A REALTIME DYNAMIC VEHICLE TEST SYSTEM

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ABSTRACT

A realtime, multi-system, dynamic vehicle test capability has been developed for the testing of tanks and large vehicles under all possible conditions of terrain and environment. The systems, produced under a turnkey contract, include: a fixed base ground data processing system; a mobile ground station with the same processing capability; two vehicle-borne systems with on-board computing, recording and telemetry; and a large integrated software package for all four systems. The mobile ground station can be mounted on a rail car, a ship or the chassis of a diesel truck capable of operating across open field terrain. All four systems have computers and realtime EU data displays. The vehicle-borne systems can be assembled and mounted inside a tank turret for underwater testing. Optionally, they can be installed in an environmental enclosure mounted to the outside of the vehicle for open field testing or tests where the armament supply hardware must be installed inside the armored vehicle. Several special sensors were developed for the vehicle-borne instrumentation to permit measurement and display of terrain contour, ground speed, track efficiency, power train performance, vehicle direction, velocity and acceleration in 3-axes, vehicle attitude and stability, dynamic gun pointing accuracy, engine and transmission performance and operator reaction to the test requirements and the vehicle environment.

INTRODUCTION

Three years ago the requirements were defined for a group of systems to be used in realtime performance monitoring and dynamic testing of large tracked and wheeled vehicles with both military and commercial applications. The need was for a turnkey capability to monitor concurrent operation of two test vehicles under any environmental condition while the vehicles are operating on any type of terrain at a fixed test range or at a remote geographical location without a test site infrastructure. The quality of vehicle performance to be measured included operator controls, vehicle direction and velocity in all axes, engine and transmission performance, drive train efficiency, track efficiency, measurement of ground terrain contour, weapons system operation and accuracy under dynamic field conditions, and vehicle operator reactions to tactical conditions and the vehicle environment.

Each of two vehicle-borne systems, as initially deployed, provided up to 186 channels of data acquisition processed in PCM format at sampling rates up to 125k sps, with growth to double that number of channels. One of the vehicle-borne systems had the PCM data telemetered via a broadband PCM/FM telemetry link in S-band with low-light level video telemetered in the baseband and PCM on a high frequency subcarrier oscillator. Both PCM and video were also recorded separately on-board the vehicle. The second vehicle-borne system used a narrow-band PCM/FM L-band telemetry link with transmission of PCM data only. Both vehicles had limited on-board EU data display capabilities. A mobile microwave repeater station was provided to permit the test vehicle to have continuous rf link integrity with the ground station when the test track terrain caused the test vehicle to operate out of line-of-sight range of either the mobile or fixed base ground stations. The test track route, across which the vehicle had to maintain telemetry link continuity with the ground station, could vary plus or minus several hundred meters from the elevation of the ground station requiring dual axis steerable antennae at the mobile ground station.

System expansion capabilities included support of up to four test vehicles operating on the test track concurrently. The test vehicles had to be able to operate up to 14 km from the fixed or mobile ground data processing stations while on any conceivable type of terrain; the mobile ground station could follow the test vehicle(s) across open terrain for extended tests beyond the telemetry link range.

A significant portion of the turnkey contract included the development of special sensors, the supply of all sensors for two test vehicles, as well as the installation in one test vehicle of one data system and all sensors necessary to demonstrate the specified functionality. The data system hardware and software documentation included procedures for sensor installation and sensor calibration. Included in the overall test capability was a sensor calibration laboratory with the hardware and software to perform any type of sensor calibration (e.g., bonded strain gauges, LVDTs, synchros, pressure and position transducers) and to semiautomatically enter the calibration data into the test facility data base.

The mobile and fixed base ground processing software systems required database support of a large number of different test vehicles and a large number of sensor classes with calibration data kept in a special realtime relational database for instant recall by vehicle number, test number, revision, date and time. Test data, to be presented in realtime in several different formats, included scrolling EU curves on color CRT terminals with color hardcopy capability, EU curves on a printer/plotter, raw data on stripchart recorders, bar graph and tabular EU data on B&W CRT terminals and alarms on the graphics terminal. Hardcopy output was provided for all realtime data presented to the test engineers. The mobile ground station provided the same functions as the fixed base ground station, but it only needed to support four test engineers and two concurrent test vehicles in close proximity and did not need to support concurrent software development and testing.

Training included all facets of the system from sensor theory, installation and calibration through operation and maintenance of the system and application software development.

On-site commissioning of the system will include 30 days of field testing of the instrumented tank across the entire test track.

SYSTEM OVERVIEW

The Realtime Dynamic Vehicle Test capability is composed of multiple systems integrated to support fixed base and remote site vehicle test operations using multiple telemetry links. Figure 1 is an illustration of the elements which comprise the complete vehicle test capability at the fixed base operations site. The remote test site location or the fixed base test track vehicle operations can be augmented by the Mobile Microwave Repeater system which permits the test vehicle to maintain telemetry link integrity while it is out of line-of-sight range of the ground station receiving antenna. It is primarily intended for use at the fixed base test track where there are two different test ranges both of which consist of extensive hilly terrain and neither of which can be covered completely by the two single-axis controllable receiving antennae. Remote site test operations composed of the mobile ground station, the mobile repeater (if required) and the test vehicle(s) are to operate at any remote geographical location without a test support infrastructure.

The fixed base ground station systems are installed in three different buildings located in the test complex infrastructure at the northeast end of the fixed vehicle test ranges. The terrain contour for one of the two test ranges is presented in Figure 2, which also depicts the buildings where the receiving antenna system, the PCM data processing system, the sensor calibration laboratory and the vehicle preparation site are located. It also depicts one of the test track routes used to test vehicle operation and performance. Not shown, but of significant importance in the system design (beyond the terrain contours) is the large stand of trees between the receiving antenna building and the observation building, placing most of the eastern end of the major test track route out of line-of-sight range from the receiving antennae. The reason for two receiving antennae is to permit concurrent testing of two vehicles as well as coverage of both test range Number 1 and test range Number 2 (not shown) and/or the vehicle preparation building.

By locating the narrowband microwave repeater system on a jeep, it is possible to position the repeater system on a high point of ground where there is line-of-sight visibility between the repeater and both the test vehicle and the receiving antenna building. The jeep provides the mobility needed to move the repeater location during the vehicle test run so this dual path LOS condition is constantly maintained.

The Realtime Dynamic Vehicle Test System is composed of six major functional elements:

1. Vehicle-borne Data Systems & Sensors
2. Mobile Microwave Repeater System
3. Mobile PCM Ground Station
4. Fixed Ground Station Antenna System
5. Fixed PCM Data Processing System
6. Sensor Calibration Laboratory

The fixed ground station antenna subsystem and the PCM data processing system are located in two different buildings because of building location and site restrictions but they represent one complete PCM ground station. The mobile PCM ground station with its integral antenna system represents a second complete PCM ground station. Complete data processing functions are available at either PCM ground station.

Sensor Calibration Laboratory

The Sensor Calibration Laboratory is located approximately 600 meters from the ground station computer building. In addition to its classical instrumentation for sensor calibration and testing, is a vehicle-borne multiplexer/encoder and an on-board microprocessor-based data display and control unit which can program and test the multiplexer via its RS-232 connection to the host CPU in the computer building. There is also a B&W CRT terminal in the calibration laboratory connected to the ground station computer for local display of processed sensor calibration data. The sensors being calibrated are connected to, and excited by, PCM encoder whose serial PCM stream is connected via cable to the decom in the computer building where calibration data is processed. Included with the calibration laboratory hardware provided are the tools, fixtures and procedures for calibration of the special sensors such as the terrain contour follower, the torque sensors and doppler velocimeters.

Fixed Base Ground Station

The fixed base PCM ground station is composed of two subsystems located in separate buildings. The receiving antenna system is located on the tower of the tallest building in the complex infrastructure to obtain the best LOS view of the entire test complex. Two remotely controlled, manually slewed, single-axis (60° look angle) broadband antennae were selected to support two concurrent telemetry links. Both antennae have integral bandpass filters and low noise preamplifiers capable of driving the 160 meters of low-loss co-axial cable between the antennae and the receivers located in the computer building. With this receiving antenna configuration, no operator need be located in the antenna building to support system operation.

The computer building contains the remainder of the hardware comprising the fixed PCM ground station. As depicted in the simplified block diagram presented as Figure 3, the fixed base PCM ground station is built around a DEC VAX-11/780 computer system with dual 125 ips/6250 bpi 9-track tape transports and three hard disks providing over 250 MB of mass storage plus a dual floppy disk drive. The computer peripherals include a color graphics terminal with a companion color plotter, a Versatec V-80 printer/plotter, two B&W alphanumeric CRT terminals and a system terminal/hardcopy unit.

There are three S-band FM receivers to support both the fixed and mobile PCM ground stations. Two Microdyne 1100AR narrowband receivers for PCM telemetry-only tests (one at each ground station) and a Terracom wideband receiver for tests transmitting both PCM and video over the same carrier. The wideband receiver is relocated between the two ground stations as required to support specific tests.

The PCM and video outputs of the receivers are routed through a patch panel to a local video recorder and video monitor plus a 14-track PCM tape recorder and the PCM decom. The decom contains a word selector unit with eight DACs to provide raw data stripchart recording. Synchronized PCM data is transferred via DMA from the decom to buffers in the host computer where it is decommutated in software with up to 120 PCM words available for realtime processing and display. The system has a much larger PCM word processing capability dependent on PCM word rate, the host CPU size and the complexity of realtime algorithms being processed.

A local time code generator/reader is provided to display test range time and to provide a time/event tape search capability for offline processing of PCM tapes recorded on-board the test vehicle. It can also be used to synchronize the portable TCGs used on-board the test vehicles to ground station time.

Mobile Ground Station

The mobile PCM ground station has all the functionality of the fixed base PCM ground station except that the computer is a VAX-11/730 with a single 45 ips 9-track tape transport and two disks providing only 130 MB of mass storage capacity. It also has only one B&W CRT terminal instead of two and it does not have a color hardcopy unit. It has a dual receiver system but only one broadband high gain dipole antenna with a look angle of approximately 60 degrees. This antenna, however, has both azimuth and elevation controls to account for potentially very wide vertical elevation differences between the mobile ground station and the test vehicle.

An airconditioned truck body (cabin) has been designed for the mobile ground station that can be mounted on a rail car, a ship, a trailer or the chassis of a truck that can operate over open terrain in snow/ice, rain or blowing sand/dust conditions found at any geographical site in the world. Photographs of the interior and exterior of the mobile cabin are presented in Figure 4. The receiving antenna mast and rotors are located on top of the cabin but are not shown in the figure.

Vehicle-Borne Systems

Each of the two vehicle-borne data systems is composed of a doppler ground speed sensor system, a two-axis rate gyro system with accelerometers and appropriate pressure, temperature, torque and position sensors connected to a 186-channel PCM encoder supported by a 30-channel thermocouple isothermal unit and a 64-channel presample conditioner unit. PCM data is recorded on-board on either a 14-track reel-to-reel tape recorder or a two-track cassette recorder as well as being telemetered to the ground station. An IRIG time code generator supplies time to the PCM encoder for embedding in the PCM data stream. Time is also displayed as one measurement on the Computer Control and Display Unit [CCDU] which provides realtime computations and display of up to five additional EU or derived parameters (in addition to time), for use by the driver or test engineer on-board the test vehicle. Up to 10 prestored scenarios can be selected at different times during the test run by the operator (from the CCDU keyboard) providing a total realtime display capability of up to sixty different measurements.

The driver and vehicle instrument panel is monitored by a low light level color TV camera whose output is recorded by an on-board video cassette recorder as well as being transmitted via the telemetry link along with the PCM data.

The PCM encoder, presample conditioners, tape recorder and time code generator can be mounted to special brackets attached to the inside walls of the tank turret (in place of the ammunition containers) for operation of the test vehicle in water of depths up to 5 meters (without armament firing capabilities). Optionally, for gun system or ballistic tests requiring ammunition, these units can be mounted on the outside of the tank in the airconditioned enclosure supplied as part of the system. Figure 5 shows two alternate locations for external mounting of the airconditioned electronics enclosure to the turret or the tank body, depending on where the majority of the sensors are located for a given test.

SENSORS

The requirements to measure the efficiency of the drive tracks under widely varying soil conditions and across all types of terrain presented measurement problems that could not be handled with classical sensors. The solution was to adapt sensors from test applications as diverse as aircraft/missile testing and farming coupled with the development of new sensor subsystems.

Nearly 600 sensors of all types were supplied with the two vehicle-borne systems to measure all of the specified functionalities. The sensors of greatest interest to the system user were those required to measure: 1.) the elevation gradient and contour of the ground over which the test vehicle is to be operated, 2.) the vehicle ground speed and 3.) torque at various points in the drive train. Ground speed, track speed, direction and vehicle attitude are integrated to determine track efficiency. The new sensors were a Terrain Contour Follower [TCF], a ground speed sensor, and specially developed torque sensors.

Terrain Contour Follower

The TCF is a custom sensor assembly developed by Via Systems Co. in Santa Barbara, California which required some parallel software development to integrate the signals from the three classical sensors (gyros, synchro, pulse rate rpm) installed on the TCF. As depicted in Figure 6, the TCF is a two-wheeled sensor assembly towed by the test vehicle, which determines the contour of the earth over which the test vehicle is passing. Terrain contour is not determined by actually measuring the tactile contour of the terrain but by measuring or describing an imaginary line above the terrain equal to the rolling radius of the rear wheel of the TCF assembly that is towed by the test vehicle. The imaginary line is not always parallel to the terrain contour due to the geometric interaction of the wheel and ground. In cases where sharp concave contours are followed by sharp convex contours, or vice versa, the imaginary line deviates from the true contour in horizontal distances and in shape. In cases where the terrain makes a simple sharp convex peak, the imaginary line will show a radiused peak, equal to the rolling radius of the wheel.

The TCF has static errors related to wheel size vs terrain contour shape and dynamic errors related to free flight and free fall of the contour following wheel due to vehicle velocity when the TCF hits a sharp bump. These errors, however, are reduced at lower vehicle velocities to acceptable levels. Figure 7 is a pictorial representation of the dynamic errors that can be encountered by the TCF due to terrain configuration and test vehicle velocity. Other errors are due to the towing dynamics of the test vehicle. All errors except the terrain contour shape to TCF wheel radius errors, however, can be reduced to acceptable levels by reducing the forward velocity of the test vehicle when making the terrain contour calibration run.

Ground Speed/Attitude Sensors

Two TRW doppler velocimeters developed to measure tractor ground speed in seeding applications were selected to measure test vehicle ground speed. Although a single unit is adequate for velocity measurements over a smooth plowed field, look angle changes due to the pitching angle changes of the horizontal axis a tank operating over open terrain required the use of two sensors. One is mounted looking forward and one looking backward on the left or right side of the vehicle at approximately the centerline of the pitch axis of the test vehicle. Each looks towards the ground at approximately a 30° angle from the vertical. The outputs of the two velocimeters are sampled independently by the data system but averaged in the ground station software to null out the ground speed velocity errors introduced by vertical pitching action of the test vehicle as it is driven over rough terrain. The doppler velocimeters are calibrated by a doppler calibrator.

An aircraft Attitude/Heading Reference System [AHRS] was initially considered for the test vehicle to determine vehicle position on the test track by measuring attitude and rates of angular change in all three axes as the vehicle moves along the test track route. Final analysis showed, however, that the three-axis AHRS accuracy was degraded too much by the rapid pitch rate changes in excess of ±40°/sec that can be experienced by a tank moving over large obstacles such as stone walls encountered on a test track. Thus, two rugged Humphrey attitude gyros plus a Condor Pacific two-axis rate gyro were substituted for the AHRS. The Humphrey gyros use synchros for angle measurements and separate two-axis, tuned rotor rate gyro system is used to measure acceleration rates in each axis for vehicle stability measurements. Altitude is integrated with angular attitude and rate to give vehicle position.

Torque Sensors

Torque measurement was another of the user’s key parameters of interest. Torque is to be measured between the engine and transmission, between the transmission and the gear box, at the left and right hand drive shafts, at the fan shaft and between the gearbox and the left and right steering shafts. This requirement could not be satisfied by off-the-shelf in-line torque transducers because there was no room in the drive train assembly at the measurement points of interest to install these types of torque sensors. Via Systems, Co., was selected to develop an integrated torque measuring system based on undercutting the drive train components and installing bonded strain gauges and slip rings on the rotating components and then calibrating the sensors on the drive train unit. Micromeasurement bonded strain gauges were selected by Via Systems who did the machining and bonding of the strain gauges and slip rings onto the rotating elements provided by the system user. Because conventional strain gauges are temperature sensitive and ambient temperatures at the places where torque was to be measured varied from the hot transmission to the hot or cold (ambient) temperature of the track drive sprocket, the torque sensing strain gauge temperature is measured at the sensor installation points by special signal conditioners, mounted on the rotating elements, which provide realtime analog compensation of the strain gauge Tempco errors. These signal conditioners also provide high level analog outputs, so the accuracy of torque measurements is not degraded by the noise generated by the slip rings. A unique mechanical fixture was developed for calibration of the torque measuring drive train elements which were calibrated across temperature (-55°C to +71°C) after installation of the strain gauges and signal conditioners on the rotating drive train components.

General Sensors

Table 1 is a list of the sensor functions and the manufacturer sources for the sensors selected to instrument the test vehicles. Optical digital shaft encoders were selected for measuring torsion bar deflection due to the need to have high accuracy readings of small angular deflections. These measurements, sampled at high speeds, are integrated in the ground station to give rate motion data. Strain gauge pressure transducers were used for fuel and engine and transmission oil pressure with Cox turbine flow sensors for fuel and engine coolant flow rates. Thermocouples were selected for engine, transmission and coolant temperatures, with IR sensors selected for temperature measurements of rotating parts. For -260°C to +600°C surface temperature measurements of elements such as exhaust manifolds, mufflers and other engine components, surface mount platinum resistance thermometers were selected. Flexible platinum detectors were selected for temperature measurements of contoured shapes such as linear control rods, gun barrels and other assemblies where only a bonded sensor could be applied.

Linear variable displacement transformers were selected to sense accelerometer and brake pedal motion. Crystal accelerometers with companion charge amplifiers are used for vibration measurements with an Endevco microphone used to monitor acoustic levels inside the turret. Empro current shunts are used for turret drive motor current measurements and monitoring the engine generator output. Engine and shaft rpm is measured with Airpax gear tooth/magnetic pulse type sensors. BLH bonded strain gauges were selected for the measurement of strain and bending of the vehicle structure and the gun barrel.

In order to accurately calibrate the terrain contour it is necessary to measure vehicle altitude very accurately (better than 0.05%). To achieve this measurement, a Rosemount Precision barometric pressure sensor designed for aircraft test applications was selected.

Another Rosemount sensor is used to measure shock pressures inside the turret when the gun is fired.

Driver actions and position, and cockpit instruments and indicators, are monitored by a 100 lux sensitivity miniature color television camera located above and behind the driver. An illustration showing the locations of the sensors on the first test vehicle is presented as Figure 8.

Sensors requiring +5 Vdc, +10 Vdc and 6V rms 2 kHz excitation voltages are powered from the data acquisition system's integral power supplies. Sensors requiring special voltages such as +12 Vdc, +28 Vdc and ±15 Vdc are powered from ac-to-dc power supplies, in turn powered from the dc-to-ac converters which generate 115 Vac 400 Hz power for data system operation from a special vehicle 26 Vdc battery pack. The instrumentation system is thus independent and isolated from the power system used to drive the tank fire control computer system, radios and other electrical functions in the tank. All sensor cabling is terminated in multiple 16-channel and 32-channel junction boxes that can also function as a patch panel interface to the on-board instrumentation system.

VEHICLE-BORNE DATA SYSTEM

Two vehicle-borne data acquisition and telemetry systems were provided as part of the deliverable hardware. Both on-board vehicle systems were essentially identical except for the PCM tape recorder, the telemetry transmitter and the use of low light level video. The wideband telemetry system in one of the test vehicles uses a Terracom S-band telemetry link composed of a 3-watt telemetry transmitter with an integral VCO for concurrent transmission of the color video signal in the baseband, with the PCM encoder modulating the high frequency VCO at 6 MHz (above the video). The transmitter output power is increased to 15 watts by an Alpha-16 rf power amplifier to overcome the increased noise encountered in a wideband telemetry link. This system also contains a Teledyne Camera Systems Model TCS-500 miniature, solid-state, low light level (100 lux), color Television camera, a TEAC Model V-1000AB-N cassette video tape recorder and a Schlumberger Model 80 14-track PCM tape recorder. The (narrowband) telemetry system used in the second test vehicle does not have the color TV camera or VTR so it uses a Loral Model CTL-705 5-watt L-band transmitter without an rf power amplifier. For PCM recording of narrowband PCM data, a 2-track Genisco Model ECR-22 cassette recorder is substituted for the wideband Schlumberger Sabre 80 14-track reel-to-reel recorder. Figure 9 is a simplified functional block diagram of the wideband vehicle-borne data system for the tank with realtime video monitoring of the driver and his instruments.

Signal Conditioning/PCM Encoding

Signal conditioning and PCM encoding are handled by a single programmable PCM encoder system supported by a thirty channel thermocouple isothermal unit [TCIU], a sixty-four channel presample conditioner unit [PCU], special strain gauge signal conditioners, charge amplifiers and power supplies. The 64-channel PCU provides either 5V or 10 Vdc sensor excitation and accepts a large family of field programmable signal conditioners, such as pre-sample filters, phase sensitive demodulators, pulse rate conditioners and bridge completion modules. The PCM encoder supports up to eleven I/O cards with from 3 to 36 channels per card, giving a single chassis a 33 to 396 channel capacity. A special I/O card permits connection of up to four additional chassis to the system, expanding the channel processing capacity to far beyond any anticipated data acquisition system needs. The following I/O complement was provided in the baseline systems.

Qty	I/O Card Description
4	32-channel differential analog multiplexers
2	3-channel pulse totalizers
1	36-channel discrete multiplexer
1	4-channel 16-bit synchro-to-digital converter
2	4-channel tachometer generator counters
1	4-channel frequency-to-digital converter

This I/O complement provides 186 channels of data. Thirty-two of the discrete channels were used to imbed IRIG time in the PCM stream, leaving four channels for dc voltages or relay contact monitoring. The encoder provides nine different analog gains from 1 to 1024 under software control on a sample by sample basis. A full scale offset is programmable on a sample by sample basis for scale expansion on channels having unipolar signals. Any size data cycle map (up to 1024 wds/minor frame and 255 minor frames per major frame) can be generated by the ground station and transferred to the test vehicle via a non-volatile Program Load Module [PLM] and the Computer Control/Display Unit [CCDU]. The CCDU also provides realtime computation and display of EU or derived parameters on-board the test vehicle. The PCM encoder can operate at any of up to 15 different PCM word rates selectable via the CCDU.

Telemetry

An isolation line terminator unit acts as an on-board PCM data junction box as well as providing power, signal and case ground isolation between the PCM encoder, the telemetry transmitter and the PCM tape recorder. It also contains the premodulation filter for the telemetry link. The PCM data going to the tape recorder is routed through the

CCDU so it can be switched from the PCM encoder output to a local PCM formatter card in the CCDU by the test operator. This gives the user the capability of recording a PCM header on the test tape which permits automatic setup of the PCM ground station when a tape is being processed offline. The CCDU data source for system testing or realtime data processing and display can be either of the two separately encoded serial streams coming from the PCM encoder. The CCDU downloads and tests the PCM encoder sampling format memory and permits on-board test or change to the address contents of any time slot in the PCM map.

Data from the test vehicle is telemetered via either a 5 watt narrowband (without video) 1530 MHz transmitter or by a wideband (PCM plus video) 1808 MHz transmitter, driving an omnidirectional antenna located on a mast secured to either the turret or the rear of the tank. The antenna ground plane is the round surface of a one-half aluminum ball with the dipole mounted to the center of the convex surface, and the transmitter and power amplifier located inside the 1/2 ball enclosure below the ground plane.

The wideband telemetry transmitter has a dc to 5 MHz frequency response on one modulation input and a dc to 750 kHz response on the second modulation input. Either a standard NTSC color video or a complete IRIG FM/FM multiplex can be applied to the wideband modulator with voice or PCM up to 1.5M bps (DM-M) applied to the narrowband modulator.

The wideband transmitter modulates a broadband RF power amplifier driving an omnidirectional end-fed stub antenna providing a gain of +3dBi. The transmitter and power amplifier are located inside the 1/2 ball enclosure to provide minimum RF power losses in the cable between the P.A. and the antenna. Power and signal cables are routed inside the mast pole supporting the antenna system.

Data Recorders

Three types of tape recorders were provided for on-board recording of PCM and video data. For wideband PCM and/or long test runs a Schlumberger Sabre 80 reel-to-reel, 14-track recorder was selected because it is the only recorder of this type that would fit through the entry hatch of the tank turret. This recorder uses up to 14 inch reels of 1-inch tape (7200 feet of tape) supporting PCM recordings of from 12 minutes at 120 ips to 25.6 hours at 15/16 ips. The 500 kHz frequency response of the recorder supports PCM bit rates up to 1.0M bps. Sewing machine mode operation (2 tracks - PCM/voice - by 7 passes) extends the recorded test time capability to 1 hr 24 min at the highest record speed (120 ips). The recorder is mounted to a shock mount to reduce vibration inputs from tank operation across open terrain, and it has an integral heater to permit operation of the test vehicle at operating temperature ranges down to -20°C. Hot temperature operation inside the tank is restricted to +40° C by the limitations of the Ampex 799 recording tape. The recorder can also be located in the airconditioned external container for operation across the full specified operational temperature range of -40°C to +50°C. The external airconditioned container is depicted in Figure 10.

For lower PCM bit rates and/or shorter duration tests requiring on-board PCM recording, a Genisco Model ECR-22 eight-track cassette recorder was selected. This recorder permits recording of serial PCM on one track and voice or IRIG time on the second track with four passes through a 600 ft endless loop cassette. Frequency response is 5 kHz (10 kbps) at 1 7/8 ips up to 160 kHz (320 kbps) at 60 ips. At 7.5 ips, this provides 1 hr 4 min (with up to 40 kbps PCM data). Auto-track switching is performed at the end of each pass through the loop but there is no data overlap so synch is temporarily lost during track switching on playback. The flutter and wow of this recorder is also quite poor, requiring use of the 3% bandwidth window on the bit synchronizer when reading a PCM track. Because it is a loop recorder, a special control panel had to be designed for control of the recorder when it is transferred to or used at the PCM ground station to read cassette data tapes. It also requires shock mounting when installed in the harsh environment of a tank. It does not have heaters so its operating temperature range must be restricted to 0°C to +50°C when it is used outside the external airconditioned equipment enclosure.

For video recording, a compact TEAC Model 1000AB-N airborne cassette recorder was selected. This unit provides up to 60 min of continuous NTSC color video recording across an operating temperature range of +50°C to +40° C. Commercial JVC cassette recorders are used at the ground station to playback the video recordings made on-board. IRIG B time can be recorded on the VCR voice track to permit correlation of video data with PCM data. An alternate time synch technique is to display time on the CCDU when it is located within the field of view of the color camera on-board the test vehicle.

Color TV Camera

A Teledyne Camera Systems Model TCS-500 miniature solid-state camera was selected for monitoring operator performance under stress conditions. The TCS-500 camera provides a resolution of 485 (V) by 384 (H) pixels under ambient light levels as low as 100 lux. Some operational light levels are in the vicinity of 10 lux or less inside a closed turret. Therefore, external lighting is required inside the turret to support nighttime test operations. The camera uses a wide range of standard C-mount lenses. The camera body is only 4.88in x 3.28in x 1.75in (excluding the lens and connectors) so it can be mounted to the turret wall above and behind the driver to monitor both his performance and his instrument panel. The camera will also be used externally, looking through a window of a special tank simulating a river bottom for underwater testing of the vehicle.

On-Board Computer/Display

Realtime processing and EU data display on-board the test vehicle are provided by an airborne Computer Control/Display Unit [CCDU], which is only 5.5 in. wide by 9.0 in. high by 6.5 in. deep and can be mounted inside the tank turret for use by the driver or on-board test engineer. It has a 32-key keyboard and a 16 character/line six line alphanumeric display panel for display of time and up to five EU or derived parameters extracted in realtime from the transmitted telemetry stream. The CPU is a 16-bit TMS 9900 microprocessor operating at 12.5 MHz and supported by 64kB of memory divided in a variable mix of EEPROM, EPROM and RAM. A photograph of the CCDU is presented in Figure 11.

The CCDU serves as a portable test set to download, store, test and modify data cycle maps in the on-board PCM encoder. It has a local PCM stream generator which can be switched to the tape recorder (temporarily) in place of the PCM encoder so PCM tape headers can be recorded. Its Program Load Module [PLM] serves as the non-volatile program transfer medium between the ground station, which generates the vehicle test PCM maps, and the on-board PCM encoder. An applications PLM stores the appropriate sensor calibration files and the EU algorithms to support the realtime processing. It is also capable of downloading computed values displayed to the driver/test engineer in realtime to the PCM encoder CPU which inserts them into the PCM stream for telemetry and recording. In this manner, the engineers at the ground station(s) see the same EU data presented on-board the test vehicle.

Up to ten different display scenarios can be prestored in the applications PLM for access by the driver/test engineer during the test run. This expands the total number of EU/derived parameters that can be computed and displayed in realtime to sixty during a single test.

FIXED BASE PCM GROUND STATION

The fixed base ground station is composed of an antenna/receiver system, PCM and video tape recorders, a PCM decom system and a host computer system using DEC’s VAX-11/780 super-minicomputer configured with two Unibuses and one Massbus. Dual TU-77 125 ips, 6250 bpi tape transports are connected to the Massbus with dual RM-80 124 MB disks serving as data disks on one Unibus. The second Unibus has a 10.4 MB removable media RL-02 system disk, two DZ-11 8-channel, asynchronous, serial interfaces plus DMA channels for the PCM decom, the IRIG time code generator and the Versatec printer/plotter. The RL-02 removable media disk on the VAX and the 9-track tapes are the database and program transfer media between the fixed and mobile ground station computers.

The antenna/receiver system is divided into antenna/ preamp and receiver/controller subsystems because the building in which the PCM ground station is located does not present an LOS view of either of the two test tracks. In order to cover the wide range of test vehicle and/or mobile repeater locations relative to the fixed ground station and support two test vehicles concurrently, it was necessary to use two receiving broadband antennae, each with remote azimuth control. Due to the 160 meter cable runs between the antennae and the receivers, it was necessary to install low noise broadband preamplifiers at the antennae to drive the low loss co-axial cable at the receiver frequency (rather than using more costly downconverters). The antenna location (on the tower of an adjacent building) was not airconditioned and the user did not want to station an operator at the antenna site during system operation, so the preamplifiers had to operate over a -20°C to +50°C temperature range.

By selecting 60° look angle, high gain dipole antennae (+9 dBi gain), the antennae could be manually controlled via conventional TV rotator hardware with 15° position resolution. The specification required a narrowband (without concurrent video) minimum LOS range of 14 km and a 9 km LOS range with the wideband PCM/video link. The minimum link ranges were essentially doubled with the addition of the mobile repeater system under optimum conditions. A functional block diagram of the entire Vehicle Test Microwave Telemetry subsystem, showing all of the link options, is depicted in Figure 12.

Demodulated data (PCM and video) is routed from the receiver system through a patch panel to the PCM decom and a video recorder and monitor. An 8-channel Gould Model 2107 pen recorder provides raw data stripchart records. A Honeywell Model 101 14-track tape recorder is used to record reconstructed PCM data coming through the telemetry link and for the replay of on-board 14-track PCM tapes.

A DSI Model 7700 bit synchronizer and a Model 7101 decom provide full PCM decommutation capability while a DSI Model 7112 word selector with 12-bit DACs provides the raw analog outputs for stripchart recording. A second bit synchronizer permits receiving and local recording of one PCM stream while data is being processed from the second PCM stream. Later, a second decom will be added to support complete realtime testing of two test vehicles concurrently.

Scrolling EU graphics are presented on a DEC VS-11 color graphics terminal and up to four channels of EU curves can be continuously recorded on the Versatec V-80 printer/plotter, providing EU stripchart records within the frequency response limits of the V-80 plot speed (1 ips ≅ 5 Hz). A Seiko Model CH-5201 color hardcopy device is provided for color hardcopy of snapshots of the scrolling EU curves presented on the VS-11 graphics terminal. Two DEC VT240 terminals are used to display vertical scrolling or fixed (horizontal) tabular EU data or EU bar charts.

Two limited distance modems and a serial PCM line are routed from the computer building to the sensor calibration laboratory where an on-board PCM encoder and a CCDU are located with another VT240 CRT terminal. This hardware plus its support software permit the user to make semi-automatic calibration of sensors and local display of the sensor calibration data at the calibration laboratory for review before it is permanently entered into the database.

Two JVC Model 6000 cassette VCRs and a Sony PVM-1900 video monitor are used for recording of telemetered video and playback of on-board video recordings. A detailed functional block diagram of the fixed base PCM ground station is depicted in Figure 13.

MOBILE PCM GROUND STATION

The mobile PCM ground station is built around DEC's VAX-11/730 computer with a single TS-11 45 ips, 800/ 1600 bpi tape transport. A single 121MB RL80 Winchester disk functions as the data disk with the 10.4MB removable RL02 disk used as the system disk and the primary transfer medium for moving programs between the fixed ground station computer and the 11/730.

The Gould stripchart recorder, Honeywell 101 PCM recorder, Datum time code generator/reader and their CPU interfaces are the same in the mobile ground station as in the fixed ground station. A VS11 color graphics terminal, a V-80 printer/plotter and one VT240 alphanumeric CRT terminal round out the MMIF for the mobile station.

An EMP 60° look angle, high gain dipole antenna with both azimuth and elevation rotors is used to manually track the test vehicle. The permanent S-band receiver is a Microdyne Model AR1100 unit (the same as the one in the fixed ground station). Space and cables are provided for relocation of the Terracom wideband receiver and/or the JVC VCR and Sony monitor from the fixed ground station to the mobile ground station for remote site tests, including video. This hardware complement, except for the extra alphanumeric CRT terminals and the color hardcopy unit, provides the mobile ground station with all of the functionality of the fixed ground station. However, because there is only one tracking antenna, the mobile station, as initially delivered, can only support one test vehicle at a time.

The mobile ground station hardware is packaged in an air-conditioned cabin which can be transported to remote test sites by several different methods of transportation. Triple heating/airconditioning units control the air temperature in the cabin to + 25°C ±10°C across an ambient temperature range of -40°C to +50°C. Any two of the three airconditioning units can carry the total conditioning load. The mobile cabin takes in filtered outdoor air via a blower and filter system that provides a positive internal pressure so the mobile station can be located in the blowing dust environment found in desert locations. An airlock with dual entry doors located on the rear end of the cabin is used for normal vehicle entry with an emergency door located on the side of the cabin. Windows are located in the doors and on both sides of the cabin for test vehicle viewing.

SOFTWARE

There are many Teledyne developed system software packages provided to support realtime testing. These, of course, are augmented by many analytical packages procured from DEC. The Teledyne developed system software represents 180k lines of code, including command procedures, Macro and Fortran statements plus their comments, that took over two years to develop. It provides the following functions:

Setup and control of the PCM decom and Honeywell recorders

Decommutation in software of up to 256 parameters for realtime processing

Digital filtering and/or simple compression of incoming data

Bipolar limit exceedance testing and alarm generation, display and recording

PCM word concatenation and unpacking of discrete words

First thru fifth order or table lookup EU conversion

Running any user generated derived parameter algorithm

Auto-calibration of raw data stripcharts

EU stripchart hardcopy plus hardcopy of graphic and/or tabular data displays

One to six stacked or overlaid scrolling EU or crossplot curves with event markers on color graphics terminals

Tabular and bar charts displays on alphanumeric CRT terminals

Disk to tape, tape to disk and tape/disk to graphics utilities

PCM to 9-track tape conversions

Time/Event/Exceedance searches of PCM tapes

Three types of plots of sensor calibration data

Generation of PCM tape headers for automatic setup of the PCM ground station

Generation of object code of data cycle maps for transfer to the vehicle-borne PCM encoder

Sensor listings

Long and short listings of PCM map time slot characteristics

Printouts of the PCM map

Generation of EU programs to run in the on-board CCDU in realtime

Generation and support of a realtime relational database to keep data and sensor calibration files by vehicle number, test number, revision and date

All of this functionality is available at either the fixed base or the mobile PCM ground stations. Removable disks or 9-track tapes are the media for program transfers between the fixed and mobile ground stations. Non-volatile (EEPROM) PLMs are the program transfer media between either the fixed or mobile PCM ground station and either of the vehicle-borne systems. PCM tapes and realtime telemetry are the data transfer media between the test vehicles and either of the PCM ground stations.

Realtime Data Processing

For realtime processing the operator may select up to 120 PCM data words from the complete data cycle for stripchart (raw data) recording and/or EU conversion and display. This is not the limit of the software's capability but it represented the specified (and delivered) requirements. Up to ten different test scenarios may be pre-stored for operator selection during the vehicle test run. Each scenario permits different processes to be applied to the same or different parameters, and different parameters to be routed to different MMIF displays or hardcopy devices.

The PCM decommutator equipment supports three modes of realtime data processing of the received data: single scan, multiple scan and continuous processing. Data flow from the decom to the CPU memory utilizes ping-pong buffers where, at any given time, one of the buffers is allocated to the reception of current input data while the content of the other one completed in the previous cycle is available for other user programs, such as data recording or realtime processing. At the completion of the current buffer update, the role of the buffers is interchanged.

Up to sixteen analog channels of the PCM stream can be applied to the DACs of the decom's PCM word selector unit for raw data stripchart recording. Any of the five selectable slo-codes from the time code generator can be applied to the stripchart recorder to provide a hardcopy time base. The DACs can be calibrated under software control. EU conversions can be made by applying a first through fifth order polynomial to the raw data. EU conversions can use either prestored sensor calibrations or a 40-point lookup table. Concatenation is performed for single measurements composed of two or more PCM words. User installed derived parameters can be calculated using raw or EU results as inputs to the equations.

Limit Exceedances/Alarms

The operator may select analog or discrete parameters from the realtime group of 120 PCM words which can be processed for limit exceedances and alarms. This process compares the raw input to operator defined high and low values established as part of the test scenario definition procedure. When an input value is found to be outside the range defined by the upper and lower limits, the content of an exceedance counter is incremented and tested. If the counter exceeds its operator set limit, an alarm condition message is dispatched to the graphics terminal. The utilization of the exceedance counter acts as a filter to preclude wild point false alarms and provides a programmer-definable noise tolerance. An operator selectable filter algorithm can be applied to analog limit exceedance tests to prevent false alarms from wild points and/or ensure that a true alarm condition exists prior to alerting the operator. The upper and lower limits for analog limit exceedance tests are operator selectable in engineering units even though the CPU makes the limit tests on raw data.

Limit exceedance can be alarmed to the operator in EU along with IRIG time of exceedance (displayed in the overhead portion of the CRT) and logged on the printer along with IRIG time when the exceedance occurs. The alarm will flash in red on the graphics terminal until acknowledged by a keystroke of the operator at which time the alarm will turn white and be logged on the line printer. When an alarmed channel's data value recedes below the alarm point, the alarm will disappear from the display and automatically log on the printer the IRIG time the channel went out of alarm.

Scrolling EU Graphics

The realtime graphics software will permit the vehicle test engineer to select from one to six parameters versus time or one to six cross-plots of one parameter versus another for display in EU on the color graphics CRT. The curves can be presented in either a stacked format or an overlay format with different (operator selectable) colors for each curve and its vertical scale presentation. The grid size for stacked presentations is proportional to the number of stacked curves simultaneously presented on the screen, i.e., for 6 curves, one-sixth the available vertical screen space per curve; 5 curves, one-fifth the screen space; 4 curves, one-fourth the screen space, etc., down to a single curve using all the available vertical screen space. A stacked, four grid scrolling EU display is depicted in Figure 14, showing an event marker.

For overlaid curves (multiple curves on a single grid), the vertical scale(s) will use all the available screen space reserved for plotting with the abscissa for each curve located on the left side of the screen and presented in the same color as the data curve.

The vertical scale factors for any curve can be operator selectable to provide vertical scale expansion of the curve, that is, if full scale for the parameter engine rpm is 0 to 3000 rpm for a diesel engine and data is to be taken for some time at a slow test vehicle velocity (1200 rpm ≅20 mph), the rpm scale factor could be selected to show 1000 to 1500 rpm. If the data goes off scale due to an increase in speed (to 1700 rpm), the scale factor would automatically be doubled (750 to 1750 rpm) and this procedure would be continued until the full scale limits of that channel (0 o 3000 rpm) were reached.

An overhead space is reserved at the bottom of the graphics terminal screen for display of test unique data such as test vehicle number, test number, driver, date of test, IRIG time, alarms and other key documentary data to be operator defined. The non-operator defined static (constant) documentary data will be obtained from the configuration header of the PCM tape. An example of a six-curve scrolling EU data presentation is shown in Figure 15. The EU curves plotted on the color graphics terminal are dynamic scrolling curves with the R.H. edge of the screen representing current time and the curve moving from right to left. The operator can select different time bases for the curve(s).

The graphic plotting software uses Newton’s interpolation (forward difference) formula to eliminate wild points. Smoothing must be operator specified. Special vertical time base event marker lines can be enabled by the operator to be drawn the full height of the screen across all curves based on discrete events or analog limits exceeded and detected by the limit exceedance program. These same vertical lines can be placed on the screen by operator actuated keystrokes which place the line at the R.H. (current time) edge of the screen or at any place on the time base by moving the cursor to the point of interest with a joystick. Different limit exceedance channels can be used to cause a vertical event marker line to be drawn on the screen. This line can also be drawn by coincidence of a predefined IRIG time with current IRIG time(s) during the run over the test track. When a time mark is automatically displayed (or manually selected by the operator), it causes a dump to the printer in tabular EU form of all PCM words being processed in realtime. In addition, the EU values of the curves are displayed numerically on the CRT adjacent to the intersection of the vertical time mark line and the data curve.

When a vertical time mark line is drawn on the CRT, the IRIG time of the line in hr:min:sec is displayed at the bottom of the line and the channel name or event is written at the top of the line. For example: exceeding a predefined driveshaft torque level might trigger the time line. At the bottom of the presentation would be the time the torque level was exceeded while at the top it would display the torque parameter number and the torque value as shown in Figure 15.

Horizontal scale factors for the graphics display may be operator selectable with time bases of 1 sec, 10 sec, 30 sec, 1 min and 3 min on the horizontal time base. When cross-plots are being made, the time base of each parameter will be the same. All curves displayed simultaneously on the same picture have the same time base.

Bar Graph/Tabular EU Displays

Three types of realtime EU data displays are provided in addition to the scrolling color graphics displays. One display format provides a dynamic EU bar graph presentation with either bipolar or unipolar data presented as bars with 0 to 100% full scale. The moving bars are updated at the computed EU output rate and identified by both a parameter name and number.

Two types of tabular EU displays are provided. One is static with only the numeric values updated twice/second while the second one is a vertically scrolling display with columns of tabular data, giving the most recent 15 seconds of values of each parameter (based on a scroll/update rate of once/second).

These EU displays are presented on B&W CRT terminals with up to eight terminals able to display different parameters in any of the three different formats. Up to ten different scenarios can be prestored to expand the total amount of different measurements that can be displayed during a single vehicle test.

Graphics/Tabular Hardcopy

It is possible for the operator to freeze the graphics or tabular displays at any time via a keystroke with a subsequent request for a hardcopy. The operator can locate a vertical marker on the scrolling graphics picture with the joystick and, when that line reaches the LH edge of the screen, it automatically freezes the picture. As soon as the picture is frozen, the operator with a second keystroke can request a hardcopy of the presentation to be plotted on the Versatec printer/plotter.

If the data source for the graphics presentation is the playback of a PCM flight tape, the picture freeze command to transfer the data from graphics terminal to the Versatec printer/plotter automatically stops the PCM recorder. This does not apply to realtime data coming through the telemetry link where the PCM recorder must continue to record all telemetry data as long as there is an acceptable signal present at the output of the bit synchronizer. Once the hardeopy is complete, an automatic command restarts the PCM recorder and plotting continues in the same manner as it was being presented prior to the freeze and/or hardcopy command. If a hardcopy is not made of the frozen picture, the operator can resume the plot sequence (i.e., start the recorder) via a separate keystroke command.

Discontinuities in data are experienced from the time the picture is frozen, until the time PCM sync is reacquired after the recorder startup, or when the operator resumes plotting via a keystroke, unless the operator elects to manually command the recorder to rewind for a few seconds prior to manually restarting the plot sequence.

Finally, when EU curves are being plotted, the EU values of the curves for each plot point may be simultaneously recorded on 9-track tape.

Hardcopy of tabular data presentations from the VT200/ 240 CRT terminals can be made on the Versatec printer/plotter or the LA120 systems terminal under operator command. When two Versatec printer/ plotters are connected to the computer, simultaneous and/or independent copies of either graphic data or tabular data may be made simultaneously by separate operators with the hardcopy command issued from its individual CRT keyboard. In addition to copies of the color graphics terminal data presentations, the V-80 can produce independent EU stripchart records at data rates up to the 1 inch/second plot rate of the V-80 (approximately 5 Hz data response). An example of the hardcopy printout of EU stripchart plots on the V-80 plotter is presented in Figure 16. Fanfold paper is used with CPU buffering of the plotted results so that the output format is in report-ready page form.

CONCLUSION

New sensors have been developed to permit testing of vehicle parameters which, heretofore, has not been possible in realtime. Aircraft flight test sensors have been integrated with commercial farming sensors to permit accurate measurements of vehicle attitude, altitude, direction and angular velocities. Realtime telemetry and video have been used to correlate operator performance under various vehicle environments. A telemetry repeater system has been used to permit continuous realtime telemetry across a hilly test track where much of the vehicle operation is not within LOS range of the ground station. The mobile ground station has been packaged in a ruggedized mobile cabin which can be safely transported over open field rough terrain at geographically remote test sites.

Linking the data processing software to the on-board computer/display and data acquisition system PCM sampling maps has ensured that the realtime data processing of any given test vehicle should be error-free as far as parameter identification. By configuring the mobile PCM ground station with the same computer functionality and man-machine interface hardware as are used at the fixed ground station, the same software is used for realtime processing at any vehicle test location so that the same test engineer can operate either system using the same procedures. The use of fixed format PCM tape headers speeds up the configuring of the ground station to process PCM tapes in the offline recreation of a vehicle test. The software for semi-automatic calibration of sensors in the test vehicle and the use of a vehicle-borne multiplexer is the sensor calibration laboratory, with this same software for laboratory calibration of sensors, speeds up the creation of sensor calibration files. Finally, the realtime availability of EU data to the test engineer (or vehicle operator) in the vehicle and/or at the ground station will shorten the field proving period of new vehicles.

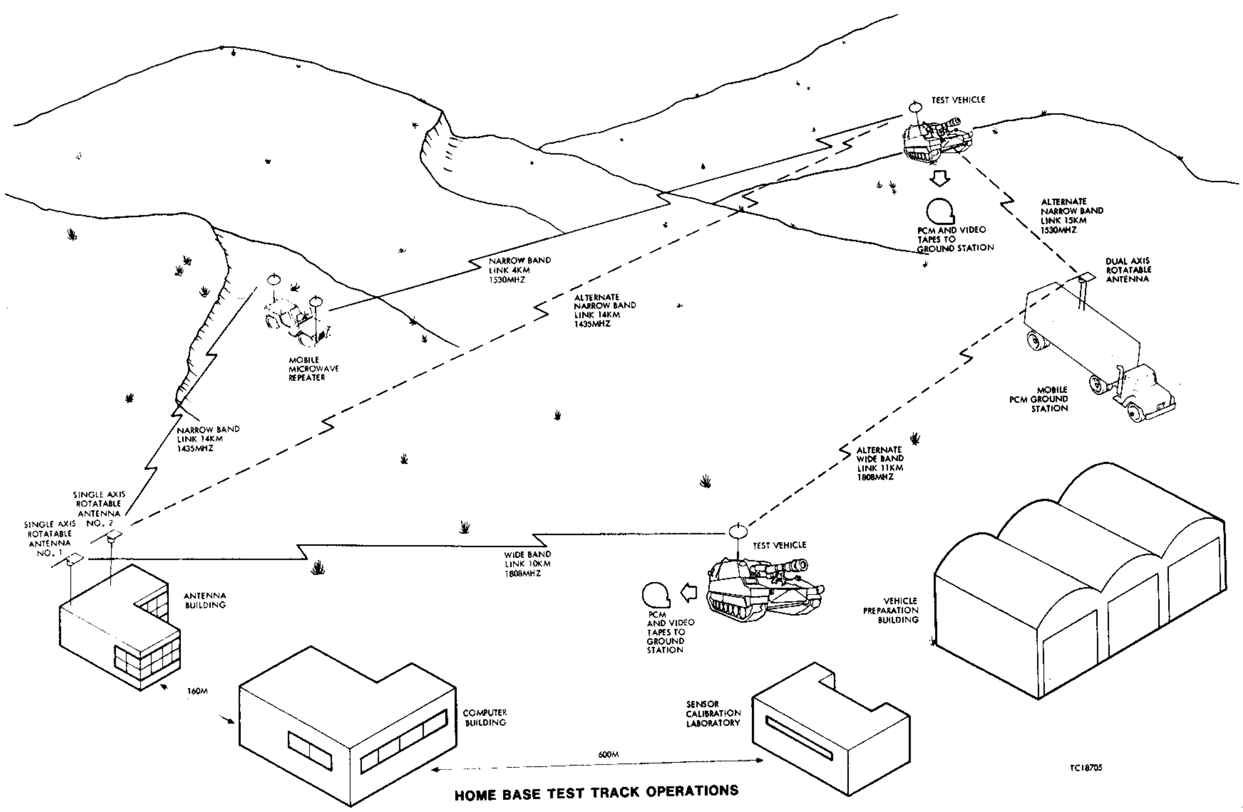

Figure 1. Fixed Base Test Operations

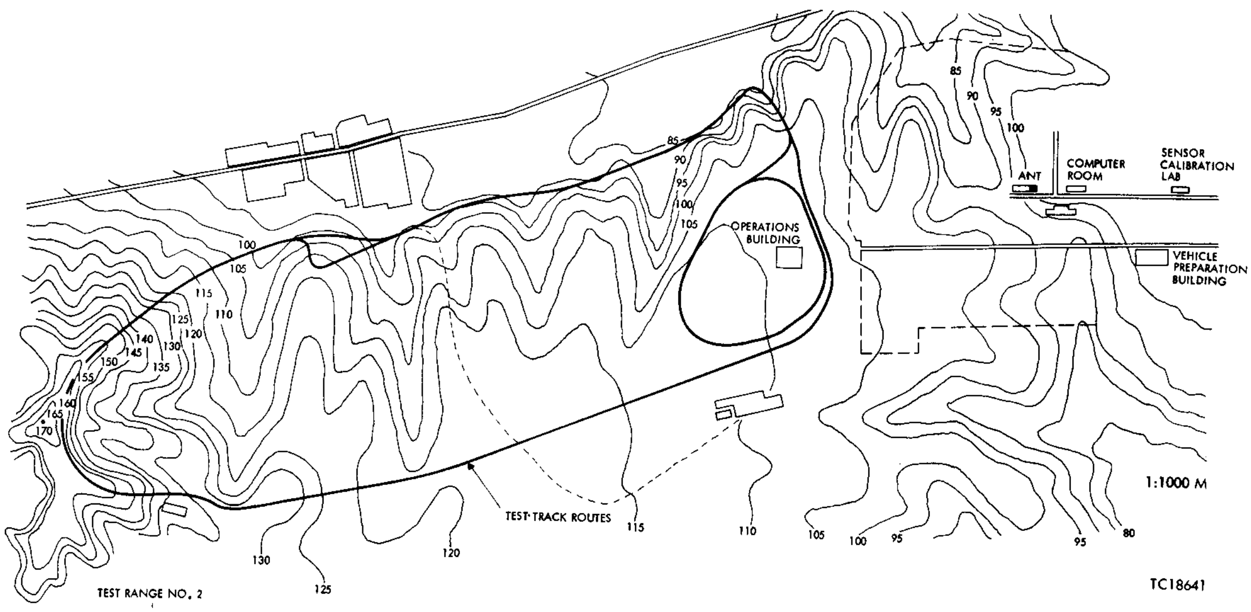

Figure 2. Topographical Map of Fixed Base Test Track

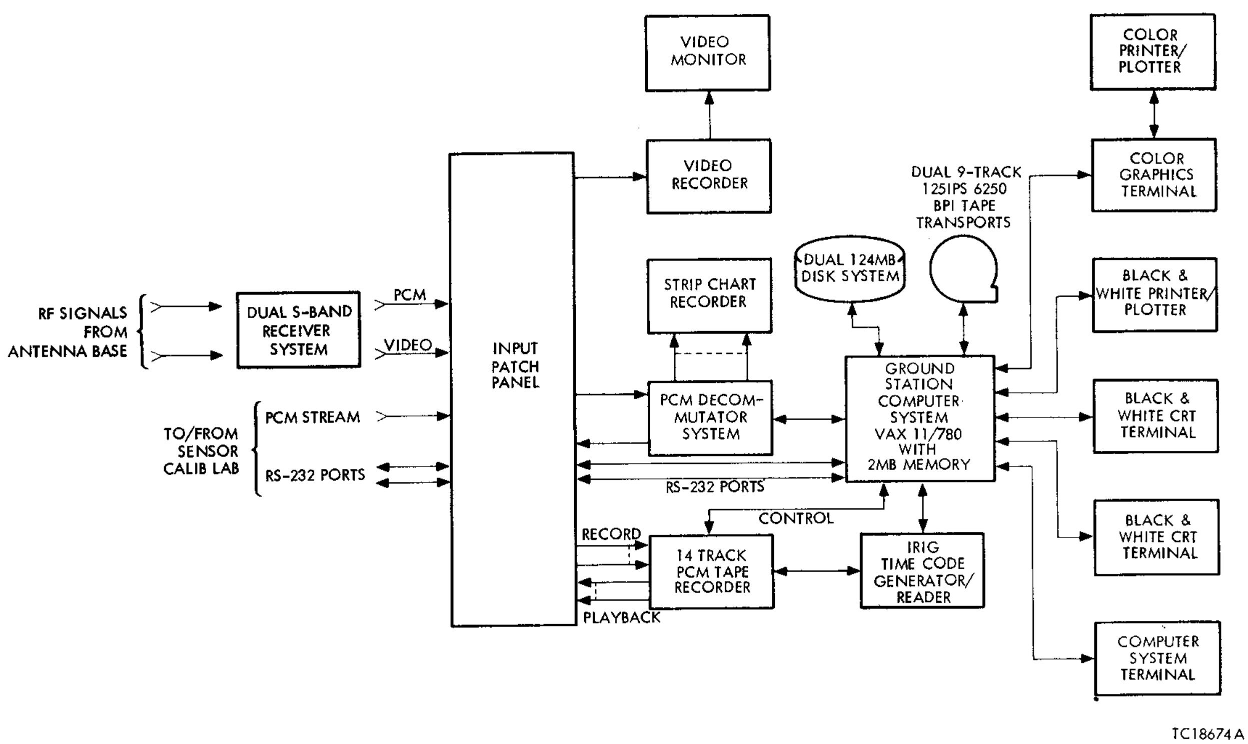

Figure 3. Fixed Base PCM Ground Station Functional Block Diagram

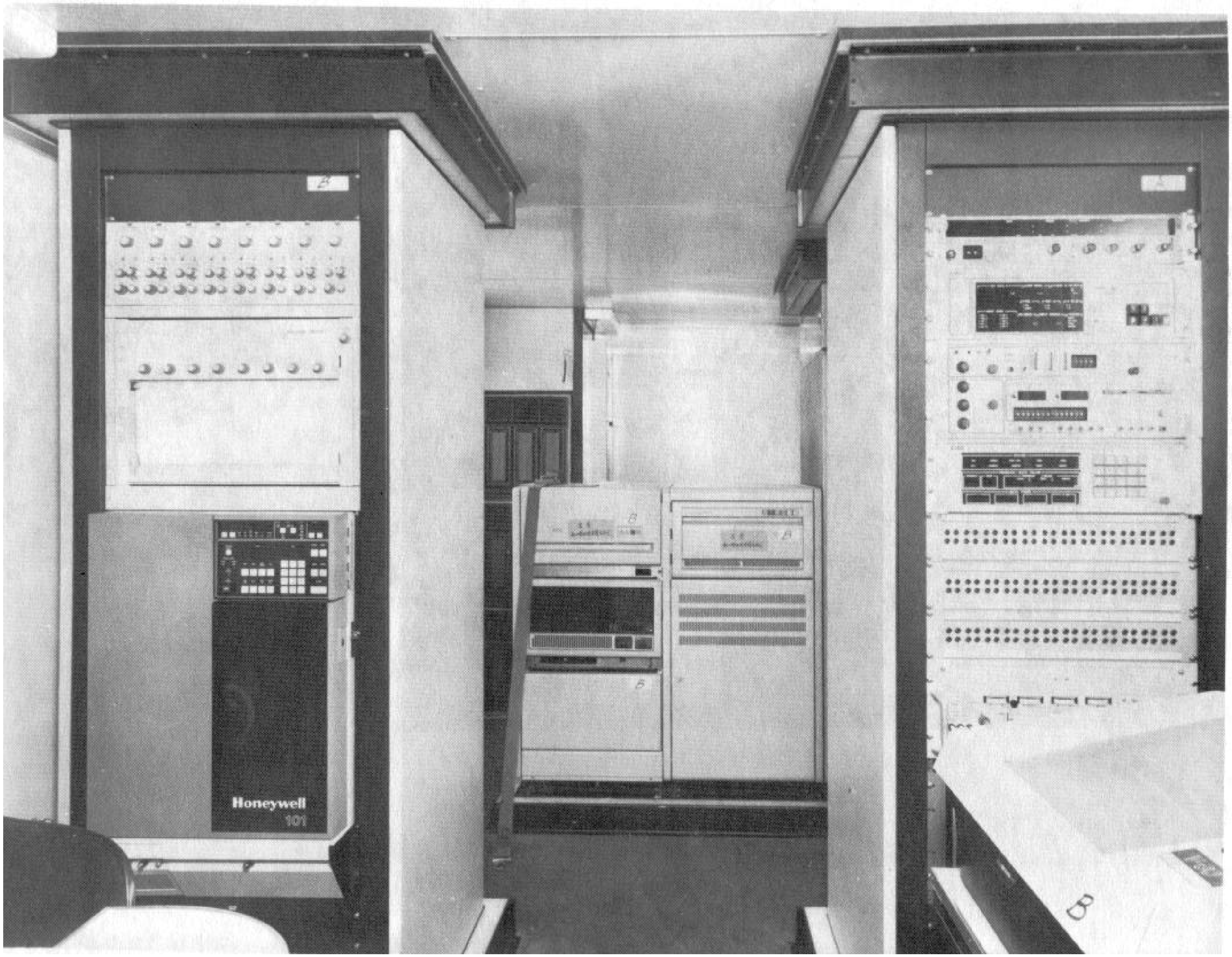

Figure 4. Mobile PCM Ground Station Photographs
Part 1

Figure 4. Mobile PCM Ground Station Photographs
Part 2

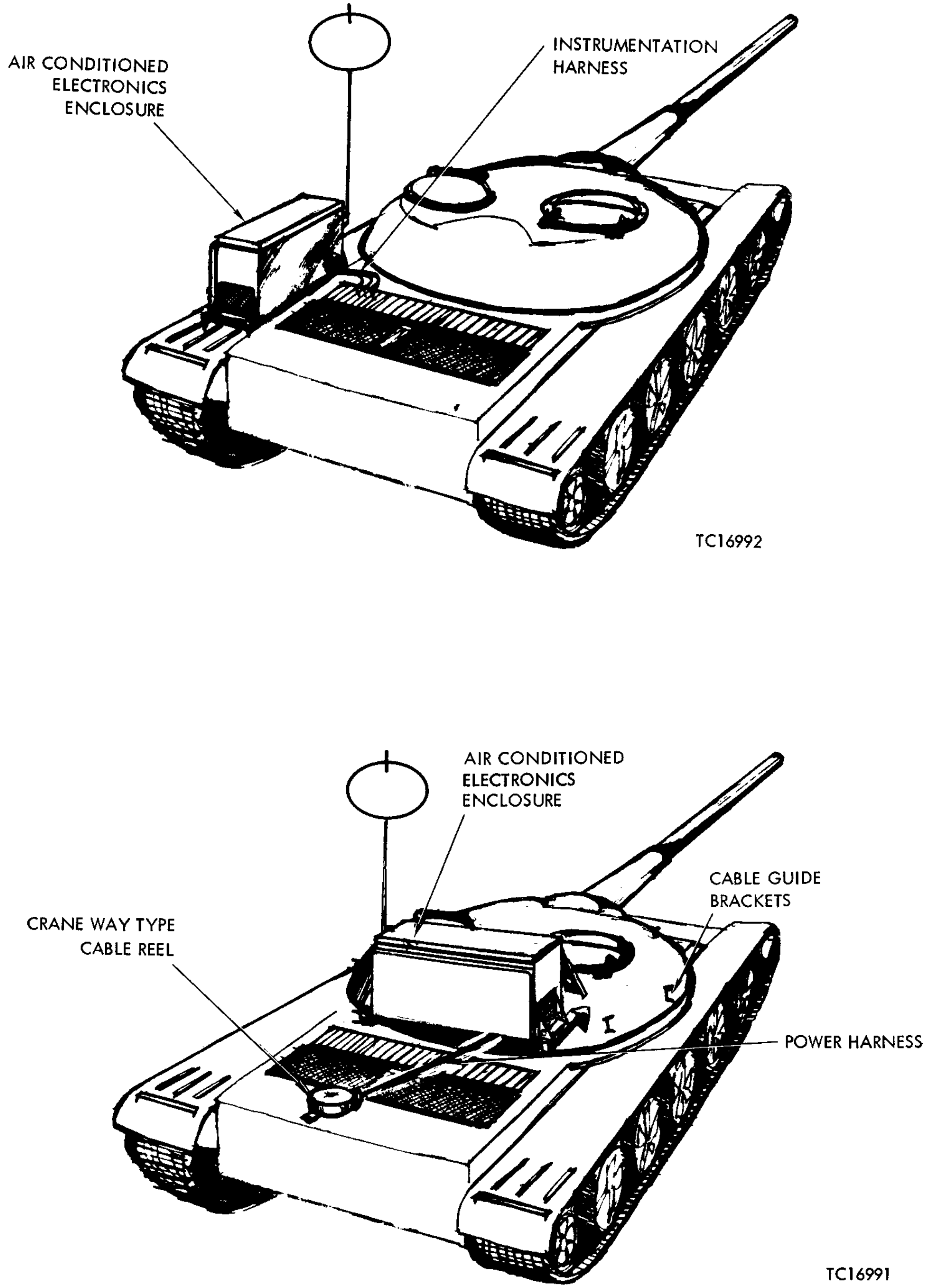

Figure 5. Externally Mounted Electronics Configuration

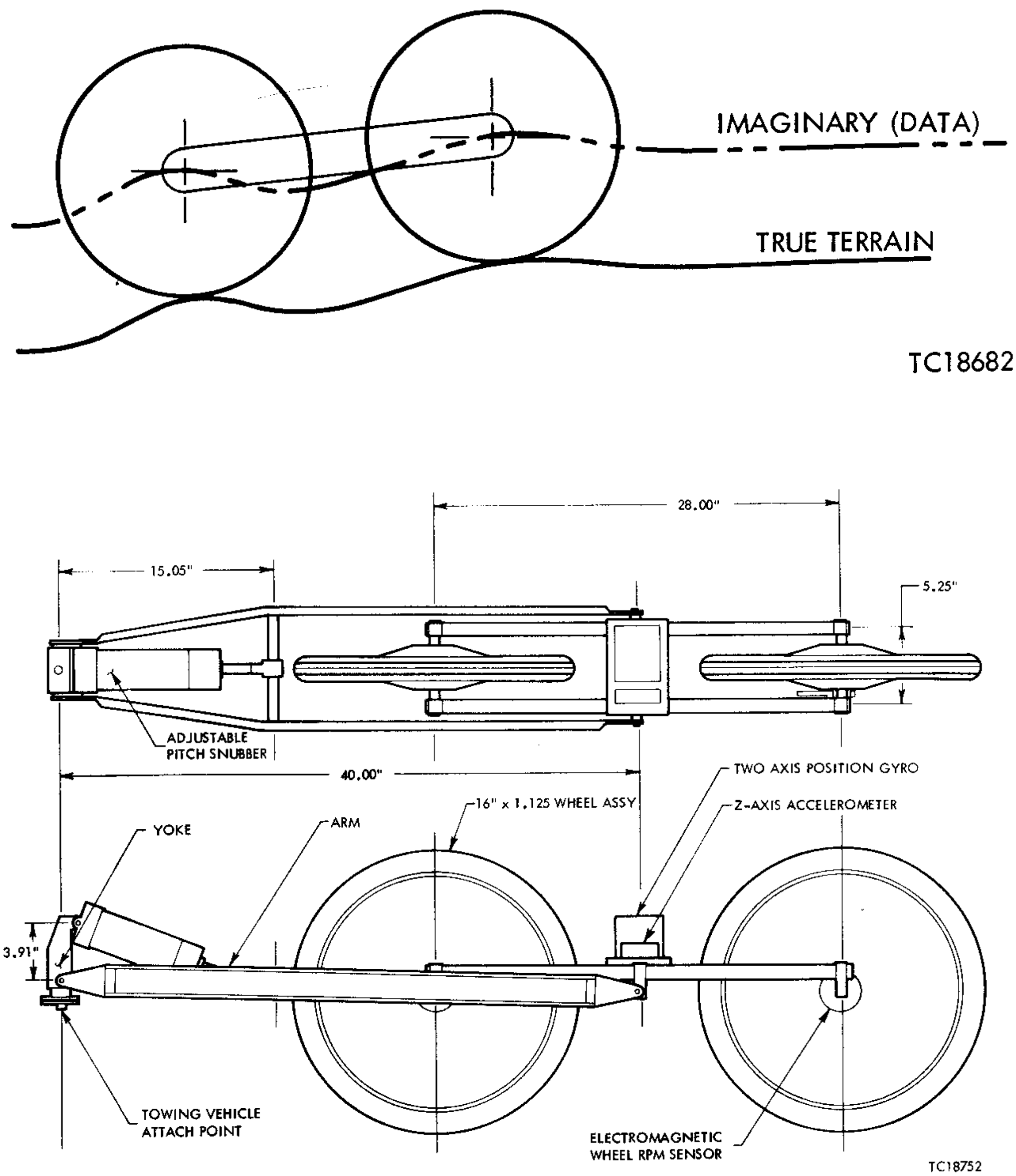

Figure 6. Terrain Contour Follower

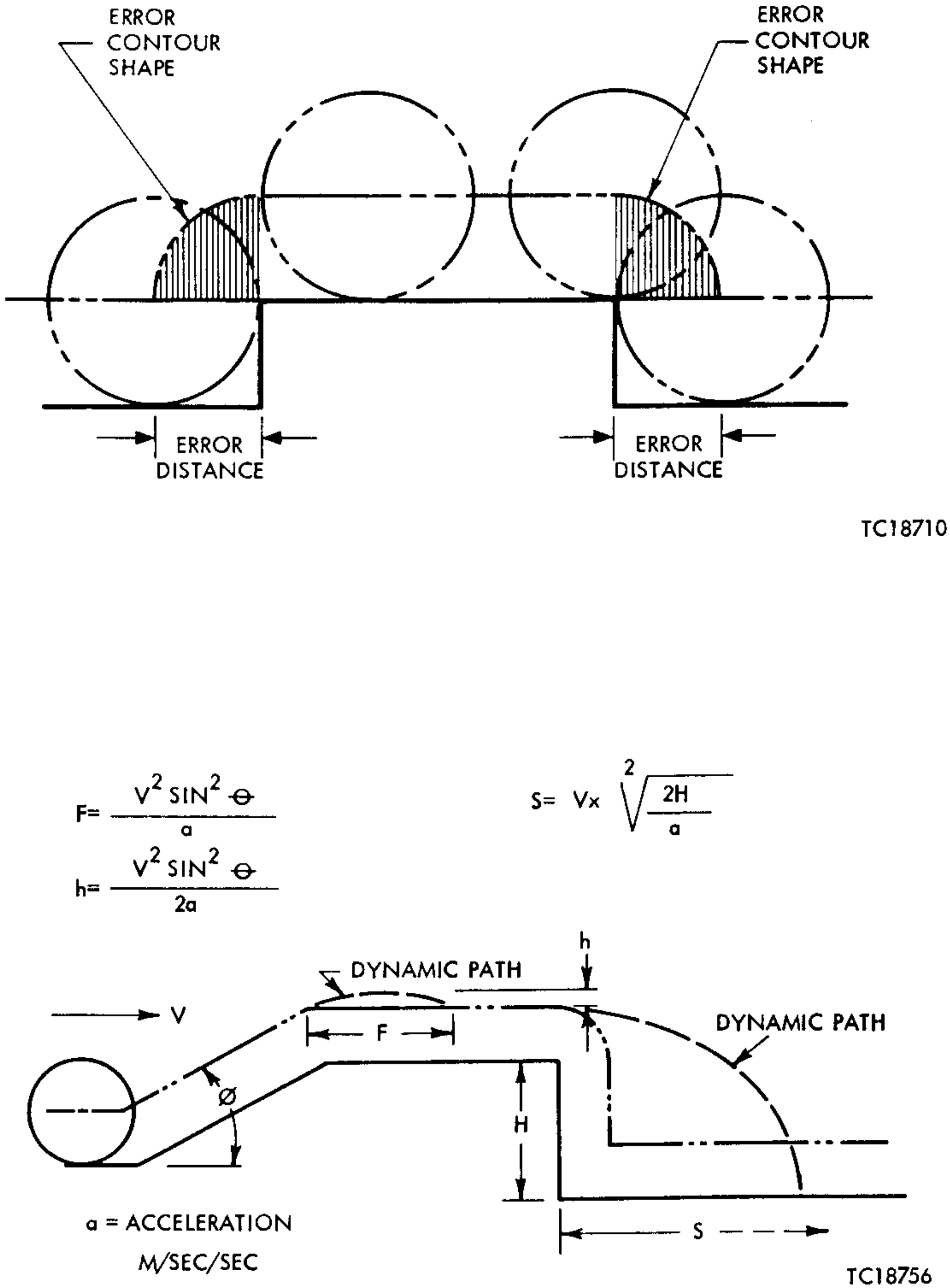

Figure 7. Terrain Contour Follower Geometric and Dynamic Error Sources

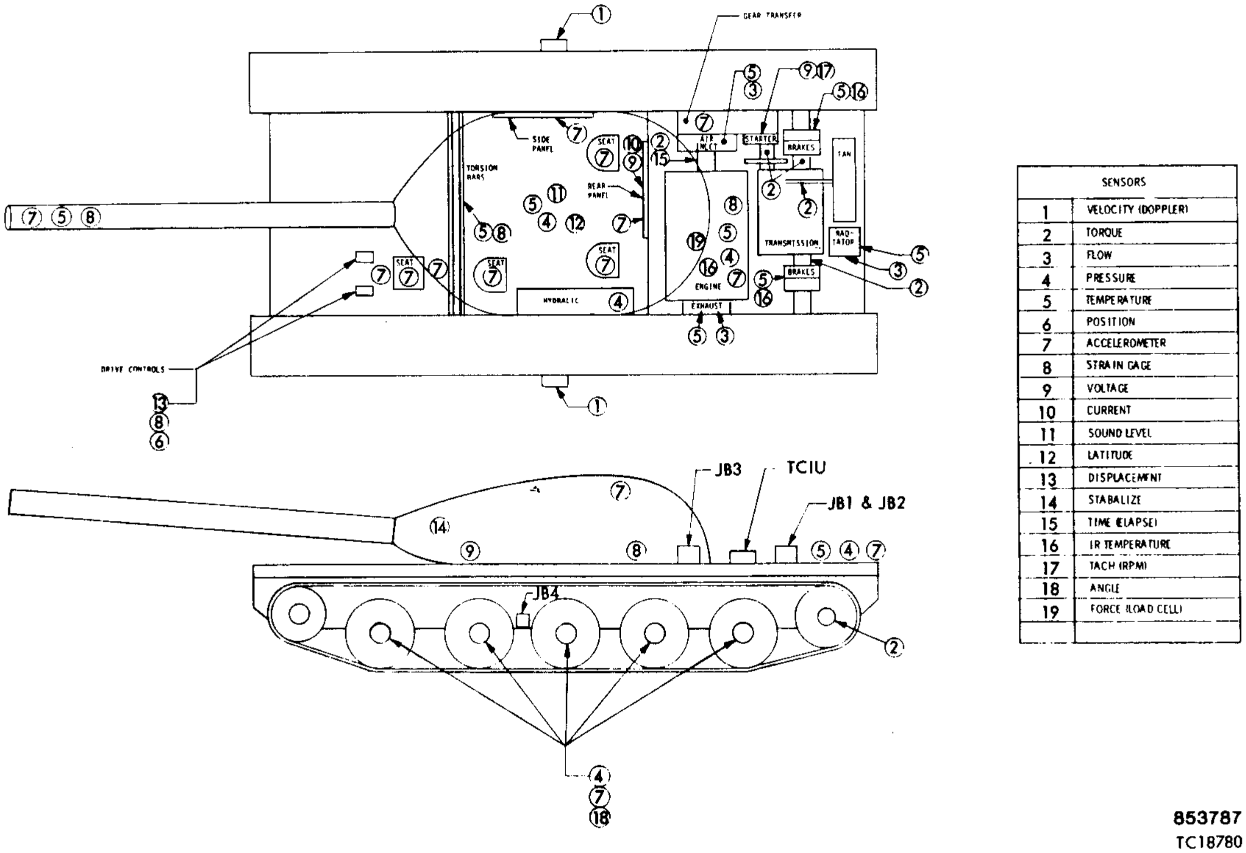

Figure 8. Test Vehicle Sensor Location

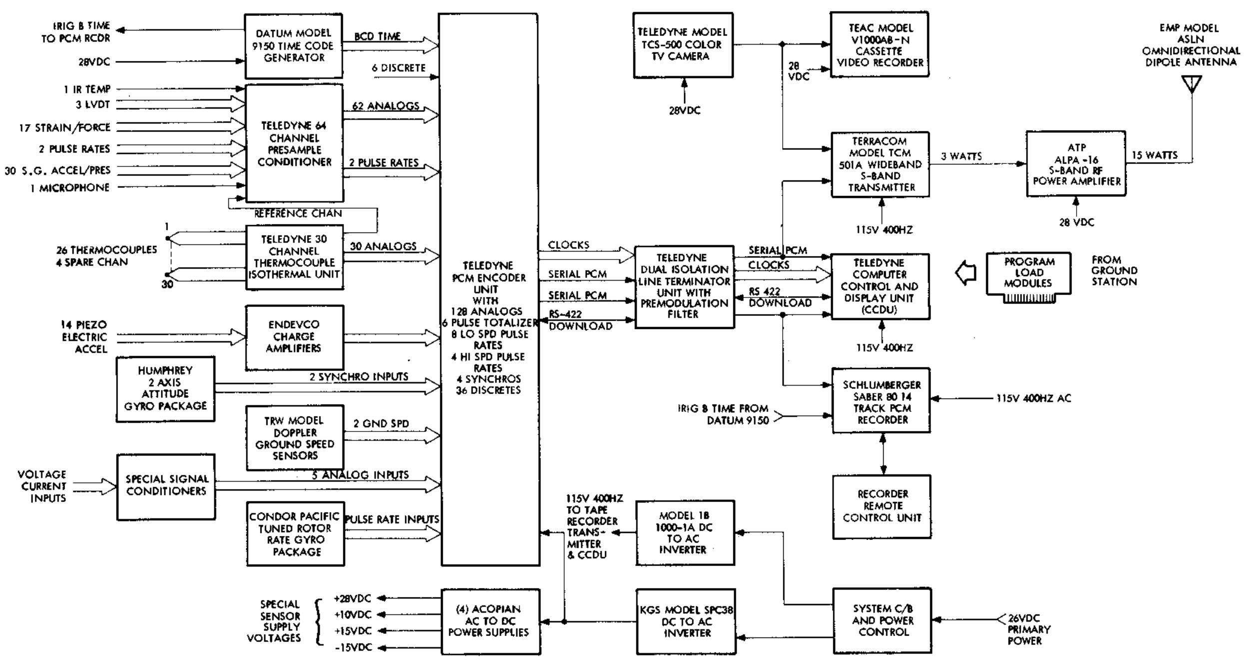

Figure 9. Vehicle-Borne Data Acquisition System Functional Block Diagram

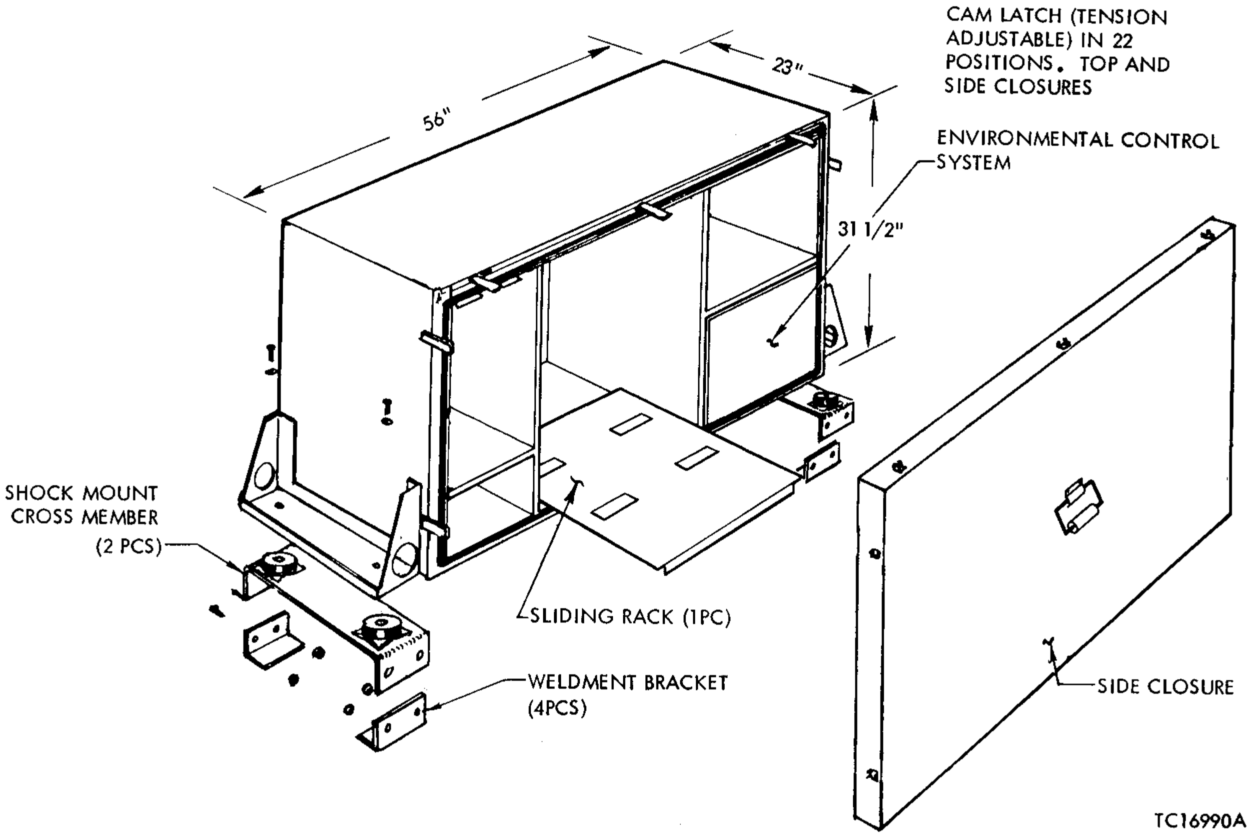

Figure 10. Airconditioning Equipment Enclosures

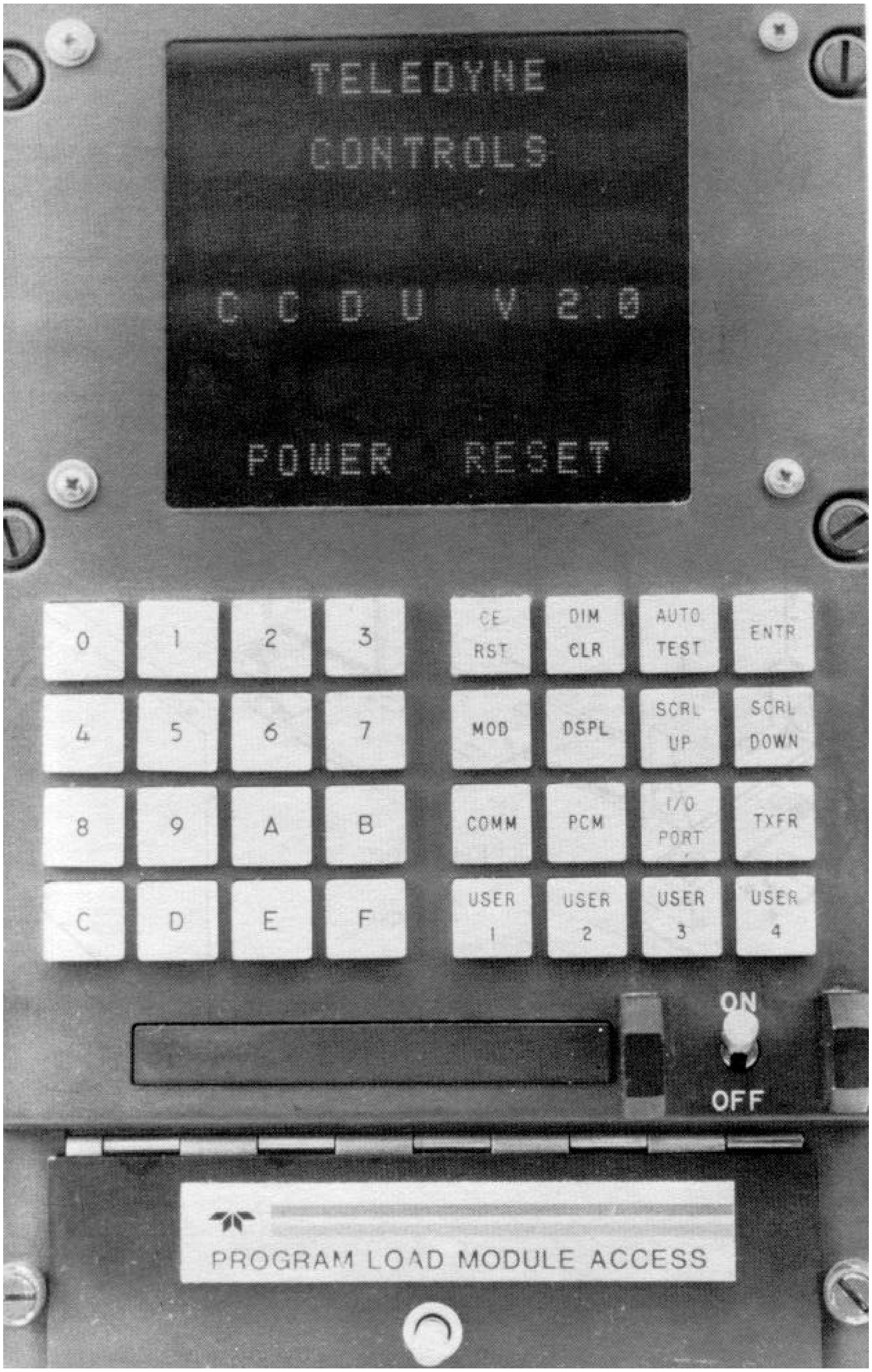

Figure 11. On-Board Computer Control/Display Unit

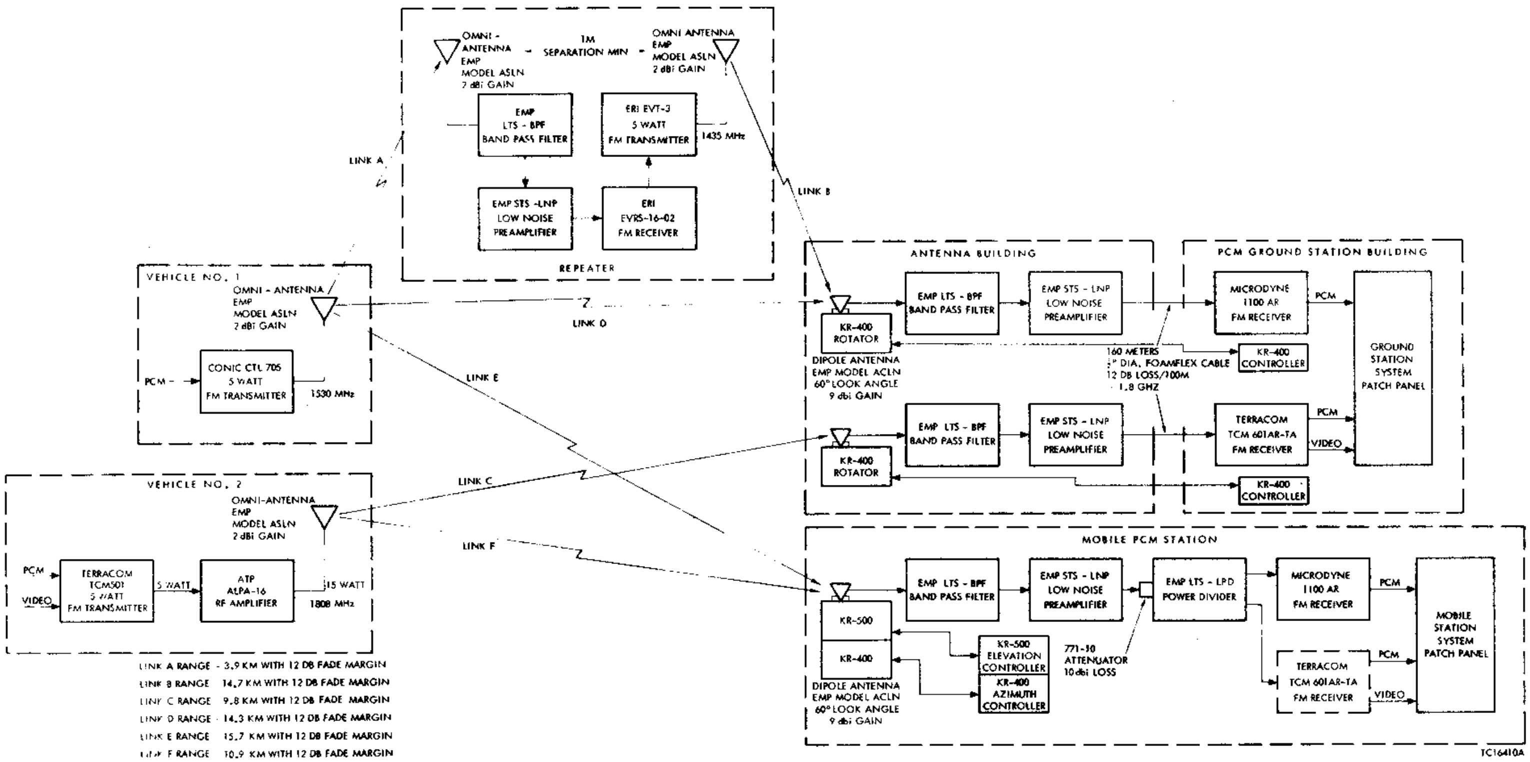

Figure 12. Vehicle Test Microwave Telemetry System

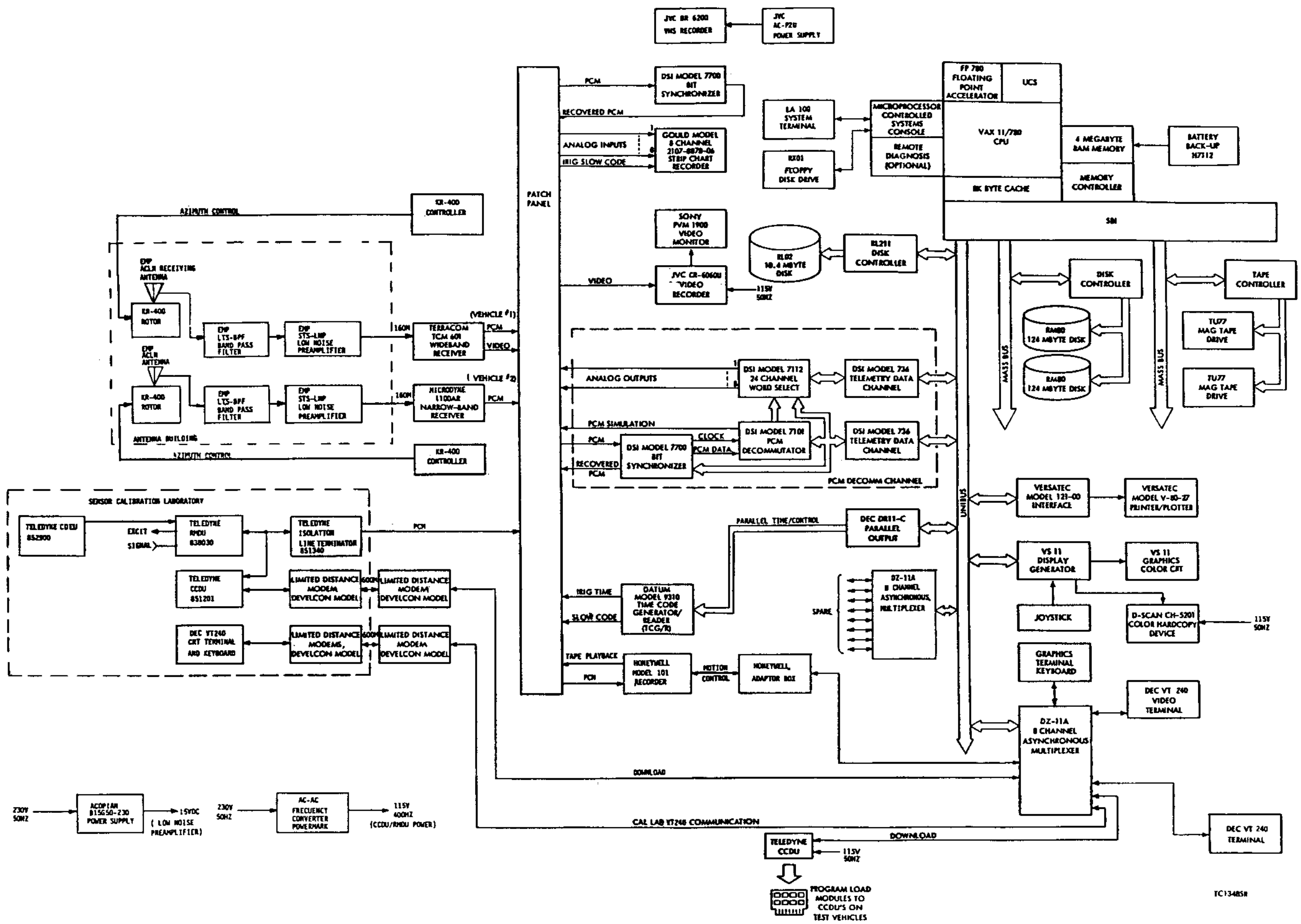

Figure 13. Fixed Base PCM Ground Station Functional Block Diagram

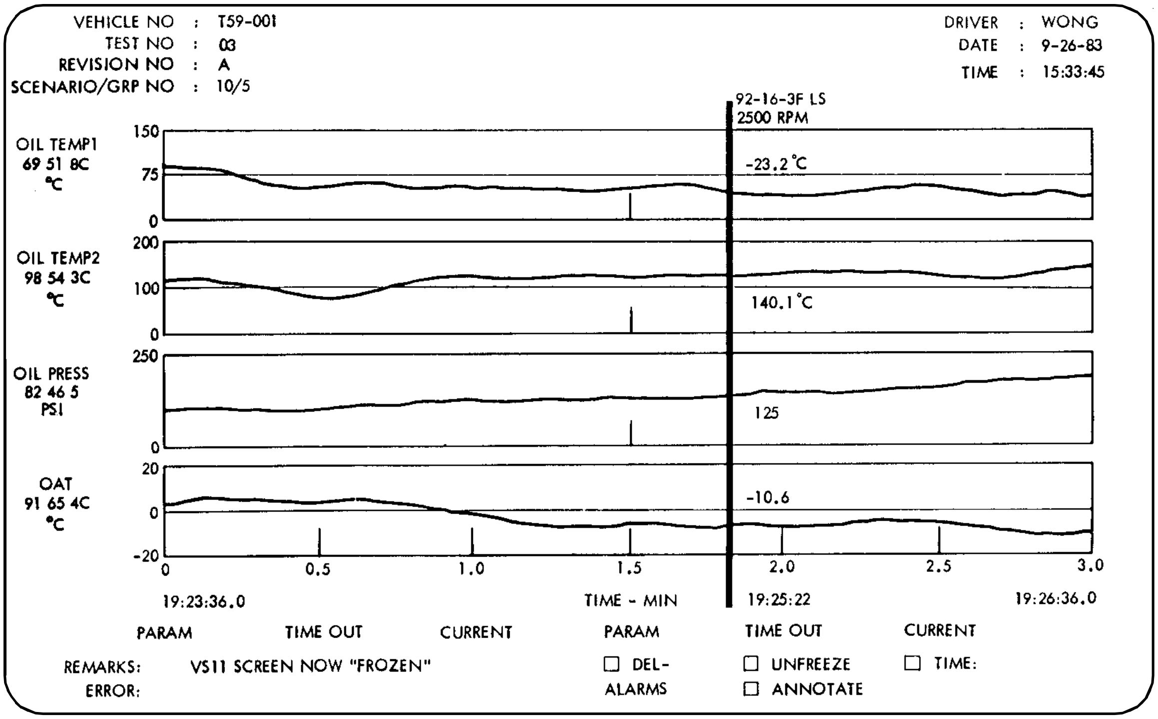

Figure 14. Stacked Four Curve Scrolling EU Display

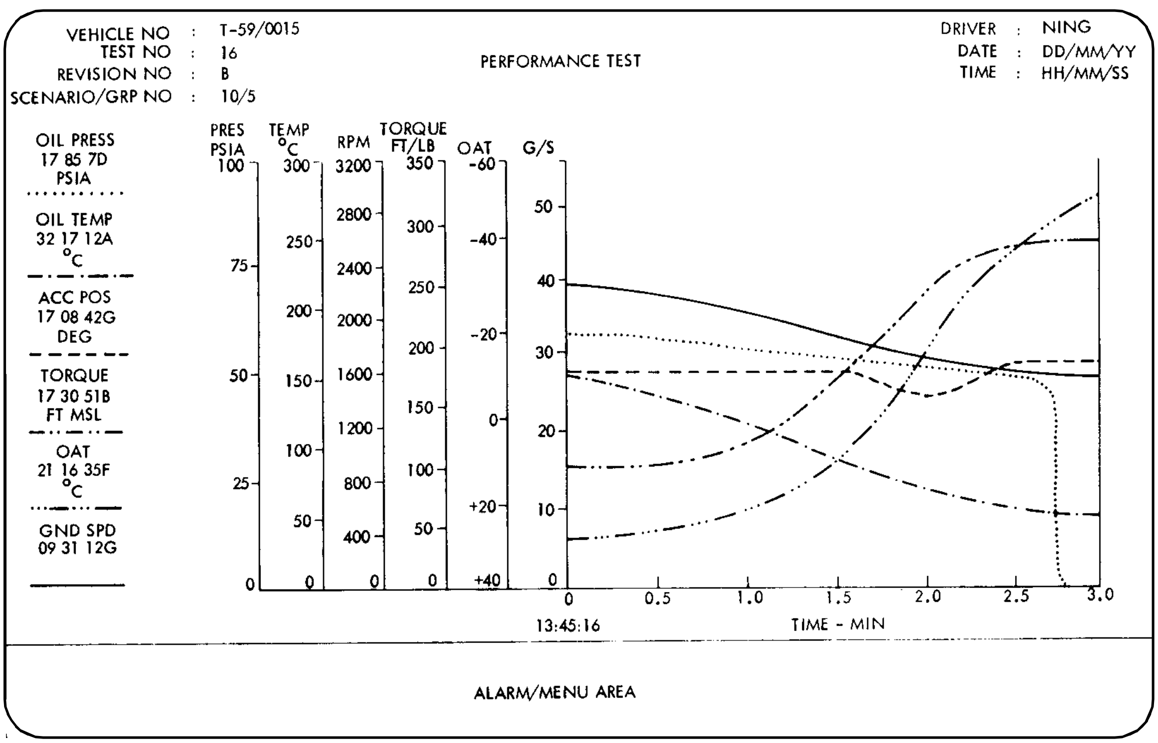

Figure 15. Overlaid Disk Curve Scrolling EU Display

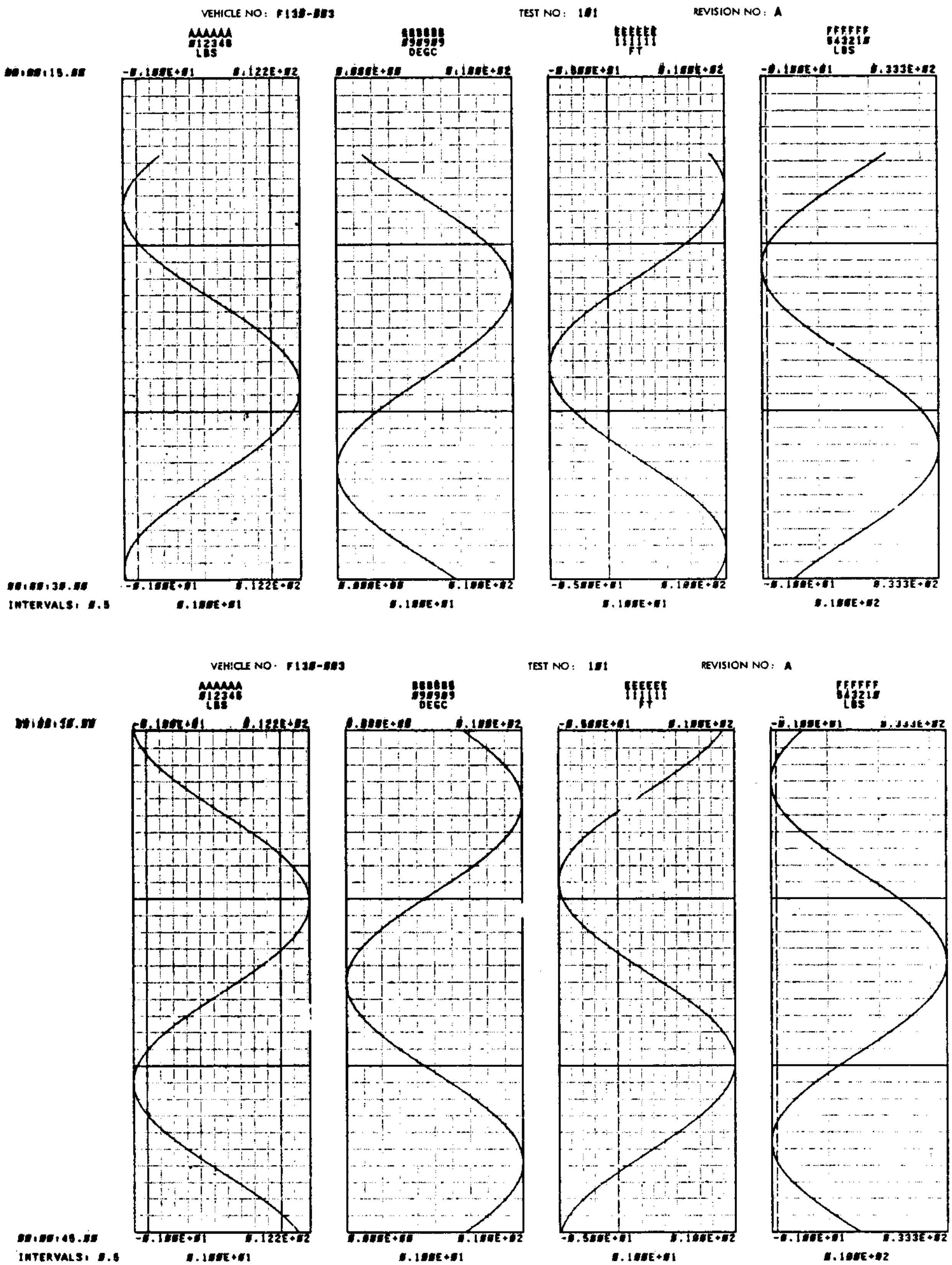

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Figure 16. EU Hardcopy Plots

TABLE 1
SENSOR LIST

Description/Function	Mfrg	Model P/N
Doppler Velocimeters	TRW	TG55-011
Doppler Calibrator	Kustom Elec.	HR-5
Vehicle Attitude Gyro System	Humphrey	VG-38, FG-23, Rs-15
Gun Barrel Stability (Two-axis Kate Sensor)	Condor Pacific	30420
Shaft (Position) Encoders	Micro-measurement	CEA-06-125VW-350 & WK-06-250BC-350
Turbine Flow Sensors	Cox	LFC6-2
Thermocouples	VSI	TC034
IR Temperature Sensors	Omega	OS-2000A, MN1604 & BB-2
LVDT Position Sensors	Schavitz	2000HCD-006 & 4000HR-006
Crystal Accelerometers (Vibration Sensors)	Endevec and Entran	2262-25, 2271A 2213E EGC-500DS & EGV3
Microphone (Acoustics)	Endevco	8550MI
Current Shunts	Empro	MLC800-50, HA-200-50 & HA300-50
RPM Sensors	Airpax	Gear Tooth/ Magnetic Pulse
Absolute Pressure	Rosemount	1201F1
Surface Temperature Sensors	Rosemount	118MG/MH
Bonded Strain Gauges (Loads/Vibrations)	BLH	FABX/FAE/FAED/FSE/ FAPR/FABR/FAPR/FAES