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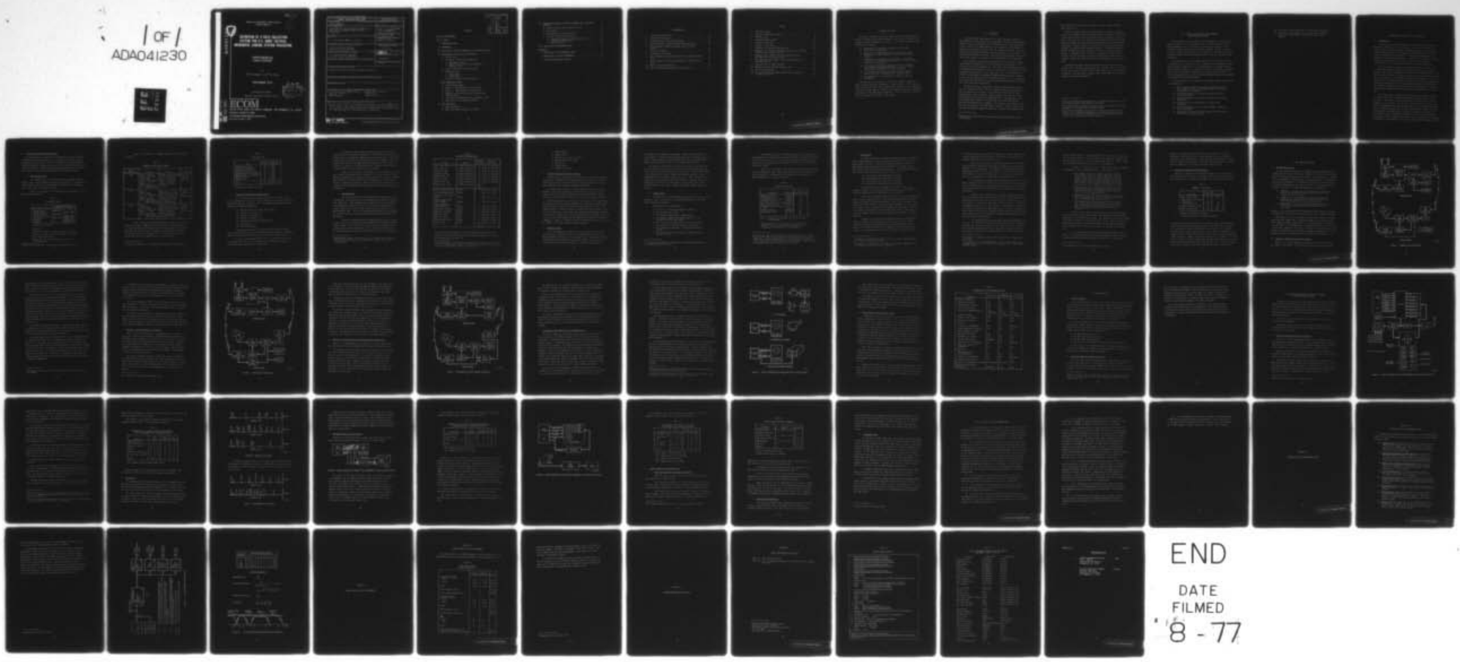

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DEFINITION OF A DATA COLLECTION SYSTEM FOR U.S. ARMY TACTICAL MICROWAVE LANDING SYSTEM EVALUATION

SUPPLEMENTAL FINAL REPORT

by

J.H. Priedigkeit and P.G. Stoltz

SEPTEMBER 1976

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The data to be collected for flight test performance evaluation of TMLS by the Army is defined. Data rates, data formats, and data processing requirements are developed. Data recording options are considered and a preliminary design for a TMLS airborne data collection system is presented.

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CONTENTS

ILLUSTRATIONS

TABLES

I PURPOSE AND SCOPE

The Army is scheduled to receive both ground and airborne Tactical Microwave Landing System (TMLS) hardware in the spring of 1978 and will evaluate this TMLS hardware for Army use. It is expected that this Army evaluation will include:

(1) Measurements to determine compliance with the TMLS procurement specifications.

(2) Flight tests to determine the basic performance capabilities of the TMLS equipment in fixed and rotary wing aircraft.

(3) Flight tests to determine the performance of the TMLS equipment in the multipath environment of airfields likely to be used by the Army.

(4) Collection of operational experience data to determine the reliability and maintainability of both the ground and airborne components of the TMLS equipment.

(5) An assessment of the TMLS equipment and performance to satisfy the Army requirements for a landing system.

(6) An assessment of the suitability of TMLS for tactical deployment.

The purpose of this study is to define an airborne flight test data collection system to accomplish (2) and (3) above. This system is part of an overall plan, which includes the preparation of an evaluation test plan for TMLS and the collection of data to document the operational performance of the TMLS ground components. These two parts of the plan are not included in the scope of this study.

II BACKGROUND

The engineering requirements for the TMLS avionics, defined in FAA ER-700-03, and the functional requirements, defined in FAA-ER-700-07, have been used as guidelines for the definition of the data collection system. However, the TMLS hardware to be evaluated is scheduled to be delivered to the Army 18 months after the completion of this study, and equipment specification and other details may change in this period. Thus this study has defined a flexible data collection system that can accommodate some change in the details of the TMLS hardware and equipment.

The functional requirements specifications for a microwave landing system (MLS), FAA-ER-700-07, define a measurement methodology for the evaluation of MLS (see Appendix A). This measurement methodology requires an independent ground-based tracker to determine the true position of the landing aircraft relative to the runway reference. The performance of the MLS is determined by comparing the MLS-indicated aircraft position to the position indicated by the ground-based tracker. It is assumed in this report that the Army will use the measurement methodology described in the FAA functional requirements.

The FAA has ordered a Precision Automated Tracking System (PATS) for the evaluation of MLS.* This is a laser ranging and tracking system that is installed in a trailer. This portable system, with an independent power supply, includes a digital computer for data processing. (See Appendix C for details and specifications.) The FAA plans to use the portable PATS facility to evaluate MLS at the National Aviation Facility Experimental Center (NAFEC). The mobility of the PATS facility will make it possible to evaluate MLS, or TMLS, at several airports under different multipath propagation conditions. Similar PATS equipment has

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*Manufactured by GTE Sylvania, Western Division, Mountain View, California 94040.

been ordered by the Army for test ranges at Yuma, Arizona and White Sands, New Mexico.

Initial testing of MLS by DoD was scheduled to begin in the fall of 1976, at the NASA facilities, Crows Landing, California. A NASA dual radar tracker would be used to determine the true position of the aircraft. The Army, Air Force, and Navy are planning to install civil MLS avionics equipment in representative military aircraft for preliminary evaluation.* NASA has agreed to provide the two way ground data link terminal† and digital data reduction facility. The Army and Navy will provide airborne data link transmitters and will use identical data formats to transmit flight test data to the ground terminal for processing. The Air Force will provide an airborne data link receiver to record all flight test data in the air for processing by the Air Force later.

The NASA dual-radar tracker and data link is a unique permanent installation at the NASA Crows Landing test facility. Thus it is assumed in this report that the PATS optical tracker will be used for the TMLS evaluation, since PATS can be moved to more remote TMLS sites as may be required in the Army evaluation.‡

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*A Basic Narrow MLS ground facility is currently being installed at the Navy Landing Field, Crows Landing, California.

†The three military services are each to procure the airborne data link components to specifications provided by NASA.

‡The NASA Crows Landing test facility is located on relatively flat terrain with a few small buildings near the airfield; thus this airfield is not considered representative of the multipath environment likely to be found at Army tactical airfields.

III DESIGN GOALS FOR THE TMLS AIRBORNE DATA COLLECTION SYSTEM

The Army plans to install TMLS avionics equipment in the UH-1 and CH-47 helicopters and in the U-21 and OV-1 fixed-wing aircraft. TMLS ground equipment is to be installed at various sites that are representative of Army tactical and fixed base airfields. Flight test data are to be collected to determine the performance of TMLS and the adequacy of TMLS to satisfy the Army requirements for a tactical instrument landing system.

The primary purpose of the TMLS airborne data collection system is to facilitate the collection of data to document the performance of TMLS during the Army flight test. A secondary purpose of the TMLS airborne data collection system is to provide a means for the in-flight assessment of the level of multipath interference at various Army airfields. As will be discussed later, a separate instrumentation package is recommended to accomplish this secondary purpose.

The design goals to be considered for the TMLS airborne data collection system are:

(1) Size, weight, and power requirements commensurate with specifications for the four Army aircraft to be used for the flight test evaluation.

(2) Turn-around time for the initial raw data processing less than 24 hours.

(3) Simplified merging of airborne data with ground tracking system data.

(4) Concentration on the collection of critical data parameters.

(5) Use of photographic or video tape recording techniques where appropriate.

(6) Simplified electrical interface between the TMLS receiver and the data recording system.

However, a suitable interface unit has to be developed to provide

(7) Real-time on-line monitoring of selected data parameters.

(8) Provision for the manual entry of supporting documentation (e.g., flight number, run number, glide slope angle).

IV DEFINITION OF THE DATA TO BE COLLECTED

A. Introduction

The data to be collected during the Army flight test evaluation of TMLS may be divided into two categories. First, it is necessary to collect data to determine whether the TMLS equipment satisfies the performance specifications when installed in Army aircraft and operated in both a low multipath environment and in multipath environments representative of Army tactical airfields. Second, it is desirable to collect data whenever possible, to document the level of the multipath interference at the particular airfields used for the flight test.

The first data set includes the azimuth angle and deviation, the elevation angle and deviation, the DME distance and rate, and the computed aircraft height information available from the TMLS avionics. This data set also includes the azimuth, elevation, and range information from the ground tracker. The airborne and ground tracker data are to be merged and processed to determine the TMLS performance as defined in Appendix A. Supporting documentation should be collected to identify the purpose of the particular flight-test, the aircraft used, the flight test location, the date and run numbers, and the personnel participating in the flight test.

The second data set should include diagnostic information such as the TMLS receiver video waveforms and selected signals from the angle processor. These data would not necessarily be collected for all test flights at all airfields. The purpose of these data is to provide supporting documentation of Army airfields with severe multipath environment where the TMLS performance may not meet specifications. With this kind of diagnostic instrumentation, it should be feasible to correlate airborne measurement of multipath amplitude with the actual measured TMLS performance. This information is valuable in the development of techniques to predict the performance of tactically deployed TMLS at proposed sites.

B. Collection of TMLS Performance Data

The methodology for measuring the performance of MLS is described in FAA-ER-700-07 (see Appendix A). To verify that the TMLS meets the performance specifications, it will be necessary to compare the TMLS indicated azimuth, elevation, and range in the flight-test aircraft with similar information obtained from an independent ground-based tracker. The merging of airborne and ground data will be discussed later.

1. TMLS Avionics Data

The specifications for the TMLS avionics equipment, FAA-ER-700-03, require that the TMLS processor provide output for azimuth angle, azimuth angle deviation, elevation angle, elevation angle deviation, range, range rate, and aircraft height.*

Table 1 is a summary of the output data specifications for the TMLS avionics processor.

Table 1

TMLS OUTPUT DATA

TMLS Output Parameter	Format Characteristic	
	Digital	Analog
Azimuth angle	ARINC-582†	--
Azimuth deviation	--	ARINC-578‡§
Elevation angle	ARINC-582†	--
Elevation deviation	--	ARINC-578‡§
DME distance	ARINC-568**	ARINC-578‡
DME rate	--	ARINC-578‡
Height††	--	ARINC-578‡

-- Output not required

†LSB 0.01°.

‡High-level output, 2.0 Vdc referenced to ground.

§Low-level output, 0.150 Vdc referenced to ground.

**LSB 0.001 nautical mile.

††Computed in the aircraft from range and elevation angle data.

*Computed in the aircraft from range and elevation angle data.

Table 2 is a summary of the ARINC* characteristics indicated in Table 1.

Table 2

SUMMARY OF ARINC DATA FORMATS

ARINC Characteristics	Digital	Analog	Flag
568	6-wire (separate clock, sync, data) 32-bit word; 11 ± 3.5 kHz clock; logic 1 = +12 V; logic 0 = 0 V; load: 600-12,000 Ω 1000-12,000 pF	Distance: proportional to time between two 7-μsec + 12 V pulse pairs. Pulse pair rate: 5 to 30 per second when DME is tracking.	+27 V, flag down; zero V, flag up.
578	2-wire; 32-bit word; 11 ± 3.5 kHz clock; logic 1 = +10 V; logic 0 = 0 V; load: 600-12,000 Ω 1000-30,000 pF	High level: +2 Vdc referenced to ground, 200 Ω to open circuit load. Low level: +150 mVdc referenced to ground, 200 Ω to open circuit load.	+28 V, flag up; 0 V, flag down.
582	2-wire; 32-bit word; 11 ± 3.5 kHz clock; logic 1 = +10 V; logic 0 = -10 V; load: 600-12,000 Ω 1000-30,000 pF	High level: +2 Vdc referenced to ground, 200 Ω to open circuit load. Low level: +2 Vdc referenced to ground, 200 Ω to open circuit load.	+28 V, flag up; 0 V, flag down.

Table 2 shows that the TMLS digital data output is to have a 32-bit word format. ARINC specifications permit a 0.5% variation in the analog output with changes in load. An 8-bit digital work is commensurate with this accuracy. Assuming the analog data is converted to a digital format for recording, Table 3 shows the number of bits and the bit rate for a sampling rate of ten per record.

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*Aeronautical Radio, Inc., 2551 River Rd., Annapolis, Maryland 21401.

Table 3

TMLS DATA BITS

Data	Number of Bits	Typical Update Rate
Azimuth angle word	32	10/s
Azimuth deviation word	8*	10/s
Elevation angle word	32	10/s
Elevation deviation word	8	10/s
DME distance word (digital)	32	10/s
DME distance word (analog)	8	10/s
DME rate word	8	10/s
Height word	8	10/s
Total	136	1360 bits/s

*Analog data recorded to 0.39%

2. Supporting Flight Test Documentation

It is essential that all data collected for the TMLS evaluation be identified in such a way that the data can be correctly associated with the flight test conditions. It is recommended that each data file contain the following information:

(1) Data of flight test (day, month, year)

(2) Location of flight test

(3) Flight or run number

(4) Purpose of flight or run

(5) Flight-test aircraft identification

(6) Aircraft pilot

(7) Observer/passenger.

Since these data will not change during an approach flight, they can be entered into the data recording system by means of a manually operated keyboard on the control panel for the data collection system.

The use of preassigned numeric codes for data entry will allow a ten-digit keyboard to be used rather than an alphanumeric keyboard, thus saving space and weight in the aircraft.

To interpret and evaluate the data, the status of all pilot operated control and function switches for the TMLS must be known. These switches can be equipped with auxiliary electrical contacts so that their positions may be sensed and recorded during the test flights. This will document the status of the TMLS avionics equipment during the data collection. The status of the TMLS flag alarm, and other alarms that may be provided for the pilot,* should also be recorded.

Table 4 is an estimate of the number of bits required to record this supporting documentation. From Table 4 it is seen that the data to identify a specific run or approach can be recorded as a header of approximately 250 bits for each block of data. Monitoring of the function switches, approximately 40 bits, should be recorded at a rate of one per second to detect unscheduled events that may occur during a specific run or approach.

3. Auxiliary Data

The signal format for both MLS and TMLS has provisions for the transmission of auxiliary data from the TMLS ground facility to the airborne TMLS users. This auxiliary data channel may be used to transmit such information as TMLS site data (e.g., split or collocated site, azimuth antenna offset from runway), runway surface conditions, and meteorological data. There is considerable flexibility in the auxiliary data format, and it is possible that the military and civilian formats may differ.

Because the auxiliary data transmission technique is identical to that used for the preamble and basic data words in the MLS and TMLS signal formats, it is felt that it is not necessary to flight test the auxiliary data channel extensively. Thus, other than observing that the data displays do function in the aircraft, there is no requirement

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*FAA-ER-700-03 requires that circuitry be provided in the airborne receiver to alert the pilot to the presence of superfluous or interfering signals.

Table 4

SUPPORTING DOCUMENTATION

Data	Format	Number of Bits	Typical Update Rate
Date (day, month, year)	8 ASCII characters	64	One per approach
Test site code	3 ASCII characters	24	One per approach
Flight ID code	3 ASCII characters	24	One per approach
Approach number	2 ASCII characters	16	One per approach
Aircraft ID code	3 ASCII characters	24	One per approach
Pilot ID code	3 ASCII characters	24	One per approach
Observer ID code	3 ASCII characters	24	One per approach
Flight object code	4 ASCII characters	32	
		232	
Selected TMLS channel	Binary	9	One per second
Selected azimuth angle	Binary	7	One per second
Selected glide slope angle	Binary	4	One per second
Course width (AUTO, FINE, COARSE)	Binary	3	One per second
Antenna selection (AUTO, MANUAL)	Binary	3	One per second
TMLS power (On-Off)	Binary	2	One per second
DME power (On-Off)	Binary	2	One per second
TMLS flag alarm	Binary	2	One per second
DME flag alarm	Binary	2	One per second
TMLS antenna relay	Binary	2	One per second
Course width	Binary	2	One per second
		38	

to record messages transmitted via the auxiliary data channel for the purpose of measuring the auxiliary data channel performance.* The data to be displayed to the pilot are:

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*The output format of the auxiliary channel will be the same as that used for the auxiliary channel input at the ground terminal. At this time it has not been specified as ASCII or binary code.

- Runway heading
- Runway status
- MLS status or class of service
- Minimum glide-slope angle
- DME readout
- Azimuth angle
- Obstacle clearance.

C. Ground Tracking Data Format and Rate

The PATS laser ground tracker includes an on-line digital computer processor for smoothing and averaging angle and range data. The PATS data output format is determined by the computer software and can be made compatible with standard communications modems.

The output data format of the PATS equipment delivered to FAA at NAFEC is serial bit, approximately 2400 bits per second, 120 bits per frame, with the data rate synchronized to the PATS digital computer. This data rate is variable and can be controlled by computer software.

The PATS equipment to be delivered to the Army, at both White Sands and Yuma, will have a standard 2400-bit-per-second modem synchronized to the range clock. Data are transmitted at 20 frames per second. Each frame consists of 120 bits and has a five-bit sync word, azimuth, elevation, and range data. Each frame also contains auxiliary data including the time code, mission ID, event count, event marker, and PATS tracker ID. It has not been established that the NAFEC and the Army data formats are compatible. However, it appears that any discrepancies could be corrected by changes in the PATS computer software programs.

D. Diagnostic Data

In a low multipath environment, it is most likely that the TMLS will perform as designed. Thus, in a low multipath environment, the TMLS evaluation will consist of collecting data to verify that the TMLS equipment performs within specifications. However, in a moderate to strong multipath environment, typical of most Army airfields, the performance of the TMLS may be degraded. Under these conditions, it is desirable to collect additional diagnostic data to determine both the level of the multipath (or other interference) that is degrading the TMLS performance and the effects on the TMLS angle processor.

For example, observation of the raw video output of the TMLS, before it goes into the angle processor, will provide information about the level of the multipath and other interference. The raw video output of the TMLS receiver may be viewed on an oscilloscope with a sweep synchronized from the TMLS receiver time gates. These data may be recorded and later viewed on a standard video tape recorder. As will be discussed in Section V-E of this report, this recorded video may be photographed at a later time to obtain a permanent graphic record if desired.

1. Digital Data

The flag logic in the TMLS airborne processor monitors several parameters that could be used for in-flight diagnostics of the TMLS angle processor performance.

These parameters confirm that:*

- The level of received RF signal is adequate.
- The facility ID is valid.
- The receiver synthesizer is phase-locked.
- The radiated signals are within limits (i.e., the ground status bit reads valid).
- There are only two dwell gates in each scan period.
- The duration of each dwell gate is within limits.
- The scanning beam envelope is stronger than the SLS signals.
- The "To" and "Fro" dwell gates are symmetrical about the midscan time.

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*See Bendix/Bell proposal to the FAA for the Common Tactical MLS configuration dated 11 June 1975.

A confidence counter in the TMLS processor is incremented when the parameters are valid and decremented when they are invalid or missing. This counter goes to zero in 1.33 seconds without valid data and will activate the flag alarm when the counter level falls to 66% of the maximum counter range.*

Table 5 is an estimate of the number of bits required to record the above diagnostic data. These diagnostic data are very important in the development of a methodology for predicting the performance of a TMLS installation at a proposed airfield.

Table 5

DIAGNOSTIC DATA BITS

Parameters	Format	Typical Number of Bits
RF signal level	Binary	7
Valid facility ID	Binary	2†
Synthesizer phase lock	Binary	2†
Ground status bit	Binary	2†
Two dwell gates per period	Binary	2†
Dwell gate duration	Binary	2†
Scanning beam exceed SLS level	Binary	2†
To-Fro symmetry	Binary	2†
Confidence counter	Binary	8
		29

Note: An update rate between 1 and 10 per second is recommended.

†This parameter can be recorded with one binary bit. However, the use of two bits is recommended to facilitate the detection of missing data.

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*At this time, some of the details of the TMLS avionics are subject to change by the TMLS contract Definition Study now in progress, and there are no current requirements for the contractors to provide external test points to facilitate these measurements in flight. Thus the equipment may have to be modified in the field.

2. Analog Data

The TMLS azimuth and elevation scanning beams have a half-power width of approximately 3° and 2°, respectively, and a scan rate of 50 microseconds per degree. Thus these beams will generate a pulse of approximately 100 and 150 microseconds duration at the TMLS receiver video as the beams scan past the user aircraft. Four possible techniques for viewing and recording these raw video pulses are:

(1) Oscilloscope and photographic recording
(2) Oscilloscope and video tape recording
(3) Oscilloscope and analog tape recording
(4) Oscilloscope and digital tape recording.

Oscilloscopes with a bandwidth of 100 kHz, or more, are a readily available off-the-shelf item and provide an excellent means for real-time monitoring of the TMLS receiver video signal.*

Video tape recording, using a TV camera to view the oscilloscope pattern, has an advantage over fast processing photographic techniques (such as Polaroid) in that time duration of the video recording can be controlled by the operator. Thus, the video equivalent of single frame or of movie films is available to the operator, as needed, to document the evidence of multipath on the raw TMLS video output. Video tape cassettes capable of 30 to 60 minutes continuous recording are readily available.

Analog tape recorders are available with direct record bandwidths of 150 kHz at a tape speed of 30 inches per second.† These recorders typically have 3600-foot reel capacity, which provides 24 minutes of recording time per reel of magnetic tape at 30 inches per second. The recording time may be easily extended to 48 minutes per

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*A bandwidth of 100 kHz will permit pulse rise times of approximately 3.5 μs to be viewed and recorded.

†For example, the Honeywell model 5600, or equivalent, Honeywell Test Instrument Division, Denver, Colorado 80217.

reel by selecting a tape speed of 15 inches per second. However, the recorder bandwidth will be reduced to 75 kHz and some detail of the scanning beam pulse rise time may be lost.

Hard-copy records may be obtained directly from the analog tape by making a high-speed strip chart recording of a reduced-speed playback of the analog tape. For example: the approximately 100 μs beam passage pulse recorded at 30 inches per second and played back at 15/16 inches per second is translated to a 3.2 ms pulse. This pulse width can be reproduced by a high-speed strip chart recorder.*

The analog tape recorder has an advantage over the other techniques identified above in that the entire video data stream is recorded. Thus other TMLS functions, such as side lobe suppression, calibration, and auxiliary data, are also recorded and are available for postflight examination.

Digital tape recording requires a data sampling technique to convert the analog video waveform into a time series of digital words. Each digital word represents the signal level at a sample point on the video pulse. To record the video pulse in fine detail, it is important to sample the pulse in 1 μs time intervals. Furthermore, to achieve 0.5% amplitude accuracy for each sample point, it will be necessary to use at least an 8-bit word. Although analog-to-digital converters with 1-MHz sampling rates are available,† recording the digital data stream requires careful consideration.

The maximum digital data recording capacity of magnetic tape recorders is controlled by tape transport speed, lineal bit density of the tape, and the number of tracks. The state of the art of off-the-shelf portable digital magnetic tape recorders is characterized by a tape speed of 60 inches per second, 600 bits per lineal inch density,

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*For example, the Honeywell model 1858 fiber-optics oscillograph, or equivalent.

†For example, Datel model ADC-H-8B has an 8-bit binary output with a maximum sample rate of 1.25 MHz (Datel Systems, Inc., Canton, Massachusetts 02021).

and 14 parallel tracks.* The application considered here is adequately met by an 8-bit word for each data sample; the remaining 6 bits of each 14-bit word block can be used for housekeeping functions. Thus, a maximum of 36,000 data words per second can be accommodated.

A number of factors have to be considered in order to establish the adequacy of the recording technique. These factors are:

- Beam passage video to be sampled (AZ video consists of two 150-μs pulses for each TO-FRO scan. With an update rate of 13.5 Hz, 4050 μs of video has to be sampled each second. For the EL channel, each video pulse is 100 μs wide and the update rate is 40.5 Hz. Thus, 8100 μs of video require sampling each second. The sum of all video samples is 12,150 μs per second.)
- Multipath video to be sampled (Allowance must be provided for the sampling of multipath video trailing beam passage video. A reasonable allowance would be 50% of the video sampling period.)
- Sampling frequency (If video is sampled at a rate lower than the desirable rate of once per microsecond, then data recording demands would be reduced.)
- Video gating (The video data stream has to be gated for a period equal to the length of the beam passage and the expected multipath duration. If this is not done, the capacity of the data recording will be exceeded.)

The above shows that if AZ and EL beam passage and multipath video are sampled once per microsecond, then an average of 18,225 words would have to be recorded each second. The 36,000 word per second capacity of the tape recorder is not exceeded in this case. Since the data sampling must take place at peak rates higher than the nominal recording rate, a buffer must be used to allow data to be recorded at a uniform rate.

It is concluded that the digital recording technique could be used for recording AZ and EL beam passage and multipath video, provided the data collection interval is limited to 18,225 μs in each second.

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*For example, the Honeywell model 5600, or equivalent.

However, a suitable interface unit has to be developed to provide synchronized time gating of the video, high-speed analog to digital conversion, and buffer storage. Hence, digital data recording of video does not appear attractive when a suitable analog technique is available with the capacity to record the entire video data stream.

E. Data Rates and Recording Requirements

Table 6 is a summary of the estimated number of bits required to record the TMLS guidance data, the ground tracker data, and the supporting documentation. Assuming a data sample rate of 10 per second, it is

Table 6

SUMMARY OF DATA RATES

Data Type	Number of Bits	Bits/Second
TMLS guidance data	136	1360*
Supporting documentation		
Run header	232	--
Avionics monitor	38	38
Digital diagnostic data	29	290*
PATS tracking data	120†	2400

*Assumed 10 updates per second.

†120 bits per frame, 20 frames per second.

seen from Table 6 that a 2400 bit per second data rate capacity would be sufficient to down-link the airborne data to the ground for recording, or to up-link the ground tracking data to the aircraft for recording. A single-channel digital data recorder with a capacity of 4800 bits per second could be used on the ground, or in the air, to record all the TMLS flight test data. However, before these data can be recorded, it is necessary to interface the data sources with the data collection system, convert analog data to digital data, and to put the data into a serial bit format. This will be discussed further in following sections of this report.

V DATA RECORDING OPTIONS

A. General Requirements

The performance evaluation of the TMLS requires airborne collection of TMLS angle and range data and the comparison of these data with independently determined aircraft position data. The performance of the TMLS is to be determined by processing the airborne data with the ground data as described in Appendix A. Although the airborne and ground data may be recorded independently, they must eventually be merged for data processing. The options for TMLS performance data recording are:

(1) Transmit, via an up-link, the independent ground tracker data to the aircraft and record both the airborne and ground data in the aircraft.

(2) Transmit, via a down-link, the airborne TMLS angle and range data to the ground tracker and record both the airborne and ground data at the ground tracker.

(3) Independently record the airborne TMLS angle and range data in the aircraft and the ground tracker data on the ground.

Options 1 and 2 provide real-time merging and allow real-time quick-look assessment of both the data collection process and the TMLS performance.

With Option 3, it is not possible to merge the airborne and ground data until the flight test is completed, making a real-time quick look at the TMLS performance impossible. It is expected that some flight test runs will be interrelated; i.e., initial conditions of one run will, in some cases, depend on the success or outcome of a previous run. Thus, without a capability for a real-time performance assessment, it is not possible to make an efficient use of the flight-test resources.

B. Option 1: Data Recorded in the Aircraft

Figure 1 is a block diagram of an airborne data collection system for flight testing TMLS. In this option, aircraft position data are

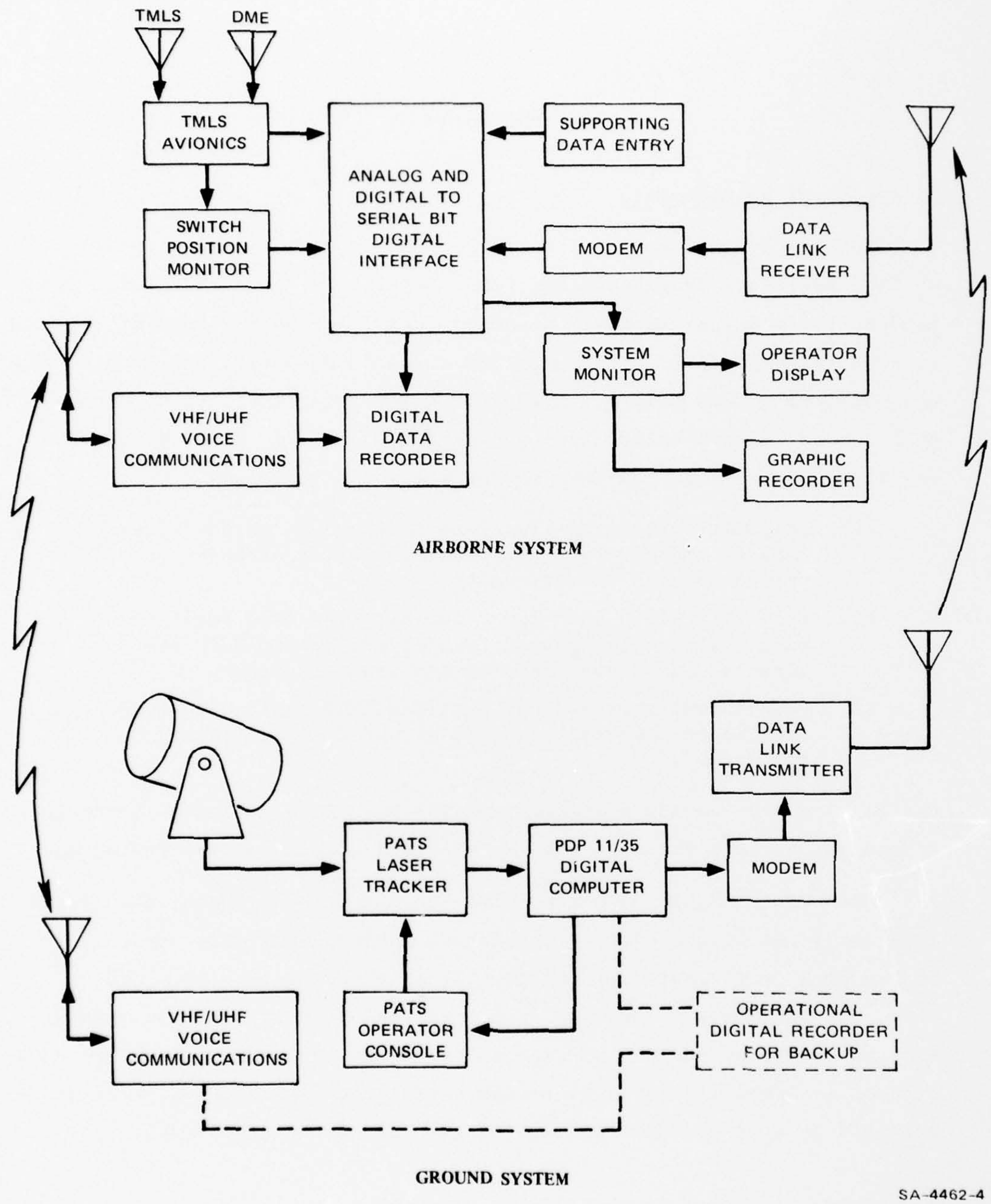

FIGURE 1 AIRBORNE DATA RECORDING

transmitted from the ground tracker to the aircraft via a digital data link. Azimuth and elevation angles, range, and time code data from the ground tracker are merged with the TMLS avionics data and recorded in the aircraft as are all voice communications and operator comments.

The aircraft crew consists of the aircraft pilot, the flight test coordinator, and an instrumentation technician. The instrumentation technician manages the overall data recording so the test coordinator can focus on assessing the quick-look data and managing the test runs. A continuous display of the deviation of the aircraft from the desired course, as well as the difference between aircraft position established by PATS and by TMLS, is provided to the test coordinator so decisions such as reruns can be made as soon as possible. The instrumentation shown in Figure 1 does not include specialized instrumentation (discussed in Part E) required for the detailed examination of multipath interference data.

The airborne equipment for Option 1 includes an interface between the TMLS and the data recording system. This interface will have to accept both digital and analog inputs from the TMLS avionics and generate a serial bit data format for digital recording.

The digital data from the ground tracker and the digital data from the TMLS interface unit will be compared in an onboard digital data processor.* The output of this processor can be used to monitor the data collection and to enable a quick assessment of the TMLS performance. The difference between the TMLS and ground tracker position can be displayed on a meter, or a strip chart recording can be made of the time history of the TMLS error. With a more sophisticated algorithm, the airborne digital processor could develop the TMLS performance statistics as defined in Appendix A.

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*A typical data processor would include a microprocessor such as the Intel 8080.

A data link receiver and an interface modem are required in the aircraft to receive and to convert the telemetered ground tracking data into signals that are compatible with digital data recording techniques. Digital instrumentation tape recorders are available that are capable of recording up to one hour of continuous data at a rate of 4800 bits per second.*

The ground equipment consists of the PATS laser tracker and a data link transmitter. Software will have to be written to program the PATS PDP 11/35 computer to generate a digital data format that is compatible with the airborne data system.

The PATS tracker facility has a digital data recording capability and can provide a digital record of the ground tracking data. This digital record can be used as a backup in case of trouble with the data link. However, merging of the backup ground data with the airborne data record requires additional computer processing, discussed under Option 3.

C. Option 2: Data Recorded on the Ground

Figure 2 is a block diagram of a ground-based data collection system for flight testing the TMLS. The TMLS avionics output data are transmitted from the flight test aircraft via a data link to the ground and merged with the PATS ground tracker data for recording. In this case, the flight-test coordinator is on the ground and the airborne equipment is managed by an observer or by the copilot. VHF or UHF aircraft voice communications can be used by the flight-test coordinator to direct the aircraft operations.

The airborne equipment includes an interface between the TMLS and the digital data modem for the data link. This interface will have to accept both digital and analog inputs, convert analog inputs to a digital format, and generate a serial bit data format for transmission by the data link. This interface is almost identical to that required for Option 1.

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*For example, the Hewlett-Packard Model 7404A.

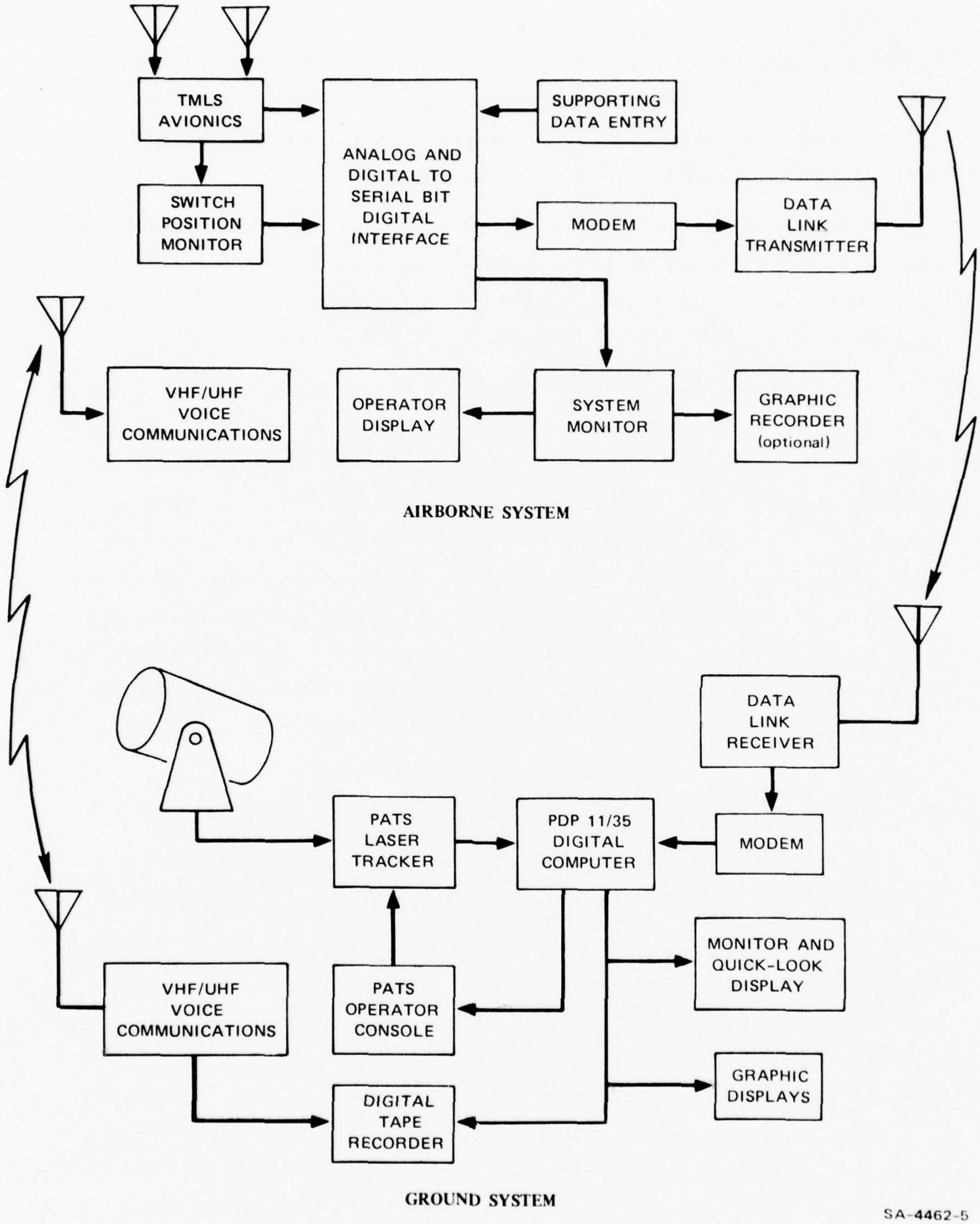

FIGURE 2 GROUND DATA RECORDING

Since the ground tracker data are not available in the aircraft, it is not feasible to generate quick-look TMLS performance information for the aircraft crew. Thus the airborne data system monitor is comparatively simple and serves only to reassure the flight crew that TMLS data are being encoded and sent to the ground station.

Although not necessary, consideration should be given to the recording of the TMLS analog outputs (azimuth angle deviation, elevation angle deviation, range, range rate, and height) on strip charts to provide the aircrew a measure of how the flight test was flown.

The PDP 11/35 digital computer and associated peripheral equipment in the PATS laser tracker trailer can provide both real-time quick-look TMLS performance data and graphic plots of the aircraft position history. Furthermore, the PDP 11/35 has the capability for the data reduction necessary to generate the TMLS performance statistics described in Appendix A, and the speed to process the TMLS approach data while the flight-test aircraft is being positioned for the next approach run. However, the data must be defined in detail, and computer software must be written. The FAA data-processing software for PATS should be examined by the Army to determine if it can be used for the TMLS evaluation.

D. Option 3: Airborne and Ground Data Recorded Independently

Figure 3 is a block diagram of a system to record the airborne and the PATS ground tracker data independently during the TMLS evaluation.

This approach does not require a data link; however, it does require the use of a common time base, such as a test-range clock, in order to merge the airborne and ground data at the end of the flight-test day. In this system, it is necessary to load both the airborne and ground digital tape records into a computer to generate a common record for the final data processing. Thus, real-time data processing is not possible, and quick-look performance data cannot be made available until the flight tests are completed for the day and the magnetic tapes are available for processing.

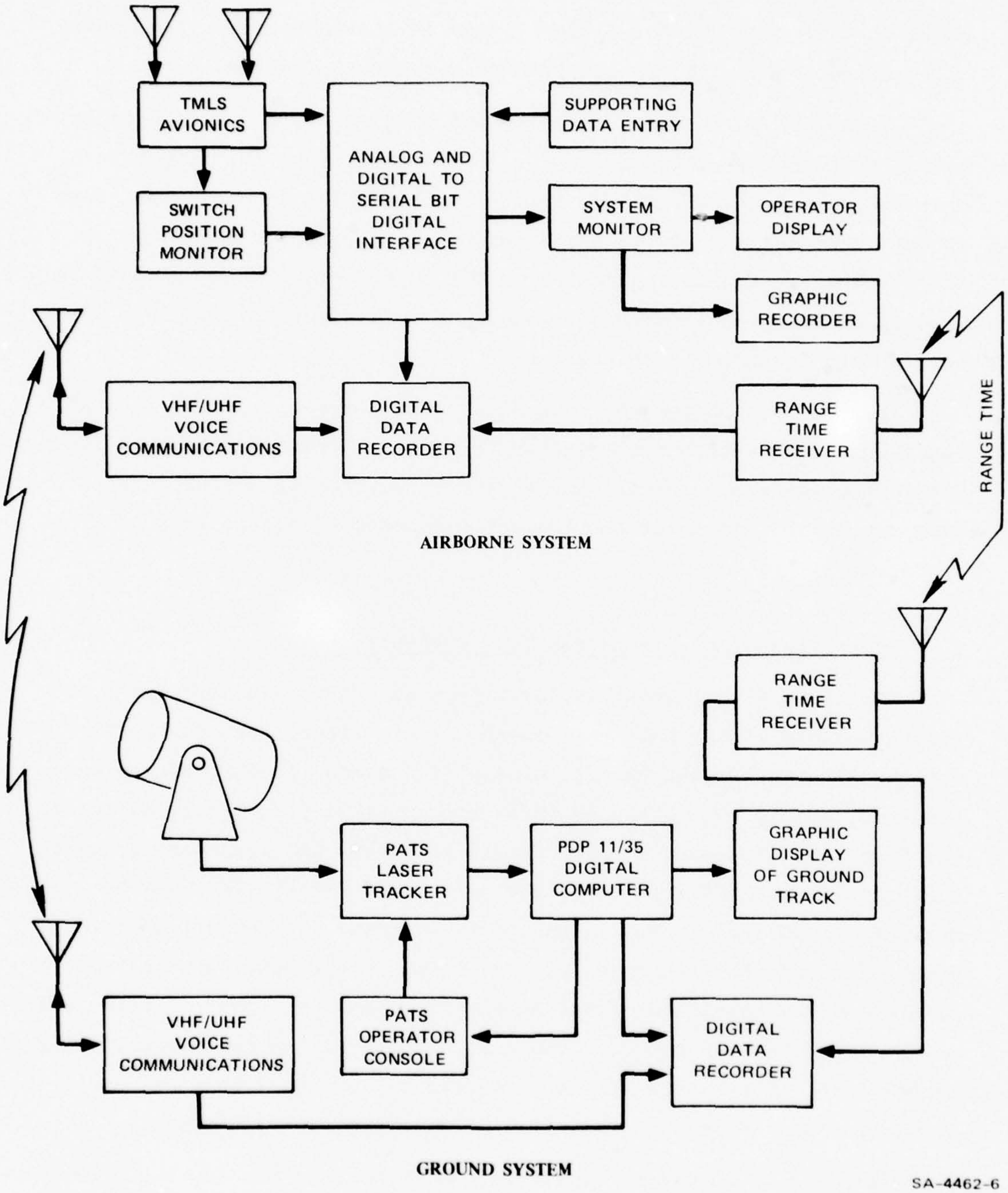

FIGURE 3 INDEPENDENT AIR AND GROUND RECORDING

The complexity of the recording equipment in the aircraft is almost equal to that required for Option 1, and an instrumentation technician is required to support the airborne data-recording system.

Quick-look performance data are not available for the flight-test coordinator either on the ground or in the air. Thus the flight-test coordinator cannot effectively control the flight-test operations from either location, and his location during the flight tests becomes discretionary. Ground-to-air VHF or UHF voice communications could be used to monitor the independent recording operations and to alert personnel to data recording problems.

In general, independent recording of airborne and ground data with postflight data merging and processing is not recommended because it does not provide a means for the real-time monitoring of the overall data recording process or the real-time assessment of the TMLS performance.

E. Specialized Instrumentation for Diagnostic Data

The three flight-test instrument options discussed above will provide a measure of the TMLS performance in the flight test multipath environment. Multipath interference will degrade the TMLS system performance, and if the multipath interference is very severe it may cause the flag alarm to appear. In moderate to strong multipath environments, typical of most Army airfields, the performance of the TMLS may be degraded. Under these conditions it is desirable to collect additional diagnostic data to determine both the level of the multipath and the effects of the multipath signal on the TMLS angle processor. Correlation may be found between the observed multipath level and the measured TMLS performance. These data will be required to develop a tactical airfield evaluation procedure for prediction of expected TMLS performance.

The effects of the multipath on the TMLS angle processor can be determined by recording the digital signals used in the flag logic circuit as described in Section III-D. The distortion of the video output of the TMLS receiver by the multipath is best observed by the use of an oscilloscope with a recording system, as described below.

Figure 4 illustrates three techniques for obtaining multipath waveforms (identified in Section IV-C) during a TMLS approach. Each technique allows the generation of a hard-copy record. Technique a uses a video tape recorder (VTR), Technique b uses a photographic camera, and Technique c uses an analog tape recorder.* A dual-trace oscilloscope display of the TMLS video signal is required for Techniques a and b, and is a desirable monitor for Technique c. Selected signal gates of the TMLS angle receiver are used to trigger the oscilloscope sweep to enable the AZ and EL video signals to be separately displayed on the dual-trace oscilloscope.

The VTR technique uses a TV camera, a VTR, and a TV monitor for display. A Polaroid camera is used to provide hard copies of selected images of the replay on the TV monitor. It is suggested that the VTR system be run continuously during the critical part of an approach. Hence, the TV camera must be mounted in an appropriate hood in front of the oscilloscope screen to permit simultaneous viewing of the CRT display by an observer. On replay after a run, specific TV frames may be frozen, viewed, and photographed to obtain hard-copy documentation of the multipath phenomena.

The VTR technique allows the capture of all data during the approach, whereas the photographic camera technique is limited in the number of pictures that can be taken on each approach.† Thus the operator must anticipate the multipath phenomena to be able to capture the most interesting aspects of a particular run. If a detailed recording of the multipath interference effects is desirable, then the VTR technique is obviously the best approach, although additional equipment must be carried in the airplane. In either case, a manned work station must be provided in the airplane.

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*Hard-copy records are generated postflight by strip chart recordings of a low-speed playback of the analog tape.

†A typical film pack consists of eight pictures. It is estimated that pictures can be taken roughly 10 to 15 seconds apart.

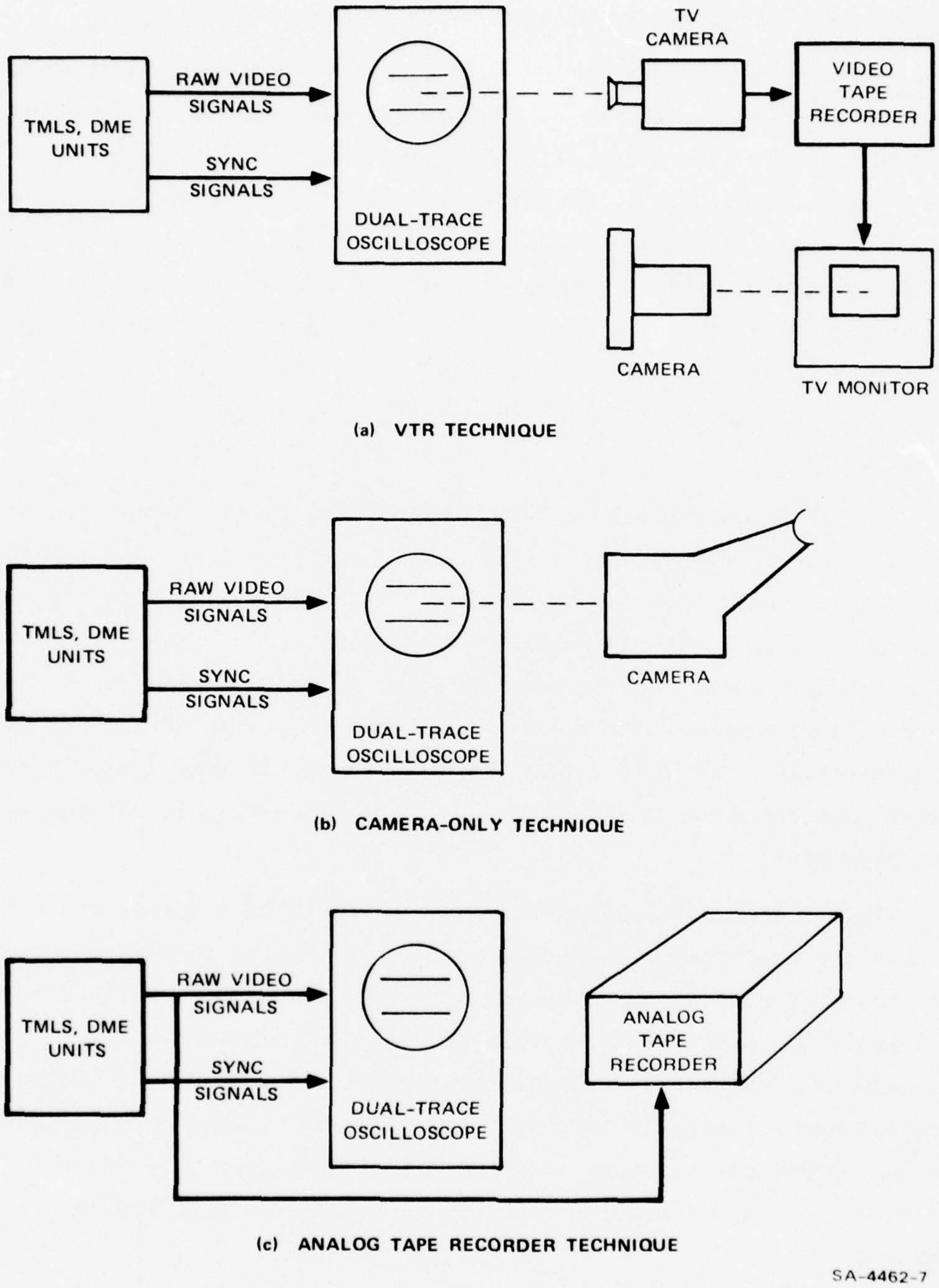

FIGURE 4 THREE TECHNIQUES FOR OBTAINING MULTIPATH WAVEFORMS

The analog tape recorder technique has the capacity to record all raw video data during the approach. Thus the entire TMLS signal format is available for postflight analysis. Playback from the analog tape recorder, and display on the oscilloscope, provide a quick-look capability.

In addition to the raw video signals, the logic signals generating the TMLS flag alarm should be recorded. These signals are described in Section III-D. With such information along with VTR, AZ, and EL video, one will be able to make a better assessment of the performance of the TMLS in a multipath environment.

F. Discussion of Data Recording Options

A comparison of the units required for the three data-recording options considered is shown in Table 7. It can be seen that Option 2, data recording on the ground, requires less equipment and personnel in the aircraft. This option has on-line access to the PDP 11/35 digital computer in the PATS trailer and can provide a real-time quick-look assessment of the TMLS performance. Furthermore, a real-time ground display of the TMLS performance will permit the TMLS to be demonstrated to both the flying and nonflying members of the aviation community. It should also be considered that the location of the flight-test co-ordinator in a quiet air-conditioned environment should contribute to increased flight-test productivity.

Video tape recording to document the multipath environment is recommended over conventional photographic techniques because data may be continuously recorded during an approach run and immediately replayed. Evidence of multipath may then be photographed and, if necessary, re-photographed with a single-frame Polaroid camera to obtain a hard-copy record.

Analog tape recording can be used to document the multipath environment. However, it is necessary to replay the recording at a lower tape speed and to rerecord on a high-speed strip chart recorder to obtain a hard-copy record. Analog tape recording has the capacity to record the entire video data stream.

Table 7

COMPARISON OF DATA RECORDING OPTIONS

Parameter	Option 1	Option 2	Option 3
Airborne Equipment			
TMLS data interface	Yes	Yes	Yes
Digital data recorder	Yes	No	Yes
Data link and modem	Yes	Yes	No
System performance monitor	Yes (complex)	Yes (simple)	Yes (simple)
Graphic recorder	Yes	Recommended	Recommended
VHF/UHF voice channel	Yes	Yes	Yes
Range time receiver	No	No	Yes
Air Crew			
Flight test coordinator	Yes	No	Optional
Instrumentation technician	Yes	Yes	Yes
Ground equipment at PATS			
Data link and modem	Yes	Yes	No
VHF/UHF voice channel	Yes	Yes	Yes
Digital data record	Optional	Yes	Yes
Data processor and display	No	Yes	Optional
Range time receiver or transmitter	No	No	Yes
Ground Crew			
PATS operator and instrumentation	Yes	Yes	Yes
Flight test coordinator	No	Yes	Optional
Postflight data merging	No	No	Yes
Quick-look performance assessment	In aircraft	On ground	None
Real-time demonstration capabilities	Limited	Good	Poor

VI DATA PROCESSING

A. TMLS Performance

Data-recording Options 1 and 2 will each generate one digital magnetic tape record that contains both the airborne TMLS aircraft position data and the PATS ground tracker position data. Data recording Option 3 will generate two digital magnetic tape records (one tape with TMLS aircraft position data and one tape with PATS ground tracker data). These two tapes will have to be computer processed to generate a single tape equivalent to that produced by either Option 1 or Option 2.*

The single magnetic tape record with both TMLS and PATS tracker data must be computer processed according to the MLS measurement methodology described in Appendix A. This will require computer software to compute the following for each TMLS approach:

- The RMS path-following error
- The 60-second time-average error
- The RMS control-motion noise
- The rate data for Automatic Flight Control Systems (AFCS).

The performance of the TMLS in various airfield environments will be evaluated by comparing the computer-processed flight-test data to the error budget for the TMLS shown in Appendix B.

B. Quick-Look TMLS Performance Assessment

To effectively control the flight test, a means should be provided to ensure that valid data are being collected. Thus, in addition to the data channel monitors used to confirm that signals are being recorded, a limited amount of real-time data processing is necessary. For Options 1

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*Computer software will be required to read the two input tapes, and to generate an output tape with the data collated by a common parameter such as range time.

and 2, this can be accomplished by comparing the aircraft TMLS position data with PATS position data. When the difference in position is within reasonable limits, there is assurance that the systems are operating properly and the data are valid. A simple strip chart recording of the difference in the azimuth, elevation, range, range rate, and height will provide a first-order assessment of the TMLS performance.

As was discussed in Section IV for Option 2, the computing power available with the PDP 11/35 in the PATS trailer will make it possible to generate both the quick-look data during the approach flight and the statistical performance summary within a few minutes after the approach is completed.

VII PRELIMINARY DESIGN OF THE TMLS AIRBORNE DATA COLLECTION SYSTEM

The data to be collected for the flight test evaluation of TMLS are defined in Section III, where it was concluded that a data rate of 2400 bits per second for the airborne and ground tracker system would be required.* It was also recommended that separate multipath diagnostic instrumentation be provided to investigate airfields that are typical of military operations.

In Section V, data recording on the ground at the PATS tracker facility was recommended.

The purpose of this section is to present a preliminary data-collection system design based on the information and conclusions thus far reached in this study.

A. TMLS Performance Data Collection System

Figure 5 is a block diagram showing the major components for an airborne TMLS data-collection system. This system provides a serial bit data stream for transmission to the ground-based PATS tracker facility where the data are recorded and processed for real time display.

The major components of the airborne equipment are an interface between the TMLS avionics, a data system monitor, a data system operating console, a data modem, and a data link transmitter.

The interface accepts both the digital and analog outputs of the TMLS avionics, the digital outputs from the TMLS selector switch sensors, and digital inputs from the data system operating console. The analog data are converted to digital and all the input data are formatted into a serial bit stream. A 2400 bit per second clock rate is used for

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*4800 bits per second when the data are merged.

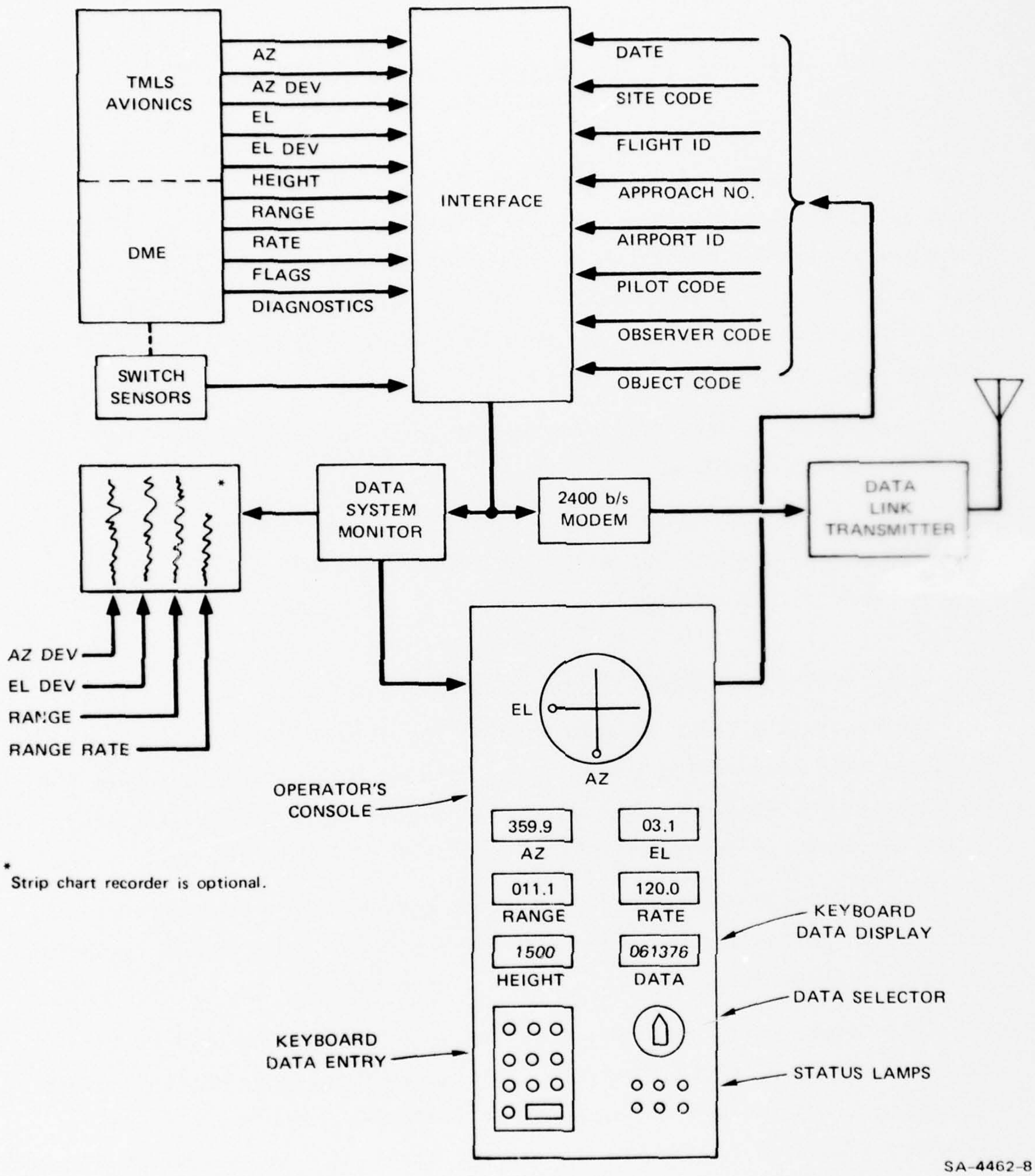

FIGURE 5 BLOCK DIAGRAM FOR TMLS PERFORMANCE DATA COLLECTION SYSTEM

compatibility with a standard 2400 bit per second data modem. The use of a microprocessor to control the data acquisition, conversion, and formatting is recommended. This will provide a flexible interface that can be adapted (programmed) to accommodate changes in signal format or interface requirements.

A data monitor samples the serial bit data stream input to the data modem and displays the transmitted data both on the operator console and on strip chart recorders in the aircraft. This ensures the airborne operator that the data collection system is operational. Depending on the data link transmitter, a demodulated RF output may be available. This would allow the operation of both the data link modem and the data link transmitter to be monitored.

The operator console has digital displays for azimuth angle, elevation angle, range, and range rate and has an analog CDI display of azimuth and elevation angle deviation. A digital display and a data input selector switch permit the operator to view the supporting documentary data as they are entered from the 10-digit numeric keyboard.*

The data modem is a standard 2400 bit per second modem, readily available.†

There are no special requirements for the data link transmitter other than a requirement to accept the modulated subcarrier generated by the data modem. This subcarrier, approximately 2400 Hz, is at a 0 dBm level. An instrumentation range telemetry unit with a carrier frequency of 400 mHz, 1000 mHz, or 2000 mHz may be used.

Assuming solid-state integrated circuits are used, it is estimated that the interface, the data system monitor, and the operator control

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*The use of numeric codes for the supporting data eliminates the requirement for an alphanumeric keyboard, thus saving considerable space on the control console.

†Such as the Model 2400 modem manufactured by International Communications Corporation, Miami, Florida 33147, or equivalent.

panel could be packaged in a volume of not more than one cubic foot. The estimated weight is about 20 pounds.

The estimated size, weight, and power requirements for the major components shown in Figure 5 are presented in Table 8.

Table 8

COMPONENT SIZE, WEIGHT, AND POWER REQUIREMENTS
FOR TMLS AIRBORNE DATA COLLECTION SYSTEM

Component	Size (inches)	Weight (pounds)	Power (watts)
Interface and data system monitor	8 x 8 x 12	10	20
Operator console	8 x 10 x 6	10	10
Modem	4 x 8 x 12	10	25
Data link transmitter	6 x 6 x 12	20	35
Strip chart recorder*	11 x 10 x 15	30	130
Total	3762 in.^{3}	85	220

*For example, Hewlett-Packard Model 740A.

Typical weights for the data modem, data link transmitter, and strip chart recorder are 15, 20, and 30 pounds, respectively.

B. Data Format

For compatibility with the PATS tracker, it is recommended that the 2400 bit per second data stream consist of 20 frames of 120 bits each. Each data frame should start with an eight-bit code to identify the start of the frame and to indicate the type of data contained in the frame.

Three data frames are needed to transmit supporting documentary data, as shown in Figure 6. Because the documentary data do not change during an approach, they are to be transmitted at the start of each new TMLS approach by pressing a button on the airborne operator's console.

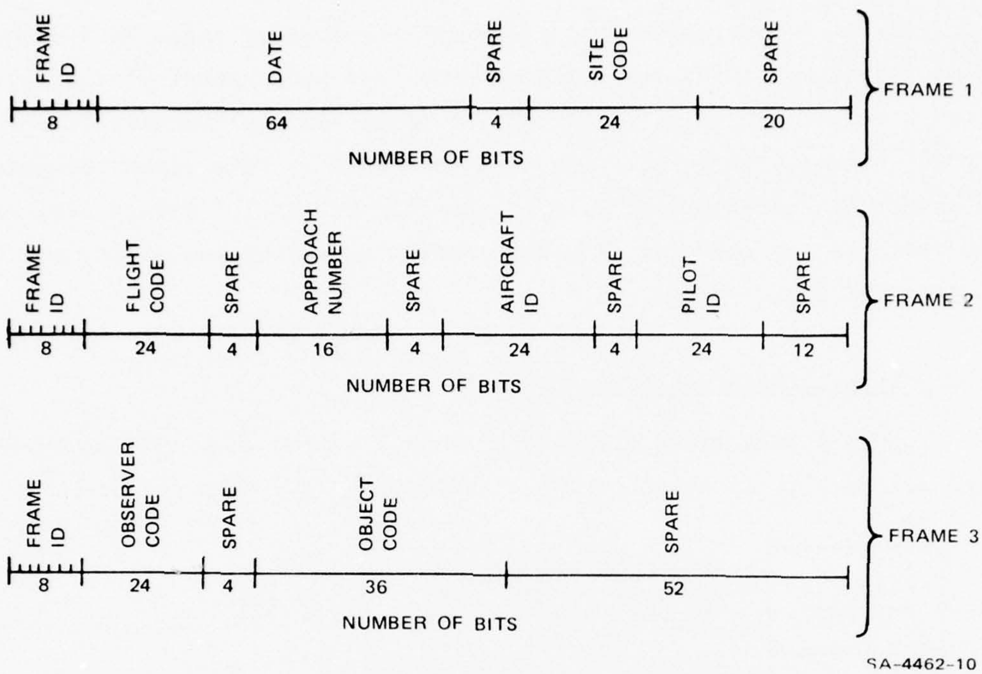

FIGURE 6 HEADER DATA FORMAT

The TMLS performance data are to be continuously transmitted during an approach at 20 frames per second. The TMLS data occupy two consecutive frames, as shown in Figure 7, to give an effective update rate of 10 per second.

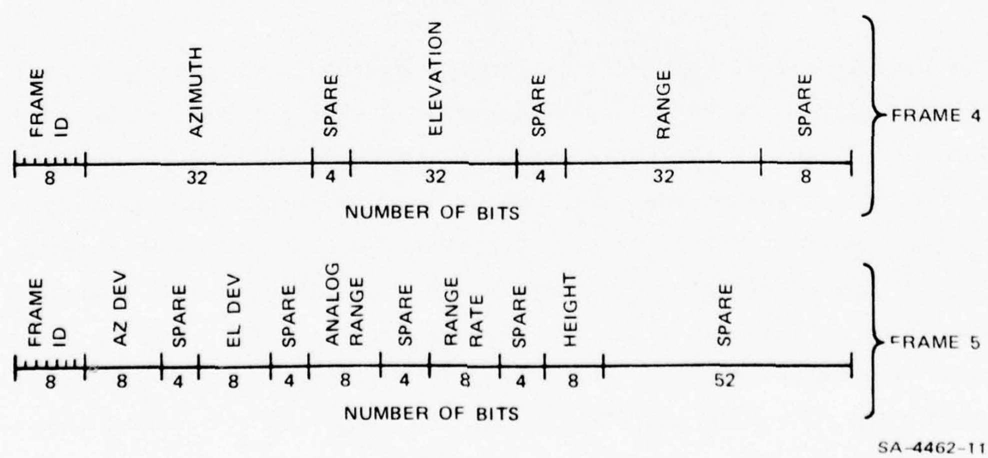

FIGURE 7 PERFORMANCE DATA FORMAT

Figures 6 and 7 show that there are a number of spare bits in each frame that can be used for system growth, for the transmission of parity bits to detect transmission errors, or both. Parity checking is recommended; however, it is not discussed in detail in this report because it is primarily a software problem at the PATS terminal. Parity bits can be generated in the airborne TMLS data system by adding one parity generator chip in the logic system.

C. Multipath Data Collection System

Figure 8 is a block diagram for a data system that uses an analog tape recorder to document multipath effects on the TMLS signal.

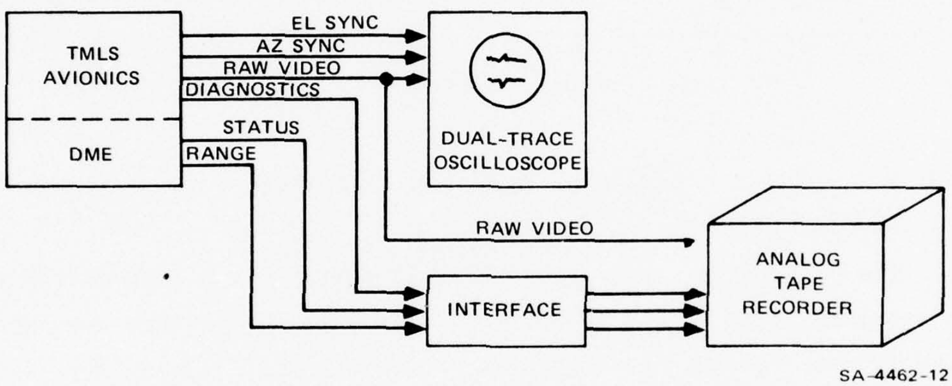

FIGURE 8 BLOCK DIAGRAM FOR ANALOG TAPE RECORDING OF TMLS MULTIPATH DATA

The purpose of this data collection system is to provide a facility to investigate--and to document--possible distortion of the raw TMLS video signal should the performance of the TMLS facility be out of tolerance. An analog tape recorder is used to record the raw video signals from the TMLS receiver. Supporting documentation is recorded on separate tracks of the tape recorder, which will require an interface between the diagnostic signal, the range output signal, and the various system status indicators. The design of this interface is straightforward since dc channels (FM-record) are available for analog tape recorders such as the Honeywell model 5600.

The estimated size, weight, and power requirements of the major components shown in Figure 8 are presented in Table 9.

Table 9

COMPONENT SIZE, WEIGHT, AND POWER REQUIREMENTS FOR MULTIPATH DATA COLLECTION SYSTEM

Component	Size (inches)	Weight (pounds)	Power (watts)
Interface unit	4 x 6 x 3	2	5
Oscilloscope*	6 x 12 x 22	26	100
Analog tape recorder†	12 x 22 x 19	95	300
Total	6672 in.^{3}	123	405

*For example, Tektronix model 446.

†For example, Honeywell model 5600.

Figure 9 is a block diagram for a multipath data collection system using a video tape recorder to record the oscilloscope traces of the azimuth and elevation video signals. Supporting documentation is also recorded on the VTR by including TMLS range data and an array of indicator lamps in the field of view of the VTR camera. The array of indicator lamps is used to display a simplified version of the TMLS angle processor diagnostic data shown in Table 5. This technique will identify the range at which the multipath distortion is observed and will provide a means to correlate the TMLS angle processor operation during the multipath investigation flights with the processor operation during the performance data collection flights.

A skilled operator will be required in the aircraft to decide when multipath distortion is present and when data are to be recorded.

The audio channel on the VTR is to be connected to the aircraft intercom system so that operator comments may be recorded with the video data.

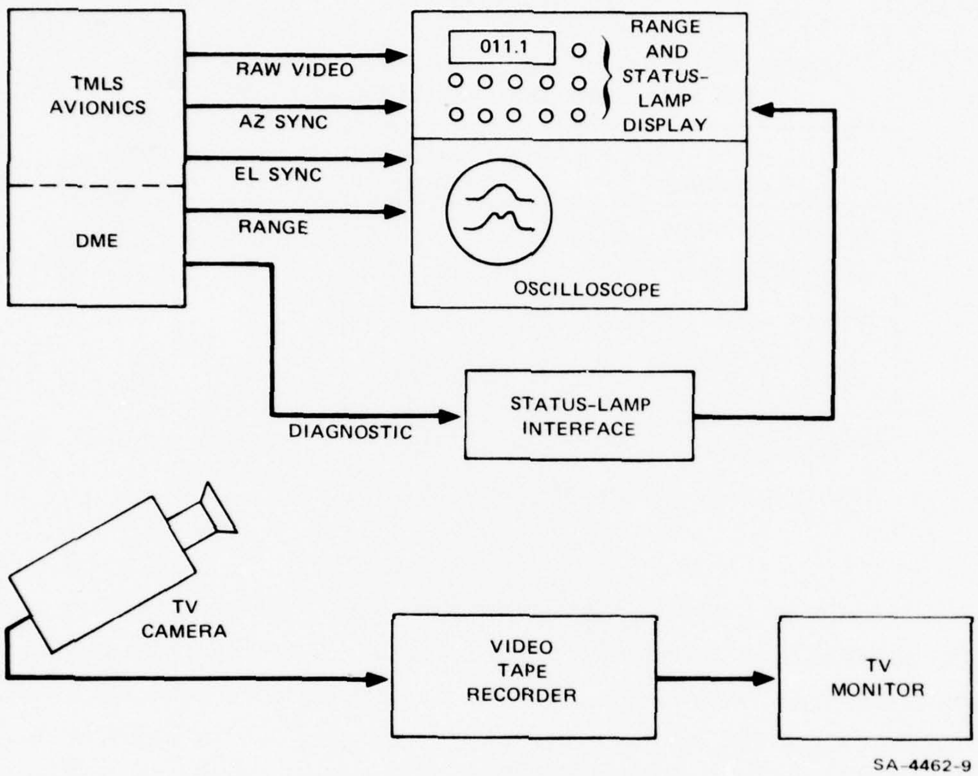

FIGURE 9 BLOCK DIAGRAM FOR VIDEO TAPE RECORDING OF TMLS MULTIPATH DATA

The estimated size, weight and power requirements for the major components shown in Figure 9 are presented in Table 10.

Table 10

VTR COMPONENT SIZE, WEIGHT, AND POWER REQUIREMENTS FOR MULTIPATH SYSTEM

Component	Size (inches)	Weight (pounds)	Power (watts)
Interface unit	6 x 6 x 10	5	10
Oscilloscope*	6 x 12 x 22	26	100
VTR†	9 x 23 x 17	70	130
TV camera‡	3.5 x 5 x 12	5	15
TV monitor§	10 x 10 x 11	12	25
Total	7203 $in.^3$	123	280

*For example, Tektronix model 446.

†For example, Sony type II VO 2600.

‡For example, GE model TE-33.

§For example, Sony model CVM-950.

D. Typical Interface Considerations

1. TMLS Angle, Range, and Height Data Output

Table 11 shows the signal levels for the digital and analog data outputs of the TMLS avionics.

The five analog outputs of the TMLS avionics are in the 0 to +2.0 Vdc range. Analog data acquisition modules are available that will convert an analog input of 0 to 5 volts to a 12-bit digital output.**

These analog data modules are available with 8- or 16-channel input capacity, and include an analog multiplexer, a sample-hold circuit, and a 12-bit analog to digital converter. The analog channel to be

**For example, DATEL Systems, Inc., Canton, Massachusetts 02021.

Table 11

SIGNAL LEVELS FOR TMLS INTERFACE

Parameter	Digital*	Analog†
Azimuth angle	1 = +10, 0 = -10 V	--
Azimuth deviation	--	0 to +2
Elevation angle	1 = +10, 0 = -10 V	--
Elevation deviation	--	0 to +2
DME distance	1 = +12, 0 = 0 V	0 to +2
DME rate	--	0 to +2
Height	--	0 to +2

*11 kHz (±3.5 kHz) clock rate.

†Volts dc with respect to ground.

digitized is selected by means of a digital address code generated by the control logic of the data collection system.

The digital data output format of the TMLS avionics is a 32-bit serial word with the logic levels shown in Table 11.

The 0 to +12 volt and -10 to +10 volt logic levels may be converted to 0 to 5 volt levels, for compatibility with standard TTL logic, by the use of resistor voltage dividers and diodes.

Since the bit rate for the TMLS digital data output is 11,000 bits per second, and the bit rate for the air-ground data link is 2400 bits per second, it will be necessary to use a shift register to hold a 32-bit TMLS data word for retransmission at the slower rate. This can be implemented easily with available standard digital logic components.

2. Supporting Documentation

The supporting documentation, keyboard entry data, and contact closure of sensor switches added to the TMLS avionics controls are basically digital in format. The control logic for the airborne data collection system can be designed to accept this input directly. However, it will be necessary to provide buffer storage for the keyboard entry data, since the data must be entered one character at a time by the operator. This is not considered to be a problem area and can easily be incorporated into the design of the airborne data collection system.

3. Diagnostic Data

At the time of this study, there was no FAA or Army requirement to make the parameters of the diagnostic data (discussed in Section IV-D) or the raw video available outside the TMLS avionics package. Discussions with the manufacturer* about the feasibility of connecting temporary test leads to the TMLS processor logic during flight tests were inconclusive because: (1) the TMLS avionics procurement is currently in a contract definition study and the equipment details are subject to change; (2) the TMLS avionics hardware is not yet built; and (3) the manufacturer is reluctant to see equipment connected to the processor that might possibly degrade the TMLS performance. Clearly, this is an area that the Army will have to explore with the TMLS equipment manufacturer.

Assuming the diagnostic data listed in Section IV-D are available, these data are digital in format and, with level converters, may be directly interfaced with the airborne data collection system.

The interface of the diagnostic data with the multipath documentation system is very simple since the binary data may be represented by an array of lamps that are either on or off to indicate a one or zero. Since these data will not have to be formatted and clocked into a serial bit data stream, the interface can be accomplished with level changers and lamp drivers.

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*Bendix, Baltimore, Maryland 21204.

VIII CONCLUSIONS AND RECOMMENDATIONS

1. It is concluded that two categories of data should be collected during the evaluation of the TMLS by the Army. First, data should be collected to evaluate the performance of the TMLS as defined in the MLS measurement methodology described in FAA-ER-700-07. Second, data should be collected to document the multipath distortions of the TMLS signal.

2. It is recommended that two separate airborne instrumentation packages be developed: one for the collection of TMLS performance data, and the other for the documentation of multipath. The reasons for this recommendation are these: Where multipath documentation is not required, or where aircraft space is limited, such as in the OV-1, only one system needs to be carried in the aircraft. Two independent data collection systems will result in smaller packaging that is more compatible with the space and weight limitations of Army aircraft. Finally, since the multipath documentation system can be used without a ground tracker facility, there is the possibility that the multipath documentation system can be used to assess the potential performance of a tactically deployed TMLS.

3. It is recommended that the TMLS performance data include supporting documentation to identify the date, test conditions, test objective, personnel, and aircraft involved in the flight test.

4. It is recommended that the parameters used in the flag logic for the TMLS angle processor be recorded with both TMLS performance data and the multipath documentation.

5. It is concluded that the availability of these parameters for recording will have to be established with the TMLS avionics manufacturer, since there is no present requirement for these parameters to be available external to the TMLS angle processor.

6. It is concluded that a 2400 bit per second data rate is sufficient to transmit the ground tracking data to the flight test aircraft, or to transmit the TMLS data to the ground, for recording.

7. It is recommended that the TMLS data in the flight test aircraft be transmitted to the ground tracker facility for recording. The reasons for this recommendation are these: The personnel and equipment requirements in the aircraft are less than are required for the other alternatives considered. The PATS ground tracker facility has an online PDP 11/35 digital computer than can provide real-time quick-look assessment of the TMLS performance. The PATS tracker facility has a digital data recording system available, and has a real-time display capability that will permit the TMLS to be demonstrated to both the flying and nonflying members of the aviation community. Finally, locating the flight test coordinator in the PATS facility, rather than in the aircraft, should result in increased flight-test productivity.

8. It is recommended that either the analog tape recorder or the video tape recorder technique be used to record the data for documentation of multipath distortion. The total estimated weight and volume of equipment and power required in the aircraft to implement these two recording techniques are similar. Analog tape recording provides an extra bonus in that the entire video data stream is recorded and is available for postflight analysis. The proposed video tape technique records only the video waveforms of the beam passage.

9. It is concluded that the estimated size, weight, and power characteristics of the TMLS performance data collection system can be made compatible with the limitations of the Army UH-1, U-21, and OV-1 aircraft.

10. It is concluded that the estimated size, weight, and power characteristics of the system to document multipath distortion are compatible with the limitations of the Army UH-1, U-21, and OV-1 aircraft.

11. It is recommended that the Army coordinate the implementation of TMLS data collection systems with the NAFEC to ensure compatibility of the airborne data format with the PATS computer, and to make maximum use of PATS computer software that may be available from the NAFEC.

Appendix A

DEFINITION OF MLS PERFORMANCE TERMS

Appendix A

DEFINITION OF MLS PERFORMANCE TERMS

The Functional Requirements Specifications for MLS, FAA-ER-700-07, define the following terms to express the angular and range performance accuracy of MLS:

(1) Angular error--The angular error is the difference between the processed sample data output and the true position angle at the sampling time. The angular error budget is divided into two categories, bias and noise, and includes the effects of the environment.

(2) Angle bias (includes receiver bias)--Bias is the long-term misalignment between a specific MLS course and a selected course, including the MLS ground system as well as the MLS airborne receiver mean errors which cannot be reduced to zero by real-time calibration techniques.

(3) Angle noise (includes receiver noise)--Angle noise is the spatial and temporal perturbations in the guidance signal. It originates from ground equipment, airborne equipment, and the environment.

(4) Path-following noise--Path-following noise is that portion of angle noise that can cause aircraft motion; it exhibits relatively slow variations.

(5) Control-motion noise--Control-motion noise is the portion of angle noise that affects control surface, wheel, column motion, and aircraft attitude; it exhibits moderately fast variations.

(6) Extraneous noise--Extraneous noise is angle noise that exhibits variations too rapid to affect aircraft control and guidance.

(7) Path-following error--Path-following error is the angular deviation from a predetermined course of an aircraft perfectly following MLS guidance commands. The error is thus due to angle bias and path-following noise in the guidance signal.

(8) Range error--The range error is the difference between the suitably processed DME range and the true distance at a specific time. DME bias and noise errors have the same general definition as angle guidance.

The above definitions will be used in the following discussions of data to be collected for the performance evolution of TMLS.

The functional requirement specifications also define a measurement methodology for MLS errors (see Figure A-1). It is important to note that the raw sample data output of the MLS receiver is filtered with a 10 radian per second low-pass smoothing filter, and that this smoothed MLS output is again filtered to obtain the bias error, the control-motion noise, and the path-following error. The characteristics of these filters are based on a wide range of existing aircraft response properties and are believed to be representative of the response properties of any foreseeable aircraft.* The filter configuration and corner frequencies for the various MLS guidance functions are shown in Figure A-2.

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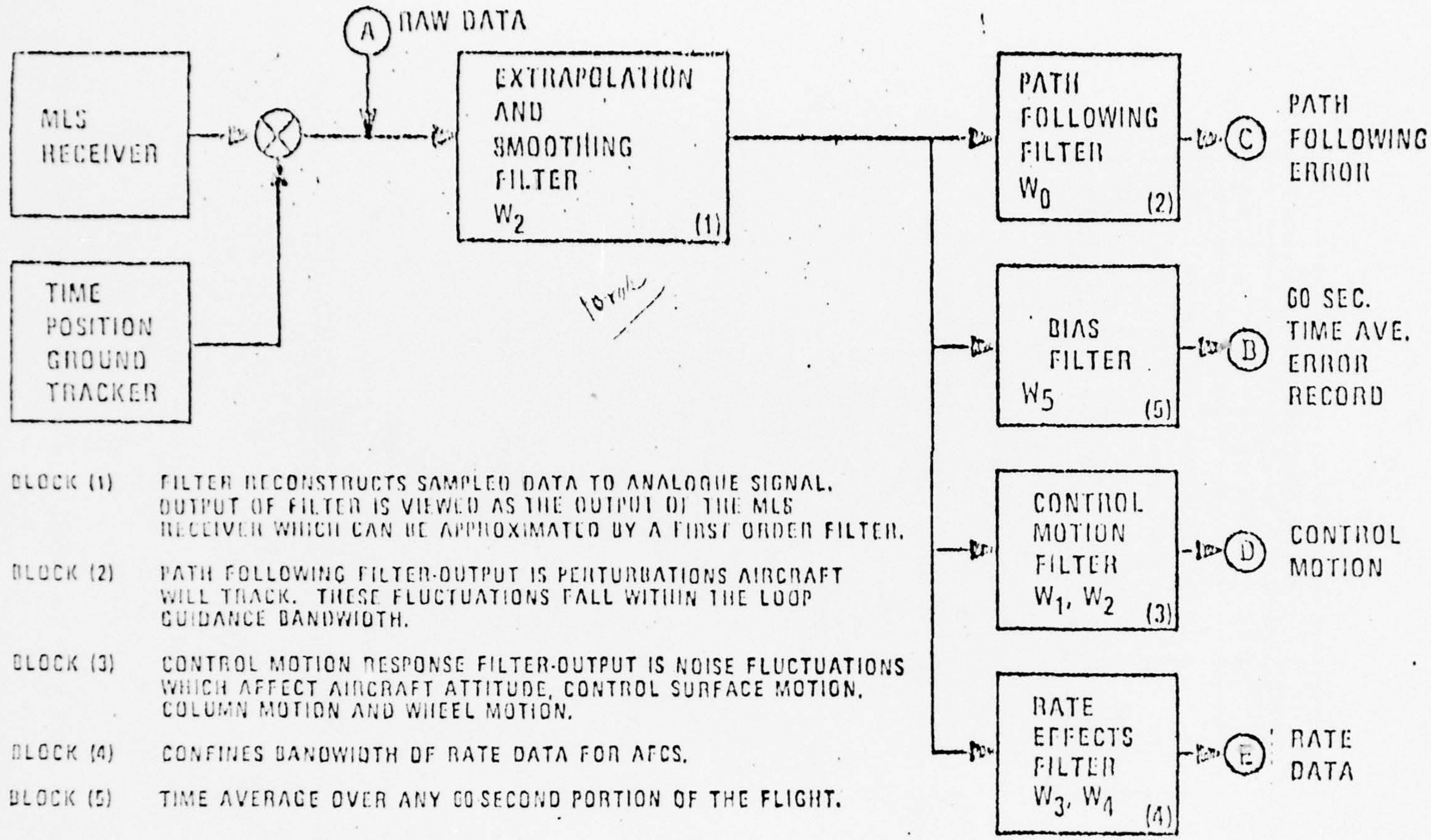
*FAA-ER-700-07, 25 February 1975.



BLOCK (1) FILTER RECONSTRUCTS SAMPLED DATA TO ANALOGUE SIGNAL. OUTPUT OF FILTER IS VIEWED AS THE OUTPUT OF THE MLS RECEIVER WHICH CAN BE APPROXIMATED BY A FIRST ORDER FILTER.

BLOCK (2) PATH FOLLOWING FILTER-OUTPUT IS PERTURBATIONS AIRCRAFT WILL TRACK. THESE FLUCTUATIONS FALL WITHIN THE LOOP GUIDANCE BANDWIDTH.

BLOCK (3) CONTROL MOTION RESPONSE FILTER-OUTPUT IS NOISE FLUCTUATIONS WHICH AFFECT AIRCRAFT ATTITUDE, CONTROL SURFACE MOTION, COLUMN MOTION AND WHEEL MOTION.

BLOCK (4) CONFINES BANDWIDTH OF RATE DATA FOR AFCS.

BLOCK (5) TIME AVERAGE OVER ANY 60 SECOND PORTION OF THE FLIGHT.

FIGURE A-1 MLS MEASUREMENT METHODOLOGY

GUIDANCE FUNCTION	CORNER FREQUENCIES (Radians/Sec)					
	ω_0	ω_1	ω_2	ω_3	ω_4	ω_5
AZ	0.5	0.3	10	2	4	0.05
EL	1.5	0.5	10	2	4	0.05
FLARE	2.0	0.5	10	2	4	0.05
DME	0.2	0.5	10	2	4	0.05

FILTER CONFIGURATIONS

SMOOTHING FILTER: $\dfrac{\omega_2}{S + \omega_2}$

PATH FOLLOWING FILTER: $\dfrac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}$; $\zeta = 1$; $\omega_0 = 0.64\ \omega_n$

$$\omega_0 = \omega_n \sqrt{1 - 2\zeta^2 + \left(4\zeta^4 - 4\zeta^2 + 2\right)^{1/2}}$$

CONTROL MOTION FILTER: $\dfrac{S}{S + \omega_1}$

RATE FILTER: $\left(\dfrac{S}{S + \omega_3}\right) \left(\dfrac{\omega_4}{S + \omega_4}\right)$

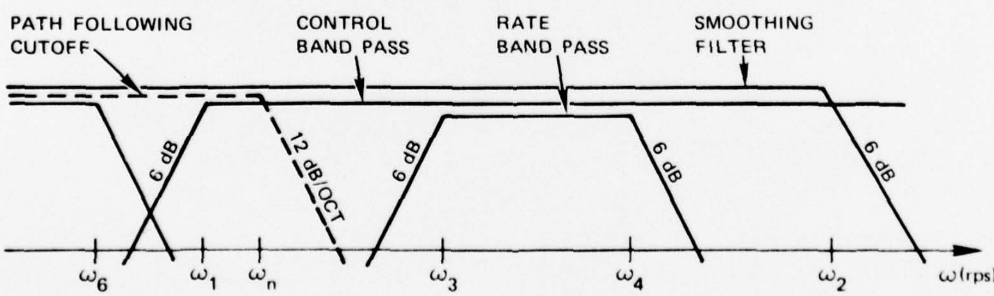


FIGURE A-2 FILTER CONFIGURATIONS AND CORNER FREQUENCIES

Appendix B

ERROR BUDGET FOR TMLS PERFORMANCE

Appendix B

ERROR BUDGET FOR TMLS PERFORMANCE

The error budget for the TMLS equipment is shown in Table B-1. The specifications for the total path-following error, including both the

Table B-1

TMLS ERROR BUDGET
ANGULAR DEVIATION (σ)

	Ground Subsystem	Airborne Subsystem	Total
Elevation Guidance			
Bias	0.024	0.010	0.026
Noise	0.018	0.018	0.026
Total	0.030	0.021	0.037
Environmental effects			0.089
Total path-following error			0.096
Azimuth Guidance			
Bias	0.16	0.02	0.16
Noise	0.07	0.036	0.08
Total	0.17	0.041	0.18
Environmental effects			0.22
Total path-following error			0.286
DME			
Bias	32'	--	
Noise	24'	--	
Total	40'	40'	
Total path-following error (without environmental effects)			57'

ground and airborne equipments and environmental effects, is 0.096° for elevation guidance and 0.286° for azimuth. These are 2σ values. The total 2σ DME ground and airborne equipment error budget is 57 feet, excluding environmental effects.*

To verify that the TMLS meets the performance specifications, it will be necessary to record the TMLS indicated azimuth, elevation, and range in the flight-test aircraft and to compare the data with similar data recorded with an independent ground-based tracker.

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*FAA-ER-700-03, 24 February 1975.

Appendix C

SYSTEM SPECIFICATIONS FOR PATS

Appendix C

SYSTEM SPECIFICATIONS FOR PATS*

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*Precision Automated Tracking System
Manufactured by GTE Sylvania
Electronic Systems Group--Western Division
P. O. Box 188
Mountain View, California 94042

Table C-1

SYSTEM SPECIFICATIONS*

1. Acquisition Dynamics (manual - using joystick and TV monitor)

   Maximum angular rate (azimuth and elevation): 100 mrad/sec
   Maximum angular acceleration (azimuth and elevation): 25 mrad/sec^2

2. Acquisition Dynamics (aided with 100 sample per second coordinate data)

   Maximum angular rate (azimuth and elevation): 500 mrad/sec
   Maximum angular acceleration (azimuth and elevation): 80 mrad/sec^2

3. Autotrack Dynamics

   Maximum angular rate (azimuth and elevation): 500 mrad/sec
   Maximum angular acceleration (azimuth and elevation): 80 mrad/sec^2

4. Angular Coverage

   Azimuth: ±170°
   Elevation: -5° to +85° (dynamic specifications #1, 2, and 3 apply for elevation angles between -5° to +45°

5. Absolute Accuracy†

   Azimuth: ±0.01 percent of range (0.1 mrad) (for target ranges of 213 to 19,812 meters)
   Elevation: ±0.01 percent of range (0.1 mrad) (for target ranges of 213 to 19,812 meters)
   Range: ±0.3 meter for target ranges of 213 to 9,144 meters
   ±0.6 meter for target ranges of 9,744 to 19,812 meters

6. Range Coverage: 305 to 19,812 meters (system accuracy maintained)

   Expected maximum range 13,048 meters
   Expected accuracy for target at 13,048 meters

   Azimuth: ±0.3 mrad
   Elevation: ±0.3 mrad
   Range: 1.5 meters

7. Leveling accuracy: ±0.025 mrad

8. Operator Displays

   Range: Digital in 0.3-meter increments
   Azimuth: Digital in milliradians with 0.1-milliradian resolution
   Elevation: Digital in milliradians with 0.1-milliradian resolution

9. Eyesafe Distances (refer to text for description): 1,067 meters, 107 meters, 11 meters, depending on laser power setting

10. Viewfinder Field-of-View: 5° to 20° with zoom control (10:1 300 mm maximum)

11. Acquisition Field-of-View: 3 mrad

12. Data Sample Rate: 100, 50, 20, or 10 sample sets per second, selectable

13. Power Requirements: Direct line or motor generator

14. Environmental Conditions (Operating):

    Ambient temperature: -20° to +120°F
    Wind: 0 to 50 knots

15. Setup Time: 1 hour

*Based on use of 7.6-centimeter-diameter 4-arc-second retroreflector.

†After computer smoothing, a weighted averaging technique is used with a sliding window of 0.1 second and a sample rate of 100 per second.

Table C-2

LIST OF EQUIPMENT INCLUDED IN THE PATS TRAILER
DELIVERED TO NAFEC, JULY 1976

Description	Model Number	Manufacturer
Telemetry Control	02-1204545-1	Sylvania
Communication Unit	02-1204581-1	Sylvania
Range Computer	02-1204579-1	Sylvania
TV Monitor	02-788263-1	Sylvania
System Control	02-787800-2	Sylvania
Laser Power Supply	02-787840-5	Sylvania
Computer Interface Unit	02-1204550-1	Sylvania
Power Distribution Panel	02-1204799-1	Sylvania
Optical Package	02-1203948-1	Sylvania
Laser Transmitter Box	02-1203901-1	Sylvania
Heat Exchanger	02-1203995-1	Sylvania
VT05 A/N Display	VT05B, M47	Digital Equipment Corp.
PDP 11/35 CPV	PDP11/35FL	Digital Equipment Corp.
DEC Pack (Disk)	RK05	Digital Equipment Corp.
DEC Expansion Box	BA11KE	Digital Equipment Corp.
7 Ch. Mag. Tape Unit (2 units)	TU10FE	Digital Equipment Corp.
DEC Card Reader	CR11	Digital Equipment Corp.
9 Ch. Mag. Tape Unit	TU10FE	Digital Equipment Corp.
Mag. Tape Controller	TM11EA	Digital Equipment Corp.
Oscilloscope	5103N	Tektronix
Tektronix Display	R-4010-1	Tektronix
TEK Hard Copy Unit	4610	Tektronix
AZ Servo Amp.	800PRA	CSR Corp.
WWV Receiver	WVTR Mark IV	Kinemetrics Inc.
Time Code Generator	8150	Systron Donner
Encoder Control Unit	ICU80/120-058N-18/18	Sequential
Paper Tape Punch	RP51075BH	Remex
Paper Tape Reader	RRS6500	Remex
Versitec Printer	LP-D1150	Versitec
HP Plotters (2 units)	7046A	H.P.
Sony Video Tape Recorder	AV3600	Sony
Teletype	33TU	Teletype Corp.
Optical Acquisition Aid	3790	Scientific Atlanta Corp.

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