MINIATURE INFRA-RED DATA ACQUISITION AND TELEMETRY SYSTEM

J.H. STOKES AND S.M. WARD
ENERGY OPTICS, INC.
LAS CRUCES, N.M. 88001

CONTRACT NASI-17944
SEPTEMBER 1985
PREFACE

This final report describes work performed at the Research and Development Laboratories of Energy Optics, Inc. for the National Aeronautics and Space Administration Langly Research Center from December 20, 1984 to June 14, 1985 in fulfillment of NASA contract #NAS1-17944, Miniature Infra Red Data Acquisition and Telemetry System.

The Vice President/Engineering of Energy Optics, Inc. is John H. Stokes and the Principal Investigator was Steven M. Ward.
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PROJECT SUMMARY

The Miniature Infrared Data Acquisition and Telemetry (MIHDAT) Phase I Study was performed to determine the technical and commercial feasibility of producing a miniaturized electro-optical telemetry system. This system would acquire and transmit experimental data from scale models in a variety of different types of wind tunnels. The following design aspects were deemed important because of the severe environment encountered in wind tunnel testing:

- low power consumption
- miniature size
- ability to operate in various energy fields
- ability to perform accurately over extended temperatures.

During the Phase I study, miniature prototype MIRDAT telemetry devices were constructed, successfully tested in the laboratory and delivered to the user for wind tunnel testing. A search was conducted for commercially available components and advanced hybrid techniques to further miniaturize the system during Phase II development. Although no telemetry systems which meet all of the user requirements are commercially available, experimental results indicate that hybrid construction techniques could produce a MIRDAT system capable of meeting those requirements. A design specification was generated from laboratory testing, user requirements and discussions with component manufacturers. Finally, a preliminary design of the proposed MIRDAT system was committed to paper for Phase II development.

The MIRDAT telemetry transmitters having a volume of only one cubic inch would have far-ranging applications, and could be beneficially applied to the fields of medicine and biomedicine, aerospace, physical security, oil field data acquisition, process control, and remote sensing.
Section 1.0

PHASE I OBJECTIVES AND QUESTIONS ADDRESSED

Currently there are no commercially available telemetry systems featuring low power consumption, miniature size, and multiple transmission media. The major objectives of the Miniature Infrared Data Acquisition and Telemetry (MIRDAT) Phase I Study were:

- Determine the feasibility of designing and constructing a miniature electro-optical telemetry system for operation in scale models in wind tunnel testing.
- Determine the commercial availability of components capable of operation in the wind tunnel environment.
- Construct prototype models of the system and perform laboratory tests.
- Create and document a preliminary design specification for Phase II development.

To achieve the above objectives, important questions raised in the Phase I proposal about the feasibility of designing and constructing a MIRDAT unit were addressed. The questions, listed below, helped to identify important areas for further study.

What environmental specifications must be addressed?

The wind tunnel environment would present diverse environmental conditions to the MIRDAT system. The system may be required to operate over the full mil spec (-55 to +125 degrees C) temperature range. The system must perform in magnetic fields exceeding 5000 gauss, and in electrically noisy environments consisting of 20 kHz switching transients at loads
exceeding 1 kW. Laser light and RF fields also typify the MIRDAT environment. The MIRDAT system would be required to operate in such an environment for test sessions lasting from a few minutes to more than half an hour.

**What quantity and types of transducers must be connected?**

Typical experiments involve the use of strain gauge balance type transducers. These devices produce millivolt output levels with excursions above and below zero volts, and require a differential analog front end for amplification. In addition, some tests require the use of pressure transducers to measure atmospheric pressures on the surface of the model under test. A telemetry system with 16 input channels (or eight differential input channels) should prove sufficient for most testing.

**What data rate and data throughput are required?**

Sample rates are typically 1 to 50 samples per second per channel. An important requirement is for the system to perform near simultaneous data gathering from all channels. Erroneous data may result if samples are taken from the channels in a skewed fashion, whereby the samples are significantly offset from one another in time. Extremely fast sampling rates could overcome this problem (i.e. sample rates at orders of magnitude greater than the frequency response of the metal structure being tested). As an alternative, a sample and hold device could be incorporated into the system to acquire data from all channels simultaneously, but a significant price would be paid
in system volume.

A study of the frequency response characteristics of objects the size, shape and volume of small wind tunnel models was undertaken as a part of the MIRDAT program. An analysis of several sizes and shapes of models was performed in order to determine their natural resonant frequencies. Figure 22 depicts the analysis and formulae used in the computation. The approximate natural resonant frequency was found to be about 2 Khz or an order of magnitude greater than the maximum proposed sample rate. The result of this finding is that if the model being tested experiences high frequency vibrations from dynamic rather than static testing, simultaneous sample and hold devices will be a necessity. Figure 20 depicts the mathematical analysis undertaken.

Is a two-way, full duplex data link useful?

The capability to transmit data and commands in both directions between the telemetry transmitter and the remote telemetry receiver could prove to be useful in some applications. This capability could be used to activate and deactivate the data acquisition system, and ultimately be used to remotely program data acquisition variables such as sample rate and amplifier gain.

What volumetric and weight limitations must be considered?

Data acquisition methods currently used in wind tunnel experiments impose physical limitations on the model under test. Conventional telemetry systems utilizing hardwire data links may produce incorrect test results because of wire-
induced turbulence and strain.

Wireless telemetry modules eliminate problems associated with hardware techniques, but the modules must be extremely small to fit within test models. Since small size is not normally a consideration in the design of telemetry systems, a major objective of the MIRDAT study was to study the physical aspects of the proposed system to determine the limits of miniaturization.

Models tested in magnetic suspension wind tunnels (typically the smallest type) are less than 16 centimeters in length and less than 2.5 centimeters in diameter. A telemetry system used in such models would be required to occupy a volume of only 2.2 centimeters in diameter by 3.8 centimeters in length. Additionally, the system must fit within the cylindrical shape of a model's fuselage. This shape was found to be extremely inefficient in terms of printed circuit board space utilization.

A successful MIRDAT system would achieve small size by employing advanced hybridization for miniaturizing the required electronics. A number of construction techniques were investigated in order to make the best possible use of available space. Different materials were investigated in order to determine the one most suitable for construction of a hybrid substrate.

What hardware interface techniques are necessary?

The MIRDAT device requires a large number of connections for data input. Most electrical connectors, including
those commonly used in micro-miniature aerospace applications, were found to be too large for the MIRDAT system (typically 1.25 centimeters in length for the male/female pair). No commercially available connector has been found which is short enough to fit within the confines of the smallest models. An interconnection technique sometimes used in printed circuit boards (when extremely low profile IC socketing is required) was chosen as the best possible compromise. This technique utilizes a hollow female pin which is pressed into the printed circuit board until it is nearly flush with the top surface. A corresponding male pin is soldered to the interconnecting wire and attached to the female pin.

Likewise, there is no room in a small model for an "on-off" switch for the telemetry system. The MIRDAT device incorporates an automatic power sequencing circuit activated by remote control which conserves the system battery during periods of inactivity.

What beam width and transmit range tradeoffs can be made?

The telemetry system is required to transmit data over short ranges, between one to five meters, within the wind tunnels. With typical wind tunnel diameters of 15 centimeters or less, narrow beam angles may be used between the MIRDAT device and its receiver. Various infra-red transponders of the type manufactured by Energy Optics can be used in larger wind tunnels and in models requiring wider beam angles and increased transmission distances. Figure 1 depicts beam angles utilized in the MIRDAT device and outlines calculations for required emission power and receiver sensitivity.
What cost constraints are practical?

A secondary objective of the MIRDAT project was the design of a system with both commercial and experimental value. As such, the device must be affordable in comparison to competitive data acquisition devices. The device should also be designed for use in various wind tunnel types and numerous types of models. Cost for hybrid MIRDAT units may range from a few hundred to a few thousand dollars, not including amortized engineering costs. Accurate cost figures will depend upon the final design and the total quantity to be manufactured. Unit cost for a MIRDAT hybrid telemetry transmitter based on parts specified in the Phase II preliminary design is estimated at $700.00 each at a production quantity of 100 units (amortized Phase II engineering costs not included). Cost at a production quantity of only five units is projected to be $2,200.00 to $2,500.00 per unit.
Section 2.0

Work Performed

The MIRDAT system is designed to provide a here-to-fore unavailable capability for extracting stress and pressure data from small aircraft models by wireless means. The system, which relies on two-way pulsed IR telemetry for remote data monitoring in wind tunnel testing, includes three microcomputer based subsystems. A miniature device mounted inside the model under test for data acquisition and transmission is called a Telemetry Transmitter Unit (TTU). A second device located outside the wind tunnel for TTU interrogation and data reception is called the Telemetry Receiver Unit (TRU). A peripheral subsystem, the Remote Control Data Terminal (RCDT), allows an operator to control the test and observe the received test data in realtime.

The MIRDAT Phase I Study afforded an opportunity to determine the feasibility of producing miniature data acquisition and telemetry units incorporating pulsed infra-red (IR) transmission. To organize the study, a feasibility test plan was developed and followed (section 2.1), and an investigation into commercially available components for the system was performed. Two types of MIRDAT prototype TTUs were constructed and tested in the laboratory.

The initial TTU prototype was a small wire-wrap device for use in firmware development and limited testing. The second configuration was a miniature MIRDAT TTU capable of operating in a scale model for limited testing by the end user. Figure 15 is a schematic of the Phase I miniature prototype. This miniature
model was invaluable for demonstrating the feasibility of the MIRDAT concept, providing a testbed for communications protocols and TRU software, and as a tool for investigating various construction techniques. The miniature MIRDAT prototype was constructed for lab testing and subsequent delivery to the user on completion of the Phase I effort. In addition, system specifications and a preliminary design for the proposed MIRDAT system were documented.

2.1 Development of Feasibility Test Plan

At the onset of the program, a meeting was held with cognizant NASA personnel in order to gain a comprehensive understanding of design goals and system requirements. A major objective of the meeting was to gather information for preparation of a preliminary design specification. This specification was delivered to NASA in the form of a system block diagram which outlined two possible approaches for the MIRDAT prototype (see Figure 2 and 3).

In addition, a general software specification was prepared to help the user expedite software interface development and testing (see Figure 4). A set of preliminary requirements was developed and integrated into the MIRDAT feasibility investigation as a result of the meeting.

To insure an orderly and timely approach to the problem, the following feasibility test plan was outlined:
FEASIBILITY TEST PLAN

I. Problem Definition
   A. Meet with user
   B. Hold staff discussions for ideas

II. Definition of Overall System Specifications
   A. Hardware
   B. Software

III. Design and Construction of Prototype Hardware
   A. Create and document design
   B. Deliver preliminary design to user
   C. Order components
   D. Construct breadboard prototype
   E. Debug and test prototype in laboratory
   F. Construct miniaturized version for delivery

IV. Specification of Prototype Software
   A. Define communications protocol
   B. Define protocol between Telemetry Receiver Unit (TRU) and RS232 interface
   C. Deliver preliminary specifications to user

V. Laboratory Testing of Prototype Software
   A. Define types of prototype tests to be performed
   B. Define on-site tests to be performed by user

VI. Integration of Test Results Into Specifications

VII. Investigation of Available Components

IX. Document Design of Commercial Version
   A. Utilize refined specifications to generate new design
   B. Perform check of selected components against operating requirements
X. Definition of Phase II Technical Objectives

A. Prepare list of anticipated problems in hybrid development
B. Prepare Phase II preliminary test plan
C. Prepare preliminary specifications for user review
D. Investigate similar data acquisition systems

XI. Preparation of Phase I Final Report

XII. Preparation of Phase II proposal

2.2 Component Selection and Search

A major portion of the time spent on MIRDAT Phase I involved the selection and subsequent availability search for suitable miniaturized components. Most if not all of the components in a hybrid circuit are either surface mounted or utilize a die on board technique. Not all devices, however, are commercially available in die or surface mounted form. Some microprocessor types, specifically those with onboard (ultra-violet) erasable memories (EPROM devices), are generally not available in miniaturized form. CMOS integrated circuits, because of their special handling and testing procedures, are also not widely available.

Part of the Phase I study involved selection of a suitable analog to digital (A/D) converter, associated front end circuitry, and signal amplifying and multiplexing devices. Care was required in the selection of these devices to insure final design performance within speed, accuracy, and power constraints.
2.3 Prototype Construction

As specified in the Phase I MIRDAT proposal, prototype units were constructed which were modeled after non-miniaturized telemetry systems previously developed at Energy Optics, Inc. These units were built to verify miniature electro-optical telemetry system designs and to demonstrate the feasibility of the concept.

While not meeting ultimate user requirements for size, power consumption, speed of operation or accuracy, the miniature prototypes were sufficiently small to fit within the confines of user scale models, thereby providing a testbed for experimentation. They were also utilized for development and testing of communications protocol firmware to be used in the modified production TRU device, previously developed for Energy Optics' commercial products. Existing protocols required modifications to provide for a low power mode of operation in the MIRDAT device.

Laboratory test results were used as a basis for the documented preliminary production design. Experiments were performed both in the laboratory and in the user's wind tunnels to verify operation of the device in high electrical and optical noise environments. Descriptions of experimental setup procedures and results are included in section 3.4.

2.4 Electro-Optics and Communications

The prototype MIRDAT system employs free-space electro-optical communication technology to transmit digital data in both directions between a telemetry transmission unit (TTU) and telemetry receiver unit (TRU). The system includes an IR
transceiver which is mounted to the interior portion of the wind
tunnel for data reception. An IR transponder, an integral part
of the TTU, faces the transceiver from the rear of the model
under test. Both devices use a Gallium Arsenide (GaAs) light
emitting diodes (LED) as a source of pulsed radiation in the near
IR spectrum (900 nanometers).

2.4.1 Transmitter (Emitter)

The transmitted radiation is non-coherent but spectrally
narrow, with a bandwidth of 50 nanometers. The LEDs are
operated in pulsed mode in order to achieve a hundredfold
increase in peak power output over CW transmission methods
(refer to section 4.0). This technique also provides a simple
method for direct digital encoding of the data. Transmitted
pulse width is nominally 1.0 microsecond.

2.4.2 Receivers and Amplifiers

The receivers used in each device employ silicon photodiodes
operated in the photoconductive mode. Incident radiation is
optically filtered to limit interference from ambient light
sources. The photodiodes are AC coupled to high gain voltage
amplifiers with cutoff frequencies designed to pass the lowest
order component of the transmitted pulse train.

2.4.3 Frequency Response and Bandwidth

Frequency response of the receiver amplifier and passband of
the optical filters were selected to achieve the maximum signal
to noise ratio at a reasonable cost. The receivers were de-
signed to reject continuous light sources and to pass only a
narrow band of light wavelengths centered around the 900
nanometer region. Electronic filtering attenuates both low and very high frequency AC signals. The combination of optical and electronic filtering eliminates interference from pulsed lasers and fluorescent lights.

2.5 EMI/RFI Shielding

Electrically the device is shielded from sources of external RF radiation. The shielding also prevents the MIRDAT from interfering with nearby instruments, due to oscillations of the internal logic and microprocessor. An LC filtering technique is used between the MIRDAT power source and electronics and at the signal input. A Faraday shield, made of Mu metal, acts as a protective outer layer. High frequency transient noise from external sources is absorbed by Ferrite beads selected to suppress frequencies above the response of the model under test.

2.6 Laboratory and Environmental Testing

MIRDAT prototype devices were subjected to a series of laboratory tests to verify proper operation. A TRU and CRT terminal were configured to establish communications in the testbed.
2.6.1 Range Tests

The electro-optics were configured to communicate over distances likely to be encountered in wind tunnel tests. Specific tests included:

- Measurement of optical power densities at distance of 4.57 meters
- Determination of required receiver sensitivity at 4.57 meters
- Measurement of transmit beam angles in mock-up tunnel
- Transmission and terminal display of simulated data.
- Temperature testing from 0°C to 55°C.

Test descriptions and results are presented in section 3.4.

2.6.2 Environmental Tests

Only limited environmental testing was performed on the Phase I prototype devices. No effort was made to construct devices capable of operating at required accuracies over extremes of temperature and humidity. Rather, the study focused on investigating the availability of components for the Phase II design which could be made to operate in harsh environments. The resulting component list was later used to produce a preliminary design for a commercial version of the MIRDAT device.
Section 3.0

RESULTS OBTAINED

User interaction provided valuable insight into the varied problems of acquiring data from extremely small scale models in wind tunnel experiments. The MIRDAT Phase I study attempted to solve as many of these problems as possible, while retaining practical solutions to the design of a miniaturized data acquisition and telemetry unit. The most desirable MIRDAT TTU would, of course, require exceedingly small amounts of physical space and electrical power. Such a telemetry unit would find wide acceptance in several industries as a data acquisition and transmitting device.

3.1 Hardware Development

A major accomplishment of the MIRDAT Phase I study was the construction of miniature prototype telemetry devices without the benefit of an in-house hybridization capability. These devices were valuable for demonstrating feasibility and verifying the electro-optical telemetry system design. Figure 21 depicts the different construction techniques considered. Once constructed, the TTUs were utilized for experiments involving EMI/RFI interference, communications protocol, and transmission range. In several instances the prototypes provided insight into the ultimate design requirements for the MIRDAT system. Although no hardware delivery was called for or specified in the Phase I contract, the miniature TTU prototype developed was delivered to the user for further testing at the conclusion of the Phase I contract. This prototype, although not as small as a production version, serves to prove the feasibility of the
MIRDAT concept.

The MIRDAT telemetry transmitter device requires support equipment to capture the electro-optical telemetry data and to transfer it to a host computer or controlling terminal. This peripheral equipment consists of an electro-optical transceiver which is an integral part of the Telemetry Receiver Unit (TRU). The transceiver attaches to the side of the wind tunnel and communicates with the TTU. The TRU relays the received data to a host computer (RCDT) in RS232 format. See Figure 5 (pictorial of MIRDAT unit) and Figure 6 (transponder mounting location).

A device previously developed at Energy Optics for reception of IR telemetry data was adapted for use in the MIRDAT program. The device is termed a transceiver to describe its ability to both transmit and receive data electro-optically. A schematic of the transceiver is shown in Figure 16. Physical appearance of the device resembles a pair of binoculars, where one tube contains the transmitting element while the other contains the receiver. The transmitting LED radiates one microsecond pulses of 0.175 watt peak optical power into a 3.0 degree, full angle beam width. The receiving device is much more sensitive than necessary for this application, having a four degree field-of-view and a field strength sensitivity of 48 nW/cm² (48 x 10⁻⁹ watts/centimeter squared).

The transceiver is attached to the TRU via a cable which passes both data and power. The transceiver attaches to the inner wall of the wind tunnel with its optics oriented toward
the rear of the test vehicle containing the TTU and its associated transponder. An alternate technique employs a prism type device to bend the infrared beams, allowing the transceiver to mount outside the tunnel with only a small portion of the optics protruding into the tunnel. Figure 6 graphically depicts both mounting techniques.

A portable data acquisition device previously developed at Energy Optics for commercial use was modified to serve as the MIRDAT TRU prototype. The TRU schematic is shown in Figure 17. The TRU consists of a single-board microcomputer with 16,384 bytes of random access memory; 8,192 bytes of program storage memory; and interfaces for RS232 and electro-optical communications. The TRU was originally developed to serve as a portable battery-powered data acquisition unit in a remote meter reading system. It contains a small, precision digital cassette recorder for mass data storage. For the MIRDAT application, the TRU was re-packaged by replacing the battery pack with an AC power supply, and the digital cassette recorder was not used.

Existing communications firmware had to be re-written for the specialized MIRDAT communications protocol. The TRU can be interconnected to either a mainframe, small personal computer, or CRT terminal for control and display of acquired data. Figure 7 lists the commands recognized by the TRU when connected to a terminal or computer. The TRU interprets commands received through its RS232 port and acts on those commands by interrogating the TTU at selected intervals. After each interrogation sequence, data collected from the TTU is passed
to the controlling device. Since the TTU is designed for low power consumption, the initial communications protocol causes it to switch from a low power quiescent state to an active state. When active, the MIRDAT gathers a set of data and transmits them electro-optically to the TRU. The TRU can be used with any future commercial versions of the MIRDAT system with only minor (software or packaging) changes required. Existing user-owned personal computers could also be used for reception and processing of data acquired by the MIRDAT device if they contain an integral RS232 port.

3.2 Range Calculations

The maximum communications range of the MIRDAT system is a function of many variables relating to the IR transmitter design, receiver design, available power, and ambient interference. Atmospheric attenuation is not considered in this application due to the limited distances and controlled nature of the experiments. In the uniform beam model seen in Figure 8, maximum communications range is a simple function of transmitter power "P" (watts) and receiver sensitivity "Ps" (watts/centimeter squared). These values are accurately measured in the laboratory by using a calibrated radiometer. Although the output of an IR LED is essentially Gaussian, good results are achieved by assuming that the LED radiation is evenly distributed over the beam's cross section. At a range R, the radiation power density "Pd" is then:

\[ Pd = P/\left(\pi (R \tan \theta/2)^2\right) \]

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where \( \Theta \) is the full angle beam divergence. In a typical example, the power density radiated by the TRU at 4.5 meters (15 feet) is:

\[
P_d = \frac{0.175}{(\pi \times (457 \tan (3^\circ/2))^2)}
\]

or

\[
P_d = \frac{0.175}{3.14 \times (457 \text{ cm} \times (\tan 1.5^\circ))^2}
\]

\[
P_d = 389 \text{ microvolts/cm}^2.
\]

The maximum communication distance can be calculated by finding the range at which the transmitter power density equals the receiver sensitivity \( P_s \):

\[
P_s = \frac{P}{(\pi \times (R \times (\tan \Theta/2))^2)}.
\]

Solving this equation for \( R \) provides a useful range equation:

\[
R = \sqrt{\left(\frac{P}{P_s \times (\pi \times (\tan \Theta/2))^2}\right)}.
\]

The maximum communication range from the TRU to the TTU can be calculated by inserting the peak TRU transmit power (0.175 watts), the TTU receiver sensitivity \((100 \times 10^{-6} \text{ W/cm}^2)\), and the transmit beam width \(3^\circ\):

\[
R = \sqrt{\left(\frac{0.175 \text{ W}}{100\text{uw} \times (\pi \times (\tan 1.5^\circ))^2}\right)}
\]

\[
R = 901 \text{ cm or 29.5 feet}.
\]

Since the MIRDAT system utilizes two-way communications, the maximum range must be calculated in both directions and the system range will be limited by the weakest link. The maximum range from the TTU transponder to the TRU transceiver is a function of the peak TTU transmit power \((0.0059 \text{ watts})\), the TRU transponder receiver sensitivity \((\text{W/cm}^2)\), and the transmit
beam width (10 degrees):

\[ R = \sqrt{\frac{P}{(P_s \times \tan(\Theta/2))^2}} \]

\[ R = \sqrt{\frac{1}{(48 \times 10^{-9} \times \tan(5^\circ))^2}} \]

\[ R = 2260 \text{ cm or 74 feet.} \]

Based on the weaker TRU to TTU link, the maximum communications range for the MIRDAT system electro-optical data link is approximately 880 centimeters or 29 feet.

3.3 Experimental Results

The following section summarizes experiments performed in Phase I. In general, the experiments provided information about prototype operation in the wind tunnel environment.
MAGNETIC FIELD EXPERIMENT

Purpose: Verification of MIRDAT prototype operation in high level DC magnetic fields.

Setup

A wire wrap prototype of the Phase I MIRDAT device was constructed and mounted in a brass enclosure (RF shield). The TTU and a version of the TRU with a hand-held transceiver were shipped to the user for testing in a magnetic suspension wind tunnel. Inputs to the MIRDAT device were configured to produce simulated data. The MIRDAT device was activated and remotely read both before and during operation in the magnetic field. Figure 9 is a picture of the MIRDAT prototype units.

Results

Error-free data was transmitted electro-optically from the MIRDAT device in both normal and magnetic operating environments. A continuous DC field in excess of 800 gauss was applied to the MIRDAT device in order to suspend it magnetically within the tunnel. The device functioned normally and transmitted data was verified to be the same value with or without the magnetic field.

Conclusion

The experiment was considered a success and the MIRDAT unit was found to be operable in high strength DC magnetic fields.
OPTICAL NOISE AND BIT ERROR RATE EXPERIMENT

Purpose: Verification of communications protocol susceptibility to undetected data errors.

Setup

A TRU transceiver and TTU transponder were placed on an optical bench at an arbitrary separation of distance of 90 centimeters. Neutral density filters were placed in the optical paths to simulate long distance by attenuating the transmitted signals. Finally, a rotating disc with variable transmissivity was placed in the optical path to provide periodic signal degradation. Known data was transmitted and continuously verified in both directions. Undetected bit errors were then counted, as were the total number of bits transmitted. An undetected error is defined as an error which is not detected as a function of either the parity or checksum functions.

Results

More than $10^8$ bits were transmitted during the experiment, with only 2 undetected errors occurring. The actual number of transmitted bits was $5.76 \times 10^8$, yielding a bit error rate of $3.4 \times 10^{-9}$. 
RECEIVER SENSITIVITY EXPERIMENT

Purpose: Performance testing of the TRU and TTU receivers to measure sensitivity for the anticipated wind tunnel experiments.

Setup

Part 1, TTU Receiver

The TTU receiver was placed on an optical bench at a distance of 90 centimeters from a test transmitter. The transmitter was operating at a 4 kHz pulse rate. A calibrated radiometer was placed in the same field of view as the receiver. The output intensity of the test emitter was reduced while the TTU receiver was observed for its ability to detect the continuous pulse train. The TTU receiver was operated at yaw angles between +7 and -7 degrees to simulate wind tunnel conditions. Using a calibrated radiometer, observations revealed that the receiver functioned properly at optical power levels as low as 100 microwatts/cm². This level may be considered a minimally acceptable signal level.

Part 2, TRU Receiver

A similar test was conducted with the TRU receiver in place of the TTU receiver. The TTU transmitter was excited and results were measured with the TRU receiver. The TRU receiver operated satisfactorily at power levels of 48 nanowatts/cm².

Conclusion

The TTU receiver must have a field strength sensitivity of at least 218 microwatts/cm² in order to insure reliable communications. This is the available optical power density at a transmission distance of 457 centimeters, with the TRU
transmitter operating at a 4° angle beam divergence. Since the measured sensitivity was found to be 100 microwatts/cm², the receiver is adequate.

A measurement of the available optical power density from the TTU diode at a beam divergence of 6 degrees yields 798 nanowatts/cm² at a distance of 457 centimeters. The TRU receiver must have a sensitivity of 798 nanowatts/cm². Since the TRU receiver had a measured sensitivity of 48 nanowatts/cm², sensitivity is more than adequate for the MIRDAT application.
OPTICAL POWER DENSITY EXPERIMENT

Purpose: Measurement of available optical power densities.

Setup and Results

Part 1, TTU Transponder

The TTU transponder was placed on an optical bench at a distance of 457 centimeters from a calibrated radiometer. The TTU transponder emitter was operated at a rate of 5000 pulses per second, while readings were simultaneously taken from the radiometer. The TRU transponder was swept through an arc of 12 degrees. Measurements taken from the radiometer were used in a range computation equation. Results were plotted (see Figure 18) and are depicted numerically below:

<table>
<thead>
<tr>
<th>Attitude (degrees)</th>
<th>Measured Value</th>
<th>Converted to ( \text{uw/cm}^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>-6.0</td>
<td>90</td>
<td>0.177</td>
</tr>
<tr>
<td>-5.5</td>
<td>150</td>
<td>0.296</td>
</tr>
<tr>
<td>-5.0</td>
<td>200</td>
<td>0.395</td>
</tr>
<tr>
<td>-4.5</td>
<td>250</td>
<td>0.493</td>
</tr>
<tr>
<td>-4.0</td>
<td>300</td>
<td>0.592</td>
</tr>
<tr>
<td>-3.5</td>
<td>400</td>
<td>0.790</td>
</tr>
<tr>
<td>-3.0</td>
<td>450</td>
<td>0.888</td>
</tr>
<tr>
<td>-2.5</td>
<td>520</td>
<td>1.02</td>
</tr>
<tr>
<td>-2.0</td>
<td>550</td>
<td>1.08</td>
</tr>
<tr>
<td>-1.5</td>
<td>580</td>
<td>1.14</td>
</tr>
<tr>
<td>-1.0</td>
<td>580</td>
<td>1.14</td>
</tr>
<tr>
<td>-0.5</td>
<td>580</td>
<td>1.14</td>
</tr>
<tr>
<td>On Axis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+0.5</td>
<td>600</td>
<td>1.18</td>
</tr>
<tr>
<td>+1.0</td>
<td>560</td>
<td>1.10</td>
</tr>
<tr>
<td>+1.5</td>
<td>540</td>
<td>1.06</td>
</tr>
<tr>
<td>+2.0</td>
<td>540</td>
<td>1.06</td>
</tr>
<tr>
<td>+2.5</td>
<td>540</td>
<td>1.06</td>
</tr>
<tr>
<td>+3.0</td>
<td>540</td>
<td>1.06</td>
</tr>
<tr>
<td>+3.5</td>
<td>540</td>
<td>1.06</td>
</tr>
<tr>
<td>+4.0</td>
<td>540</td>
<td>1.06</td>
</tr>
<tr>
<td>+4.5</td>
<td>520</td>
<td>1.02</td>
</tr>
<tr>
<td>+5.0</td>
<td>480</td>
<td>0.948</td>
</tr>
<tr>
<td>+5.5</td>
<td>440</td>
<td>0.860</td>
</tr>
<tr>
<td>+6.0</td>
<td>380</td>
<td>0.750</td>
</tr>
</tbody>
</table>

26
\[
\frac{W}{cm^2} = \text{Radiometer output (mV} \times \text{Neutral Density Factor)}
\]

Radiometer Calibration Constant

or \[
1.18 \times 16
\]

or \[
2.33 \times 10^{-6} W/cm^2 \text{ or } 233 \text{ microwatts/cm}^2
\]

8,100,000

**Part 2, TRU Transmitter**

An identical test was performed on the TRU transceiver. TRU output power density plot is found in Figure 19. Results for this test are as follows:

<table>
<thead>
<tr>
<th>Attitude (degrees)</th>
<th>Measured Value</th>
<th>Converted to (\mu W/cm^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2.5</td>
<td>.200</td>
<td>98.7</td>
</tr>
<tr>
<td>-2.0</td>
<td>.280</td>
<td>138.2</td>
</tr>
<tr>
<td>-1.5</td>
<td>.480</td>
<td>237.0</td>
</tr>
<tr>
<td>-1.0</td>
<td>.680</td>
<td>335.1</td>
</tr>
<tr>
<td>-0.5</td>
<td>.800</td>
<td>395.0</td>
</tr>
<tr>
<td>On Axis</td>
<td>.840</td>
<td>414.8</td>
</tr>
<tr>
<td>+0.5</td>
<td>.720</td>
<td>355.5</td>
</tr>
<tr>
<td>+1.0</td>
<td>.440</td>
<td>217.2</td>
</tr>
<tr>
<td>+1.5</td>
<td>.240</td>
<td>118.5</td>
</tr>
<tr>
<td>+2.0</td>
<td>.160</td>
<td>79.0</td>
</tr>
<tr>
<td>+2.5</td>
<td>.120</td>
<td>59.2</td>
</tr>
<tr>
<td>+3.0</td>
<td>.090</td>
<td>44.4</td>
</tr>
</tbody>
</table>

\[
\frac{W}{cm^2} = \text{Radiometer output (V} \times \text{Neutral Density Factor)}
\]

Radiometer Calibration Constant

or \[
W/cm^2 = .84 \times 4000
\]

or \[
.415 \text{ mw/cm}^2
\]

8,100,000

**Conclusion**

The TRU receiver, must have a sensitivity of at least 798 nanowatts/cm² to insure satisfactory communications. The TTU receiver, which in turn communicates with the TRU transmitter, must have a sensitivity of 218 microwatts/cm² to insure satisfactory communications.
Section 4.0

Electro-Optical Communication Methods and Theory

A variety of methods exist for effecting communications using electro-optics. These methods usually involve imposing the information to be transmitted upon some form of light beam. The beam is modulated in a manner that allows the information to be decoded by a receiving device.

Some of the more typical methods employed are CW modes such as amplitude modulation (AM), frequency modulation (FM), frequency shift keying (FSK), pulse code modulation (PCM), and pulse modes such as direct digital transmission. Each of these methods exhibit advantages and disadvantages as noted below:

<table>
<thead>
<tr>
<th>METHOD</th>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM</td>
<td>Easy to implement</td>
<td>Poor range, high power consumption, noisy</td>
</tr>
<tr>
<td>FM</td>
<td>Wide bandwidth</td>
<td>Complex to implement, noisy</td>
</tr>
<tr>
<td>FSK</td>
<td>Easy to implement, works well withPLLs, noise immune</td>
<td>High power consumption, short range</td>
</tr>
<tr>
<td>PCM</td>
<td>Implemented digitally</td>
<td>Complex timing, high power</td>
</tr>
<tr>
<td>Pulse Mode</td>
<td>Low power, long range, noise-immune</td>
<td>Extremely complex timing (requires microprocessor)</td>
</tr>
</tbody>
</table>

From the standpoint of power consumption versus range, no communication method other than direct digital pulse mode lends itself to an application such as MIRDAT. Briefly stated, in the direct digital pulse mode of data transmission, both ends of the link must be in precise synchronization with one another. Digital 1s are represented by the transmission of an IR pulse, and digital 0s are represented by the properly timed
absence of an IR pulse in the serial bit stream. When the transmitter initiates a communications sequence, a synchronization pulse is first transmitted for the purpose of establishing proper timing. The receiving device then waits for a precise interval of time before interrogating its receiver. With this method of communication, the presence or absence of digital 1 bits latched by the receiver bears a direct correspondence to the data bits sent by the transmitting device. Figure 10 depicts a representative transmitted bit stream, showing the synchronization or start pulses and the receive listening periods (windows).

Software (in the controlling microprocessors on both ends of the link) controls timing of the transmitted pulses and detection windows. Several parity bits are transmitted and subsequently tested by the receiving microprocessor. Data is transmitted in groups of bytes called blocks. These blocks may range from 16 to 1024 bytes in length. At the end of each block a checksum byte (the summation of all previously transmitted data) is sent.

The receiving computer calculates its own version of the checksum and compares it to the value received. Errors in transmission, either in the form of parity errors or checksum errors, cause the last data block to be re-transmitted. A continuous exchange (handshake) takes place between the two computers during data communications. Bits are transmitted to acknowledge the successful completion of data blocks and data bytes. Figure 11 illustrates the interchange which takes place during the transfer of a 2-byte block of data. The MIRDAT
communications protocol is divided into initialization and data transfer phases. Each phase is discussed below.

The TRU initiates communications activity by sending a burst of sync bits to the MIRDAT unit. These sync bits or pulses increment a hardware pulse integrator, which applies full power to the unit upon reaching a pre-determined count. The MIRDAT unit uses the precise timing of the pulses (5 kHz or an interpulse period of 200 microseconds) to verify interrogation by the TRU. The unit counts properly timed infra-red pulses until a total of six have been received, and then transmits an acknowledge doublet (spaced at 100 microseconds) 100 microseconds after the sixth sync bit is received. The TRU looks for the acknowledge doublet after each sync bit is sent.

If the TRU sees the first acknowledge bit at the correct time, it waits another 100 microseconds and then looks for the second bit rather than transmitting another sync pulse. If the two acknowledge bits are received, the TRU switches to receive mode and waits for the data to be transmitted by the MIRDAT unit. The TRU returns to transmitting sync bits if the second acknowledge bit is not received and/or properly timed, and continues to perform this sequence until stopped by the console operator.

The MIRDAT unit initiates a data transfer phase after obtaining required data from the data collection devices. The received data is first processed through a Single Error Correction Double Error Detection (SECDED) algorithm (discussed later in this report). Each data byte is transmitted as a 13-bit byte consisting of a start bit (always 1), followed by the 8
data bits of the byte, followed by four parity bits.

The TRU firmware generates a precisely timed window when it expects to receive a bit. If a pulse is received during the window the MIRDAT interprets it as a 1 bit. The initial window is infinitely long to capture the start bit. Detection of the start bit triggers timing for the remaining 12 bits, therefore, the timing is re-synchronized with each start bit to virtually eliminate timing errors. Since both the TRU and MIRDAT units know the exact amount of data to be transferred in each communications sequence, no headers or trailing bytes are required. The transmission period is thus minimized.

An error detection and correction scheme, closely following the design of R.W. Hamming of Bell Telephone Laboratories, was chosen to insure data validity and reliability. In this scheme four parity bits are generated for each data byte, so that a comparison of checked and received data parity bits generates a pointer (syndrome) to the bit which is in error. Complementing this bit and re-checking the parity will provide a corrected data byte if the syndrome is zero. On-the-fly correction is impossible, however, if the syndrome does not reduce to zero after complementing the designated bit, since more than one bit is in error. It is entirely possible that the parity bit itself is the error bit, but this has no effect whatsoever on the validity of this procedure.
ESTIMATE OF TECHNICAL FEASIBILITY

Based on the findings of this Phase I feasibility study, a miniature data acquisition and telemetry system utilizing electro-optical data transmission is possible to produce using hybrid construction techniques. A careful system design will result in a device which is useful in a variety of applications. Figure 12 depicts Phase II design specifications and goals. Figures 13 and 14 depict the suggested Phase II amplifier frontend and system block diagram.

5.1 Anticipated Benefits

In addition to the obvious benefits the MIRDAT system would bring to wind tunnel testing, a commercial version of the system would be applicable to many areas. Although well-established commercial systems are currently available, no miniaturized systems exist. Potential uses for miniaturized data acquisition and telemetry equipment, such as diagnostic monitoring of automobiles, aircraft, and robots, offer an opportunity for MIRDAT application.

5.2 Technical Limitations

The Phase II MIRDAT design represents the integration of many different design constraints. In such a highly complex system the physical constraints interrelate. Each design variable has an effect on the others, such as available size versus battery capacity versus operating time. The following sections address design parameters (in order of decreasing importance) that became a part of the Phase II design.
5.2.1 Physical

The device's maximum size is a constraint that cannot be compromised. In order for the MIRDAT TTU to be useful in new applications as well as in diverse wind tunnel applications, overall size of the device had to remain within the design goals specified by the end user. A size of less than 2.5 centimeters in diameter and 5 centimeters in length (including connectors, power source, optics, and protective housing) is required.

In addition, the method used for interconnecting cables and changing batteries must be simple, direct, and reliable in order to minimize setup time for experiments. The device must be physically protected both from rough handling and from external sources of electrical, magnetic, and optical noise. The basic physical layout of the device should lend itself well to placement within a heated cavity so that slightly larger models can be tested in cryogenic tunnels in the future.

5.2.2 System Accuracy

A number of factors determine accuracy of the MIRDAT system. Of primary concern is the fact that such a small device has no room for trimming components on the analog portion of the circuitry. All system error parameters such as DC offset, linearity, and gain errors must be corrected by the computer which eventually receives the telemetry data. A calibration program and procedure must be developed to enable this computer to account for error terms.

Selection of system components is also important. Circuitry used for data input scaling or analog to digital conversion must
achieve the accuracy desired by the customer (+/- 1/4% full scale). This accuracy must further be maintained over the full operational temperature range of the device, which for Phase II versions is specified as -55 degrees C to 125 degrees C.

Speed of data sampling and conversion is also critical to system accuracy. Data sample rates for each channel should be variable from less than 1 per second to 50 per second to insure measurement of rapid transient responses from the model under test. Since a number of data channels may be used for a test, it is desirable to take samples from each channel simultaneously, or nearly so. Data skewing results when samples are taken from sensors placed in different locations on the model. Data skewing is generally prevented when sampling rates are at least twice the maximum frequency response of the material used in the model under test. Although the samples are not truly received simultaneously, the faster sampling rate prevents skewed results. The prototype MIRDAT device can sample at a rate of only 100 microseconds between channels. This results in a maximum skew of only 700 microseconds between channels 1 and 8.

5.2.3 Power

A major concern is the total power consumed by the MIRDAT device in relation to its total overall size, operating time, operating speed, and transmission distance. The Phase II device will utilize a CMOS microprocessor to consume far less power than the NMOS prototype. Batteries for the Phase II device can be the flat button type of lithium, rechargeable lithium, or nickel-cadmium. The operating time must be maintained at 30 minutes.
minimum and the transmission distance at 4.5 to 6.0 meters. A CMOS analog to digital converter has been specified to further lower power consumption while providing reasonable (50 to 100 microsecond) conversion speeds.

A power budget (analysis) of the proposed Phase II device was performed. Based on both typical and worst-case estimates, the following results were obtained:

<table>
<thead>
<tr>
<th>Component</th>
<th>QUIESCENT</th>
<th>ACTIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Front End (8 channel)</td>
<td>.001 A</td>
<td>.035 A</td>
</tr>
<tr>
<td>A/D Converter</td>
<td>.001 A</td>
<td>.010 A</td>
</tr>
<tr>
<td>Microprocessor</td>
<td>--</td>
<td>.015 A</td>
</tr>
<tr>
<td>Power Control Circuit</td>
<td>.005 A</td>
<td>.005 A</td>
</tr>
<tr>
<td>Transponder</td>
<td>.010 A</td>
<td>.075 A</td>
</tr>
<tr>
<td>Total</td>
<td>.017 A</td>
<td>.140 A</td>
</tr>
</tbody>
</table>

The .140 A figure represents a worst case, since the microprocessor, A/D converter, and transponder cannot all be active at the same instant. Also the active state occurs only during data acquisition and transmission. Actual worst case average consumption will likely be closer to .1 A. The system will be active 100% of the time only at the highest possible data acquisition rate. At low data acquisition rates, the duty cycle may drop as low as 10%. A battery capacity of at least 0.1 ampere hours should be utilized to insure operation during extended tests (30 minutes or more).

5.2.4 Noise

The MIRDAT Phase II design incorporates both mechanical and electrical means to prevent errors or improper operation caused by sources of electrical, optical, or magnetic (EMI) noise. The device is housed in a small metal canister or cylinder which
shields it from magnetic fields. A screened port provides a pathway of entry and exit for the optical signals. The interconnecting data cables pass through ferrite beads selected to attenuate any high frequency noise components of the signal.

5.2.5 System Design Constraints

Thick film hybrid construction techniques are required to achieve the MIRDAT system design goals set forth in this report. Components which have been subjected to full military testing are required for the device to operate in the widely varying temperature extremes encountered in wind tunnel tests. Low temperature (cryogenic) operation is feasible in larger versions of the device which would contain heater elements for the internal electronics. In addition, differing coefficients of expansion would be encountered at low temperatures among the different metals used to construct the device. Considerable design effort must be expended to insure mechanical integrity at low temperature extremes.

Low temperature operation, however, is not without benefits. Electro-optical data transmission generally benefits from low temperatures. Also, the self-heating effects in the emitting device would be greatly reduced or eliminated. Optical (shot) noise in the receiver would be reduced in low temperatures. In general, transmitters of lower power and receivers of reduced sensitivity could be used at low temperatures to achieve the same transmission distances.
Computation of Receive Sensitivity: \[ P_d = \frac{P_t}{\pi (d \tan \frac{\theta}{2})^2} \] Computation of Emitted Power: 

Computation of Emitted Power: \[ P_t = P_d \pi (d \tan \frac{\theta}{2})^2 \] Computation of Receive Sensitivity:

TRANSMIT/RECEIVE BEAM PATTERNS

Fig. 1
MIRDAT CMOS MICRO PROCESSOR
WITH EXTERNAL EEPROM VERSION

Fig. 2
MIRDAT SINGLE CHIP MICROCOMPUTER VERSION

Fig. 3
PHASE I SOFTWARE SPECIFICATION

The MIRDAT system is scheduled for delivery to NASA in prototype form in early June 1985. Our goal is to deliver a prototype piece of hardware which demonstrates our ability to construct a data acquisition system using micro miniaturization. We plan to make use of existing software and communications protocol in order to complete the project in a timely and cost effective manner. Accordingly, the MIRDAT prototype shall function as follows:

1. The existing EOI IRMADAC data communications protocol (2 way) shall be used.

2. Attached to the start of each communications attempt will be a 5kHz "wake-up" header similar to that utilized in the AA-MCU1 device.

3. No attempt will be made to massage or manipulate any of the analog data. Upon interrogation by the TRU all data shall be transmitted four times electro-optically to the Telemetry Receiver Unit (TRU).

4. The TRU shall consist of an AA version MCU (less tape drive) with outboard (bread boarded) RS232 level compatible drivers. The TRU shall perform an error detection and correction on the 16 analog values at the completion of the data transmission.

5. Each interrogation by the TRU will end with transmission of an RS232 data packet to a host computer or terminal.

6. The MIRDAT system will revert to a low power mode of operation after a data transmission (successful or otherwise).

7. The MIRDAT system (when doing data acquisition) shall attempt to acquire data from all channels at the fastest possible rate in order to minimize the skew time between sets of data samples.

Fig. 4

40
8. The actual A/D converter to be used will be specified at a later date.

9. The processor to be used in the MIRDAT system shall be either an 803S or NSC800.

10. A prototype MIRDAT and TRU should be available for software testing by 3/18/85.

11. RS232 data packets shall be formatted as follows: (ASCII)

<table>
<thead>
<tr>
<th>SOM</th>
<th>Ch #</th>
<th>SP</th>
<th>VVVV</th>
<th>CR</th>
<th>LF</th>
<th>Ch #</th>
<th>VVV</th>
<th>CR</th>
<th>LF</th>
<th>EOM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NN+1</td>
</tr>
</tbody>
</table>

12. The TRU shall respond to the following commands from:

<table>
<thead>
<tr>
<th>STX</th>
<th>0</th>
<th>N</th>
<th>N</th>
<th>N</th>
<th>CR</th>
<th>= Acquisition Rate in Milliseconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>STX</td>
<td>1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>CR</td>
<td>= Start Test</td>
</tr>
<tr>
<td>STX</td>
<td>2</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>CR</td>
<td>= Terminate Test</td>
</tr>
</tbody>
</table>

STX = Control "C"

Fig. 4 Con't.
<table>
<thead>
<tr>
<th>COMMAND</th>
<th>ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC 0 NNN &lt;CR&gt;</td>
<td>Set sample period where N = no. of 100 millisecond periods between samples. Default = 10 per second</td>
</tr>
<tr>
<td>AC1 &lt;CR&gt;</td>
<td>Begin test and sample mirdat unit at intervals as specified above.</td>
</tr>
<tr>
<td>AC2 &lt;CR&gt;</td>
<td>Terminate test</td>
</tr>
<tr>
<td>&quot;DEL&quot;</td>
<td>Interrupt test if communications have been suspended AC1&lt;CR&gt; will restart.</td>
</tr>
</tbody>
</table>

TELEMETRY RECEIVER UNIT COMMAND SUMMARY

Fig. 7

44
LED

\[ P = \text{Peak Transmit Power (radiant flux)} \text{ watts} \]
\[ P_d = \text{Power Density (irradiance)} \text{ watts/cm}^2 \]
\[ \theta = \text{Full Angle Beam Divergence} \]
\[ R = \text{Range} \]
\[ r = \text{Radius of Beam Cross Section} \]

**UNIFORM BEAM MODEL**

*Fig. 8*
Mirdat Transmitter

100 Microseconds/Bit

Sync

TRU Receive Window

Window Spacing = 100 Microseconds

5 Microsecond Wide Window

Transmitted Bit Stream

Fig. 10
Example of 2 Byte Data Transfer

Fig. 11
SPECIFICATIONS FOR PHASE II MIRDAT

Physical

Diameter: 2.2 cm or less
Length: 1.8 cm or less
Weight: 2.5 oz
Container: Mu metal canister
Transmission range: 4.5 meters
Transmission rate: 20,000 bps
Environmental range: -55 to +125 degrees C

Electrical

Power source: Internal batteries (replaceable)
Operating time: 30 minutes, +1.5 hours quiescent
Power consumption: Operating (transmit) 100 mA
Quiescent 10 mA or less

Data Acquisition System

No. of channels: 8, with differential inputs
Sample rate: Variable from 1 per 5 seconds to 50 per second
A/D converter: 12 bit
Front end: Instrumentation amplifiers ± 5 mV
full scale, with sample and hold on each channel.
Overall system accuracy: ± 1/4% FS over operating temperature range*

* To achieve this accuracy, all error such as drift, offset, linearity, and others will require compensation in and by the receiving computer. Size limitations prevent the use of trimming devices within the MIRDAT unit itself.
PHASE II ANALOG FRONT END SCHEMATIC

Fig. 13
MIRDAT PHASE II BLOCK DIAGRAM

Fig. 14
Power Density at 15'

Radiometer Output
In Millivolts

\[ \text{Total Power} = Pt = \pi (d \tan \frac{1}{2} \alpha)^2 (P_{\text{max}}) \]

Where \( \alpha = 10^\circ \), \( P_{\text{max}} = 1.18 \mu \text{w/cm}^2 \)
\( d = 457 \text{ cm (15')} \)

Gaussian Integration Yields
5.92 mw Total Power

\[ \pi (457 (\tan 5^\circ))^2 \times 1.18 \times 10^{-6} = 5.92 \times 10^{-3} \text{ w} \]

Fig. 18

Output Power Density Plot TTU Transmitter
Radiometer Output in Millivolts

1000
800
600
400
200

Total Power =
Pt = \pi (d \tan \frac{1}{2} \angle)^2 (P_{\text{max}})
Where \angle = 2.7^\circ, P_{\text{max}} = .415 \text{ m w/cm}^2
d = 457 \text{ cm (15')}

Gaussian Integration Yields .150 watts Total Power

Fig. 19
OBJECT #1 -
6" LONG 1" OD. SOLID ALUMINUM ROD

OBJECT #2 -
6" LONG 1" OUT. DIA. 0.9" INSIDE DIA. ALUMINUM TUBE

FIND:
1ST MODE NATURAL RESONANCE (MOST PROMINENT)
EQUATION: (FOR LATERAL VIBRATION)

\[ \omega_n = (\pi^2 \frac{E I}{m l^4})^{1/2} \text{ (natural frequency in (rad/sec))} \]

\[ (\pi^2)^{1/2} \text{ (except values in those, no units) = 22.3733} \]

\[ E = \text{modulus of elasticity) = } 10 \times 10^6 \text{ lbs/in}^2 \]

\[ 1.44 \times 10^9 \text{ lbs/ft}^3 \text{ (in terms of feet)} \]

\[ \rho = \text{density for longitudinal vibrations) = 165 \text{ lbs/ft}^3 \]

VOLUME OF SOLID \( V_1 = 0.0027 \text{ ft}^3 \)

\[ V_1 = \frac{\pi}{2} \left( \frac{0.083}{4} \right) [0.504] = 0.0027 \text{ ft}^3 \]

VOLUME OF TUBE \( V_2 = 0.0005 \text{ ft}^3 \)

\[ V_2 = 0.0027 - \left[ \pi \left( \frac{0.075}{4} \right) \left( \frac{0.504}{4} \right) \right] = 0.0005 \text{ ft}^3 \]

\[ m_1 = \text{mass per unit length of solid rod) = 0.891 \text{ lbs/ft}} \]

\[ m_1 = (0.0054 \text{ ft}^3) (165 \text{ lbs/ft}^3) = 0.891 \text{ lbs/ft} \]

\[ m_2 = \text{mass per unit length of tube) = 0.165 \text{ lbs/ft} \]

\[ m_2 = (0.0014 \text{ ft}^3) (165 \text{ lbs/ft}^3) = 0.165 \text{ lbs/ft} \]

\[ I_1 = \text{moment of inertia, solid) } m_1 \frac{l^2}{12} = 1.179 \times 10^{-5} \text{ slugs ft}^2 \]

\[ I_1 = (0.0027 \text{ ft}^3) (165 \text{ lbs/ft}^3) / 32.2 \text{ ft/sec}^2 = 0.0137 \text{ slugs ft}^2 \]

\[ I = \text{moment of inertia, tube) } m_2 \left( \frac{r^2 + y^2}{2} \right) = 3.9 \times 10^{-6} \text{ slugs ft}^2 \]

\[ I = (0.0027 \text{ ft}^3) (0.0415)^2 + (0.0375)^2 / 32.2 \text{ ft/sec}^2 = 0.0025 \text{ slugs ft}^2 \]

FREQUENCY ANALYSIS

Fig. 20

57
LATERAL VIBRATION (at 2^nd mode resonance)

(SOLID) \[ w_n = (\beta_n L)^2 \sqrt{\frac{EI}{\rho L^4}} \]

\[ w_n = (22.3733) \sqrt{\frac{(1.44 \times 10^9 \text{ lbs/ft}^2) (1.179 \times 10^{-5} \text{ slugs} \text{ ft}^2)}{(0.891 \text{ lbs/ft}) (0.50)^4}} \]

\[ w_n = 12354.3 \text{ rad/sec} \]
\[ w_n = (12354.3/2\pi) = 1.9 \text{ kHz} \]

(TUBE)

\[ w_n = (22.3733) \sqrt{\frac{(1.44 \times 10^9 \text{ lbs/ft}^2) (3.9 \times 10^{-6} \text{ slugs} \text{ ft}^2)}{(0.165 \text{ lbs/ft}^2) (0.50)^4}} \]

\[ w_n = 16510.55 \text{ rad/sec} \]
\[ w_n = (16510.55/2\pi) = 2.6 \text{ kHz} \]

LONGITUDINAL VIBRATION (at 1^st mode resonance)
(SAME FOR SOLID OR TUBE CONFIGURATION)

EQUATION: \[ w_i = \frac{\pi}{L} \sqrt{\frac{E}{\rho}} \]

\[ w_i = \frac{\pi}{(0.50)} \sqrt{\frac{(1.44 \times 10^9 \text{ lbs/ft}^2)}{(165 \text{ lbs/ft}^2)}} \]

\[ w_i = 18561.75 \text{ rad/sec} \]
\[ w_i = (18561.75/2\pi) = 2.9 \text{ kHz} \]

Fig. 20 con't.
CONSTRUCTION TECHNIQUES

Fig. 21
APPENDIX A

SOFTWARE DOCUMENTATION TELEMETRY TRANSMITTER UNIT
AVOCET SYSTEMS 8051 CROSS-ASSEMBLER - VERSION 1.10

MIRDAT - MICRO I/R DATA ACQUISITION TOOL
---- DOCUMENTATION ----

ENERGY OPTICS, INCORPORATED
524 NORTH CAMPO
LAS CRUCES, NM. 88001

AUTHOR: P. L. HANSEN

WRITTEN: 05/03/85

DESCRIPTION:

THE NORMAL STATE OF MIRDAT IS ASLEEP. UPON RECEIPT
OF A HARDWARE DETERMINED NUMBER OF I/R PULSES, POWER
WILL BE APPLIED AND THE INITIALIZATION PHASE BEGINS.

FIRST ALL RAM IS CLEARED TO A KNOWN STATE OF ZEROS,
AND ALL PORTS OF THE 8751 ARE INITIALIZED TO ONES.
AN INTERNAL COUNTER IS SET TO -1 AND EXTERNAL MODE
SO THAT WHEN THE NEXT I/R BIT IS DETECTED, THE COUNTER
WILL OVERFLOW CAUSING AN INTERRUPT.

THE INTERRUPT PROCESSING CODE THEN STARTS THE INTERNAL
TIMER, WHICH WAS PRESET DURING INITIALIZATION TO CAUSE
AN INTERRUPT EVERY 100 MICROSECONDS, AND FURTHER IN-TER-
RUPTS FROM THE COUNTER ARE DISABLED. ALL TIMING HERE-
AFTER WILL BE BASED ON THE INTERNAL TIMER INTERRUPTS.

AFTER SIX (6) BITS, SPACED AT 200 USEC INTERVALS, HAVE
BEEN SUCCESSFULLY RECEIVED, AND ACKNOWLEDGE SEQUENCE OF
TWO (2) BITS, SPACED AT 100 USEC INTERVALS, IS TRANS-
MITTED, 100 USEC AFTER THE SIXTH BIT.

ALL TIMING IS NOW TEMPORARILY HALTED, AND THE ANALOG
TO DIGITAL CONVERTER IS STARTED. THE RESULTS OBTAINED
FROM ALL SIXTEEN (16) CHANNELS ARE RECORDED IN LOCAL
RAM. THE DATA IS THEN RUN THROUGH A HAMMING ALGORITHM
TO GENERATE A SET OF CHECK BITS TO ENSURE DATA VALIDITY.

THE FOUR (4) HAMMING CHECK (SYNDROME) BITS FOR EACH DATA
BYTE ARE PACKED INTO EIGHT (8) BIT BYTES AND STORED AT
THE END OF THE OUTPUT DATA BUFFER.

THE ACCUMULATED DATA IS THEN TRANSMITTED VIA THE I/P
OPTICAL LINK AS A NINE (9) BIT BYTE (START BIT AND
EIGHT (8) DATA BITS) AT A RATE OF 100 USEC PER BIT.
THE SEPARATION BETWEEN THE BYTES IS 300 USECS. THE
ENTIRE 24 BYTE BUFFER IS TRANSMITTED AS A CONTINUOUS
STREAM OF DATA.

UPON COMPLETION OF THE TRANSMISSION SEQUENCE, THE
SYSTEM RETURNS TO A SLEEPING STATE.
AVOCET SYSTEMS 8051 CROSS-ASSEMBLER - VERSION 1.10

MIRDAT - MICRO I/R DATA ACQUISITION TOOL

---- CONSTANTS AND DEFINITIONS ----

; BIT CONSTANTS

0060    IPMD    EQU   01100000B ;TIMER 1 (COUNT/MODE 2)
0002    ITMD    EQU   00000010B ;TIMER 0 (TIME/MODE 2)

; OTHER CONSTANTS

0018    BSIZ    EQU   24 ;XMIT BUFFEP SIZE
0023    BTIM    EQU   35 ;DATA BIT TIME (100 USEC)
000F    CHAN    EQU   15 ;ADC HIGH CHANNEL
0010    CSIZ    EQU   16 ;ADC BUFFEP SIZE

; BUFFER ASSIGNMENTS

0050    CBUF    EQU   60H ;(24) ADC DATA BUFFEP
007F    RTOP    EQU   7FH ;(127) TOP OF RAM .MSB
0050    STAK    EQU   50H ;(16) SYSTEM STACK (TOP)
AVOCET SYSTEMS 8051 CROSS-ASSEMBLER - VERSION 1.10

MIRDAT - MICRO I/R DATA ACQUISITION TOOL

---- ENTRY POINTS ----

; RESET ENTRY POINT
0000 ORG RESET
0000 020030 RST: JMP IPE ;INITIALIZE PROGRAM

; EXT - EXTERNAL INTERRUPT
0003 ORG EXTIO
0003 04 EXT: INC A ;SET COMPLETE FLAG
0004 32 RETI

; TIM - TIMER 0 OVERFLOW INTERRUPT
000B ORG TIMER0
000B 04 TIM: INC A ;SET OCCURED FLAG
000C 32 RETI ;CLEAR STACK

; CNT - TIMER 1 OVERFLOW INTERRUPT
001B ORG TIMER1
001B D28C CNT: SETB TR0 ;START BIT TIMER
001D 04 INC A
001E 32 RETI ;CLEAR STACK
AVOCET SYSTEMS 8051 CROSS-ASSEMBLER - VERSION 1.10

MIRDAT - MICRO I/R DATA ACQUISITION TOOL

---- PROGRAM INITIALIZATION ----

; BYPASS INTERRUPT AREA

0030           ORG    30H

; IPE - INITIALIZE PROGRAM FOR EXECUTION

0030 75A800    IPE:    MOV     IE,#0       ; CLEAR INTERRUPTS
0033 758150    MOV     SP,#STAK
0036 787F      MOV     R0,#RTOP
0038 E4       CLP     A

0039 F6       IPE1:    MOV     @R0,A       ; CLEAR A BYTE
003A D8FD     DJNZ    R0,IPE1       ; UNTIL DONE

003C 14       DEC     A
003D F580     MOV     P0,A       ; INITIALIZE POPTS
003F F590     MOV     P1,A
0041 F5A0     MOV     P2,A
0043 F5B0     MOV     P3,A

0045 F58D    MOV     TH1,A       ; SET COUNTER INITIAL COUNT
0047 F58B    MOV     TL1,A
0049 74DD    MOV     A,-BTIM
004B F58C    MOV     TH0,A       ; SET BIT TIMING
004D 2412    ADD     A,#18
004F F58A    MOV     TL0,A       ; SET FIRST BIT
0051 758962    MOV     TMOD,#IRMD OP ITMD
0054 758800    MOV     TCON,#0       ; INITIALIZE Timers
0057 D2AB    SETB    ET1       ; ENABLE I/P INTERRUPT
0059 D2BE    SETB    TP1       ; ENABLE COUNTER
005B D2AF    SETB    EA       ; ENABLE ALL INTEPPUPTS
005D E4      CLP     A
005E 60FE    JZ      $       ; WAIT FOR INTERRUPT

; WHEN INTEPPUPT OCCUPIES, FALL THROUH TO 'ECS"
AVOCET SYSTEMS 8051 CROSS-ASSEMBLER - VERSION 1.10

MIRDAT - MICRO I/R DATA ACQUISITION TOOL

---- INTERRUPT PROCESSING ----

; ECS - ESTABLISH COMMUNICATIONS SYNC
; VERIFIES THAT SIX (6) SYNC BITS ARE RECEIVED AT THE PROPER TIMING INTERVAL.

0060 D2A9 ECS: SETB ET0 ; ENABLE TIMER INTERRUPT
0062 C2AB CLR ET1 ; BUT NOT I/R INPUT?
0064 7B00 MOV R3,#0 ; PETR1 COUNT 256:
0066 7A06 ECS1: MOV R2,#6 ; BIT COUNTER
0068 74FE ECS2: MOV A,#-2
006A 70FE JNZ $ ; WAIT 2 BIT TIMES
006C C29F CLR TF1 ; NOW LOOK FOR A BIT
006E 7F02 MOV R7,#2
0070 DFFE DJNZ R7,$ ; DELAY 20 USEC
0072 00 NOP
0073 308F22 JNB TF1,ECS3 ; IF NO BIT FOUND
0076 DAF0 DJNZ R2,ECS2 ; ELSE LOOP
0078 E4 CLR A
0079 60FE JZ $ ; WAIT 1 BIT TIME
007B C2B6 CLR WR ; XMIT ON
007D D2B6 SETB WR ; XMIT OFF
007F E4 CLP A
0080 60FE JZ $ ; WAIT 1 BIT TIME
0082 C2B6 CLR WP ; XMIT ON
0084 D2B6 SETB WP ; XMIT OFF
0086 75A800 MOV IE,#0 ; STOP INTERRUPTS
0088 758800 MOV TCON,#0 ; AND TIMERS
008A 12009E CALL ACD ; ACCUMULATE A/D DATA
008C 120090 CALL GHC ; GENERATE CHECK BITS
008E 120100 CALL TDB ; AND SEND IT OUT
0090 02009A JMP ECS4 ; AND THAT'S IT
0092 DECC ECS3: DJNZ R3,ECS1 ; IF MORE PETRIES
0094 C297 ECS4: CLP P1.7 ; TURN OFF POWER
0096 80FE JMP $ ; AND DIE RIGHT HERE

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AVOCET SYSTEMS 8051 CROSS-ASSEMBLER - VERSION 1.10

MIRDAT - MICRO I/R DATA ACQUISITION TOOL

---- COMMON SUBROUTINES ----

ACD - ACCUMULATE CONVERTER DATA

; OBTAINS ALL 16 CHANNELS OF DATA FROM THE
; ADC AND SAVES IN LOCAL RAM.
; EXIT (R0) - BUFFER POINTER

009E D2A8 ACD:
00A0 786F MOV R0,#CBUF+CSIZ-1 ;BUFFER POINTER
00A2 7A0F MOV R2,#CHAN ;LOOP COUNTER

00A4 1200EC ACD1:
00A7 18 DEC R0 ; ADJUST POINTER
00A8 DAFA DJNZ R2,ACD1 ; UNTIL DONE

00AA 1200EC CALL RCD ;GET FINAL CHANNEL
00AD C2A8 CLR EX0 ;KILL INTERRUPTS
00AF 22 RET

GHC - GENERATE HAMMING CODE SYNDROME BITS

; COMPUTES THE HAMMING CODE CHECK (SYNDROME)
; BITS FOR THE CURRENT DATA BUFFER, THE SYNDROME BITS
; ARE ADDED TO THE END OF THE DATA BUFFER.

00B0 7B60 GHC:
00B2 7970 MOV R1,#CBUF+CSIZ ;CHECK BIT BUFFER
00B4 7A08 MOV R2,#CSIZ/2 ;LOOP COUNTER

00B6 7B02 GHC1:
00B8 7C00 MOV P3,#2 ;INNER LOOP COUNTER

00BA C3 GHC2:
00BB 74F0 MOV A,#0F0H
00BD 56 ANL A,@R0 ;CB1
00BE 20D001 JB P,GHC3 ;IF ALREADY ODD

00C1 B3 GHC3:
00C2 CC XCH A,P4
00C3 38 RLC A ;ACCUMULATE CB1

00C4 CC XCH A,R4
00C5 748E MOV A,#0EH
00C7 56 ANL A,@R0 ;CB2
00CB 20D001 JB P,GHC4

00CE CC GHC4:
00CC CC XCH A,R4
00CD 33 RLC A ;ACCUMULATE CB2
00CE CC XCH A,R4

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AVOCET SYSTEMS 8051 CROSS-ASSEMBLER - VERSION 1.10

MIRDAT - MICRO I/R DATA ACQUISITION TOOL

---- COMMON SUBROUTINES ----

00CF 746D MOV A,#6DH ;CB3
00D1 56 ANL A,@R0
00D2 20D001 JB P,GHC5
00D5 B3 CPL C
00D6 CC GHC5: XCH A,R4
00D7 33 RLC A ;ACCUMULATE CB3
00D8 CC XCH A,R4
00D9 745B MOV A,#5BH ;CB4
00DB 56 ANL A,@R0
00DC 20D001 JE P,GHC6
00DF B3 CPL C
00E0 CC GHC6: XCH A,R4
00E1 33 PLCY A ;ACCUMULATE CB4
00E2 CC XCH A,R4
00E3 08 INC R0 ;ADVANCE DATA POINTEP
00E4 DBD4 DJNZ R3,GHC2 ; GO FOR NEXT BYTE
00E6 EC MOV A,R4 ;STOP CHECK BITS
00E7 F7 MOV @R1,A
00E8 09 INC R1
00E9 DACB DJNZ R2,GHC1 ; UNTIL DONE
00EB 22 RET

; RCD - READ ADC DATA
; INITIATES A CONVERSION SEQUENCE AND STORES THE RESULT.
; ENTRY (R0) - DATA BUFFER POINTEP
; (R2) - DATA CHANNEL (0 - 15)

00EC 8A90 PCD: MOV P1,R2 ;SET ADC CHANNEL
00EE D2AF SETB EA ;ENABLE INTERRUPTS
00F0 D294 SETB P1.4 ;START CONVERSION
00F2 C294 CPL P1.4
00F4 E4 CLR A
00F5 60FE JZ $ ;WAIT FOR INTERRUPT
00F7 C2AF CLR EA ;TURN OFF INTERRUPTS
00F9 D295 SETB P1.5 ;ENABLE OUTPUT
00FB A680 MOV @R0,P0 ;READ/STORE DATA
00FD C295 CPL P1.5
00FF 22 PET

A - 8
; TDB - TRANSMIT DATA BUFFER
; SENDS THE 24 BYTE DATA BUFFER OVER THE OPTICAL LINK. EACH BYTE CONSISTS OF A START BIT AND 8 DATA BITS.

0100 74DD  TDB:  MOV  A,#-BTIM  ;SET BIT TIMER
            MOV  TH0,A
            MOV  TL0,A
0104 F58A  MOV  ET0       ;ENABLE TIMEP INTERRUPT
            MOV  TR0       ;STAPT TIMEP
0108 D2FA  SETB  EA       ;ENABLE ALL INTERRUPTS
010A D2FB  SETB  A
010C E4    CLR  $A
010D 7860  MOV  P0,#CBUF  ;DATA POINTER
010F 7D18  MOV  R5,#BSIZ  ;BUFFER SIZE

0110 7E08  TDB1: MOV  R6,#8  ;BIT COUNTER
0113 60FE  JC  $   ;WAIT FOR BIT TIME
0115 C2B6  CLR  WR
0117 D2B6  SETB  WP  ;SEND START BIT

0119 E6    TDB2: MOV  A,@R0  ;GET DATA BYTE
011A 03    RR  A  ;LSB TO MSB
011B F6    MOV  @R0,A  ;PESTOPE
011C 20E706 JB  ACC.7,TDB3  ;IF LSB = 1
011F E4    CLR  A
0120 60FE  JC  $  ;WAIT FOR BIT TIME
0122 02012C JMP  TDB4

0125 E4    TDB3:  CLR  A  ;WAIT FOR BIT TIME
0126 60FE  JZ  $  ;SEND A BIT
0128 C2B6  CLR  WP
012A D2B6  SETE  WP

012C DEEB  TDB4:  DJNZ  R6,TDB2  ;LOOP FOR NEXT BIT
012E 03    INC  P0  ;ADVANCE DATA POINTER
012F 74FE  MOV  A,#-2
0131 70FE  JNZ  $  ;WAIT INTERBYTE GAP
0133 DDDC  DJNZ  R5,TDB1  ;LOOP FOR NEXT BYTE
0135 75A800 MOV  IE,#0  ;STOP INTERRUPTS
0136 75880C MOV  TCON,#0  ; AND TIMERS
0138 22    PET

0000  END
--- SYMBOL TABLE ---

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<th>SYMBOL</th>
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<td>00B0</td>
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APPENDIX B

SOFTWARE DOCUMENTATION TELEMETRY RECEIVER UNIT
TRUOS - TELEMETRY RECEIVER UNIT OPERATING SYSTEM

ENERGY OPTICS, INC.
224 NORTH CAMPO
LAS CRUCES, NM. 88001

AUTHOR: R. L. HANSEN
WRITTEN: 04/30/85

TRUOS - IS AN OPERATING SYSTEM DESIGNED THE COMMUNICATE WITH AND RECEIVED TELEMETRY DATA FROM THE "MIRBAT" TELEMETRY DEVICE.

; SYSTEM CONSTANTS

0010 BSIZ EQU 16 ;STANDARD BLOCK SIZE
0006 CSIZ EQU 6 ;COMMAND BUFFER SIZE
0008 HSIZ EQU BSIZ/2 ;HAMMING CODE BUFFER SIZE
607E STAK EQU 607EH ;TOP OF SYSTEM STACK

; I/O DEFINITIONS

6100 APRT EQU 6100H ;NSC800 PORT A ADDRESS
6104 ADDR EQU APRT+4 ;PORT A DATA DIR REG
6109 BCLR EQU APRT+9 ;PORT B CLEAR BIT
610D BSET EQU APRT+13 ;PORT B SET BIT
610A CCLR EQU APRT+10 ;PORT C CLEAR BIT
610E CSET EQU APRT+14 ;PORT C SET BIT
0002 SIDR EQU 00000010B ;SERIAL INPUT DATA REG
000D SIOD EQU 000000H ;SERIAL DATA PORT
E001 SIOS EQU SIOD+1 ;SERIAL STATUS PORT
0001 STDR EQU 00000001B ;SERIAL OUTPUT DATA REG

; SIO PORT COMMANDS

0040 SIIR EQU 40H ;INTERNAL RESET
0080 SIXR EQU 80H ;EXTERNAL RESET

; PORT "C" COMMANDS

0002 RECV EQU 00000010B ;RECEIVER CLR BIT
0001 XMIT EQU 00000001B ;TRANSMIT BIT
; TIMER 0 - BAUD RATE GENERATOR

6115   TBRG   EQU   APRT+21 ;GENERATOR START
6114   TBRS   EQU   APRT+20 ;GENERATOR STOP
6110   TDIV   EQU   APRT+16 ;GENERATOR MODULUS REG
6118   TMOD   EQU   APRT+24 ;GENERATOR MODE REG

; TIMER 1 - INTERRUPT TIMER

6112   IDIV   EQU   APRT+18 ;TIMER DIVIDER
6119   IMOD   EQU   APRT+25 ;TIMER MODE
6116   ISTP   EQU   APRT+22 ;TIMER STOP
6117   ISTR   EQU   APRT+23 ;TIMER START

; ASCII CHARACTER DEFINITIONS

0008   BS    EQU   08H ;BACKSPACE
000D   CR    EQU   0DH ;RETURN
0004   EDT   EQU   04H ;END OF TEXT
001B   ESC   EQU   1BH ;ESCAPE
000A   LF    EQU   0AH ;LINE FEED
001F   NL    EQU   1FH ;NEW LINE
0011   SOM   EQU   01H ;START OF MESSAGE
0003   STX   EQU   03H ;START OF TEXT

SUBTL ---- INITIALIZATION ----
PAGE
; INITIALIZATION

; RST - RESTART/POWER UP ENTRY POINT

0000' F3 RST:   DI ;ENSURE INTERRUPTS OFF
0001' 31  607E   LD  SP,STAK ;SET STACK POINTER

; INITIALIZE PORTS

0004' 21  6104   LD  HL,ADDR
0007' 36  00   LD  (HL),0 ;PORT A ALL INPUT
0009' 23   INC  HL
000A' 36  FF   LD  (HL),OFFH ;PORT B ALL OUTPUT
000C' 23   INC  HL
000D' 36  2F   LD  (HL),00101111B ;PORT C 0-3 AND TIMER 1 OUTPUT
000F' 23   INC  HL
0010' 36  00   LD  (HL),0 ;ALL PORTS BASIC I/O

; INITIALIZE BAUD RATE GENERATOR

0012' 21  6118   LD  HL,TMOD
0015' 36  05   LD  (HL),00000101B ;TO - SQUARE WAVE MODE
0017' 21  000C   LD  HL,12
001A' 22  6110   LD  (TDIV),HL ;TO - DIVISOR (153.6 KHZ)
001D' 32  6115   LD  (TBRG),A ;AND START TIMER 0

; CLEAR SYSTEM RAM

0020' 21  0000"   LD  HL,CBUF
0023' 11  0001"   LD  DE,CBUF+1
0026' 01  3FFF   LD  BC,16*1024-1
0029' 36  00   LD  (HL),0
002B' ED  60   LDIR ;CLEAR RAM

; POWER UP RS-232 POWER

002D' 3E  60   LD  A,01100000B
002F' 32  610D   LD  (BSET),A ;POWER UP 12 VOLTS
0032' 18  10   JR  CIN ;SKIP INTERRUPT AREA

; TIMER 1 INTERRUPT AREA

0034' DS  RST++38H-* ;LOCATE INTERRUPT

0038' 32  6116   INT:  LD  (IPTP),A ;STOP THE TIMER
003B' 31  607E   LD  SP,STAK ;CLEAR UP THE STACK
003E' 21  03A4'   LD  HL,TMSG ;"** INTERRUPT **"
0041' C3  032F'   JP  TEM1 ;SEND MESSAGE

PAGE

B - 4
--- INITIALIZATION ---

; CONTINUE INITIALIZATION

0044' 3E 64  CIN:  LD  A,100  ;WAIT FOR STABLE POWER
0046' CD 027F'  CALL  MSD

; INITIALIZE CONTROL LINES

0049' 3E 03  LD  A,RECV+XMIT
004B' 32 610A  LD  (CCLR),A  ;SET UP CONTROL LINES

; INITIALIZE USART

004E' 3E 80  LD  A,SIIXR
0050' 32 610D  LD  (BSET),A  ;RESET USART
0053' 3E 0A  LD  A,10
0055' CD 027F'  CALL  MSD
0058' 3E 80  LD  A,SIIXR
005A' 32 6109  LD  (BCLR),A  ;CLEAR RESET
005D' AF  XOR  A
005E' 32 E001  LD  (SIOS),A  ;CLEAR BUFFERS
0061' 32 E001  LD  (SIOS),A
0064' 32 E001  LD  (SIOS),A
0067' 3E 40  LD  A,SIIR
0069' 32 E001  LD  (SIOS),A  ;DO INTERNAL RESET
006C' E5  PUSH  HL  ;SMALL DELAY
006D' E1  POP  HL
006E' 3E 4E  LD  A,01001110B  ;16X, 8BIT, NOP, ISTOP
0070' 32 E001  LD  (SIOS),A
0073' 3E 27  LD  A,00100111B  ;XMIT/RECV ENABLE, DTR/RTS
0075' 32 E001  LD  (SIOS),A
0078' 3A E000  LD  A,(SIOD)
007B' 3A E000  LD  A,(SIOD)  ;CLEAR RECEIVE BUFFER
007E' 21 010A  LD  HL,10AH
0081' 22 0037"  LD  (CCNT),HL  ;SET DEFAULT TIME
0084' 22 0039"  LD  (CTIM),HL

SUBTTL  ---- MAIN PROGRAM ----
MAIN PROGRAM LOOP

WE LOOP HERE WAITING FOR A COMMAND FROM
THE TERMINAL OPERATOR.

0087' FD 21 0039'' MCL: LD IY,CTIM ;SET INTERVAL TIMER
008B' 21 0000'' LD HL,CBUF
008E' F3 DI ;ENSURE NO INTERRUPTS
008F' 22 0035'' LD (BPTR),HL
0092' 36 FF LD (HL),OFFH ;SET INVALID BUFFER
0094' 3A 003C'' MCL1: LD A,(TFLG)
0097' B7 OR A
0098' CA 00AC' JP Z,MCL2 ;IF NOT IN TEST MODE
009B' 3E 64 LD A,100
009D' CD 027F' CALL MSD ;DELAY 100 MSEC
00A0' FD 35 00 DEC (IY)
00A3' C2 00AC' JP NZ,MCL2 ;IF NOT TIME
00A6' FD 35 01 DEC (IY+1)
00A9' CA 0126' JP Z,ROD ;IF TIME TO TEST
00AC' 3A E001 MCL2: LD A,(SIOS)
00AF' EA 02 AND SIDR
00B1' CA 0094' JP Z,MCL1 ;IF NO INPUT DATA REQUEST
00B4' 3A E000 LD A,(SIOD) ;READ BYTE
00B7' FE 1B CP ESC
00B9' CA 0000' JP Z,ROST ;IF RESET COMMAND
00BC' 21 0000'' LD HL,CBUF
00BF' 34 INC (HL)
00C0' 35 DEC (HL)
00C1' F2 00CB' JP P,MCL3 ;IF VALID BUFFER
00C4' FE 03 CP STX
00C6' C2 0094' JP NZ,MCL1 ;IF NOT START OF COMMAND
00C9' 3E 24 LD A,'$'
00CB' FE 0D MCL3: CP CR
00CD' CA 0104' JP Z,MCL5 ;IF COMMAND TERMINATE
00D0' FE 08 CP BS
00D2' CA 00E6' JP Z,MCL4 ;IF BACKSPACE
00D5' CD 031E' CALL STC ;ECHO CHARACTER
00D8' 2A 0035'' LD HL,(BPTR)
00DB' 77 LD (HL),A ;STOW IN BUFFER
00DC' 23 INC HL
00DD' 22 0035'' LD (BPTR),HL ;UPDATE POINTER
00E0' 7D LD A,L
00E1' FE 06 CP CSIZ

B - 6
--- MAIN PROGRAM ---

`; IF BUFFER NOT FULL`

`JP NZ,MCL1`

```assembly
00E3' C2 0094' JP NZ,MCL1 ; IF BUFFER NOT FULL

; BACKSPACE COMMAND BUFFER
```

```assembly
00E4' 2A 0035'' MCL4: LD HL,(BPTR)
00E5' 7D LD A,L
00EA' B7 OR A
00EB' CA 0087' JP Z,MCL ; IF AT START OF LINE
00EE' 2B DEC HL
00EF' 22 0035'' LD (BPTR),HL ; BACKOFF POINTER
00F2' 3E 08 LD A,BS
00F4' CD 031E' CALL STC ; BACKSPACE TERMINAL
00F7' 3E 20 LD A,'`
00F9' CD 031E' CALL STC ; CLEAR DISPLAY CHAR
00FC' 3E 08 LD A,BS
00FE' CD 031E' CALL STC ; POSITION CURSOR
0101' C3 0094' JP MCL1 ; AND LOOP

; INTERPRET COMMAND
```

```assembly
0104' 3E 1F MCL5: LD A,ML
0106' CD 031E' CALL STC ; SEND ACKNOWLEDGE TO TERM
0109' 11 0001'' LD DE,CBUF+1
010C' 1A LD A,(DE) ; GET COMMAND
010D' FE 30 CP 'O'
010F' CA 0150' JP Z,SCT ; IF SET CYCLE TIME
0112' FE 31 CP '1'
0114' CA 017B' JP Z,STM ; IF START TEST
0117' FE 32 CP '2'
0119' CA 011F' JP Z,CTM ; IF STOP TEST
011C' C3 032C' JP TEM ; SEND ERROR MESSAGE

SUBTTL ---- COMMAND PROCESSORS ----
```
; CTM - CLEAR TEST MODE
; CLEARS THE TEST MODE FLAG
  011F' AF  CTM: XOR A
  0120' 32 003C'' LD (TFLG),A
  0123' C3 0087' JP MCL ;BACK TO MAIN LOOP

; ROD - READ OPTICAL DATA
; READS A BUFFER FULL OF DATA FROM MIRDAT.
  0126' 2A 0037'' ROD: LD HL,(CCNT) ;RESET TIMER
  0129' 22 0039'' LD (CTIM),HL
  012C' CD 01FC' CALL ECS ;GET IN SYNC
  012F' CD 0308' CALL SIT ;INITIALIZE INTERRUPT
  0132' 3E 03  LD A,3
  0134' CD 027F' CALL MSD ;DELAY 3 MSEC
  0137' 11 0008'' LD DE,RBUF ;DATA BUFFER POINTER
  013A' 06 18  LD B,BSIZ+HSIZ ;BLOCK SIZE COUNTER
  013C' CD 0299' ROD1: CALL RDB ;GET NEXT DATA BYTE
  013F' 12  LD (DE),A ;STORE IT
  0140' 13  INC DE ;ADVANCE POINTER
  0141' 10 F9 DJNZ ROD1 ;UNTIL BLOCK RECEIVED
  0143' 32 6116  LD (ISTP),A ;STOP TIMER
  0146' F3  DI
  0147' CD 033C' CALL VDB ;VALIDATE DATA BUFFER
  014A' CD 0294' CALL SBT ;SEND BUFFER TO TERMINAL
  014D' C3 0087' JP MCL ;BACK TO MAIN LOOP

; SCT - SET CYCLE TIME
; ASSEMBLES INPUT CYCLE TIME, CONVERTS IT TO BINARY AND STORES IN "CCNT".
  0150' 06 03  SCT: LD B,3 ;MAXIMUM COUNT
  0152' 21 0000 LD HL,0 ;ASSEMBLY BUFFER
  0155' 13  SCT1: INC DE ;ADVANCE INPUT POINTER
  0156' 1A  LD A,(DE) ;GET NEXT CHAR
  0157' FE 0D CP CR
  0159' CA 0174' JP Z,SCT2 ;IF END OF COMMAND
  015C' D4 30 SUB 'O'
  015E' DA 032C' JP C,TEM ;IF NOT DECIMAL DIGIT
  0161' FE 0A  CP 10
  0163' D2 032C' JP NC,TEM ;IF NOT DECIMAL DIGIT
0166'  D5         PUSH DE
0167'  29        ADD HL,HL ;#2
0168'  54        LD  D,H
0169'  5D        LD  E,L
016A'  29        ADD HL,HL ;#4
016B'  29        ADD HL,HL ;#8
016C'  19        ADD HL,DE ;#10
016D'  16 00     LD  D,0
016F'  5F        LD  E,A ;NEW DIGIT
0170'  19        ADD HL,DE
0171'  D1        POP DE
0172'  1E  E1    DJNZ SCT1 ;UNTIL DONE
0174'  24        SCT2: INC H
0175'  22 0037'' LD  (CCNT),HL ;SET COUNTER
0176'  C3 0087'  JP  MCL ; AND RETURN

; STM - START TEST MODE
; ; SETS TEST MODE FLAG AND INITIALIZES
; TESTING.
017B'  32 003C'' STM: LD  (TFLG),A ;SET FLAG
017E'  C3 0126'  JP  ROD ; AND INITIALIZE TESTING

SUBTTL ---- SUBROUTINES ----

PAGE
**DCN** - DISPLAY CHANNEL NUMBER

CONVERTS VALUE TO DECIMAL VALUE AND SENDS TO THE TERMINAL

ENTRY (A) - VALUE

```
0181' 21 003B'' DCN: LD HL,TEMP
0184' C6 01 ADD A,1 ;CHAN 1..16
0186' 27 DAA
0187' 77 LD (HL),A
0188' CD 018B' CALL DCN1 ;DISPLAY UPPER DIGIT
018B' 3E 30 DCN1: LD A,'0' ;CONVERT TO ASCII
018D' ED 6F RLD
018F' CD 031E' CALL STC ;DISPLAY DIGIT
0192' C9 RET
```

**DDV** - DISPLAY DECIMAL VALUE

CONVERTS INPUT VALUE TO A FRACTIONAL DECIMAL VOLTAGE IN THE RANGE 0 - 5 VOLTS, AND SENDS THE RESULT TO THE TERMINAL.

ENTRY (A) - INPUT VALUE

```
0193' D5 DDV: PUSH DE ;SAVE REGISTERS
0194' C5 PUSH BC
0195' 11 00C4 LD DE,196 ;CONVERSION VALUE
0198' 21 0000 LD HL,0 ;INITIALIZE RESULT
019B' 06 08 LD B,8 ;LOOP COUNT
019D' F5 PUSH AF ;SAVE INPUT
019E' CB 3F DDV1: SRL A ;LSB TO CY
01A0' D2 01A4' JP NC,DDV2 ;IF NO BIT
01A3' 19 ADD HL,DE ;ADD MULTIPLIER
01A4' EB DDV2: EX DE,HL
01A5' 29 ADD HL,HL ;SHIFT MULTIPLIER
01A6' EB EX DE,HL
01A7' 10 F5 DJNZ DDV1 ;IF MORE BITS
01A9' F1 POP AF
01AA' B7 OR A
01AB' F2 01B2' JP P,DDV3 ;IF < 2.5 VOLTS
01AE' 11 0014 LD DE,20 ;ROUND UP
01B1' 19 ADD HL,DE
01B2' DD 21 03B' DDV3: LD IX,DDV1 ;DIVISOR TABLE
01B6' FD 21 0030'' LD IY,DDVT ;RESULT POINTER
```
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---- SUBROUTINES ----

01BA' DD 5E 00
01BD' DD 23
01BF' DD 56 00
01C2' DD 23
01C4' 7A
01C5' B3
01C6' EA 01DC'
01C9' 97
01CA' ED 52
01CC' DA 01D3'
01CF' 3C
01D0' C3 01CA'
01D3' 19
01D4' FD 77 00
01D7' FD 23
01D9' C3 01BA'
01DC' FD 75 00
01DF' 21 0030'
01E2' 3E 30
01E4' 86
01E5' 23
01E6' CD 031E'
01E9' 3E 2E
01EB' CD 031E'
01EE' 06 03
01F0' 3E 30
01F2' 86
01F3' 23
01F4' CD 031E'
01F7' 10 F7
01F9' C1
01FA' D1
01FB' C9

DDV4: LD E,(IX)
DDV5: SBC HL,DE
DDV6: ADD HL,DE
DDV7: JP Z,DDV7
DDV8: LD (IX),L
DDV9: LD HL,RSLT
DDV10: LD A, O'
DDV11: ADD A,(HL)
DDV12: INR HL
DDV13: CALL STC
DDV14: LD A,

01FC' 21 6100
01FF' 3E 02
0201' 3E 01

ECS: LD HL,A,RECV
ECS1: LD A,XMIT

; ECS - ESTABLISH COMMUNICATIONS SYNC
; SENDS A SERIES OF BITS SPACED AT 200 USEC
; INTERVALS, LOOKING FOR A SYNC ACKNOWLEDGE BETWEEN
; EACH BIT.
; ( INSTRUCTION TIMING IS CRITICAL! DO NOT CHANGE )
; ( TIMING IS DEPENDENT ON A 8.0 MHZ XTAL )

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--- SUBROUTINES ---

0203' 32 610E  ; LD (CSET),A ; BIT ON
0206' 32 610A  ; LD (CCLR),A ; BIT OFF
0209' 06 1F    ; LD B,31
020B' 10 FE    ; DJNZ $ ; DELAY 90 USEC
020D' 3E 02    ; LD A,RECV
020F' 32 610E  ; LD (CSET),A ; OPEN RECEIVE WINDOW
0212' 06 05    ; LD B,5
0214' 10 FE    ; DJNZ $ ; DELAY 20 USEC
0216' ED 57    ; LD A,I
0218' B6       ; OR (HL) ; GET INPUT
0219' 32 A10A  ; LD (CCLR),A ; CLOSE THE WINDOW
021C' FA 0230' ; JP M,ECS3 ; IF BIT PRESENT
021F' 06 0F    ; ECS2: LD B,15
0221' 10 FE    ; DJNZ $ ; DELAY 90 USEC
0223' 13       ; INC DE
0224' 1B       ; DEC DE
0225' 3A E001  ; LD A,(SIOS) ; GET SERIAL STATUS
0228' E6 02   ; AND SIDR
022A' CA 0201' ; JP Z,ECS1 ; IF NO ABORT REQUEST
022D' C3 0000' ; JP RST ; (<< ABORT >>)
0230' 3E 00    ; ECS3: LD A,0
0232' ED 44    ; NEG ; TIME USER UPPER
0234' 06 14    ; LD B,20
0236' 10 FE    ; DJNZ $ ; DELAY 80 USEC
0238' 3E 02    ; LD A,RECV
023A' 32 610E  ; LD (CSET),A ; OPEN WINDOW
023D' 06 05    ; LD B,5
023F' 10 FE    ; DJNZ $ ; DELAY 20 USEC
0241' ED 57    ; LD A,I
0243' B6       ; OR (HL)
0244' 32 610A  ; LD (CCLR),A ; CLOSE WINDOW
0247' F2 021F' ; JP P,ECS2 ; IF BIT IS NOT PRESENT
024A' C9       ; RET ; ELSE RETURN

; GCB - GENERATE CORRECTION BIT
; COMPUTES THE BIT VALUE WHICH MUST BE CORRECTED
; ENTRY (A) - SYNDROME ERROR BITS
; EXIT (C) - CORRECTION BIT VALUE

024B' E5       ; GCB: PUSH HL
024C' D5       ; PUSH DE
024D' 16 00    ; LD D,0
024F' 5F        ; LD E,A ; OFFSET VALUE
0250' 21 03C1'  LD  HL,STBL ;TABLE POINTER
0253' 19  ADD  HL,DE
0254' 4E  LD  C,(HL) ;CORRECT BIT VALUE
0255' D1  POP  DE
0256' E1  POP  HL
0257' C9  RET

; GHC - GENERATE HAMMING CODE SYNDROME BITS
; COMPUTES THE HAMMING SYNDROME BITS FOR A SUPPLIED BYTE OF DATA.
; ENTRY (C) - DATA BYTE
; EXIT (C) - SYNDROME BITS (MSB)

0258' C5  GHC:  PUSH BC
0259' 06 00  LD  B,0 ;INITIALIZE SYNDROME BITS
025B' 3E FO  LD  A,FOH
025D' A1  AND  C ;CHECK SB4
025E' E2 0263'  JP  PO,GHC1

0261' CB D8  SET  3,B
0263' 3E 6E  GHC1:  LD  A,8EH
0265' A1  AND  C ;CHECK SB3
0266' E2 026B'  JP  PO,GHC2

0269' CB D0  SET  2,B
026B' 3E 6D  GHC2:  LD  A,6DH
026D' A1  AND  C ;CHECK SB2
026E' E2 0273'  JP  PO,GHC3

0271' CB C8  SET  1,B
0273' 3E 5B  GHC3:  LD  A,5BH
0275' A1  AND  C ;CHECK SB1
0276' E2 027B'  JP  PO,GHC4

0279' CB C0  SET  0,B
027B' 78  GHC4:  LD  A,B ;GET RESULT
027C' C1  POP  BC
027D' 4F  LD  C,A
027E' C9  RET

; MSD - MILLISECOND DELAY
; AN INLINE DELAY OF "n" MILISECONDS.
; ENTRY (A) - MILLISECOND COUNTER

027F' C5  MSD:  PUSH BC
0280' 0E 03  MSD1:  LD  C,3 ;LOOP COUNTER
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--- SUBROUTINES ---

```
0282' 06 64 MSD2: LD B,100
0284' 10 FE DJNZ $
0286' 0D 0D DEC C
0287' C2 0282' JP NZ,MSD2 ;IF NOT 1 MILLISECOND
0288' 3D 0D DEC A
0289' CA 0297' JP Z,MSD3 ;IF COUNT EXPIRED
028E' 06 00 LD B,0
0290' 06 00 LD B,0 ;EVEN OUT TIMING
0292' 0B 00 LD C,0
0294' C3 0280' JP MSD1 ; AND LOOP
0297' C1 MSD3: POP BC
0298' C9 RET

RDB - READ DATA BYTE
READS A BYTE OF DATA FROM THE OPTICAL INTERFACE
( INSTRUCTION TIMING IS CRITICAL! DO NOT CHANGE )
( TIMING IS DEPENDENT ON 8.0 MHZ XTAL )

0299' D9 RDB: EXX ;SAVE USER REGISTERS
029A' 16 00 LD D,0 ;CLEAR ASSEMBLY BUFFER
029C' 21 6100 LD HL,APRT ;INPUT POINTER
029F' 0E 08 LD C,8 ;BIT COUNTER
02A1' 3E 02 LD A,RECV
02A3' 32 610E LD (CSET),A ;OPEN WINDOW
02A6' B6 RDB1: OR (HL) ;WAIT FOR START BIT
02A7' F2 02A6' JP P,RDB1
02AA' 3E 02 LD A,RECV
02AC' 32 610A LD (CCLR),A ;CLOSE WINDOW
02AF' 06 17 LD B,23
02B1' 10 FE DJNZ $ ;DELAY 90 USEC
02B3' ED 57 LD A,I
02B5' 3E 02 RDB2: LD A,RECV
02B7' 32 610E LD (CSET),A ;OPEN WINDOW
02BA' 06 04 LD B,4
02BC' 10 FE DJNZ $ ;DELAY 20 USEC
02BE' ED 57 LD A,I
02C0' B6 OR (HL) ;GET BIT
02C1' 32 610A LD (CCLR),A ;CLOSE WINDOW
02C4' 17 RLA ;BIT TO CY
02C5' CB 1A RR D ;ASSEMBLE BIT
```

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TRUOS - TELEMETRY RECEIVER UNIT OPERATING SYSTEM

---- SUBROUTINES ----

02C7' 06 14
02C9' 10 FE
02CB' 13
02CC' 18
02CD' 0D
02CE' C2 02B5'
02D1' 7A
02D2' D9
02D3' C9

; SBT - SEND BUFFER TO TERMINAL
; FORMATS BUFFER FULL OF DATA AND SENDS IT TO THE TERMINAL.

02D4' 3E 1F
02D6' CD 031E'
02D9' 11 0008''
02DC' 06 10
02DE' 0E 00

02E0' 79
02E1' CD 0181'
02E4' 3E 20
02E6' CD 031E'
02E9' 1A
02EA' 13
02EB' CD 0193'
02EE' 2A 003D''
02F1' 29
02F2' 22 003D''
02F5' D2 02FD'

02F8' 3E 2A
02FA' CD 031E'

02FD' 3E 1F
02FF' CD 031E'
0302' 0C
0303' 10 DB
0305' 3E 1F
0307' CD 031E'
030A' C9

; SIT - SET INTERRUPT TIMER
; INITIALIZES THE INTERRUPT TIMER TO CAUSE AN INTERRUPT IN 1 SECOND
030B 32 6116 SIT: LD (ISTP),A ;ENSURE TIMER STOPPED
030E 3E 09 LD A,$0001001B
0310 32 6119 LD (IMOD),A ;T1 = EVENT COUNTER
0313 21 FFFF LD HL,-1 ;850 MILLISECONDS
0316 22 6112 LD (IDIV),HL
0319 32 6117 LD (ISTR),A ;START THE TIMER
031C FB EI ;ENABLE INTERRUPT'S
031D C9 RET

; STC - SEND TERMINAL CHARACTER
; SENDS A CHARACTER TO THE TERMINAL
031E 32 E000 STC: LD (SIOD),A ;SEND CHARACTER
0321 F5 PUSH AF

0322 3A E001 STC1: LD A,(SIOS)
0325 E6 01 AND STDR
0327 CA 0322 JP Z,STC1 ;IF XMIT BUSY

032A F1 POP AF
032B C9 RET

; TEM - TRANSMIT ERROR MESSAGE
; SENDS AN ERROR MESSAGE TO THE CONSOLE
032C 21 038D TEM: LD HL,IMSG
032F 7E TEM1: LD A,(HL) ;GET NEXT CHAR
0330 23 INC HL
0331 CD 031E CALL STC ;SEND TO TERMINAL
0334 FE 04 CP EOT
0336 C2 032F JP NZ,TEM1 ;IF NOT END OF TEXT
0339 C3 0087 JP NZL ; ELSE BACK TO MAIN

; VDB - VALIDATE DATA BUFFER
; PERFORMS A VALIDITY CHECK OF THE RECEIVE INPUT
; DATA BUFFER RECEIVED FROM "MI~DAT".
033C 11 0020 VDB: LD DE,BBUF ;CHECK BIT BUFFER POINTER
033F 21 0018 LD HL,RBUF+BSIZ ;CHECK BIT POINTER
0342 06 08 LD B,BSIZ/2
0344 97 SUB A
0345 ED 6F VDB1: RLD

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TRUOS - TELEMETRY RECEIVER UNIT OPERATING SYSTEM

--- SUBROUTINES ---

0347' 12
0348' 13
0349' ED 6F
034B' 12
034C' 13
034D' 23
034E' 10 F5
0250' DD 21 0008"
0254' 21 0020"
0257' 11 0000
025A' 06 10
025C' DD 4E 00
025F' CD 0258'
0262' 7E
0263' A9
0264' CA 037F'
0267' CD 024B'
026A' CA 037F'
026D' DD 7E 00
0270' A9
0271' DD 77 00
0274' 4F
0275' CD 0258'
0276' 7E
0278' 7E
027A' CA 037F'
027D' CB C3
037F' EB
0380' 29
0381' EB
0382' DD 23
0384' 23
0385' 16 D5
0387' ED 53 003D'
038B' C9
036C' 00

--- SUBTTL --- MESSAGES/TABLES/BUFFERS/VARIABLES ---

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MESSAGES

038D' 21 21 20 49  IMSC:  DB  '** INVALID COMMAND **',NL,EOT
0391' 4E 56 41 4C
0395' 49 44 20 43
0399' 4F 4D 4D 41
039D' 4E 44 20 21
03A1' 21 1F 04
03A4' 22 20 2A 20  TMSG:  DB  '** INTERRUPT **',NL,EOT
03A8' 49 4E 54 45
03AC' 52 52 55 50
03B0' 54 20 2A 20
03B4' 2A 1F 04

TABLES

03B7' 2710 03E8  DBUT:  DW  10000,1000,100,10,0
03BB' 000A 0000
03BF' 0000
03C1' 00 00 00  STBL:  DB  0,0,0
03C4' 01  DB  1  ;0
03C5' 00  DB  0
03C6' 02 04 08  DB  2,4,8  ;1,2,3
03C9' 00  DB  0
03CA' 10 20 40 80  Dd  16,32,64,128  ;2,3,4,5
03CE' 00 00 00 00  DB  0,0,0,0

BUFFERS

;; (COMMAND BUFFER MUST BE FIRST ITEM )

03D2

DSEG

0000" 0000  CBUF:  DS  CSIZ+2  ;COMMAND INPUT BUFFER
0008" 0000  RBUF:  DS  BSIZ-HSIZ  ;RECEIVE BUFFER
0020" 0000  BBUF:  DS  BSIZ  ;CHECK BIT BUFFER
0030" 0000  RSLT:  DS  5  ;QUOTIENT BUFFER

VARIABLES

0035" 0000  BFTR:  DW  0  ;INPUT BUFFER POINTER
0037" 0000  CCNT:  DW  0  ;TEST CYCLE TIME
0039" 0000  CTIM:  DW  0  ;TEST CYCLE TIMER
003B" 00  TEMP:  DB  0  ;WORKSPACE
003C" 00  TFLG:  DB  0  ;TEST FLAG
003D" 0000  VFLG:  DW  0  ;VALID DATA FLAG

SUBTTL  ---- SYMBOL REF TABLE ----

END
### TRUOS - TELEMETRY RECEIVER UNIT OPERATING SYSTEM

#### SYMBOL REF TABLE

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<td><strong>Symbols:</strong></td>
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<tr>
<td>6109  BCLR  0035&quot;  BPRR  0008  BS</td>
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<td>610D  BSET  0010  BSIZE  0000&quot;  CBUF</td>
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<td>018B' DCMI  0193'  DDU  019E'  DDU1</td>
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<td>01A4' DDU2  0182'  DDU3  018A'  DDU4</td>
</tr>
<tr>
<td>01CA' DDU5  01D3'  DDU6  01DC'  DDU7</td>
</tr>
<tr>
<td>01FO' DDU8  03B7'  DDU7  01FC'  ECS</td>
</tr>
<tr>
<td>0201' ECS1  021F'  ECS2  0230'  ECS3</td>
</tr>
<tr>
<td>0004  EDT   001B  ESC   024B'  GCB</td>
</tr>
<tr>
<td>0258' GHC   0263'  GHC1  026B'  GHC2</td>
</tr>
<tr>
<td>0273' GHC3  027B'  GHC4  0008  HSIZ</td>
</tr>
<tr>
<td>6112  IDIV  6119  IMOD  038D'  IMSG</td>
</tr>
<tr>
<td>0038' INT   6116  ISTR  6117  ISTR</td>
</tr>
<tr>
<td>000A  LF    0087'  MCL   0094'  MCL1</td>
</tr>
<tr>
<td>00AC' MCL2  00CB'  MCL3  00E6'  MCL4</td>
</tr>
<tr>
<td>0104' MCL5  027F'  MSD   0280'  MSD1</td>
</tr>
<tr>
<td>0282' MSD2  0297'  MSD3  001F   NL</td>
</tr>
<tr>
<td>0008&quot; RBUF  0299'  RDB   02A6'  RDB1</td>
</tr>
<tr>
<td>0285' RDB2  0002  RCVR  0126'  ROD</td>
</tr>
<tr>
<td>013C' ROD1  0030&quot;  RSLT  0000'  RST</td>
</tr>
<tr>
<td>02B4' SBT   02E0'  SBT1  02FD'  SBT2</td>
</tr>
<tr>
<td>0150' SCT   0155'  SCT1  0174'  SCT2</td>
</tr>
<tr>
<td>0002  SIDR  0040  SIIR   0000'  SIDD</td>
</tr>
<tr>
<td>E001  SIOS  030B'  SIT    0080  SIR</td>
</tr>
<tr>
<td>0001  SOM   607E  STAX   03C1'  STBL</td>
</tr>
<tr>
<td>031E' STC   0322'  STC1  0001  STR</td>
</tr>
<tr>
<td>017B' STM   0003  STX    6115  TBRG</td>
</tr>
<tr>
<td>6114  TBRG  6110  TDIV   032C'  TEM</td>
</tr>
<tr>
<td>032F' TEM1  003B&quot;  TEMP  003C&quot;  TFLG</td>
</tr>
<tr>
<td>6118  TMOD  03A4'  TMSG  033C'  VDB</td>
</tr>
<tr>
<td>0345' VDB1  035C&quot;  VDB2  037F'  VDB3</td>
</tr>
<tr>
<td>003D&quot; VFLG  0001  XMIT</td>
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</table>

No Fatal error(s)
The Miniature Infrared Data Acquisition and Telemetry (MIRDAT) Phase I Study was performed to determine the technical and commercial feasibility of producing a miniaturized electro-optical telemetry system. This system acquires and transmits experimental data from aircraft scale models for real-time monitoring in wind tunnels.

During the Phase I Study, miniature prototype MIRDAT telemetry devices were constructed, successfully tested in the laboratory and delivered to the user for wind tunnel testing. A search was conducted for commercially available components and advanced hybrid techniques to further miniaturize the system during Phase II development. A design specification was generated from laboratory testing, user requirements and discussions with component manufacturers. Finally, a preliminary design of the proposed MIRDAT system was documented for Phase II development.
End of Document