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EMR 827053

DOE/NASA WIND TURBINE DATA ACQUISITION SYSTEM (PART 1: EQUIPMENT)

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by O.J. Strock

EMR DATA SYSTEMS
SANGAMO WESTON

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center
Contract DEN 3-98

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1. SUMMARY

Large quantities of data must be collected, stored, and analyzed in connection with research and development programs on Wind Turbines. This document describes the hardware configuration of the Wind Energy Remote Data Acquisition System assembled by EMR Data Systems and used on the NASA/DOE Wind Energy Program.

Features of these systems include:

- Complete, integrated, functional packages
- Modular, flexible, easy to operate
- Standard data multiplex formats
- Standard intermediate tape storage format
- Standard computer output tape format

The data collection equipment on the Wind Turbine includes:

- Wide choice of measurement types
- Operation in any Wind Turbine environment
- Remotely-operated calibration
- 32 measurements per unit --

  96 per Wind Turbine --
  Expandable to 120 per Wind Turbine
- 16 measurements per slip-ring from Hub
- Lightning protection

The ground-based analysis equipment features:

- Up to 2000 feet separation from measurement sources
- Mobile computer laboratory
- Several types of stations for various stages of data analysis on-site
- Easy-to-operate computer system for automatic analysis of data
- Spectrum analysis and input to computer
- Variety of display types --

Printer	Plotter/Printer
Strip Charts	CRT Display
- Data compression to prevent computer overload
- Time-tags with all data

2. BACKGROUND

Wind energy has been used by man for centuries. Windmills existed in ancient Greece, and may well have been in use before then. Use also was common throughout medieval Europe. Common uses for these early machines included power sources for grain milling, water pumping, and timber milling.

Experience with wind machines in the U.S. dates from the mid-18th century. A commercial market for wind turbines in rural areas existed during the 1930's, but this market disappeared when the Rural Electrification Administration was formed. As a result of the current national effort to develop alternative energy sources, wind energy systems have re-emerged as one of the technologies with a potential for providing a significant energy contribution over the near-to-mid-term.

The Federal Wind Program was initiated in 1973 as a part of the nation's solar energy program. The first wind energy workshop was held in 1973 to review past work in wind energy and to assess the potential of wind power. From this workshop it became evident that it was desirable to test a representative large wind turbine as quickly as possible to provide engineering data for use as a base for the entire wind energy program. During FY 1974 a 5-year wind energy program plan was developed as part of the Solar Energy Plan of the Project Independence Blueprint. This wind energy program included the 1973 workshop recommendation to proceed with the design, building and testing of a nominal 100 kW, 125-foot-diameter rotor wind turbine; this wind turbine was designated Mod-0.

The NASA-Lewis Research Center was delegated the responsibility for designing, building and testing the Mod-0 wind turbine as part of the wind energy program being managed by the National Science Foundation. The Mod-0 became operational in September 1975. In January 1975 the responsibility for managing the wind energy program was transferred to the Energy Research and Development Administration (ERDA) and then the recently formed Department of Energy (DOE). NASA has continued to manage the Mod-0 project and several other large wind turbine projects. These other projects include three 200 kW wind turbines similar to Mod-0 (designated Mod-0A)and one 200-foot-diameter 2000 kW wind turbine (designated Mod-1).

In December 1976, EMR Data Systems won through a competitive bid, the contract to design and build a mobile data system for the acquisition and processing of wind turbine engineering data in support of Mod-0A and Mod-1. In November 1978, EMR Data Systems was awarded the present contract for operation and maintenance of the NASA/DOE Wind Energy Remote Data System.

This report discusses in detail the hardware configuration of this Wind Energy Remote Data System as of November 1979. This contract is under the technical management of Dr. Harold E. Neustadter at NASA's Lewis Research Center.

3. DATA COLLECTION AND ANALYSIS - AN OVERVIEW

The typical Wind Turbine installation is shown in Figure 3-1. For analysis of performance, data must be collected in the Hub, Nacelle, and Base of the turbine, and analyzed visually and/or by computer.

Data collection is accomplished by three Remote Multiplexing Units (RMU) at each Wind Turbine. Each RMU has 32 active inputs (expandable to 40); data from each RMU is multiplexed onto two subcarrier multiplexes for storage and/or analysis.

Actual routing and storage of the data takes either of several forms:

1. When a Wind Turbine is being installed, a "Maxi-Van" is taken to the site for several months. The equipment in this van allows detailed analysis of data from the new Wind Turbine, and also provides a facility for playback of tapes from other sites.

2. Another mobile laboratory is housed in a "Mini-Van", and can be used for quick-look analysis of data from a Wind Turbine after the Maxi-Van has been removed. This station offers analog display of several measurements, as well as some computation and display in digital form. All data is recorded on instrumentation tape for playback and more detailed analysis in the Maxi-Van or at Plumbrook.

3. Where no on-site data analysis is available, a Stand-Alone Instrumentation Recorder (SAIR) collects data subcarriers of interest. These tape recordings can be analyzed at the Maxi-Van. In addition, each site has the capability to display on an analog chart recorder a limited number of channels.

4. The Plumbrook site (Mod 0) data system is being updated to include facilities for replay and detailed analysis of tapes from other Wind Turbine sites.

Significantly, all recorded data tapes are in the same format, such that any tape can be analyzed at the Maxi-Van (or at Plumbrook in the near future).

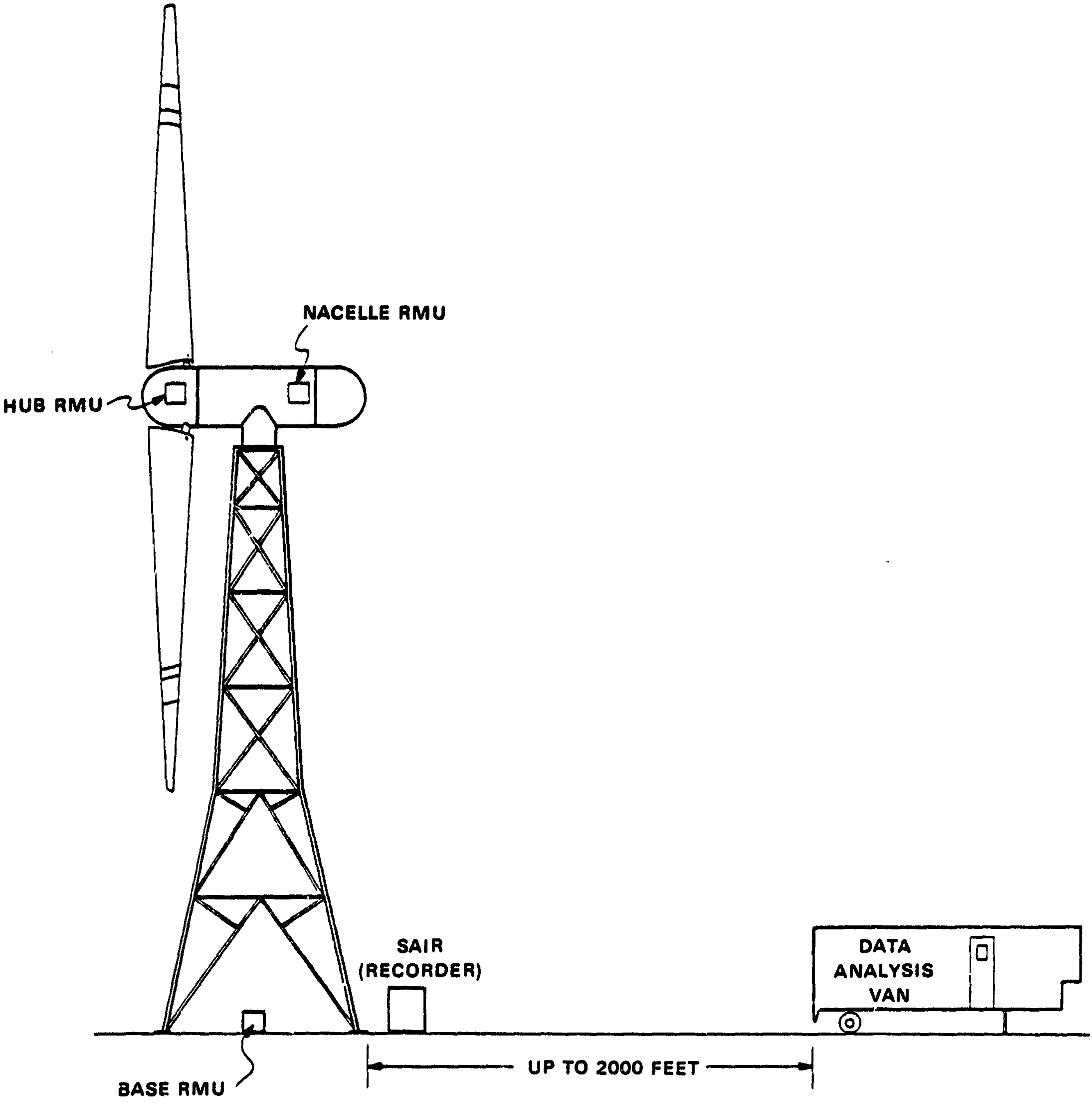


Figure 3-1. Typical Wind Turbine Site

4. REMOTE MULTIPLEXING UNIT (RMU)

4.1 General

For Wind Turbine research, NASA has determined that approximately 32 data measurement points of interest are located in the Nacelle, another 32 in the Hub, and another 32 in the Base. Consequently, an installation contains an RMU in each of these three locations to accept low-level or high-level data from various types of transducers, condition each data measurement (scale and offset) to a common range, frequency-multiplex the measurements (two groups of 16 per RMU), add a reference frequency to each group, amplify each group (plus a separate multiplex composed of some measurements from each group), output the basic groups to data analysis equipment, and output the separate multiplex to the tape recorder (SAIR).

All basic RMU's are identical, yet are flexible by choice of options and plug-in components, so that an RMU can be used to monitor either Nacelle, Hub, or Base data. One option is available in the RMU to add thermocouple reference junctions (10 or 20) so that thermocouples can be used as data collection devices in the Nacelle. Two types of signal conditioner plug-ins are used, one for thermocouple or other low-level data transducers, and the other for bridge-type transducers.

Figure 4-1 shows the functions of an RMU, while Figure 4-2 shows one of the two multiplexes in the RMU.

Each Type 1 Signal Conditioner provides excitation for a bridge transducer, calibration (on command), differential data amplification, and band-limited (low-pass filtered) output. Each Type 2 Signal Conditioner accepts a thermocouple or other low-level input and provides calibration (on command), differential data amplification, and band-limited (low-pass filtered) output with data response of DC to 40 Hz.

Each signal conditioner output modulates a Voltage-Controlled Oscillator (VCO). The 16 VCO's in each group are spaced at intervals of 500 Hz in the spectrum, and zero to full-scale data from a signal conditioner frequency-modulates a subcarrier over a range of ±250 Hz. Subcarrier center frequencies in each group are:

1000 Hz
1500 Hz
2000 Hz
2500 Hz
3000 Hz
3500 Hz
4000 Hz
4500 Hz
5000 Hz
5500 Hz
6000 Hz
6500 Hz
7000 Hz
7500 Hz
8000 Hz
8500 Hz

A precise reference tone of 9500 Hz is added to each group for later use in demultiplexing and tape speed error compensation.

Each multiplexed group (subcarriers and reference) is amplified for driving an output cable up to 2000 feet long.

Switches allow selection of a compatible group of subcarriers in the RMU for separate amplification and output to the SAIR (recorder).

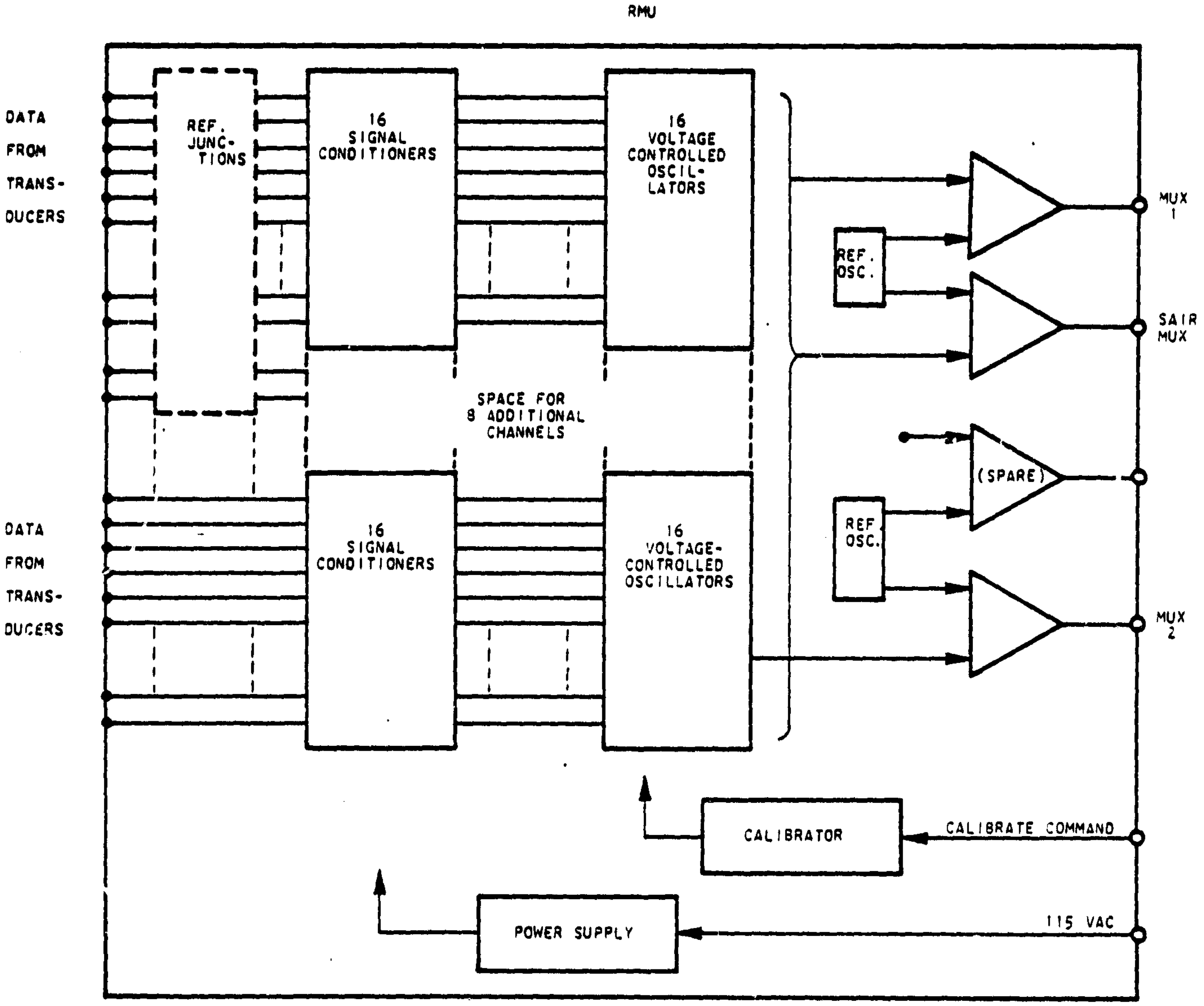


Figure 4-1. Remote Multiplexing Unit (RMU)

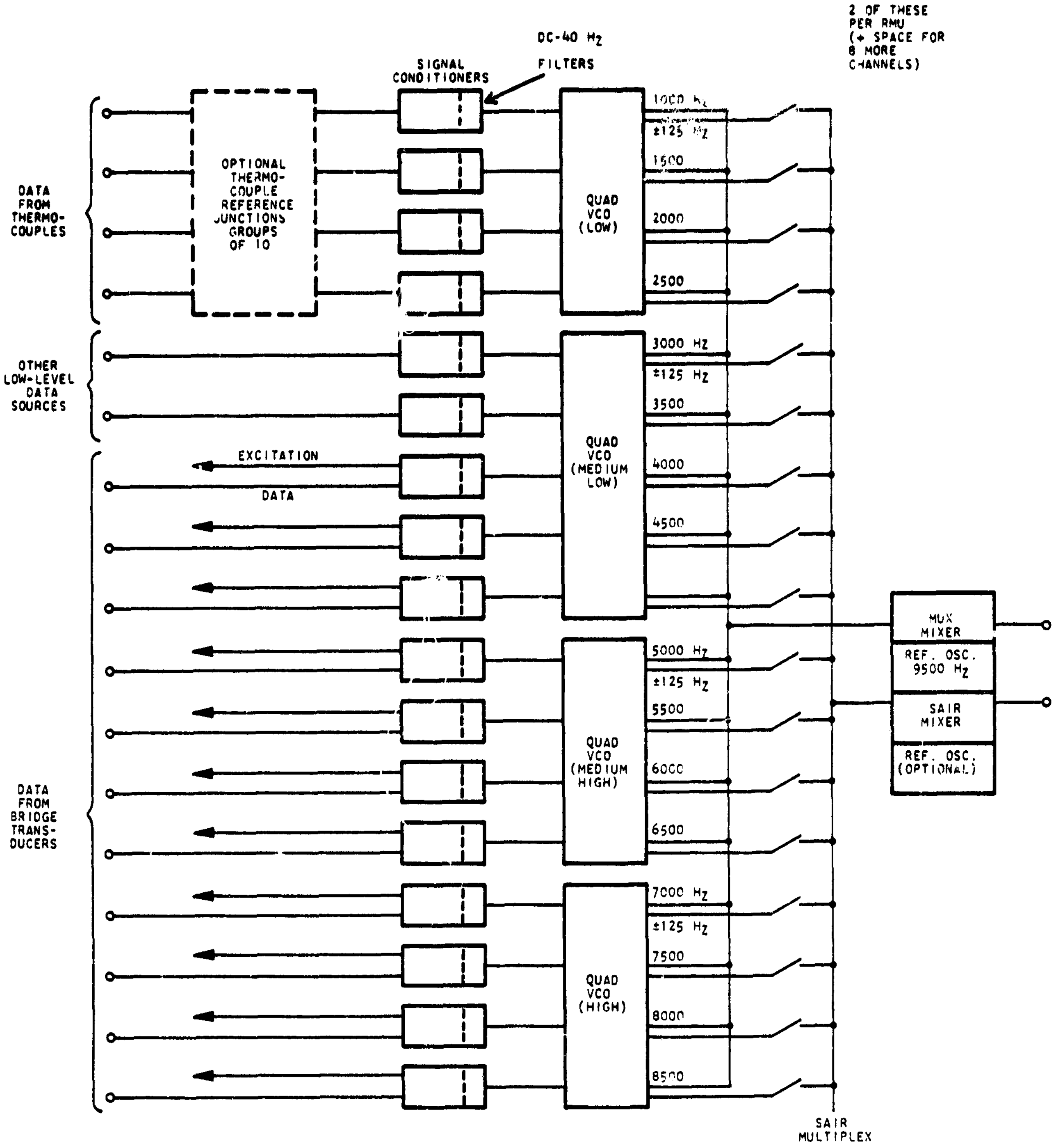


Figure 4-2. RMU Multiplex

Upon command from an external source, all channels in an RMU are set first to zero and then to full scale for end-to-end system calibration.

Each RMU operates from a 115V AC, 60 Hz power source. Operating voltages are developed and regulated internally.

4.2 Signal Conditioning

The Signal Conditioners for each RMU supply all of the circuitry necessary to interface various types of transducers to the inputs of the VCO's. Features include:

1. Completion networks for bridge or potentiometric devices.
2. Capability for voltage attenuation or amplification to provide normalized inputs to the multiplex system.
3. Calibration capability, two-point.
4. Interchangeability to allow a given system channel to process various types of transducers.
5. Low-pass filtering to restrict bandwidth (typically DC to 40 Hz).
6. Stable performance over broad temperature variations.

Each signal conditioner module is of printed-circuit card construction. The mechanical dimensions of the signal conditioner cards are identical.

By changing a single plug-in module, the low-pass cutoff frequency can be easily changed to satisfy different data bandwidth requirements.

Although all potentiometers and test points required for normal operation are readily accessible from the top of the RMU, a plug-in extender board is also supplied for servicing.

4.2.1 Bridge Signal Conditioner

The Bridge Signal Conditioner card (see Figure 4-3) provides the bridge completion, excitation, calibration, amplification, and low-pass filter functions required for operation with standard strain gage transducers. Specifically, each card contains the following:

1. Excitation regulator to provide from 2 to 10V to a bridge transducer at impedances down to 100 ohms.
2. Bridge completion network and shunt calibration relays.
3. Differential amplifier, with gain programmable from 5 to 2500.
4. Low-pass active Butterworth filter, 4 poles, with cutoff programmable from 10 Hz to 1 kHz via plug-in module. Typically in the RMU, this is DC to 40 Hz.

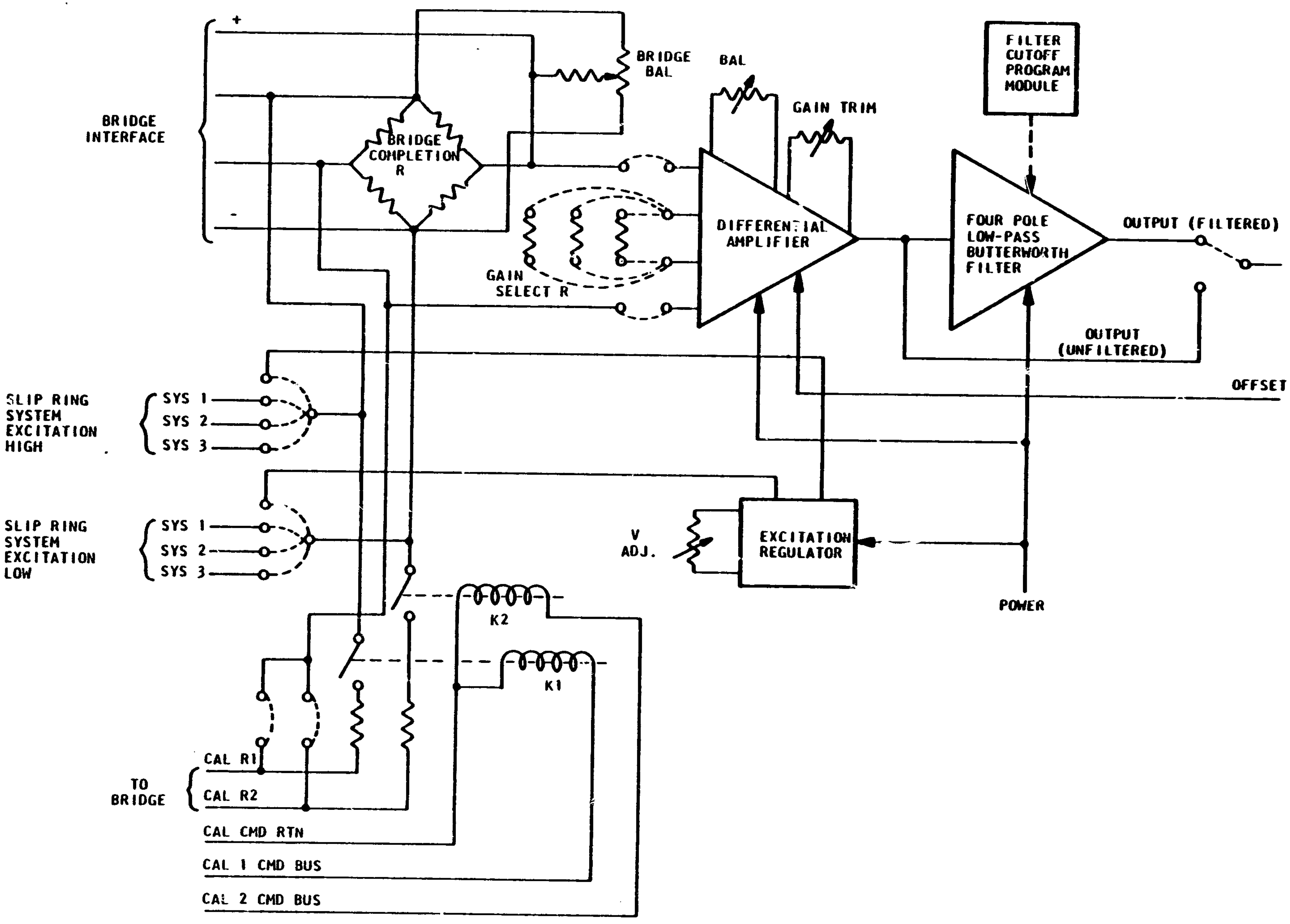


Figure 4-3. Bridge Signal Conditioner Block Diagram

The Bridge Signal Conditioner card meets the following specifications:

Bridge Excitation --

- Excitation Voltage: Adjustable 2 to 10V
- Output Current: 100 mA at 10V
- Regulation: 0.1% no load to full load
- Stability: 0.1% over temperature range

Bridge Handling Capability --

- Impedance: 100Ω to 5 kΩ
- Unbalance: At least 2%
- Bridge Type: 1 arm, 2 arm or 4 arm

Amplifier Performance --

- Input Type: Differential
- Common Mode Rejection: Greater than 105 dB at DC to 60 Hz (±5V)
- Input Level: ±2 mV pk-pk to ±1V pk-pk
- Gain: 5 to 2500, programmable
- Input Overvoltage: ±10V DC will not cause damage
- Stability: Less than $2 \mu V/^{o}C$ RTI, $\pm 50 \mu V/^{o}C$ RTO
- Output Offset: 0 to +5V

Output Filter --

- Type: Butterworth low-pass active
- Number of Poles: 4
- Slope: 24 dB/octave
- Cutoff: 10 Hz to 1000 Hz, programmable. Set to 40 Hz in the RMU.

4.2.2 Voltage Output/Thermocouple Signal Conditioner

This Signal Conditioner Card (see Figure 4-4) provides adjustable low-level differential input capability required by thermocouples, RTD's, and other low-level devices. This unit also provides voltage substitution for calibration purposes. Furthermore, attenuation capability is provided at the input. These features will allow both amplification and attenuation of input voltages to match the input source. Current-to-voltage conversion can also be provided through the installation of a resistor across the input terminals of the amplifier.

A four-pole programmable output filter is also provided, with cutoff frequency programmable via plug-in module.

Specifications for this conditioner are as follows:

Amplifier Performance --

Input Type:	Differential
Common Mode Rejection:	Greater than 105 dB at DC to 60 Hz (±5V)
Input Level:	5 mV pk-pk to 5V pk-pk
Gain:	1 to 1000, programmable
Attenuation:	As required via resistor divider
Input Overvoltage:	±10V DC will not cause damage
Stability:	Less than 2 μV/^{o}C RTI, ±50 μV/^{o}C RTO
Output Offset:	0 to +5V

Output Filter --

Type:	Butterworth low-pass active
Number of Poles:	4
Slope:	24 dB/octave
Cutoff:	10 Hz to 1000 Hz, programmable. Set to 40 Hz in the RMU.

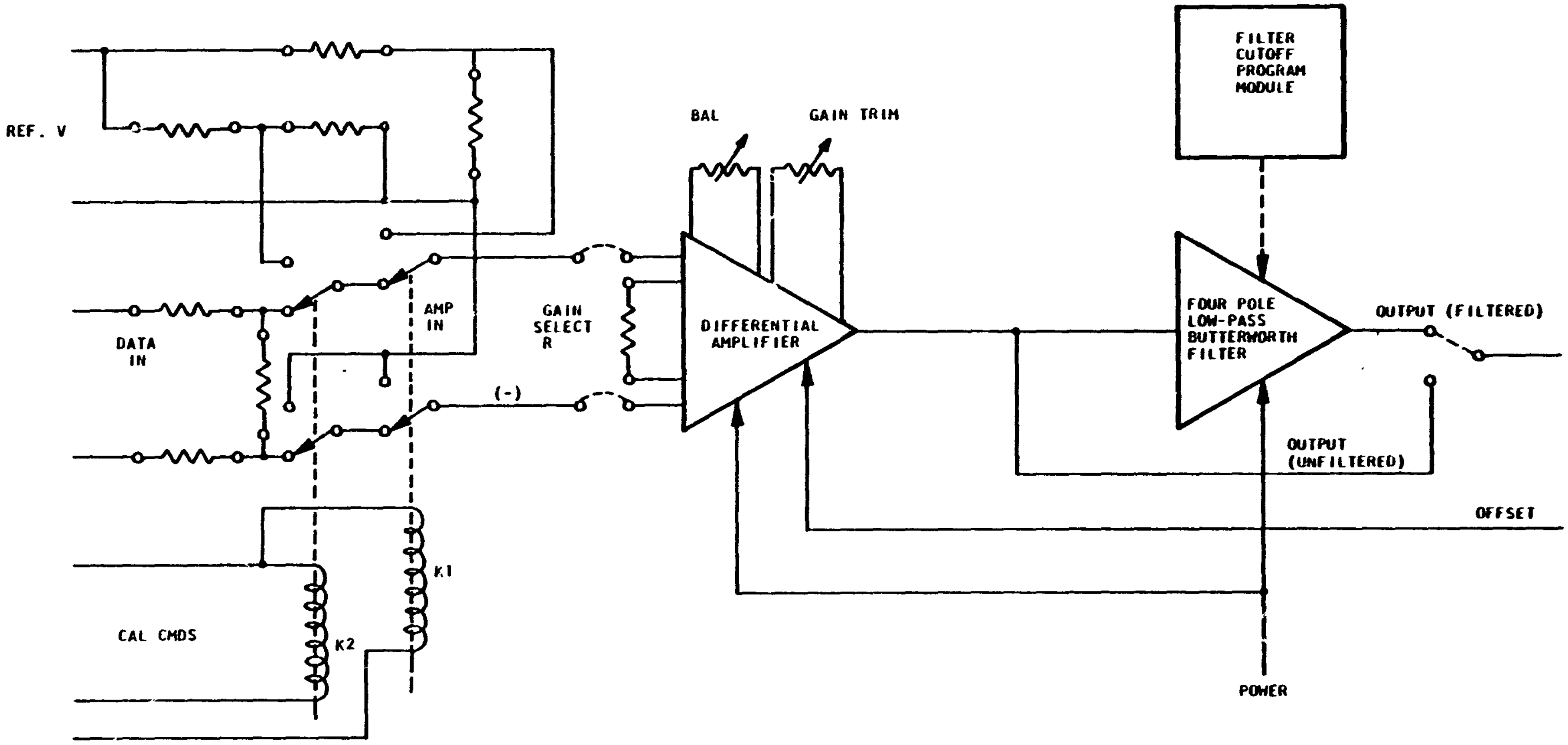


Figure 4-4. Voltage Output/Thermocouple Signal Conditioner Block Diagram

4.3 FM Multiplexing Equipment

The FM multiplex baseband is configured using the following constraints:

1. Data bandwidth for each 16-channel multiplex is at least DC to 40 Hz.
2. The FM system operates with a deviation ratio of at least 3, with 40 Hz data.
3. The FM multiplex baseband falls within the bandwidth of a Wideband I analog tape recorder operating at 15/16 ips.
4. Overall system accuracy is 1.5% or better.
5. Frequencies are submultiples of standard IRIG frequencies.

Each 16-channel FM multiplex system consists of 16 VCO's and a mixer amplifier, capable of driving up to 2,000 feet of coaxial cable or twisted-shielded pair. Each of the two 16-channel multiplexes within each subsystem is identical. Each VCO is a plug-in module, and addition or removal of a VCO from the multiplex will not degrade system operation. Each subsystem has built-in provision for accommodating additional VCO channels.

An additional oscillator slot has been furnished to allow inclusion of a 15 kHz reference in each multiplex output. At a speed-up ratio of 16:1, the standard 240 kHz reference will be thus generated.

The selected baseband frequencies are derived from the standard Group A IRIG CBW channels by dividing the frequency, deviation and low-pass output filter by a factor of 16. Utilization of these standard IRIG frequencies as a base has desirable side benefits, inasmuch as any standard data reduction system can then demodulate the proposed baseband structure by operating the tape recorder at 16 times the normal speed (16 x 15/16 = 15 ips).

4.3.1 Voltage-Controlled Oscillators

The VCO's selected for this application are Micro-electronic Airborne VCO's. These thick-film hybrid units offer excellent stability, very low power consumption, small weight and volume, and exceptional immunity to vibration and shock.

The VCO has printed-circuit type mounting with a standard 14-lead DIP. This very convenient package size allows four channels of VCO's and two mixers per printed-circuit card. A special low-impedance output from each VCO enables selection of particular channels for multiplexing on the SAIR summing bus. This is accomplished via a DIP switch which enables selection of any or all of the channels on each card.

Key specifications for the constant-bandwidth VCO are as follows:

General Performance Specifications --

Temperature Stability of Output Frequency:	±2% BW for center frequency and bandwidth variations from a reference frequency from -35°C to +55°C
Bandedge Accuracy:	±1% BW
Linearity:	±0.2% BW, best straight line, maintained from -35°C to +55°C
Time Stability:	±0.25% BW for 8 hours at 25°C after a 5-minute stabilization
Distortion:	<1.0% anywhere within the passband

Note: BW is bandwidth, edge to edge.

4.4 Calibration

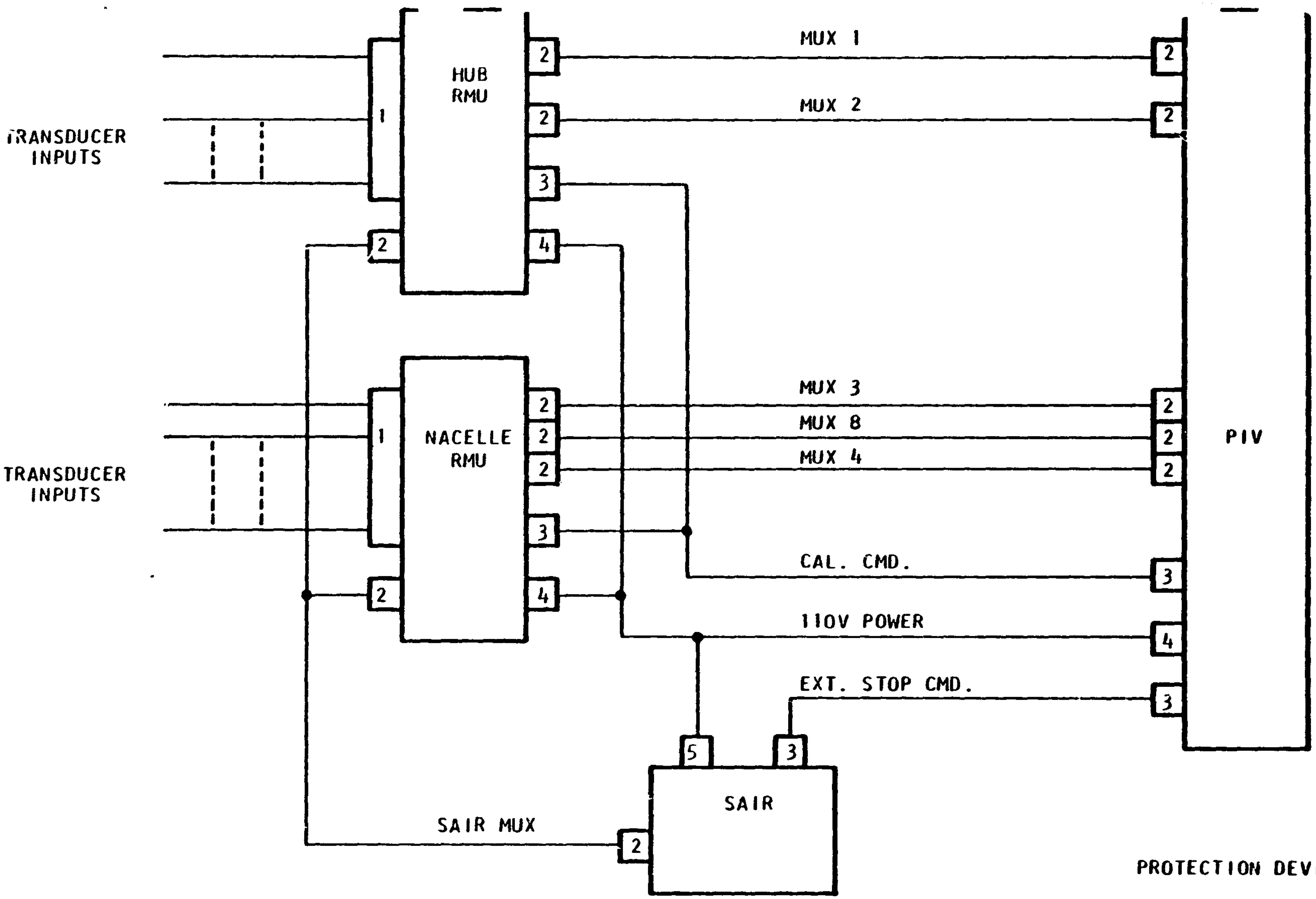
End-to-end system calibration is provided via shunt or voltage substitution directly at the transducer inputs. Specifically, each signal conditioning card contains the appropriate calibration relays, voltage sources, and resistive dividers for independent two-point calibration. Calibration is achieved by application of two calibration commands. These commands in turn actuate a calibration control relay within the RMU that selects either zero or gain shunt/voltage calibration. The relay calibration current is provided by the internal RMU supply; only the nominal 25 mA current drain of each RMU calibrate relay need by switch-closed from remote point. This prevents the line losses that would result if the total calibration current were to be supplied remotely.

The pull-in current voltage for the calibrate relays is in excess of 16V. This and additional filtering preclude inadvertent actuation of the calibrate circuitry. Furthermore, the fail mode of the calibrate relay is in the "data" position, such that data will not be lost even in the event of failure of the calibrate relays.

The equipment uses 0.1% resistors in the voltage divider and shunt calibration networks. With 0.1% values, a worst case of 0.2% calibration accuracy is assured. Since this is almost 10 times better than the system accuracy requirement of 1.5%, this tolerance represents a judicious compromise between cost and calibration accuracy.

4.5 Lightning Protection

The structure of Wind Turbine generators is such that direct lightning strikes are inevitable. Therefore, lightning protection is provided at all inputs and outputs of the RMU's. Figure 4-5 is the lightning protection block diagram. All inputs to the RMU's are protected with Metal Oxide Varistors as noted. Although the current rating of these devices is not sufficient to protect against a direct hit on a specific transducer, it will definitely provide protection for hits on the Nacelle or Tower. These MOV varistors are basically voltage-dependent resistors which perform in a manner similar to back-to-back zener diodes. This provides protection (for both AC and DC circuits) from the voltage transients induced by lightning and/or inductive switching.



CODE	PROTECTION DEVICE
1	MOV V22ZA3
2	MOV V22ZA3
3	MOV V47ZA7
4	310
5	MOV V130LA10

Figure 4-5. Lightning Protection Block Diagram

For protection of multiplex and calibrate command lines, the system uses MOV V22ZA3 and V47ZA7 devices. For protection of electronic hardware within the PIV and the power supply within the RMU, a power line plug-in protector is used. This unit offers surge protection via an electrode gas tube.

A detailed schematic of the input protection is depicted in Figure 4-6. It will be noted that lightning protectors are placed across each differential amplifier input and excitation supply, as well as from each of these lines to the common shield. An interesting and fortuitous note concerning varistors is that the catastrophic failure mode is inherently one of short-circuit failure. Thus, if a direct hit should occur on a transducer input, the varistor will short, providing a shunt path for the excessive current. Although this will not guarantee protection of other circuitry within the unit, it certainly will assist.

4.6 Packaging

The RMU mechanical design is shown in the package and connector panel drawings, Figures 4-7 and 4-8. The packaging concept used for the RMU uses a NEMA type enclosure to provide the watertight external enclosure. Internally, the RMU uses the rugged airborne card enclosure that has been successfully on flight test programs for helicopters and fighter aircraft. This type of enclosure and mounting system provides satisfactory operation in kinetic environments far in excess of the stated requirements. This could be extremely valuable in the case of a failure mode which results in excessive system vibration. The system can be counted upon to continue to gather data which will aid in the analysis of system failure.

The RMU is packaged in an aluminum NEMA-12 enclosure. Basic dimensions of the enclosure are 20 x 20 x 8 inches with a foot-print mounting of 22.5 x 22.5 x 9 inches. This enclosure is designed for outdoor mounting and protects the electronic equipment from rain, dust, snow, etc. The sealed door is hinged and has provisions for padlocking to prevent vandalism. MS type connectors are used for all inputs/outputs.

These printed-circuit cards are designed for operation in shipboard and coastal area environments. The conformal-coated cards preclude fungus growth, prevent moisture absorption, and still enable simple field repair without the requirement for special tools or solvents.

4.7 Environmental Capability

Since Wind Turbine Systems are tested and used in diverse locations, the system is designed to operate over wide temperature and humidity extremes. Furthermore, the Hub subsystem is subjected to an acceleration and vibration environment which is comparable to the kinetic environment of helicopters. The environmental requirements of the remote subsystems are equivalent to that specified for helicopters in MIL-STD-810B. Specific environmental specifications are as follows:

Temperature:	-35°C to +55°C
Altitude:	Sea level to 10,000 feet
Humidity:	0 to 100% (non-condensing)
Vibration:	MIL-STD-810C for helicopters
Acceleration:	MIL-STD-810C for helicopters

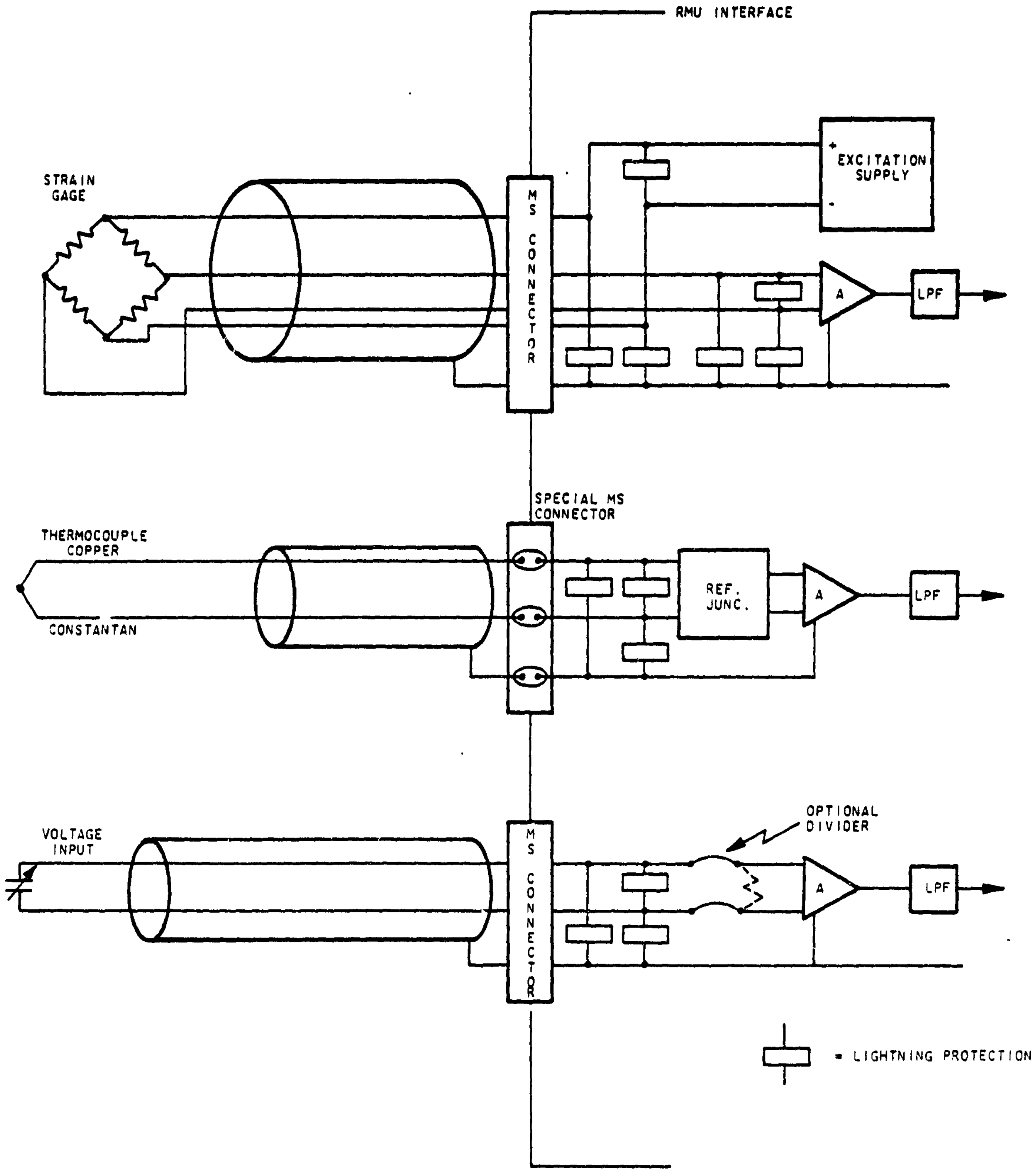


Figure 4-6. Input Protection Block Diagram

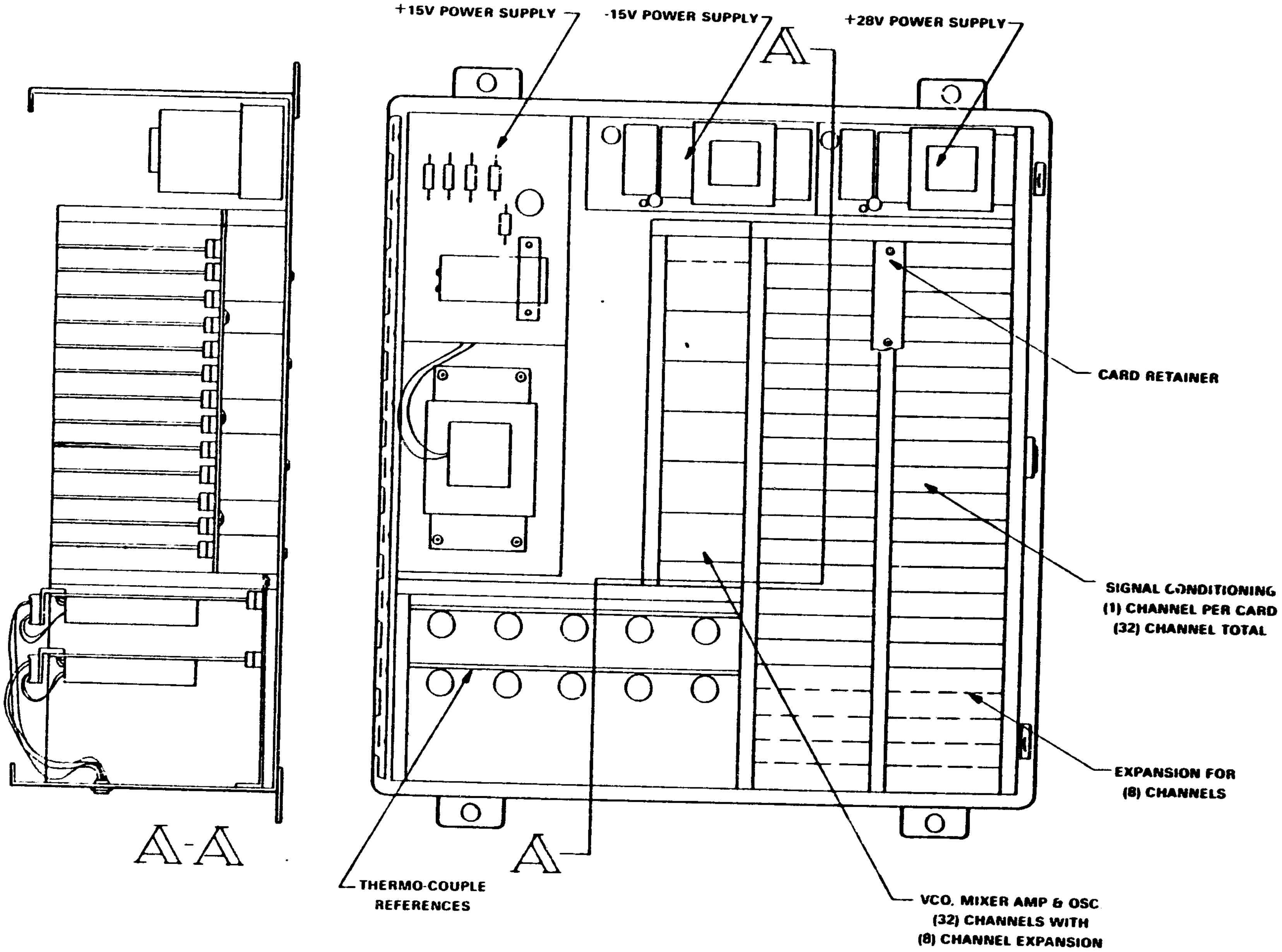
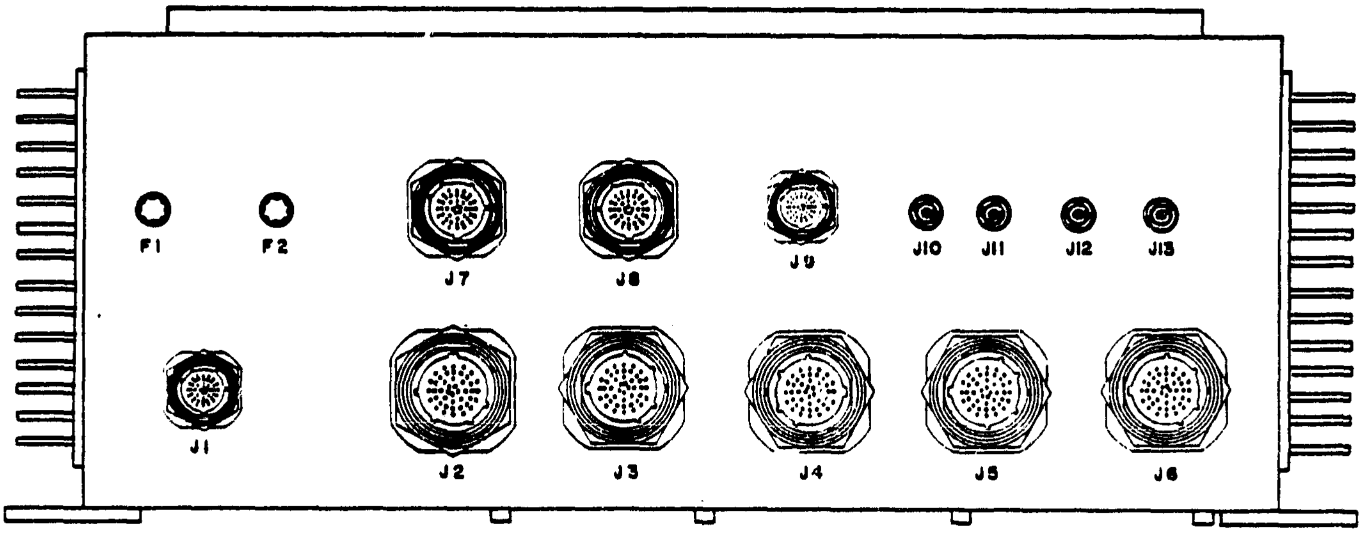


Figure 4-7. RMU Mechanical Design



MATING CONNECTORS ARE SUPPLIED FOR ALL
CONNECTORS IN USE ON EACH RMU.

Figure 4-8. Connector Panel Layout

Shock:	MIL-STD-810C for helicopters
EMI:	System will be designed to operate in the high current and magnetic field environment found in close proximity to power generators of up to 2.5 MW, and fields up to 75 A/M at lightning frequencies.

The NEMA-12 enclosure is black-anodized for protection against salt spray environment. To prevent possible salt spray contamination during maintenance, all printed-wiring boards are conformal coated.

The interior structure of the RMU is designed to withstand the specified ±15g acceleration, and the vibration and shock environments normally encountered in mobile and aircraft transportation. A temperature rise of 30°C can be expected within the enclosure, and a case temperature rise of less than 20°C. This will result in a maximum internal temperature of 85°C, which is within the operating specifications of the electronics and power supplies.

4.8 Primary Power

Each RMU utilizes standard 60 Hz, single phase, 105 to 125V AC power. Power supplies are selected for worst-case current conditions.

All power supplies have external overload protection and automatic electronic current limiting at a preset value, thereby providing protection for the load as well as the power supply. Figure 4-9 summarizes each RMU power requirement on a worst-case and typical basis.

		Typical			Worst Case		
	Item	Current	Qty.	Total	Current	Qty.	Total
+15V Supply	376-02	50 mA	20	1A	150 mA	40	6A
	377-02	20 mA	20	0.4A 1.4A	50 mA		
-15V Supply	376-02	20 mA	20	0.4A	50 mA	20	1A
	377-02	20 mA	20	0.4A 0.8A	50 mA	20	1A
+28V Supply	30C1	5 mA	40	0.200A	6 mA	40	0.240
	30M1	5 mA	3	0.015	6 mA	3	0.018
	30R1	3 mA	2	0.006	3.5 mA	2	0.007
	37X CAL	(OFF)		0 0.221A	25 mA	40	1.00 1.265A

Power Supply Ratings:

+15V, 6A; -15V, 2A; +28V, 1.5A

Figure 4-9. Power Requirements

5. MAGNETIC TAPE RECORDERS

5.1 General

To provide interim storage of subcarrier multiplexes in analog form, an IRIG-standard instrumentation tape recorder is provided at each Wind Turbine site to store important data.

Different recorders are used, with the selection at each site based on the phase of study at that site. In each case, however, certain characteristics are common to all other recorders:

1. All data is recorded on IRIG-standard 1-inch tape, and can be played back on any similar IRIG transport.
2. Recording is in the direct mode, Wideband I (approximately 12 kHz response at 15/16 inch per second tape speed).
3. Each machine operates on 104-126 volt, 47-63 Hz primary power.
4. Each transport is rack-mounted.

5.2 Type Recorder (Maxi-Van and Plumbrook)

The "Type A" Recorders have 7-channel capability, and hold 14-inch reels (9200 feet of 1-mil tape). They have the ability to reproduce tapes from Type A or Type B transports in use at other Wind Turbine sites.

5.3 Type B Recorder (Mini-Van and SAIR)

The "Type B" Recorders have 4-channel capability, and hold 14-inch reels (9200 feet of 1-mil tape). They have the ability to reproduce tapes from other Type B transports in use at Wind Turbine sites.

6. SUBCARRIER DEMODULATION

6.1 Description

All Wind Turbine data is contained in the six frequency-multiplexed subcarriers from the Remote Multiplexing Units (RMU's). Electrically, the multiplexes are identical and can be treated identically during the separation and demodulation process.

Separation and demodulation in all stations (except small analog checkout boxes) is handled as shown in Figure 6-1.

A multiplex is routed directly to the first four Dual Discriminators in a group, where bandpass filters are tuned to select the lower eight subcarriers (1000, 1500 --- 4500 Hz). Each is demodulated to yield analog data; a 40 Hz low-pass output filter prepares the data for output. Each output can be adjusted, but is set to ±10 volts for this system. Drive current is 50 milliamperes.

Because the deviation percentage is relatively low on the upper eight subcarriers (±2.9% at the upper end of the group), performance of the conventional system would be somewhat degraded for these subcarriers. In order to obtain optimum performance (high accuracy, low drift), these eight subcarriers are down-translated ("subtracted" from the 9500 Hz reference tone) to yield a new multiplex where the lowest deviation percentage is ±5.5%, and the accuracy and drift performance in a discriminator are excellent. The last four discriminators in the subsystem are, therefore, a "mirror image" of the first four in frequency assignment. Data outputs are filtered and amplified as described above.

It will be noted that discriminator output data is available for use in analog form. The system can include strip chart recorders, meters, or other analog devices as desired.

One feature of the system which improves data accuracy on playback of multiplexes from Recorders is automatic tape speed error compensation. The aforementioned reference tone is demodulated in the Reference Discriminator; any variations from the precise 9500 Hz tone are proportional to tape speed errors, and are output as electronic correction signals to the Data Discriminators in the subsystem.

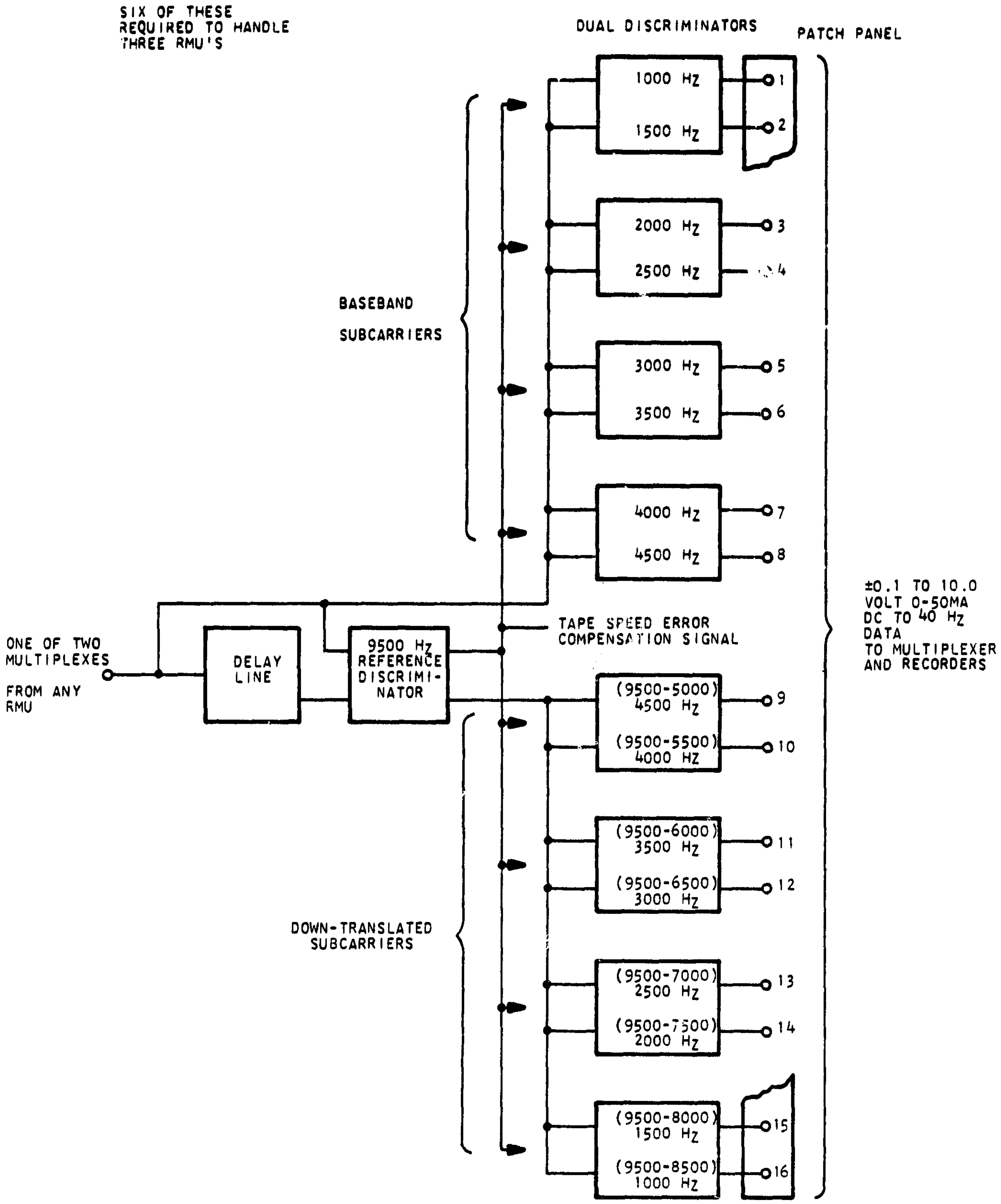


Figure 6-1. Discriminators

7. DATA ANALYSIS VAN ("MAXI-VAN")

7.1 General

Real-Time Wind Turbine data from the Hub (2 multiplexes, 32 channels total), Nacelle (2 multiplexes, 32 channels total), and Base (2 multiplexes, 32 channels total), or playback from the SAIR recorder (3 multiplexes, 48 channels total) is separated and demodulated as described in Section 6, and prepared for computer entry as illustrated in Figure 7-1. A total of 96 channels can be separated, demodulated, and filtered by the equipment. Signal patching capability is shown in Figures 7-2 and 7-3.

7.2 Data Multiplexer-Encoder and Time Code

A 96-channel multiplexer samples all discriminator outputs sequentially, looking at each cycle of 40 Hz data at least five times in order to obtain a faithful representation of the data for computer entry. Five looks at each cycle of 40 Hz data per second is 200 looks per second per channel, or about 20k words per second total.

Each data sample is converted to a 12-bit word and output as bit-parallel word-serial data, suitable for data compression and computer entry.

Simultaneously, whether in real time or tape playback, time code representing the exact time of occurrence of the data is recognized by the Time Generator/Translator. Registers keep track of time, resolved to one millisecond, and output pulses are generated coincident with each millisecond and each second. The registers are frozen and dumped on command to tag the data for computer entry.

Figure 7-4 shows data and time entry into the Compressor, and the Computer, and output to various peripherals after processing.

7.3 Data Compression

7.3.1 Background

In the typical Wind Turbine, most measurements prove to be of no interest to the research scientist. Each data point must be examined, however, in order not to miss the significant occurrences. Time does not permit this examination in the Computer, since too much time would be used in software manipulation of the data. By performing this examination in a pre-processor, however, and discarding all except the significant data, the load on the analysis computer is reduced dramatically and a relatively small computer is able to do a king-sized job.

In this system, a unique hardware device is used as a Pre-Processor/Data Compressor. The device examines each measurement as it occurs, and applies certain algorithm tests to the data. Only those occurrences which pass these tests are presented to the Computer. Since this is a hardware device, processing time on each sample is extremely short, and up to 98% of the data can be discarded.

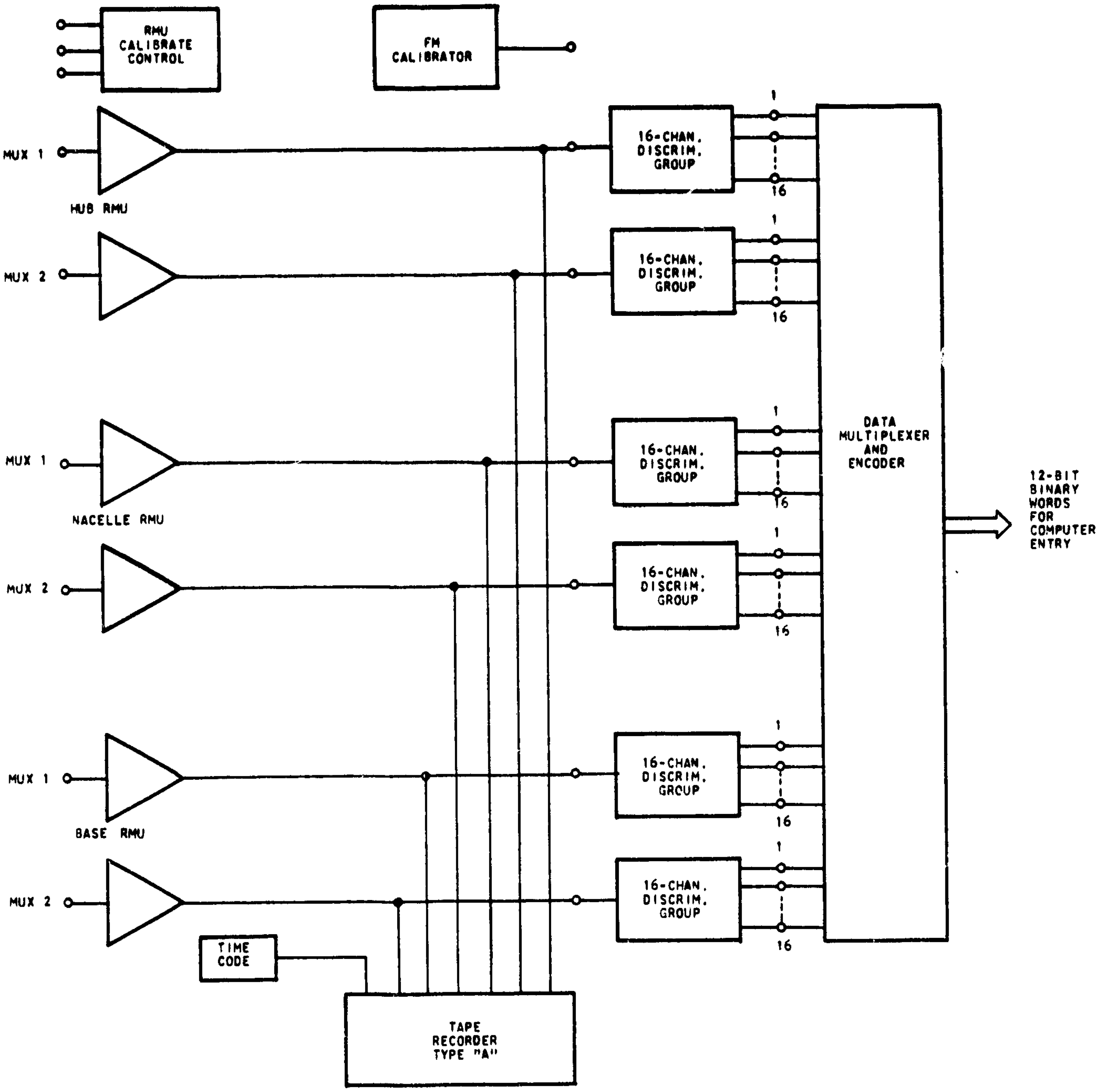


Figure 7-1. Preparation for Computer Entry

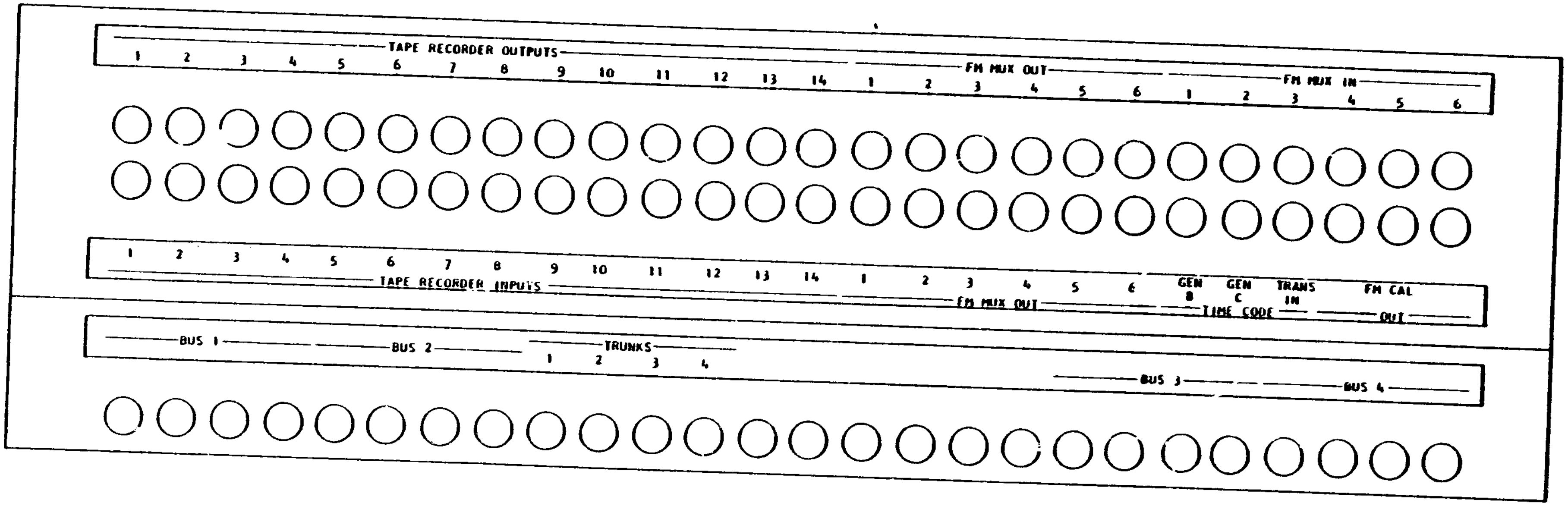


Figure 7-2. Input Patch Panel

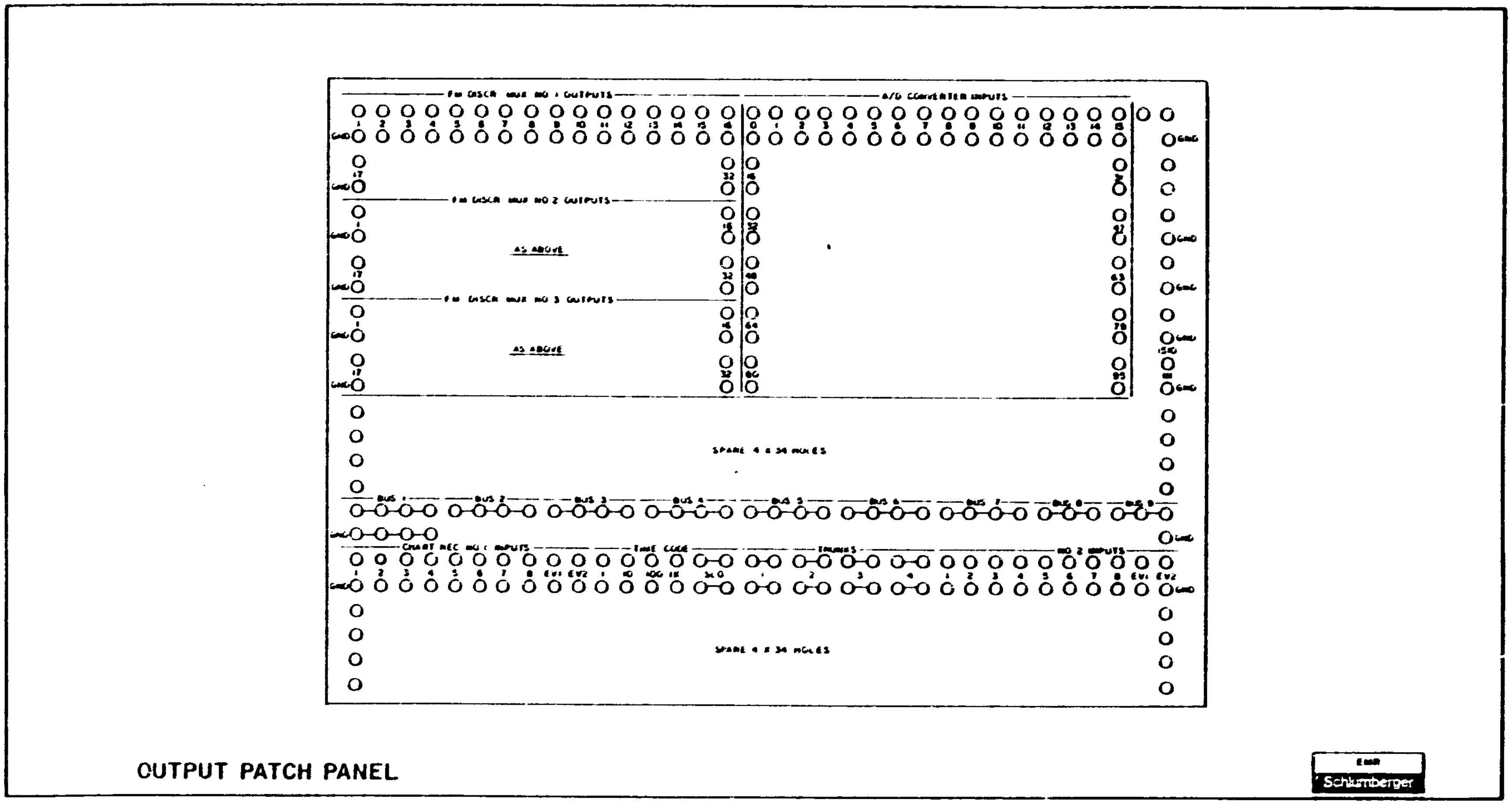


Figure 7-3. Output Patch Panel

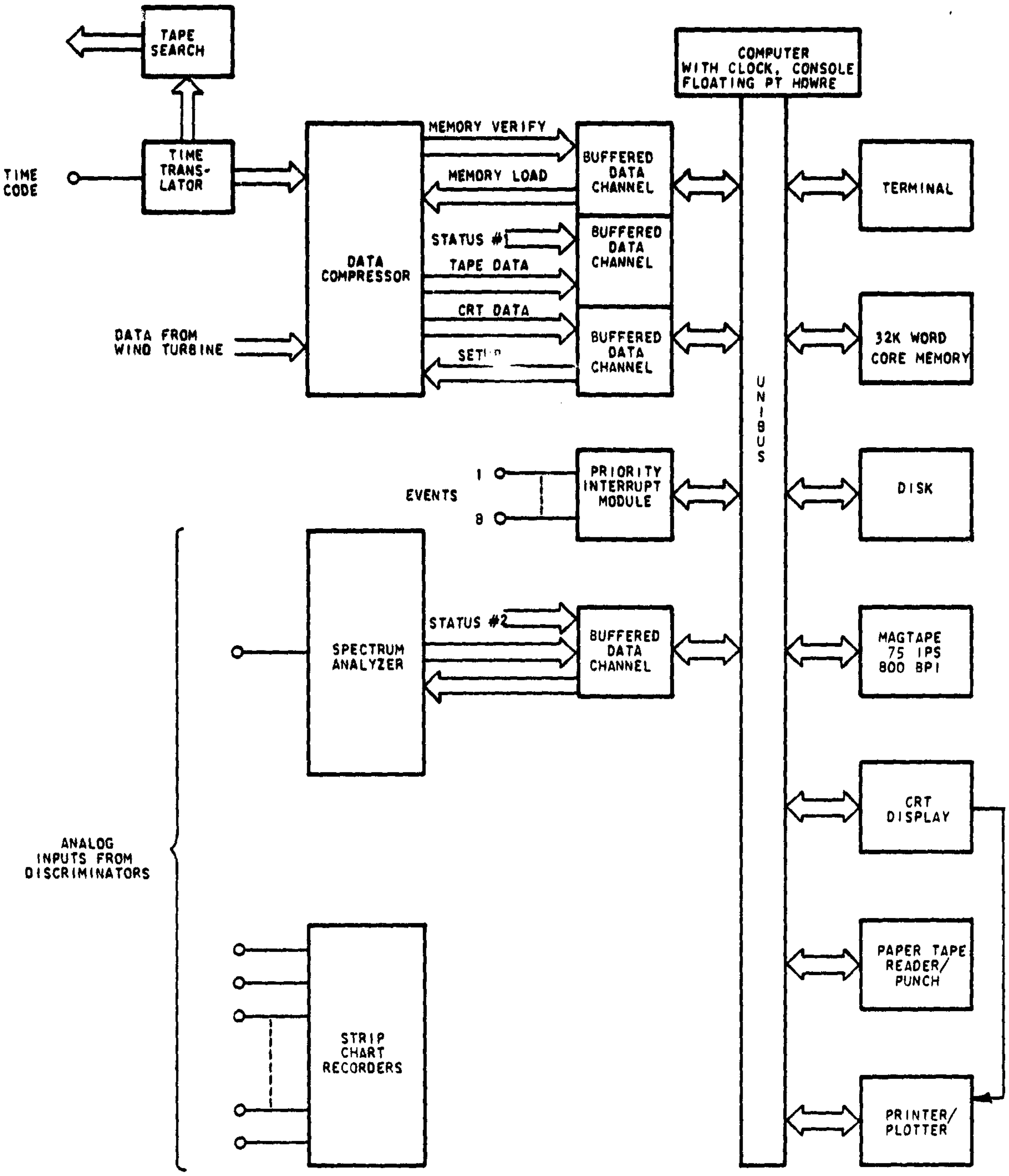


Figure 7-4. Computer Subsystem

7.3.2 Functions

A simplified functional illustration of the Compressor is shown in Figure 7-5. Measurements are input via Port 1 along with time (one millisecond resolution). When the momentary input rate exceeds the throughput rate of the algorithm processor, an input FIFO acts as a buffer.

Each measurement is assigned an interim identifier, consisting of the input port number and word number in the data frame, plus status bits. The identifier becomes a pointer to the 16-word algorithm processor which is unique to that measurement, and which contains all instructions and constants necessary to examine the data content each time the measurement occurs.

Four major modes are possible under program control:

a. Normal compression -- each measurement is examined and passed or rejected according to its algorithm test(s).

b. Limited-group compression -- high-priority processing takes place; measurements which are not in the high-priority group are rejected without test.

c. Force-one-look operation -- one output is made of each measurement (or of certain selected measurements), whether or not it passes the algorithm test.

d. Throughput -- all data is output without test.

7.3.3 Data Testing

Each measurement value is tested in accordance with the appropriately selected algorithm or algorithms (see Table 7-1). If it fails the test(s), it is rejected; if it passes one or more, it is output.

If the "status" bit in the algorithm process is set, a status word and tag are generated and output with the measurement. This word tells which algorithms were applied to the word, and why the data passed.

One bit in the algorithm process is an "alarm" bit. If this is set for a given measurement, an alarm pulse is generated and output whenever the measurement passes the test(s). This can be used to trigger a computer interrupt, or to cause other action in the station.

Each passed measurement is accomplished by a "tag," preassigned to identify the data to the computer. By selection of the tag content, programmers can make optimum use of this important tool.

Part of the algorithm processor information tells the Compressor where to send each measurement and tag (Port 1, 2, and/or 3). Ports 1 and 2 are conventional 16-bit outputs, while at Port 3 the data and tag are on separate sets of lines. In this system, Port 1 outputs data for the CRT display and Port 2 outputs data to be recorded on computer data tape.

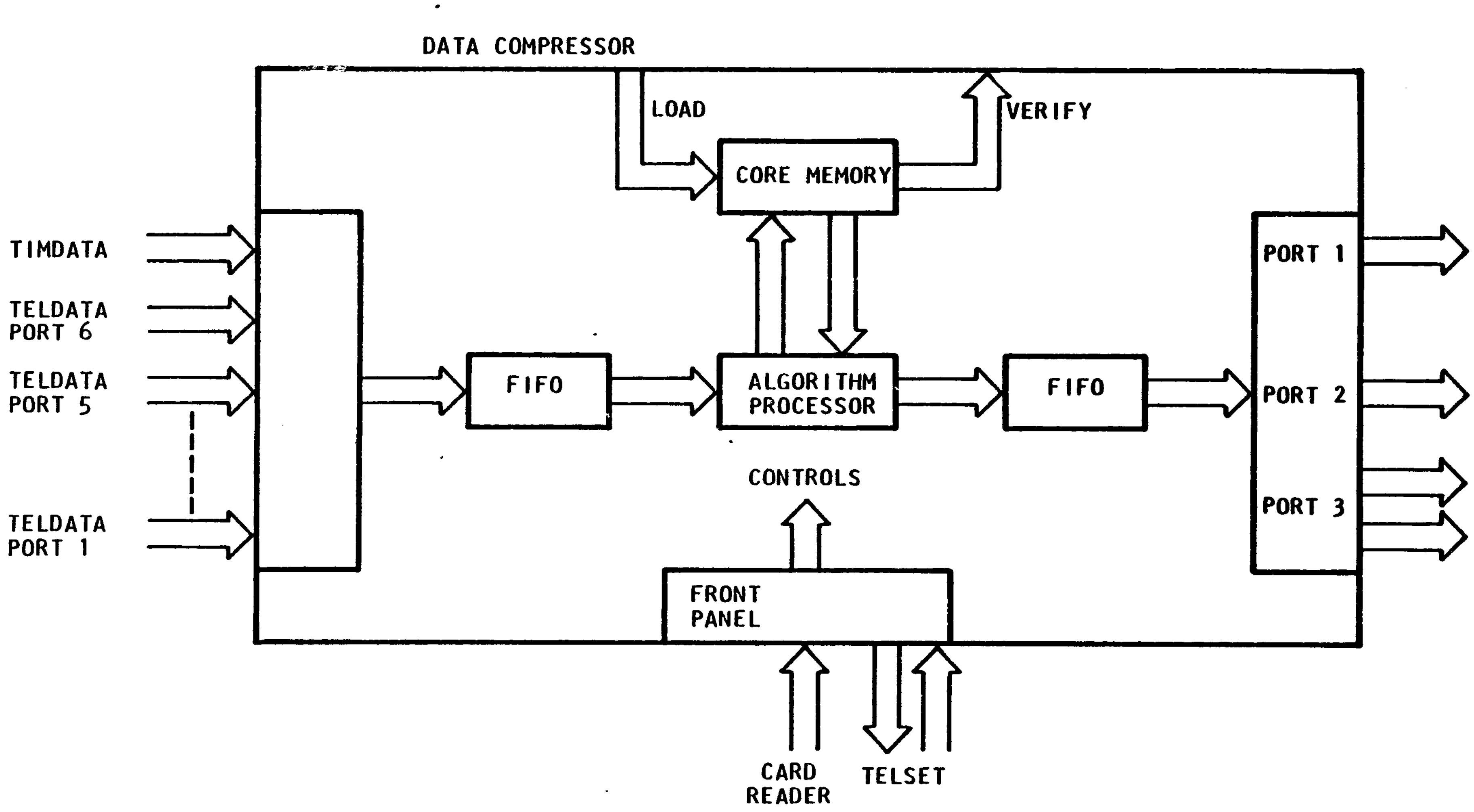


Figure 7-5. Data Compression Subsystem

Table 7-1. Algorithm Processes

MNEMONIC	ALGORITHM DESCRIPTION	MICROSECONDS	
		PASS	NO PASS
REJ	Reject without test.	---	0.9
THR	Throughput (pass) without test.	2.9	---
BMA or NBM	Bit Match or No Bit Match o Test the designated bits. Pass the word if there is: (a) Bit Match, or (b) No Bit Match. o Constants to be put into memory for each measurement: (a) Bits to be tested, and (b) Pattern to be matched by these bits.	4.6	3.3
ILI or OLI	In Limits or Out of Limits o Test the data value to see if it is within the designated limits. Pass the word if it is: (a) In Limits, or (b) Out of Limits. o Constants to be put into memory for each measurement: (a) Upper Limit, and (b) Lower Limit.	4.6	3.3
BCH	Bit Change o Compare the word with its most recent value on a bit by bit basis. Pass the word if there has been a Bit Change in the bits of interest. o Constant to be put into memory for each measurement: Bits to be examined.	5.4	3.3
ZFN	Delta o Compare the data value with its last output value. Pass the word if the value differs from the last output value by more than a specified delta (change). o Constant to be put into memory for each measurement: Allowable delta.	5.4	3.3
NSE	N-Sequential o Discard "N-1" Sequential occurrences of the measurement, then pass the measurement once. o Constant to be put into memory for each measurement: "N."	5.3	3.6

Chained algorithms require less than the sums of their individual processing times. Words in a subframe require 0.84 microseconds longer for processing; words in a sub-subframe require an additional 1.68 microseconds.

7.3.4 Time Merging

Time is merged with incoming data every millisecond or every frame. Minor time (milliseconds) is input with a unique tag; every second (or subframe, etc.) major time (seconds/minutes and hours/days) is input.

7.4 Telemetry Interface

7.4.1 General

In order for data processing to be handled efficiently in the computer, it is necessary that telemetry and time data be arranged properly in preassigned buffer sections of the computer memory. Data rates can be very high in a telemetry system, data flow is continuous, every data word must be entered properly, a new buffer area must be ready for data whenever one is completely filled, and each buffer area must begin coincident with the start of a frame so that words can be identified by memory location. All of these conditions brought about the need for interface hardware and software, and resulted in the development of the Buffered Data Channel, Priority Interrupt Module, and TELEVENT software. Figure 7-6 shows these modules in the system.

In preparation for typical data handling, the operator enters information at the system keyboard which enables the Buffered Data Channel to establish two areas in computer memory as data buffers. These areas are typically the same size as the desired records on output magnetic tape or disk storage (up to 4096 words). Instructions are given by the operator which specify also the routines which will be initiated by various occurrences ("events") in the incoming data -- when each buffer area is full, when frame synchronization or subframe synchronization occurs, when a given time-of-day is reached, etc.

After the system is set up, action is completely automatic. The Buffered Data Channel recognizes an event which prepares it for data entry, then an event which signals the presence of the word which should go into the first buffer location, and so on. Each time a lull occurs in data entry (frame synchronization pattern. for example), a pulse from the Time Code Translator automatically switches action from the data port (A) to the time port (B) for the time merging. When each buffer area is filled, the Buffered Data Channel automatically shifts to the other buffer area, and action is started to process and/or store data from the just-completed buffer.

Data and commands are output from another buffer area through the "0" port automatically at the proper times under program control, also.

Any events can be entered into the Priority Interrupt Module, linked to programs which have been stored and converted to the appropriate interrupt processes. Any event of overriding priority can be serviced in 2.5 microseconds; return to the original program takes place 1.5 microseconds after the interrupt program is completed.

7.5 Direct-Memory Bus

This Computer has a universal 16-bit interface bus for high-speed (up to 1,200,000 words per second) bit-parallel data transfers. These buses are the key to efficient data transfers within a system.

The Buffered Data Channel interfaces directly with the 56-line bus. When data words are ready for buffer entry, a bus request is issued, the computer grants

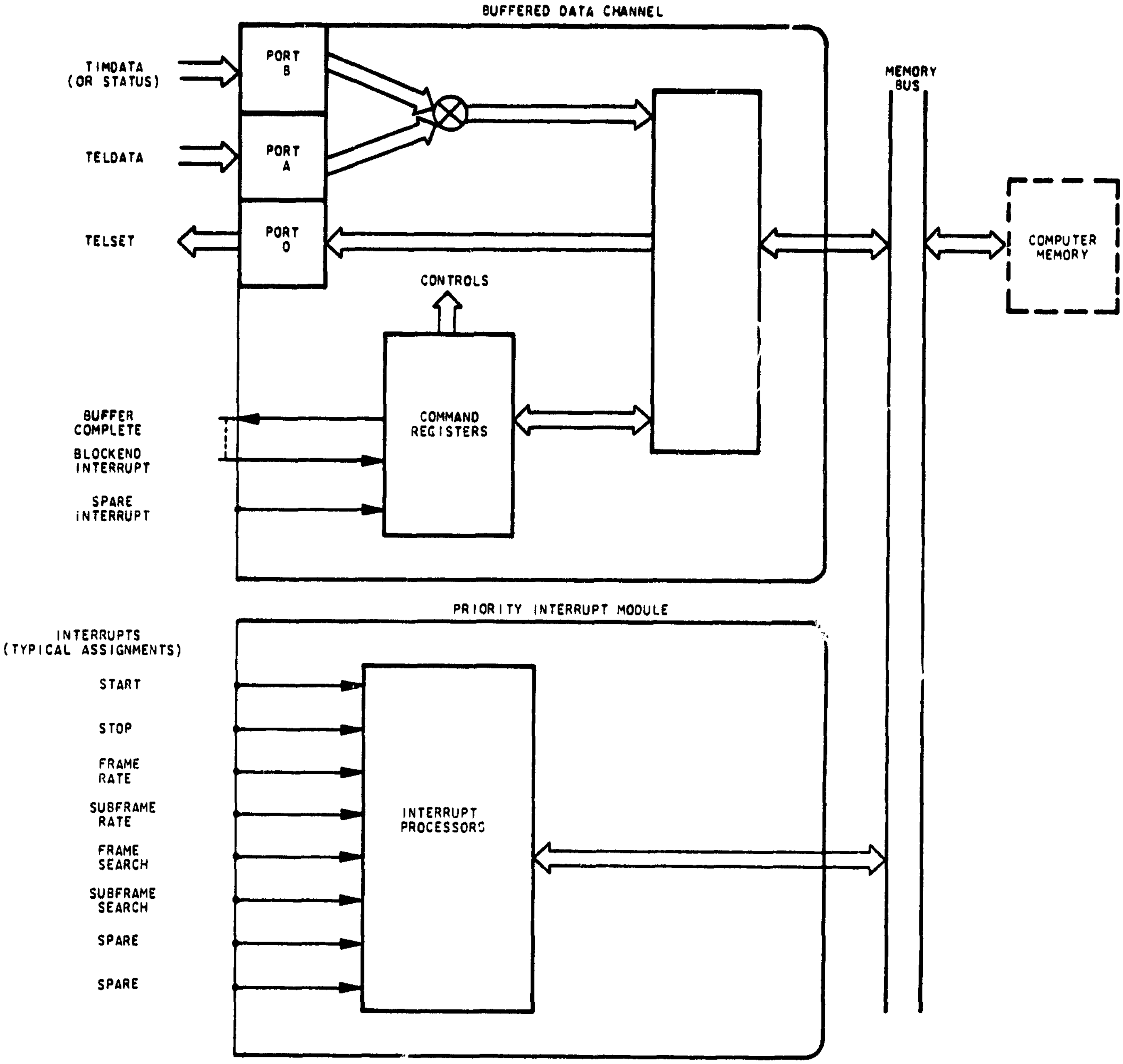


Figure 7-6. Interface to Computer

the request, and words are transferred to memory without computer intervention as described already. Similarly, when data from a buffer is to be transferred to a mass storage device such as a magnetic tape or disk, the transfer takes place at high speed via bus without attention from the computer. Once the computer has established the right to deal directly with memory, the device becomes the "master" and core memory is the "slave." The relative importance of the device is established by a priority structure; if two devices ask for the bus at the same time, the higher priority device will receive control.

In a somewhat similar manner, the Priority Interrupt Module deals with the computer. When an interrupt occurs, the module locates the memory address at which the associated service routine is located, and the computer runs the appropriate program. Relative priorities in the module are established by jumper wires on the module.

Once data is stored in buffer memory, any device on the bus has access to the data. The bus architecture means that the computer does not have or need separate input/output instructions. The same instruction which performs a register-to-register transfer within the central processor can also transfer data to memory, or from memory, or from a device to another device on the bus. Data can be processed within the computer while a device is bringing data into memory, and there is no interference.

7.6 Central Processor

The Computer has these features:

- 16-bit operation, with memory addressable as bytes or as words. The 16-bit word, when used as an address, gives direct addressing up to 64k bytes (32k words). The user has access to 28k words in a 32k memory.
- Processing of either bytes or words.
- Asynchronous operation, meaning that system data rates can be changed by changing peripherals. Each pair of system elements runs at its own top speed.
- Direct memory access (DMA) by use of the bus.
- Eight internal general-purpose hardware registers.
- Automatic priority interrupt structure.
- Vectored interrupts for fast response to inputs.
- Single- and double-operand instructions.
- Power-fail and automatic-restart capability.
- Memory addressing to 128k words (124k usable), by use of two additional bits for location address.
- Fast processing speeds.
- Hardware multiply and divide capability.

7.7 Operator Interfaces

7.7.1 Terminal

The console Terminal has 30 character-per-second throughput, insured by a "catch-up" mode which is activated any time that more than one character is in the 16-character buffer. Also it has quiet operation, infinitely variable vertical paper adjustment, variable paper width, and multi-part paper capability.

The typewriter-style keyboard assures easy operator adaptation. The 7-wire print head is designed to have long life and produce extremely clear characters.

7.7.2 Paper Tape Reader/Punch

A paper tape reader/punch in the system permits program development, system loading, and diagnostics loading. It reads conventional 8-level fan-fold paper tapes at 300 characters per second, or punches at 50 characters per second.

7.8 Mass Storage

7.8.1 Cartridge Disk

The system contains a Cartridge Disk controller with one Disk Drive. The disk provides a total of 2.6 million words of storage. Another Disk Drive could be added to the system later if desired; the controller handles multiple drives.

The cartridge disk subsystem is designed to offer high performance and combine current technology with reliability and maintenance features.

- Capacity:

  5.2 million bytes (2.6 million words) per drive (formatted)

- Performance:

  55 milliseconds average seek time

  256,000 bytes per second peak transfer rate

The disk is a top-loading, rack-mounted, cartridge drive. Average access time to any word on the disk, including head positioning and rotational latency, is less than 68 milliseconds. Cartridge interchangeability is assured. An embedded closed-loop servo positioning system provides the disk with data integrity and reliability, since the servo information is continuously sampled by the same head that reads and writes the data. Read and recording techniques are implemented by a phase-locked-loop clock system and modified frequency modulation (MFM) recording. Cyclical Redundancy Checking (CRC) is performed on all data transferred to and from the disk.

7.8.2 Tape Recorder/Reproducer

One Digital Magnetic Tape Controller/Tape Drive is used to read or write industry-compatible digital magnetic tapes. The tape unit provides for recording data during analog tape playback. The tape can then be played back for data processing and analysis. Tape unit characteristics: seven tracks, 800 bytes per inch, 75 inches per second. The tape unit records each data word as two bytes. At 800 bytes per inch, the tape unit will handle the data at an average rate of approximately 48,000 bytes per second. Since two bytes are required to write one data word, the average input rate from the telemetry front end to the computer can be up to 24,000 words per second on a continuous basis.

The unit will be updated to 9-track, 1600 bpi operation.

7.9 Displays

7.9.1 CRT Display

The system includes a CRT Display Unit. The CRT is an alphanumeric display 8.5 inches wide and 4.5 inches high; it has 24 lines, 80 characters per line. The character code is ASCII, 96 printing (including space) upper and lower case. The display has a keyboard and a composite video output. The refresh rate is 60 Hz.

7.9.2 Printer/Plotter

The printer/plotter, also usable as a hard copy unit for the CRT Display, is a high-resolution printer/plotter with a Matrix Controller.

The printer/plotter is an electrostatic device with no moving parts in the writing process, high output speeds, the ability to produce high quality plots and graphs, and the ability to accommodate a wide variety of fonts, languages and letter sizes. The machine is interfaced to both the Computer and the CRT display.

The device has the following characteristics:

- Hardware character generation.
- 7 x 9 dot matrix for generated characters.
- Standard 64-character ASCII character set. Optional 96 or 128 character ASCII character set.
- Plot width of 10.24 inches on 11-inch wide paper.
- Roll or fan-fold paper.
- 132 columns per line, 12.5 characters per inch.
- Print speed of 500 lines-per-minute. Plot speed of 1.2 inches-per-second.
- Resolution of 100 dots per inch vertical and horizontal.

7.9.3 Strip Chart Recorders

Information in the analog domain is available for display on the two 8-channel strip chart recorders. Each channel is printed with 40 millimeter, 50 division scale for viewing, and writes at a speed which is selectable by the operator.

7.10 "TELEVENT" Software

7.10.1 General

In the typical computer system, the computer is the "boss." It asks for data when all previously-assigned tasks have been completed. Most data sources are responsive to on-off commands from the computer, and will hold data indefinitely between requests. The magnetic tape recorder, disk, or other peripheral is always ready, but never "impatient."

On the other hand, in this telemetry/computer system, the data stream is generated in the Wind Turbine and cannot be controlled by the computer. The multiplexer generates a frame pulse and then scans a frame of data, each measurement of which is quantized and output as a word. On completion of a frame, another frame pulse is generated immediately, then another frame of data. Whether the data is to be entered into the computer immediately (in real time), or later (via playback of instrumentation tape recordings), the data words occur in the same continuous sequence, interrupted only by periodic frame pulses.

This telemetry/computer hardware is keyed to the occurrence of synchronization, and enters every data word from every frame. The entry of data is started coincident with the beginning of one of the frames, so that the words of the frame can be organized in buffer memory in an identifiable manner. When a section of buffer memory is filled, another section is opened instantly and the necessary action started to process or store data from the first buffer while the second is filling. Each frame is tagged with the time of occurrence. All of this takes place at data rates as high as 250k words (up to 16 bits each) per second, without the loss of a single word! The entire process can be started, stopped, or modified by an engineer or technician, rather than by a specially-trained programmer.

This system contains parallel data words with timing signals, a computer using the bus as a direct access to memory, a Buffered Data Channel and Priority Interrupt Module for data and event interfaces in an intimate hardware/software configuration, and TELEVENT (telemetry event-related) software, operating under one of the standard software systems to perform all of the special functions which are required to handle telemetry data.

TELEVENT software performs five functions in the system. These are:

1. Set up the telemetry front end equipment characteristics automatically to enable it to acquire the data formats which are expected (TELSET).

2. Set up one or more paths for entry of data into the buffer memory, and determine the characteristics of the buffer areas.

3. Merge and enter high-speed data (TELDATA) and time (TIMDATA) into alternate buffer areas as described above.

4. Process or output the contents of each newly-filled buffer as rapidly as it is filled, to get it ready for new data.

5. Run low-priority programs if time permits, on a priority-interrupt basis.

TELEVENT software is engineer-operated, and does not require a knowledge of computer programming language.

7.10.2 Use of Events

After initial setup by an operator, all TELEVENT functions are caused automatically on the occurrence and recognition of specific events. This feature is an absolute necessity in a telemetry/computer software system since no operator would be able to respond manually at the data rates which are common in telemetry.

The choice of events to control a system is made at the time of system design and depends on the needs of the user. Even after a system is in use, more events can be added or the priorities or related processes revised by EMR or a trained user.

Events are input to the system via the Buffered Data Channel (two event inputs per module) and the Priority Interrupt Module (eight event inputs per module).

7.10.3 Data Acquisition, Display, and Storage Software

TELEVENT provides the CONNECT, EXECUTE and HALT directives for operator control of data acquisition. The CONNECT directive is used to establish a software interface between real-time programs and the significant events that cause their execution. There are two major real-time tasks required for the MDS:

- o Real-time alphanumeric CRT display
- o Digital tape formatting

The alphanumeric CRT display requirement is fulfilled through the use of Real-Time Data Monitoring Software (RTDMS).

The digital tape formatting requirement is accommodated through the use of Real-Time Mag Tape Formatter (RTMTF).

7.10.3.1 Real-Time Magnetic Tape Formatting (RTMTF)

The following features of RTMTF provide a high performance mag tape support capability:

- o Unique parity error handling.
- o Interrupt handling.
- o Multiple controllers and multiple drives with no additional software required.
- o Different types of controllers (low performance to high performance).
- o Tape switching (if second tape is available).
- o Data in an easy-to-recover format.
- o FORTRAN compatibility.

RTMTF provides operator parameter specifications including:

- Rewind
- File definition
- Logical unit assignment
- Tape header information
- Pre-record identification/description

Tape formats are shown in Figures 7-7 and 7-8.

7.10.3.2 Real-Time Data Monitoring Software (RTDMS)

RTDMS software may be operated simultaneously with digital tape formatting, or digital magnetic tapes generated by TELEVENT may be played back and processed by RTDMS in the off-line mode. During setup, the user selects which channels of data are to be monitored. He also must enter alphanumeric name and unit designator fields and engineering unit conversion coefficients.

Any order of engineering unit conversion may be specified for any channel of data. This setup information is usually entered before real-time processing is started. However, changes can be made during real-time operation through operator interaction at the CRT keyboard. Complete setup software is included as part of the RTDMS package. The user specifies a refresh time interval, during which time the RTDMS will find the maximum and minimum data values and calculate the average data value for each selected channel. When the time interval has passed, the collected time slice of data is processed for output, and a new time slice is begun.

The output consists of a 72-character line for each channel of data selected for monitoring. The following items are displayed for each channel (see example below):

- Average value in engineering units (E.U.)
- Maximum value in E.U.
- Minimum value in E.U.
- Measurement name (as wind velocity)
- Engineering unit designator (as miles per hour)
- Tag (word or channel number)

The terminating time of each time slice and a header line describing the columns of data are output with each slice of data. An example of the output:

```
000:00:10:26.0
TAG    MEASUREMENT    AVERAGE    UNITS    MAXIMUM    MINIMUM

 1        SPEED        100.00     MPH      120.00      80.00
 2      OIL PRES        80.60     PSI       80.80      80.4
 3     WATER TEMP      190.50     DEG      191.00     190.0
 :
 :
 n    ACCELERATION       6.00     G's        1.11       7.75
```

Modules within RTDMS, as well as other support software, include the following paragraphs.

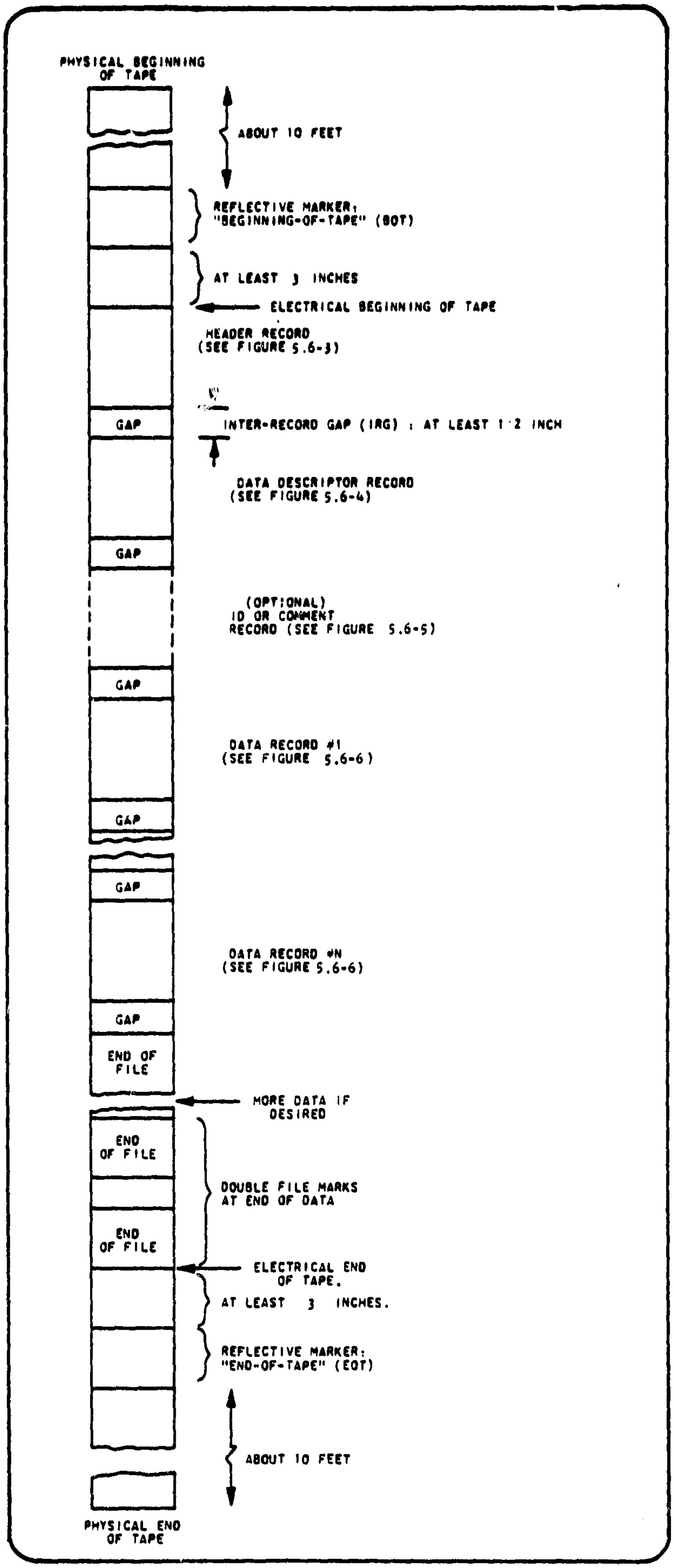


Figure 7-7. Tape Format, Overall View

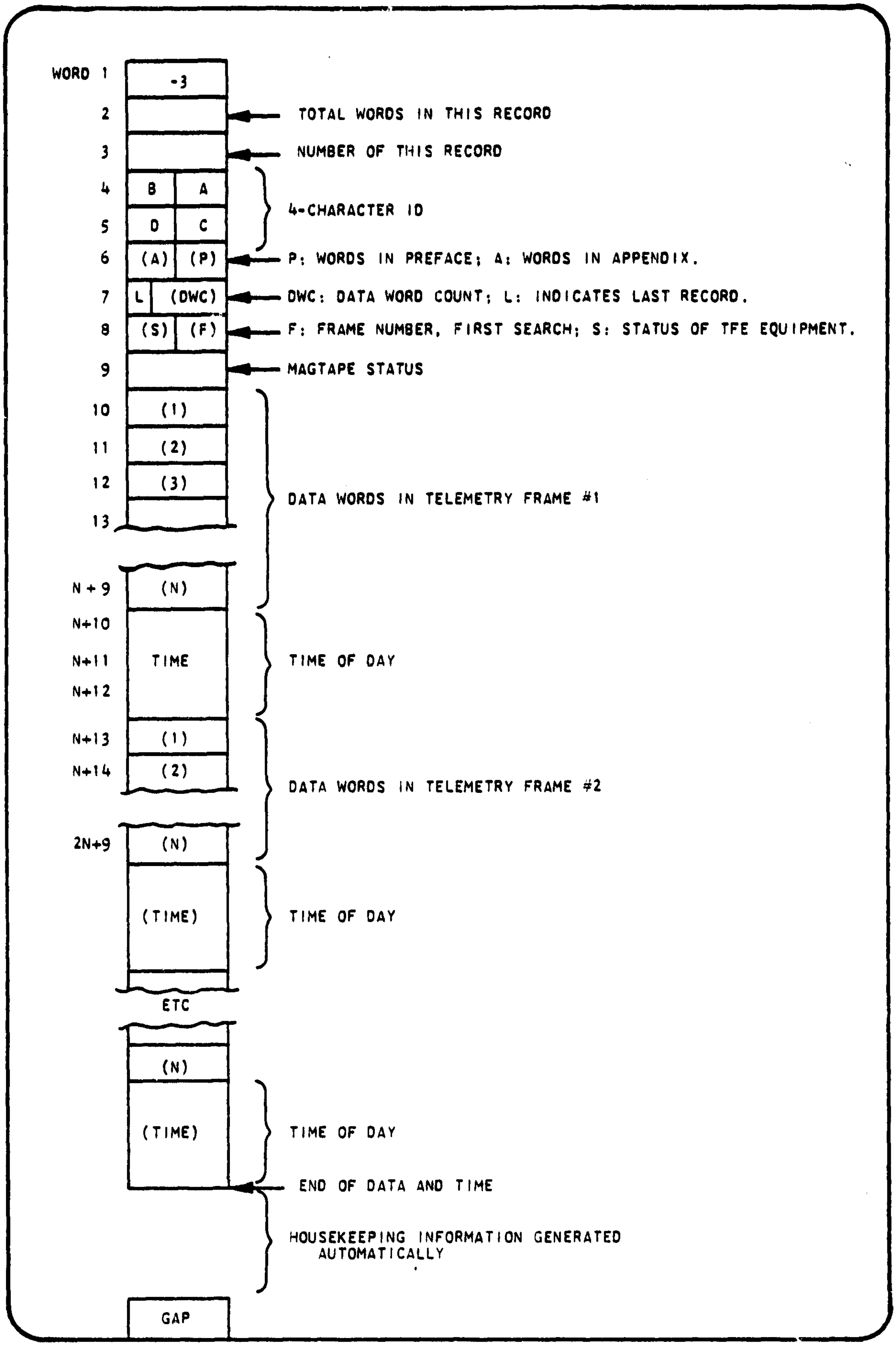


Figure 7-8. Data Record

7.10.3.2.1 The Decommutation Software (DECOM) allows NASA to route selected channels of data to the process which accumulates data for the average, minimum and maximum calculations.

7.10.3.2.2 The Data Base software allows NASA to set up a data base using TELEVENT. The memory resource allocator allocates core as the data base is being set up. For the RTDMS, an area of core is allocated for each selected data channel. This area is used to store real-time data, alphanumerics, and engineering unit coefficients associated with the channel.

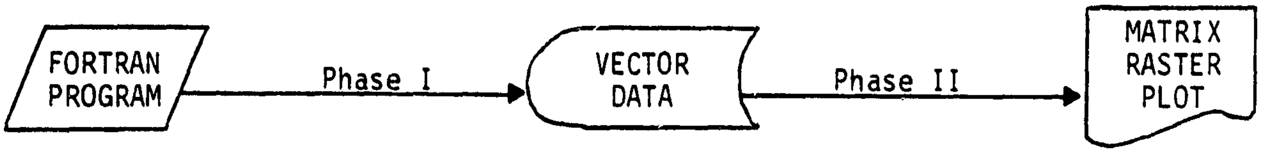
7.10.3.2.3 The Output Processor software (DISPLA) is used to do engineering units conversion and formatted output to the alphanumeric CRT.

7.10.3.2.4 Printer/Plotter Software

Versaplot 1 is a subroutine for use with the system printer/plotter. Predefined operations incorporated within the subroutines provide the power to execute detailed functions without difficult programming. At the same time, variable arguments with preset values carried in the program give the programmer an efficient way to adapt to special plotting requirements.

Using the seven Versaplot utility subroutines, the programmer can write any general-purpose graphics program by describing vector plots as he would with a pen. The software converts the plot to raster data.

Since raster-scan plotting proceeds in one direction only, Versaplot utilizes a two-phase plotting technique. In the first phase, the entire plot image is generated in vector data from a Fortran program containing Versaplot subroutines. In the second phase (handled automatically by Versaplot software), the plot is considered as a series of sequential bands. The vector data for one band at a time are scanned and then converted to raster data for plotting.



Versaplot Operation

Bands may be as small as a single scan or as large as the total page, but usually they consist of 16 to 32 rasters and require 4096 to 8192 bytes per band. The size of the bands used in each case is determined by the programmer. Versaplot plots a typical 11 x 8-1/2 inch original plot in a few minutes, and additional copies in less than ten seconds each.

Raster scan graphics are plotted using seven basic FORTRAN callable subroutines:

Draw
Scan
Tone
Mode
Note
Axes
Form

7.10.3.2.5 Digital-Tape-to-Plotter Software

A program (DTPLOT) allows NASA to specify data parameters previously recorded on digital tape to be plotted on the printer/plotter through the use of Versaplot software.

The user invokes DTPLOT by issuing a "RUN DTPLOT" directive. DTPLOT then requests the following arguments from the user:

- Digital Tape Run ID
- Time Slice
- Channel ID's of data to be plotted
- Abscissa (i.e., X axis) Time Range

The DTPLOT program searches the digital tape for the specified Run ID; searches the specified Run for the desired time slice; and reads into the computer all data for the specified channels within the specified time slice. DTPLOT automatically scales the Y-axis to provide maximum deflection of the data for each channel specified. DTPLOT creates a plot image of vector data on the system disk. Once the image is created, Versaplot software automatically converts the vector data to raster data, and transfers the plot image from disk to the plotter.

All plots are represented in engineering units with E.U. conversion being done by DTPLOT from data base records for the Run specified. Both axes of the plot are labeled numerically and include a minimum of ten (10) major divisions and five (5) minor divisions to facilitate visual interpretation. All plots are labeled with the time during which the data was recorded and an English title of the parameter being plotted.

7.10.3.2.6 Diagnostic Software

Diagnostics are used to give users a reasonable assurance that the computer system is operational prior to its usage. Diagnostics are written to test most logic functions of the equipment. They also provide for dynamic testing of most functions.

Diagnostics provided with this system are stand-alone programs. There are one or more diagnostics for each computer peripheral and several tests for the processor and memory. Diagnostics are also used by the computer maintenance engineer to determine failing functions, and aid him in analyzing failures. Diagnostics, along with a CRT, multimeter, and logic diagrams, are the primary tools for computer system maintenance.

The system software includes diagnostics for the following units:

- Processor
- Memory
- Floating Point Unit
- Bootstrap Loader
- Real-Time Clock
- Disk
- Keyboard Terminal

- Paper Tape Reader/Punch
- Mag Tape Unit
- Asynchronous Interface

The diagnostic software package consists of:

- Disk cartridge containing all diagnostic programs listed above.
- Writeup for each test.

7.11 Computer Software

In a system such as this, the operators are most aware of applications software which relate to test data or to the telemetry front end. However, all of the applications software is controlled by the top-level system -- the computer operating system -- even though it may be relatively transparent to the users. In this computer, a Disk Operating System (DOS) is used to operate the hardware and to call and supervise TELEVENT. This is one of three acceptable software systems; DOS was chosen because it is extremely efficient in a real-time application. Since this is a single-purpose system, no sophisticated software is needed.

The Disk Operating System (DOS) is a powerful, keyboard-oriented, program development system designed for use on this computer. The DOS Monitor facilitates use of a wide range of peripherals.

The DOS Monitor supports the user throughout the development and execution of his program by:

- providing convenient access to system programs and utilities such as a FORTRAN Compiler, an Assembler, a Linker, a debugging package, an Editor, a file utility package, etc.;
- performing input/output transfers at four different levels, ranging from direct access of device drivers to full formatting capabilities, while providing the convenience of complete device independence;
- providing a file system for management of secondary storage; and
- providing a versatile set of keyboard commands for use in controlling the flow of programs.

System programs and utilities can be called into core from disk or from mag tape, with Monitor commands issued directly at the keyboard. This feature eliminates the need to manipulate numerous paper tapes, and provides the user with an efficient and convenient programming tool.

DOS gives NASA the capability of complete device independence. Programs can be written without concern for specific I/O devices. When the program is run, NASA can select the most effective or convenient I/O device available for the function to be performed. In addition, if the system configuration is altered, many programs can take advantage of the new configuration without being rewritten. Logical names can be assigned to devices within the system, enabling symbolic referencing of any device. No concern need be given to I/O buffer size within the user program, yet the user can alternatively retain direct control of I/O buffers.

All the input/output (I/O) transfers are handled by the Monitor in any of three user-selected levels: READ/WRITE, RECORD/BLOCK, and TRAN. READ/WRITE is a formatted level of I/O in which the user can specify any one of nine options. RECORD/BLOCK is a file-structured, random-access I/O level with no formatting. TRAN does basic I/O operations at the device driver level. All inputs and outputs are concurrent and interrupt-driven.

The file system on secondary storage uses two types of files: linked and contiguous. Linked files can grow serially, and have no logical limit on their size. Contiguous files must have their lengths declared before use, but can be randomly accessed by RECORD or BLOCK I/O requests. All blocks in a contiguous file are physically adjacent, while blocks in a linked file are typically not adjacent (the first word of each block contains the address of the next block). Files can be deleted or created at any time, and are referenced by name.

The user communicates with the Monitor through keyboard instructions called commands, and through programmed instructions called requests.

Keyboard commands enable the user to load and run programs; assign I/O devices or files; start or re-start programs at specific addresses; modify the contents of memory locations; retrieve system information such as time of day and date; and dump core. Users can utilize programmed requests, which are macros assembled into the user's program and through which the user specifies the operation to be performed by the Monitor. Some programmed requests are used to access input/output transfer facilities, and to specify where the data is, where it is going, and what format it is in. In these cases, Monitor will take care of bringing drivers in from disk, performing data transfer, and notifying the user of the status of the transfer. Other requests access Monitor facilities to query system variables (time of day, date, and system status), and to specify special functions for devices.

Principal DOS System Programs are:

Text Editor

Assembler

Linker

File Utility Package

Debugging Program

FORTRAN IV

System Librarian

File Compare

File Dump

File Verify

7.12 Spectrum Analyzer

The ability to input spectral data to the Computer is provided by the Digital Real-Time Spectrum Analyzer. This has accuracy and ease of operation in real-time spectrum analysis. It is an all-digital instrument which covers the frequency range from 0.1 Hz to 25.6 kHz with 256 lines of resolution in 10 standard bands. A built-in CRT displays the real-time or averaged spectrum, and a LED display indicates amplitude in dB or frequency by means of an intensified spot cursor. Both rectangular and Hanning weighting are standard.

The averager operates in the linear, exponential, or peak modes, with the number of statistically independent spectra averaged selectable from one to 1024. The time remaining to complete an average is indicated on the front-panel LED display, and an "average complete" light illuminates to indicate the end of the averaging cycle. When averaging in the linear mode, the averaged spectrum can be held after the selected number of sums, or the instrument can then automatically switch to the exponential mode.

The full-scale input sensitivity range is 0.1V to 10V in five steps of 10 dB each. The input signal is converted to 8-bit digital form which, in conjunction with a unique "dither" technique, provides a true dynamic range in excess of 60 dB. The time domain waveform stored in the input memory can be viewed on the built-in CRT, and provision has been made to capture and display transients.

An XY recorder output has been provided for obtaining hard copy plots of amplitude vs. frequency. A built-in frequency marker permits XY plots to be made which begin and end at any predetermined points in the spectrum. Amplitude calibration levels of 0 dB, -20 dB, -40 dB, and -60 dB are provided for calibrating the Y axis.

The key specifications are as follows:

Frequency:	0.1 Hz - 25.6 Hz to 0.1 kHz - 25.6 kHz in 10 ranges.
Resolution:	256 frequency lines.
Display:	CRT.
Accuracy:	Frequency = ±0.1%. Spectrum = 0.1 dB + 0.1% full scale. Frequency Response = ±0.2 dB.
Spectrum Averaging:	1 to 1024, 9 binarily related ranges.
Dynamic Range:	60 dB.
Window Functions:	Rectangular or Hanning.

7.13 Equipment Van ("Maxi-Van") Figure 7-9

The van is built on a standard running gear. The chassis is designed to assure proper cooling, ride, handling, structural integrity and floor layout.

The size and weight are such that the van may be transported over public roads without special permits or approvals. The standard highway, safety pollution and noise requirements are satisfied and certified (including the special California requirements). The propulsion system is a standard, gasoline-fueled, 440-cubic inch engine with three-speed automatic transmission. An 85-gallon gas tank ensures adequate cruising range. The suspension is an air-ride type on both front and rear axles. The chassis with tandem rear axle is rated at 21,000 pounds gross weight. The total estimated PIV weight, including all racks, hardware, spares, personnel and a full gas tank does not exceed 18,500 pounds. The van is also equipped with a leveling jack for stabilizing the vehicle when it is stationed at a specific Wind Turbine site. With the maximum gross weight of 21,000 pounds, the van is capable of maintaining the legal highway speed limit of 55 miles per hour.

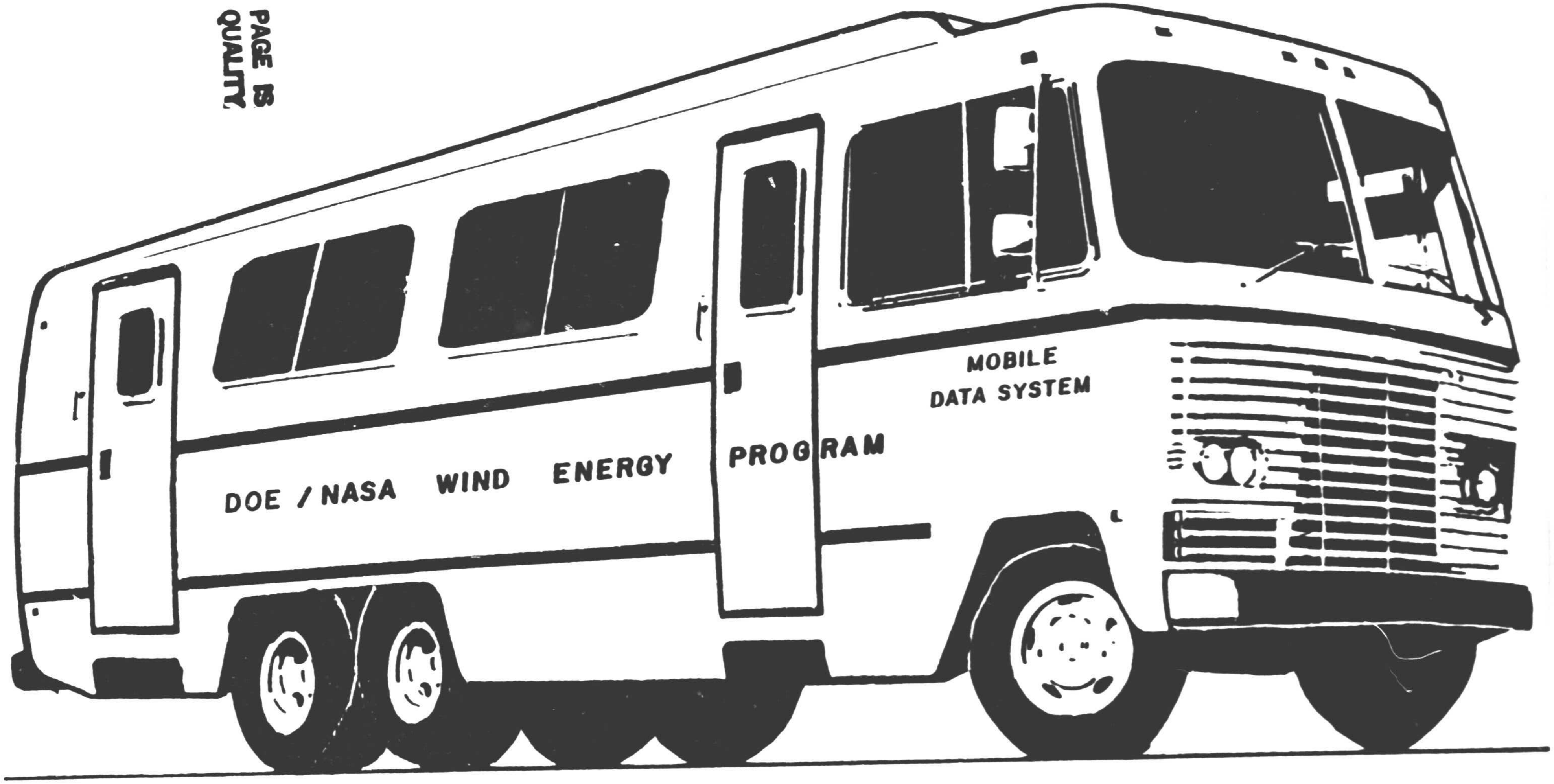


Figure 7-9. Equipment Van

Both the vehicle cooling system and the internal equipment cooling system are capable of operating at altitudes up to 10,000 feet and ambient air temperatures up to 50°C (122°F). Equipment cooling is provided via forced air supplied by two 24,000 BTU commercial air conditioners. The actual room air conditioning is provided by three 13,500 BTU roof-mounted units. The two units are mounted inside the van as shown in the layout, Figure 7-10.

The power dissipation of the internal equipments does not exceed 10,000W. Based on this and a personnel complement of up to five, the total air conditioning and heating requirements are 88,500 BTU's and 56,000W in order to maintain the required internal temperature range when the exterior environment changes from -20°F to +120°F.

The van frame, members, and understructure are coated with a commercial undercoating material. Although the roof of the PIV is of fiberglas construction, the interior surface of all of the metal exterior side panels is coated with a rust inhibitive material.

The van is painted red, white and blue.

The interior is finished in a manner that very accurately simulates standard laboratory conditions. Acoustic tiles are used on the ceiling in order to reduce the noise level within the van. The van meets the National Electrical Code for power distribution wiring.

The rack layout of the van is shown in Figure 7-11. All of the computer and telemetry equipment is mounted in standard 19 inch racks, each of which is bolted in at least two places to the vehicle floor and ceiling or walls. The system operator normally sits in the area of the Printer, which allows him to control the acquisition through that terminal, load and operate both the digital and analog tapes, and provide suitable patching for changing the system configuration.

The display area is located away from the system control area in the rear. This enables the observer and any visitors to view data on the strip charts, printer/plotter, CRT display, or Spectrum Analyzer without interfering with system control. Seating, work bench and storage areas have been provided for over the rear wheel wells. Both front and rear doors are provided. Visitors can enter through the rear door without disturbing the operator at the front of the vehicle.

The 30-foot van provides adequate working area while maintaining a vehicle length that can be readily handled by a non-professional driver.

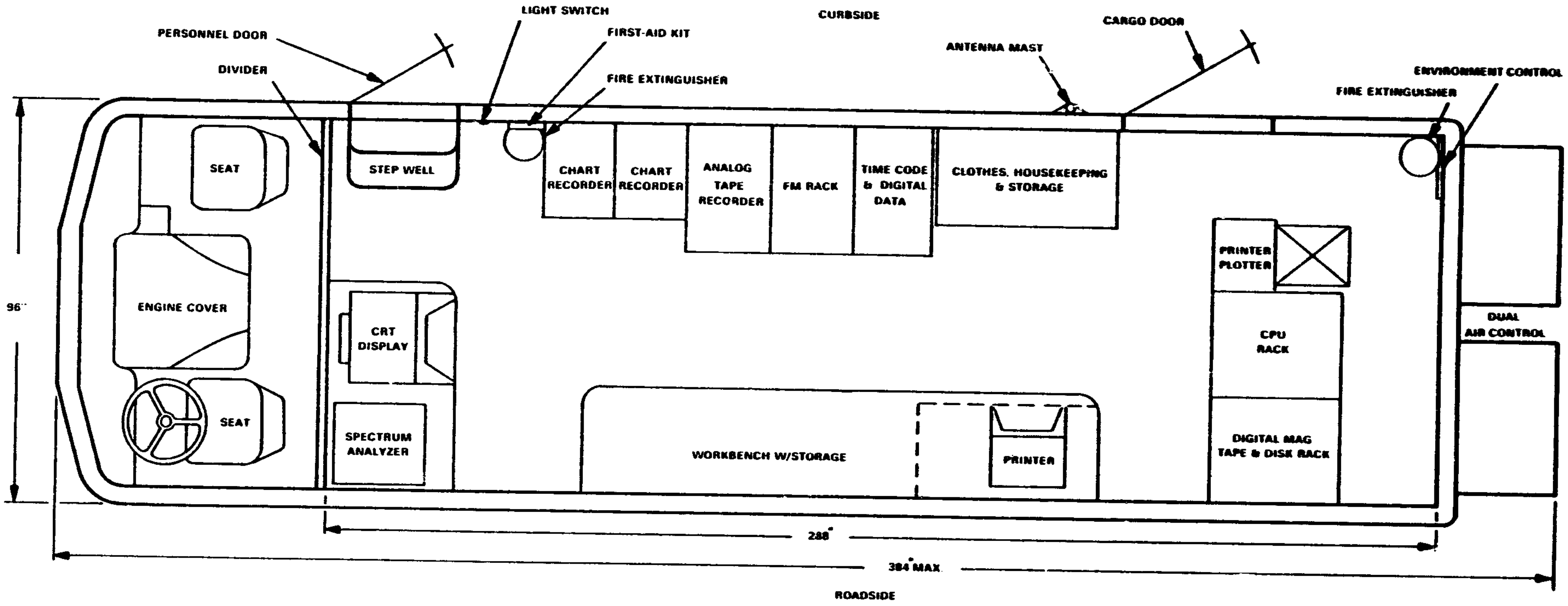


Figure 7-10. Van Floor Layout

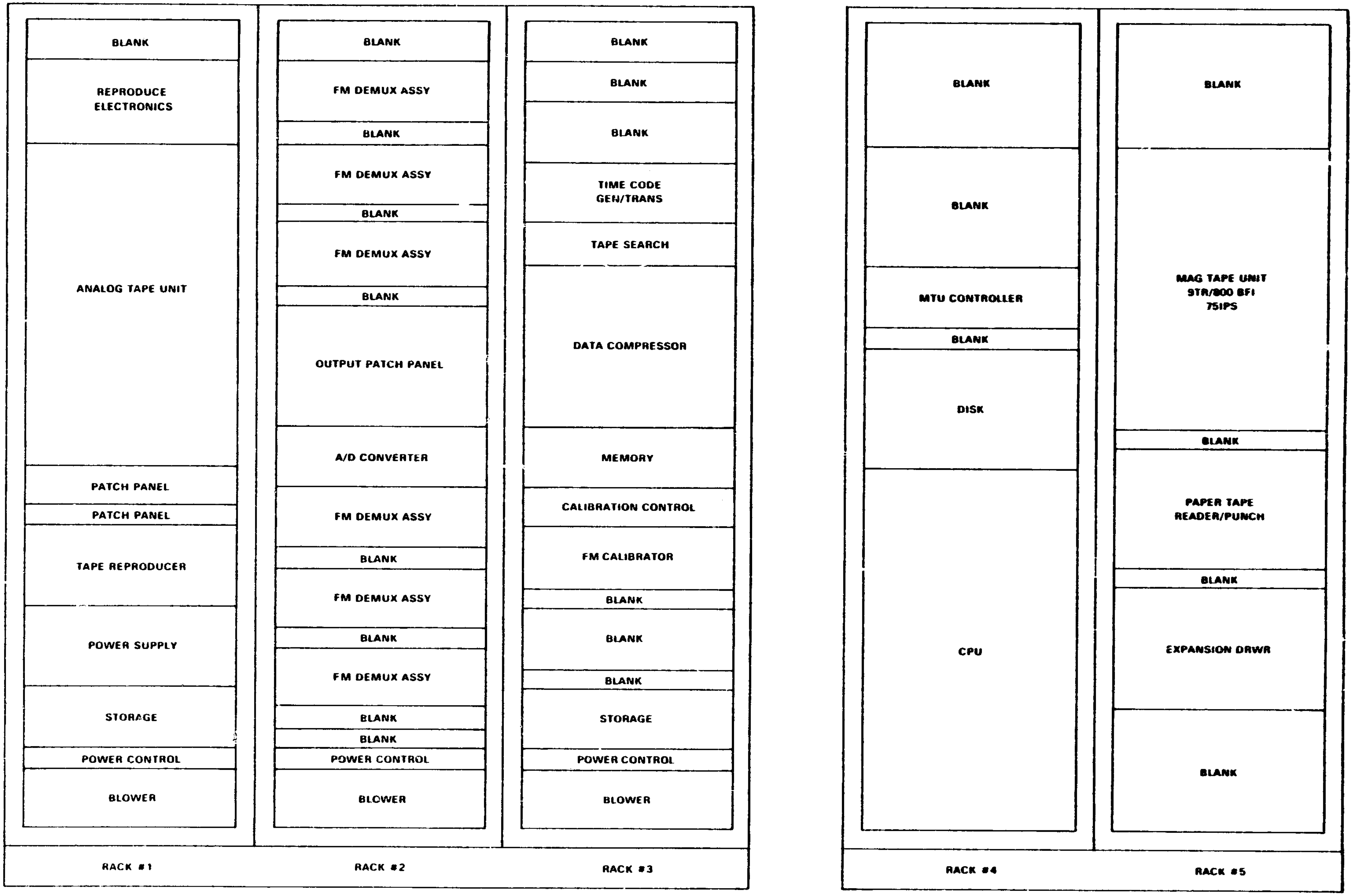


Figure 7-11. Van Rack Layout

8. MINI-VAN SYSTEM

8.1 Description

For those cases where a Wind Turbine is to be operated without full on-site data analysis equipment, the equipment as described herein is used as a data analysis system.

Figure 8-1 is a block diagram of the Mini-Van system. The six data multiplexes from the Wind Turbine are routed to an input patch panel, and to a Tape Recorder Type "B", Section 5. Any two of the multiplexes, either in real time or in tape playback, can be patched to the two Detranslators. (See Section 6 for discussion of the detranslator concept.)

Each detranslator section yields two "half-multiplexes", each composed of eight subcarriers equally spaced at 1000 to 4500 Hz. Any two of these half-multiplexes can be patched to the two discriminator sections as shown.

Demodulation of the 16 subcarriers in the two half-multiplexes produces data from 16 of the Wind Turbine transducers. Any data outputs can be patched to the two strip chart recorders, which have six 50-millimeter records per unit.

In addition, all 16 data outputs from the Discriminators are routed to a Multiplexer-Encoder, where each is sampled every 0.2 second, converted into a digital word, and entered into the Microprocessor System.

Every six seconds, the microprocessor computes for each measurement the average value of the past 30 samples and displays this, plus maximum and minimum values, on a Cathode-ray tube (CRT) terminal. The display format is shown in Figure 8-2.

For permanent records, data may be transferred from the CRT to a printer automatically.

System operation is extremely simple. Once data source patching is accomplished to get the desired measurements to the discriminators for demodulation, the necessary data sampling, computation, and display are automatic. A data base in the microprocessor contains operator-defined information, stored and indexed by sensor ID, for display of the sensor name (up to 24 alphanumeric characters) and unit of measurement (up to 8 characters).

Each measurement is converted from a binary representation to a decimal value by the microprocessor. Constants are entered into the data base for each measurement for these calculations; up to 5th-order polynomial conversions are made by the system to derive engineering-unit decimal values for display.

The station is housed in a mini-van, and operates from a source of 115 volt 60 Hz power.

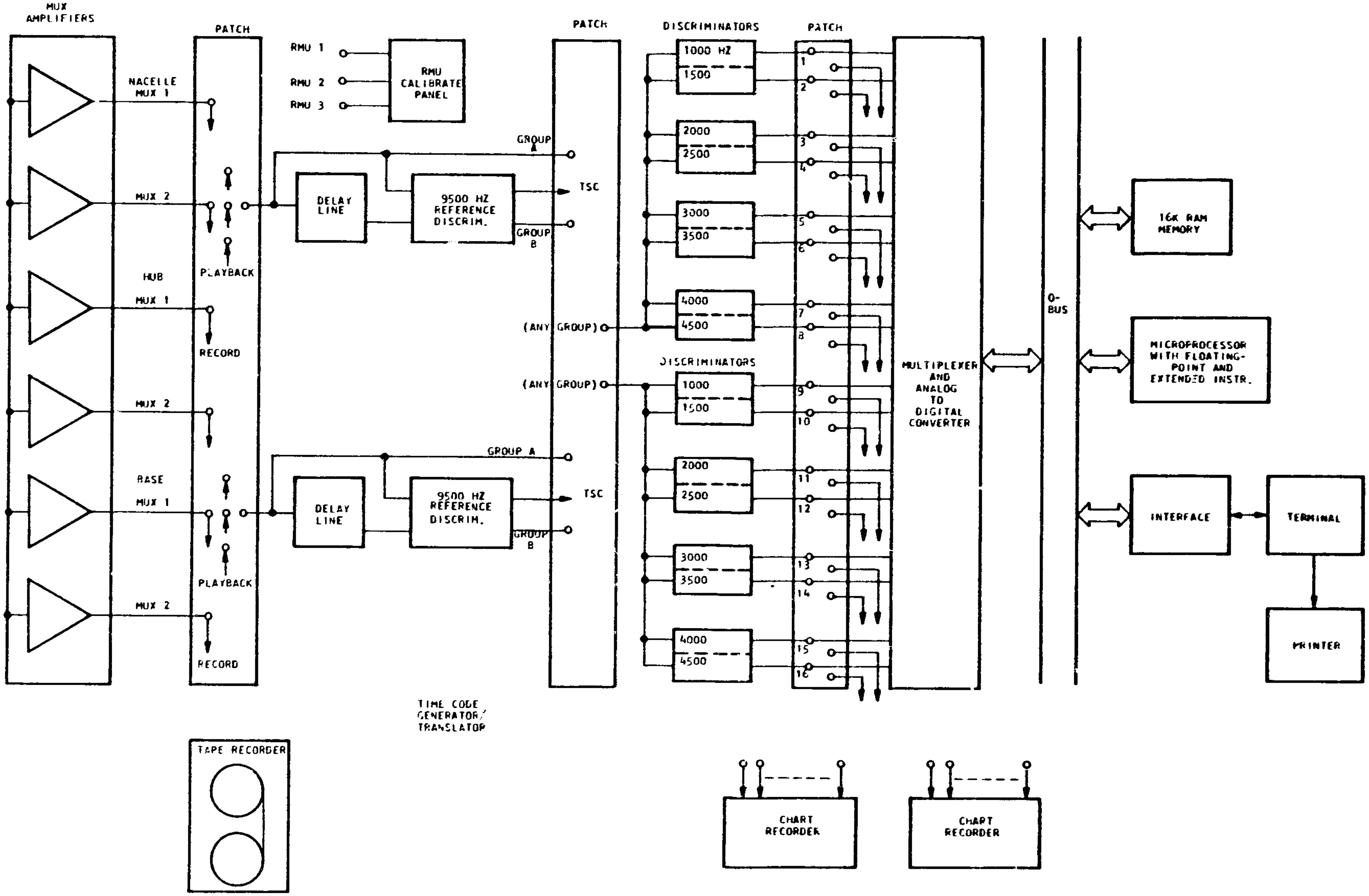
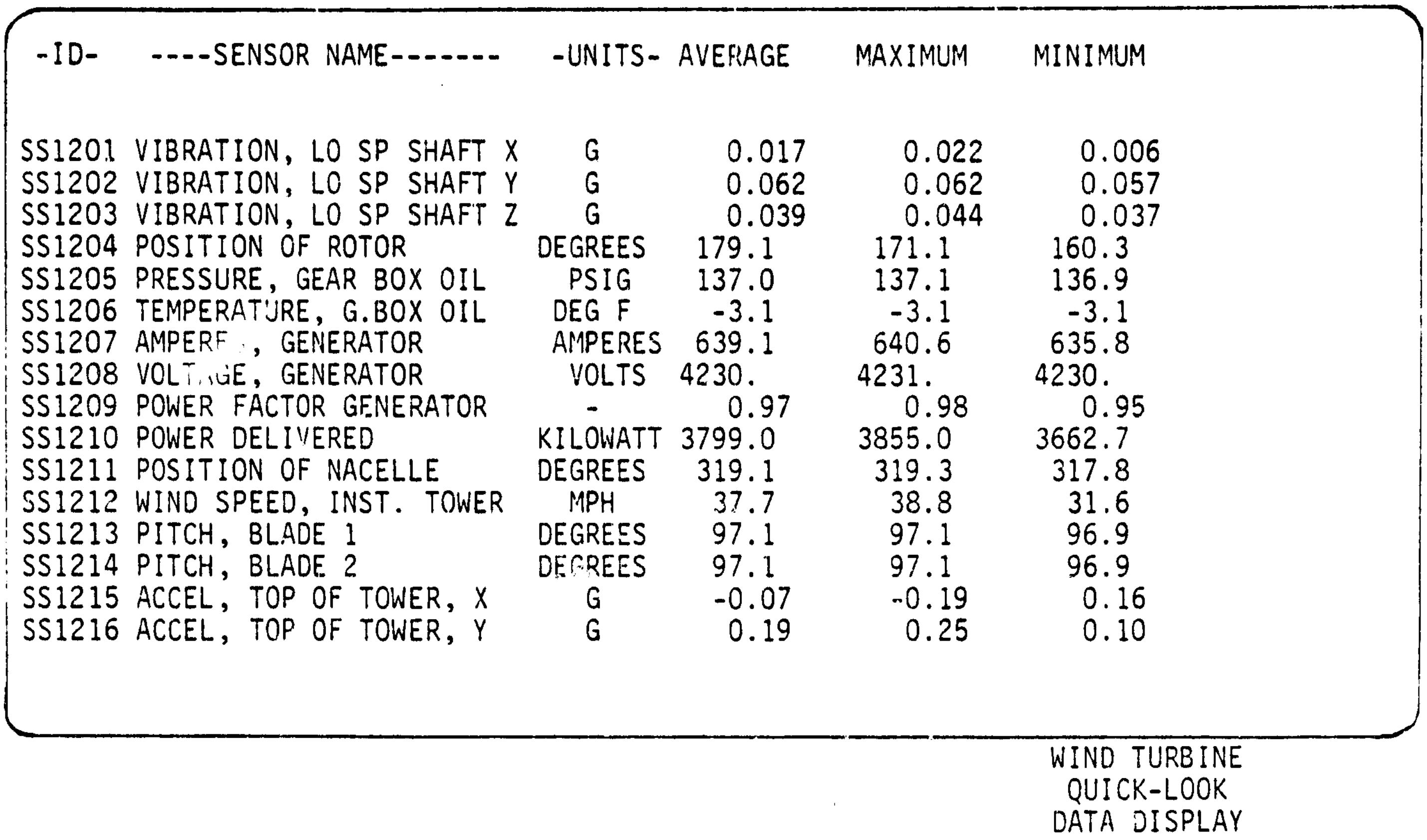


Figure 8-1. Mini-Van Block Diagram



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-ID-    ----SENSOR NAME-------    -UNITS- AVERAGE    MAXIMUM    MINIMUM


SS1201 VIBRATION, LO SP SHAFT X    G        0.017      0.022      0.006
SS1202 VIBRATION, LO SP SHAFT Y    G        0.062      0.062      0.057
SS1203 VIBRATION, LO SP SHAFT Z    G        0.039      0.044      0.037
SS1204 POSITION OF ROTOR        DEGREES   179.1      171.1      160.3
SS1205 PRESSURE, GEAR BOX OIL     PSIG    137.0      137.1      136.9
SS1206 TEMPERATURE, G.BOX OIL    DEG F     -3.1       -3.1       -3.1
SS1207 AMPERES, GENERATOR        AMPERES  639.1      640.6      635.8
SS1208 VOLTAGE, GENERATOR          VOLTS 4230.      4231.      4230.
SS1209 POWER FACTOR GENERATOR       -        0.97       0.98       0.95
SS1210 POWER DELIVERED          KILOWATT 3799.0     3855.0     3662.7
SS1211 POSITION OF NACELLE      DEGREES   319.1      319.3      317.8
SS1212 WIND SPEED, INST. TOWER     MPH     37.7       38.8       31.6
SS1213 PITCH, BLADE 1           DEGREES    97.1       97.1       96.9
SS1214 PITCH, BLADE 2           DEGREES    97.1       97.1       96.9
SS1215 ACCEL, TOP OF TOWER, X      G       -0.07      -0.19       0.16
SS1216 ACCEL, TOP OF TOWER, Y      G        0.19       0.25       0.10
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WIND TURBINE
QUICK-LOOK
DATA DISPLAY

Figure 8-2. Quick-Look Data Display