HIGH SHOCK, COMPUTERIZED, MINIATURE, AIRBORNE PCM/FM TELEMETRY SYSTEM

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ABSTRACT

Aydin Vector Division has developed and manufactured an airborne, high shock, wideband FM/FM telemetry system for Saab Missiles AB in Sweden. This system was presented in the ITC Proceedings of 1988, Volume XXIV, pp 71-84 (Ref [1]). Three such systems were supplied. Saab Missiles AB also awarded Aydin Vector Division with an additional order for a larger number of high shock, computer based, specially designed, miniature PCM/FM airborne telemetry systems. These systems were developed, manufactured and supplied to Saab Missiles AB, and have been extensively and successfully used in the Swedish program. The PCM/FM telemetry package described in this paper was used for the system testing and the firing trials program of a mortar projectile, where the measurement requirements included micro processor interfaces, as well as a high amount of analog and bi-level data channels. The paper covers the specifications of the PCM/FM system mentioned above, the concept that was used to meet these specifications, the system’s mechanical and electrical design, the packaging technique and some of the test results.

INTRODUCTION

It is becoming more and more popular to use telemetry systems in order to test small projectiles during the development and testing phases. The development of sophisticated projectiles requires multiparameter telemetry systems which have to meet very unique and comprehensive measurement specifications for the program involved. The space available for the airborne telemetry system in such projectiles is, by the nature of the test object, very small. Also, the environmental requirements for such a system are very severe, especially in terms of high shock survival. In this case, the development of a sophisticated, high-shock, multiparameter, miniature, airborne telemetry system becomes a real professional and technical challenge for any supplier of such equipment.

The successful development of such a system depends on the capabilities of the customer/subcontractor team as follows: direct experience in related fields on Hi-g design, packaging and manufacturing (see Ref [2]); adequate technical and professional resources during the design, development and qualification phases; proper selection of the system design approach (both electrical and mechanical) and adequate test facilities for verification. This is the reason that the ability to produce complex miniature telemetry systems and to have them function successfully and reliably in ultra-severe environments, is rare and is always achieved at the cost of great effort in order to perfect the art, for an art it surely is! Two requirements therefore emerge as a prerequisite if such an exercise is to be brought to a successful conclusion: proven hardware and experience.

GENERAL SYSTEM SPECIFICATIONS

The PCM/FM telemetry system consists of the following three main units:

- battery/power converters
- signal conditioning/PCM encoder
- telemetry transmitter

It is mounted in a rigid metal housing, forming the rear section of a mortar projectile. The TM-system is connected to measurement points in the projectile’s elecronics system, and to measurement transducers installed in the projectile. The RF signal is transferred to the ground stations using a wrap-around antenna, grooved into the housing of the TM section.

The Battery Pack is designed for a self-contained operating time of 180 seconds. It provides an input for external power supply, for testing and final check-out purposes, and also for battery steering commands and battery charge. All the required power converters are included to enable the system to operate on a single DC power source of 22.8 volts nominal. Reverse polarity protection is provided. The signal conditioning/PCM encoder section is designed to accept different type of input signals:

- 2 parallel digital data interfaces (micro processor ports)
- 1 pulse counter input
- 20 discrete bi-level signals
- 32 analog signals

The two digital data interfaces utilize the use of the general micro processor data and address busses, including a few strobe signals. This method requires a minimum amount of signal conditioning in the projectile electronics unit (i.e. buffer amplifiers). The TM-system is addressed by the micro processor as any other output device. The data is received by the TM system and stored in a common random access memory (RAM), in a location that is controlled by the data contents and by the active microprocessor port. The PCM encoder is able to read from the RAM as the format is generated and transmitted. The TM system output rate is somewhat higher than the input rate, allowing an oversample situation, which assures correct data flow through the TM system without any data loss. The data integrity is maintained by the use of a flag bit, indicating old/new data, which enables the ground evaluation system to restore data blocks as they were transferred to the TM system. The system is designed to avoid data loss due to multiple access requests to the RAM. The PCM encoder reads RAM data nondestructively, resulting in real-time performance even for micro-processor data.

The counter input is designed to reset a 10 bit counter on the positive edge of a pulse signal, and to increment the counter with a high frequency, crystal controlled clock, to provide for an accurate time syncroniczation in the measurement data. The counter contents is sampled by the PCM encoder as any other 10 bit data word.

The bi-level signals are threshold detected and grouped together into two 10 bit words.

The analog signals are of four categories:

- 20 single ended, high level attenuated with fixed measurement ranges
- 8 single ended, with programmable measurement ranges
- 2 differential with charge amplifiers
- 2 differential with thermistor signal conditioning

Each analog signal occupies one 10 bit data word when it is sampled in the PCM format. The over all accuracy for the analog single ended signals is better than 1% of full scale. The corresponding figure for the differential signals is 3%.

The PCM format can be easily modified by reprogramming of an accessible, UV-eraseable PROM-device. Due to the limited space available, some of the PCM parameters are fixed (i.e. bit frequency, word- and frame length, measurement ranges and offset levels), while some essential parameters are user-reprogrammable (i.e. sample rates, format layout). The bit rate is crystal-controlled and set to just below 1 Mbit per second. The accuracy is ±0.05% at room ambient and the stability is ±0.05% (during reasonable combinations of the environmental requirements). The PCM format has the following specifications:

- Word structure:
  11 bits/word (10 bits data, 1 bit odd parity), binary coded analog data
- Frame structure:
  128 words/subframe
  32 subframes/format
- Frame synchronization:
  2 words frame sync
  1 word sub-frame identification (SFID)

Based on the format specifications, sample rates from 15 Hz to 15 kHz (commutation rates of 1:32 through 32:1) are available and selectable under PROM-control.

The PCM output is NRZ-M and is pre-mod filtered before it is fed to the TM transmitter. The TM-system provides outputs for electrical supply of transducers: unregulated battery supply and stabilized voltages of +/- 15 VDC and +5 VDC. For diagnostics reasons, the unfiltered PCM output together with some clock- and synchronization signals are also available at a special test connector.

The transmitter operates in the upper S-band frequency (deviation +/- 300 kHz), with a typical output power of 250 mW into a 50 ohm load. The TM system is designed to withstand extremely severe environments as it is launched from a trench mortar, and to produce reliable and accurate measurement data when the projectile is in the trajectory. The system is required to function while beeing exposed to the following specification levels:

Longitudinal shock:	10000 g’s, duration 6 ms, halfsine +/- 6000 g’s, 2 kHz sine wave, 100 ms
Transverse shock:	+/- 590 g’s, 500 Hz sine wave, 100 ms
Random vibration:	0.04 g^2/Hz, 20 - 2000 Hz for 60 s in each direction
Rotation:	less than 25 rps
Temperature:	-25 to +70°C temperature stabilized -10 to +70°C for full battery performance
Relative humidity:	5 to 95%
Air pressure:	50 to 300 kPa

The weight of the complete TM system is approximately 2.5 kgs, with the calculated center of gravity no more than 1 mm from the center line. The calculated MTBF is more than 750 h.

TECHNICAL DESCRIPTION

To meet the specifications and the technical requirements as described above, the following design approach was used.

The TM system is based on a micromodular pulse coded encoder, designed for flexible use in any airborne application - the Aydin Vector MMP 900. The system performance is based on previous experience and the up-to-date development status of the baseline encoder. The basic circuit design is derived from, or is a modification of, an existing and well proven product. To meet the stringent volume restrictions in combination with very severe measurement requirements, the encoder is using specially packaged hybrid circuits configured to survive high shock environments. The transmitter is an exsisting, high-shock ruggedized unit, and the battery pack is built up using rechargeable nickel/cadmium batteries assembled in a rigid structure. Each of the units is more thoroughly described below.

The battery pack consists of 19 SAFT Model 450SC-2/3AF ni/cad cells. Each cell has a capacity of 450 mA/h. The cells are connected in series to produce 22.8 VDc nominally. The battery pack contains one tier of 19 cells which is held in place by foam potting. The complete battery pack is capable of supplying 1 amp for a period of at least 180 seconds under the specified environmental conditions. Battery charge is performed using a constant current source of 45 mA at a drive voltage of 32 V. To prevent from reverse charging of battery cells during operation, the discharge voltage of the battery pack is limited to 19 V. The battery pack capacity has been designed for the specified operating time over the entire operating temperature range. Experience has shown that the battery pack can provide system operaion for more than 10 minutes at room ambient temperature.

The Power supply assembly is built up using AVD-1006 and AVD-1010 DC/DC converters and a discrete power steering network. DC/DC conversion is executed using a synchronous non saturating method, where all transformer switching activity is synchronized to the PCM word rate to optimize system signal to noise ratio performance. The converter is capable of working with either battery or external supply voltage in the range of 22.8 ± 4.0 VDc and provides the following outputs:

- ±15 VDc	PCM encoder Analog circuits
- + 5	PCM encoder Digital circuits
- +15 Vdc ± 0.25 VDc max 100 mA,	External signal conditioning
- -15 Vdc ± 0.25 VDc max 40 mA,	External signal conditioning
- + 5 Vdc ± 0.25 VDc max 35 mA,	External signal conditioning

The external transducer signal conditioning voltages are short circuit protected. The voltage levels are monitored through the PCM data channels. The converter circuit has full ground isolation between input and output power. Isolation is also provided between signal, power and chassis ground.

The power steering network controls the power source to be either the internal battery pack or an external power supply of 22.8 ± 4 VDc with a ripple of no more than ± 50 mV. Superimposed transients of 200 V, 0.15 microseconds duration with a 100 milliseconds repetition period can be tolerated for system operation within specifications. Battery On and Battery Off commands are accepted from an external voltage source of 22.8 VDc to control the switching circuit. A latching function is provided to keep the system in the current operational mode. Reverse polarity protection (down to - 40 V) is provided to prevent from damage due to mishandling. Application of voltages in the range of 0 to 18.8 volts will not damage the PCM encoder, but will cause a degradation of the system performance.

The signal conditioning/PCM encoder is built up using the following hybrid circuits:

- MPCA-10-3 Charge amplifiers
- MP-980H Analog multiplexer
- AD-981H Analog/Digital converter
- PD-929H Bi-level multiplexer
- CM-982H Counter module
- MI-983H Micro processor interface
- PR-914H Programmer
- TF-979H Timer/Formatter
- AVD-1004 PCM MPX output filter
- Discrete components for temperature conditioning

The PCM encoder inputs are grouped into four categories of analog data:

- high level
  (limited to ± 2.5 V or 0-5 V full scale)
- high level attenuated
  (limited to -25 V and + 35 V full scale)
- vibration
- temperature

These analog inputs are conditioned, normalized, time division multiplexed, sampled and held, digitized, formatted and serially transmitted by the PCM encoder.

The high level analog channels are directly connected to the MP-980H analog multiplexer, which contains two HI-506A 16 channel switches. The input impedance of these channels is more than 5 megohms shunted by 200 pF during sampling as well as non-sampling intervals (more than 1 kohms during power off).

The high level attenuated analog signals are connected to the same analog hybrid module after passing a fixed, factory presettable, active attenuation network. The input impedance of these channels is 50 kohms ± 5% shunted by 50 pF regardless of the power supply status. Vibration transducer signal conditioning is provided using the MPCA-10-3 charge amplifier module, and the output signal from the charge amplifier is also fed to the MP-980H, together with the temperature transducer channels where a resistive network is used for signal conditioning before the analog multiplexer. The charge amplifiers are set to ±2.5 V output for an input of ±175 pC. The measurement frequency range is 50 to 1500 Hz.

The discrete, bi-level inputs are multiplexed by the PD-929H module threshold detected by the TF-979H module. Inputs are sampled in a byte serial/bit parallel mode. The 20 inputs are grouped into two 10-bit words. The input impedance is more than 50 kohms shunted by 50 pF during sampling intervals and more than 5 megohms during non-sampling intervals (more than 50 kohms during power off). The threshold voltage is accurately set to 2.0 ± 0.1 V, using voltage comparators. When an input is left floating, a logic “0” will be indicated by the corresponding data bit.

The pulse input is fed to the CM-982H module, where it is threshold detected in the same way as the bi-level inputs. A positive transition of the pulse causes reset of a 10-bit counter, which is incremented by a high frequency clock. The clock signal is derived from the PCM bit clock, which is crystal controlled and thus accurate and stable. The counter contents are then sampled by the PCM encoder as a 10-bit word, representing the elapsed time between the last positive pulse transition and the current sample.

The two microprocessor inputs are connected to the MI-983H hybrid module, which contains all the signal conditioning and logic circuits to provide the required interface. The current data bus is latched and the information is written into its proper block space within the RAM. The address logic contained inside the module always writes data within the blocks at the same address location starting from a block zero point, which is decoded from the contents of the particular micro processor port’s bus. Block start is controlled by the contents of the first data word in each message from the different ports. A status bit, indicating whether data has been previously read, is stored along with each data word. The TM system always addresses the same memory location for corresponding PCM word and frame numbers. Priority control logic within the module guarantees that no interference between reading and writing takes place.

The interface is designed for a block size of 1024 eight bit words for port #1 and 256 eight bit words for port #2. The inputs may be totally asynchronous with respect to each other and with respect to the PCM read operations. A maximum data rate of 200 ns/word for port #1 and 1000 ns/word for port #2 is accepted. Data block frequency must be less than the lowest sample rate to ensure no data loss.

The multiplexed output of the analog multiplexer module (MP-980H) is routed to the sample/hold and analog to digital converter module (AD-981H). The front-end consists of a high speed, high accuracy sample and hold amplifier (HA-2420). The output is digitized by a 10 bit monolitic analog to digital converter (ADC-910-ET). The device can be set to convert either unipolar signals (O - 5 V) or bipolar signals (±2.5 V) on an individual channel basis. The conversion is made by the successive approximations method withinin about 8 microseconds. The result of the conversion is formatted serially for transmission to the TF-979H module. All conversion control circuitry is located inside the AD-981H, which reduces the amount of interconnections and optimizes the resulted converted data settling time performance within the PCM encoder.

Central PCM clock and basic control signals are generated inside the timer/formatter module (TF-979H). A high stability, high shock ruggedized crystal generates the basic clock which is then derived into the system bit clock, word clock and other timing signals. Output coding (NRZ-M) and data formatting circuitry (both parallel and serial inputs from the A/D, CM, MI and PR modules) are also contained within the TF-979H module.

The PCM sampling format is controlled by the programmer (PR-914H). This module reads the contents of the accessible, UV-eraseable EPROM which has been loaded by the user according to the desired sampling format. Each memory location contains a specific HEX command which the programmer reads and decodes. It then turns on the appropriate multiplexer channel by transmitting a 16 bit address on an internal bus. Each multiplexer will only respond to certain addresses from the programmer. Specific formatting features such as sub/supercommutation, frame sync code selection and SFID word location are as well controlled by the programmer. This module also sets the analog range to unipolar or bipolar, by sending specific addresses to the A/D converter module (AD-981H).

The NRZ-M output is conditioned by a 6-pole Bessel response low pass premodulation filter (AVD-1004). The -3dB point of the filter is factory preset to the required frequency. The amplitude of the filter output is adjusted to ±2.5 V. The output of the filter is short circuit protected and is capable of driving loads of 500 ohms in parallel with up to 1000 pF. Filter output impedance is less than 10 ohms.

The Telemetry Transmitter is a standard Aydin Vector Model T-602HS FM Transmitter with implemented modifications for wider frequency response. The center frequency is crystal controlled, and the deviation is set to ±300 kHz for the premodulation filter output voltage used. The power output is more than 200 mW into 50 ohm RF load. The transmitter is used as a common chassis, signal and system ground reference point for the over all TM system.

SYSTEM DESCRIPTION

The system packaging is based on the standard Aydin Vector high shock hybrid technique, where the IC components are mounted on ceramic boards, which are conformal coated and installed in hermetically sealed hybrid modules. A combination of hybrids and discrete components are mounted on multi-layer printed wiring boards. The boards are interconnected using a multi-layer mother board arrangement, where the plug-in is made through Cannon type MTN microconnectors. The TM system is built up with the battery pack at the rear end as shown in Figure 1. The transmitter section is mounted on top of the battery pack. This section contains the TM transmitter, surrounded by the circuit boards, that include the power steering network. The PCM section is mounted on top of the transmitter section. External connections are made using cables routed through the top cover of the PCM section. A Cannon micro miniature connector on one side of the TM system makes the diagnostic outputs available to the user. The RF cable is brought out at the rear end of the system, for connection to the wrap-around TM antenna.

The following circuit board layout is used (see PCM block diagram in Figure 2):

PCM section:

- A1: PR-914H, EPROM
- A2: TF-979H, AVD-1004, crystal
- A3: MI-983H, RAM
- A4: PD-929H, CM-982H, test connector
- A5: AD-981H, MP-980H
- A6: MPCA-10-3 (2 ea), discrete components
- A7A,B,C: AVD-1006, AVD-1010 power converters

TM transmitter section:

- A8,A9: discrete components, power steering

The Battery Pack is contained in a potted metal housing, and the TM transmitter is mounted between rigid metal plates. Each circuit board in the PCM section is installed in a metal framework. This part of the system is not potted, but held together by accurately designed metal frames. This is done in order to make it possible to remove circuit boards for test, repair, modification and reprogramming. The PCM section is sealed by a metal top cover plate, which makes the TM system self contained as one unit. The system is shipped in a specially designed metal housing.

Figure 3 and Figure 4 illustrate photographs of the TM system, complete and partially disassembled, respectively.

TEST RESULTS

The telemetry system was designed and developed in close cooperation between Aydin Vector and Saab Missiles AB. The task was performed as a continuation of the development program for three FM/FM TM systems, described in Ref [1].

Comprehensive qualification tests of the first manufactured system were carried out at Aydin Vector. The unit was subjected to and tested during all specified environmental conditions, with the exception of final high shock testing. This test took place in Sweden, using a rail gun facility, specially designed for the development program of the Swedish projectile. The system passed the qualification testing with approved results.

The production units were subjected to acceptance tests at Aydin Vector before delivery, using a specially designed test station including a micro processor simulator. For delivery, the systems were installed in shipping housings, supplied by Saab Missiles AB. At this stage, the TM system cables were terminated with standard Cannon type D connectors for test and calibration means.

When received at Saab Missiles AB, systems acceptance testing and recalibrations were performed, before the systems were beeing mounted in projectile aft bodies. The wrap around TM antenna (Haigh-Farr Model 4025), mounted in a groove in the housing surface, was connected to the TM system and the test connector approached through an opening in the housing. Integration tests were carried out with the complete projectile electronics and the measurement transducers (rate gyros, accelerometers, vibration and temperature sensors), to ensure correct system performance before projectile launch.

The deliveries were completed in 1988 and the systems have been extensively used for a large number of tests, covering rail-gun, rocket launch and trench mortar live firings. Reliable TM data with extremely good quality has been collected using fixed and tracking receive antennas. The test data has been subjected to real time and quick look evaluations as well as comprehensive and advanced post simulation analyses, using computer simulation methods.

The rail gun is designed for a smooth recovery. Some of the systems have been reused for many successive (and sucessful) test firings. When rocket launched and mortar fired, the systems were recovered after landing in the target area, which in most cases have been stone, sand and soil based. In a few cases the landing conditions were water with sand bottom. In almost all of the cases the recovered systems have proven to be very reliable and consistent with respect to the technical performance. No degradation has been noted for the measurement characteristics and when re-calibrated after firings, the systems have met the required specifications. The experience gained from successive test firings demonstrated that the battery pack showed a slow degradation in capacity. Due to the modular design, it has been possible to change the battery pack and even to re-use the same systems with successful results.

ACKNOWLEDGMENT

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KEYWORDS

PCM - Pulse Code Modulation
FM - Frequency Modulation
TM - Telemetry
High shock
Packaging technique

REFERENCES

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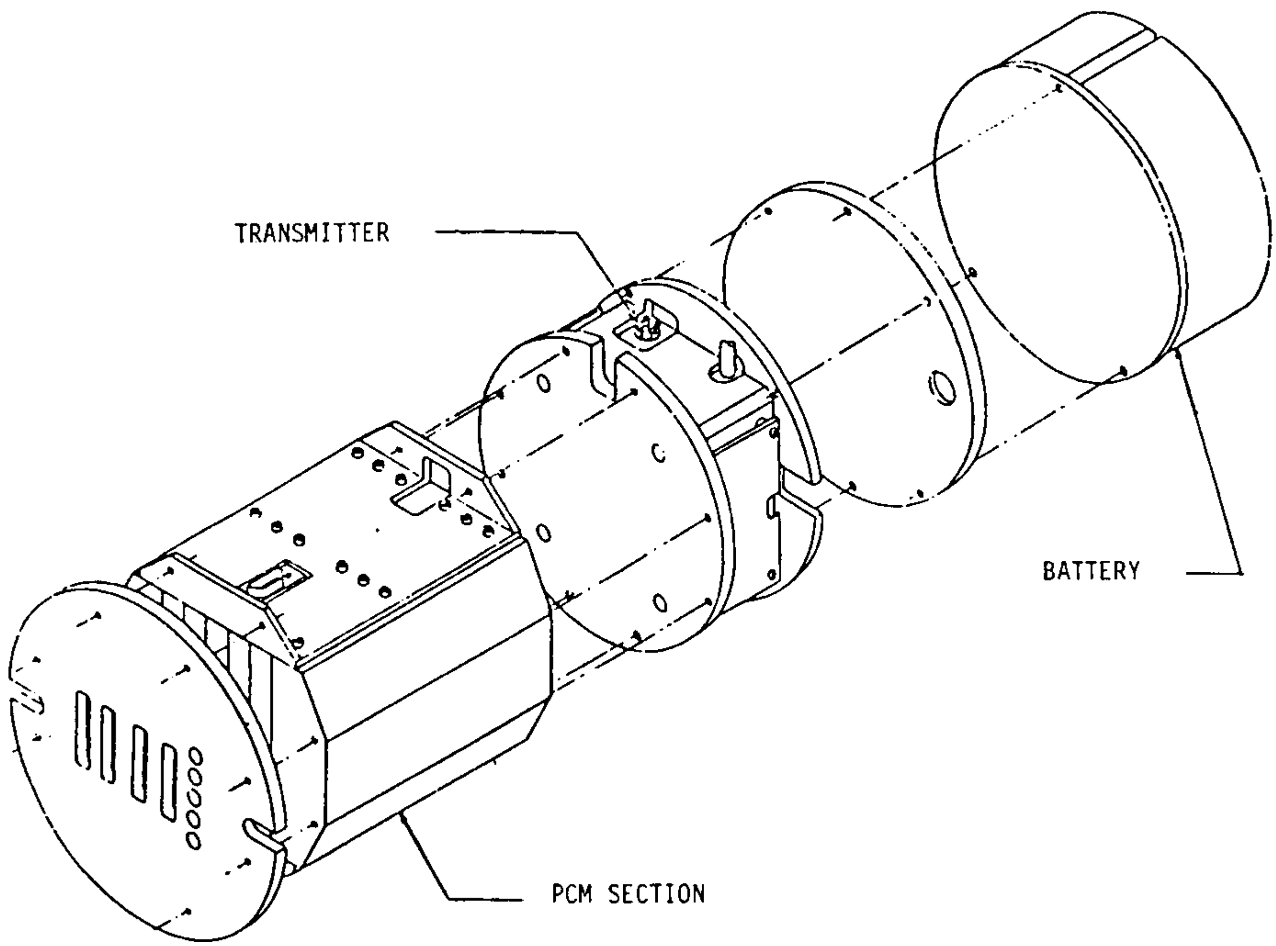

Figure 1
FMT-783 PCM TELEMETRY SYSTEM

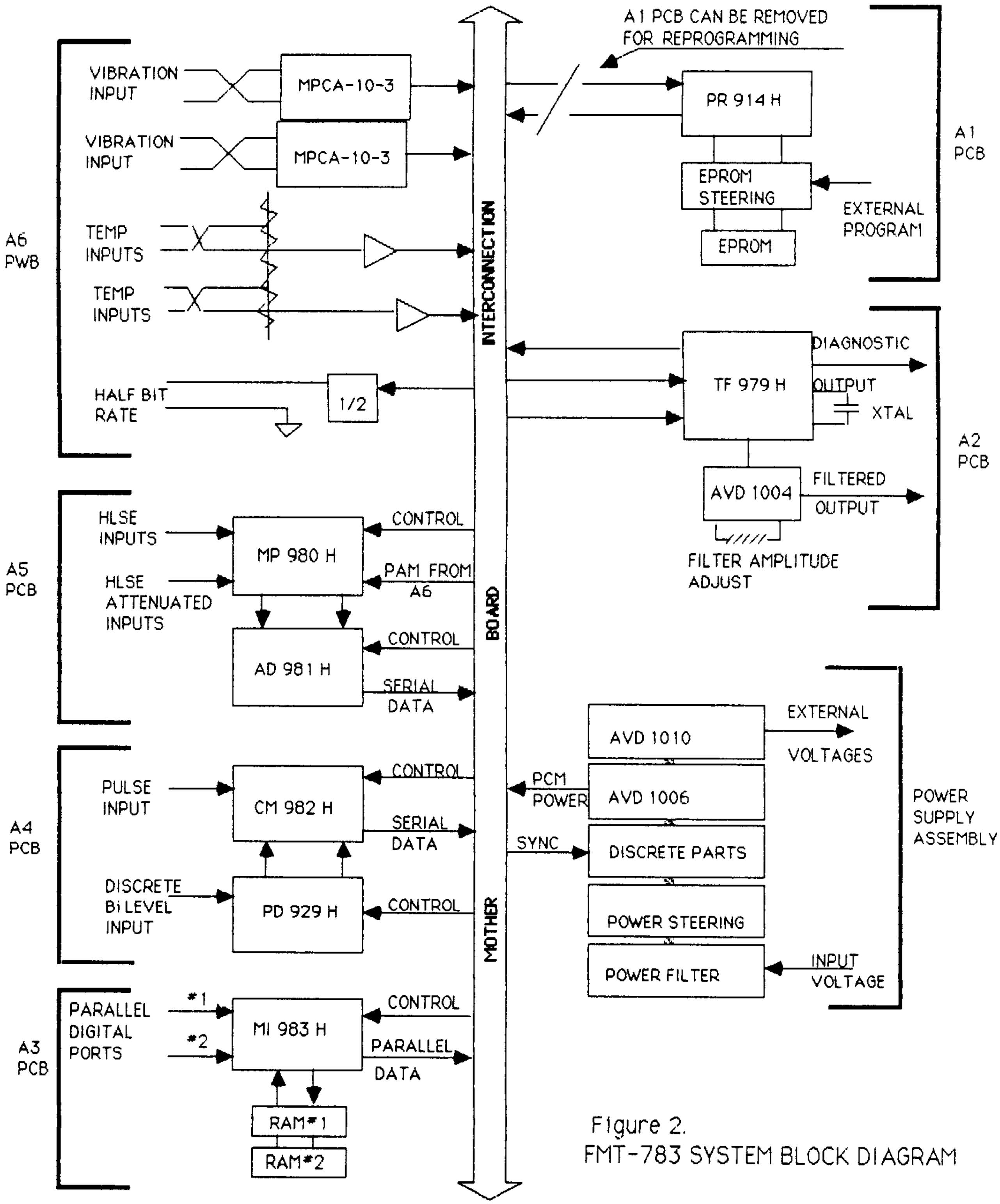

Figure 2.
FMT-783 SYSTEM BLOCK DIAGRAM

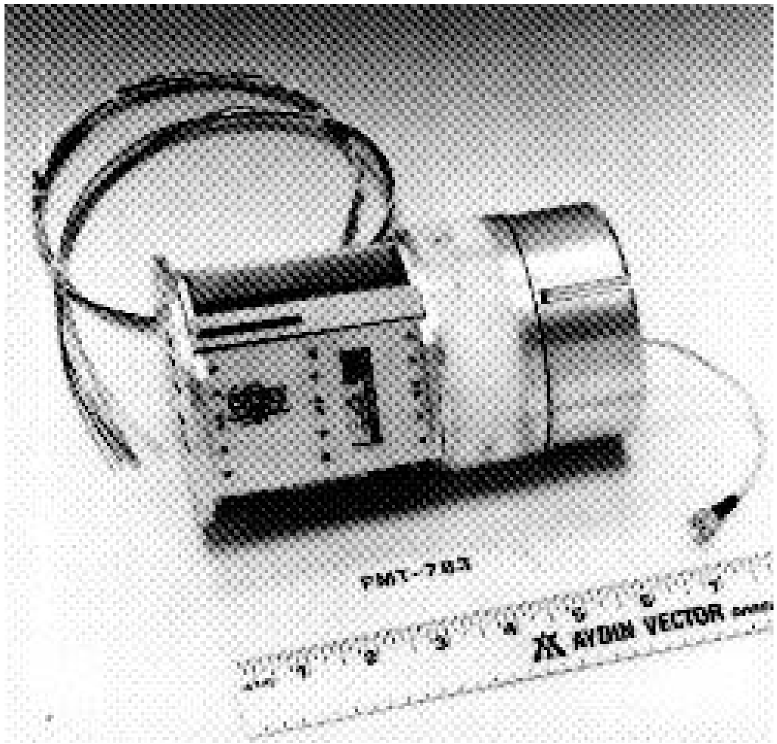

Figure 3.
PCM TELEMETRY PACKAGE

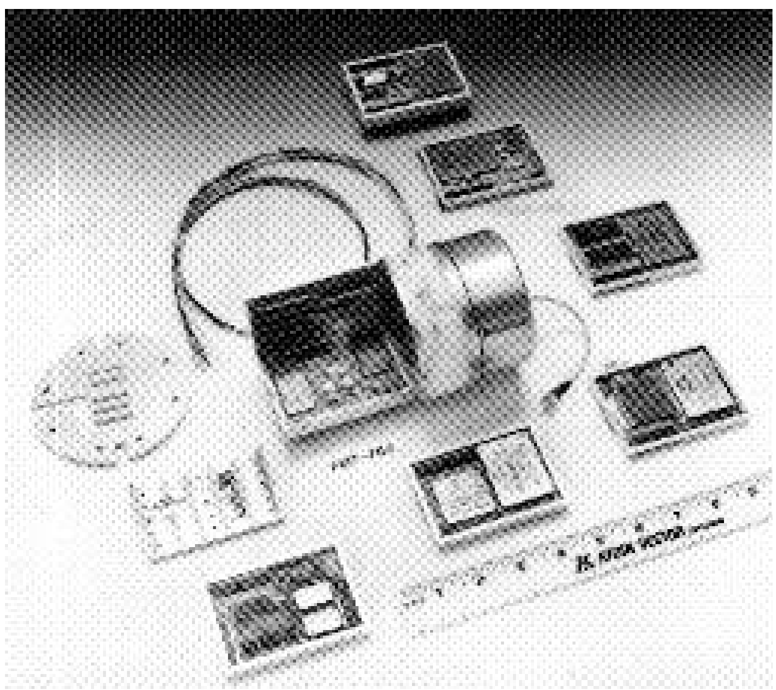

Figure 4.
PCM TELEMETRY SYSTEM, PARTIALLY DISASSEMBLED