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TRANSIENT PULSE MONITOR

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SRI International is developing a transient pulse monitor to measure the characteristics of electrostatic discharges on spacecraft. This report describes the design at the first assembled test (15 July 1989).

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1.0 INTRODUCTION

1.1 Purpose of TPM

The Transient Pulse Monitor (TPM) detects and characterizes static discharges on orbiting satellites. The TPM instrument provides a suite of electrical transient sensors to support the Photovoltaics Space Power Plus Diagnostics (PASP Plus) experiment. It measures the transient electric fields and currents that result from electrostatic discharges and thus reveals whether operations of the PASP Plus experiment lead to discharges.

1.2 Scope of Report

This report details changes in the status of the TPM for PASP Plus since the previous interim technical report (Thayer et al., 1988)* and until 15 July 1989.

* Thayer, J. S., Nanevicz, J. E., and Dana, D. R., "Transient Pulse Monitor," Scientific Report No. 1, AFGL-TR-88-0147, AFGL, Air Force Systems Command, Hanscom Air Force Base, Massachusetts, 20 May 1988, ADA201211.

2.0 DESIGN PROGRESS

2.1 TPM System Design

2.1.1 System Configuration

The TPM was originally designed to interface with several experiments on the Interaction Measurement Payload for Shuttle (IMPS). Because of the disruption in shuttle schedules, the Air Force redirected the IMPS effort toward a smaller experiment, PASP Plus, consisting of the PASP and several supporting instruments, including the TPM. Since a carrier for PASP Plus has not yet been chosen, its physical configuration is also not yet fully determined.

The TPM configuration remains as described in Interim Technical Report 1, except that only two of the TPM's six channels are committed **(Figure 1)**. One electric field sensor will be mounted on the PASP array, and one current sensor will be mounted inside the PASP Plus electronics box to monitor the high-voltage power supply used to bias the array. The remaining four channels have uncommitted electric-field sensors. A possible use for these extra channels would be to locate several sensors around the periphery of the PASP array, which would allow rough measurement of the locations of individual discharges. Distributing sensors around other parts of the carrier (depending on the eventual choice of carrier) would generate additional useful data.

2.1.2 Electrical Interface with PASP Plus

The shift from IMPS to PASP Plus has had little effect on the electrical interfaces of the TPM. The interface for PASP Plus was designed to conform to the existing TPM interface. The primary change is that the TPM will be polled for data at 2 Hz, instead of the 10 Hz rate planned for IMPS.

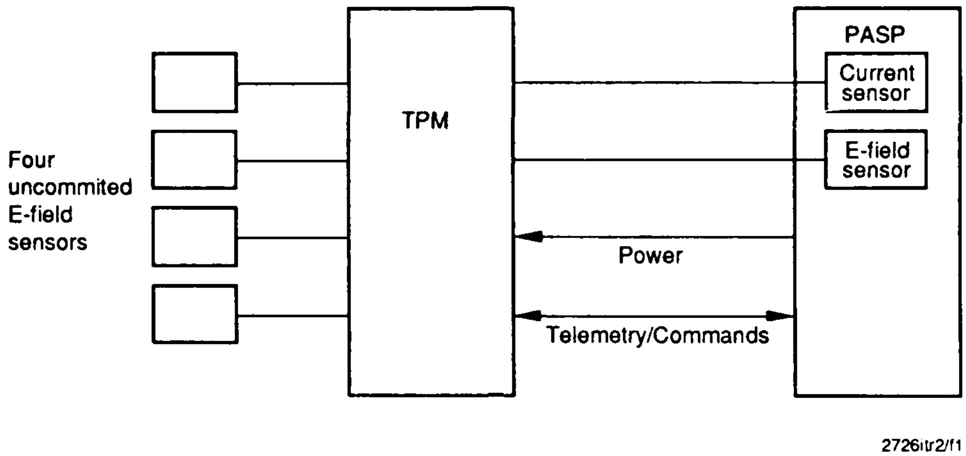

Figure 1. TPM System Configuration.

SRI supplied a duplicate of the TPM interface circuit board to JPL for their use as a TPM emulator. Testing with this duplicate board would guarantee interface compatibility between PASP Plus and TPM. Later interface testing between the assembled TPM and the PASP Plus brassboard system was indeed successful.

2.1.3 Integration Considerations

Since the TPM measures transients from all sources, not just static discharges, it can be considered sensitive to electromagnetic interference. Although its internal operation is not affected by interference, the data of interest could be masked by interfering signals from other equipment. For this reason, extra caution is necessary when integrating the TPM with equipment that could be a source of interference.

While testing the sensors, we discovered that low-frequency signals conducted on the cable shields (such as could be induced by strong interference) could couple through to the center conductor and be detected by the pulse analyzers. This could cause signals, other than those normally picked up by the sensors, to be erroneously read as discharge pulses.

Whether this is a problem depends on the system configuration and can be determined only by system testing. Physical isolation from interference sources may be the best way to avoid it.

We determined that a direct connection between circuit ground and the sensor chassis could reduce the circuit's susceptibility to interference coupling. However, this measure conflicts with the PASP Plus requirement that circuitry be isolated from the chassis. Alternatively, interference coupling can be reduced by reducing the length of cable connecting the sensors to the TPM processor. Using a cable with better inherent shielding (ideally, semi-rigid coax) could also make a substantial difference.

2.2 Sensors

2.2.1 E-field Sensor

The final electric field sensor design is shown in **Figure 2.** To maintain versatility, the housing was designed to be as compact as possible and to accommodate interchangeable baseplates with custom mounting hole patterns. The sensor plate configuration achieves excellent electrical isolation from the case by using a thin sheet of Teflon as a standoff. Pressure on the Teflon is distributed around the border of the plate to prevent cold flow, and none of the Teflon surface is exposed to external charging. The volume of each sensor is 54 cm^3, excluding connectors.

The field sensor circuit **(Figure 3)** has been tailored to complement the characteristics of the pulse analyzers and to efficiently drive balanced coaxial cables. The circuit is powered by ±10.5 V from the central processor and dissipates approximately 150 mW.

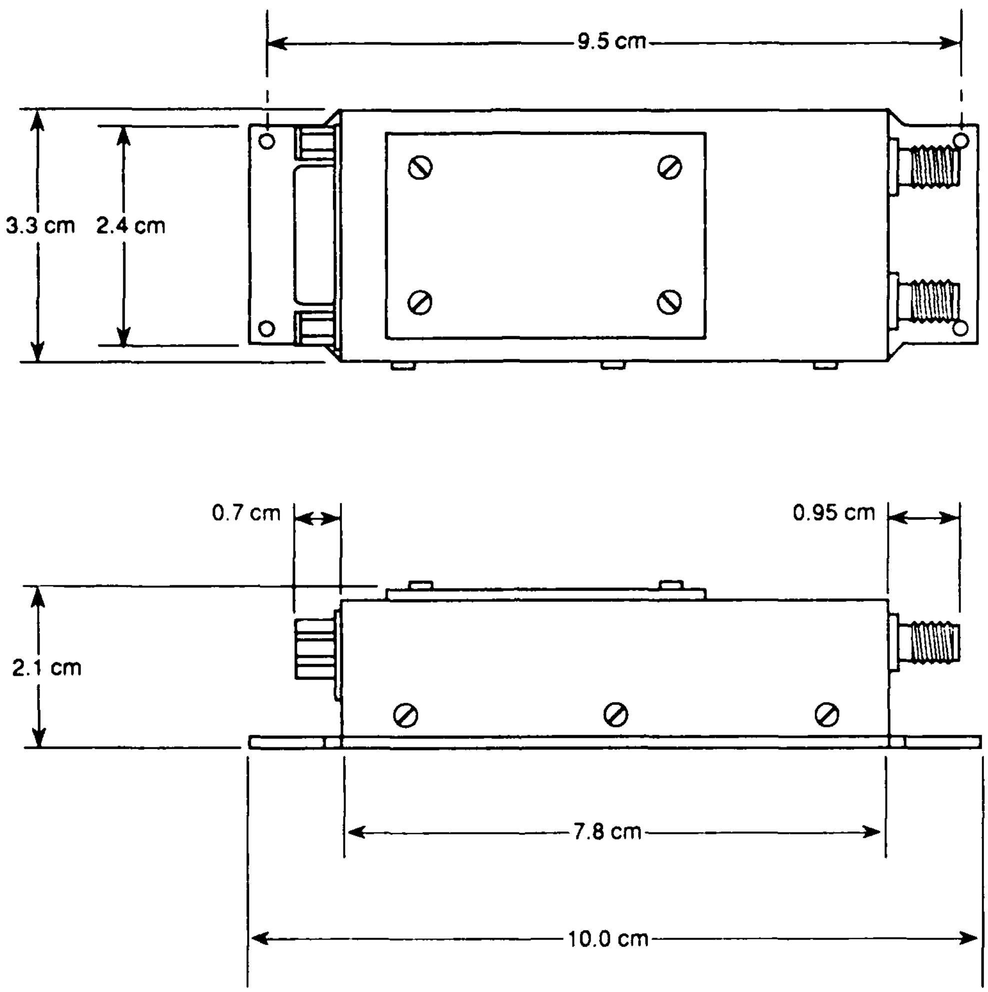

Figure 2. Electric-Field Sensor Configuration.

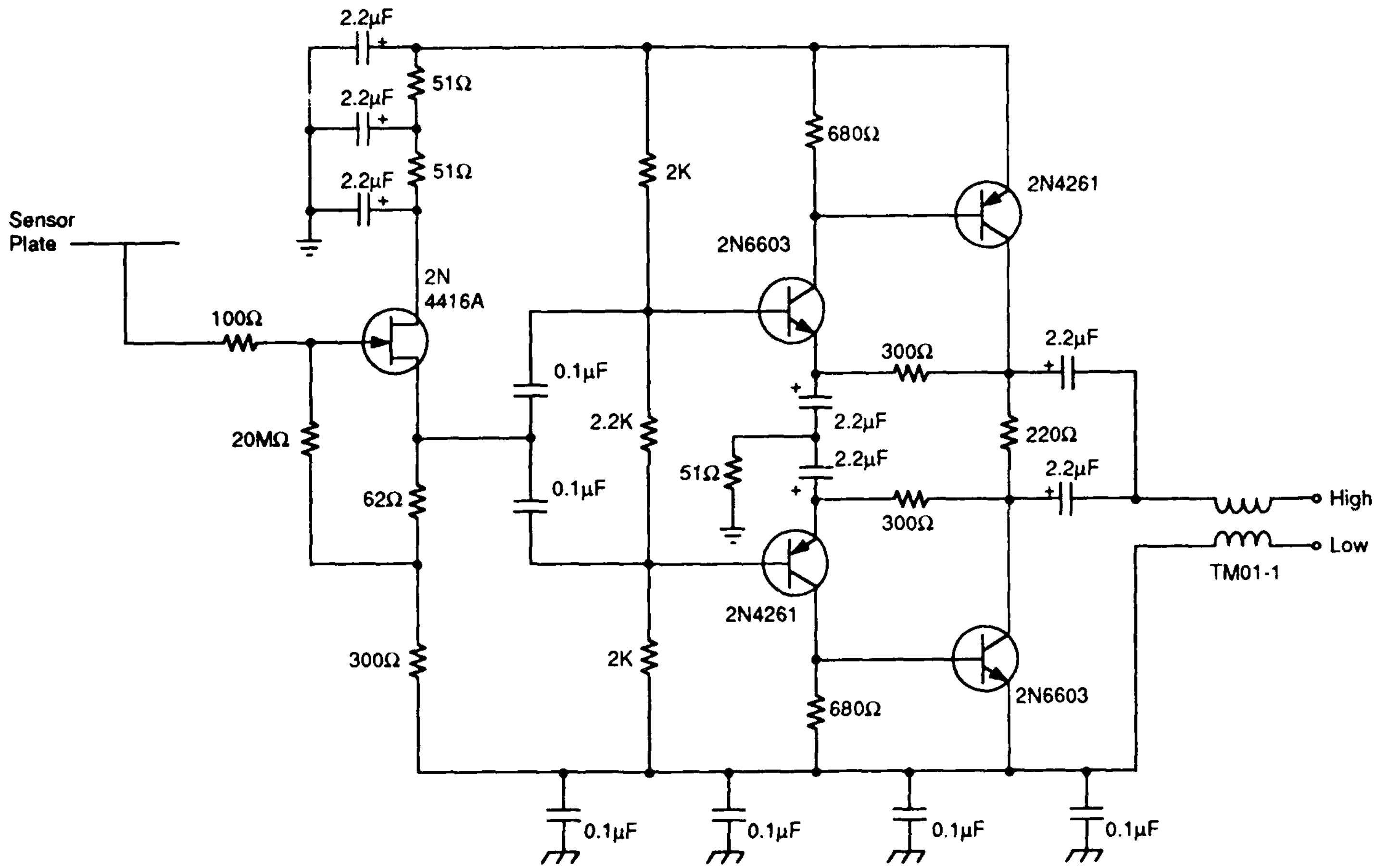

Figure 3. Electric-Field Sensor Schematic.

2.2.2 Current Sensor

The current sensor consists of a Tektronix CT-2, repackaged and adapted to drive a balanced pair of coaxial cables. The sensor housing is shown in **Figure 4.** JPL has successfully integrated a sensor of this type into its PASP Plus brassboard.

2.3 Central Processor

2.3.1 Pulse Analyzers

Only minor refinements of the pulse analyzer circuits have been needed since the previous report. Because of the circuits' high gain and wide frequency response, great care was taken in the layout of the circuit board to ensure circuit stability. An instability observed in several prototypes was corrected with some changes to the layout and a part substitution.

2.3.2 Pulse Counters

The pulse counter thresholds have four possible values that are selectable through the command interface. The threshold prevents counting of small noise pulses that may not be of interest to the experiment. After initial functional testing of the pulse analyzer boards, we chose values for the thresholds that will allow the pulse count function to be useful in a variety of noise conditions. The thresholds correspond approximately to 3.5 kV/m, 900 V/m, 200 V/m, and 60 V/m.

2.3.3 Data Interface

The shift from IMPS to PASP Plus has had some effect on the data interfaces of the TPM. In order for JPL to develop and test the TPM interface, SRI supplied a duplicate of the TPM interface circuit board, which JPL used as a TPM emulator. Testing with this duplicate board guaranteed interface compatibility between the PASP and TPM.

The TPM will be polled for data at 2 Hz, instead of the 10 Hz rate originally planned for IMPS operation. Since the TPM data are split

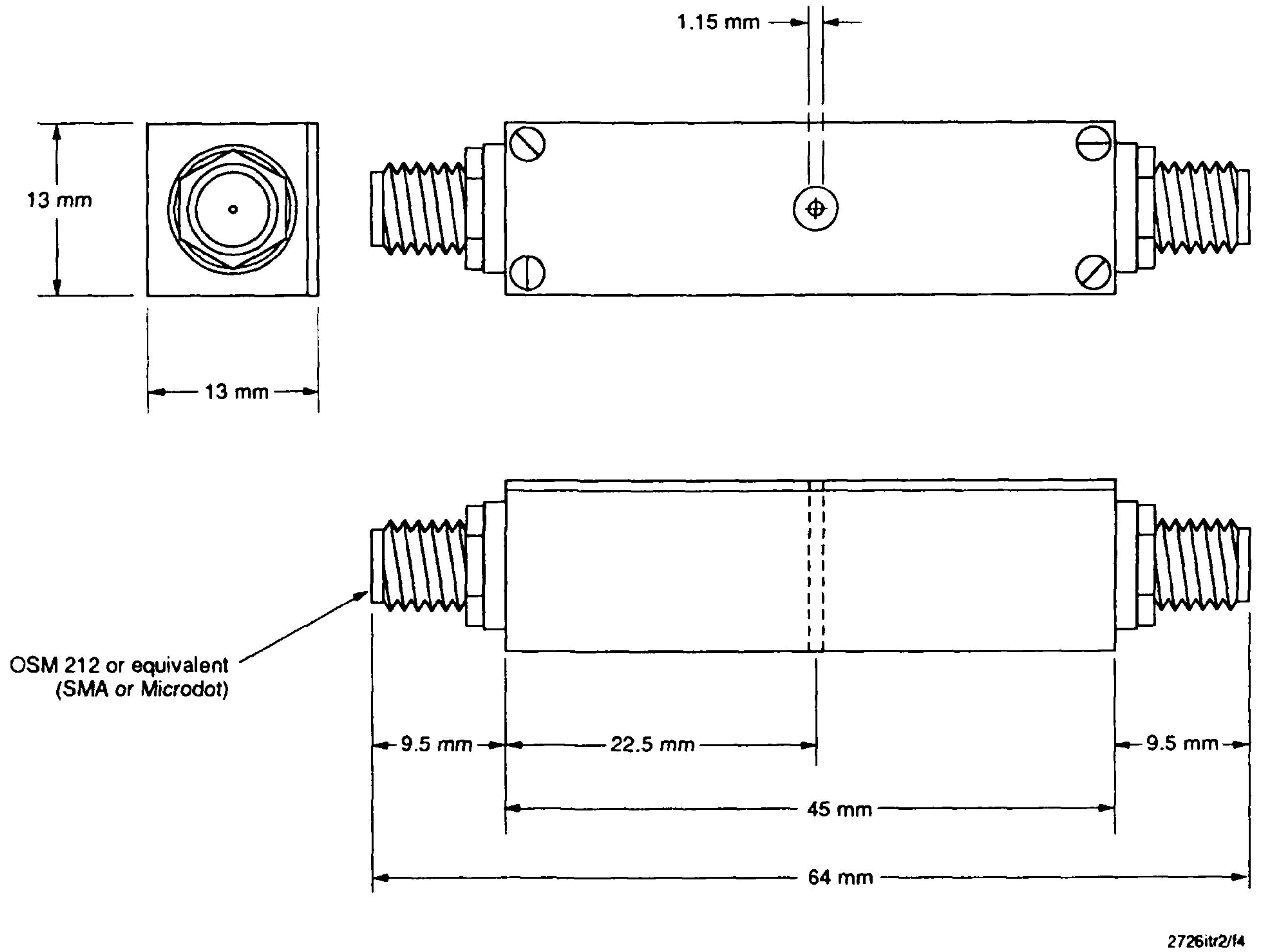

Figure 4. Current Probe Configuration.

between two packets, the effective sampling rate is one-half the polling rate, or 1 Hz, and one complete set of TPM data will represent the pulse parameters measured in the previous 1 s. The TPM will operate properly at any rate from 2 Hz to 10 Hz.

The arrangement of data within the packets has been changed slightly to simplify internal wiring. The final packet structure is shown in **Figure 5.** This change does not affect the way PASP Plus handles the packets, but the order in which data are presented to the ground support equipment. The TPM Ground Support Equipment (GSE) software has been modified to accommodate the change.

2.3.4 Motherboard

The six pulse analyzer boards and the digital interface board are interconnected by a motherboard. This approach allows the system to be easily assembled and minimizes the space and effort required for wiring. The final motherboard was designed as a two-sided printed circuit board with relatively wide (and in some cases redundant) traces, for high reliability. The traces carrying power were designed with especially generous derating.

2.3.5 Power Supply

The power supply has been redesigned since the previous report **(Figure 6).** The new design uses a prepackaged hybrid dc-to-dc converter to replace a great deal of discrete circuitry. The converter was screened by the manufacturer, using MIL-STD-883B, to quality levels comparable to the other circuitry in the TPM. Its rugged hybrid construction is in some ways superior to what we could achieve using discrete parts.

The dc-to-dc converter accepts input voltages over the range of approximately 16 to 40 V and produces ±12 V outputs. A companion filter designed by the manufacturer reduces conducted interference produced by the 200 kHz switching regulator. Additional circuitry filters out high-frequency noise on the outputs that could interfere with the TPM and regulates the outputs to the ±10.5 V required by the pulse analyzer boards

FIRST PACKET

	MSB	LSB
1	Sequence Count	0
2	Positive Amplitude 0	
3	Negative Amplitude 0	
4	Positive Derivative 0	
5	Negative Derivative 0	
6	Integral 0	
7	PAMP2	
8	NAMP2	
9	PDER2	
10	NDER2	
11	INT2	
12	PAMP1	
13	NAMP1	
14	PDER1	
15	NDER1	
16	INT1	
17	Count 5	Count 4
18	Count 3	Count 2
19	Count 1	Count 0
20	Pulse Cycles	
21	VSUP	
22	TEMP	

SECOND PACKET

	MSB							LSB	
23	Sequence Count							1	
24	PAMP3								
25	NAMP3								
26	PDER3								
27	NDER3								
28	INT3								
29	PAMP4								
30	NAMP4								
31	PDER4								
32	NDER4								
33	INT4								
34	PAMP5								
35	NAMP5								
36	PDER5								
37	NDER5								
38	INT5								
39	Thrsh3		Thrsh2		Thrsh1		Thrsh0		
40	Thrsh5		Thrsh4		Command				
41	PA0	NA0	PD0	ND0	I0	PA2	NA2	PD2	Parity
42	ND2	I2	PA1	NA1	PD1	ND1	I1	PA3	Parity
43	NA3	PD3	ND3	I3	PA4	NA4	PD4	ND4	Parity
44	I4	PA5	NA5	PD5	ND5	I5			Parity

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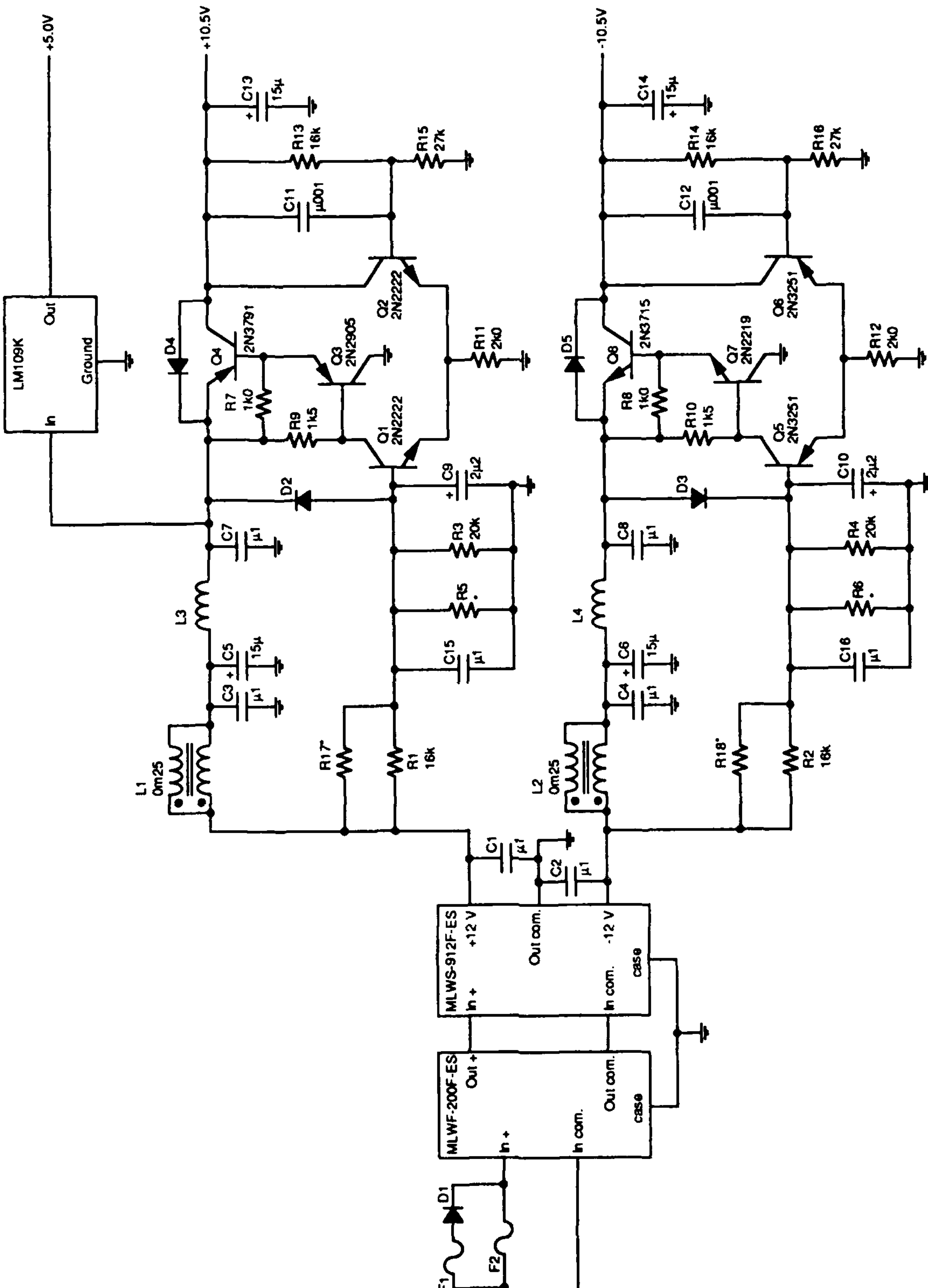
Figure 5. Telemetry Packet Structure.



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*Select value to trim output voltage

Figure 6. Power Supply Schematic.

and 5 V for the digital interface circuitry. Regulation of the outputs over the input range of 24 to 32 V is much better than 1%. The +10.5 V output, whose regulation is especially important to the performance of the pulse analyzers, is continuously monitored and incorporated into the output data so that any change during a mission can be noted. Small changes in the -10.5 V and +5 V outputs are not significant; significant changes or failures in these voltages can be discerned indirectly from the output data.

Because of the capacitive input of the dc-to-dc converter, the supply can have a short but large inrush current pulse when input power is switched on. To measure this, we set up a worst-case experiment in which the power from a very low impedance source (a power supply with a 1000 μF capacitor added to the output, with short leads) was applied through a switch. The result **(Figure 7)** was a peak inrush current of 22 A that lasted less than 50 μs. We consulted with a parts specialist at JPL and determined this pulse would not degrade the 2 A fuses used to protect the TPM power input. In addition, the higher source impedance of realistic power wiring will likely reduce the peak current.

2.4 Mechanical Design

The TPM central processor box **(Figure 8)** is assembled from five walls, a baseplate, and a cover, each of which is machined from solid aluminum. The basic wall thickness is 0.06 inch, with a number of ribs to provide stiffness. The envelope volume is approximately 7100 cm^3, excluding the baseplate and connectors.

The pulse analyzer and digital interface boards form a stack. Each board is supported on the sides by spring-metal card guides, on the front and back by brackets that screw into the walls, and in the middle by machined spacers on each board that form a stack. Bolts run through the four spacer stacks to keep the assembly rigid. An inner wall supports the card guides into which the analog boards slide, and acts as an electromagnetic partition between the power supply and pulse analyzer boards.

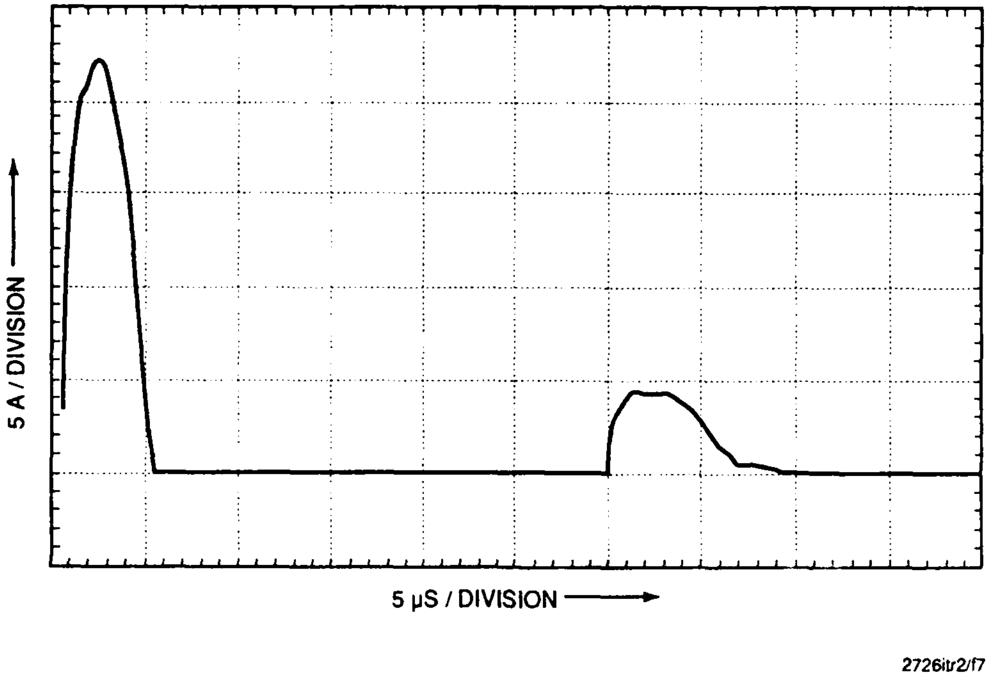

Figure 7. Power Supply Inrush Current.

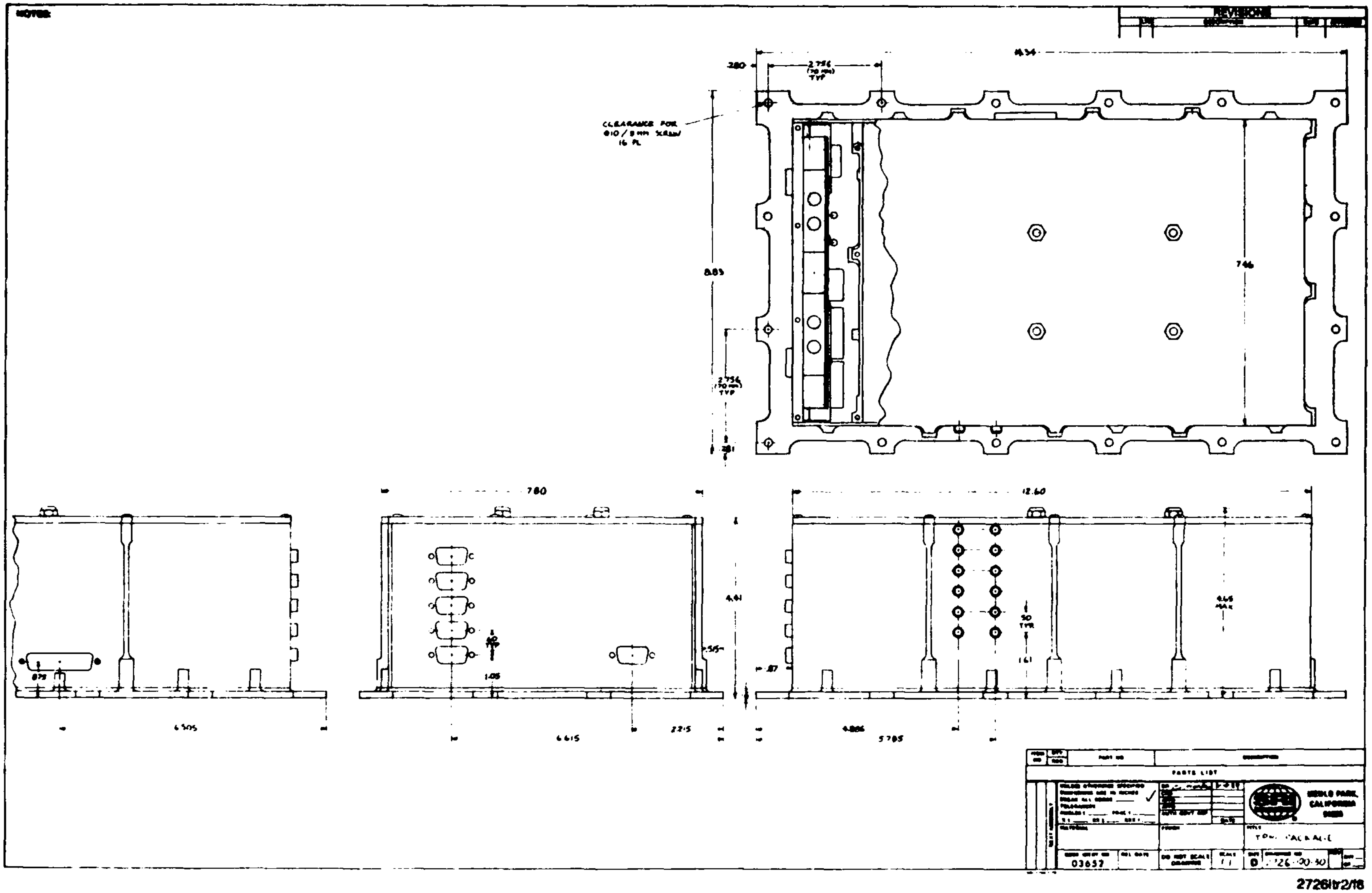

Figure 8. Central Processor Configuration.

The power supply board includes integral mounting brackets that provide mechanical support for the heavy parts and thermal conductivity to the outside wall. Thermally conducting electrical insulators isolate both the primary and secondary sides of the power supply from chassis ground.

2.5 Ground Support Equipment

The operation of the TPM GSE is the same as described in the previous report, except that the stimulus has been redesigned. We found that the previous design was not optimum for full functional testing of the TPM because it could not generate the very fast rates of rise the TPM can measure. The new design is based on a battery-powered pulser that generates 20 V pulses, of either polarity, with a 200 ps rise time and 2 μs fall time. These pulse parameters are in the correct proportion to give equivalent responses from all the TPM pulse analyzers. A built-in attenuator allows the output amplitude to be varied in 10 dB steps over a 60 dB range, which also varies the derivative and integral parameters proportionally. The pulser drives a sensor stimulus attachment that capacitively couples the pulses to the sensor plate. Capacitive coupling accurately simulates the normal stimulation of the sensor by ambient electric fields of appropriate magnitude.

3.0 TPM PERFORMANCE

3.1 Performance Characterization

During the design and prototyping of the TPM, we developed a method to fully characterize pulse analyzer responses to input stimuli **(Figure 9)**. A computer directs a programmable pulse generator to produce pulses of various amplitudes, rise times, and fall times, and digitizes the TPM's response to each pulse shape. The data can then be processed to show the response of each pulse analyzer circuit to variations in the applicable parameter.

The calibration program sets the pulse generator to produce triangular pulses with constant rise and fall times while the amplitude is varied **(Figure 10)**. Since the peak amplitude, peak derivative, and pulse integral all vary proportionally with the pulse amplitude, this process generates a complete family of responses in each parameter channel as a function of amplitude.

Although one family of constant-pulse-shape pulses gives a complete calibration response for each parameter, many families of constant-pulse-shape responses can be recorded. These data can then be arranged to correspond to families of constant-parameter inputs **(Figure 11)**. For example, various combinations of pulse duration and peak amplitude can result in the same value of integral. Ideally, the TPM integral channel would respond identically to all these pulses. Its deviation from this ideal can be assessed using the automated process described.

After the TPM's response has been fully characterized, the resulting data can be used to produce calibration curves and lookup tables for processing flight data.

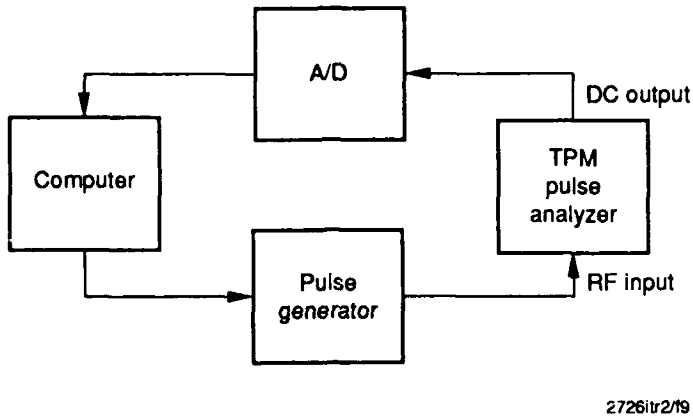

Figure 9. TPM Performance Characterization Setup.

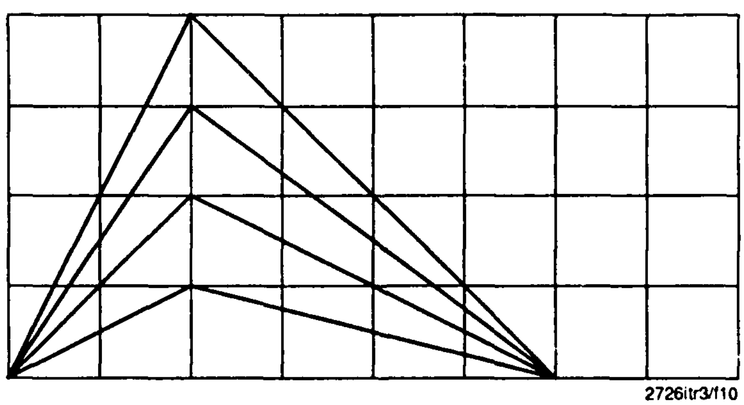

Figure 10. Constant-Pulse-Shape Family.

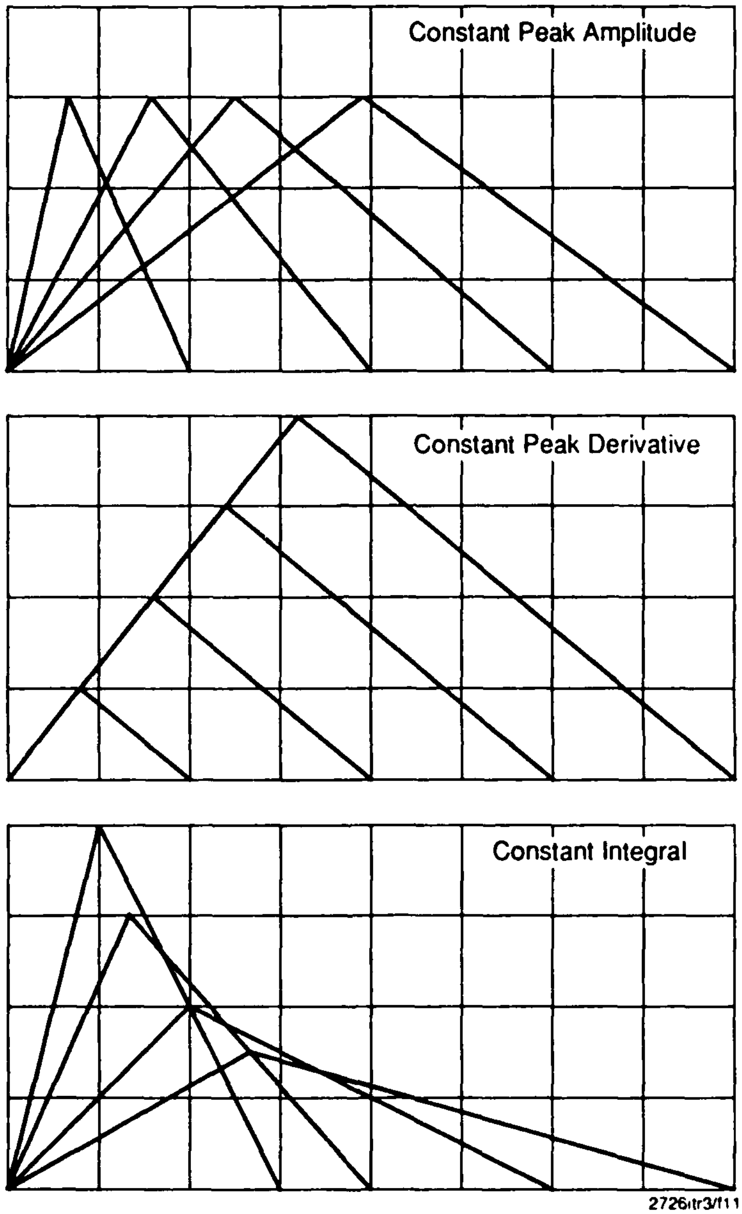

Figure 11. Constant-Parameter Pulse Families.

3.2 Peak Amplitude Detector Performance

Figure 12 shows the peak amplitude detector response of a typical TPM channel. The X axis represents the logarithm of peak input amplitude (decibels relative to 1 V calculated as 20·log[input]), and the Y axis shows the TPM pulse analyzer's dc output after it has been digitized (full-scale output is 255). An individual curve on the graph represents the response to a constant-pulse-shape family of triangular pulses with varying amplitude. The composite set of curves represents the TPM response to pulse inputs ranging from 10 ns to 10 μs. In actual measurements, the pulse length will be unknown, so the differences between these curves represent an uncertainty factor in the amplitude measurement. For pulses over the full range of widths and amplitudes (a 60 dB range in each case), this uncertainty is less than ±3 dB. In practice, the uncertainty is lower, because the range of pulse widths generated by electrostatic discharges is more typically 100 ns to 1 μs.

A lookup table for converting flight data to engineering units is compiled by averaging the curves from the various pulse widths. The same process is used to characterize the derivative and integral detectors.

3.3 Peak Derivative Detector Performance

Figure 13 shows the peak derivative detector response of a typical TPM channel. The X axis represents the logarithm of peak input derivative (decibels relative to 1 V/s), and the Y axis shows the TPM pulse analyzer's dc output after it has been digitized. The derivative channel of the TPM is less sensitive to pulse width than the amplitude channel, so its deviation over the range of widths is less than ±2 dB.

3.4 Integral Detector Performance

Figure 14 shows the integral detector response of a typical TPM channel. The X axis represents the logarithm of the integrated magnitude (decibels relative to 1 Vs), and the Y axis shows the TPM pulse analyzer's dc output after it has been digitized. The deviation in readings for

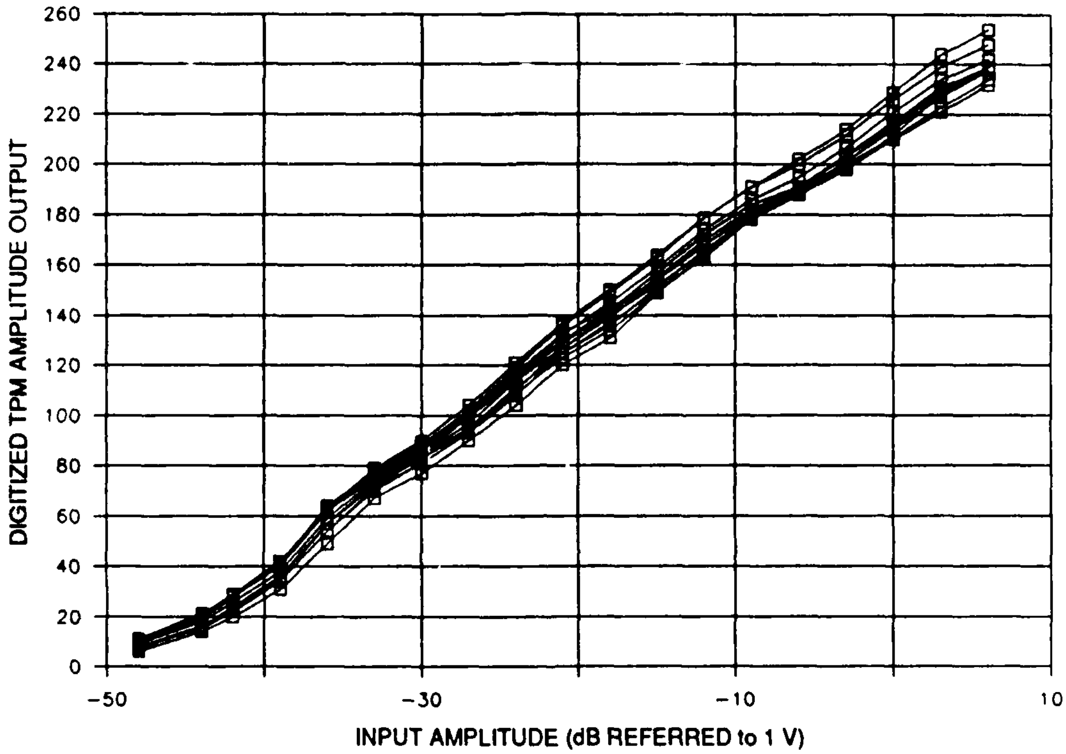

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Figure 12. Typical Amplitude Detector Response.

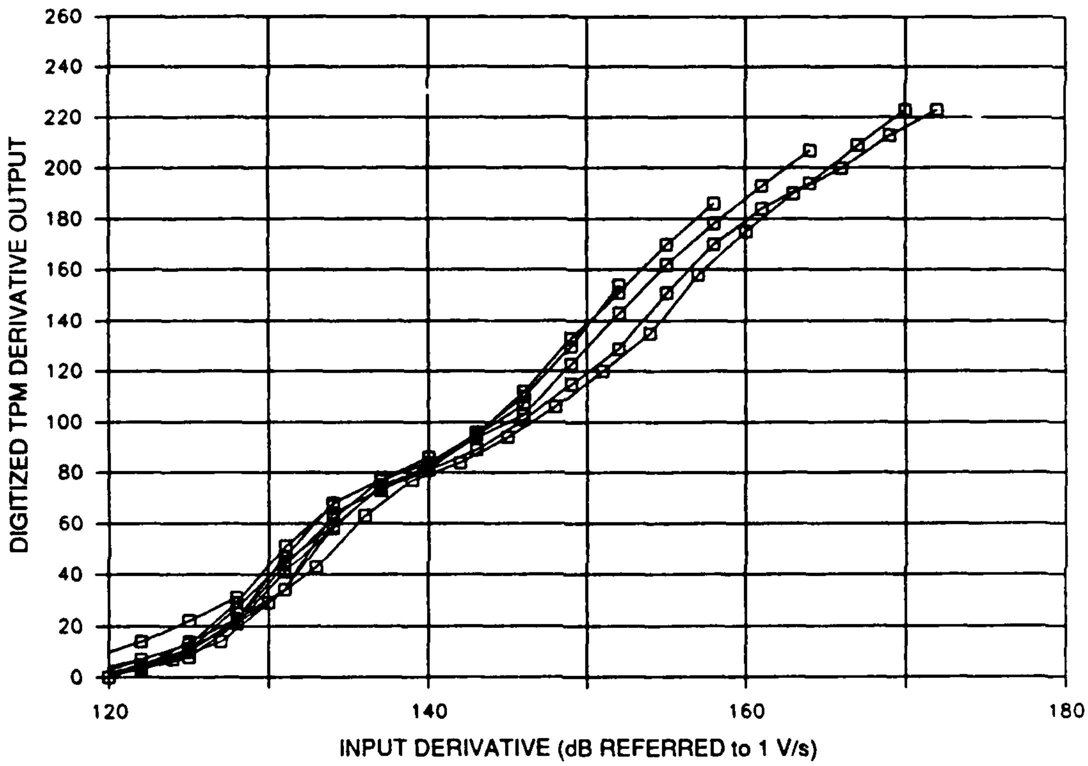

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Figure 13. Typical Derivative Detector Response.

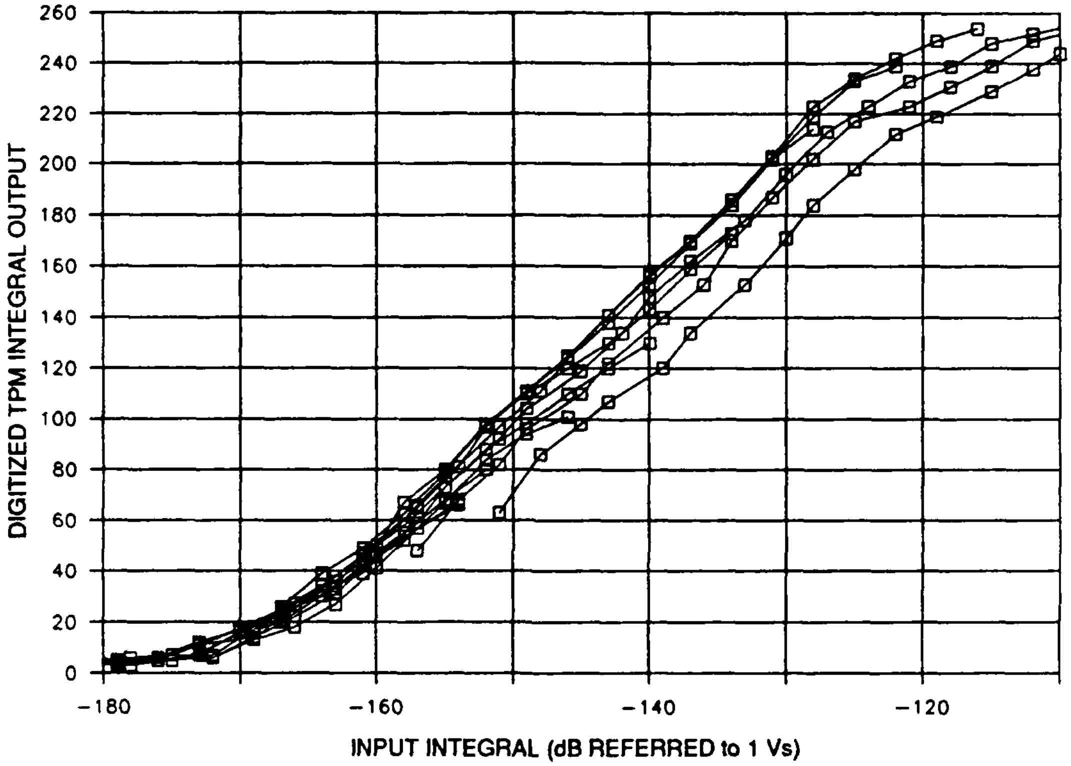

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Figure 14. Typical Integral Detector Response.

identical integral inputs is approximately ±2 dB, over the pulse width range of 10 ns to 5 μs. Like all the pulse analyzers, the integral channel rejects very long pulses that are not likely to result from static discharges. The lowest curve on the graph represents the response to a triangular pulse with 20 μs duration measured at the base.

3.5 Power Supply Performance

The performance of the pulse analyzer depends on well-regulated power. Drift in the +10.5 V supplied to the analyzers can cause changes in gain and frequency response. Engineering bench tests have shown that output voltage varies approximately 0.1% with input voltages from 20 to 38 V, and approximately 0.2% with temperatures from 25 to 75°C. We plan further tests at low temperatures.

Figure 15 shows input current and power as a function of input voltage for the complete TPM system. The TPM operates with voltages from 18 to 38 V, with total power consumption of between 12 and 13 W. It can withstand continuous inputs ranging down to 0 V without any adverse effects.

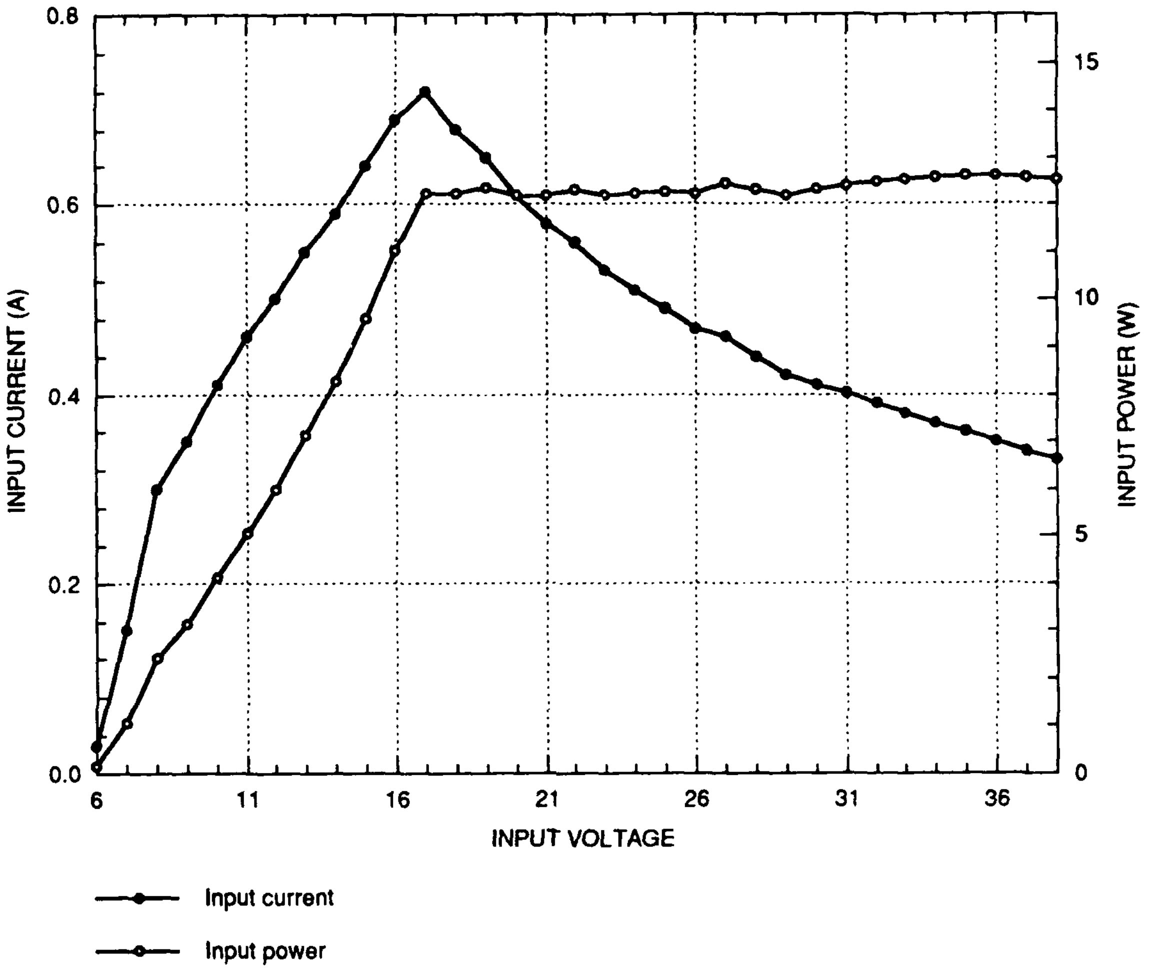

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Figure 15. TPM Input Current and Power.

4.0 FABRICATION AND ASSEMBLY

4.1 Circuit Boards

The pulse analyzer and digital interface circuit boards were fabricated by subcontractors, and we carefully inspected them for correctness and workmanship before assembly. We ordered more boards than required for actual assembly so that we could select the best of each type. We judged several of the digital interface boards to be marginal in quality and discarded them.

We used NASA's "Requirements for Soldered Electrical Connections" [NHB 5300.4(3A-1)] as a guide for assembly and inspection of the TPM printed circuit boards. The pulse analyzer boards, each of which uses approximately 2000 parts, required special care in assembly, not only because of the number of parts but also because of their compact arrangement. Each assembly was carefully compared to a prototype model to ensure proper installation of parts, and the solder joints were continuously inspected.

After the pulse analyzer boards were assembled, they were tested by the design engineer using both dc and ac techniques to verify successful operation. These tests revealed only a few misplaced components, which were easily corrected. We completely assembled seven pulse analyzer boards, leaving one as a spare.

The digital interface board was inoperative after initial assembly. We traced the problem to a bad integrated circuit. We replaced this IC, and after repair, verified that the board's function was restored.

We did not conformally coat the circuit boards for the first assembled tests, in case repair or rework was indicated by the results of the tests. After completion of all function tests and some limited thermal cycling, we will coat the boards to make them flight-ready.

4.2 Power Supply

The power supply board is simpler than the other circuit boards and does not require plated-through holes, so it was suitable for fabrication at SRI. We assembled it with techniques similar to the others, but its mechanical and electronic assembly are more interrelated because of its thermal design. The dc-to-dc converter module and output transistors, which dissipate most of the power, must be bolted to their heat sinks before completion of soldering, to reduce stress on the solder joints. Silicone rubber pads are sandwiched between the components and their heat sinks to increase thermal contact in a vacuum, and in some cases to provide electrical insulation. Electrical insulation is necessary to isolate the power supply inputs and outputs from the metal case and spacecraft chassis.

4.3 Current Sensors

The current sensor consists of passive electronic components housed in a machined aluminum box. The components are supported by an internal aluminum bracket and a berylium copper spring. The internal assembly is potted in silicone rubber to make it immune to vibration.

We assembled two current sensors: one to be the flight model, and one to be used in the PASP Plus brassboard and as a spare.

4.4 Electric Field Sensors

The electric field sensors' assembly is essentially permanent, unlike that of the processor. To keep the sensor small, we had to take some permanent steps, such as conformal coating of the boards, on initial assembly. However, we fully tested the circuitry before and after final assembly and do not expect to need any rework or repair. We built six electric field sensors, leaving one as a spare.