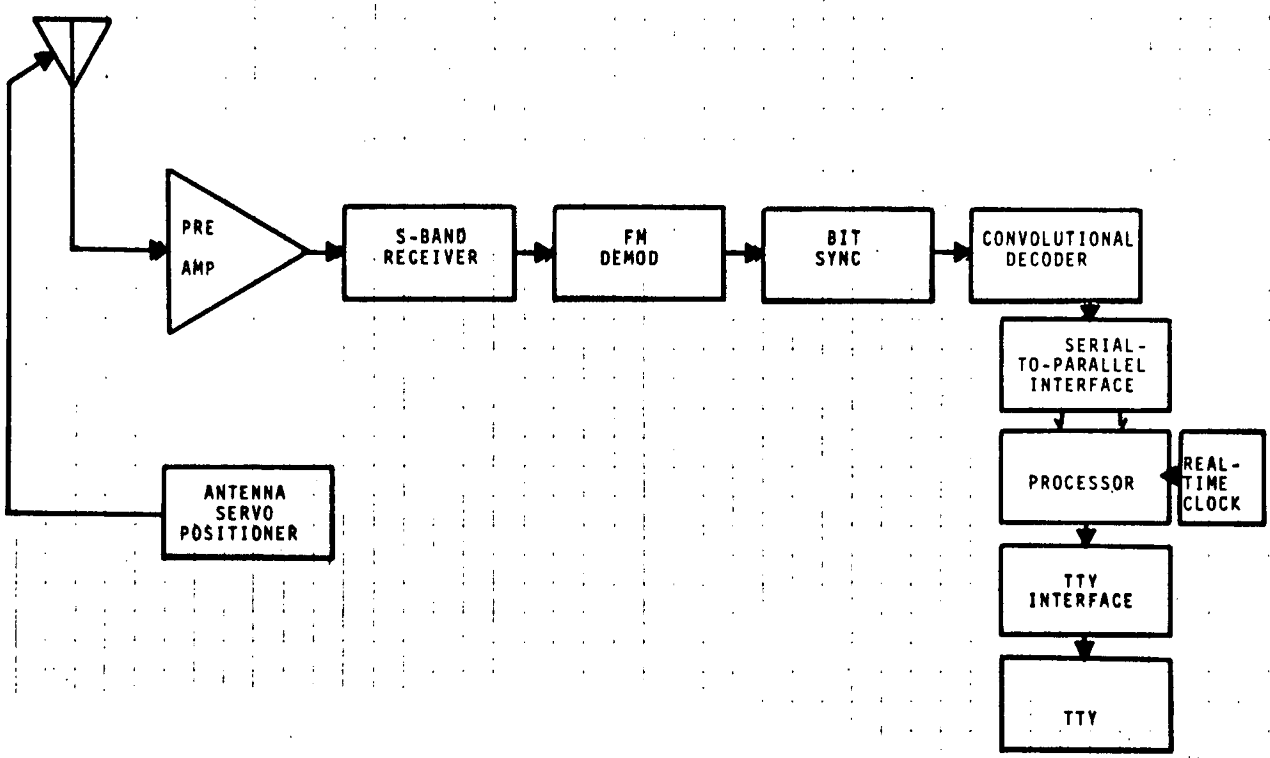


Figure 4.3.1-1. LUT Configuration 1 - "Bent-Pipe" S-Band Relay

In order to reduce the effects of rf cable losses and minimize the system noise temperature, a broadband pre-amplifier is located at the antenna. The preamplifier should be a transistorized amplifier rather than a paramp due to its higher reliability, lower cost, and adequate performance. Weather protection should be provided in the form of a weathertight enclosure, but temperature control should not be required except perhaps under extreme and unusual conditions.

The preamplified S-Band signal is routed to the receiver, which is located in the operator's area along with the remainder of the LUT equipment. The S-Band receiver should have as a minimum a signal strength indicator (for tracking purposes), automatic frequency control (to compensate for doppler drift and other frequency uncertainties), and a video response capable of handling the 1.024 MHz subcarrier frequency. The subcarrier is phase modulated onto the S-Band carrier frequency, and the data is FSK modulated onto the 1.024 MHz subcarrier.

The subcarrier output of the receiver is routed to the FM demodulator unit, where the subcarrier frequency is acquired, filtered, and demodulated to produce a digital output signal consisting of the original 5 Kbps DCP message. This message is encoded with a rate 1/2, constraint length 5 convolutional code, which is necessary because of the marginal performance of the DCP uplink to the spacecraft.

The digital bit stream from the FM demodulator is routed to the bit synchronizer, which derives the bit timing to produce a clock and data output signal for processing.

Digital processing consists of deriving the original DCP data from the decoded data. This process is performed by the maximum likelihood decoder shown in Figure 3.4-1. With "soft" bit decisions in the bit synchronizer, each data bit is represented by a three-digit binary number. A logic "0" of high confidence is given by "000", while a high confidence logic "1" is represented by "111". Using this as its input, the decoder is able to contribute at least 4 db of processing gain to the system performance. In this manner, the relatively weak DCP uplink is protected from high bit error rates, thereby improving the total system performance.

The reconstructed DCP data is delivered in serial form to the serial-to-parallel converter, where it is collected for the processor. The processor may be a specially designed hardwired processor whose sole function is to format the DCP message and output it to the teletype printer, or the processor could be a much more flexible programmable minicomputer. If the minicomputer is used, it could be used to process the DCP data prior to display and to compare data values from each DCP, calculate mean and average parameter values, look for values above or below thresholds, or compare against expected values. In addition, the processor can be used for other purposes as well, such as the prediction of orbital position during a pass based on ephemeris data supplied in advance by NASA.

As an output medium, the teletype machine offers the most economical and practical solution. Each DCP message is permanently recorded for later analysis; the bell may be used as an alarm or operator alert siganl; both input to and output from the processor is possible, allowing the operator to modify his threshold values or other stored parameters; the TTY machine is considerably less expensive than a line printer, CRT display, or other standard output device. For these and other reasons, the TTY is ideally suited for the local user terminal application.

In order to record the time of reception of each DCP message, a real-time clock completes the equipment complement of the terminal. This device supplies GMT or local time to the processor so that the time of data collection is identified for later analysis of the data.

4.3.1.2 Configuration 2 - Spacecraft Demodulates and Decodes (S-Band Downlink)

A block diagram for configuration 2 is given in Figure 4.3.1-2. In this system, the DCP UHF uplink is received and detected in the spacecraft, the resultant data is decoded, and the restored 2.5 Kbps data is used to modulate the carrier of an S-Band transmitter. Adequate system performance is obtained and local terminal cost is reduced if this option is employed, since the subcarrier demodulator and convolutional decoder are not required at each ground station.

The S-Band signal is received by the manually positioned medium-gain antenna, preamplified by the transistorized preamp, and routed to the S-Band receiver, just as described for configuration 1. The receiver is not required to demodulate a PM/FSK signal, however, but instead an FSK modulated carrier. In order to maximize the performance, the carrier deviation is very wide with respect to the data rate, and the receiver must be capable of demodulating such a siganl.

The output of the receiver is a digital bit stream which is routed to the bit synchronizer. The bit synchronizer accepts the noisy receiver output and generates a clean data signal plus a bit timing clock signal. The data is then ready for processing.

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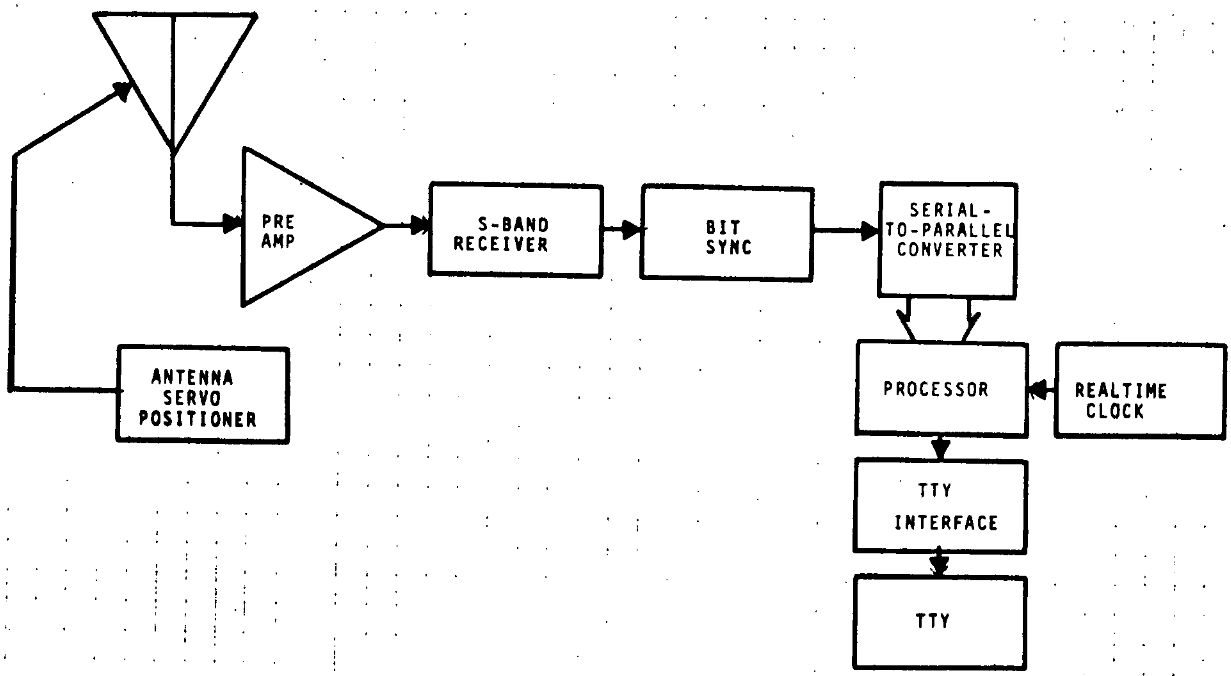


Figure 4.3.1-2. LUT Configuration 2 - Spacecraft Demodulates and Decodes (S-Band Downlink)

The serial data stream from the bit synchronizer is fed into the serial-to-parallel converter where it is collected for parallel delivery to the processor. The processor accepts this data in word length form and processes it according to its internally programmed scheme.

Just as described for configuration 1, the processor could be either a specially designed hardwired processor which serves only to format the data for output, or it could be a programmable mini-computer which can be used for other purposes as well.

The configuration 2 system described here provides a considerably less expensive S-Band terminal than that of configuration 1, since there is no requirement for either a subcarrier demodulator, soft-bit-decision bit synchronizer (considerably less sophistication is required in acquisition, filtering, and decision circuitry), or convolutional decoder at the local user terminals. The complexity associated with this equipment would then be located in the spacecraft, but the requirements of the individual terminals is simplified.

4.3.1.3 Configuration 3 - Spacecraft Demodulates, LUT Decodes (S-Band Downlink)

A block diagram of configuration 3 for the local user terminals is shown in Figure 4.3.1-3. This option offers a compromise between configurations 1 and 2, with the spacecraft demodulating the DCP uplink channel and transmitting an FSK modulated S-Band carrier signal, but the decoding function is performed within the local terminal.

As before, the S-Band medium-gain antenna is manually controlled to follow the satellite through its orbital path using the receiver's signal strength meter as a feedback monitor. The signal is preamplified as before and detected by the receiver as a wideband deviation FSK signal directly modulated on the carrier. Therefore, the receiver output is the detected data stream, which is routed to the bit synchronizer.

The bit synchronizer is itself a compromise in complexity between that required for configurations 1 and 2. Because the spacecraft data demodulation removes the frequency uncertainty from the uplink channel, the filtering and acquisition circuits are simplified from that of configuration 1. But because the LUT must decode the data, three-bit quantization ("soft" bit decision) of the data level is still required. This three-bit, eight-level data representation and a bit timing clock pulse are derived by the bit synchronizer and delivered to the decoder.

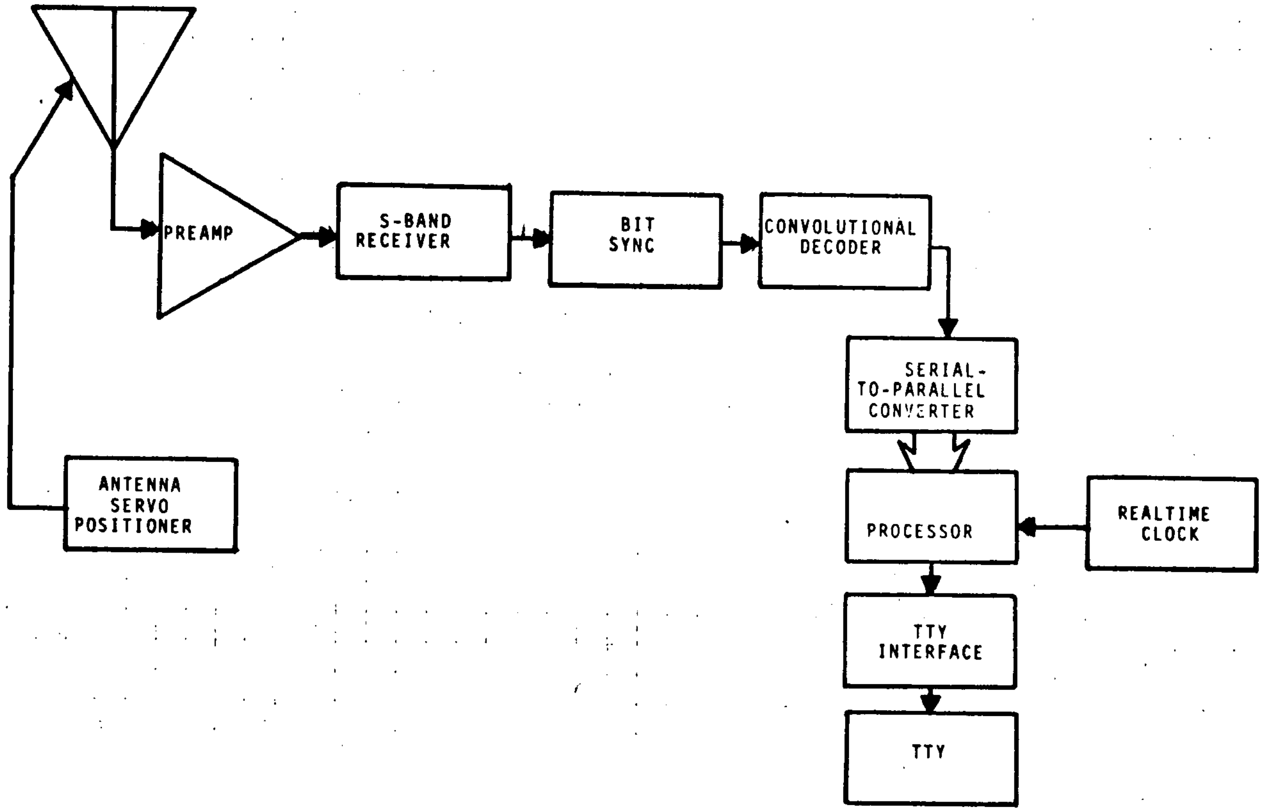


Figure 4.3.1-3. Configuration 3 - Spacecraft Demodulates, LUT Decodes (S-Band Downlink)

Just as in configuration 1, the decoder accepts the convolutional encoded data and derives the original DCP data, adding at least 4 db processing gain in the process. This decoded data stream is presented in serial form to the serial-to-parallel converter, where it is accumulated and routed to the processor in word-length form.

As before, the processor may be designed with varying levels of complexity and capabilities, but the TTY machine is the most desirable display device for this application.

The optional configuration described above provides a system which compromises on the degree of complexity to be shared between the satellite and local terminal. Each of the three systems described above utilizes S-Band frequencies for the downlink, so that antennas, receivers, and preamps are identical in each configuration with the trade-offs being in the areas of demodulation and decoding equipment. It is also instructive to examine other frequency bands to determine performance and cost parameters for various LUT configurations.

4.3.1.4 Configuration 4 - Spacecraft Demodulates and Decodes (VHF Downlink)

The block diagram for this optional system is given in Figure 4.3.1-4. In a manner similar to that described for the configuration 2 system, the spacecraft receives the DCP data, demodulates the message, and decodes the convolutional encoded bit stream. The decoded data in this option, however, is used to modulate the carrier of a VHF transmitter.

The VHF signal is received by a manually positioned crossed-yagi antenna. This antenna may be identical to that used for Automatic Picture Transmission (APT) receiving stations. (The frequency of operation is about 136 MHz, which is well within the bandwidth limitations of that antenna. Should the actual frequency employed be outside the bandwidth of the APT antenna, slight modifications would render the center frequency compatible with the requirements.) The antenna position is controlled in a fashion similar to that described for S-Band. However, the VHF antenna servo motors are constant-speed, requiring start-stop antenna movements. However, the antenna beamwidth is quite broad, and only a few repositionings of the antenna is required during each pass of the satellite.

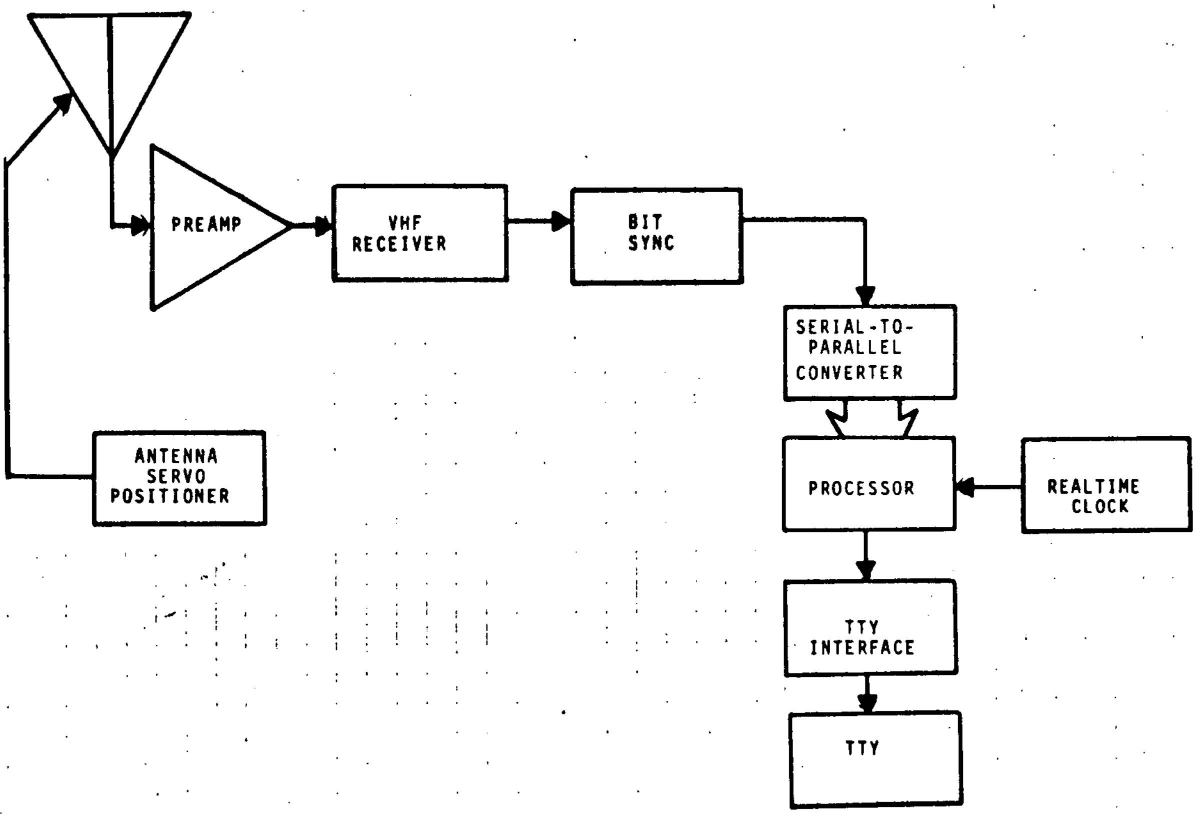


Figure 4.3.1-4. Configuration 4 - VHF Downlink

Just as was the case for the S-Band systems, a small preamplifier is mounted at the antenna pedestal to reduce the system noise temperature by minimizing the effects of cable losses. The antenna used for APT stations has an integral preamplifier included, or another inexpensive general purpose broadband preamplifier would be required if a different antenna were selected for use.

The amplified signal is then delivered to the VHF receiver, where the FSK-modulated data is detected. This receiver can be a relatively inexpensive unit designed for general purpose voice FM systems. The detected output is then routed to a simple bit synchronizer. Sophisticated filtering, acquisition, and bit decision circuitry is not required, as the spacecraft demodulation removes the uplink frequency uncertainty and the decoding process restores the original DCP data and no decoding is required at the LUT. The bit synchronizer output is then routed to the serial-to-parallel converter and the remainder of the processing and display system. This portion of the system is identical to that described for the earlier configurations.

A variation of the VHF option, which may be referred to here as configuration 4A, uses a relatively omni-directional antenna that does not require repositioning during a pass. Link calculations show that sufficient margin exists in the above system that the reduced gain of a turnstile-type or similar antenna could be used with a resultant adequate level of performance for the system. This system would, however, be more susceptible to RFI problems than would the narrower-beam directional antenna, and its use would be predicated on local conditions.

4.3.1.5 Configuration 5 - UHF Downlink

The block diagram representing this system is shown in Figure 4.3.1-5. Actually, there is very little difference in system operation between this system and the VHF system. Except for the frequency of operation, and therefore the antenna-preamp-receiver model types, all other details are identical to that described above for configuration 4. The signal is received at the antenna, applied to a preamplifier to minimize cable loss effects, detected by the UHF FM receiver, and then delivered to the bit synchronizer and display subsystem.

In the VHF option, there was sufficient link margin to permit the use of an omni-directional stationary antenna. While this degrades the link margin by 12 db, the savings in cost, complexity, and operator requirements for the antenna system justifies consideration of the trade-off. However, the link performance for UHF is considerably

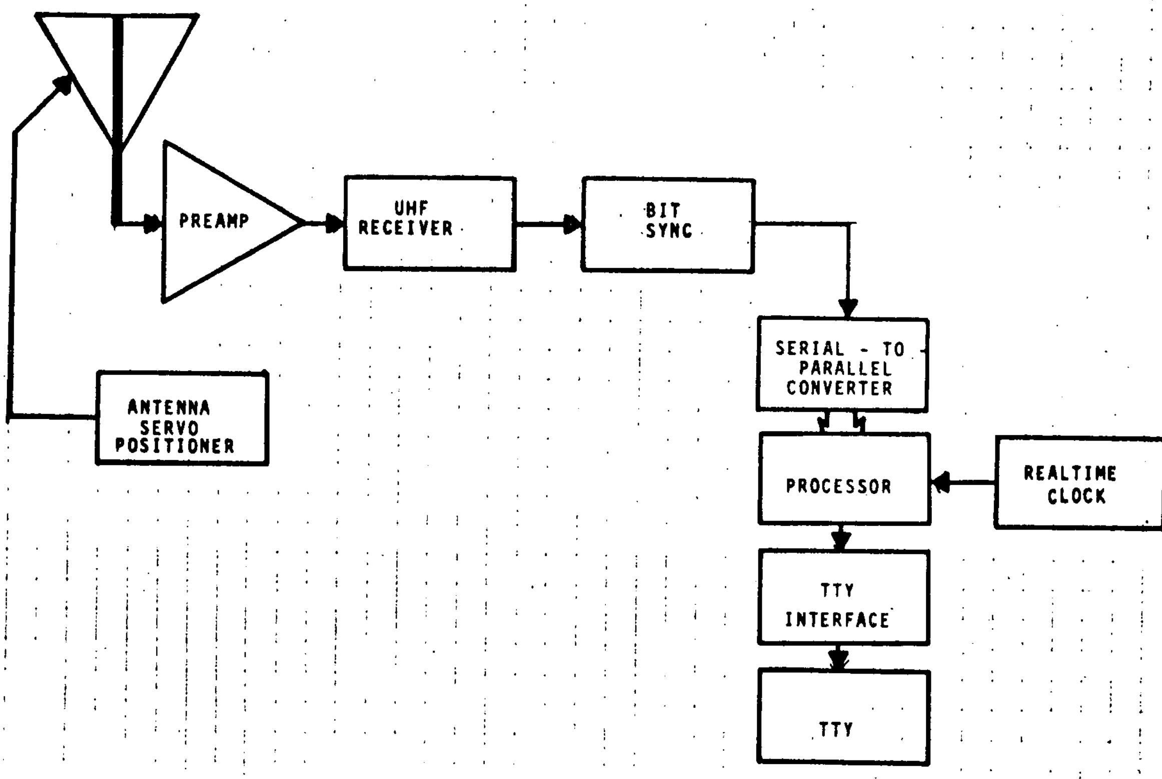


Figure 4.3.1-5. Configuration 5 - UHF Downlink

below that of the VHF system, due to the greater path losses at the higher frequency and the lack of compensating higher antenna gains. The total reduction in performance is 8 db, which precludes the further reduction necessitated in the omni-directional antenna. If it is desired to consider the use of omni-directional and stationary antennas, the only practical solution is an increase in transmitter power level. However, this solution, with its attendent higher costs and higher power supply requirements, would require careful consideration of such factors as quantity of users, cost tradeoffs, and utility benefits derived.

4.3.2 Specifications and Detailed Component Description

The majority of the equipment considered for use in the Local User Terminal configurations is commercially available, while only a relatively few devices must be designed for this application. This section will present brief specifications for each element in the systems and a discussion of typical equipment which meets those requirements. It must be noted that the equipment presented here is not the only choice available, nor is it necessarily the absolute best choice. The equipment described is chosen as being typical of that available which meets the requirements at a cost typical of that to be expected.

For the equipment which must be designed expecially for these applications, the equipment costs presented do not include any non-recurring design and tooling costs, but only represent the per-unit recurring costs for production quantities limited to this system application.

4.3.2.1 S-Band Antenna

In order to minimize the LUT costs, the S-Band antenna should be of broad enough beamwidth to permit manual tracking of the satellite. With this as the paramount consideration, the following specifications apply:

Polarization:	Right-hand circular
Type:	Parabolic dish
Diameter:	4 feet (6 feet for Conf. 1)
Gain:	26.0 db minimum at 2287 MHz (30 db for 6 feet)
Beamwidth:	7 degrees minimum at 2287 MHz (5 degrees for 6 feet) (half-power points)

Position Control:	Variable speed manual remote servo control
Maximum slew rate:	3 degrees/second in elevation, 7.5 degrees/second in azimuth
Position Accuracy:	± 1.0 degrees
Wind Speed:	40 mph, operational
Travel Limits:	0 - 90°, elevation, 0-360° azimuth

An antenna system which meets these requirements is the Scientific Atlanta S405-3D Positioner and an Andrews 60004-21 antenna for configurations 2 and 3, or a 60006-21 antenna where the higher gain of a 6-foot reflector is required. The S405-3D positioner is used with a Model 4114 Dual Axis control unit, providing the required independent elevation and azimuth controls, and a Model 4422-44 Position Readout panel. This equipment includes variable speed dc motors, providing a smoothly operating variable speed drive for both axes of the positioner. The motor speed is controlled by the operator at the 4114 Control Unit. This scheme is recommended in lieu of a constant-speed on-off drive because of the relatively narrow 7 degree beamwidth for the 4 foot dish and the even narrower 5 degrees for the 6-foot dish. This is considered to be more than adequate for a variable-speed system, but is too narrow for a constant speed system, which would require many small on-off corrections during each pass. The antenna parabaloid itself includes a helical feed for right-hand-circular polarization. Circular polarization is desirable rather than linear because of the polarization stability throughout the satellite pass. Linear polarization would be subject to rotation as the satellite antenna changed its relative attitude during the period of intercept, and some means of switching or rotating the ground station plane of polarization would be required to prevent excessive reductions in signal strength. Circular polarization eliminates the problem, and should therefore be employed.

4.3.2.2 UHF Antenna

Because the free-space path losses are less at UHF than at S-Band, lower gain antennas may be used at the LUT. In order to provide sufficient gain margin, however, a directional antenna yielding at least 10-12 db gain is required. Such an antenna must be steerable to follow the satellite across its path, but is of sufficiently wide beamwidth that an on-off constant speed antenna positioner would suffice, rather than a variable-speed, servo-controlled device. With these general requirements, the following specifications apply:

Polarization:	Right-Hand Circular
Type:	Crossed Yagi or Helical
Gain:	12 dbi at 465 MHz
Beamwidth:	25 degrees minimum for both elevation and azimuth
Slew rate:	3 degrees per second minimum

An antenna which meets the above requirements is the TACO H-085. The bandwidth of this eight-turn helical covers the frequency range from 300 to 520 MHz, with a VSWR less than 1.4:1. Its nominal gain is 12.5 dbic, and its beamwidth is 31 degrees in the E-plane and 27.5 degrees in the H-plane. These characteristics make it ideally suited for this application.

The rotator for this antenna could be the same type as that used for the EMR 100D VHF antenna system. Basically, this consists of two independent orthogonally mounted constant-speed motor drives with remote control-indicators. Because of the relatively wide beamwidth of the TACO helix, the start-stop positioning of the constant-speed positioner motors is acceptable.

4.3.2.3 VHF Antenna

The VHF antenna required for the medium-orbiting satellite ground station is very similar in requirements to the UHF antenna described above. Because of polarization reversal in a satellite, a circularly polarized antenna system eliminates the need to switch between horizontal and vertical polarizations. Low-cost constant-speed rotator drives are feasible with the relatively wide beamwidths associated with antennas having a gain of 10-12 dbi, and these values are quite feasible for this system. The general specifications for this antenna are as follows:

Polarization:	Right-hand circular
Gain:	12 dbi
Frequency:	136.5 MHz
Feed Impedance:	50 ohms
Slew Rate:	3 degrees/sec minimum
Beamwidth:	20 degrees minimum, elevation and azimuth

An antenna meeting all these requirements is the EMR Model 100D Dual Yagi antenna. This antenna consists of two ten-element yagi antennas mounted mutually perpendicular to provide a circularly polarized antenna system. Positioning is obtained by remotely controlling two independent orthogonal drive motors. This antenna also includes in its pedestal a broadband preamplifier to provide the required low system noise figure. This antenna system has been used successfully in a very similar application to the DCS system, having been designed for Automatic Picture Transmission receiving stations.

Because the system margin is quite large for the VHF configuration, consideration can be given to employing a fixed antenna. This antenna must still have circular polarization, but instead of a directional beam should have nearly hemispherical coverage. The same type of antenna is currently in use at UHF on the DCP in the ERTS system. Such an antenna has a bifolium radiation pattern, providing about +3 db gain at low elevation angles and lower gain (-3 db) at the zenith. This pattern provides nearly uniform received signal strength regardless of the satellite position, and is ideally suited for this application. Unattended operation is possible, since positioning the antenna is unnecessary. Care must be taken in employing such an antenna, however, since the effects of local rfi are intensified over those encountered when a directional antenna is used. For remote areas, however, this omni-directional antenna could be readily employed.

4.3.2.4 S-Band Preamplifier

In order to minimize the effects of cable losses on overall system noise figure, a broadband preamplifier should be included in the system. This unit must be mounted as closely as possible to the antenna itself so that the system maintains maximum sensitivity, preferably on the pedestal itself. Because the unit would be subjected to all the vagaries of weather, it must be either weathertight itself or enclosed in a weathertight container. General specifications for such a device are:

Gain:	20 db minimum
Center Frequency:	2287 MHz
Bandwidth:	100 MHz
Noise Figure:	3.5 db nominal
VSWR:	1.5:1 maximum, input and output
Operating Temperature:	-55°C to +50°C
Supply voltage:	110 VAC, 50-60 Hz

A microwave transistor amplifier which satisfies these requirements is the International Microwave Corporation series of units. The part number for a device particularly suited to these specifications is the S10-2287-20CA. Other options are available with different gain, center frequency, bandwidth, etc., but with little or no cost variations.

4.3.2.5 UHF Preamplifier

Just as with the S-Band system, the UHF configuration requires an antenna-mounted preamplifier with sufficient gain to minimize the system noise figure. Again, this preamplifier, being mounted on or near the antenna pedestal, must be protected from the extremes of weather. General requirements for the UHF preamplifier are as follows:

Center Frequency:	465 MHz
Gain:	20 db minimum
Noise Figure:	5 db maximum

Because of the proximity of this frequency to the Amateur and Citizen's Radio bands, there are several inexpensive models available which may be used for this application. Among them is the Vanguard Model 202 preamplifier. This unit, like most other such inexpensive models, is not sealed against the weather and would require a protective enclosure. The unit is tuneable to any frequency in the 300-475 MHz band, and has about 20 db gain at 465 MHz. Because of its very low cost, this unit is quite desireable for this application.

4.3.2.6 VHF Preamplifier

Even though the VHF configuration has a considerable amount of link margin, particularly if high-gain directional antennas are utilized, the use of a preamplifier is highly desireable in order to minimize cable loss effects. Like the S-Band and UHF preamplifiers, the preamplifier should be located at or near the antenna pedestal. General requirements for the preamplifier are:

Frequency:	136.5 MHz
Bandwidth:	2 MHz minimum
Gain:	20 db
Noise Figure:	4 db maximum

As with the UHF preamplifier, there are several inexpensive preamplifier units from which to choose, due to the proximity of other popular bands. In addition, the low-cost directional antenna manufactured by EMR Aerospace Systems (Model 100D) contains its own integral preamplifier. If this antenna is used, there would be no need for an additional preamplifier unit. If, however, an omni-directional antenna is used to eliminate the requirement for satellite tracking, then a separate preamplifier would be required. A preamplifier which fulfills the requirements listed above is the Vanguard Labs Model 102. This unit can be supplied with a weathertight housing at a very nominal cost, and would be ideally suited for this application.

4.3.2.7 S-Band Receiver

The requirements for the S-Band receiver depend heavily on the particular configuration selected for implementation. If configuration 1 is employed, the receiver must be capable of demodulating a phase-modulated carrier and recovering a 1.024 MHz subcarrier. If another S-Band downlink configuration is chosen, the receiver must be capable of demodulating an FSK-modulated carrier with very high modulation coefficients. The output signal for such a configuration would be digital data without requiring subsequent subcarrier demodulation. Basic requirements for the S-Band receiver are as follows:

Frequency:	2287 MHz
IF Bandwidth:	3 MHz for subcarrier modulation; 200 KHz for 5 KBPS data (125 KHz for 2.5 KBPS data), with direct carrier FSK modulation
AFC Tracking:	± 250 KHz about center frequency
AFC Search and Lock:	± 250 KHz range minimum for acquisition
AGC Metering:	Indicate signal-level-above-noise for antenna positioning indicator
Tuning Meter:	Center-zero meter to provide indication of signal position in IF passband.

A receiver which can be used for either the direct carrier or subcarrier modulation systems is the Microdyne Model 1100AR Telemetry Data Receiver. This unit is modular in design, allowing the receiver to be configured to the degree required for a particular system application. For the configuration requiring subcarrier reception, the plug-in units required are:

(1) Model 1100AR Basic Receiver Unit

(2) Model 1115-T(A) RF Tuner

(3) Model 1129-I(A) (1.5 MHz) IF Filter

(4) Model 1151-D(B) Phase Demodulator

(5) Model CR-65U (2287.5 MHz) Crystal

(6) AFC Amplifier 300-070A

For the direct carrier FSK modulation, the units required are (1), (2), (5) and (6) above, but with the following filter and demodulation:

(3) Model 1136-I(A) (KHz) IF Filter

(4) Model 1142-D(A) FM demodulator

4.3.2.8 UHF Receiver

The recommended modulation for UHF frequencies is direct FSK modulation of the carrier signal. The UHF receiver must, therefore, be capable of receiving in the FM or FSK mode at a frequency of about 465 MHz. In order to optimize the receiver performance, a deviation of about 120 KHz should be employed for a data rate of 2.5 or 5.0 KBPS, with an if bandwidth of about 150 KHz. This combination accommodates the expected frequency uncertainty and provides the most receiver sensitivity to the data. Other pertinent requirements of this receiver are as set forth below:

Operating Frequency:	465 MHz
Type of Reception:	FM/FSK
IF bandwidth:	150 KHz
AFC:	± 50 KHz minimum
Metering:	Signal Strength, Tuning

In addition, a crystal marker oscillator is desireable to aid in calibration of the tuning head indicator.

One candidate receiver for use in this application is Astro Communications Laboratory Model SR-209. This receiver is designed as a modular unit, accepting a variety of plug-in tuners and IF filters. It may also be configured with an optional spectrum display unit, which may be used as an aid in tuning the receiver. However, this option is not required as a part of the receiver unit.

4.3.2.9 VHF Receiver

In the VHF frequency configuration, every effort has been made to minimize the total cost of the Local User Terminal. Decoding of the DCP message has been assumed to be performed in the satellite, and the antenna selected for use at the local terminal is an inexpensive type designed originally for APT terminals. The receiver for this system may also be selected from vendors of equipment designed for other applications. Requirements for the receiver are:

Frequency:	136.5 MHz
IF Bandwidth:	30 KHz
Type of Reception:	FM or FSK
Metering:	Signal Strength

A candidate receiver for this system is the Vanguard Labs Model FMR-260-PLL, with modifications. This unit is particularly attractive because of its exceptionally low cost, but must have certain modifications incorporated before it may be used in the system. First, the receiver AGC line must be wired to an external meter for signal strength indication. This function is required in order to manually position the VHF antenna in order to maintain a maximum received signal level. Secondly, the receiver is designed to operate from a 12 VDC power source, so that a small power supply would be required to power the unit. Both modifications are simple and inexpensive to implement, so that the Vanguard unit may be considered a viable candidate for use.

4.3.2.10 <u>Subcarrier Demodulator</u>

The only configuration in which subcarrier modulation is recommended is configuration 1, in which the satellite acts as a frequency translator only. The incoming DCP signal is reduced in frequency from 401.55 MHz to 1.024 MHz, which is then used as a subcarrier on the S-Band downlink. Because the DCP message is not demodulated, the frequency uncertainty associated with the 1.024 MHz signal is the combined uncertainty of the DCP oscillator, spacecraft receiver oscillators, and uplink and downlink doppler shifts. These combined uncertainties require that the input bandwidth to the subcarrier demodulator be 100 KHz. However, the already small link margin requires that this large uncertainty be removed and that the noise bandwidth be reduced to no more than 20 KHz. Therefore the demodulator must incorporate a "comb filter", consisting of six overlapping 20 KHz filters which give a total coverage of 100 KHz. Upon detection of signal presence in one of the filter channels, the outputs of the other five are then inhibited, thus reducing the overall bandwidth from 100 KHz to 20 KHz.

An additional constraint must be placed on the demodulator. Because the subcarrier is present only during the 38 millisecond period that a DCP is actually transmitting data, the demodulator must be capable of very rapid acquisition and lock-up to the signal.

These and other pertinent requirements are listed below.

Modulation Type:	FSK
Center Frequency:	1.024 MHz
Overall Bandwidth:	100 KHz, consisting of six overlapping 20 KHz channels
Acquisition Time:	3 milliseconds maximum
Output bandwidth:	.5 - 20 KHz minimum
Output bit rate:	5 KBPS nominal, Manchester II coding
Message duration:	38 milliseconds
Deviation:	$\pm$ 5.5 KHz for 5 KBPS bit rate

No commercially available demodulators are known to meet these requirements. Radiation has built a device that performs these functions for the ERTS Regional Collection Centers and this is the only known requirement that exists for this unit. The device is suitable for use in this application, as the signal received by the configuration 1 option is identical to that received at the ERTS Regional Collection Center.

4.3.2.11 Bit Synchronizer

Either of two types of bit synchronizer may be required in the LUT, depending on whether or not the convolutional decoder is required. In order to achieve maximum processing gain from the decoder, it is necessary for each bit from the synchronizer be represented by a quantized 8-level representation consisting of three bits, 000 through 111. A high-confidence "zero" would be represented by "000" and a high-confidence "one" would be represented by "111". Lesser confidence levels would be represented by appropriate intermediate values. These value judgements would be used by the decoder to arrive at a maximum-likelihood bit decision, yielding a higher processing gain for the decoder. This and other basic requirements for the Bit Synchronizer are as given below:

Data Format:	Manchester II
Input Data:	Bilevel digital
Output Data:	Eight-level quantized (000 through 111) three bit representation, plus clock
Message Duration:	38 miliseconds
Data Rate:	5 KBPS
Acquisition Time:	400 microseconds maximum

For those configurations where the decoding process is performed on the spacecraft, the requirement for a three-bit representation of the data is no longer present, and the data rate is only 2.5 KBPS. Additionally, the rapid acquisition time may be relaxed if the spacecraft transmitter is designed to transmit all "0" data during the time between messages, allowing the bit synchronizer to maintain a locked condition. (The data display system would then ignore all data until the first bit, a "1", in the DCP identification code appeared.)

The more complicated bit synchronizer is of such a specialized nature that the only available unit to meet the requirements is a special design which, like the aforementioned subcarrier demodulator, was built especially for the ERTS Regional Collection Centers.

The second and simpler unit described is a much more standard device. One available unit which meets the requirements is the Data Control Systems Model 4703-101.

4.3.2.12 Convolutional Decoder

When used in the Local User Terminal, the convolutional decoder accepts the rate one-half, constraint-length-five convolutionally encoded DCP data from the bit synchronizer, derives the original DCP data using a maximum-likelihood algorithm, and presents this data to the display subsystem. In order to achieve the maximum amount of processing gain, it is necessary for the decoder to operate on "soft" bit decisions, or data bits which are represented by an eight-level quantization. Using this technique, those bits which are most likely known as "1" or "0" carry more weight in the decoding process than noisier bits whose value is known with lesser confidence. Using this "maximum likelihood" technique, a lower bit error rate can be achieved at a given level of signal-to-noise ratio than by other decoding algorithms. General requirements for the decoder are as follows:

Type:	Convolutional, Rate one-half, constraint length five
Processing Algorithm:	Maximum likelihood
Input Signal:	5000 symbols per second (5 KBPS)
Quantization:	Eight level, three-digit code
Output Signal:	2.5 KBPS hard decision
Processing Gain:	4.5 db minimum at 10^{-5} BER

Because of the specially designed nature of this decoder, it is not commercially available as a standard device. However, Radiation has designed a unit to meet these requirements for the ERTS Regional Collection Center. Because the requirements of the LUT device are identical with those of the Regional Collection Center, the same design may be used in this application.

4.3.2.13 Display Subsystem

While actually composed of several individual "modules", the display subsystem of the LUT is best described as a single entity. This subsystem accepts each DCP message from the bit synchronizer or convolutional decoder, performs desired reformatting or annotating, and presents this data in a useable form to the human operator. The display subsystem is critical to the utility of the local terminal. The best antenna, the most sophisticated receiver, the widest gain margins, are only as good as the usefulness of the data presented to the user. Therefore, it is recommended that the LUT data display subsystem utilize a general purpose minicomputer which can perform the required data manipulations necessary for each user. As a minimum, the display system should present to the operator (1) the identification code of the transmitting DCP, (2) the value of the data parameter in each of the eight DCP data slots, and (3) the time of day when the message was received. In addition, there may be a need for further processing prior to display. Perhaps it would be desireable to display only values above or below a threshold, or to compute mean values of several data samples, or any of a number of other processing operations requiring computational capabilities. For the minimum requirement, a dedicated, hard-wired circuit board display processor would suffice. But for the added flexibility, capacity, and computational ability, the programmable minicomputer is unsurpassed.

General requirements for the data display subsystem are as follows:

Input Data:	Serial bit stream, 76 bits per DCP message, 2.5 KBPS bit rate
Input Interrupt:	First bit of message is "1". All leading "O"s ignored.
Data Format:	12 identification bits, followed by eight words of 8 bits each.
Message Input Rate:	Random
Output Message:	Programmable, includes time-of-day, DCP identification, data values
Real-time Clock:	Each message annotated with time of reception. Clock initialization and reset via TTY keyboard
Output Media:	TTY printer, punched paper tape
Input Media:	TTY keyboard, punched paper tape
Output Data Rate:	Consistent with number of deployed DCP's. All possible DCP's reporting must be processed within a 3-minute period.

Obviously, particular user requirements may add to, alter, or otherwise tailor the above requirements to suit the needs of each LUT. This "requirements flexibility" is the major advantage of a programmable minicomputer.

A system which fulfills the above requirements is the Texas Instruments Model 980A Processor, with various options, and the ASR 33 Teletype unit. Required options are (1) Interval Timer module to maintain time-of-day, (2) Data Module to provide the serial data input interface, and (3) TTY Interface kit. Other options, such as high-speed printer, tape recorder, disc or drum storage, etc., are available if particular user needs require them.

4.3.3 Software Requirements

Because a programmable computer has been recommended for use as a data display device, some description of the software program is in order. Because each user's requirements are not specifically defined, or may change from time to time, the flexibility of the program approach is of major importance. But as a minimum, the following software program would present a good, usable display of hard-copy data to the user. The program would accept, asynchronously, data words from the station bit demodulator or decoder. Each data message consists of 76 bits: 12 ID bits plus 8 words of 8 bits each containing data.

The 12 ID bits are to be compared against a table of possible values. Those messages containing ID codes not included in the table of possible values are to be discarded. These values are the ID codes for all DCP's of interest to the user. Those messages correlating to values included in the table are to be further processed. Provision shall be included in the program to alter the list of possible ID codes in the table via a TTY keyboard.

The eight words of 8 bits each will then be presented for output to a TTY printer. The format of the output data must clearly and unambiguously present each channel for separate evaluation.

As an option, one, two, or more (up to a total of eight) channels could be combined for a single output. These combinations will be adjacent channels, and shall be optional to the user via keyboard identification.

The selection from the keyboard could be as follows:

$AAAAB_1B_2B_3B_4B_5B_6B_7B_8$

where AAAA is the octal representation of the data platform ID code and B_1 through B_8 are channel selectors. A "0" indicates a separate channel, and a "1" indicates a combined channel. For example, the code

351701100111

would specify 5 data channels from platform 3517. The five channels would be one 8-bit channel, one 16-bit channel, two 8-bit channels, and one 24-bit channel.

The format of the output data should be fixed point decimal. The range of values for an 8-bit word would be unscaled, 0 to 255. The order of output channels shall be the same as the order from the bit demodulator (computer input). The presentation would be

TIME	ID	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8
xx:xx:xx	xxxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx

The first bit received in an 8-bit word shall be the least significant bit. Provision must be made within the program to store at least 10 lines of output data to reduce the possibility of data loss due to the delay of the TTY printer.

The current real time shall be obtained via a real time clock, with hours-minute-second data available through the I/O interface. The current time shall be included with each output, as shown in the format above.

4.3.4 LUT Cost Estimates

Cost estimates for the various LUT configurations are shown in Table 4.3.4-1 and -2. These estimates were prepared according to the cost estimate guidelines given in Section 2.1 which should be carefully reviewed prior to comparing the relative costs.

For these estimates, equipment prices for currently available off-the-shelf or pre-designed items which most nearly fulfill the requirements of the LUT have been gathered. In many cases the equipment available adequately meets the requirements. In some cases, such as the VHF receiver, the device currently available must be slightly modified to be suitable for use (signal strength output, mounting facilities, etc.). In these cases, reasonable cost estimates for the modifications have been included in the cost estimates given.

TABLE 4.3.4-1

SUMMARY OF LUT RECURRING COSTS

MEDIUM ORBITING SATELLITE
S-BAND OPTIONS

EQUIPMENT REQUIRED	CONF. I-S-BAND RELAY		CONF 2	CONF-3-LUT DECODES	
	HARDWARE DECODER	COMPUTER DECODER	S/C DECODES	HARDWARE DECODER	COMPUTER DECODER
Antenna (Andrews 60006-21)	$1,200	$1,200			
(Andrews 60004-21)			$1,000	$1,000	$1,000
Pedestal & Control (Scientific Atlanta)	7,000	7,000	7,000	7,000	7,000
Preamplifier (IMC 510-1700-30-CA)	1,600	1,600	1,600	1,600	1,600
Receiver (Microdyne 1100AR)	6,700	6,700	6,200	6,200	6,200
*FM Subcarrier Demod (RAD Special)	5,900	5,900	-	-	-
*Bit Sync (RAD or DCS 4703)	5,000 RAD	5,000 RAD	1,200 DCS	5,000 RAD	5,000 RAD
*Decoder (RAD Special)	6,500	-	-	6,500	-
Minicomputer with TTY (TI 960A)	5,400	5,400	5,400	5,400	5,400
Disc Drive (Potter DD480)		1,000			1,000
Rack	1,000	1,000	1,000	1,000	1,000
Miscellaneous	1,000	1,000	1,000	1,000	1,000
*Integration and Test	2,000	2,000	2,000	2,000	2,000
TOTAL	$43,300	$37,800	$26,400	$36,700	$31,200

*Cost assumes quantity of 100 would be built.

TABLE 4.3.4-2

SUMMARY OF LUT RECURRING COSTS

MEDIUM ORBITING SATELLITE
VHF & UHF DOWNLINK OPTIONS

EQUIPMENT REQUIRED	CONFIGURATION 4, VHF DOWNLINK			
	TRACKING ANTENNA		OMNI ANTENNA	UHF
	APT MODIFIED	NEW STATION	NEW STATION	DOWNLINK
Antenna (EMR 100D)	$ -	$ 2,900	$ -	
Antenna (EMR 100D with UHF Helix)				$ 3,000
Antenna (RAD Special)	-	-	300	
Preamplifier (Vanguard 102)	-	-	50	
Preamplifier (Vanguard 202 Modified)				50
Receiver (Vanguard FMR 260-PLL)	-	200	200	
Receiver (ACL SR-209)				2,700
Bit Sync (DCS 4703-101)	1,200	1,200	1,200	1,200
Minicomputer with TTY (TI 980A)	5,400	5,400	5,400	5,400
Rack	50	400	400	400
Miscellaneous	50	1,000	1,000	1,000
*Integration and Test	1,500	2,000	2,000	2,000
TOTAL	$7,750	$13,100	$10,550	$15,750

* Cost assumes quantity of 100 would be built.

The Radiation manufactured items, such as the FM subcarrier demodulator bit sync and maximum likelihood convolutional decoder, which are shown in Table 4.3.4-1, were selected because these designs have been successfully proven in the hardware currently in use for DCS data in the ERTS Regional Collection Centers. No other equipment meeting the requirements is available off-the-shelf. The cost estimates shown assume that the proven designs would be "streamlined" to use printed circuit and other labor and cost savings manufacturing techniques. The non-recurring cost of optimizing the designs would be reasonable in view of the anticipated quantity of ≥ 100 which would be built. The present units were handwired and ROM cost estimates to duplicate the units, using the original manufacturing techniques are prohibitive, as shown by the following costs:

Item	QTY of 1	1 Additional
FM Subcarrier Demod	\$28,200	\$16,700
Convolution Decoder	\$29,000	\$14,700
Bit Sync	\$17,700	\$ 9,400

Probable recurring costs of LUT test and integration (assuming a manufacturing program of ≥ 100 LUT's) have been included; but no G&A overhead fees on vendor purchased items or profit on the finished LUT have been included. The cost estimates are FOB at the manufacturer and, the user would have additional expenses for facility preparation and shipping.

4.3.5 Summary of LUT Configurations

The Local User Terminals described provide a series of optional configurations from the very simple to the very complex. As would be expected, the simpler the LUT, the more complex must be the satellite configuration. These choices then provide a wide range of configurations from which to select the degrees of relative complexity which is best suited to the projected usage. As the quantity of expected terminals is increased, the trade-off on relative complexity in the spacecraft and in the LUT would justify a simpler terminal cost, allowing more users to own their own stations.

Along with various degrees of complexity in the functions performed (decoding, resolution of frequency error, etc.), a variation in frequency band was considered to provide a trade-off of terminal cost equipment with the carrier frequency selected. In general, the lower the carrier frequency, the less the cost of the receiving equipment, but the greater the susceptibility to such undesireable effects as RFI and atmospheric noise effects.

Of the five configurations compared, the least expensive system consisted of a VHF receiver terminal, with the signal processing (convolutional decoding) performed in the spacecraft. The most complex ground station, but the one requiring the least expensive satellite equipment, consisted of a system similar to that required for ERTS 1 systems, with all the processing being performed at the local terminal and the satellite providing only a frequency translation system.

A typical LUT station configuration excluding the antenna system is shown in Figure 4.3.5-1.

4.4 Conclusions

The recurring costs for a "piggyback" medium orbiting satellite DCS system with one back-up hardware system and assuming 100 local user terminals is shown in Table 4.4-1 for the five configurations and options that were studied. Note that the VHF configurations give the lowest system hardware recurring cost.

A summary of the various trade items is shown in Table 4.4-2 and make the VHF configurations appear even more attractive. However, if the VHF system satellite penalties for the additional size and weight required are taken into account the weighted overall system costs will be closer together. This would permit the final choice to rest on a variety of factors such as frequency availability, RF interference and non-recurring costs.

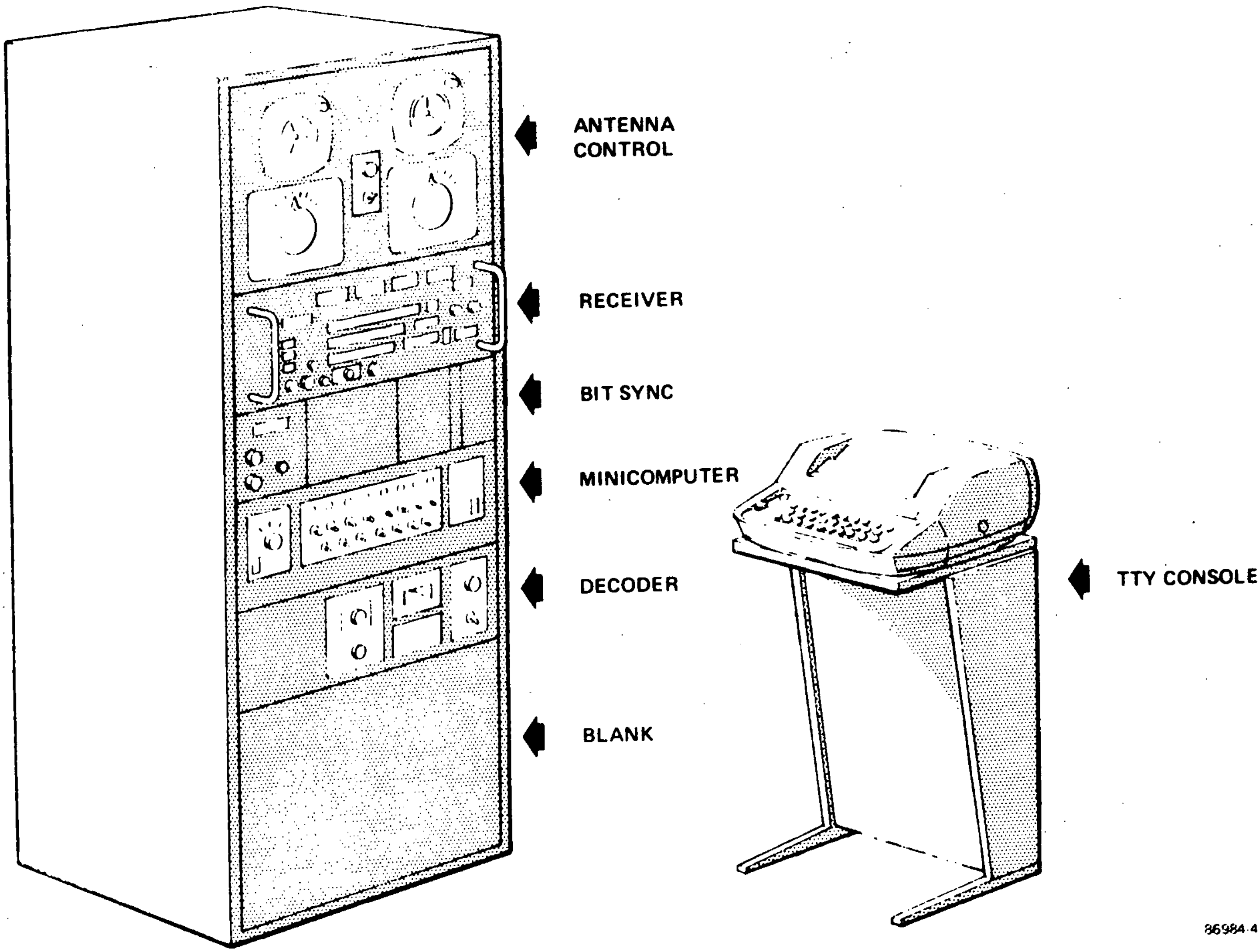


Figure 4.3.5-1. Typical LUT Station Configuration Medium Orbiting Satellite DCS Configurations

TABLE 4.4-1

MEDIUM ORBITING SATELLITE DCS CONFIGURATIONS SUMMARY
RECURRING COSTS ONLY

	1 BENT PIPE RELAY, S-BAND		2 ON-BRD PROCESSING	3 LUT DECODES S-BAND DOWNLINK		4 ON-BRD PROC., VHF			5 ON-BRD PROC.
						TRACKING ANT.		OMNI	
	HDWARE DECODER	COMP. DECODER	S-BAND DOWNLINK	HDWARE DECODER	COMP. DECODER	APT MOD	NEW LUT	NEW LUT	UHF DOWNLIN:
SATELLITE HARDWARE									
1 Flight System	$ 162K	$ 162K	$ 492K	$ 372K	$ 372K	$ 476K	$ 476K	$ 476K	$ 487K
1 Backup System	162K	162K	492K	372K	372K	476K	476K	476K	487K
LOCAL USER TERMINAL									
Assume 100 LUT's	4,330K	3,780K	2,640K	3,670K	3,120K	775K	1,310K	1,055K	1,575K
TOTAL	$4,654K	$4,104K	$3,624K	$4,214K	$3,764K	$1,723K	$2,262K	$2,007K	$2,349K

TABLE 4.4-2

TRADE SUMMARY - MEDIUM ORBITING SATELLITE DCS CONFIGURATIONS

ITEMS	CONFIGURATIONS
• Satellite Components	
Least Recurring Cost	Configuration 1, S-Band Relay
Least Size & Weight	Configuration 1, S-Band Relay
Least Power	Configuration 4, VHF
• LUT Hardware	
Least Recurring Cost	Configuration 4, VHF Downlink with Modified Apt Station
• Lowest System Hardware Recurring Cost	Configuration 4, VHF Downlink with Modified Apt Station
1 Sat (+ Backup) & 100 LUT's	
• Best Downlink Gain Margin	Configuration 4, VHF
• Least RF Interference	S-Band

5.0 GEO-SYNCHRONOUS SATELLITE DCS CONFIGURATIONS

This section presents the results of the trade study of six geo-synchronous satellite data collection system configurations for future SMS or SEOS type satellites. The study was performed per the ground rules of Section 2.0 and thus assumes the use of the ERTS DCP in all configurations.

The six geo-synchronous satellite and local user terminal configurations which were studied included three S-Band downlink configurations, a UHF downlink configuration, and two VHF downlink configurations. The system block diagrams are shown in Figures 5.0-1 through 5.0-5 for configurations 6 through 11 respectively (7 and 8 are both on Figure 5.0-2).

Configuration 6 with the high-capacity ground relay and double bent-pipe approach in the satellite is similar to the planned SMS system. Configuration 10 is just a VHF downlink version of configuration 6. Configurations 7 and 8 are on-board processing configurations with S-Band downlinks with configuration 8 having an S-Band to VHF conversion in the LUT. Configurations 9 and 11 are on-board processing configurations with UHF and VHF downlinks respectively.

5.1 System Analysis

The geo-synchronous satellite data collection systems are very attractive because of the fixed position of the satellite relative to the earth. This permits continuous data collection, removes the doppler frequency shifts, and permits the use of a fixed ground antenna. The prime disadvantage is the considerable additional path loss in the uplink and downlink resulting from the 22,000 N. mile range.

The uplink antenna gains can be reduced at the expense of increased DCP transmitter power or reduced data rate. A reduced data rate looks very attractive since the satellite is continuously visible. Reducing the data rate and increasing the transmission time results in co-channel interference problems depending on the number of visible DCP's. These considerations were outside the scope of this study as per the ground rules; however, in addition to the preceding power and rate changes, the following Table 5.1-1 of possible changes to the ERTS DCP message structure were briefly considered and are recommended for more detailed consideration.

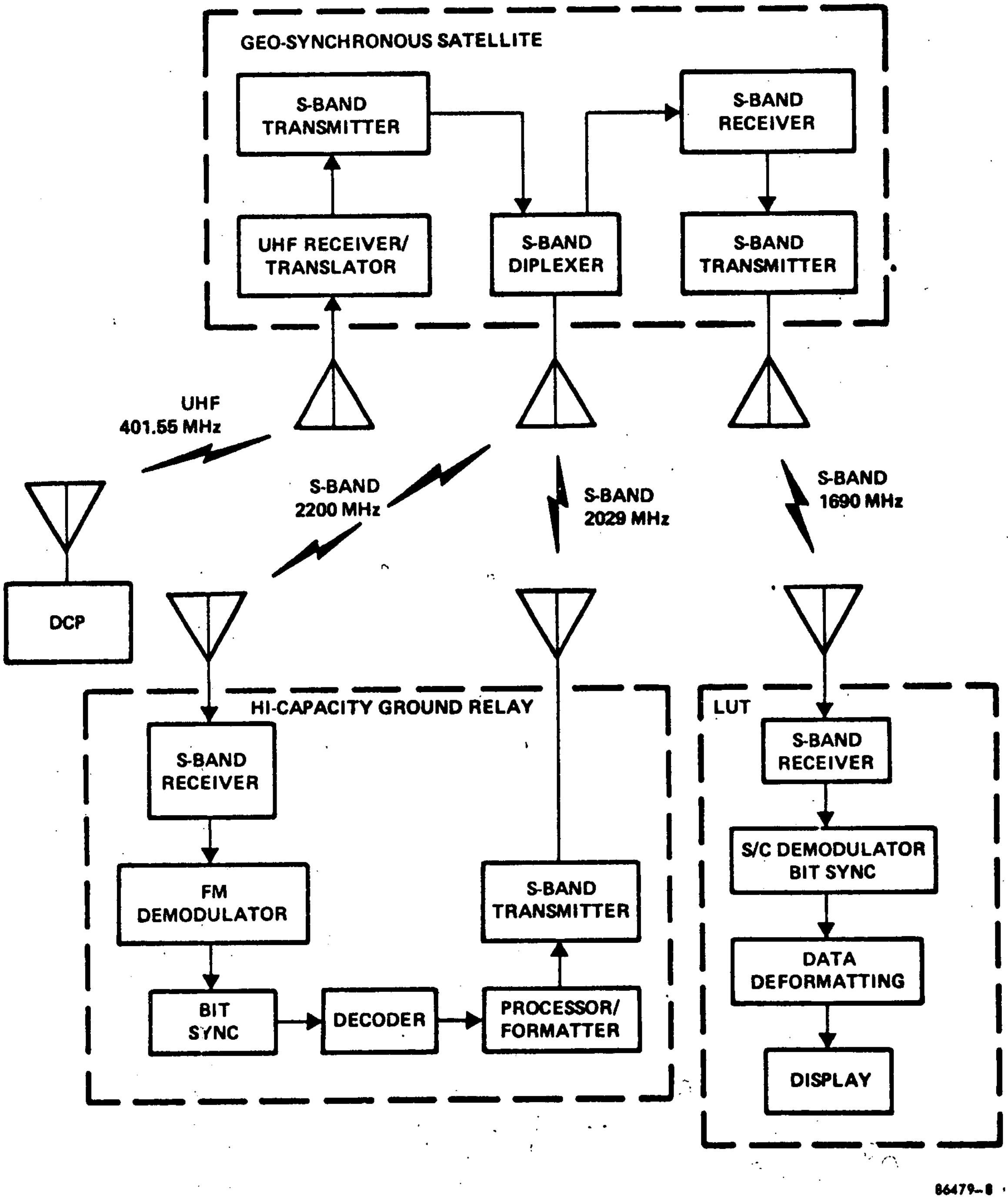


Figure 5.0-1. Geo-Synchronous Satellite Configuration 6, Hi-Cap Relay, S-Band Downlink

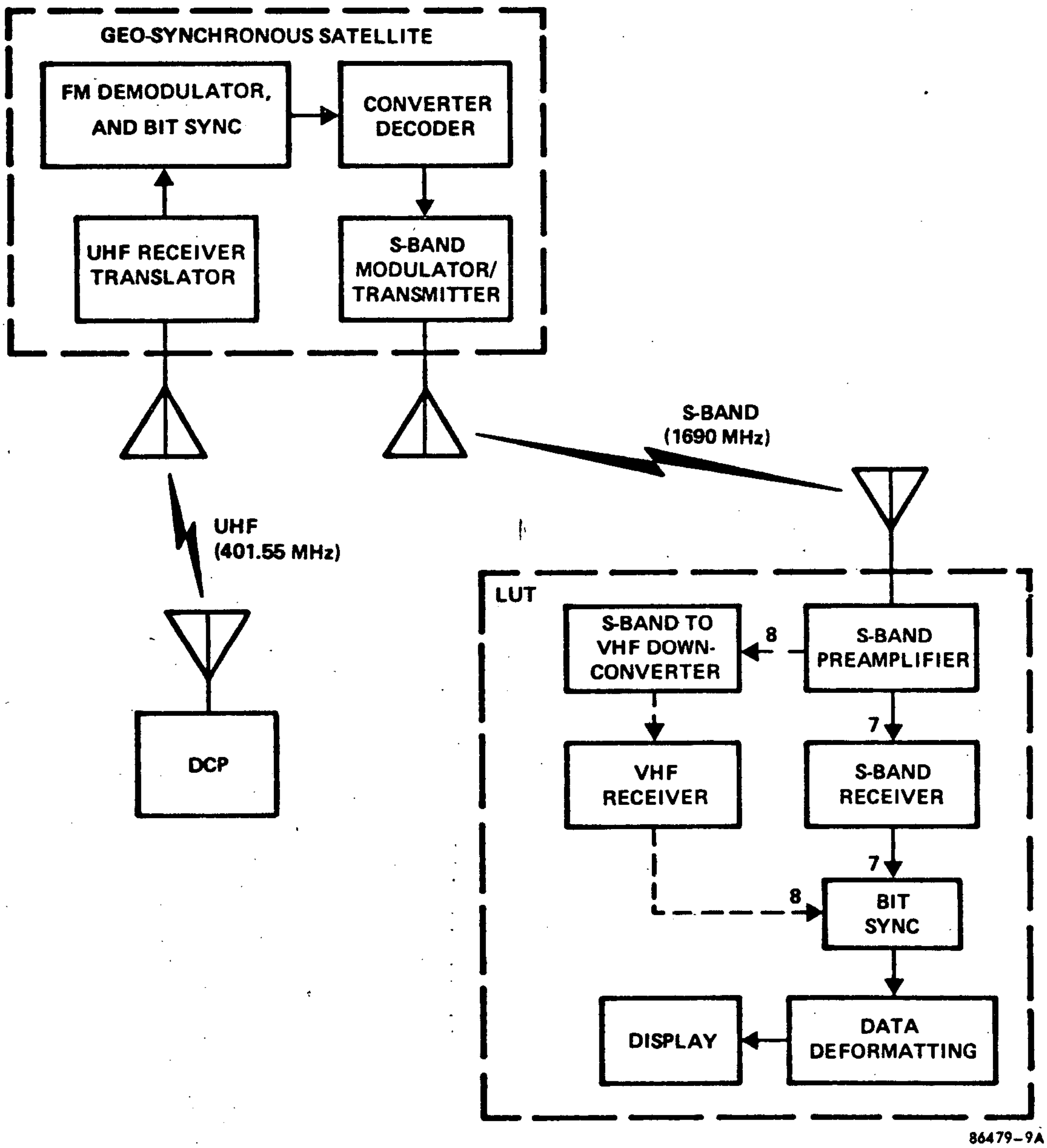


Figure 5.0-2. Geo-Synchronous Satellite Configurations 7 and 8, On-Board Processing, S-Band Downlink and S-Band to VHF Conversion in LUT

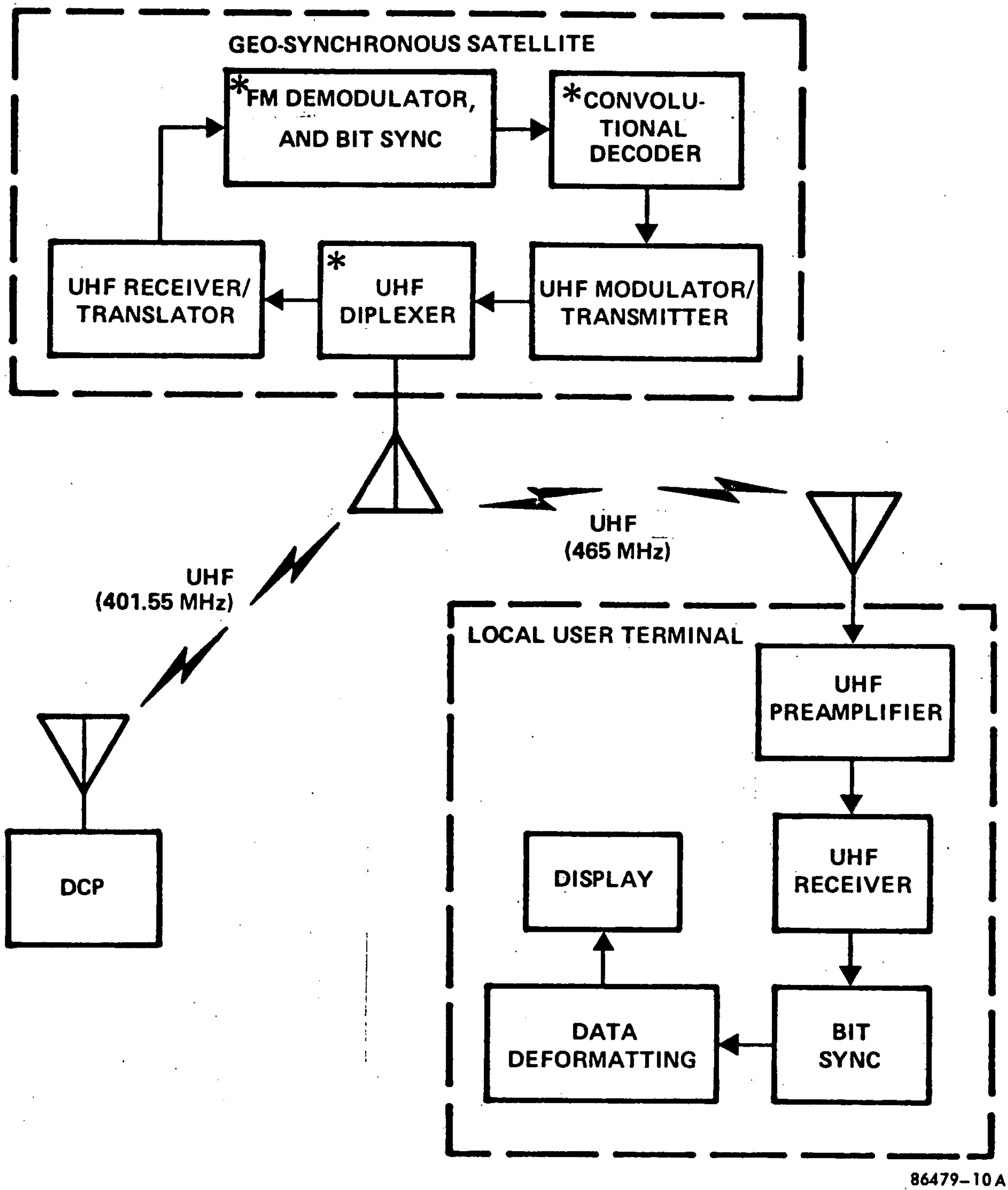


Figure 5.0-3. Geo-Synchronous Satellite Configuration 9, On-Board Processing, UHF Downlink

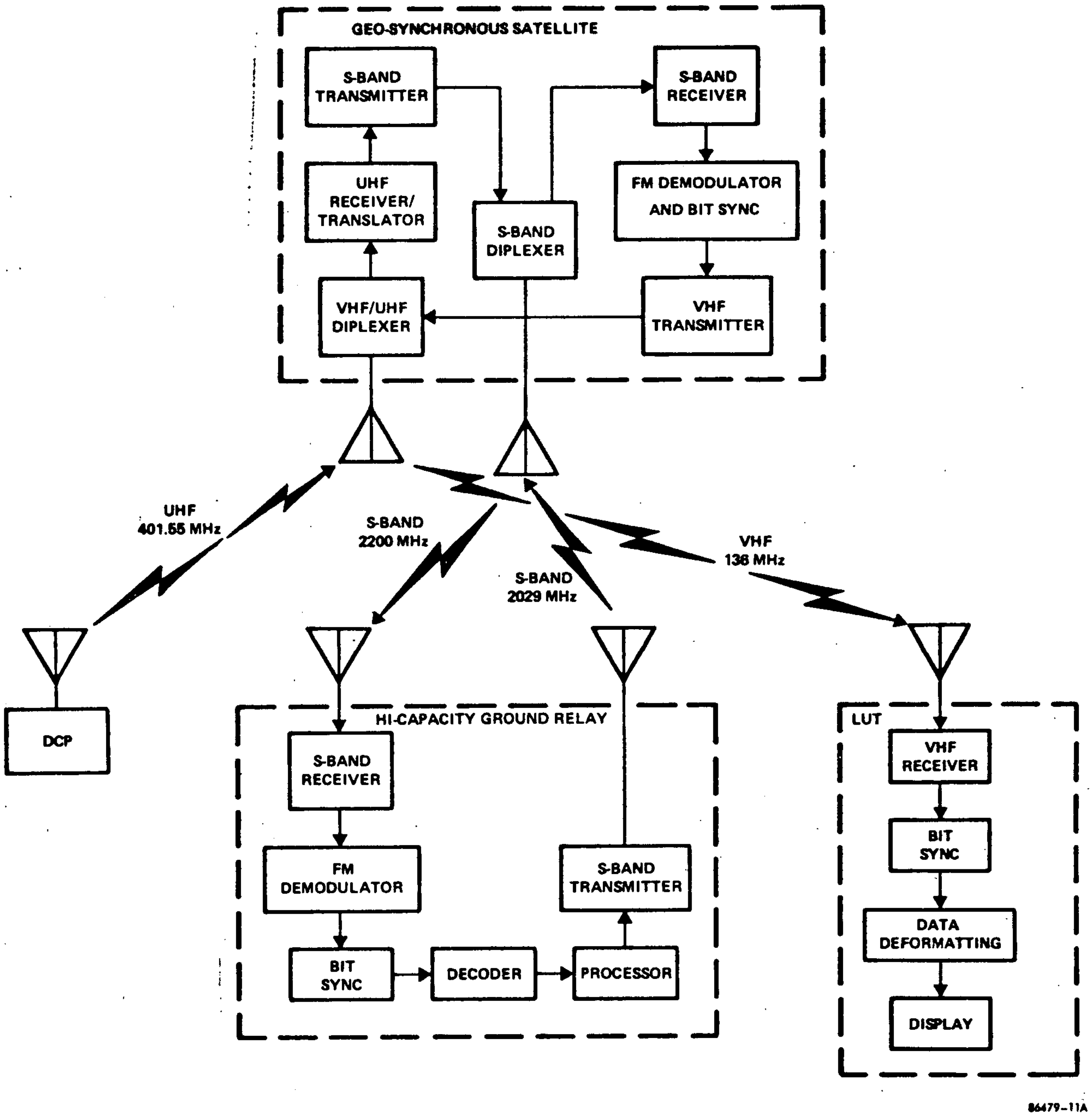


Figure 5.0-4. Geo-Synchronous Satellite Configuration 10, Hi-Cap Relay, VHF Downlink

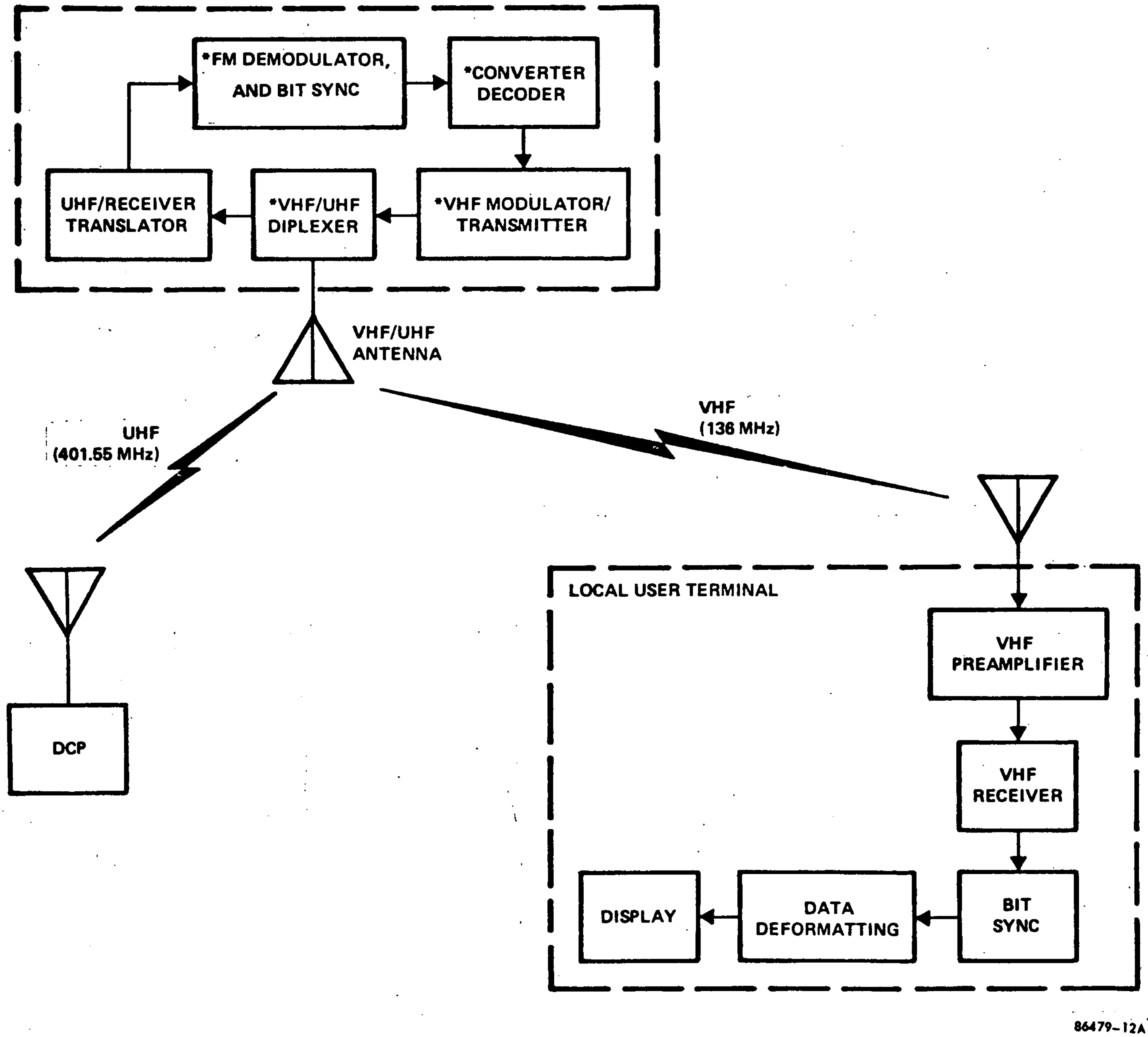


Figure 5.0-5. Geo-Synchronous Satellite Configuration 11, On-Board Processing, VHF Downlink

TABLE 5.1-1

* POSSIBLE CHANGES TO ERTS DCP MESSAGE STRUCTURE

FOR GEO-SYNCHRONOUS SATELLITE DCS CONFIGURATION

1. LONGER PREAMBLE

   - Allows more acquisition time for PSK instead of FSK

2. ADD SECOND IDENTIFICATION FIELD

   - Because over 1/3 of earth's surface is in view of the spacecraft, user identification code as well as DCP identification code may be desirable.

3. LOWER MESSAGE REPETITION RATE

   - Requirement for one valid message in 12 hours does not require transmission every 180 seconds with geo-synchronous satellite.

4. USE MULTIPLE CHANNEL FREQUENCIES

   - Avoid traffic congestions.

* NOTE: Present study assumes ERTS DCP's with only the antenna modification

5.1.1 Discussion of Candidate System Alternatives

The use of a high capacity ground relay with two receiver/translator and retransmit systems on the satellite is a cost effective system approach since it reduces both satellite and local user terminal complexity. The system as shown in configuration 6 with an S-Band downlink and configuration 10 with a VHF downlink makes this possible at the expense of requiring the ground relay stations. Note that configuration 10 also requires an FM demodulator and Bit Synchronizer unit in the satellite to remove a portion of the frequency uncertainty and permit the use of a narrow 30 KHz VHF downlink.

The on-board processing configurations (7, 8, 9, and 11) are similar to the medium orbiting satellite on-board processing configurations with the exception of the much higher gain antennas required to close the up and down links. Obviously the size, weight, non-recurring, and recurring cost of these antennas, particularly at VHF and UHF, is a significant problem.

A five watt downlink satellite transmitter was used in all the configurations for this trade study. System tradeoffs of satellite cost versus antenna size and transmitter power particularly at VHF and UHF are definitely required to minimize satellite cost for a given approach.

5.1.2 DCP Antenna Modification

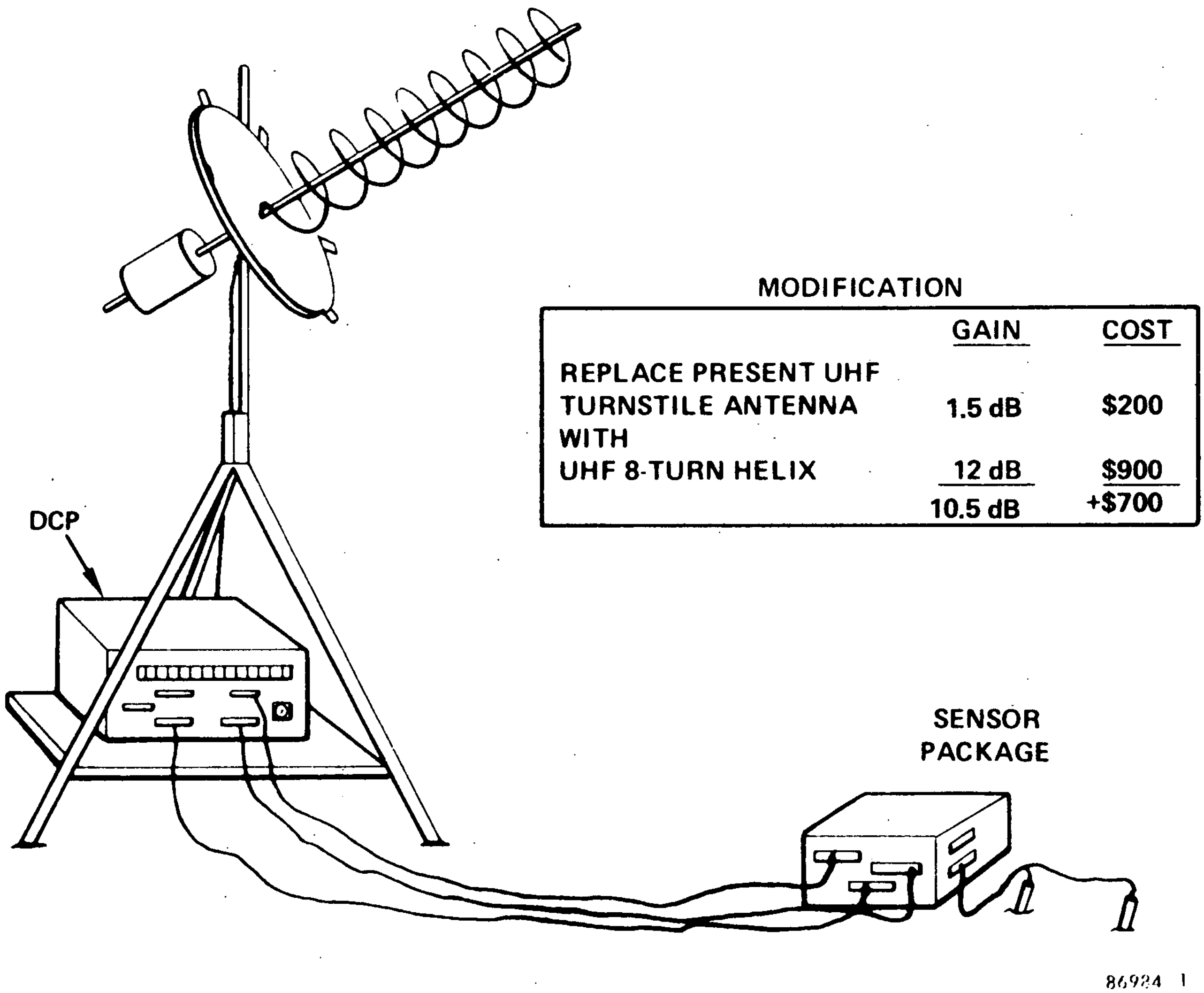
The ERTS DCP antenna gain is presently only 1.5 db and is inadequate for use with a reasonable geo-synchronous satellite configuration. The DCP antenna modification used for the purposes of this study is shown in Figure 5.1-1. The modification would replace the present antenna with an 8 turn helix to increase the gain to 12 db at an additional cost of about $700.00.

5.1.3 Modulation Choices

The basic modulation trades were discussed in Section 4.1.3. The downlink modulation trades and choices for the geo-synchronous satellite configurations are shown in Table 5.1.3-1 for the 2.5 KBPS uncoded data case. If confidence bits are desired the trade is as shown in Table 5.1.3-2.

5.1.4 Link Analyses

For the geo-synchronous satellite configurations the UHF DCP uplink analysis is shown in Table 5.1.4-1. The satellite to LUT downlink analyses are shown in Tables 5.1.4-2, -3, and -4 for the S-Band, UHF and VHF cases respectively.



MODIFICATION

	GAIN	COST
REPLACE PRESENT UHF TURNSTILE ANTENNA	1.5 dB	$200
WITH UHF 8-TURN HELIX	12 dB	$900
	10.5 dB	+$700

Figure 5.1-1. DCP Antenna Modification for Geo-Synchronous Satellite

TABLE 5.1.3-1

GEO-SYNCHRONOUS SATELLITE

DCS DOWNLINK MODULATION CHOICES
FOR 2.5 Kbps UNCODED DATA

	S-BAND DOWN LINK	VHF DOWN LINK	UHF DOWN LINK
FIRST CHOICE	DIRECT FSK	DIRECT PSK	DIRECT FSK
C/KT REQ.	51.5 db/Hz	46.0 db/Hz	50.8 db/Hz
GM	8.9 db	13.8 db	6.2 db
PRICE	$6200 MICRODYNE	$200 VANGUARD	$2700 ACL
SECOND CHOICE	DIRECT PSK	DIRECT FSK	DIRECT PSK
C/KT	46.0 db/Hz	52.6 db/Hz	46.0 db/Hz
GM	14.0 db	7.2 db	11.0 db
PRICE	$6700 MICRODYNE	$200 VANGUARD	$7825 S/A
PRICE DIFF.	$500	0	$5125
DECISION	ADEQUATE GM SO CHOOSE FSK	ADEQUATE GM SO CHOOSE PSK BECAUSE NO PRICE DIFF.	ADEQUATE GM CHOOSE FSK BECAUSE OF PRICE DIFF.

TABLE 5.1.3-2

GEO-SYNCHRONOUS SATELLITE

DCS DOWN LINK MODULATION CHOICES
FOR 5 K bps UNCODED DATA WITH CONFIDENCE BITS

	S-BAND DOWN LINK	VHF DOWN LINK	UHF DOWN LINK
FIRST CHOICE	DIRECT FSK	DIRECT PSK	DIRECT FSK
C/KT REQ.	53.3 db/Hz	49.0 db/Hz	52.8 db/Hz
GM	9.5 db	10.2 db	4.2 db
RECVR PRICE	$6200 MICRODYNE 1100 AR	$200 VANGUARD	$2700 ACL SR 209
SECOND CHOICE	DIRECT PSK	DIRECT FSK	DIRECT PSK
C/KT REQ.	49.0 db/Hz	55.3 db/Hz	49.0 db/Hz
GM	14.0 db	3.9 db	8 db
RECVR PRICE	$6700 MICRODYNE 1100 AR	$200 VANGUARD	$7825 S/A
PRICE DIFF.	-$500	0	-$5125
DECISION	ADEQUATE GM SO CHOOSE FSK	INADEQUATE GM SO CHOOSE PSK	LOW GM BUT CHOOSE FSK

TABLE 5.1.4-1

LINK BUDGET

GEO-SYNCHRONOUS SATELLITE

UHF DCP UPLINK (401 MHz)

XMTR Power	+ 37 dbm
Losses	- 1 db
Gain (helical antenna)	+ 12 db
ERP	+ 48 dbm
Free-Space Loss	- 176.6 db
Incident rf Power	- 128.6 dbm
Misc. Losses	- 1 db
Antenna Gain	+ 18 db
Rec'd Signal Level	- 111.6 dbm
System Noise Figure	3 db
Noise Temp (600°K)	27.8 db/°K
KT	- 170.8 dbm/Hz
C/KT	+ 59.2 db/Hz
S/N (60 KHz IF)	11.4 db
S/N Req'd (10^{-5} BER with Coding)	7.8 db
Margin	3.6 db

Table 5.1.4-2

LINK BUDGET
FOR
GEOSYNCHRONOUS SATELLITE
S-BAND (1690 MHZ) Downlink to LUT

Transmitter Power	+ 37 dBm
Losses (cable, etc.)	- 1 dB
Antenna Gain (27" dish)	+ 19 dB
Off-Beam-Center Loss	- 3 dB
ERP (at 9° Look Angle)	+ 52 dBm
Free-Space Loss	-189.5 dB
Polarization Losses	- .5 dB
Pointing Error	- .5 dB
Antenna Gain (6' dish)	+ 27.6 dB
Received Signal Level	110.9 dBm
Noise Temperature (513°K)	27.1 dB-°K
Boltzmann's Constant	-198.6 dBm/Hz-°K
Noise Density	-171.5 dBm/Hz
C/KT	60.6 dB-Hz

Table 5.1.4-3

LINK BUDGET

FOR

GEO-SYNCHRONOUS SATELLITE

UHF (465 MHz)

XMTR Power	+ 37 dBm
Losses	- 1 dB
Antenna Gain	18
Off-Beam-Center Loss	- 3
ERP	+ 51 dB
Free Space Loss (21,800 n.m.)	-178 dB
Polarization Loss	- .5 dB
Pointing Error	- .5 dB
Antenna Gain	+ 15 dB
Received Signal Level	-113 dBm
Noise Temperature (733°K)	28.6 dB-°K
Boltzmann's Constant	-198.6 dBm/Hz-°K
KT	-170 dBm-Hz
C/KT	+57 dB-Hz

Table 5.1.4-4

LINK BUDGET
FOR
GEOSYNCHRONOUS SATELLITE
VHF (136 MHZ) Downlink to LUT

Transmitter Power	+ 37 dBm
Losses (cable, etc.)	- 1 dB
Antenna Gain	+ 13 dB
Off-Beam-Center Loss	- 1 dB
ERP	+ 48 dBm
Free-Space Loss	-167.2 dB
Polarization Loss	- .5 dB
Pointing Error	- .5 dB
Antenna Gain	+ 12 dB
Received Signal Level	-108.2 dBm
Noise Temperature (1150°K)	30.6 dB-°K
Boltzmann's Constant	-198.6 dBm/Hz-°K
Noise Density	-168 dBm/Hz
C/KT	59.8 dB

5.1.5 Link Summary

A summary of the required C/KT and downlink gain margins for the six configurations is shown in Table 5.1.5-1.

5.1.6 High Capacity Relay Requirements

In configurations 6 and 10, a system is proposed to remove complexity from both the local user terminals and from the satellite. Because size, weight, power drain, and reliability are of such vital concern in a satellite system, the cost of a satellite-borne system is many times greater than that of a groundbased system performing the same functions. On the other hand, the large quantity of local terminals could more than offset the lower cost of an individual terminal. Additionally, as the cost of a terminal is decreased, more and more potential users are able to own and operate their own terminals.

The use of ground relay system affords a technique to allow both a simple satellite and a simple local terminal. The satellite receives the DCP transmission at UHF, translates this signal to an S-Band carrier, and relays the message to a High-Capacity Relay Station. The relay station as shown in Figure 5.1.6-1 receives the translated signal, detects the message, and decodes the convolutionally encoded DCP message. The decoded message is the reconstructed and transmitted back to the satellite on a separate carrier frequency. The satellite receives this signal, and performs a second translation to an S-Band (configuration 6) or VHF (configuration 10) downlink channel for reception by the LUT.

The requirement for the relay station is then merely to provide the decoding process introduced by the DCP. The station is very similar to that already incorporated as a part of the Synchronous Meteorological Satellite (SMS) System, and could in fact utilize the same station equipment. If this were done, all that would be required as additional equipment would be the subcarrier demodulator, bit synchronizer, convolutional decoder, and a simple reformatter and subcarrier modulator. If it is assumed that the same satellite is used as a carrier for SMS and the system considered here, then the antennas, receiver, and transmitters used for SMS could be utilized for the Environmental Data Collection System as well, thus further reducing the cost of new equipment. The approximate recurring cost for the additional equipment is shown in Table 5.1.6-1.

In this manner, the cost of a few terminals greatly reduces the required complexity of a satellite system while at the same time requiring only a simple local user terminal.

TABLE 5.1.5-1

SUMMARY OF REQUIRED C/KT AND DOWNLINK GAIN MARGINS

FOR GEO-SYNCHRONOUS SATELLITE CONFIGURATIONS

GEO-SYNCHRONOUS SATELLITE	C/KT REQUIRED FOR BER 10^{-5}	GAIN MARGIN
CONF. 6: Hi-Cap Relay, S-Band	51.5 db/Hz	8.9 db
CONF. 7: On-Board Proc., S-Band	51.5 db/Hz	9.5 db
CONF. 8: On-Board Proc., S-Band to VHF Conversion at LUT	51.5 db/Hz	9.5 db
CONF. 9: On-Board Proc. UHF Downlink	50.8 db/Hz	6.2 db
CONF. 10: Hi-Cap Ground Relay, VHF Downlink	46.0 db/Hz	13.8 db
CONF. 11: On-Board Proc., VHF Downlink	46.0 db/Hz	13.8 db

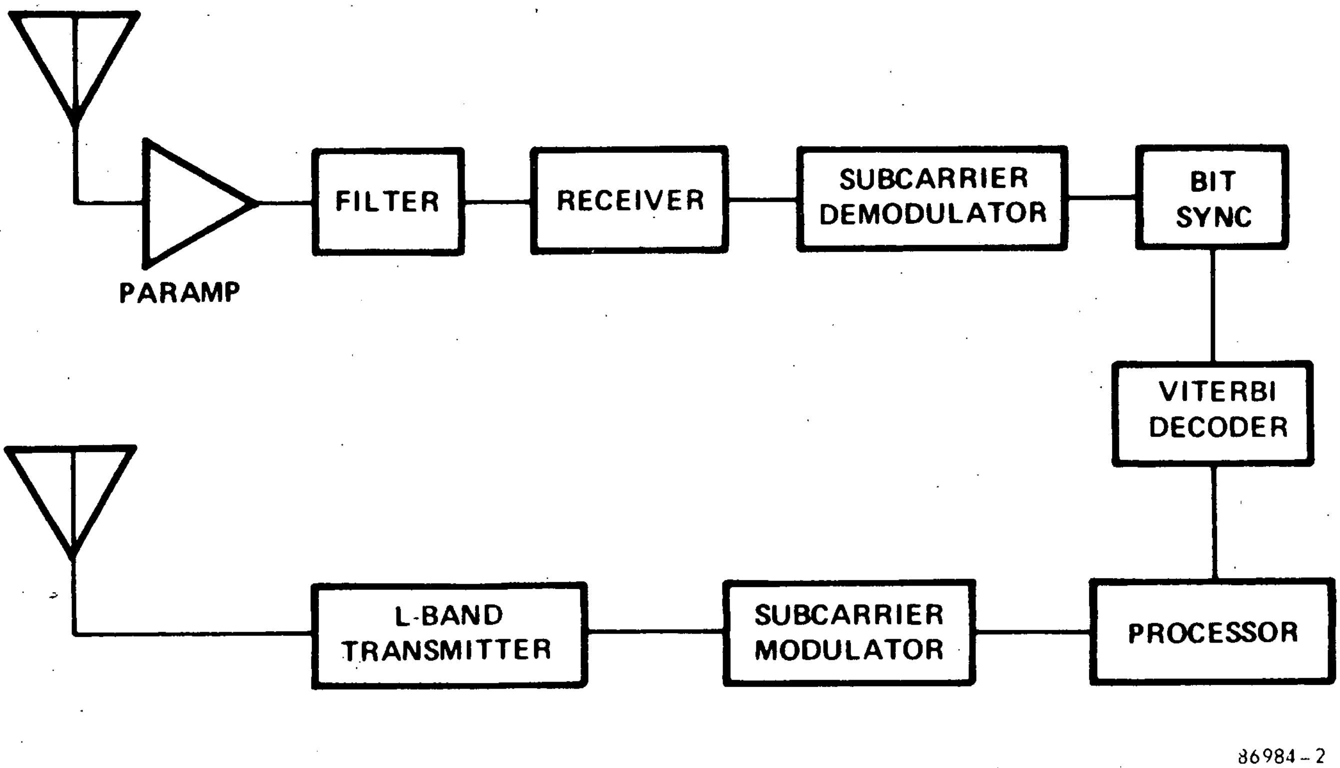


Figure 5.1.6-1. Possible Relay Configuration

Table 5.1.6.1

Geo-Synchronous Satellite Hi-Cap

Relay Terminal Recurring Costs

Equipment Required	Cost
Subcarrier Demod	$ 12,000
Bit Sync	2,400
Decoder	8,000
Minicomputer with TTY	5,400
Subcarrier Modulator	1,200
Rack	400
Misc (wire, cable, etc.)	1,600
Integration and Test	14,000
Total -5W Transmitter	$ 45,000

5.1.7 Use of Minicomputer for Decoding Convolutional Encoded Data

The geo-synchronous satellite configurations severely restrict the practicality of using a minicomputer to decode convolutional encoded data. As discussed in Section 4.1.7.1 the minicomputer could be used for the medium orbiting configurations because of the 90 minutes or so available for off-line processing between passes. With the present ERTS DCP system and the fact that a geo-synchronous satellite is continuously in view of the LUT, a 1 micro-second cycle time computer requiring 3 seconds to decode each DCP message could handle at most the data from only one DCP. Since a portion of the data from all DCP's must be decoded to determine which data is from a particular user's DCPs, present minicomputers could not be practically used with an ERTS DCP geo-synchronous satellite configuration. With appropriate changes to the ERTS DCP, this situation could change; however, the use of a hard-wired maximum likelihood decoder is assumed for the various LUT configurations in this section.

5.2 Spacecraft Configuration

5.2.1 General Description

The spacecraft hardware selections for the six geo-synchronous satellite DCS configurations are shown in the combined block diagram of Figure 5.2.1-1. Recurring costs, plus size, weight, and power requirements, if any, are shown. This discussion deals only with the "piggy back" DCS system; thus, the other essential satellite components such as power supply, thermal control, etc., are not shown.

5.2.2 Detailed Component Discussion

Since many of the required spacecraft components are common to all or part of the five configurations, the components will be discussed individually rather than by configuration.

5.2.2.1 UHF Satellite Antenna - 9' Diameter Dish

The UHF Antenna selected for the purposes of this trade study is a currently designed deployable 9' diameter dish. The ROM cost estimate for the antenna is approximately $150K with the non-recurring initial costs to manufacture the first item being approximately $300K. The antenna would have the following specifications:

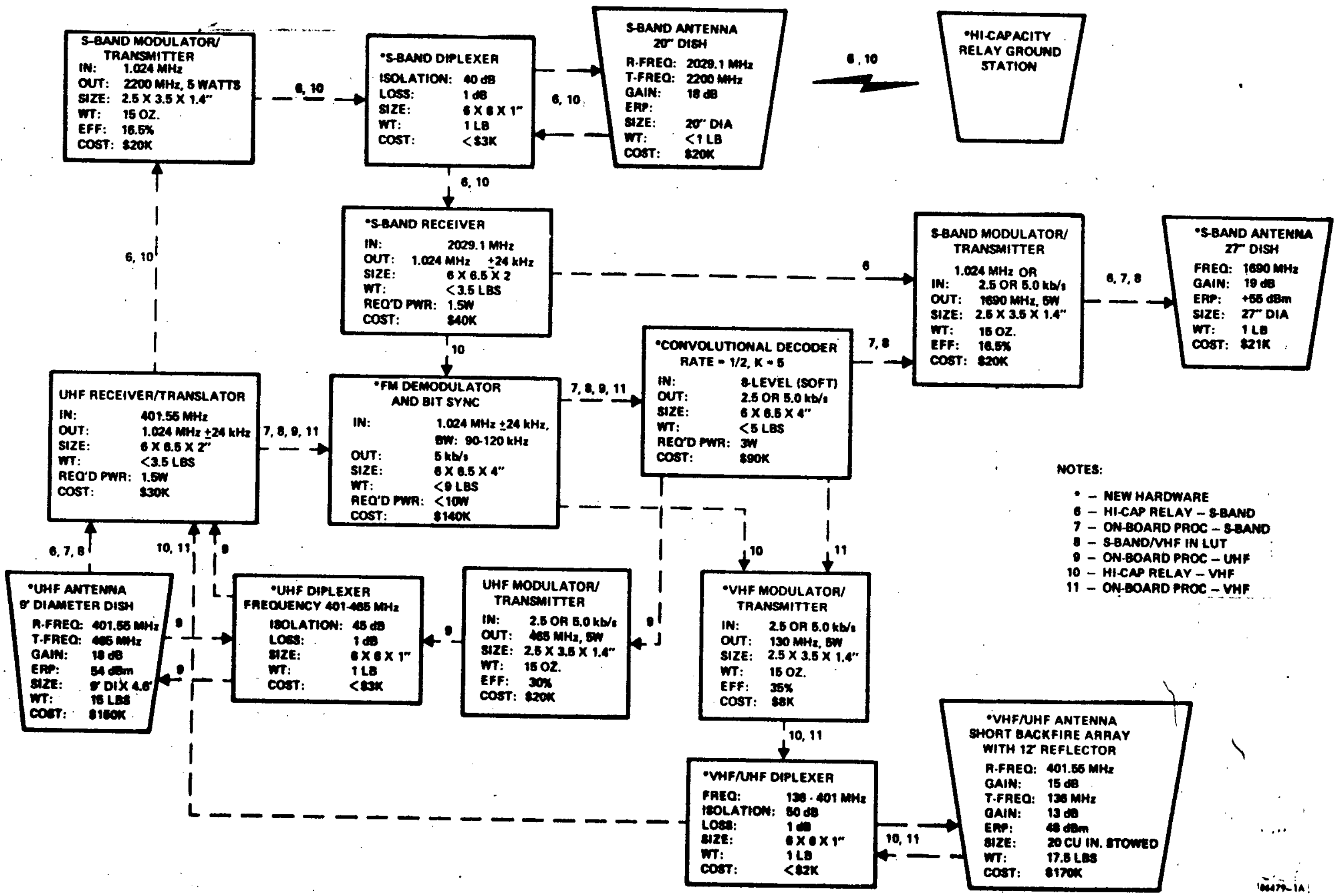


Figure 5.2.1-1. Geo-Synchronous Satellite DCS Configurations

Receive Frequency	401.55 MHz
Gain	18 db Minimum
Transmit Frequency	465.0 MHz
Gain	18 db Minimum
VSWR	1.5:1
Size	9' Diameter x 4.6' Deployed 19.5'' x 4.6' Stowed
Weight	15 lbs

5.2.2.2 UHF Receiver/Translator

The ERTS-1 UHF receiver/translator was also selected for all 6 geo-synchronous satellite configurations because of its relative low cost and space qualified design. The specifications were given in Section 4.2.2.2.

5.2.2.3 S-Band Modulator/Transmitter

Same as unit described in Section 4.2.2.3 except for output frequencies of 2200 MHz in one case and 1690 MHz in another.

5.2.2.4 S-Band Diplexer

The high capacity ground relay configurations require an S-Band diplexer. S-Band circulator designs requiring only minor modifications are available to meet the following specifications:

Receive Frequency	2029.1 MHz
Transmit Frequency	2200 MHz
Isolation	40 db
Loss	1 db
Size	6x6x1''
Weight	1 lb

5.2.2.5 S-Band Antennas - 20" Dish and 27" Dish

Two S-Band antennas are shown in Figure 5.2.1-1, a 20" dish for communicating with the high capacity ground relay station and a 27" dish for the LUT downlink. The antennas would have the following specifications:

20" Dish

Receive Frequency	2029.1 MHz
Transmit Frequency	2200 MHz
Gain	18 db
Size	20" diameter
Weight	1 lb

27" Dish

Transmit Frequency	1690 MHz
Gain	19 db
Size	27" Diameter
Weight	1

5.2.2.6 S-Band Receiver/Translator

An S-Band receiver is required for receiving the 2029.1 MHz high capacity ground relay signal for configurations 6 and 10. The unit would have specifications similar to the UHF receiver/translator of Section 4.2.2.2 except for the input frequency.

5.2.2.7 FM Demodulator and Bit Sync

This unit is identical to the unit described in Section 4.2.2.5 for the medium orbiting configurations.

5.2.2.8 Convolutional Decoder

This unit is identical to the unit described in Section 4.2.2.6.

5.2.2.9 VHF and UHF Modulator/Transmitters

These units are identical to the items described in Section 4.2.2.7.

5.2.2.10 UHF Diplexer

This unit is identical to the unit described in Section 4.2.2.8.

5.2.2.11 VHF/UHF Diplexer

A VHF/UHF diplexer with the exact frequency range required is not readily available in space qualified form. Modifications of existing designs for a frequency range of 136-401 MHz would be a simple task. Brief specifications for such a unit are as follows:

Receive Frequency	401 MHz
Transmit Frequency	136 MHz
Isolation	50 db
Loss	1 db
Size	6x6x1"
Weight	1 lb

5.2.2.12 VHF/UHF Antenna-Deployable Short Backfire Array with 12' Reflector

The VHF/UHF antenna selected for this trade study is a Radiation designed unit consisting of two stacked short backfire antennas with a 12' reflector. The feed structure of the short backfire antennas produces an end-firing effect which results in high efficiencies when based upon aperture area. Numerous models built at Radiation and others in the literature have demonstrated 75 percent to 85 percent efficiency. The unit is illustrated in Figure 5.2.1-2 and has the following specifications:

Receive Frequency	401.55 MHz
Gain	15 db
Transmit Frequency	136 MHz
Gain	13 db
Size	20 cu in. stowed
Weight	17.5 lbs

5.2.3 Satellite Hardware Cost Estimates

The cost estimates presented in this section are for recurring hardware and testing only. The satellite hardware costs assume that a minimum quantity of six systems, three flight systems and three backups, would be built. The recurring cost estimates, including system integration and test for the six geo-synchronous satellite configurations are shown in the following two tables, 5.2.3-1 and -2. The items which are not available off-the-shelf or with negligible non-recurring cost are marked with an asterisk.

5.2.4 Size, Weight and Power Considerations

The size, weight, and power requirements are critical to the overall cost of a deployed satellite system. The amount of non-recurring dollars required to minimize the size, weight, and power requirements of a given system must be traded against the additional cost of deploying reasonably well designed but not non-optimized satellite hardware. The scope of this study did not permit any system optimization.

The systems shown in Figure 5.2.1-1 are a low-cost compilation of space qualified components with reasonable designs and hence reasonable costs. Using these items with the best size, weight, and power requirements available resulted in the values shown in Table 5.2.4-1.

TABLE 5.2.3-1
SUMMARY OF SATELLITE HARDWARE RECURRING COSTS
GEO-SYNCHRONOUS SATELLITE
S-BAND OPTIONS, CONFIGURATION 6, 7, & 8

EQUIPMENT REQUIRED	CONFIG 6 HI-CAP GROUND RELAY DECODES	CONFIG 7 SPACECRAFT DECODES	CONFIG 8 S-BAND TO VHF DWN CONVERSION
UHF ANTENNA (9' Dish)	$150 K	$150 K	$150 K
UHF RECVR/TRANSLATOR	30 K	30 K	30 K
S-BAND TRANSMITTER (2200 MHz, 5 Watts)	20 K		
*S-BAND DIPLEXER	3 K		
*S-BAND ANTENNA (20" Dish)	20 K		
*S-BAND RECVR	40 K		
*FM DEMOD & BIT SYNC		140 K	140 K
*CONVOLUTIONAL DECODER		90 K	90 K
S-BAND MOD/XMITTER (1690 MHz, 5 Watts)	20 K	20 K	20 K
*S-BAND ANTENNA (27" Dish)	21 K	21 K	21 K
SUBTOTAL HARDWARE	$304 K	$451 K	$451 K
INTEGRATION & TEST	200 K	200 K	200 K
TOTAL	$504 K	$651 K	$651 K

TABLE 5.2.3-2
SUMMARY OF SATELLITE HARDWARE RECURRING COSTS
GEO-SYNCHRONOUS SATELLITE
UHF & VHF DOWNLINKS, CONFIGURATIONS 9, 10, 11

EQUIPMENT REQUIRED	CONFIG 9 ON-BRD PROC. UHF DOWNLINK	CONFIG 10 HI-CAP RELAY VHF DOWNLINK	CONFIG 11 ON-BRD PROC. VHF DOWNLINK
* UHF ANTENNA (9' Dish)	$150 K		
* VHF/UHF ANTENNA (Deployable Short Back-fire Array)		$170 K	$170 K
UHF DIPLEXER (401-465 MHz)	3 K		
* VHF/UHF DIPLEXER (136-401 MHz)			2 K
UHF RECVR/ TRANSLATOR	30 K	30 K	30 K
S-BAND TRANSMITTER (2200 MHz, 5 Watts)		20 K	
*S-BAND DIPLEXER		3 K	
* S-BAND ANTENNA (20" Dish)		20 K	
* S-BAND RECVR		40 K	
* FM DEMOD & BIT SYNC	140 K	140 K	140 K
* CONVOLUTIONAL DECODER	90 K		90 K
VHF MOD/XMITTER (136 MHz, 5 Watts)		8 K	8 K
UHF MOD/XMITTER (465 MHz, 5 Watts)	20 K		
SUBTOTAL HARDWARE	$433 K	$431 K	$462 K
INTEGRATION & TEST	200 K	200 K	200 K
TOTAL	$633 K	$631 K	$640 K

TABLE 5.2.4-1
SUMMARY - SATELLITE COMPONENT SIZE, WEIGHT, & POWER
GEO-SYNCHRONOUS SATELLITE DCS CONFIGURATIONS

	CONFIGURATIONS					
COMP. SUMMARY	# 6 HI-CAP GRND RELAY-S-BND	# 7 SAT. DECODES S-BAND	# 8 S-BND TO VHF DWN CONVERSIONS	# 9 ON-BRD PROC UHF	# 10 HI-CAP REL VHF	# 11 ON-BRD PROC VHF
No. of Items	8	6	6	6	9	6
Total Internal Volume (Cu. In.)	216	402	402	438	442	472
Total Weight (ozs)	430	551	551	567	626	603
Total Power (Watts)	63.6	44.8	44.8	31.0	61.4	28.7

5.2.5 Summary of Satellite Hardware Trades for Geo-Synchronous Satellite DCS Systems

As shown in Tables 5.2.3-1 and -2, the lowest cost satellite hardware system is configuration 6, the S-Band double "bent-pipe" system with the high-capacity ground relay. The cost difference between that system and the other five satellite systems (which are roughly the same cost) is about 25%. Because of its relative simplicity, configuration 6 has the least size and weight; but because of its two S-Band transmitters, it has the largest power requirement.

The UHF and VHF on-board processing configurations are attractive because of their low power requirements, the physical size, complexity and non-recurring cost of the deployable downlink antennas is a problem but the overall impact is reduced by using the antenna for both the DCP uplink and LUT downlink.

5.3 LUT Configuration

A total of six separate systems were examined utilizing a geo-synchronous satellite as the DCS relay for DCP data. Each of these systems employed a different local terminal configuration, with VHF, UHF, and S-Band carrier frequencies examined for applicability.

5.3.1 General Description

5.3.1.1 Configuration 6-High Capacity Ground Relay, S-Band Downlink

The configuration first examined utilized a system in which the signal received by the LUT consisted of an S-Band carrier with a 1.024 MHz subcarrier introduced by the satellite receiver-translator. This system is similar to that of configuration 1 using a medium-orbiting satellite such as ERTS 1, except that the signal relayed to the LUT does not have a convolutionally encoded format. The DCP message is decoded in an intermediate step by the High-Capacity Relay terminal. Further, because the subcarrier frequency is not derived directly from the DCP message, the very stringent acquire-and-lock requirements of the subcarrier signal even with no data modulations, so that the LUT demodulator may attain the signal, and its associated AFC circuits remove any frequency uncertainties in the translated signal.

The LUT, then, is composed of a system as shown in Figure 5.3.1-1. The S-Band signal is received by a fixed antenna with a six-foot diameter. Because the satellite is geo-synchronous, the antenna need be positioned only at installation, with perhaps only periodic adjustments. No tracking capability is required. A pedestal-mounted preamplifier

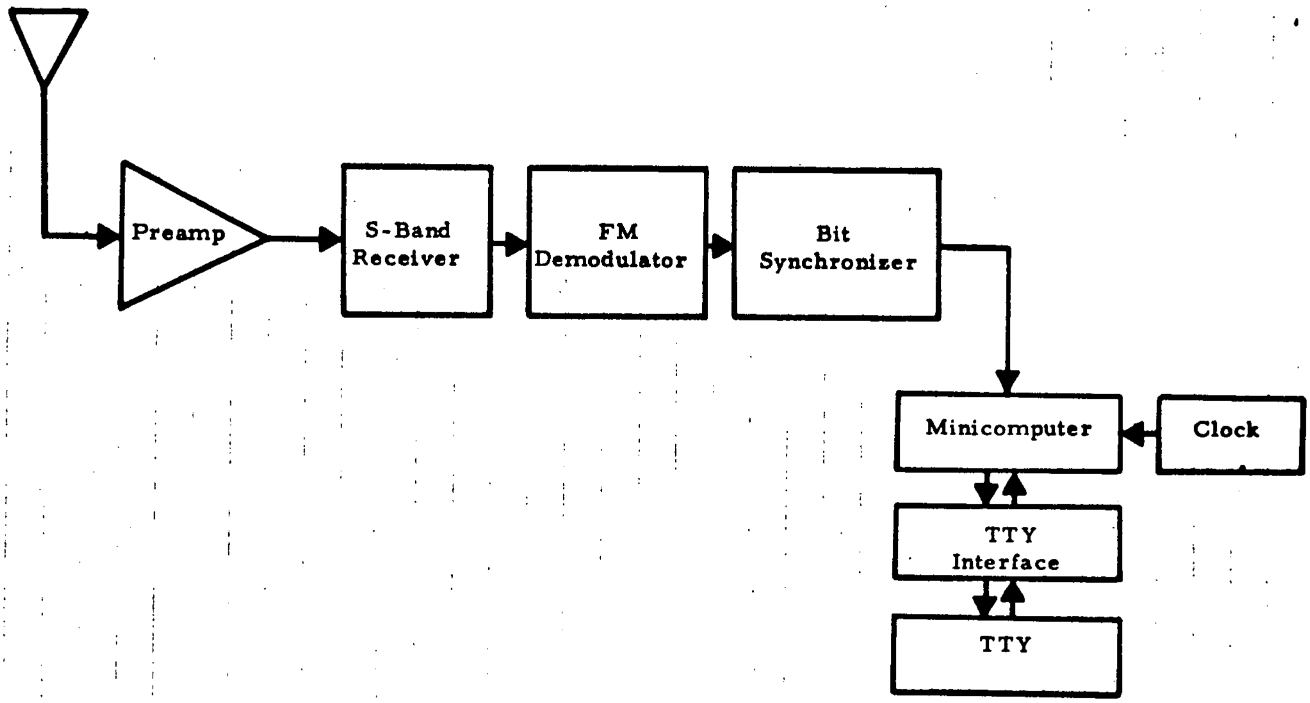


Figure 5.3.1-1. Configuration 6 - Local User Terminal System

maintains maximum system sensitivity, reducing the effects of the feed line from the antenna to the receiver. The amplified signal is then routed to the S-Band receiver, where the 1690 MHz carrier frequency is detected and the 1.024 MHz subcarrier signal extracted. After proper filtering in the receiver, the subcarrier signal is then delivered to the subcarrier demodulator accepts the 1.024 MHz signal and detects the FSK-modulated message. This message is a decoded DCP message of 38 milliseconds duration, occurring at random intervals. However, because the High-Capacity relay maintains a constant subcarrier frequency, simple demodulators will perform adequately.

The demodulated bit stream is then routed to the bit synchronizer where the bit decisions are made and a bit clock signal is generated. These two signals are then presented to the processor for any data processing and display required.

The data processing scheme may depend heavily on the individual user requirements. A typical user could best be served by a programmable minicomputer with a memory capacity that would permit an appropriate amount of processing prior to presentation on the display device. This processing may consist of scaling of parameters, detection of threshold values, computations of mean values, observation of parameters over extended periods of time, or any of a number of other functions. Further, if a programmable computer is used, the processing scheme can be altered at any time to accommodate changes in the user's requirements.

As a display device, the teletype machine offers the best compromise. While it is an inherently slower device than many other media, it is inexpensive, provides a permanent copy, may be operated unattended, and provides an input media when accompanied by the common keyboard or paper tape reader. In addition, the faster devices may only be required if a large number of DCP's are deployed and in use by the user. For these reasons, the teletype machine is the best selection for a display device.

5.3.1.2 Configuration 7 - S-Band Downlink With Spacecraft Processing

The configuration 7 system is very similar to configuration 6, except that the satellite performs all the decoding functions, eliminating the requirement for the High-Capacity Relay ground station. Because the satellite hardware does not consist only of receiver-translators and transmitters, but detects the DCP message to the bit stream itself, it is not necessary to utilize subcarrier transmission to the LUT. The data signal is modulated directly onto the S-Band carrier signal. Furthermore, because the decoding function is performed in the spacecraft, there is no requirement for a convolutional decoder at the LUT.

Figure 5.3.1-2 presents a block diagram of the LUT for configuration 7. The signal is received by the fixed six-foot diameter antenna, and amplified by the transistorized preamplifier to reduce the system noise figure. The amplified signal is then routed to receiver where the 2.5 KBPS DCP message is detected. This signal is then routed to the bit synchronizer for bit decisions and the generation of a clock signal. These are then delivered to the processor, where formatting, processing, or other manipulation of the data is accomplished. The final results are then displayed to the operator, along with the time of message reception as derived by the associated real-time clock, through the teletype machine.

As noted, configuration 7 differs from configuration 6 in the LUT hardware only to the extent that no subcarrier demodulators are required.

5.3.1.3 Configuration 8 - S-Band to VHF Downconversion

In order to reduce the total cost of the LUT for a system such as that described for configuration 7, it is possible to use a fixed oscillator/mixer and downconverter, translating the S-Band signal to VHF. The relatively expensive S-Band receiver may then be deleted from the station hardware and a much less expensive VHF receiver be used instead.

Figure 5.3.1-3 presents the block diagram for such a system. The S-Band signal is received by the six-foot antenna and the pedestal-mounted transistorized preamplifier. Then, before being delivered to the receiver, it is mixed with a fixed frequency to translate the signal from S-Band to VHF. If the downlink carrier is 1690 MHz, the local oscillator frequency could be 1554 MHz to produce a 136 MHz center frequency to the receiver. This VHF signal is then taken to an inexpensive VHF receiver where the DCP message is detected. The signal-plus-noise output of the receiver is then taken by the bit synchronizer, where bit decisions and a clock signal are produced. These are then routed to the processor for any required data manipulation takes place prior to display on the station teletype machine.

This system provides a means of lowering the cost of the local user terminal without requiring a concommitantly increased satellite cost.

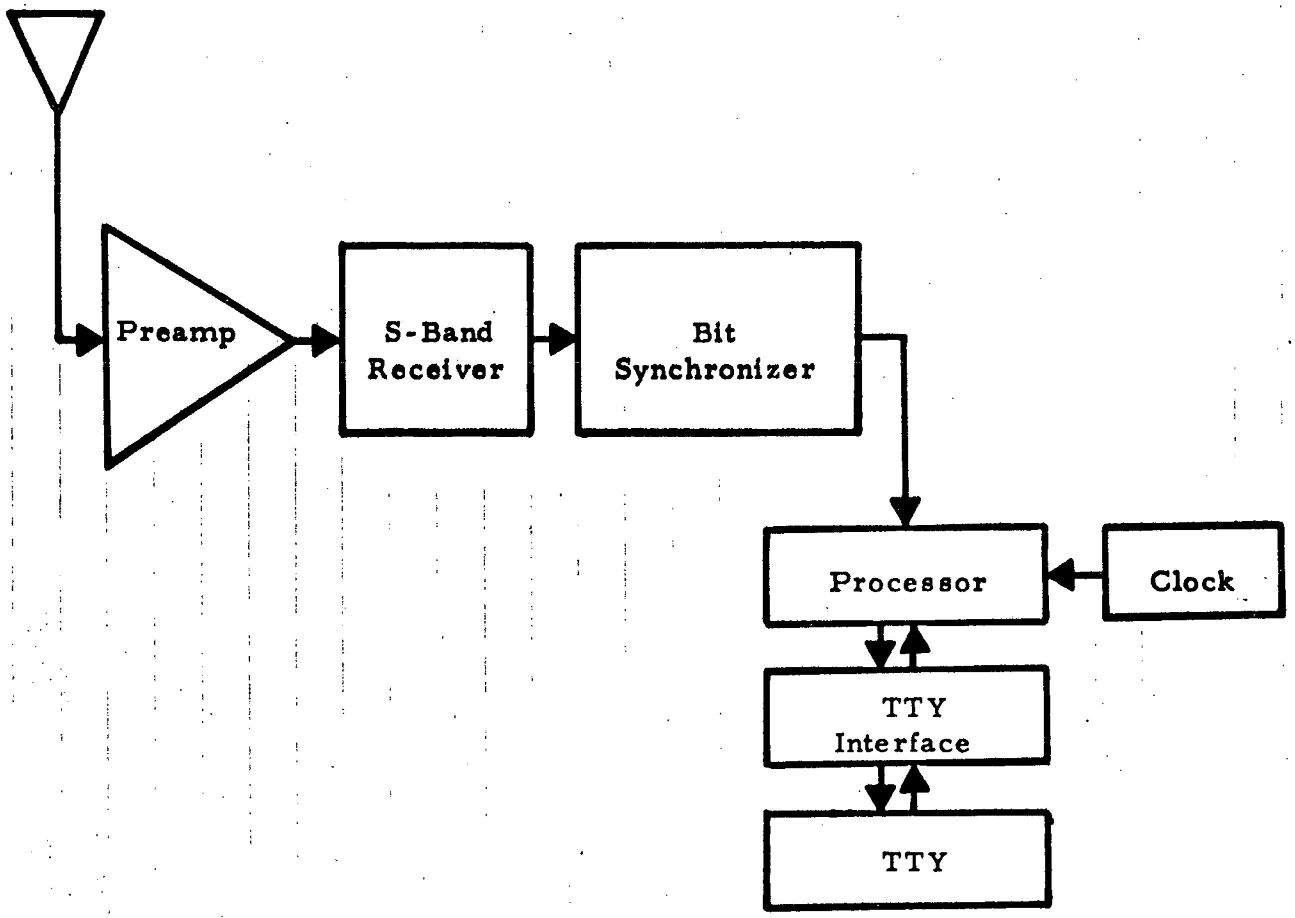


Figure 5.3.1-2. Configuration 7 - Spacecraft Processing, S-Band Downlink

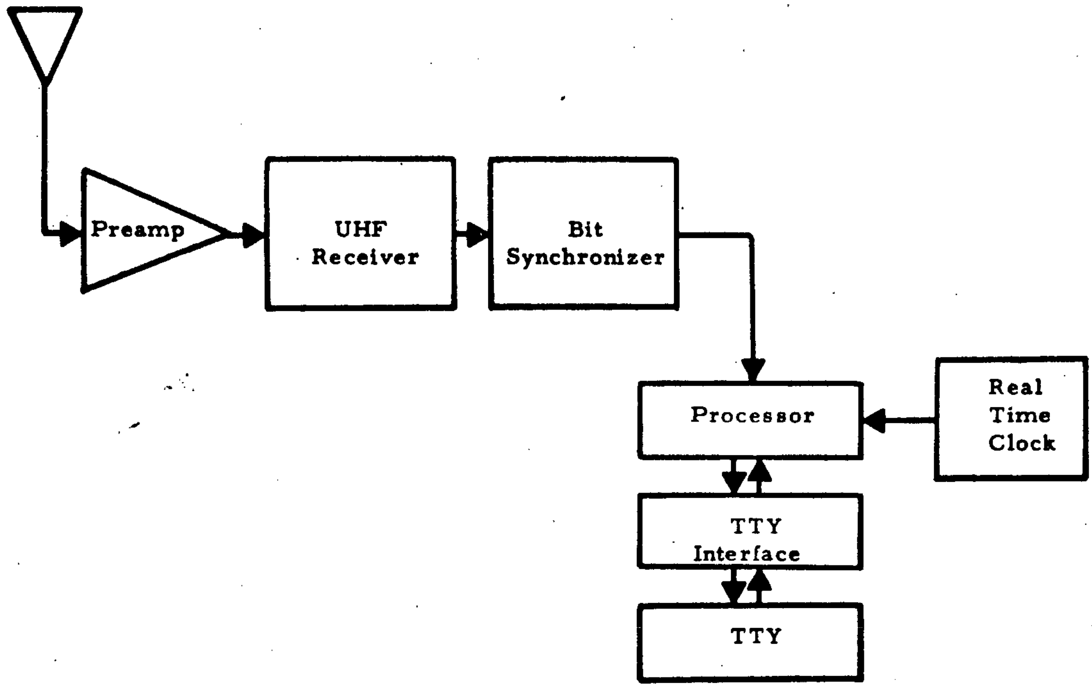


Figure 5.3.1-4. Configuration 9 - UHF Downlink

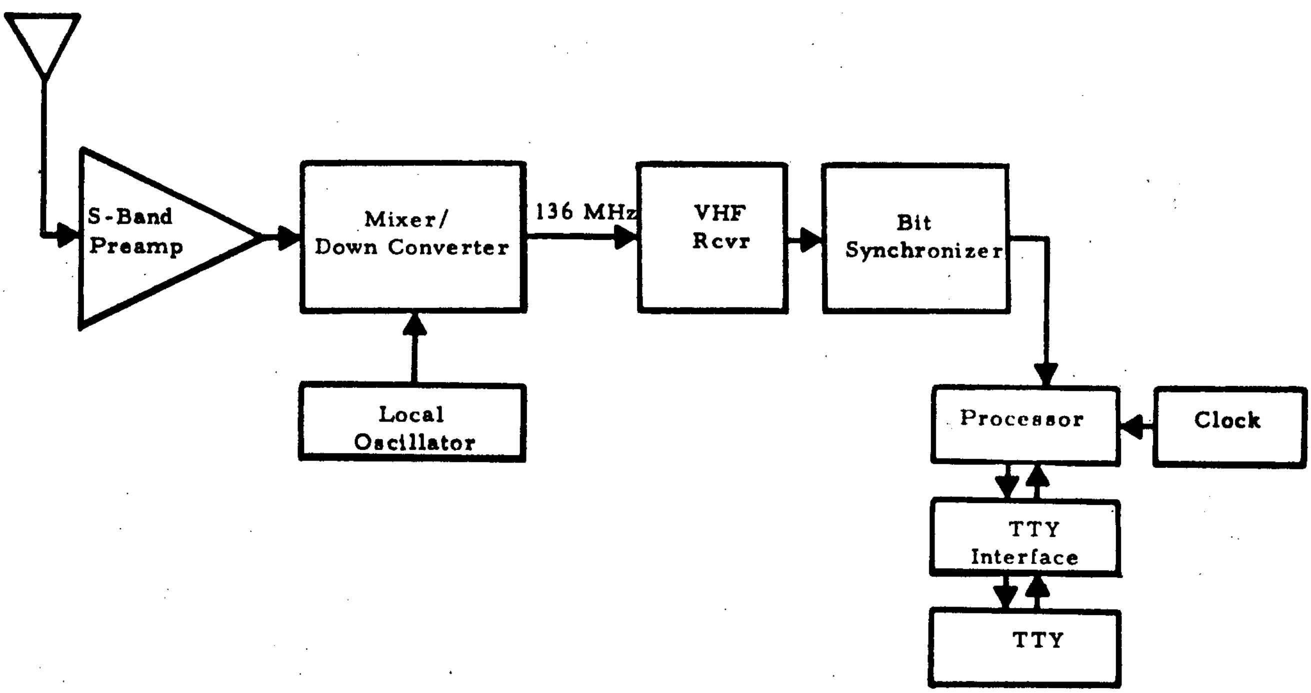


Figure 5.3.1-3. Configuration 8 - S-Band to VHF Downconversion

5.3.1.4 Configuration 9 - UHF Downlink

This optional configuration considers a UHF downlink frequency rather than S-Band. The spacecraft again performs all the decoding functions, transmitting a UHF signal with direct carrier modulation. In order to minimize the overall cost of the system, FSK modulation is recommended at the DCP data rate of 2.5 KBPS.

A block diagram of this LUT configuration is shown in Figure 5.3.1-4. The signal is received by the fixed antenna, which could be a 10-turn helix providing about 15 db gain at 465 MHz. This signal is then amplified by a pedestal-mounted preamplifier to reduce the overall system noise figure prior to being passed down the cable line to the receiver. The receiver detects the FSK signal and presents the bilevel signal-plus-noise output to the bit synchronizer where bit decisions are made and a bit timing clock signal is generated.

These signals are then routed to the processor for any necessary manipulations prior to display on the teletype output machine.

5.3.1.5 Configuration 10 - High Capacity Relay, VHF Downlink

In configuration 1, a High Capacity Relay ground station was employed to provide the required decoding function for the DCP message, and an S-Band carrier was utilized for the downlink to the LUT. In this optional configuration, the ground relay station again provides the decoding function, but the LUT costs are reduced by the implementation of a VHF carrier frequency for the downlink. Because the overall frequency uncertainty involved using a receiver-translator is much greater than the total IF bandwidth of inexpensive VHF receivers, it is therefore necessary that the ground relay signal received by the spacecraft be detected to the digital bit stream prior to directly modulating the downlink transmitter. Therefore the LUT design for configuration 10 is identifical to that for configuration 11.

5.3.1.6 Configuration 11 - VHF Downlink

In this configuration (and in configuration 10 as well), the downlink signal consists of a VHF carrier with directly modulated FSK data consisting of the decoded DCP message. Each message occurs at random times, but the presence of a carrier signal is maintained at all times by the spacecraft transmitter, allowing the LUT receiver to remain tuned to the downlink frequency. A block diagram of this design is shown in Figure 5.3.1-5.

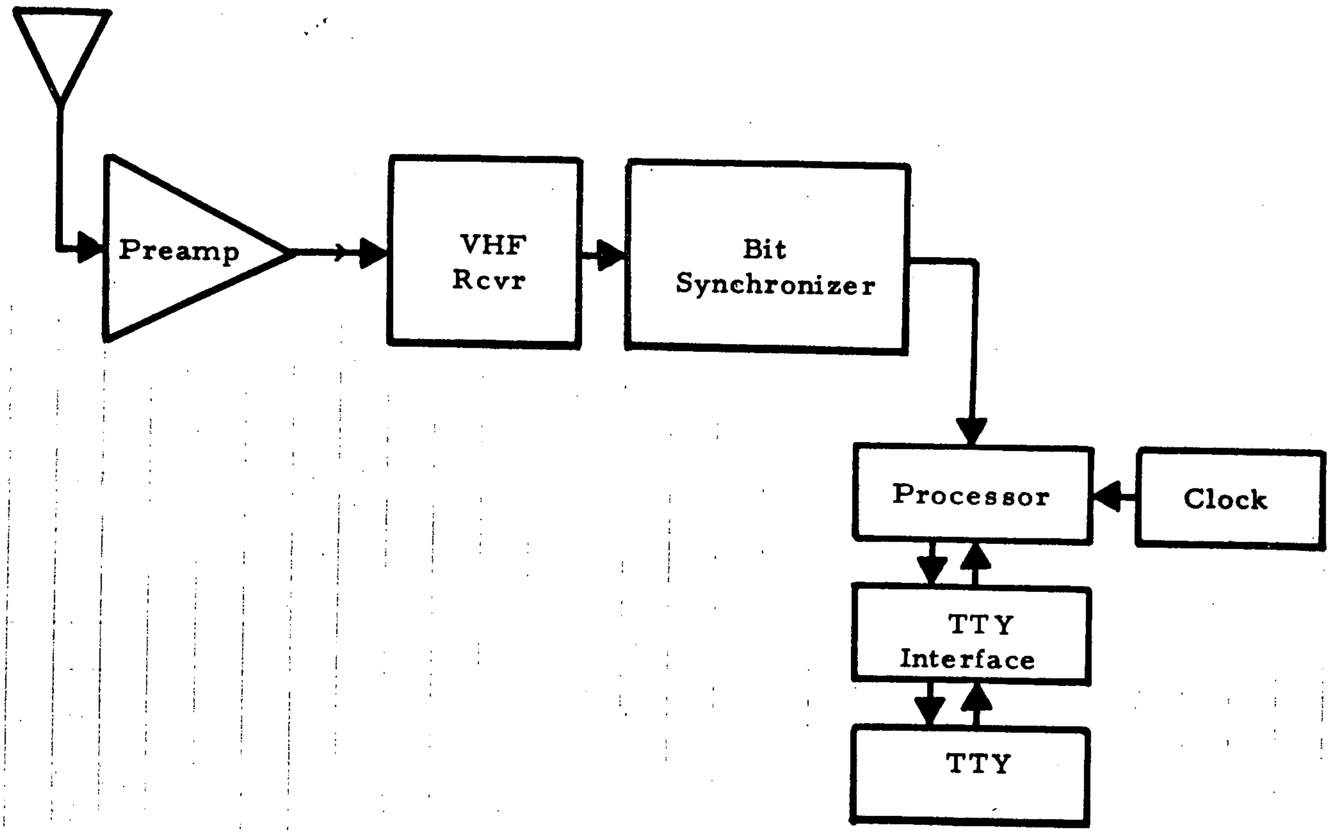


Figure 5.3.1-5. Configurations 10 and 11 - VHF Downlink

The signal is received by the fixed cross-polarized yagi antenna and amplified by a pedestal-mounted preamplifier to minimize the overall system noise figure. The signal is then delivered to the inexpensive VHF receiver where the FSK signal is demodulated and the digital bit stream derived.

The signal-plus-noise output of the VHF receiver is then taken by the bit synchronizer, which makes bit decisions on the data signal and generates a bit timing signal. These signals are taken by the processor, and the data is then processed in accordance with the stored program prior to display on the teletype machine, where it is then made available to the user.

5.3.2 Specifications and Detailed Component Descriptions

For the most part, the equipment required for an LUT operating with a geo-synchronous satellite is the same as that required when operating with a medium-orbiting satellite except in the area of the antenna systems. Further, because no decoding function is performed at the LUT, there is no requirement for a decoder, nor for the rapid-acquisition subcarrier demodulators or bit synchronizers. The equipment described in Section 4.3.2 applies here as well for the same requirements. As noted, only the antennas differ. The antennas required for the geo-synchronous system have, in general, more gain but no positioning requirements.

5.3.2.1 S-Band Antenna

The S-Band antenna should be a parabolic reflector of at least six feet diameter, with a circularly polarized feed system. The antenna should be fixed mounted in a manner sufficient to prevent movement in local storm wind conditions. The gain of the antenna must be at least 27 db at 1690 MHz.

An antenna such as the Andrews 60006-14 could be used in this application with a slight modification to the feed system to extend its range to 1690 MHz.

5.3.2.2 UHF Antenna

The UHF antenna should be circularly polarized with at least 15 db gain. A helical or crossed yagi antenna would be suitable for use. Mounting must be sufficiently stable to prevent the antenna pointing direction from being deflected away from the satellite position.

An antenna which would be suitable in this system is the TACO H-105 helical antenna. Its frequency range extends from 300-520 MHz, accommodating the 465 MHz downlink perfectly. The antenna is a ten-turn system providing over 15 db gain.

5.3.2.3 The VHF antenna is similar in requirement to the UHF antenna, except that less gain is required due to the lower path loss at 136 MHz than at 465 MHz. Good performance is achieved if the antenna has about 12 db gain.

An antenna which fulfills the requirements of the system is the TACO Model XY-073 crossed yagi antenna. It consists of 7 elements including driven element, reflectors, and directors, and has a tuned frequency of 136.5 MHz, with a gain of at least 12 db.

5.3.3 LUT Cost Estimates

Cost estimates for the various LUT configurations are shown in Table 5.3.3-1 for the S-Band configurations and Table 5.3.3-2 for the UHF and VHF configurations. These estimates were prepared according to the cost estimate guidelines given in Section 2.1 and are thus recurring cost estimates only.

5.3.4 Software Requirements

Because the data received by the LUT is independent of whether the relay satellite is medium orbiting or geo-synchronous, the software requirements of the user are expected to be identical to those described in Paragraph 4.3.4. Some changes may be useful, however. Because the area of interest for the user is under continuous coverage, there may be a greater requirement to have some sort of alert capability to warn of impending emergencies (such as a seismic occurrance presaging an earthquake). The software package must then be able to detect such alert situations and activate I/O channels according to particular user requirements.

5.3.5 Summary of LUT Configurations

For the geo-synchronous satellite system, six separate systems were considered requiring five individual LUT designs. These designs ranged from the simple to the complex, depending on carrier frequency, existence of subcarrier channels, etc. The actual selection of the system that provides the best tradeoff between LUT complexity, satellite complexity, and ground relay complexity must of course depend on the relative number of terminals that can be expected to be incorporated. As the number of local terminals increases, it becomes more and more desireable to simplify the design of the LUT and consequently lower its cost, with a justifiable increase in relay complexity.

TABLE 5.3.3-1
SUMMARY OF LUT RECURRING COSTS
GEO-SYNCHRONOUS SATELLITE
S-BAND OPTIONS

EQUIPMENT REQUIRED	CONFIG 6 HI-CAP GROUND RELAY DECODES	CONFIG 7 SPACECRAFT DECODES	CONFIG 8 S-BAND TO VHF DOWNCONVERSION
ANTENNA (ANDREWS 60006-14)	$1,500	$1,500	$1,500
PREAMPLIFIER (IMC-S10-1700-30-CA)	1,600	1,600	1,600
LOCAL OSCILLATOR (GREENRAY EY118BD)			750
MIXER-DOWN CONV. (REVCOM M16)			200
RECEIVER (MICRODYNE 1100AR)	6,200	6,200	
RECEIVER (VANGUARD 260-PLL)			200
BIT SYNC (DCS 4703-101)	1,200	1,200	1,200
MINICOMPUTER WITH TTY (TI 980A)	5,400	5,400	5,400
RACK	400	400	400
MISCELLANEOUS	1,000	1,000	750
INTEGRATION AND TEST	3,000	3,000	2,000
TOTAL	$20,100	$20,100	$14,000

TABLE 5.3.3-2
SUMMARY OF LUT RECURRING COSTS
GEO-SYNCHRONOUS SATELLITE
UHF & VHF DOWNLINK CONFIGURATION 9, 10 & 11

EQUIPMENT REQUIRED	CONFIGURATION 9 UHF DOWNLINK	CONFIGURATION 10 & 11 VHF DOWNLINK
ANTENNA (TACO SY-073)	$ 900	$ 900
PREAMPLIFIER (VANGUARD 202 MODIFIED)	50	
PREAMPLIFIER (VANGUARD 102)		50
RECEIVER (VANGUARD FMR 260-PLL)		200
RECEIVER (ACL SR-209)	2,700	
BIT SYNC (DCS 4703-101)	1,200	1,200
MINICOMPUTER WITH TTY (TI 980A)	5,400	5,400
RACK	400	400
MISCELLANEOUS	1,000	1,000
INTEGRATION AND TEST	2,000	2,000
TOTAL	$13,650	$11,150

5.4 Conclusions

Since a minimum of three geo-synchronous satellites are required to give world-wide coverage, the recurring costs for a three satellite "piggyback" DCS system with three backup hardware systems and 100 local user terminals is shown in Table 5.4-1 for each of the six configurations. The VHF systems give the lowest total system cost, but they have only a 1% cost advantage over the lowest cost S-Band system, namely configuration 6, the High Capacity Ground Relay System.

A summary of the various trade items is shown in Table 5.4-2. The VHF on-board processing configuration requires the least satellite electrical power, but has a considerable size and weight disadvantage relative to the S-Band high capacity ground relay system; and thus, with appropriate weighting penalties, the weighted overall system recurring costs would be very close. The decision as to the correct choice for a world-wide geo-synchronous satellite DCS study must rest on other factors such as frequency availability, RF interference, non-recurring costs, the actual satellites to be used, and the total number of LUT's anticipated.

TABLE 5.4-1
GEO-SYNCHRONOUS SATELLITE DCS CONFIGURATIONS SUMMARY
RECURRING COSTS ONLY

	6 HI-CAP GRND RELAY DECODES	7 SPACE-CRAFT DECODES	8 S-BAND TO VHF DOWN CONV	9 ON-BRD PROC UHF DWNLNK	10 HI-CAP RELAY VHF DWNLNK	11 ON-BRD PROC VHF DWNLINK
SATELLITE HARDWARE 1 Flight Systems	$ 504 K	$ 651 K	$ 651 K	$ 633 K	$ 631 K	$ 640 K
1 Backup System	504 K	651 K	651 K	633 K	631 K	640 K
HI-CAP GRND RELAY	45 K				45 K	
LOCAL USER TERMINAL Assume 100 LUT's	2,010 K	2,010 K	1,400 K	1,365 K	1,115 K	1,115 K
FOR A 1 SATELLITE & BACKUP SYSTEM TOTAL	3,063 K	3,312 K	2,702 K	2,631 K	2,412 K	2, 395 K
FOR A 3 SATELLITE & 3 BACKUP SYSTEM + 100 LUT's TOTAL	$5,079 K	$5,916 K	$5,306 K	$5,263 K	$4,946 K	$4,955 K

TABLE 5.4-2
TRADE SUMMARY - GEO-SYNCHRONOUS SATELLITE DCS CONFIGURATIONS

ITEMS	CONFIGURATIONS
• SATELLITE COMPONENTS	
Least Recurring Cost	Config. 6, Hi-Cap. Grnd Relay, S-Band
Least Size & Weight	Config. 6, Hi-Cap. Grnd. Relay, S-Band
Least Required Power	Config. 7, 8, 9, & 11
• LUT HARDWARE	
Least Recurring Cost	Config. 10, Hi-Cap. Grnd. Relay, VHF & Config. 11, On-Brd. Proc., VHF
• BEST DOWNLINK GAIN MARGIN	Config. 10, Hi-Cap. Grnd. Relay VHF & Config. 11, On-Brd. Proc., VHF
• LOWEST SYSTEM HARDWARE RECURRING COST FOR 3 SATELLITES (+3 BACKUPS + 100 LUTS)	Config. 11, On-Brd. Processing VHF

APPENDIX A

Minicomputer Survey

A survey of minicomputers available as of May 15, 1971 is included in this appendix. The level of capabilities and performance has increased considerably since this survey while costs have continued to decrease.

Table I

The machines in this survey are listed
in descending order of word length, from 16 to 8 bits.

MANUFACTURER AND MODEL NUMBER	Digital Equipment PDP-15	Computer Automation 216/116	Control Data 1700	Data General Nova 1200	Data General Supernova	Data Mate Computer Systems 16	Digital Equipment PDP-11/20	Electronic Associates 640	EMR 6130	General Automation SPC-16	General Automation 18/30	GRI Computer 909
MEMORY												
Memory Cycle Time, μs	0.8	2.6/1.6	1.1	1.2	.8	1.0	1.2	1.65	0.775	0.960	1.2	1.76
Memory Word Length, Bits	16	16	16	16	6	16	16	16	16	16	16	16
Minimum Memory Size, Words	4K	4K	4K	1K	K	4K	4K	4K	8K	4K	4K	1K
Memory Increment Size, Words	4K	4K	4K	1K, 2K, 4K	K	4K	4K	4K	8K	4K	4K	1K, 4K
Maximum Memory Size, Words	128K	16K	32K	32K	2K	32K	64K	32K	32K	32K	32K	32K
Parity Check	Optional	None	Standard	None	one	Optional	Optional	None	Standard	None	Standard	None
Memory Protect	Optional	None	Standard	Optional	ptional	Standard	Optional	Standard	Standard	Optional	Standard	None
READ ONLY MEMORY	None	Optional	None	Optional	ptional	None	Optional	None	None	Optional	Optional	Optional
CPU FEATURES												
Instruction Word Length(s), Bits	16	16	16	16	6	16	16	16/32	16/32	16/32	16	16
Number of Accumulators or General-Purpose Registers That Can Be Used as Accumulators	1	1	2	4	[illegible]	2	8	2	2	16	16	1
Number of Hardware Registers Not Including Index Registers	9	6	8	10	0	6	12	9	4	22	20	4
Number of Index Registers (Hardware, Memory, or Other Technique)	1 Hardware	1 Hardware	1 Hardware 1 Memory	2 Hardware 16 Memory	Hardware 16 Memory	1 Hardware	8 Hardware	1 Hardware	3 Hardware	8 Hardware	3 Hardware	1
Indirect Addressing (Multilevel, Single Level, or None)	Single Level	Multilevel	Multilevel	Multilevel	ultilevel	Multilevel	Multilevel	Multilevel	Multilevel	Multilevel	Single Level	Single Level
ARITHMETIC OPERATION CAPABILITY												
Add Time for Full Word, μs	1.6	5.3/3.2	2.2	1.35	.8	2.0	2.3	3.3	1.9	0.96	2.4	1.76
Fixed-Point Hardware Multiply/Divide	Optional	Standard	Standard	Optional	ptional	Standard	Optional	Standard	Standard	Optional	Standard	Optional
Multiply, μs	7.4	12.6/13.6	7	6.6	.8	6	4.3	18.15	6.4	9.6	12.0	10.0
Divide, μs	7.8	13.1/14.4	9	6.8	.8	7	4.8	18.875	9.6	17.6	13.2	11.7
INPUT/OUTPUT CAPABILITY												
Data-Path Width, Bits	16	8/16	16	16	16	16	16	16	16	16	16	16
Direct Memory Access (DMA) Channel	Standard	Optional	Optional	Standard	Standard	Optional	Standard	Optional	Standard	Optional	Optional	Standard
Maximum DMA Word-Transfer Rate	1 MHz	625 KHz	900 KHz	833 KHz	34 KHz	1 MHz	833 MHz	600 KHz	1.26 MHz	1.0 MHz	833 KHz	570 KHz
Number of External Priority Interrupt Levels in Basic System	8	3	16	16		8	4	7	None	3	8	16
Maximum Number of External Interrupts	36	256	16	62	32	64	64	64	136	64	89	64
OTHER FEATURES												
Power Failure and Automatic Restart	Optional	Optional	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard
Real-Time Clock or Internal Timer	Optional	Optional	Optional	Optional	Optional	Optional	Optional	Optional	Optional	Optional	Standard	Optional
SOFTWARE												
Assembler (1 Pass, 2 Pass, Both)	2 Pass	2 Pass	2 Pass	2 Pass	2 Pass	2 Pass	2 Pass	2 Pass	Both	2 Pass	2 Pass	No
Relocatable Assembler	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Minimum Core Size Necessary to Use Relocatable Assembler	8K	4K	4K	4K	4K	4K	8K	8K	8K	8K	4K	—
Macro Assembler Capability	Yes	No	Yes	No	No	Yes	Yes	No	Yes	No	Yes	No
Real-Time Executive Monitor Available	Yes	No	Yes	Yes	Yes	No	No	No	Yes	Yes	No	No
Disc Operating System Available	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
BASIC MAINFRAME COSTS												
Basic System Price with 4K Words Including Power Supplies	$16,500	$7,900/ $9,490	$29,000	$5,100	$9,350	$13,900	$10,800	$26,500	N/A	$10,000	$18,000	$8,390
Total System Price Including ASR-33 Teletype and CPU	$16,500	$10,000/ $10,500	$35,000 (ASR-35)	$6,700	$10,880	$18,900	$10,800	$27,700	—	$11,200	$19,800	$9,900
Basic System Price with 8K Words Including Adequate Power Supplies, Enclosure, and Control Panel	$22,500	$12,840/ $12,290	$37,000	$7,665	$12,718	$20,400	$14,300	$35,500	$39,500	$14,200	$26,000	$11,830
Total System Price Including ASR-33 Teletype and CPU	$22,500	$14,850/ $14,300	$43,000 (ASR-35)	$9,265	$14,318	$22,400	$14,300	$36,700	$41,000	$15,000	$26,800	$13,140
PERIPHERALS AVAILABLE												
Magnetic Tape	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Approximate Price for Operational Unit Including Controller and Necessary Options	$22,000	$5,700/ $10,000	$22,500	$9,900	$9,900	$19,500	$22,000	$30,000/ $32,000	$35,000/ $67,200	$11,000	$14,000/ $26,000	—
Mass Storage Device	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Approximate Price for Operational Unit Including Controller and Necessary Options	$9,750	$6,500/ $9,950	$27,500	$7,250/ $9,750	$7,250/ $9,750	$19,000/ $45,000	$9,750	$24,500	$20,200/ $54,700	$9,000/ $15,000	$14,000/ $30,000	—
High-Speed Paper Tape Reader	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Speed, Characters per Second	300	300	350	300	300	300	300	300	300	300	300	300
Approximate Price of Operational Unit	Comb. $4,800	$2,200	$4,500	$2,650	$2,650	$2,000	$2,000	Comb. $8,400	Comb. $10,000	$3,000	$2,500	$2,050
High-Speed Paper Tape Punch	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Speed, Characters per Second	50	60	120	63.3	63.3	120	50	120	60	120	60	50
Approximate Price of Operational Unit	Comb. $4,800	$3,300	$5,100	$2,200	$2,200	$4,000	$2,000	Comb. $8,400	Comb. $10,000	$4,000	$3,000	$1,750

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MANUFACTURER AND MODEL NUMBER	Hewlett-Packard 2114B/2114C	Hewlett-Packard 2116B/2116C	Honeywell H-316	Honeywell 516	Information Technology ITI-4900 (Model 20)	Interdata 4/5	IBM 1130	IBM 1800	Lockheed Electronics MAC-16/MAC Jr.	Raytheon 703	Raytheon 704	Raytheon 706
MEMORY												
Memory Cycle Time, μs	2.0	1.6	1.6	0.96	0.975/1.75	1.0	2.2/3.6	2/4	1.0	1.75	1.5	0.9
Memory Word Length, Bits	16	16	16	16	16	16	16	16	16	16	16	16
Minimum Memory Size, Words	4K	8K	4K	4K	4K	2K	4K	4K	4K	4K	4K	4K
Memory Increment Size, Words	4K	8K	4K	4K	4K	2K, 4K	4K	4K	4K	4K	4K	4K
Maximum Memory Size, Words	8K/16K	32K	16K	32K	32K	32K	32K	64K	64K/8K	32K	16K	32K
Parity Check	Optional	Optional	None	Optional	Optional	Optional	Standard	Standard	Optional	None	None	Optional
Memory Protect	None	Optional	None	Optional	Optional	Optional	None	Standard	Optional	None	None	Optional
READ ONLY MEMORY	None	None	None	None	None	Standard	None	None	None	None	None	None
CPU FEATURES												
Instruction Word Length(s), Bits	16	16	16	16/32	16/32	16/32	16/32	16/32	16	16	16	16
Number of Accumulators or General-Purpose Registers That Can Be Used as Accumulators	2	2	2	2	8	16	2	2	1	1	1	1
Number of Hardware Registers Not Including Index Registers	7	7	4	5	16	33	7	7	6	6	6	6
Number of Index Registers (Hardware, Memory, or Other Technique)	None	None	1 Hardware	1 Hardware	8 Hardware	15	3 Memory	3 Hardware	4 Memory	1 Hardware	1 Hardware	1 Hardware
Indirect Addressing (Multilevel, Single Level, or None)	Multilevel	Multilevel	Multilevel	Multilevel	Multilevel	None	Single Level	Single Level	Multilevel	None	None	None
ARITHMETIC OPERATION CAPABILITY												
Add Time for Full Word, μs	4.0	3.2	3.2	1.92	1.95	3.2	4.88	4.25	2.0	3.5	2.0	1.8
Fixed-Point Hardware Multiply/Divide	Optional	Optional	Optional	Optional	Optional	Opt./Stand.	Standard	Standard	Optional	Optional	Optional	Optional
Multiply, μs	24	19.2	8.8	5.28	10	22.8	15.67	15.25	9	14.9	7	6.3
Divide, μs	26	20.8	16	10	25	38	46.36	42.75	12	24	10	9
INPUT/OUTPUT CAPABILITY												
Data-Path Width, Bits	16	16	16	16	16	8	16	16	16	16	16	16
Direct Memory Access (DMA) Channel	Optional	Optional	Optional	Optional	Optional	Optional	Standard	Standard	Stand./Opt.	Optional	Optional	Optional
Maximum DMA Word-Transfer Rate	500 KHz	625 KHz	1 MHz	1 MHz	1 MHz	900 KHz	460 KHz	500 KHz	800 KHz	571 KHz	1.1 MHz	1.1 MHz
Number of External Priority Interrupt Levels in Basic System	8	16	2	2	8	2	6	12	8/4	1	1	1
Maximum Number of External Interrupts	56	48	50	48	256	255	96	384	64/16	16	16	16
OTHER FEATURES												
Power Failure and Automatic Restart	Optional	Standard	Standard	Standard	Optional	Optional	None	Optional	Standard	Optional	Optional	Optional
Real-Time Clock or Internal Timer	Optional	Optional	Optional	Optional	Optional	Optional	None	Standard	Standard	Optional	Optional	Optional
SOFTWARE												
Assembler (1 Pass, 2 Pass, Both)	2 Pass	2 Pass	Both	Both	1 Pass	Both	2 Pass	2 Pass	2 Pass	Both	Both	Both
Relocatable Assembler	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Minimum Core Size Necessary to Use Relocatable Assembler	4K	4K	4K	8K	4K	4K	4K	4K	4K	4K	4K	4K
Macro Assembler Capability	No	No	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Real-Time Executive Monitor Available	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes
Disc Operating System Available	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes
BASIC MAINFRAME COSTS												
Basic System Price with 4K Words Including Power Supplies	$6,500	N/A	$8,400	$23,800	$9,950	$8,500/ $10,500	$25,880	$47,300	$11,200/ $7,900	$15,000	$10,000	$19,000
Total System Price Including ASR 33 Teletype and CPU	$10,500	—	$10,100	$25,000	$12,450	$10,100/ $12,100	$25,880	$50,230	$12,800/ $9,500	$15,000	$11,900	$19,000
Basic System Price with 8K Words Including Adequate Power Supplies, Enclosure, and Control Panel	$13,000	$24,000/ $14,000	$11,900	$31,800	$15,950	$11,700/ $13,700	$34,030	$55,700	$15,150/ $11,000	$23,000	$15,600	$24,600
Total System Price Including ASR-33 Teletype and CPU	$15,000	$26,000/ $16,000	$13,600	$33,000	$18,450	$13,300/ $15,300	$34,030	$58,630	$16,750/ $12,600	$23,000	$17,500	$24,600
PERIPHERALS AVAILABLE												
Magnetic Tape	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Approximate Price for Operational Unit Including Controller and Necessary Options	$9,500/ $15,000	$9,500/ $21,500	$23,355/ $35,430	$23,335/ $35,430	$18,000	$9,900	—	$15,620	$6,000/ $10,000	$10,500/ $28,000	$10,500/ $29,000	$10,500/ $28,000
Mass Storage Device	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Approximate Price for Operational Unit Including Controller and Necessary Options	$16,000/ $31,500	$16,000/ $31,500	$12,300/ $36,000	$22,300/ $36,000	—	$17,400	Included	$13,800	$17,000	$21,500	$21,500	$21,500
High-Speed Paper Tape Reader	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Speed, Characters per Second	500	500	300	300	300	300	60	—	300	300	300	300
Approximate Price of Operational Unit	$2,100	$2,100	$3,800	$3,800	$2,500	$2,500	$1,720	—	$2,200	$3,300	$3,000	$3,000
High-Speed Paper Tape Punch	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes
Speed, Characters per Second	120	120	110	110	50	60	—	—	60	110	110	110
Approximate Price of Operational Unit	$4,100	$4,100	$4,500	$4,500	$3,000	$3,900	—	—	$2,700	$4,200	$4,000	$4,000

MANUFACTURER AND MODEL NUMBER	Redcor RC-70	Scientific Control 4700	Spiras Systems 65	Systems Engineering Labs 810A	Systems Engineering Labs 810B	Tempo Computers Tempo 1	Texas Instruments 960	Texas Instruments 980	Varian 620-i	Varian 620-f	Westinghouse 2500	Westinghouse P-2000
MEMORY												
Memory Cycle Time, µs	0.860	0.920	1.8	1.75	0.750	0.9	1.0	1.0	1.8	0.750	0.750	3.0
Memory Word Length, Bits	16	16	16	16	16	16	16	16	16/18	16	16	16
Minimum Memory Size, Words	4K	4K	4K	4K	8K	4K	4K	4K	4K	4K	4K	4K
Memory Increment Size, Words	4K	4K	4K	4K	8K	4K	4K	4K	4K	4K	4K	4K
Maximum Memory Size, Words	16K	64K	64K	32K	32K	64K	64K	64K	32K	32K	64K	64K
Parity Check	Standard	Optional	None	Optional	Standard	Optional	Standard	Standard	Optional	Optional	Optional	None
Memory Protect	Standard	Optional	Yes	Optional	Optional	Optional	Optional	Optional	Optional	Optional	Optional	Optional
READ ONLY MEMORY	None	Standard	Standard	None	None	None	Standard	Standard	None	Optional	None	None
CPU FEATURES												
Instruction Word Length(s), Bits	16/32	16/32	16/32	16	16	16/32	16	16/32	16/32	16/32	16	16
Number of Accumulators or General-Purpose Registers That Can Be Used as Accumulators	1	3	4	2	2	2	2	4	2	2	2	1
Number of Hardware Registers Not Including Index Registers	5	10	6	2	2	7	7	8	6	6	16	16
Number of Index Registers (Hardware, Memory, or Other Technique)	1 Memory	1 Hardware	1	1 Hardware	2 Hardware	1 Hardware	1 Hardware	1 Hardware	2 Hardware	2 Hardware	2	2
Indirect Addressing (Multilevel, Single Level, or None)	Single Level	Multilevel	Multilevel	Multilevel	Multilevel	Multilevel	Multilevel	Multilevel	Multilevel	Multilevel	Multilevel	Multilevel
ARITHMETIC OPERATION CAPABILITY												
Add Time for Full Word, µs	1.9	1.84	3.6	3.5	1.5	1.8	6.0	2.0	3.6	1.5	2.0	5.5
Fixed-Point Hardware Multiply/Divide	Standard	Optional	Standard	Standard	Standard	Optional	None	Standard	Optional	Optional	Standard	Optional
Multiply, µs	6.2	6.44	17	7	4.5	7.0	—	6.5	10	5	5	28.6
Divide, µs	11.4	6.9	30	10.5	8.25	9.0	—	8.0	12	7	7	43.8
INPUT/OUTPUT CAPABILITY												
Data-Path Width, Bits	16	8/16	16	16	16	8/16	16	16	16/18	16	16	16
Direct Memory Access (DMA) Channel	Optional	Optional	Standard	Optional	Optional	Optional	Standard	Standard	Optional	Optional	Optional	Optional
Maximum DMA Word-Transfer Rate	1.1 MHz	1.1 MHz	500 KHz	572 KHz	1.33 MHz	800 KHz	1 MHz	1 MHz	200 KHz	1.3 MHz	850 KHz	300 KHz
Number of External Priority Interrupt Levels in Basic System	1	2	64	3	3	4	3	3	None	None	2	8
Maximum Number of External Interrupts	32	256	64	96	96	256	256	256	64	64	64	64
OTHER FEATURES												
Power Failure and Automatic Restart	Optional	Standard	Optional	Standard	Standard	Standard	Standard	Standard	Optional	Optional	Optional	Optional
Real-Time Clock or Internal Timer	Optional	Optional	Optional	Optional	Optional	Optional	Standard	Standard	Optional	Optional	Optional	Standard
SOFTWARE												
Assembler (1 Pass, 2 Pass, Both)	1 Pass	2 Pass	1 Pass	2 Pass	2 Pass	Both	2 Pass	2 Pass	2 Pass	2 Pass	1 Pass	2 Pass
Relocatable Assembler	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes
Minimum Core Size Necessary to Use Relocatable Assembler	4K	4K	4K	8K	8K	4K	—	4K	—	8K	4K	8K
Macro Assembler Capability	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes
Real-Time Executive Monitor Available	No	Yes	No	No	Yes	No	Yes	Yes	No	No	Yes	Yes
Disc Operating System Available	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes
BASIC MAINFRAME COSTS												
Basic System Price with 4K Words Including Power Supplies	$14,900	$14,900	$14,900	$18,000	N/A	$13,900	$14,500	$16,700	$9,950	$10,500	$9,950	$10,000
Total System Price Including ASR-33 Teletype and CPU	$16,700	$18,500	$16,800	$18,000	—	$15,600	$16,400	$18,600	$11,750	$12,300	$11,850	$15,000 (ASR-35)
Basic System Price with 8K Words Including Adequate Power Supplies, Enclosure, and Control Panel	$24,000	$22,300	$20,300	$23,000	$30,000	$19,700	$19,000	$21,200	$15,850	$13,000	$14,450	$17,400
Total System Price Including ASR-33 Teletype and CPU	$24,000	$24,000	$22,200	$23,000	$30,000	$21,500	$20,900	$23,100	$17,650	$14,800	$16,350	$22,400 (ASR-35)
PERIPHERALS AVAILABLE												
Magnetic Tape	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Approximate Price for Operational Unit Including Controller and Necessary Options	$12,000	$24,000	$12,900	$24,000	$30,000	$12,000	$12,265	$12,265	N/A	$27,900	$10,000	—
Mass Storage Device	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Approximate Price for Operational Unit Including Controller and Necessary Options	$15,000	$19,500	$20,000	$30,000	$34,000	$18,600	$23,200	$23,200	N/A	$22,500	$14,000	N/A
High-Speed Paper Tape Reader	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Speed, Characters per Second	300	300	300	300	300	400	300	300	300	300	300	300
Approximate Price of Operational Unit	$2,800	$3,000	$3,500	$4,000	$4,000	$2,700	$2,800	$3,250	$2,900	$2,900	$3,200	$3,000
High-Speed Paper Tape Punch	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Speed, Characters per Second	120		120	100	100	120	60	60	60	60	120	60
Approximate Price of Operational Unit	$4,000	$4,000	$3,950	$4,000	$4,000	$4,100	$3,000	$3,450	$3,300	$3,300	$2,900	$4,000

MANUFACTURER AND MODEL NUMBER	Xerox Data Systems Sigma 3	Digital Equipment PDP-8/E	Digital Equipment PDP-8/I	Digital Equipment PDP-8/L	Honeywell 112	General Automation SPC-12	Interdata Model 1	Motorola MDP-1000	Business Information Technology BIT-483	Computer Automation 208/808/108	Micro Systems 800	Micro Systems 810	Varian 620/i
MEMORY													
Memory Cycle Time, μs	0.975	1.2	1.5	1.6	1.69	2.0	1.0	2.16	0.96	2.6/6.0/1.6	1.1	1.1	1.8
Memory Word Length, Bits	16	12	12	12	12	8	8	8	8	8	8	8	8
Minimum Memory Size, Words	8K	4K	4K	4K	4K	4K	2K	4K	1K	4K	1K	1K	4K
Memory Increment Size, Words	8K	4K	4K	4K	4K	4K	2K	4K	4K	4K	1K, 4K	1K, 4K	4K
Maximum Memory Size, Words	64K	32K	32K	8K	8K	16K	16K	16K	64K	16K	32K	32K	32K
Parity Check	Standard	Optional	Optional	Optional	Optional	Optional	Optional	None	Optional	None	Optional	Optional	Optional
Memory Protect	Optional	Standard	Standard	Standard	Optional	None	Optional	None	None	None	Optional	Optional	Standard
READ ONLY MEMORY	None	None	None	None	None	Optional	Standard	None	None	None	Standard	Standard	None
CPU FEATURES													
Instruction Word Length(s), Bits	16/32	12	12/24	12/24	12	8/12/16	16	12	8/16	8/16	16	8/16/24	8/16
Number of Accumulators or General-Purpose Registers That Can Be Used as Accumulators	8	1	1	1	2	4	1	4	1	1	15(8)	2	7
Number of Hardware Registers Not Including Index Registers	2	4	4	4	9	8	—	9	11	8	15(8)	4	7
Number of Index Registers (Hardware, Memory, or Other Technique)	8 Hardware	8 Memory	8 Memory	8 Memory	None	3 Hardware	15 Memory	3 Hardware	None	None	—	1 Hardware	1 Hardware
Indirect Addressing (Multilevel, Single Level, or None)	Multilevel	Single Level	Single Level	Single Level	Single Level	Single Level	None	Single Level	Single Level	Multilevel	None	Single Level	Single Level
ARITHMETIC OPERATION CAPABILITY													
Add Time for Full Word, μs	1.95	2.6	3.0	3.0	7.63	4.2	3.0	4.32	2.3	5.3/24/3.2	10	10	4.5
Fixed-Point Hardware Multiply/Divide	Optional	Optional	Optional	None	None	None	None	None	None	None	None	None	None
Multiply, μs	7.80	3.3	4.8	—	—	—	—	—	—	—	—	—	—
Divide, μs	8.12	3.9	5.2	—	—	—	—	—	—	—	—	—	—
INPUT/OUTPUT CAPABILITY													
Data-Path Width, Bits	16	12	12	12	12	8/12	8	8	8	8	8	8	8/16
Direct Memory Access (DMA) Channel	Optional	Optional	Optional	Optional	Optional	Optional	Standard	Optional	Standard	Standard	Optional	Optional	Optional
Maximum DMA Word-Transfer Rate	850 KHz	833 KHz	666 KHz	625 KHz	295 KHz	430 KHz	1 MHz	400 KHz	1 MHz	68/25/120 KHz	910 KHz	910 KHz	660 KHz
Number of External Priority Interrupt Levels in Basic System	4	1	1	1	1	2	2	2	8	3	None	8	3
Maximum Number of External Interrupts	64	64	64	64	16	256	256	64	32	64	—	64	11
OTHER FEATURES													
Power Failure and Automatic Restart	Optional	Optional	Optional	Optional	Standard	Optional	Optional	Optional	Standard	Optional	Optional	Optional	Optional
Real-Time Clock or Internal Timer	Optional	Optional	Optional	Optional	Optional	Standard	Standard	Standard	Optional	Optional	Optional	Optional	Optional
SOFTWARE													
Assembler (1 Pass, 2 Pass, Both)	2 Pass	Both	Both	Both	2 Pass	1 Pass	Both	2 Pass	2 Pass	2 Pass	—	Both	2 Pass
Relocatable Assembler	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	—	No	Yes
Minimum Core Size Necessary to Use Relocatable Assembler	8K	8K	8K	8K	—	4K	4K	4K	N/A	—	—	—	4K
Macro Assembler Capability	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	—	No	No
Real-Time Executive Monitor Available	Yes	No	No	No	No	Yes	No	Yes	Yes	No	No	No	No
Disc Operating System Available	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	No	No	No
BASIC MAINFRAME COSTS													
Basic System Price with 4K Words Including Power Supplies	N/A	$4,990	$12,800	$8,500	$5,250	$5,000	$4,950	$8,500	$9,010	$5,190/$4,990/$5,490	$4,650	$6,430	$6,000
Total System Price Including ASR-33 Teletype and CPU	—	$6,490	$12,800	$8,500	$6,950	$6,200	$6,150	$9,700	$9,010	$7,200/$7,000/$7,800	$5,850	$7,630	$7,400
Basic System Price with 8K Words Including Adequate Power Supplies, Enclosure, and Control Panel	$24,000	$7,990	$16,300	$13,200	$7,910	$8,400	$7,350	$11,500	$11,250	$7,790/$7,690/$8,090	$6,750	$8,530	$8,500
Total System Price Including ASR-33 Teletype and CPU	$24,000	$9,490	$16,300	$13,200	$9,610	$9,600	$8,550	$12,700	$11,250	$9,500/$9,700/$10,100	$7,950	$9,730	$9,900
PERIPHERALS AVAILABLE													
Magnetic Tape	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
Approximate Price for Operational Unit Including Controller and Necessary Options	$25,000	$24,700	$24,700	$24,700	N/A	$11,000	$9,900	$18,000	$16,700/$22,800	$5,700/$10,000	—	—	$9,000
Mass Storage Device	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Approximate Price for Operational Unit Including Controller and Necessary Options	$26,000	$8,700	$8,700/$15,700	$8,700/$15,700	N/A	$6,000/$15,000	$17,400	$12,000/$19,500	$7,390	$8,500/$9,950	N/A	N/A	N/A
High-Speed Paper Tape Reader	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Speed, Characters per Second	300	300	300	300	300	300	300	300	300	300	300	300	300
Approximate Price of Operational Unit	Comb. $12,000	$2,000	$2,000	$2,000	$3,000	$3,000	$2,500	$3,000	$2,500	$2,200	$2,750	$2,750	$2,900
High-Speed Paper Tape Punch	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Speed, Characters per Second	120	50	50	50	—	120	60	120	60	60	110	110	60
Approximate Price of Operational Unit	Comb. $12,000	$2,000	$2,000	$2,000	—	$4,000	$3,800	$4,000	$3,950	$3,300	$3,000	$3,000	$3,300

APPENDIX B

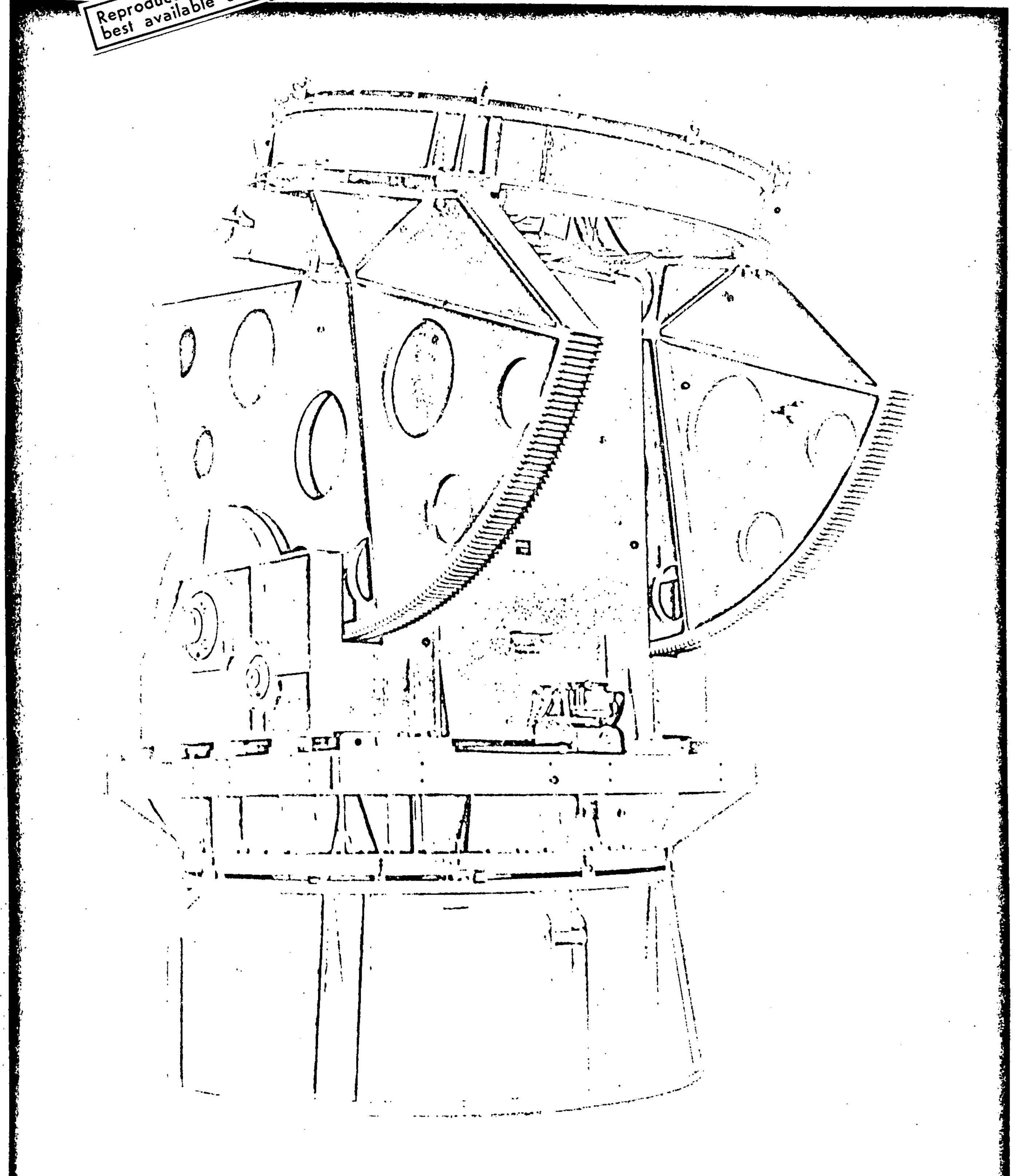
Vendor Briefs

Supplied here are copies of technical description material available from several manufacturers on critical hardware items in the various configuration designs. This material provides a good introduction to the equipment selected for the comparison study.

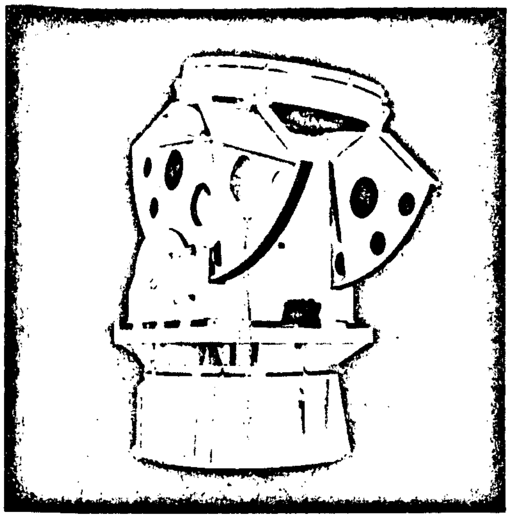
S-BAND ANTENNA POSITIONER

AND CONTROLS

Instrumentation Positioners
Series 5100-5500



Scientific-Atlanta



Scientific-Atlanta offers more than sixty standard instrumentation positioners for supporting and positioning test devices, antennas, model range towers, and test vehicles. Antenna pattern measurement, tracking, and precision positioning of test devices are a few of the applications for these positioners.

Scientific-Atlanta instrumentation positioners have proven their reliability the world over. In addition to meeting the strict requirements for standard antenna pattern measurements, these positioners are also suitable for automatic program operation and for use with Scientific-Atlanta digital recording systems. The Series 5100-5500 Positioners have been employed in a number of operational systems for DF, surveillance, and telemetry applications. These positioning systems are well suited for manual and semi-automatic operation where high performance, auto-track systems are not required.

There are five basic groups of positioners that comprise the Series 5100 through 5500. Within each group, which defines the axis orientation of the positioner, are specific model numbers based on load rating and various options. A wide selection of models in both single and multi-axis units are available to support loads ranging from 50 lbs. to 200 tons. The five basic groups of positioner are:

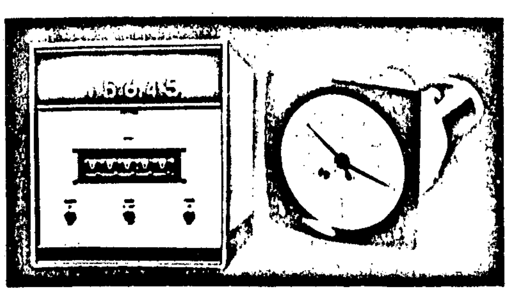
1. Series 5100 Azimuth
2. Series 5200 Elevation
3. Series 5300 Azimuth-over-Elevation
4. Series 5400 Elevation-over-Azimuth
5. Series 5500 Azimuth (Polarization)-over-Elevation-over-Azimuth

All of the positioners are equipped with DC drive motors in each axis so that speed and direction of rotation can be remotely controlled.

SYNCHRO ANGLE READOUT

All Scientific-Atlanta Series 5100-5500 Positioners are furnished with dual (1:1 and 36:1) synchro transmitters in each axis for position data take-off. The synchros can be connected to a Series 4400 Position Indicator, Model 1841 Digital Synchro Display, or a Scientific-Atlanta Pattern Recorder.

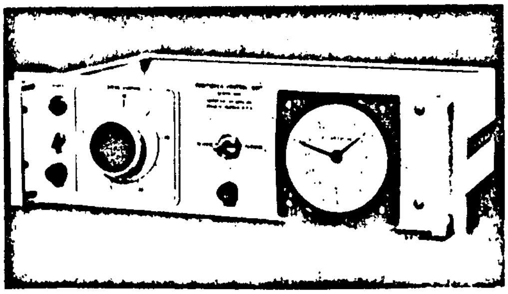
An anti-backlash gear assembly, independent of the drive-gear assembly, is used to drive the synchro data package. This method of direct gearing the synchro transmitters to the turntable minimizes the effect of torsional load stresses and drive train backlash on the positioner readout accuracy. The angular accuracy of the synchro readout depends on several factors (positioner size, gear train, electrical accuracy of synchro, etc.) and is specified for each positioner. The specified accuracies are for the positioner data pickoff and do not include errors in the indicator system.

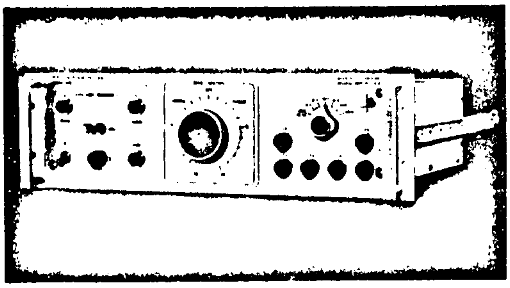


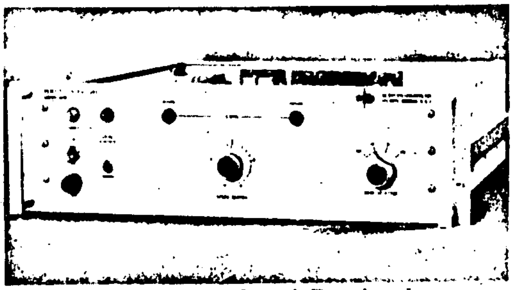
Model 1841 Digital Synchro Display

Series 4400 Position Indicator

CONTROL UNIT


Model 4111 Control Unit


Model 4112 Control Unit


Series 4100 Precision, Speed-Regulated Control Unit

The positioner control unit suggested for each positioner in the following specification charts is based on the minimum requirements for the positioner specified. For example, single-axis control units are recommended for the Series 5100 Azimuth and Series 5200 Elevation Positioners. For multi-axis positioners and single-axis positioners with model towers, multi-axis control units are recommended.

For additional information on control units including the precision, speed-regulated systems, please refer to the Series 4100 Positioner Controls data sheet.

For the dual axis (Series 5300 and 5400) positioners equipped with fractional horsepower motors, a dual-axis control unit, Model 4114, provides simultaneous, independent operation of each axis. Special positioner wiring is required for operation with the Model 4114 Control Unit, therefore, please add the suffix"–D" to the positioner model number for proper interface.

CONTROL CABLE

The suggested control cable listed in the following positioner specification charts is all-weather type cable that is suitable for above ground use or direct burial. The suggested cable assumes the application of a standard positioner configuration (with limit switch and dual synchro transmitters). The model number suffix indicates the number of conductors in the cable.

If special slip ring wiring is included in the positioner or an auxiliary assembly such as a model tower is to be added, please consult the factory or your local representative for assistance in selecting the appropriate control cable.

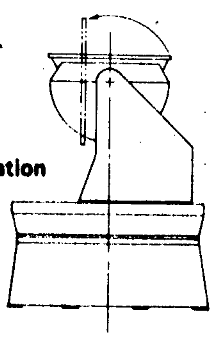
Because of the many possible cabling variations, assistance is also recommended in the selection of cables for systems employing speed-regulated control systems.

CONTINUOUS ROTATION

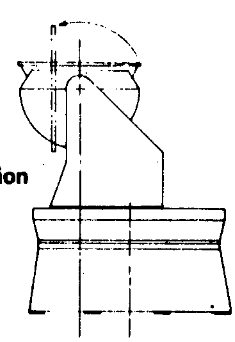
In many measurement applications it is desirable to provide continuous azimuth axis rotation of a positioner. The principal advantage of continuous rotation is the elimination of the time-consuming retrace to return to a starting point. Continuous rotation can be provided in the azimuth axis by the addition of a coaxial rotary joint and, when required, a slip ring assembly.

SERIES 5400 ELEVATION-OVER-AZIMUTH POSITIONERS

Characteristics	Model Numbers	5403-1	5405-3	5415-7	5423B-7	5426-7	5429-7	5431-20
Total Bending Moment (ft-lbs)		200	1,000	2,500	10,000	10,000	30,000	30,000
Total Vertical Load (lbs)		200	1,000	2,500	10,000	10,000	30,000	30,000
Drive Motor Horsepower	Elevation	1/15	1/3	1/2	3/4	3/4	3/4	2
	Azimuth	1/15	1/3	3/4	3/4	3/4	3/4	2
Delivered Torque (ft-lbs)	Elevation	200	1,000	2,500	10,000	10,000	30,000	30,000
	Azimuth	100	500	1,270	3,500	9,000	9,000	18,000
Withstand Torque (ft-lbs)	Elevation	200	1,000	2,500	10,000	10,000	30,000	30,000
	Azimuth	200	600	1,850	4,200	14,000	14,000	25,000
Max. Full Load Operating Speed	Elevation (deg/min)	180	200	145	40	40	20	50
	Azimuth (rpm)	1.3	1.3	1.2	0.5	0.2	0.2	0.3
Readout Position Accuracy	Elevation (deg)	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Azimuth (deg)	0.05	0.03	0.03	0.03	0.02	0.02	0.02
Total Max. Drive Gear Backlash	Elevation (deg)	0.10	0.08	0.05	0.05	0.05	0.03	0.03
	Azimuth (deg)	0.20	0.15	0.10	0.08	0.08	0.08	0.05
Total Elevation Limit-To-Limit Travel (degrees)		+91,−64	+95,−45	+95,−45	+92,−45	+92,−45	+92,−45	+92,−45
Platform Size (inches)		12x13-1/2	(1)	28x28	36x36	36x36	42x42	42x42
Azimuth Center Access Hole Diameter (inches)		3-3/4	3	3	3	6	6	6
Base Outside Diameter (inches)		(2)	24	28-3/4	36	56	56	56
Total Height at 0° Elevation (inches)		31-3/8	35-1/2	45-1/2	53-1/4	83-1/8	90	90
Recommended Positioner Control		4112	4112	4112	4112	4112	4112	4123
Recommended Cable		2 ea 5051-12						(3)
Net Weight (lbs)		205	480	800	1,450	4,100	4,850	5,270
Shipping Weight (lbs)		270	585	960	1,720	4,580	5,480	5,900
Option "−R" Coaxial Rotary Joint (Az Axis only)		YES	YES	YES	YES	YES	YES	YES
Option "−T" Tachometer (Speed Control)		NA	YES	YES	YES	YES	YES	STD
Option "−16" 16-Conductor Slip Ring (Az axis only)		NA	YES	YES	YES	YES	YES	(4)
Option "−24" 24-Conductor Slip Ring (Az axis only)		NA	YES	YES	YES	YES	YES	(4)
Option "−32" 32-Conductor Slip Ring (Az axis only)		NA	NA	NA	NA	YES	YES	(4)



"C" Configuration



"E" Configuration

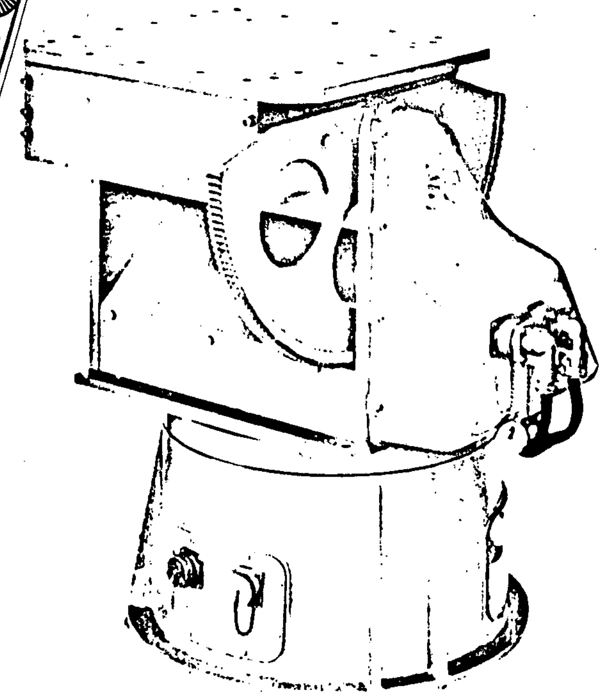
Series 5400 Elevation-Over-Azimuth Antenna Positioners permit the rotation of elevation at fixed positions of azimuth. This particular orthogonal operation is desired in a telemetry application. The positioners listed above may be considered for operation in a temperate climate or within the confines of a radome for a low cost, manual telemetry application. For the majority of tracking situations, however, the Series 3000 Positioners described in a separate engineering data sheet will offer significantly more flexibility.

The Series 5400 Positioners are normally assembled in the "E" configuration as shown in the diagram. The "C" configuration, as shown in the diagram, is available on all models except the Model 5403-1. Please specify the "C" configuration by adding the suffix "−C" to the positioner model number.

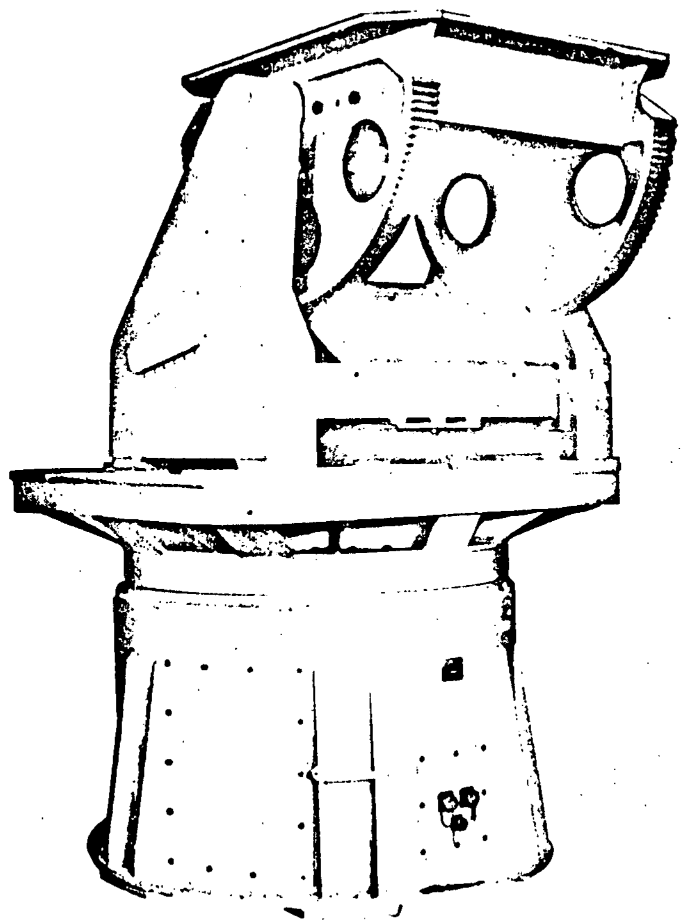
1. 18-1/2 x 21-3/8.
2. 13-1/4 x 17-1/8.
3. Consult factory.
4. Special slip ring required for positioners with 2 and 5 hp drive motors.

5445-20	5445-50	5446-20	5447-50
75,000	75,000	75,000	75,000
40,000	40,000	40,000	40,000
2	5	2	5
2	5	2	5
75,000	75,000	75,000	75,000
18,000	18,000	30,000	65,000
75,000	75,000	75,000	75,000
25,000	25,000	42,000	65,000
15	45	15	45
0.3	0.9	0.14	0.16
0.05	0.05	0.05	0.05
0.02	0.02	0.02	0.02
0.03	0.03	0.03	0.03
0.05	0.05	0.05	0.04
+92,−45	+92,−45	+92,−45	+92,−45
50x50	50x50	50x50	50x50
6	6	8	8
56	56	76	76
106-3/4	106-3/4	108-3/4	108-3/4
4123	4153	4123	4153
(3)	(3)	(3)	(3)
9,400	9,500	18,000	18,000
10,000	11,000	NA	NA

YES	YES	YES	YES
STD	STD	STD	STD
(4)	(4)	(4)	(4)
(4)	(4)	(4)	(4)
(4)	(4)	(4)	(4)

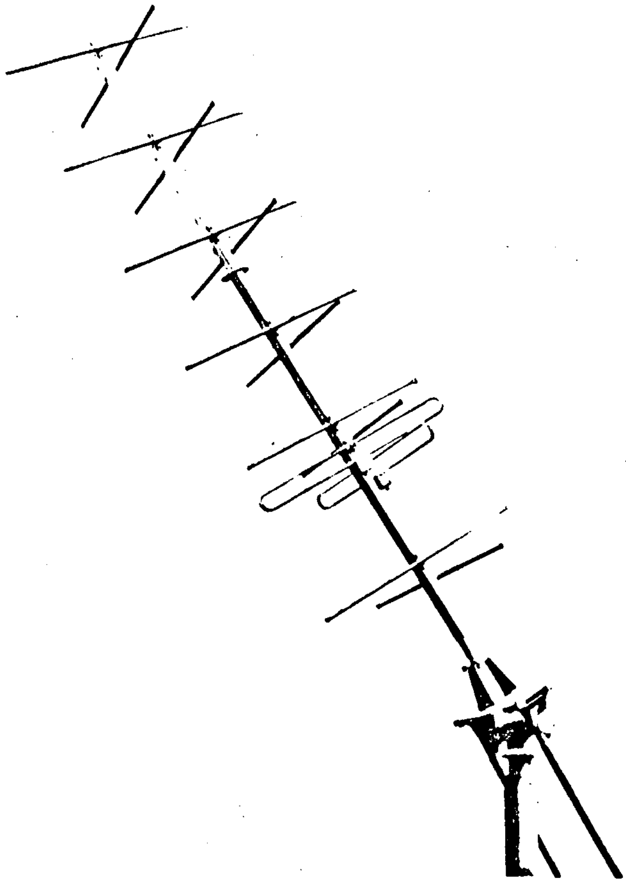


Model 5405-3



Model 5429-7

VHF ANTENNA



TACO cross-polarized yagi antennas comprise two discrete yagis mounted on a common crossarm and orthogonal to each other. These antennas are designed for use singly or in multiple arrays, having been originally designed for use aboard TACO's many monopulse tracking and telemetry arrays. Each TACO cross-polarized yagi is ruggedly constructed of high-strength aluminum and is designed to withstand severe environmental conditions. Two grades are available, as indicated in the Model number; XY for rugged and XYR for extra rugged. Dual output models may be fed in-phase for vertical polarization, 180° out-of-phase for horizontal polarization, or 90° leading or lagging for RH or LH circular polarization.

OPTIONAL according to your requirements are:

- Polarization (RH or LH circular) single output or dual output
- Type of connector (N, HN, C or LC; single or dual output)
- Finish or color (iridite, vinyl gray, NASA white or special)
- Mount-stub length (6 to 30 in.,) or flange w/no stub

[Please specify the above when ordering or requesting a quotation.]

TYPICAL CROSS-POLARIZED YAGI

ELECTRICAL

Model	Freq. (MHz)	Gain (dBic)	E-PLANE (Typ.) HPBW (deg.)	E-PLANE (Typ.) Side-Lobes (dB)	H-PLANE (Typ.) HPBW (deg.)	H-PLANE (Typ.) Side-Lobes (dB)	Axial Ratio (dB)	F-B Ratio (dB)	Nom. VSWR	TERMINAL Type	TERMINAL Imp	CW Pwr. (W)
XY-072	123.0	11.5	41.5	-15.0	46.5	- 9.0	2.0	22.0	<1.5:1	N(2)	50	500
XY-092	123.0	12.0	32.0	-12.0	36.0	- 9.5	4.0	22.0	<1.4:1	N(2)	50	500
XYR-092*	123.0	12.5	41.0	-15.0	43.0	- 7.0	3.0	22.0	<1.2:1	N(2)	50	500
XY-102	123.0	13.0	37.0	-11.0	41.0	- 9.5	3.0	23.0	<1.3:1	N(2)	50	500
XYR-033*	137.0	7.0	39.0	-17.0	45.0	-10.0	2.0	16.0	<1.5:1	N(2)	50	500
XY-073	136.5	12.0	42.0	-13.0	48.0	- 8.0	3.0	23.0	<1.4:1	N(2)	50	500
XY-093	136.5	12.5	34.0	-13.0	33.0	- 9.5	3.0	22.0	<1.4:1	N(2)	50	500
XYR-093*	137.0	12.0	39.0	-17.0	45.0	-10.0	2.0	22.0	<1.2:1	N(2)	50	500
XY-113	136.5	13.5	35.0	-16.0	34.0	- 9.5	3.0	23.0	<1.3:1	N(2)	50	500
XYR-113*	137.0	12.5	46.5	-13.0	46.0	-12.5	1.0	20.0	<1.5:1	N**	50	250
XY-074	148.0	12.0	32.0	-13.0	29.0	-11.0	4.0	23.0	<1.3:1	N(2)	50	500
XY-094	148.0	13.0	39.0	-17.5	39.0	- 9.5	3.0	22.0	<1.4:1	N(2)	50	500
XYR-094*	148.0	12.0	40.0	-16.0	45.0	-13.0	2.0	22.0	<1.2:1	N(2)	50	500

*EXTRA-RUGGED CONSTRUCTION
**OPTIONAL: RH OR LH CIRCULAR POLARIZATION

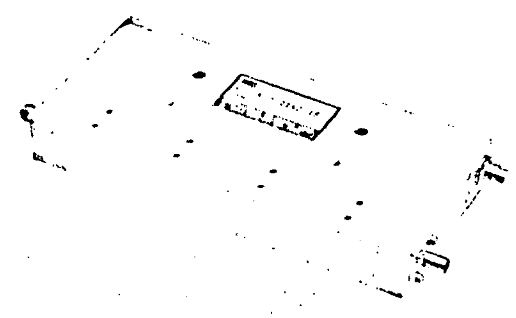
S-BAND PREAMPLIFIER

DATA SHEET MTA-2

MICROWAVE TRANSISTOR AMPLIFIERS 1.2-4.2 GHz

GENERAL

Exceptionally low noise figures, which characterize these amplifiers, and the good input and output matches, are a result of a unique interstage coupling technique. This coupling method provides high efficiency per transistor stage and a maximally flat response with filter type skirts. IMC has provided low noise space qualified units and now incorporates these space qualified design features on all our Microwave Transistor Amplifiers for increased reliability. This reliability is due to the increased transistor stage efficiency thus requiring fewer stages, simplified designs utilizing fewer components and milled aluminum housings providing excellent heat dissipation. All IMC amplifiers are unconditionally stable under all environmental and load conditions. They exhibit negligible gain and pass band flatness variation with temperature. International Microwave's Microwave Transistor Amplifiers are ideal as low noise preamplifiers for telemetry, communications and radar; IF Amplifiers for high IF receivers, and Repeater Amplifiers for systems where passive repeaters are not sufficient.



DESIGN FEATURES

1) **Lowest noise figure of any advertised MTA's**
2) **Space qualified models available**
3) **Excellent input match (VSWR as low as 1.2:1)**
4) **Unconditionally stable**

SPECIFICATIONS

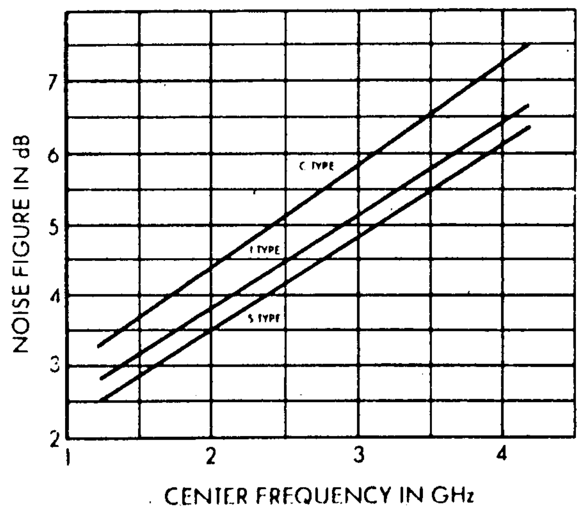
Model	High Performance (S)	Isolated Broadband (I)	Standard (C)
Frequency Range	1.2-4.2 GHz	1.2-4.2 GHz	1.2-4.2 GHz
Bandwidth (1 dB PT.)	Up to 20%	Up to 35%	Up to 10%
Noise Figure	2.5-6.3 dB	2.8-6.8 dB	3.0-7.5 dB
Gain	10-40 dB	10-30 dB	10-40 dB
Gain Flatness	±0.5 dB	±0.75 dB	±0.5 dB
Output Power for 1 dB Compression**	+10 dBm Max.	+10 dBm Max.	0 dBm Max.
VSWR: Input	1.25*	1.2	1.5
Output	1.5	1.5	1.8
Operating Temperature	−55 to +85°C	−55 to +85°C	−20 to +71°C
Maximum RF Input Power	5W peak, o.5W average		
Supply Voltages	+12 to +28V DC, −12 to −28V DC, 110V AC, 220V AC		
Connectors, Input and Output	TNC, N, SMA		
Connectors Power	DC – Selectro 3032 or Solder Terminal AC – PT02E-8-4P		

OPTIONS: 1) Gain (±0.25 dB) and Phase (±3°) matching can be provided over 10% bandwidths.
2) TDA – MTA combinations are available providing extra low noise figure and increased dynamic range for any frequency from 3.7 – 5.0 GHz.

*Input VSWR over middle 10% bandwidth.
**Refer to curve on back of sheet.

IMC INTERNATIONAL MICROWAVE CORPORATION 33 RIVER ROAD / COS COB / CONN / 06807 / USA
PHONE 203-661-5924 / TWX 710-579-2925

NOISE FIGURE vs FREQUENCY



ORDERING INFORMATION

S—High Performance MTA
I—Isolated, Broadband MTA
C—Standard MTA

Bandwidth : 10

Center Frequency (MHz)

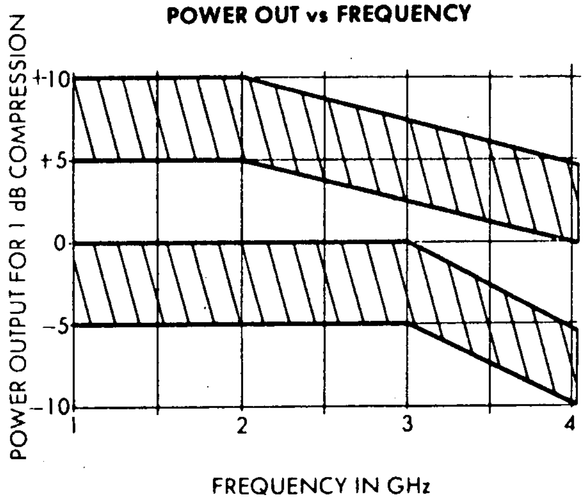
Gain (dB)

SUFFIXES

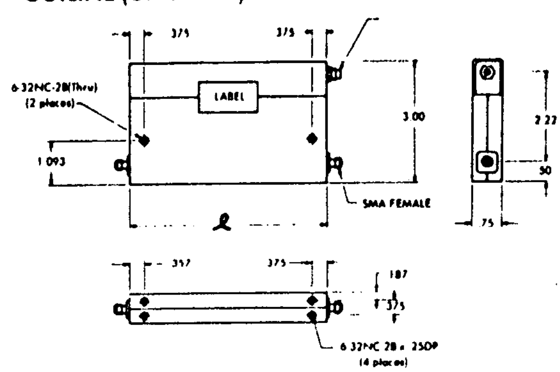
NONE –Uncased, –12V DC
C –Cased, weatherproof –12V DC
CA –Cased, 110V ac
CF –Cased, 220V AC
S –Special Power, Specify
CS –Cased special power

S | 05 | 2000 | 20 | C — Designates special low noise unit with 2 GHz center frequency, BW - 50 MHz, Gain 20 dB, cased, -12V DC.

POWER OUT vs FREQUENCY



OUTLINE (UNCASED)



LENGTH vs NUMBER OF STAGES

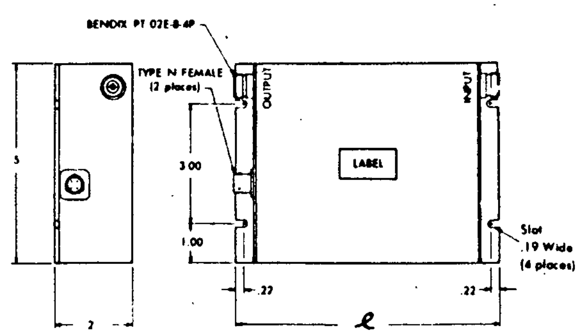
Number of Stages	Length (ℓ)							
	Uncased				Cased			
	1 GHz	2 GHz	3 GHz	4 GHz	1 GHz	2 GHz	3 GHz	4 GHz
2	3 4	3 1	2.9	2.7	5.05	4 7	3.5	3.3
3	5 0	4 25	3 8	3 5	6.75	6.0	5 5	4.2
4	6.7	5 4	4.8	4.25	8.45	7 0	6 4	5.8

NOTES: 1) For isolated units with video bandwidths, add 1.1 inches to length.
2) Dimensions are typical. Smaller units available.

TYPICAL UNIT SPECIFICATIONS

Model No.	Frequency (GHz)	Noise Figure (dB)	Gain (dB)	VSWR In Out	Gain Flatness	Operating Voltage and Current
C10 1200 20	1 15 1 25	3.5	20	1 5 1.8	±0 5	+12V DC ≈15 mA
S10 1500 17CA	1 45 1 55	3 1	17	1 25 1.5	±0.5	110V AC CASED
I70 2050 18S	1 7 2 4	4 5	18	1 2 1 2	±0 75	+24V DC ≈15 mA
C20 2000 15S	1 9 2 1	5 1	15	1 5 1 8	±0 5	+24V DC ≈15 mA
S10 2250 30CS	2 2 2 3	3 8	30	1 25 1 5	±0 5	+28V DC ≈30 mA
S50 3950-20	3 7 4 2	6.0	20	1 25 1 5	±0 5	+12V DC ≈15 mA

OUTLINE (CASED)



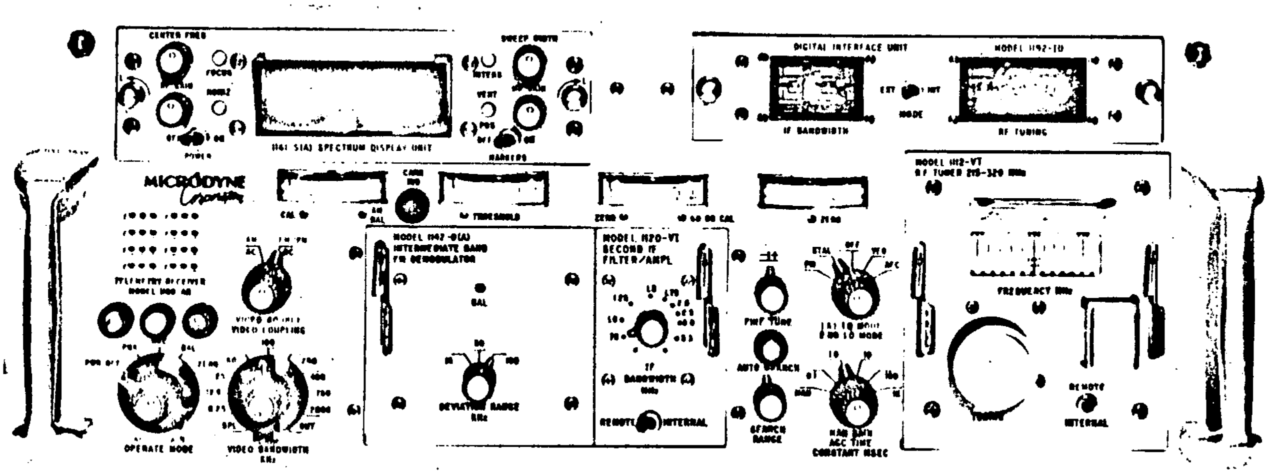
INTERNATIONAL MICROWAVE CORPORATION
33 RIVER ROAD / COS COB / CONN / 06807 / USA
PHONE 203-661-5924 / TWX 710-579-2925

S-BAND RECEIVER

MICRODYNE Corporation

1100-AR TELEMETRY RECEIVER

"a second-generation integrated circuit telemetry receiver"



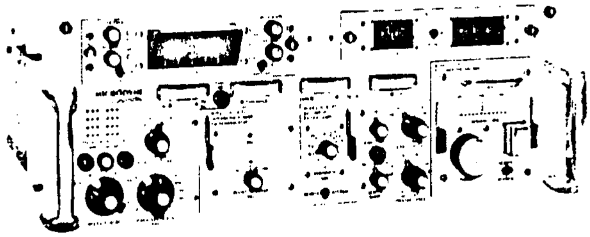
- **ELECTRONIC TUNING** — Standard Voltage Tuned RF tuner modules and Second IF filter/amplifier modules for operation in either local or remote modes.
- **INTEGRATED CIRCUIT DESIGN** — Increases receiver reliability to a calculated MTBF in excess of 7500 hours. Increases maintainability so that MTR is approximately 15 minutes.
- **OPTIMUM IF PHASE LINEARITY AND SELECTIVITY** — No filter shape factor compromise or degrading of overall receiver selectivity.
- **FREQUENCY CORRECTION DURING PRE-D PLAYBACK** — Receiver accepts 10 MHz playback data from any one Pre-D up converter and translates the spectrum to first IF frequency for demodulation rather than the second IF.
- **AUTOMATIC SEARCH AND ACQUISITION AFC** — Entire cycle is completely automatic at any input level between threshold and 0 dBm.
- **HIGH PERFORMANCE AFC** — Any error at the 10 MHz input is compensated by high drift reduction AFC/APC action and the spectrum is balanced around f_c rather than offset by the accumulated error.

The First Computer Programmable Telemetry Receiver Featuring Electronic Tuning and Electronic Bandwidth Adjustment

GENERAL DESCRIPTION

PERFORMANCE

The Microdyne Model 1100-AR Telemetry Data and Tracking receiver is an advanced general purpose telemetry receiver featuring solid-state design through full use of integrated circuits and subminiature components. The 1100-AR is capable of receiving and processing any telemetry data format. The standard frequency ranges include 105 to 2300 MHz. Through its electronic tuning capabilities, the 1100-AR may be operated by remote control or integrated into a computerized receiving system.



ELECTRONIC TUNING

Standard modules available for use with the 1100-AR include voltage tuned RF tuner modules and voltage tuned second IF filter/amplifier modules. These modules may be operated in either local or remote modes. Front panel controls are provided for local tuning and bandwidth selection; a rear panel connector is provided to control the logic functions to allow remote tuning and bandwidth selection.

INTEGRATED CIRCUIT DESIGN

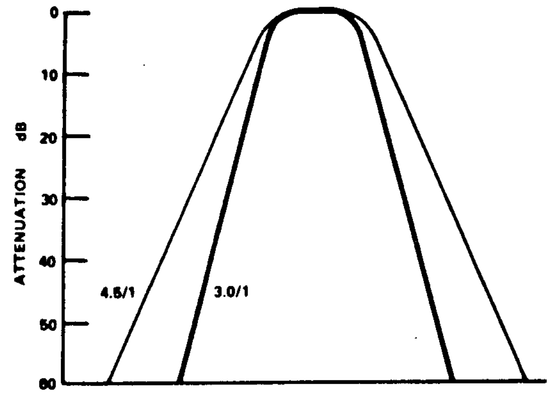
The use of monolithic integrated circuits reduces component density and increases overall receiver reliability to a calculated MTBF in excess of 7500 hours. Reduced component density increases maintainability to the extent that the MTR for the 1100-AR is approximately 15 minutes. Total modular design also simplifies spare parts provisioning. A further advantage of the reduced component density is the ability to provide optimum operational capabilities in a given amount of rack space.

OPTIMIZED GAIN DISTRIBUTION

Gain distribution is optimized by controlling signal and noise levels at all receiver interface points. Receiver gain, prior to 2nd IF band limiting, is as low as possible to achieve optimum receiver noise figure characteristics. The overall result is the industry's first receiver capable of meeting the stringent intermodulation requirements of present day telemetry users.

OPTIMUM IF PHASE LINEARITY AND SELECTIVITY

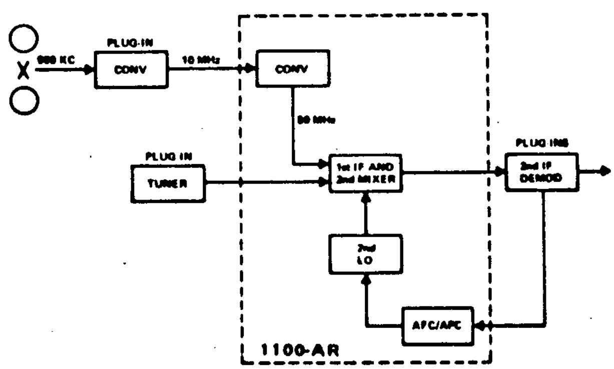
The 1100-AR employs linear-phase steep-skirted IF filters to optimize phase non-linearity in the 2nd IF filter amplifier without compromising the filter shape factor and subsequently degrading overall receiver selectivity. Normally, the steep-skirted filters provide an 8° phase linearity (within 80% of the -3 dB passband) while maintaining a 3.0:1 shape factor for all IF filters having bandwidths of 100 KHz or greater.



Comparison of IF Selectivity, 4.5/1 vs 3.0/1 Shape Factors

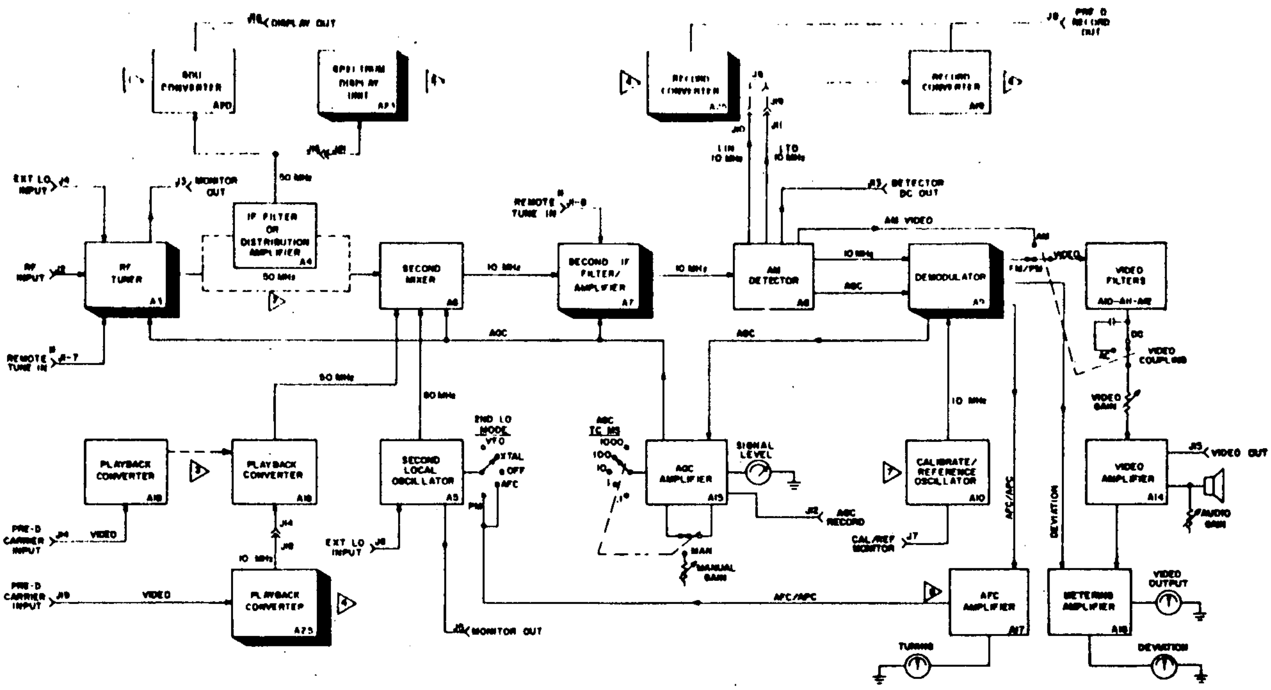
FREQUENCY CORRECTION DURING PLAYBACK

To compensate for frequency offset, introduced in the record and playback of Pre-D data and the resulting degradation caused by non-symmetrical passage of data through the second IF filter, the 1100-AR accepts 10 MHz playback data from any one Pre-D up-converter and translates the spectrum to the first IF frequency for demodulation rather than the second IF. Any error at the 10 MHz input to the receiver is compensated by high drift reduction AFC/APC action and the spectrum is balanced around f_c rather than offset by the accumulated error.



BASIC RECEIVER CONFIGURATIONS

Physically, the receiver is offered in two basic configurations: the 1100-AR and the 1100-AR(5). Both configurations are composed of the front panel, base chassis, and a module complement consisting of front panel and internal plug-in units. Additionally, the 1100-AR includes front panel mounting provisions for a spectrum display and a Pre-D converter.



1100-AR Functional Block Diagram

Functionally, the building block concept of modular construction allows the 1100-AR to be configured for a wide variety of purposes and uses. In its most basic configuration it is a low cost general purpose receiver while in the other configuration it is a complex data receiver with Pre-D record and playback capabilities, automatic search and lock for signal acquisition, and spectrum analysis. If desired, the unit can be completely controlled by a computer or from a remote location.

Remote/computer control is made possible by the electronic tuning features of the RF tuners and second IF filter/amplifiers developed by Microdyne. Through use of the appropriate digital interface units, the voltage tuned units can be controlled in frequency and bandwidth by analog inputs derived from digital information supplied by a computer or remote control console.

Other advanced features available include the choice of two types of AFC circuitry. One circuit offers the greatest economic advantage by providing high drift reduction AFC only: the other provides variable automatic search and lock as well as high drift reduction AFC. The front panel adjustable search continues until a threshold signal appears in the 2nd IF passband. At this point receiver lock is automatically accomplished.

Front panel controls are grouped logically for ease of operation with concentric switches used in related areas. Multicolor lamps indicate playback, receive, or calibration operating modes, carrier present, and automatic search. Meters display video output level, signal level, loop stress, and deviation. Calibration controls are conveniently located adjacent to each respective meter.

APPLICATIONS

PREDETECTION RECORDING

The 1100-AR can be used in predetection recording systems. An auxiliary front panel plug-in slot can accommodate either an 1181-PP(A) Predetection Playback Converter or an 1171-PR(A) Predetection Record Converter. These units provide a full capability for Pre-D up and Pre-D down conversion with a choice of six switch selectable record frequencies. Single frequency up and down converters are also available as internal plug-in modules.

DIVERSITY COMBINING

The 1100-AR Receivers are also adaptable to Predetection or Postdetection diversity combining applications. The receiver AGC outputs which are available for controlling the combiner also have several operational advantages. These include reversible polarity, adjustable slope, and a zero offset adjustment.

Additionally, the Receiver furnishes two logic signals indicating loss of carrier and AFC/APC search. Microdyne Combiners use these signals to prevent combined output degradation during a loss of carrier in one channel.

REMOTE/COMPUTER CONTROL

The 1100-AR is capable of operation in an unattended environment. The receiver operating frequency and the 2nd IF Bandwidth can be selected and optimized from a remote location by means of the electronic tuning features included within the receiver. An automatic search AFC insures signal acquisition or reacquisition without the need of operator intervention.

SPECIFICATIONS

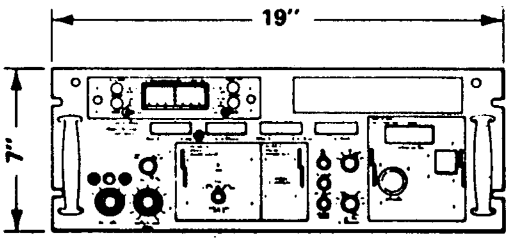
Electrical:

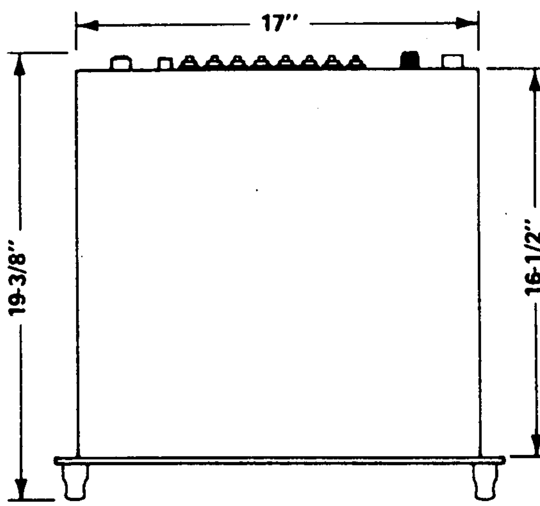
Receiver Type	Double superheterodyne; 50 MHz first IF; 10 MHz second IF.
Frequency Range	105-6000 MHz as determined by plug-in RF tuner.
Input Impedance	50 ohms, unbalanced.
Noise Figure	5.5 to 10.0 dB depending on RF tuner used.
VSWR	2.7 maximum, depending on RF tuner used.
Image Rejection	80 dB minimum.
IF Rejection	90 dB minimum.
Dynamic Range	Threshold to -10 dBm (threshold is defined as a 6 dB signal-to-noise ratio in the 2nd IF Passband).
First LO Characteristics:	
Modes	Switch selectable VFO, crystal, off (external input).
Stability	
VFO	±0.001% per degree C.
Crystal	±0.0005% with oven, 0.005% without oven.
Second LO Characteristics:	
Modes	Switch selectable, VFO, crystal, AFC, PM, off (external input).
Stability	
VFO	±0.001% per degree C.
Crystal	±0.005%
AFC Characteristics:	
Tracking Range	±400 KHz in addition to ±250 KHz vernier control.
Acquisition Range	Up to ±400 KHz from center frequencies in addition to ±250 KHz vernier control.
Drift Rejection Factor	Up to 10,000:1.
Search Range	50 KHz to greater than 800 KHz; approximately symmetrical about second LO frequency as set by front panel vernier control.
Search Rate	1.5 MHz/second.
PM Characteristics:	
Control Range	+250 KHz in addition to second LO vernier range.
Search Range	50 KHz to greater than 250 KHz; approximately symmetrical about second LO frequency set by fine tune control.
Phase Loop Bandwidth	10, 30, 100, 300, 1000 Hz as determined by positioning of PM demodulator loop bandwidth switch.
Demodulation:	
FM Demodulation	Refer to FM demodulator specifications.
PM Demodulation	Refer to PM demodulator specifications.
AM Demodulation:	
AM Response	5 Hz to one-half IF bandwidth (1.6 MHz maximum).
AM Distortion	Less than 3% with 90% modulation at a 1 KHz rate.
AGC Time Constant	Switch selectable; 0.1, 1.0, 10, 100, 1000 msec. normally supplied. Others available.
Video Characteristics:	
Output Impedance	75 ohms.
Rated Output	4 volts peak-to-peak.
Maximum Output	10 volts peak-to-peak.
Distortion	Less than 0.5% at rated output; less than 1% maximum output.
Source	Plug-in demodulator or AM detector.
Coupling	AC or DC; switch selectable.
Response	AC coupled - 5 Hz to 2.0 MHz + 1.0 dB, -3 dB. DC coupled - DC to 2.0 MHz + 1.0 dB, -3 dB.
Power Requirements	115/230V AC ±10%, 50-400 Hz, 50 watts maximum.

SPECIFICATIONS (con't)

Environmental:	
Temperature Range:	
Storage	-62° to $+65^{\circ}$C.
Operating	0° to $+50^{\circ}$C.
Atmospheric Pressure:	
Storage	to 50,000 feet.
Operating	to 15,000 feet.
Humidity	Up to 95% relative
Mechanical:	
Height	5-7/32 1100-AR(5); 7-31/43 1100-AR.
Width	19 inches.
Depth	19-1/4 inches.
Weight	1100-AR(5) approximately 35 pounds. 1100-AR approximately 42 pounds.

DIMENSIONS





REAR PANEL CONNECTIONS

J1 ACCESSORY CONNECTOR – DC voltage outputs, loop lock monitoring, "carrier on" relav contacts, and remote tuning of the IF bandwidth and RF tuner.

J2 RF IN: Input to tuner, 50 ohms, unbalanced.

J3 1ST LO OUT: Output for monitoring submultiple of first LO injection frequency, 50 ohms, -13 dBm nominal level.

*J4 1ST LO IN: Input for injecting external submultiple for first LO, 50 ohms, -13 dBm nominal level.

J5 2ND LO OUT: Output for monitoring second LO injection frequency, 60 MHz +0.5 MHz, 50 ohms, -13 dBm nominal level.

*J6 2ND LO IN: Input for injecting external second LO frequency, 60 MHz +0.5 MHz, 50 ohms, -13 dBm nominal level.

J7 REF OSC OUT: Output for monitoring calibration/reference oscillator, 10 MHz, 50 ohms, -13 dBm nominal level.

**J8 PRE-D REC OUT: Output from optional record converter. Choice of 900, 800, 600, 450, 225, and 112.5 KHz 75 ohms, 4V p-p level.

**J9 PRE-D CONV IN: Input to predetection record converter, 10 MHz, 75 ohms, 4V p-p level.

*J10 10 MHz OUTPUT LTD: Output for limited 2nd IF signal, 50 ohms, -10 dBm nominal level.

J11 10 MHz OUTPUT LIN: Output for linear 2nd IF signal, 50 ohms, -10 dBm nominal level.

J12 AGC REC OUT: Record output from AGC amplifier, 0 to 8 volts into 1K load, polarity selectable.

*J13 AM DET DC OUT: High impedance monitor output for AM detector.

**J14 PBK IN: Input to internal playback converter, record carrier or 10 MHz depending on configuration, 50 ohms.

J15 VIDEO OUT: Output for filtered video signals, 75 ohms, 10V p-p maximum

J16 DISPLAY OUT: Output for external SDU, 50 MHz, 50 ohms (30 MHz, 50 ohms, optional).

J17 POWER IN: Input for AC power.

*J18 AUX (ACC) OUT: Output from front panel predetection playback or record converter, 75/50 ohms.

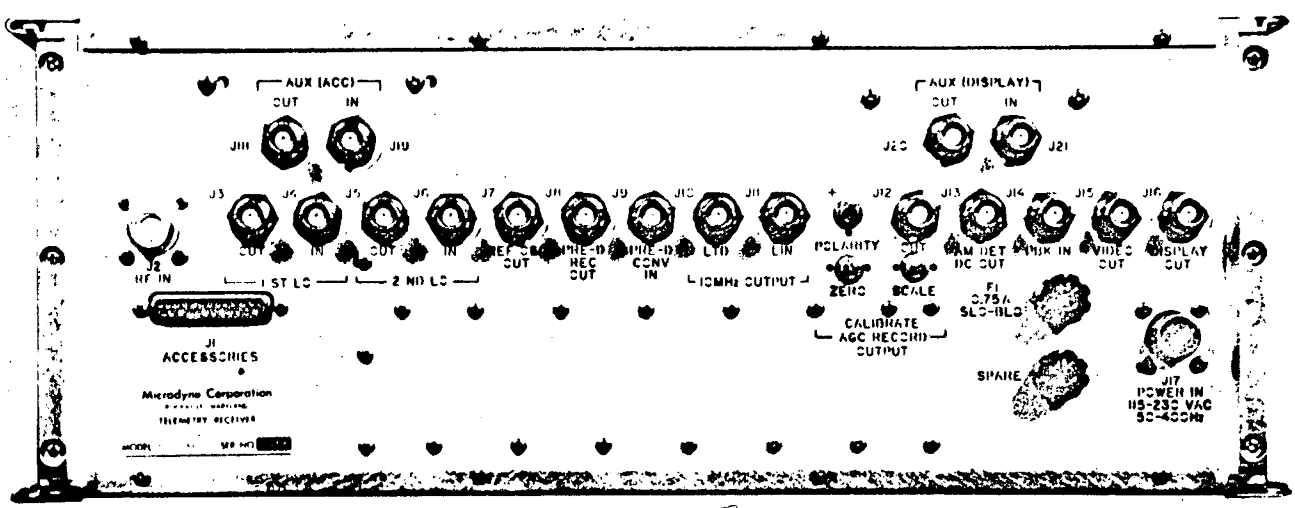
*J19 AUX (ACC) IN: Input to front panel predetection playback or record converter, 50 ohms.

J20 AUX (DISPLAY): Output.

J21 AUX (DISPLAY): Input to front panel spectrum display unit, 50 MHz, 50 ohms.

NOTE: The rear panel output connections as indicated "NON ASTERISK" are standard items supplied with the receiver.
Any one or a combination of those BNC rear panel connections shown with a "SINGLE ASTERISK" will be supplied for a nominal additional charge.

**These BNC rear panel connectors are required ONLY when the associated OPTIONAL plug-in modules are included in the receiver, base chassis.



RF TUNERS

The Microdyne series of RF tuners includes both manually and electronically tuned units. The electronically tuned units feature voltage tuned pre-selector and local oscillators. These units may be used for operation under remote control and are also available in weatherized antenna mounting configurations.

A VT suffix indicates voltage tuned units; the T(A) series is mechanically tuned. RF tuners with a VT(2) through VT(10) suffix offer discrete programmable selection of up to 10 independent fixed frequencies for crystal controlled operation. All of the RF tuners as a result of their superior design have improved image and IF rejection, excellent intermodulation characteristics, and substantially reduced first LO radiation.

SPECIFICATIONS

Input Impedance:
50 ohms nominal

Noise Figure:
5.5 to 10.0 dB depending on model

Image Rejection:
80 dB minimum

IF Rejection:
90 dB minimum

Spurious Rejection:
60 dB minimum

First Local Oscillator Type:
Crystal or VFO controlled by mode switch on base chassis.

LO Tracking:
50 MHz above RF input

LO Stability:
VFO 0.001% per degree C
Crystal 0.005% without oven
Crystal 0.0005% with oven

LO Radiation:
-81 dBm (20 uv) maximum
-87 dBm on special order

First IF Frequency:
50 MHz

First IF Bandwidth:
3.5 to 6.0 MHz depending on tuner

First IF Filters:
Narrow, standard, and wideband filters plug into base chassis. Standard bandwidths are 600 KHz, 1.25 MHz, 4.0 MHz and 7.0 MHz.

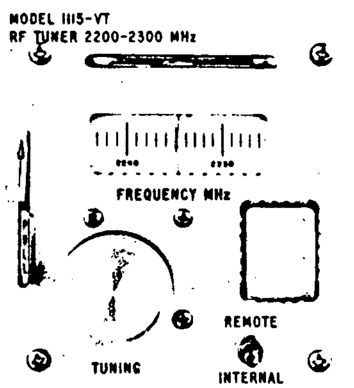
STANDARD RF TUNERS

		NOISE FIGURE	
Model	Frequency (MHz)	Max. dB	Nominal dB
1111-T(A)	105-155	5.5	4.5
1111-VT	105-155	5.5	4.5
1111-VT(T)	162-174	6.5	5.0
1112-T(A)	215-320	6.5	5.0
1112-VT	215-320	6.5	5.0
1112-VT(4)	215-320	6.5	5.0
1112-VT(10)	215-320	6.5	5.0
1113-T(A)	285-410	7.5	6.0
1113-VT	285-410	7.5	6.0
1114-T(A)	1435-1540	10.0	9.0
*1114-T(L)	1430-1553	10.0	9.0
1114-VT	1435-1540	10.0	9.0
1115-T(A)	2200-2300	10.0	9.0
1115-VT	2200-2300	10.0	9.0
*1116-T(A)	1700-1800 or 1750-1850 (specify)	10.0	9.5
*1116-T(A)(N)	1640-1720	10.0	9.5
*1116-T(A)(S)	1540-1660	10.0	9.5
*1116-VT	1700-1800 or 1750-1850 (specify)	10.0	9.5
1117-T(A)	215-410	8.5	6.5

* Units available upon special order.

MODELS

1114-VT, 1115-VT, 1116-VT, RF Tuners for S and L Bands.



These S and L-Band Tuners feature all electronic tuning achieved with a unique solid-state tuning element. This approach eliminates mechanical tuning either contacting or non-contacting and results in greatly improved reliability.

Tuning is accomplished with a potentiometer located on the front panel. A front panel LOCAL/REMOTE switch can be used to transfer the tuning function to the rear panel accessory connector and tuning can be accomplished from a remote location or computer interface.

Another advantage of this tuner is the elimination of backlash and wear to gear trains and mechanically tuned preselectors. The tuning element is a ten-turn conductive plastic potentiometer with infinite resolution.

SPECIFICATIONS

Tuning Range:

1114-VT – 1435-1540 MHz
1116-VT – 1700-1800 MHz or 1750-1850 MHz (Specify)
1115-VT 2200-2300 MHz

Input Impedance: Operates from 50 ohm source.

Noise Figure: 9 dB typical 10 dB maximum.

Image Rejection: 60 dB minimum.

IF Rejection: 90 dB minimum.

Spurious Rejection: 60 dB minimum.

Spurious Emissions: Meets or exceeds MIL-STD-826A and MIL-STD-461A

First Local Oscillator:

Type - Crystal or VFO controlled by 1st LO mode switch on base unit. Injection frequency 50 MHz above RF input.

Stability -
VFO - ±0.001% per degree C
Crystal -
With oven - ±0.0005%
Without oven - ±0.005%
Monitor Output -
Frequency - Submultiple of injection frequency
Voltage - 50 mv into 50 ohms (-13 dBm) nominal

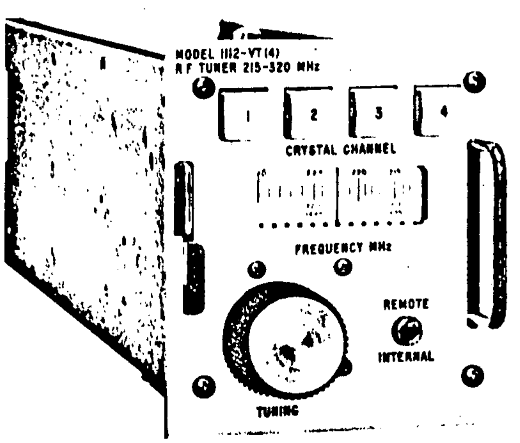
First IF:

Output Frequency - 50.0 MHz
Bandwidth - 6.0 MHz

Dynamic Range: Nominally -10 dBm to noise threshold of the receiver.

MODELS

1112-VT(2-10), Multi-Crystal Channel P Band Tuners.



The 1112-VT(2-10) RF Tuner offers the unique operational capability of front panel selectable crystal channel operation.

As shown, the 1112-VT(4) allows instant operator selection of any one of a number of desired crystal channels.

Local selection is accomplished by means of the front panel switches provided and Remote selection is accomplished by applying discrete DC voltages to the tuner control lines via the 1100-AR receiver rear apron accessory jack.

Upon customer request, up to ten (10) crystal channels can be provided for Local or Remote Tuner Operation.

All crystals are mounted within the tuner housing and are readily accessible to the operator to obtain a different selection of crystal channels.

The 1112-VT(2-10) Tuner features complete solid state tuning.

When ordering, indicate number of selectable crystal channels (from 2 to 10) as shown in examples below:

1112-VT(4), Four (4) crystal channel capability
1112-VT(9), Nine (9) crystal channel capability

SPECIFICATIONS

Frequency Range: 215-320 MHz

Input Impedance: Operates from 50 ohm source

Noise Figure: Nom. 6.5 dB maximum

Image Rejection: 80 dB minimum

IF Rejection: 90 dB minimum

Spurious Rejection: 60 dB minimum

Spurious Emissions: Meets or exceeds MIL-STD-461A and MIL-826A

First Local Oscillator:

Type - Crystal or VFO controlled by 1st LO mode switch on base unit. Injection frequency 50 MHz above RF input.

Stability -
VFO - ±0.001% per degree C
Crystal - ±0.005%

Monitor Output:

Frequency - submultiple of injection frequency.
Voltage - 50 mv into 50 ohms (-13 dBm)

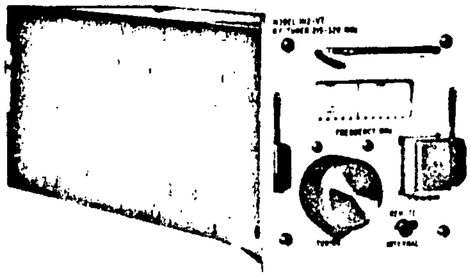
First IF:

Output frequency - 50.0 MHz
Bandwidth - 4.5 MHz (wider on special order).

Dynamic Range: Nominally -10 dBm to noise threshold of the receiver.

Dial Calibration: Calibration furnished for L-band (1435-1540 MHz) and S-band (2200-2300 MHz) in addition to P-band (215-320 MHz). Specify high side or low side conversion to obtain proper calibration direction and starting point.

MODEL
1112-VT P-Band RF Tuner.



The 1112-VT Tuner features the same unique solid-state tuning element described earlier.

The 1112-VT contains a proportional-oven controlled, voltage-tuned VFO. This eliminates frequency change due to mechanical instability and substantially reduces drift due to ambient temperature change.

SPECIFICATIONS

Frequency Range: 215-320 MHz

Input Impedance: Operates from 50 ohm source

Noise Figure: 6.5 dB maximum

Image Rejection: 80 dB minimum

IF Rejection: 90 dB minimum

Spurious Rejection: 60 dB minimum

Spurious Emissions: Meets or exceeds MIL-STD-461A and MIL-STD-826A

First Local Oscillator:

Type - Crystal or VFO controlled by 1st LO mode switch on base unit. Injection frequency 50 MHz above RF input.

Stability -
VFO - ±0.001% per degree C
Crystal -
With oven - ±0.0005%
Without oven - ±0.005%

Monitor Output:

Frequency - Submultiple of injection frequency.

Voltage - 50 mv into 50 ohms (-13 dBm)

First IF:

Output frequency - 50.0 MHz
Bandwidth - 4.5 MHz (wider on special order)

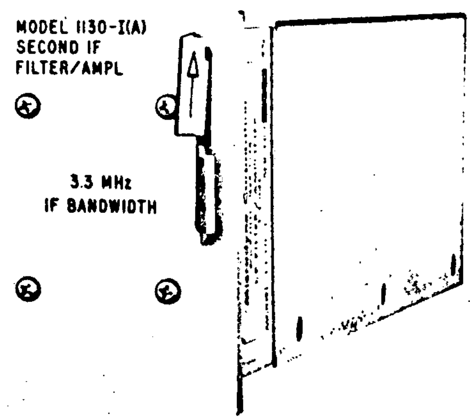
Dynamic Range: Nominally -10 dBm to noise threshold of the receiver.

SPECIFICATIONS (con't)

Dial Calibration: Calibration furnished for L-band (1435-1540 MHz) and S-band (2200-2300 MHz) in addition to P-band (215-320 MHz). Specify high side or low side conversion to obtain proper calibration direction and starting point.

2ND IF FILTER/AMPLIFIERS

The second IF filter/amplifier is a front panel plug-in module used to establish the bandwidth of the 10 MHz second IF signal. The modules are available in both fixed and variable bandwidths.



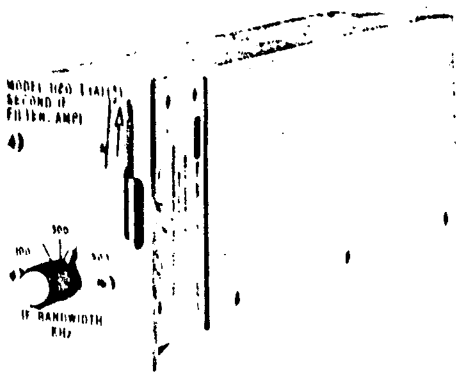
AVAILABLE FIXED BANDWIDTH FILTER AMPLIFIERS

Each of the fixed bandwidth modules sets a single bandwidth in the range of 10 KHz to 6 MHz. These units are also available as switch-selectable bandwidth modules with up to three filter/amplifiers installed in a housing equipped with a front panel selector switch.

The following modules are available to the user who requires only one fixed bandwidth at a time.

Model 1121-I(A)	10 KHz
Model 1122-I(A)	30 KHz
Model 1123-I(A)	50 KHz
Model 1124-I(A)	100 KHz
Model 1125-I(A)	300 KHz
Model 1126-I(A)	500 KHz
Model 1127-I(A)	750 KHz
Model 1128-I(A)	1.0 MHz
Model 1129-I(A)	1.5 MHz
Model 1130-I(A)	3.3 MHz
Model 1134-I(A)	4.0 MHz
Model 1135-I(A)	6.0 MHz
Model 1136-I(A)	200 KHz
Model 1137-I(A)	2.4 MHz
Model 1138-I(A)	2.4 MHz
Model 1139-I(A)	5.0 MHz

2ND IF FILTER/AMPLIFIERS (con't)



Plug-in units can also be supplied with up to 3 switch selected fixed bandwidths. These are designated the 1120-I(A)( ) series. Examples are as follows:

1120-I(2)(A)(50-100) A two-filter unit with 50 and 100 KHz bandwidths.

1120-I(3)(A)(50-100-500) A three-filter unit with 50, 100 and 500 KHz bandwidths.

Bandpass Peak-To-Valley Ratio:

0.5 dB maximum

Center Frequency:

10.000 MHz

Selectivity:

2.5 to 1 at 60/6 dB bandwidth ratio, 3.0:1 at 60/3 dB BW ratio

Phase Linearity:

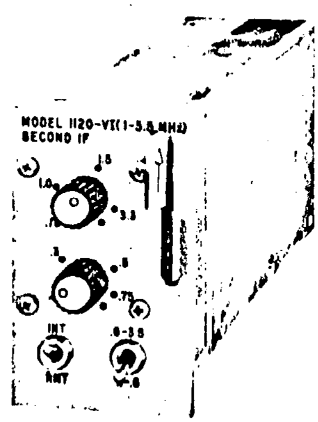
$\pm 8^{\circ}$ over 80% of the -3 dB bandwidth for bandwidths of 100 KHz or greater.

Note: $\pm 3^{\circ}$ phase linear filters available upon special request.

Symmetry:

10% maximum.

VARIABLE BANDWIDTH FILTER/AMPLIFIERS



These units provide infinite bandwidth selection from 100 to 600 KHz and from 600 KHz to 3.5 MHz and have the ability to select any standard IRIG bandwidth or any other bandwidth within these ranges. Bandwidth selection is accomplished by a front panel continuously variable control with a calibrated dial.

Remote or computer selection of the desired bandwidth is also possible through the accessory connector located at the rear panel of the receiver.

Available Bandwidths

The following modules are available to the customer who requires continuous wide range bandwidth selection and/or computer or remote operation.

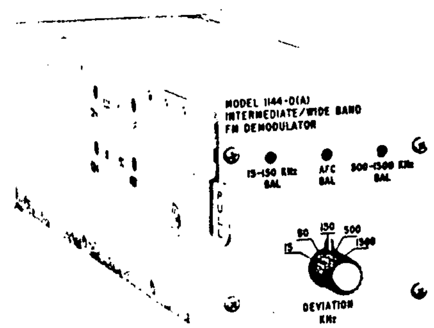
Model 1120-VI (100-600 KHz) - Continuous IF bandwidth 100 to 600 KHz

Model 1120-VI (0.6-3.5 MHz) - Continuous IF bandwidth 0.600 MHz to 3.5 MHz

*Model 1120-VI (100/3500 KHz) - Combines the salient operating features of the two individual modules described above.

These plug-in units are directly interchangeable with the 1120 series fixed frequency IF Filter/Amplifiers.

FM DEMODULATORS



PLUG-IN FM DEMODULATORS

Three FM Demodulator plug-in modules cover the entire range of IF bandwidths. Advanced capture techniques permit excellent operation in a high multipath or adjacent channel interference environment. Extremely high limiter overdrive minimizes data loss on instantaneous signal drop-out. Phase-lock demodulators are available as an optional feature. Standard configurations contain a mean of peak AFC detector. As an option, however, these units can be supplied with front panel selection of the AFC detection mode with averaging or mean of peaks -- to insure effective AFC under a variety of modulation formats. Three overlapping FM Demodulators are available:

	Model	Range of IF Bandwidths
Narrow	1141-D(A)	10 KHz to 60 KHz
Intermediate	1142-D(A)	50 KHz to 1 MHz
Wide	1143-D(A)	750 KHz to 6 MHz
Intermediate	1144-D(A)	50 KHz to 6 MHz

FM Response

1141-D(A)	10 KHz
1142-D(A)	350 KHz
1143-D(A)	1.2 MHz

Limiting:

50 dB limiter overdrive

Linearity:

1141-D(A)	Less than 2% distortion at 10 KHz peak deviation
1142-D(A)	1% over ±200 KHz
1143-D(A)	1% ±500 KHz 2% ±750 KHz 5% ±1.5 MHz

AM Rejection:

40 dB typical (50% AM)

Capture Ratio:

0.8

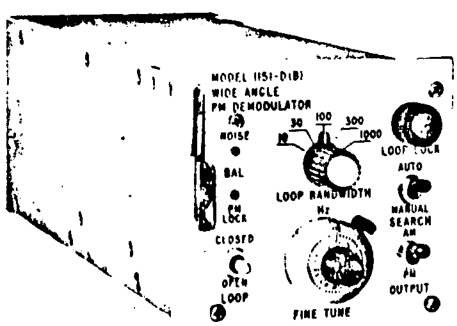
Deviation for Rated Video Output:

1141-D(A)	1.5 KHz maximum
1142-D(A)	15 KHz maximum
1143-D(A)	100 KHz maximum

Deviation Meter Range Selector:

1141-D(A)	1.5, 5.0, 15 KHz full scale
1142-D(A)	15, 50, 150 KHz full scale
1143-D(A)	150, 500, 1500 KHz full scale

PHASE DEMODULATORS



Microdyne phase demodulators operate in a long loop mode using a 10 MHz crystal oscillator as a reference. Phase control is applied to the receiver 60 MHz second local oscillator. An automatic phase lock feature provides essentially the same performance characteristics of the AFC circuit, where the search rate control is determined by the loop bandwidth so the probability of acquisition at threshold is greater than 90% of any given sweep.

The model 1151-D(B) is an extremely wide angle unit capable of retrieving phase modulation with peak-to-peak deviations up to 5.5 radians.

The 1151-D(A)(B) provides an anti-sideband lock feature. Synchronous AM is provided as a standard feature in all Microdyne phase demodulators.

The model 1152-D(A), sine detector provides phase lock demodulation of a phase modulated RF carrier with deviations up to +70 degrees. Selection of video output from PM, AM or synchronous AM demodulator is provided by means of a front panel switch.

SPECIFICATIONS

Phase Lock Loop Bandwidth:

10, 30, 100, 300, 1000 Hz switch selectable. Other loop bandwidths are available upon special order.

Tracking Range: ±250 KHz minimum.

Fine Tuning Range: ±250 KHz minimum.

Range of IF Bandwidth:

10 KHz to 6 MHz (determined by IF filters).

Coherent AGC:

Supplied by synchronous AM detector.

Residual Phase Noise:

Less than 2^0 RMS for 10 Hz loop bandwidth.

Phase Deviation for Rated Output: ±10 degrees.

Synchronous AM Output:

20% AM will produce rated output.

Automatic Search:

50 KHz to greater than 250 KHz determined by loop bandwidth control setting.

Locking Threshold:

Dependent on IF Bandwidth/Loop Bandwidth ratio. Phase lock design threshold: -19 dB SNR in the IF bandwidth or +6 dB SNR in the loop (whichever is the higher input signal level).

Static Phase Error: 10 degrees maximum.

Frequency Response (PM):

To 2.0 MHz. Low frequency roll-off determined by selected loop bandwidth.

Frequency Response (Synchronous AM):

5 Hz to 500 KHz, low frequency response may be modified by AGC time constant.

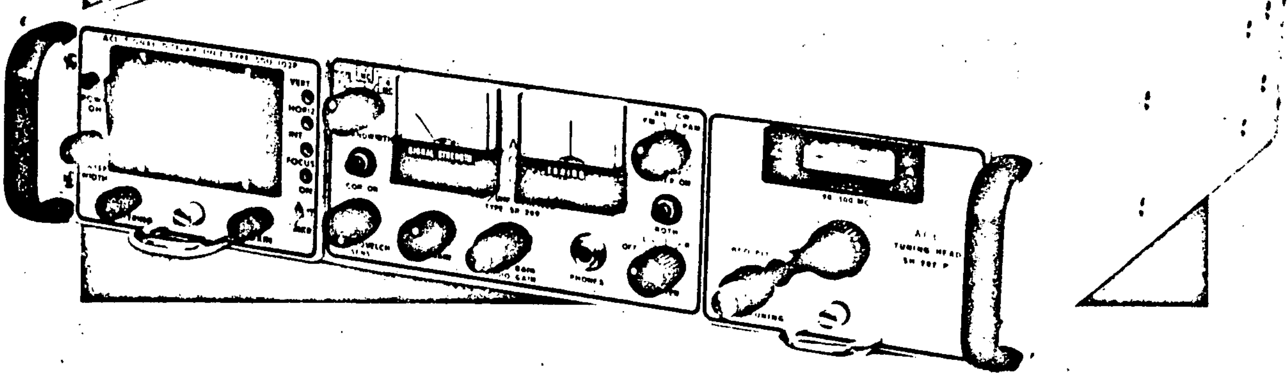
UHF RECEIVER

The SR-209

Receiving System

BY ACL *FOR*

- Surveillance
- Telemetry
- RFI
- Antenna Pattern
- Spectrum Analysis
- Field Strength
- RF Monitoring
- Laboratory
- General HF/VHF/UHF Communications



The first and only completely solid state, modular receiving system with such outstanding features as

- *AM-FM-CW Pulse Reception*
- *Frequency Range of 2 MHz to 7 GHz*
- *Wide Selection IF Bandwidths*
- *Low Noise Figure*
- *Companion Signal Display Units*
- *Optional Battery Operation*
- *Low Oscillator Radiation*

and Many More Features

ACL

ASTRO COMMUNICATION LABORATORY

• A DIVISION OF AIKEN INDUSTRIES, INC. •

9125 GAITHER ROAD, GAITHERSBURG, MD. 20760

TELEPHONE (301) 948-5210 TXW 710-828-9706

6/71

The Astro Communication Laboratory type SR-209 solid state, modular receiving system is an extremely unique and highly versatile communication system. It is capable of reception of AM, FM, CW and Pulse signals in the frequency range of 2 MHz to 7 GHz. It will accommodate a signal display unit to provide a visual display of signals in a band around the received signal. It will accept a rechargeable nickel cadmium battery pack for portable operation. The receiver is small; designed for standard 19 inch rack mounting; the panel is only 3½ inches high.

The system is entirely solid state and with the ACL modular concept provides excellent MTBF and reduces maintenance to a very minimum. Printed circuit boards are used extensively and provide a reliability and ease of servicing. For example the power supply circuitry is a plug-in printed circuit board as are the audio, video, AGC and others. The IF amplifier with matching FM demodulator is a plug-in board. To provide an even greater reliability and superior performance FET's are being used in all circuits where feasible.

In the SR-209 receiver three IF amplifier FM demodulator boards may be used at one time with operational selection by front panel switch. For VHF/UHF wide selection of IF bandwidths from 10 KHz to 8 MHz are available. In HF there are three bandwidths as specified.

The unusually wide frequency range of 2 MHz to 7 GHz for a manually tuned receiver is provided through the use of ten plug-in RF tuning heads. There are three such tuners in the HF range (2 MHz to 6 MHz, 6 MHz to 20MHz and 20MHz to 45MHz) which carry the series 100 designation. In the VHF frequencies there are three tuning heads, four in UHF and one in SHF to 7000 MHz as shown on the specifications. These are designated series 200 tuners.

The basic SR-209 receiver will accept any two plug-in tuners at one time. A front panel switch enables the selection of either tuner. If a visual display of the signal is desired, one tuner may be replaced by the ACL type SDU-102AP plug-in signal display unit for VHF/UHF/SHF ranges or the SDU-101AP for the above three series 100 HF tuners.

To make the receiver completely self-sufficient for field use a battery pack plug-in unit may be used in lieu of one tuner. No adjustments or changes in the receiver are necessary when this nickel cadmium battery pack is installed. A built-in charger is provided in the battery pack unit.

As in all ACL receivers the front ends employ at least two section preselectors at the RF input to provide maximum reduction of cross modulation and intermodulation interferences.

The SR-209 basic receiver contains a carrier operated relay to control accessary equipment such as recorders. All operating controls are located on the front panel of the SR-209 and except for the phone jack all inputs and outputs are located on the rear panel. An exception to this is the optional first local oscillator output which is provided on the plug-in tuning head panel. Two meters, one for tuning and one for signal strength, are on the receiver front panel.

SPECIFICATIONS

Type of Reception	AM, FM, CW, and Pulse
Input Impedance	50 ohms nominal, unbalanced to ground
AM Stability	VHF: Output varies less than 6 db for input range of 70 db above 3.5 uv UHF: Output varies less than 6 db for input range of 70 db above 5 uv
FM Stability	IF Bandwidths from 10 to 300 KHz: Output varies less than 2db for input above 1.5 uv IF bandwidths 500 KHz and wider: Output varies less than 2 db for input above 4 uv
Pulse Stability	Output varies less than 10 db for input range of 70 db above 5 uv
Audio Power Output	100 mw minimum into 600 ohm load for external speaker
Video Amplifier Output	5 V P-P maximum output into a 93 ohm load
Video Amplifier Response	Varies less than 3 db from 20 cps to 4 mcs when terminated with a 93 ohm load
Video Output Impedance	93 ohms unbalanced, BNC connector
BFO	Operable with 10 to 250 KHz bandwidths BFO Pitch: ±20 KHz minimum
Signal Display Output	21.4 mc center frequency
Rear Panel Connections	RF Input (50 ohms), Output for External Signal Display Unit, External Speaker Output, AC Power Input, Video Output, COR Delay On-Off, COR Switch Output
Meters	Tuning Meter, Signal Strength Meter
Front Panel Controls	Power On-Off, Audio Gain, Video Gain, RF Gain, IF Bandwidth Selection, AM-FM-CW-Pulse Function Switch, COR Visual Indicator, COR Sensitivity Adjustment, Phone Jack
Weight	Approximately 30 pounds
Dimensions	3½" H x 16⅞" W x 15-1/16" D, Standard 19" rack mounting
Power	Input: 50-400 cps, 115 vac (230 vac opt.), Wattage: Approximately 25 watts (with SDU)
Finish	Gray Enamel per MIL-E-15090, Color No. 26329, Federal Standard 595; Hard anodized satin finish overlay with black etched lettering

PLUG-IN RF TUNING HEADS

All plug-in tuning heads are designed for installation in the receiver without adjustment or alignment of any kind. All plug-in tuning heads employ at least a two-section preselector at the RF input. All tuners have AGC to allow handling of large RF signals. AFC is also provided. Local Oscillator output is provided through front panel connector.

Model	Tuning Range	NF Max.	IF Rej. Min.	Image Rej. Min.	Osc. Rad. Max.
SH-102 P	2- 6 MHz	8 db	60 db	60 db	5 uv
SH-103 P	6- 20 MHz	6 db	90 db	60 db	5 uv
SH-104 P	20- 45 MHz	6 db	90 db	60 db	5 uv
SH-200 P-1	20- 45 MHz	4.5 db	90 db	65 db	10 uv
SH-201 P-1	30- 100 MHz	4.5 db (to 90 MHz) 5.5 db (above 90 MHz)	60 db	60 db	8 uv
SH-202 P-1	90- 300 MHz	6.5 db	80 db	50 db	15 uv to 260 MHz (25 uv above 260 MHz)
SH-203 P-1	250- 500 MHz	10.0 db	90 db	60 db	5 uv
SH-204 P-1	490-1000 MHz	12.0 db	90 db	80 db	50 uv
SH-205 P-1	1- 2 GHz	14.0 db	90 db	60 db	300 uv
SH-206 AP-1	2- 4 GHz	15.0 db	90 db	60 db	300 uv
SH-207 P-1	4- 7 GHz	16.0 db	90 db	50 db	300 uv

IF AMPLIFIER/DEMODULATOR SPECIFICATIONS

Operated with	IF Board Model	Bandwidth (3 db, KHz)	Center Frequency MHz	BFO	AM Sensitivity Required RF Input to Produce 10 db (S+N)/N Minimum	FM Sensitivity Required RF Input to Produce 21 db (S+N)/N Minimum	FM Deviation Sensitivity Volts/KHz Minimum (at Video Output)
SH-100 Series RF Tuning Heads	IF-112-01	1	0.455	Available	– 118 dbm, 50% at 400 cps rate		0.40
	IF-112-05	5	0.455	Available	– 110 dbm, 50% at 400 cps rate		0.40
	IF-112-10	10	0.455	Available	– 107 dbm, 50% at 1 KHz rate		0.40
SH-200 Series RF Tuning Heads	IF-220-10	10	21.4 & 1.65	Available	VHF: 2 uv, 50% mod. at 1 KHz rate produce 17 db (S + N)/N minimum	2 uv, mod. at 1 KHz rate, 3.5 KHz dev.	0.40
	IF-220-20	20	21.4 & 1.65	Available	VHF: 2 uv, 50% mod. at 1 KHz rate produce 17 db (S + N)/N minimum	2 uv, mod. at 1 KHz rate, 7 KHz dev.	0.40
	IF-211-60	60	21.4 & 2.5	Available	VHF: 2 uv, 50% mod. at 1 KHz rate	2 uv, mod. at 1 KHz rate, 20 KHz dev.	0.15
	IF-211-75	75	21.4 & 2.5	Available	VHF: 2 uv, 50% mod. at 1 KHz rate	2 uv, mod. at 1 KHz rate, 25 KHz dev.	0.15
	IF-211-100	100	21.4 & 2.5	Available	VHF: 3 uv, 50% mod. at 1 KHz rate UHF: 5 uv, 50% mod. at 1 KHz rate	3 uv, mod. at 1 KHz rate, 30 KHz dev. 5 uv, mod. at 1 KHz rate, 30 KHz dev.	0.15
	IF-211-150	150	21.4 & 2.5	Available	VHF: 3.5 uv, 50% mod. at 1 KHz rate UHF: 6 uv, 50% mod. at 1 KHz rate	3.5 uv, mod. at 1 KHz rate, 50 KHz dev. 6 uv, mod. at 1 KHz rate, 50 KHz dev.	0.01
	IF-212-300	300	21.4	No	VHF: 4 uv, 50% mod. at 1 KHz rate UHF: 8 uv, 50% mod. at 1 KHz rate	4 uv, mod. at 1 KHz rate, 100 KHz dev. 8 uv, mod. at 1 KHz rate, 100 KHz dev.	0.03
	IF-212-500	500	21.4	No	VHF: 5 uv, 50% mod. at 1 KHz rate UHF: 10 uv, 50% mod. at 1 KHz rate	5 uv, mod. at 1 KHz rate, 170 KHz dev. 10 uv, mod. at 1 KHz rate, 170 KHz dev.	0.02
	IF-212-1000	1000	21.4	No	VHF: 10 uv, 50% mod. at 1 KHz rate UHF: 20 uv, 50% mod. at 1 KHz rate	10 uv, mod at 1 KHz rate, 330 KHz dev. 20 uv, mod. at 1 KHz rate, 330 KHz dev.	0.01
	IF-212-2000	2000	21.4	No	VHF: 13 uv, 50% mod. at 1 KHz rate UHF: 26 uv, 50% mod. at 1 KHz rate	13 uv, mod. at 1 KHz rate, 670 KHz dev. 26 uv, mod. at 1 KHz rate, 670 KHz dev.	0.005
	IF-212-3000	3000	21.4	No	VHF: 14 uv, 50% mod. at 1 KHz rate UHF: 28 uv, 50% mod. at 1 KHz rate	14 uv, mod. at 1 KHz rate, 1000 KHz dev. 28 uv, mod. at 1 KHz rate, 1000 KHz dev.	0.003
	IF-212-4000	4000	21.4	No	UHF: 30 uv, 50% mod. at 1 KHz rate	30 uv, mod. at 1 KHz rate, 1350 KHz dev.	0.003
	IF-212-8000	8000	21.4	No	UHF: 35 uv, 50% mod. at 1 KHz rate	35 uv, mod. at 1 KHz rate, 1350 KHz dev.	0.003

PLUG-IN DISPLAY UNITS

ACL provides two signal display units, both of which are plug-in assemblies. The SDU-100P is used with the series 100 tuners and the SDU-102AP with the series 200 tuners. They are designed to provide a visual display of the signal to which the receiver is tuned.

CRT Size .... Standard 1" x 3" display

Sweepwidth .... SDU-102AP From DC to 3 MHz Continuously adjustable; SDU-100P 0 to 10 KHz and 0 to 50 KHz Continuously adjustable

Resolution .... SDU-102AP 10 KHz; SDU-100P 400 Hz and 2 KHz

Sweep Rate .... SDU-102AP 20 Hz; SDU-100P 4 Hz

IF Frequency .... SDU-102AP 1st IF, 4.3 MHz; 2nd IF, 455 KHz; SDU-100P 1st IF, 80 KHz; 2nd IF, 15 KHz

Amplitude Response .... ±1.5 db within any sweepwidth

Sensitivity .... 10 uv at SDU input produces 1" deflection

Crystal Marker .... SDU-102AP 21.4 MHz center frequency marker (Sideband markers available on SDU-102AP on request); SDU-100P 455 KHz center frequency marker

Linearity .... 5% within any sweepwidth

Dimensions .... 3½" H x 5" W x 14" D

Weight .... 6 lbs.

Power .... Input — ±12 VDC (no external power required when plugged into SDU-101 or into SR-209

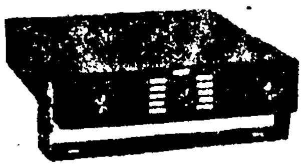
Finish .... Matches SDU-101 or SR-209

VHF and UHF PREAMP and VHF RECEIVER

Here's a veritable

Vanguard of Values...

RECEIVERS



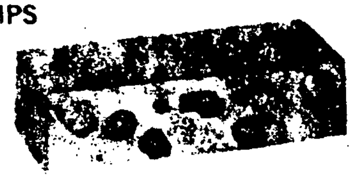
VHF FM RECEIVER
11 CHANNELS · 135-250 MHz

• 11 crystal-controlled channels. • Available in your choice of frequencies from 135-250 MHz in any one segment from 1-4 MHz wide. • I. F. bandwidth (channel selectivity) available in your choice of ±7.5 kHz or ±15 kHz. • 8-pole quartz filter and a 4-pole ceramic filter gives more than 60 dB rejection at 2X channel bandwidth. • Frequency trimmers for each crystal. • .2 to .3 μvolt for 20 dB quieting. • Dual-gate MOSFETS and integrated circuits. • Self-contained speaker and external speaker jack. • Mobile mount and tilt stand • Anodized alum. Case, 6" x 7" x 1⅝".

Model FMR-250-11 price:
135-180 MHz **$109.95**
181-250 MHz **$119.95**
Price includes one .001% crystal. Additional crystals $6.95 each.

HOW TO ORDER: State model, input and output frequencies and bandwidth where applicable. Remit in full, including sales tax if you reside in N.Y. State, direct to Vanguard Labs. Prices include postage by regular parcel post. For air mail or special delivery include extra amount; excess will be refunded.

PRE-AMPS



HIGH GAIN · LOW NOISE

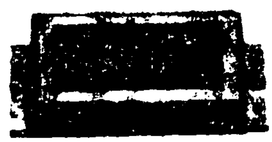
35 dB power gain, 2.5-3.0 dB N.F. at 150 MHz, 2 stage, R.F. protected, dual-gate MOSFETS. Manual gain control and provision for AGC. 4⅜" x 1⅞" x 1⅝" aluminum case with BNC receptacles and power switch. Available factory tuned to the frequency of your choice from 5 MHz to 350 MHz with approximately 3% bandwidth. Up to 10% B.W. available on special order.

Model 201 price: 5-200 MHz $21.95
201-350 MHz $24.95

UHF 3 to 5 dB MAX. N.F. 20 dB MIN. POWER GAIN

The Model 202 uses 2 of T.I.'s super low noise J-FETS in our special circuit board design which gives a minimum of 20 dB power gain at 450 MHz. Stability is such that you can have mismatched loads without it oscillating and you can retune (using the capped openings in the case) over a 15-20 MHz range simply by peaking for maximum signal. Available tuned to the frequency of your choice between 300-475 MHz. 4⅜" x 1⅞" x 1⅝" aluminum case with BNC receptacles and power switch.

Model 202 price: $31.95



LESS THAN 2 dB N.F. GAIN
20 dB @ 150 MHz.
SIZE: 2½" X ⅝" X 1"

Features a super low noise J-FET rated by T.I. as typically 1.2 dB N.F @ 150 MHz (transistor data curves supplied with unit) and guaranteed by our lab to give under 2 dB actual N.F in our circuit. Transistor is mounted in a socket with gold plated contacts. 4 precision trimmers make possible tuning for optimum desired results over a wide range of conditions. We supply it tuned for minimum noise figure across 50 ohms input and output resistance. Fully shielded in aluminum case with feed-thru solder terminals. Supplied with mounting kit for installing inside or outside your receiver. Tuned to the frequency of your choice from 135 MHz to 250 MHz with approximately 2.4 MHz bandwidth.

Model 102 price: $19.95

Vanguard Labs

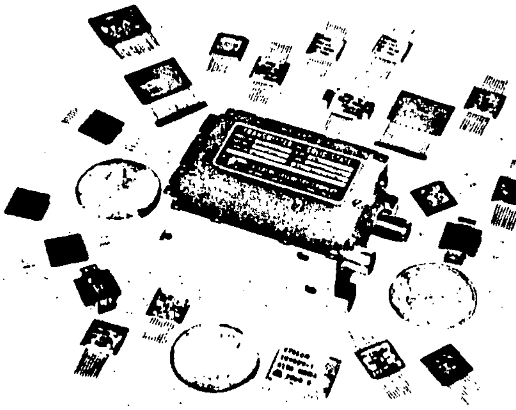
196-23 JAMAICA AVE.
HOLLIS, N.Y. 11423

SPACECRAFT VHF, UHF

and S-BAND RECEIVERS

TELEDYNE TELEMETRY

TR-2300 SERIES MINIATURE TRANSMITTERS
VHF, L-, S- & C-BAND



Teledyne Telemetry Company's new line of miniature transmitters incorporates the outstanding features of the already successful Type TR-2200 series transmitters to provide output power levels from 0.5 to 20 watts in less than 12 cubic inches. Designed especially for missile and satellite applications where space is a premium, the series TR-2300 transmitters are capable of frequency stabilities exceeding the requirements of IRIG Standard 106-69. Additional high performance features include broadband modulation frequency response, high modulation sensitivities, wideband carrier deviation and low incidental frequency modulation.

At the higher frequencies a miniature isolator/bandpass filter assembly provides good harmonic rejection and allows stable operation into any load impedance including an open or short circuit. A hybrid integrated-circuit voltage regulator offers immunity to power line noise/transients and voltage variations. The ruggedized aluminum housing provides individually shielded compartments for power and RF isolation between stages.

The wideband performance capability of the modulator permits applications other than conventional telemetry data transmission, including real-time, high resolution video, high frequency PCM (bit rates up to 10 megabits NRZ), and multiplexed high frequency subcarriers.

Aerospace Travel:
- Data, Voice, Television

Oceanography:
- Mini-sub Control and Communication

Earth Resources and Weather Satellites

Pollution Monitors:
- Ocean Buoys, Remote Air Sampling

Air and Sea Navigation Satellites

Military and AEC Data Collection

Fish and Animal Behavior Studies

Earth Movement Studies

Bio-medical Data Collection

Industrial Telemetry:
- Pipeline and Powerline

Public Safety:
- Police and Fire

Traffic Control:
- Highway, Rail and Air

Consumer TV and Data Transmission

VHF-BAND	215 - 265 MHz	
L-BAND	1435 - 1540 MHz	
S-BAND	2200 - 2300 MHz	
C-BAND	4400 - 5000 MHz	

(Other frequency options available)

TR-2300-02	2.0W min	Available Thru	C-BAND
TR-2300-05	5.0W min	Available Thru	S-BAND
TR-2300-10	10.0W min	Available Thru	1 GHz
TR-2300-20	20.0W min	Available Thru	400 MHz

These powers are obtainable under temperature and voltage extremes.

Operation within specifications at any VSWR up to 1.5:1 at any phase angle. An integral circulator allows continuous operation into open or short circuit load at any phase angle.

Matched to 50 ohm nonreactive load.

Conforms with IRIG 106-69.

Input impedance from 50 ohms to 1 megohm available (depending on required deviation sensitivity).

Less than 500 Hz under quiescent conditions. Less than 5 KHz under combined environments.

True FM.

±1.0 db from dc to 1.0 MHz standard; up to 10 MHz available on option.

Intermodulation products of any four tones separated by 20 KHz and providing a total peak deviation of within ±1 MHz will be 40 db below any one tone.

Better than 1% best straight line to ±1.0 MHz.

±500 KHz/volt standard; over ±2 MHz/volt RMS available on option.

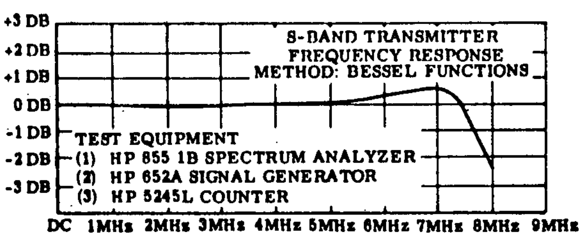
±1.0 MHz standard; to ±10 MHz available on option.

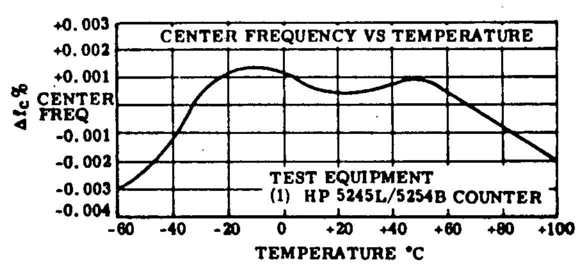
Per IRIG 106-69 (±.003%).

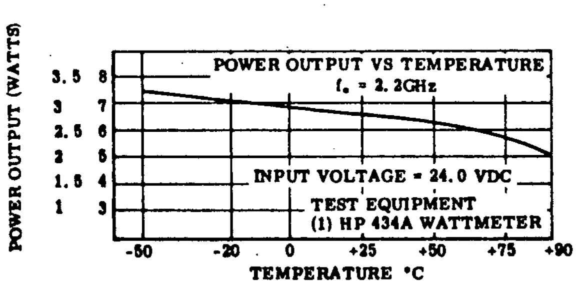
The power, modulation and chassis grounds are common. Isolated grounds available on option.

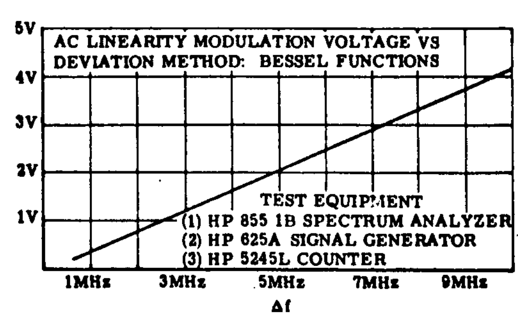
For 5 W min	18.0%	16.5%
For 2 W min	17.5%	16.0%
For 1 W min	14.0%	13.0%
For 1/2 W min	11.0%	10.0%

28 ±4 volts dc, 29 ±4 volts with optional reverse polarity protection. Current drain is dependent on min/max power range specified. Transient protection to +80 volts.









VHF-BAND	215 - 265 MHz
L-BAND	1435 - 1540 MHz
S-BAND	2200 - 2300 MHz
C-BAND	4400 - 5000 MHz

(Other frequency options available)

TR-2300-02	2.0W min	Available Thru	C-BAND
TR-2300-05	5.0W min	Available Thru	S-BAND
TR-2300-10	10.0W min	Available Thru	1 GHz
TR-2300-20	20.0W min	Available Thru	400 MHz

These powers are obtainable under temperature and voltage extremes.

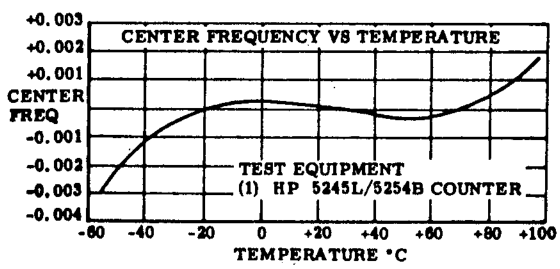
Operation within specifications at any VSWR up to 1.5:1 at any phase angle. An integral circulator allows continuous operation into open or short circuit load at any phase angle.

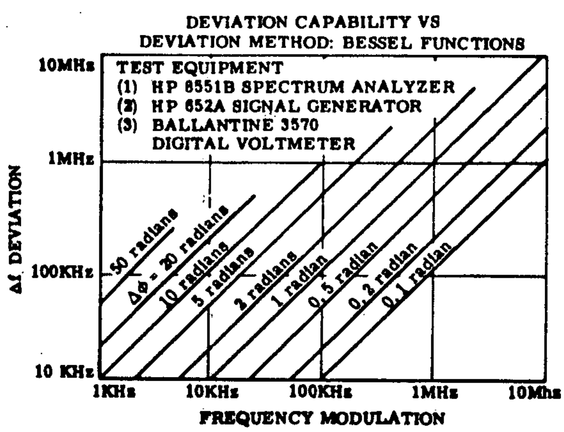
Matched to 50 ohm nonreactive load.

Conforms with IRIG 106-69.

Input impedance from 50 ohms to 1 megohm available (depending on required deviation sensitivity).

Less than 500 Hz under quiescent conditions. Less than 5 KHz under combined environments.





True PM.

±1.5 db from dc to 1.0 MHz standard; up to 10 MHz available on option.

Up to MI = 25 and not to exceed ±500 KHz.

Better than 2% best straight line.

5 radian/volt standard. Higher sensitivity available on option.

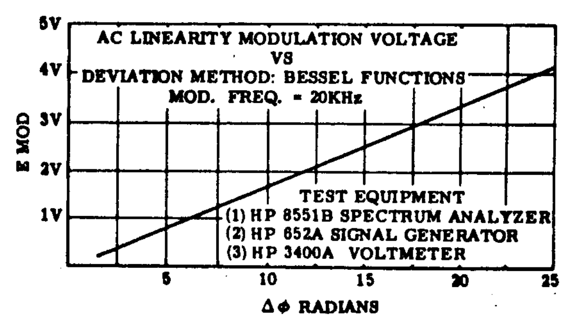
Less than 2%.

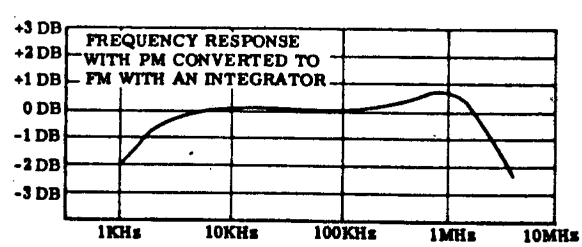
Per IRIG 106-69 (±.003%).

The power, modulation and chassis grounds are common. Isolated grounds available on option.

For 5 W min	16.0%	14.5%
For 2 W min	17.5%	16.0%
For 1 W min	14.0%	13.0%
For 1/2 W min	11.0%	10.0%

28 ±4 volts dc, 29 ±4 volts with optional reverse polarity protection. Current drain is dependent on min/max power range specified, Transient protection to +80 volts.





VHF-BAND	215 - 265 MHz
L-BAND	1435 - 1540 MHz
S-BAND	2200 - 2300 MHz
C-BAND	4400 - 5000 MHz

(Other frequency options available)

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TR-2300-10	10.0 W min	Available Thru	1 GHz
TR-2300-20	20.0 W min	Available Thru	400 MHz

These powers are obtainable under temperature and voltage extremes.

Operation within specifications at any VSWR up to 1.5:1 at any phase angle. An integral circulator allows continuous operation into open or short circuit load at any phase angle.

Matched to 50 ohm nonreactive load.

Conforms with IRIG 106-69.

Input impedance from 50 ohms to 1 megohm available (depending on required deviation sensitivity).

AM TRANSMITTER:

100 MHz to 800 MHz.

To 5 Watt.

DC to 5 MHz.

Per IRIG 106-69(±.005% optl)

Less than 500 Hz under quiescent conditions. Less than 5 KHz under combined environments.

Less than 1.0 megabits.
Less than 10 megabits (optional).

Up to 40 nanosec rise time.
Up to 40 nanosec fall time.

Less than 2%.

Per IRIG 106-69 (±.003%).

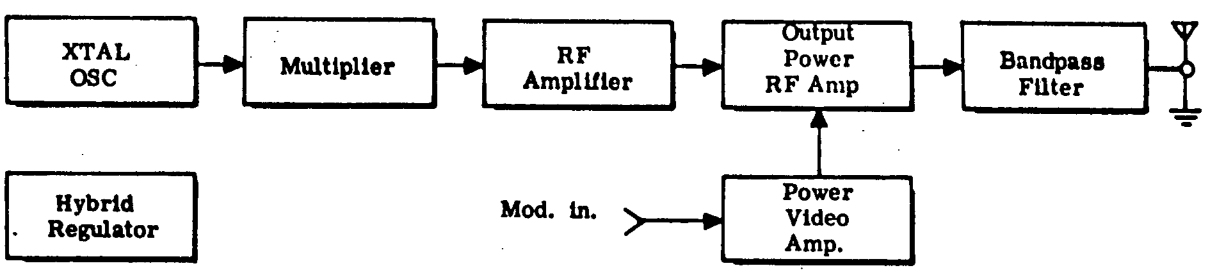
The power, modulation and chassis grounds are common. Isolated grounds available on option.

For 5 W min	16.0%	14.5%
For 2 W min	17.5%	16.0%
For 1 W min	14.0%	13.0%
For 1/2 W min	11.0%	10.0%

28 ±4 volts dc, 29 ±4 volts with optional reverse polarity protection. Current drain is dependent on min/max power range specified, Transient protection to +80 volts.

Less than 500 Hz under quiescent conditions. Less than 5 KHz under combined environments.

28 ±4 volts dc, 29 ±4 volts with optional reverse polarity protection.



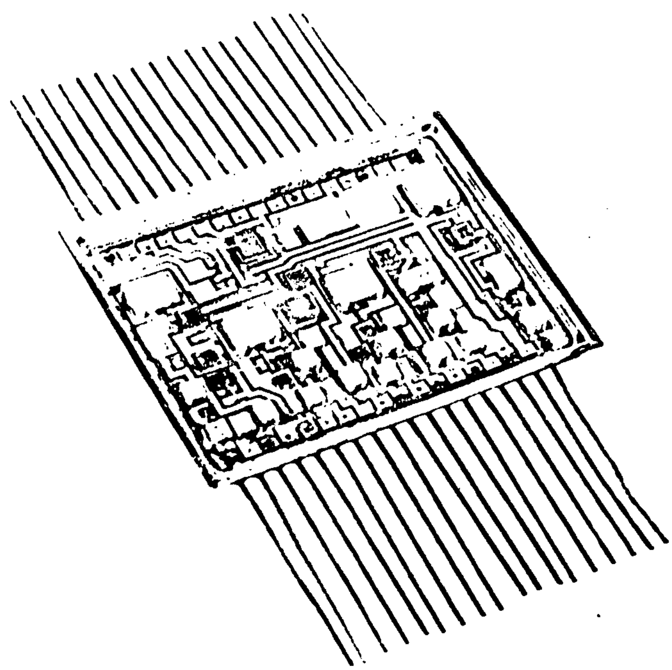
TR-2300 - AM Transmitter, Functional Block Diagram

Space applications of telemetry equipment demand the highest achievable reliability and minimum space and weight as paramount design criteria. To achieve this goal, Teledyne developed the Microelectronic Modular Assembly (MEMA). The MEMA is a unique approach to high density microminiature packaging of integrated circuits achieving a tremendous advance in space and weight reduction and increased reliability.

The MEMA has a successful field proven reliability and is currently used in Teledyne Telemetry's commutators and PCM systems providing space and weight reductions greater than 50 percent with higher reliability than discrete component counterparts.

In 1968 the MEMA was constructed to utilize this successful integration approach for RF circuits in the transmitters. A benefit of a common substrate is the improved thermal interface between the components, thereby allowing better tracking of the components timing temperature changes.

The MEMA's consistently provide more gain and output power than the discrete equivalent. This is due to the better layout that allows a much shorter bypass and increased Q at frequencies up to 900 MHz.



The following features built into the TR-2300 transmitter are the result of many years of design improvement, based on field operational data from our standard line, plus new, more reliable components.

The TR-2300 has the highest performance, reliability and efficiency to size ratio yet.

- Construction: Printed circuit boards mounted in a shield compartmented milled aluminum housing.
- Light weight and small in size.
- VHF-, L-, S- or C-BANDS.
- Video Frequency Response.
- AM, PSK, FSK, PM or FM Modulation.
- Output Power: To 5 Watts minimum at S-BAND.
- Ferrite Isolator protects final application.
- Operational burn-in.
- Component Screening.
- O-Ring Sealed Unit: The leak rate is less than 1×10^{-7} cc/second - (suitable for two years in space).
- Microelectronic Module Assemblies (MEMA): Miniature hybrid circuits used for input power regulator, frequency modulated oscillator, and crystal oscillator-multiplier.
- High DC to RF efficiency.
- Reverse voltage protection.
- All semiconductors derated 50% for a high reliability.
- Quartz crystal frequency stability.
- Low quiescent IFM and IAM.
- Low intermodulation distortion (-40 db).

Type TR-2300 transmitters will conform to the electrical specifications while being subjected to each of the following environmental conditions.

-20°C to +80°C (Base Plate) -40°C to 85°C optional.

20 g's from 20 to 2000 Hz in any axis. Option: Up to 60 g's random.

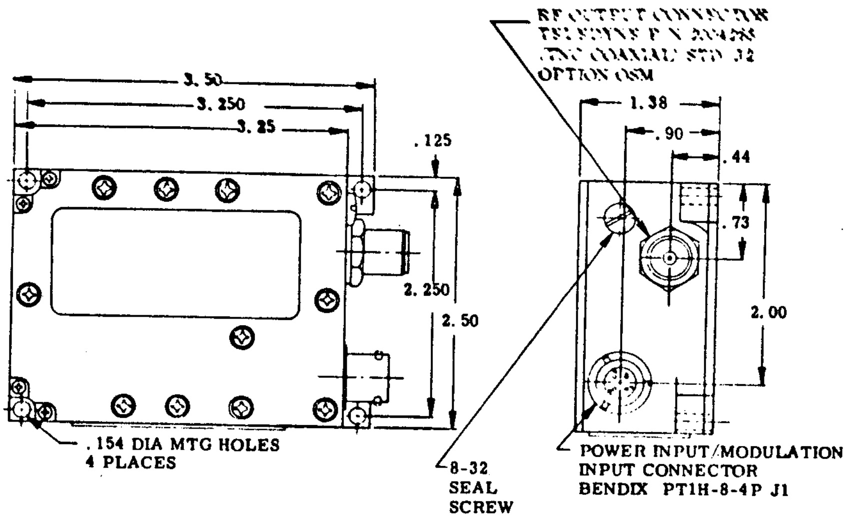
Less than 12 cubic inches.

100 g's in any axis.

100 g's, 8 msec in any axis. Option: Up to 1600 g's 1 msec in any axis.

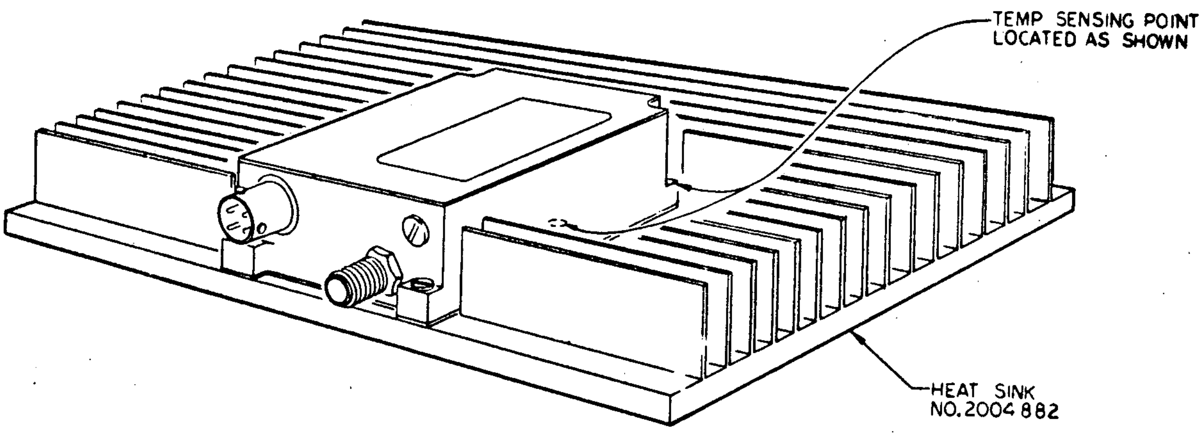
Unlimited; sealed case for missile and aircraft applications. Vented case for spacecraft applications.

15 ounces (maximum) (S-BAND).



The line of transmitters described by this data sheet cannot be operated for any length of time unless in excellent thermal contact with an adequate heat sink. One heat sink design, which is suitable for laboratory testing, is shown below. When ventilated, it will prevent the case temperature of the transmitter from rising above the upper limits.

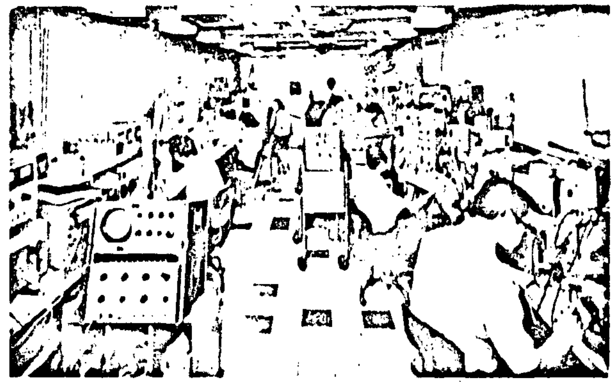
Teledyne Telemetry Company recommends the use of two thermocouples when measuring base plate temperatures to insure the adequacy of the thermal interface and heat sink. One thermocouple should be mounted on the base plate below one corner of the transmitter case. The second thermocouple should be located between the transmitter case and the heat sink on the center line of the case, and approximately three-fourths of the distance from the connector end as shown. The outputs of these thermocouples must be monitored during heat runs. If a differential of more than 2°C-3°C develops, the thermal contact or heat sink is inadequate and should be checked before tests are continued. Thermal grease, such as Dow-Corning 340, may be used.



The high caliber of the engineering staff has been a major contributing factor to Teledyne Telemetry's outstanding growth and achievements in the field of telemetry components and systems. Teledyne Telemetry's senior personnel are well recognized authorities in their field. Their combined creative talents have resulted in the design of highly sophisticated state-of-the-art telemetry equipment.

Rapidly increasing requirements for sophisticated telemetry transmitters places great demands on the telemetry industry for advancing the technological state-of-the art. As each new demand is challenged and new technological breakthroughs are accomplished, specifications become more exigent, research and development goals are raised, and the evolutionary process continues to recycle and never ends.

Teledyne Telemetry has kept abreast of this technological revolution and has made major contributions by placing paramount importance on research and development. The success with which this challenge has been met has been a major factor contributing to the company's enviable position as a leading supplier of reliable telemetry equipment to almost every major aerospace program.

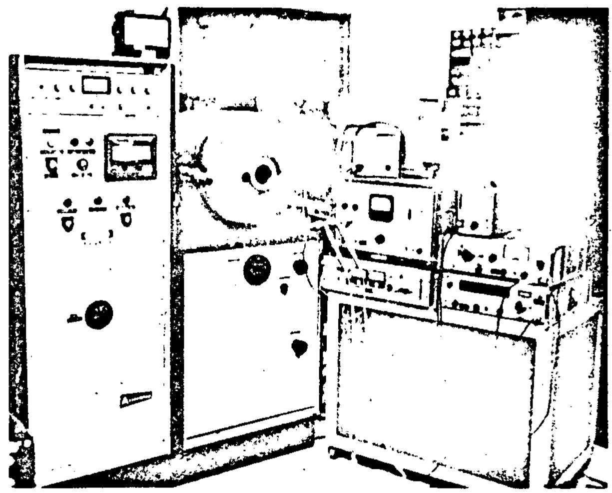


SHIELDED ROOM FOR RESEARCH AND DEVELOPMENT

At Teledyne Telemetry, product reliability is synonymous with the company name. This is reflected in the growth of the company to a leading position in the manufacture of sophisticated telemetry equipment.

To assure the reliability of Teledyne Telemetry products, a total reliability system has been developed which extends from design, during fabrication and test, through delivery.

Teledyne Telemetry provides the highest reliability product, consistent with sound design practices and customer requirements.

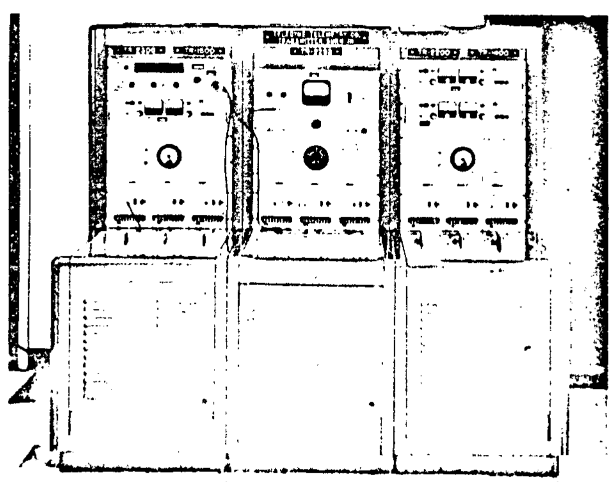


THERMAL VACUUM TESTING

Teledyne Telemetry takes personal pride in the quality of its products. The transition from research and engineering development into production hardware is controlled by a quality system which meets MIL-Q-9858A and NHB 5300. 4 (1B).

This quality system provides checkpoints all along the way from design, through procurement, into fabrication and test, to delivery. Manufacturing processes are checked and verified, all parts are purchased to Teledyne controlled requirements, and workmanship is inspected against proven standards and specifications.

Quality is something that Teledyne Telemetry feels it owes to the customer, and takes pride in manufacturing the highest quality products.



TRANSMITTER POWER BURN-IN

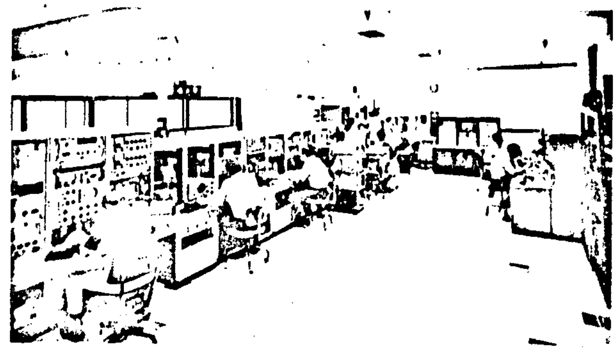
Teledyne Telemetry has complete manufacturing facilities which conform to the requirements of NASA Specification NHB 5300.4 (3A) as well as the requirements of every major Aerospace Company and government agency in the United States.

Providing an unequaled capability for meeting immediate quantity and quality production is a complete complement of highly skilled and of specially trained technicians, operators and assemblers using the newest techniques in precision integrated modular manufacturing, produced over 100 S-BAND transmitters in October 1967.

ASSEMBLY AREA FOR TRANSMITTERS

Teledyne Telemetry's test facilities are modern and highly sophisticated, and are fully capable of complete operational testing of a complete line of digital analog and RF state-of-the-art components and systems.

Also included in Teledyne Telemetry's test capabilities are such environmental capabilities as Sine and Random Vibration, Helium Leak Detection, Thermal Vacuum Testing and Power Burn-in and aging equipment for RF components. Screen Rooms are utilized for operational testing of RF components and systems.



TEST AREA FOR TRANSMITTERS

Transmitters may be ordered by using the following model number code system.

For example, a series TR-2302 transmitter with a 2-watt output, standard connector configuration, phase modulated standard frequency response, a transmitting frequency of 2254.5 MHz, and reverse voltage protection, the model number would be: TR-2302-02A21-2254.5A.

Quotations for special units may be furnished by using the model code designation with the nonstandard feature (s) coded and clearly specified. Nonstandard requirements should be specified in detail along with the model coded designation.

TR-2302 X X X X X X X X X X X

Output Power	Code
1/2-watt	0.5
1-watt	01
2-watt	02
5-watt	05
*10-watt	10
*20-watt	20

Connector Configuration	Code
Standard	A
Other (Specify)	B

Modulator	Code
True FM	1
True PM	2
PM to FM	3
PSK	4
FSK	5
Pulsed	6
AM	7

Frequency Response & Sensitivity	Code
Standard	1
Optional (Specify)	2

Carrier Frequency: (Specify in MHz)

Options	Code
Reverse Voltage	A
Current Limiting	B
Modulation Isolation	C
Video Response	D

*VHF Frequencies Only

Specifications are based on Teledyne test procedures and are subject to verification for each order.

TELEDYNE TELEMETRY

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