# A SHOCK HARDENED DELAYED TRANSMISSION SYSTEM FOR TRANSIENT DATA ACQUISITION*

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**Summary** A shock hardened, delayed transmission PCM system for use in an artillery projectile instrumentation program is reported. The output of the projectile mounted PCM encoder is coupled to an MOS shift register memory to delay data transmission until projectile flight, thus eliminating the requirement for a real-time transmission link for in-barrel data. The capabilities to monitor both in-barrel phenomena and flight performance parameters are included. Windowing of the transient, in-barrel data is accomplished by threshold discrimination within the projectile mounted system. System design, operation and ground support requirements are discussed with flight test results presented.

**Introduction** The use of a 155 mm M2, long-tom cannon and specially modified projectiles to provide a method of subjecting test components to high shocks (16,000g's) for long duration (20 msec) has created the need for a shock hardened telemetry link. The telemetry system is to be used to monitor component performance while the projectile is being launched from the 155 mm cannon.

A projectile mounted FM/FM system utilizing a P band RF transmitter to provide a real-time, in-bore telemetry link was reported earlier.[(1)] Since the cutoff frequency for a 155 mm circular waveguide is 1100 MHz, the P band (220-260 MHz) transmitter can not be used to transmit directly while the projectile is in the barrel. To provide a means of coupling the RF energy out-of-the-barrel during projectile launch, a wire is inserted into the barrel and placed in close proximity to the nose mounted antenna. The wire is excited by the RF energy and acts as a reradiator external to the barrel.

During the development of the P band FM/FM technique, considerable difficulty was experienced in maintaining the integrity of the RF link while the projectile was traversing the barrel. L band transmitters, designed to survive high shock levels, were evaluated for use as the in-barrel transmission link. While these transmitters did indeed

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survive the gun launch environment, large shock induced transient frequency shifts prevented RF reception with standard telemetry receivers.

Both the P band and L band transmitters survived the gun launch and operated properly within milliseconds after the projectile exited the barrel. This characteristic suggested the use of a data acquisition technique that would delay transmission of the data gathered in-barrel until the projectile was in-flight. A program was begun to develop a delay transmission technique to complement the continuing development of the real-time RF link.

**System Benchmarks** To properly evaluate the proposed delayed transmission techniques, the followings system benchmarks were established.

**Adaptability** Since the development of the delayed transmission technique was being pursued concurrently with the real time transmission technique, any method developed should not be limited to the projectile instrumentation but should be adaptable to other programs where real time RF data transmission was not possible. As a system goal the technique should be capable of data acquisition with or without the use of an RF link.

During the development of the actual hardware it was anticipated some components would not be shock hardened enough to withstand the environment. To facilitate postmortem analysis of units that fail in testing and to accommodate needed design changes, the packaging technique should lend itself readily to component replacement and yet provide a rugged method of component mounting and interconnection. The packaging should accommodate these design changes easily and be of a modular construction. The modular construction would provide a broader application range without extensive modifications to the mechanical design.

The system should provide both a real time data transmission capability and a delayed data transmission capability. Either option should be available on command.

The format of the output data should be compatible with all RF transmitters being evaluated for real time transmission. Since several phase modulated, crystal controlled transmitters were being considered, the output data format should not require a DC response in the transmission link.

**Support Development** Testing commitments required that a fully operational system be available with a short lead time. This requirement as well as the expenditure usually associated with the development of special purpose components, dictated the use of standard, commercially available devices. In conjunction with this requirement, any technique developed should be compatible with existing ground support facilities.

**Data Quality Assurance** To assure the data transmitted in delayed time was not distorted by the delaying media, a data confidence signal should be included in the data. A method to exercise the system in all modes just prior to launch should be included to assure proper operation before launch.

**Data Requirements** A review of the 155 mm test firings requiring instrumentation revealed any system developed should contain a minimum of 5 data channels with each channel providing a 500 Hz frequency response. The majority of the testing commitments require instrumentation be provided for a minimum of 15 milliseconds.

**Environmental Requirements** The system should survive and operate during a launch acceleration of 16,500g's, 15 msec haversine, coupled with an angular acceleration of 320,000 rad/sec$^2$ of the same duration and signature. The delayed transmission is to be operative following the above shock signature and during the subsequent spinning projectile flight. The projectile will be spinning at approximately 250 rev/sec.

The system is to operate over the temperature range of -40°C to +80°C.

**Support Constraints** Due to short lead times allowable in the 155 mm test program, the requirement to develop a technique within existing device technology and existing ground support facilities was deemed paramount. A review of the ground support facilities revealed equipment was available to support either an FM/FM or a PCM/FM telemetry link.

The RF link could be P, L, or S band as telemetry receivers were available for support in these three frequency bands.

These support facilities required either the data be transmitted within a few seconds after the projectile exited the barrel or be stored in some nonvolatile media for interrogation in the laboratory. Package recovery and subsequent laboratory interrogation eliminated the capability of providing quick-look data in the field and the use of this technique also inhibited full operation checkout just prior to launch. Both of these features could be achieved by using a standard PCM encoder with a temporary storage capability and reading out the data in an acceptable PCM format.

A six bit PCM encoder provided sufficient accuracy to satisfy the data requirements and a sample rate of 2500 samples/sec/channel provided the required channel bandwidth requirements. Temporary storage of the data obtained from five channels in the 20 msec period the projectile is traversing the barrel would require 250 words,,or 1500 bits, of memory capacity, exclusive of any "quality words" or synchronization information. To satisfy the "quality word" requirement and provide sufficient synchronization information should the rapid variation in the RF energy received from the spinning projectile result in “burst” records, a major and a minor synchronization pattern were included in the memory. The resultant 1800 bit storage and transmission format is depicted in figure 1. Arranging the format in the matrix form shown offered several advantages when the ground support capabilities for decommutation were considered.

The major sync selected for the 1800 bit main frame was a 30 bit (5 word) code in accordance with NASA-X-560-63-2. Each six word time slot contains a minor sync pattern and the desired 5 analog channels with a complementing minor sync pattern used on alternating 6 word groups. Forty-nine samples of each channel are obtained and stored in one memory load cycle.

The data format of figure 1 could be decommutated using either of two methods. The first would consider the format shown as a PCM frame containing 300 words with 5 words of synchronization data per frame. By programming the variable radix counters that controlled the decommutation in a 6 x 50 configuration, the apparent super-commutated data could be easily stripped out with DAC’s controlled only by the 1 through 6 count. The second method would define the PCM format as containing a six word frame and the frame synchronization pattern would be the minor sync pattern. Since the minor sync is complemented every 6 words the PCM decom would be programmed to accept a “Frame Complementing” synchronization code. The major sync pattern would then be defined as a unique recycling subframe code and would be used to identify the beginning of the memory cycle. Again the DAC’s would require only a 1 through 6 count for decommutation.

An MOS shift register, formed into a continuous loop for storage, offered the simplest memory design since it was directly compatible with the serial PCM output. The PCM/shift register system is placed in an arm condition before launch such that logical zeroes are continuously shifted within the register. Upon firing, major sync is first read into the register followed by the remaining format. This insures major sync is in the register for data synchronization in the event the shift register loop is closed prematurely.

Initiating the storage cycle is a critical factor due to the limited memory capacity. The timing problems associated with initiating the memory storage cycle from ground control are prohibitive; therefore, initiation is coupled to projectile motion to insure proper windowing of the desired transient data.

The PCM system, as depicted in the block diagram of figure 2, consists of two six-channel multiplexers, a six-bit successive approximation Analog to Digital Converter (ADC) and a recirculating MOS memory for temporary data storage. Multiplexer selection is controlled by a programing or control section which allows one bank of six analog channels to be monitored at a time. The NRZ-L PCM encoder output can be channeled into the MOS memory for storage or the memory can be bypassed. Either information source (memory contents or direct PCM encoder output) can then be selected and passed through a Bi-Phase-Level converter section and pre-mod filter to the transmitter.

System operation can best be explained by considering a requirement to monitor two events which occur at different times during a projectile flight. One multiplexer would time sequence in-barrel data channels while the other multiplexer would sequence the out-of-barrel data channels. After tile projectile is inserted into the gun barrel, the PCM system is armed (memory cleared to all zeroes) and the six in-barrel data channels are monitored. Upon firing, memory store cycle is initiated when the digitized output of a preselected in-barrel data channel exceeds a programed threshold voltage. This event will enable the MOS memory input from the PCM encoder. Once the MOS register is filled to capacity with in-barrel PCM data and synchronization patterns, the register input is switched from the PCM encoder output to the register output to provide recirculating storage. The MOS shift register contents will then be continuously recirculated (as long as power is supplied) providing storage of the in-barrel information.

Once the gun barrel is cleared, the in-barrel information stored in the recirculating MOS memory is transmitted upon command of tile programer, avoiding transmission problems associated with the in-barrel environment (transmitter stability, etc.). During the remainder of the projectile flight information can be transmitted in real time from either multiplexer.

**Packaging** Three approaches were considered for packaging the system in the projectile space available: standard printed circuit boards, cordwood modules, and hybrid. Each was evaluated based upon size, ruggedness, repairability, and development time required. The hybrid method, while offering small size which is advantageous for the gun environment, required an excessive development time. The alloted space eliminated the printed circuit technology due to the complexity of the system. Cordwood construction offered a compromise between hybrid and PC boards when considering size restraints. In addition to dense component packaging, cordwood modules with welded component interconnections offered an extremely rugged construction technique yet maintained repairability.

A complete system constructed using the cordwood welded module technique is depicted in figure 3.

Each integrated circuit planned for system use was subjected to 10,000g’s @3.0 milliseconds in a 5 1/2" airgun as a shock qualification test. Standard off-the-shelf devices were employed in the majority of the design with the only non-standard items being state-of-the-art 900 bit MOS shift registers.

Extensive air gun testing was performed on the pre-regulator and DC/DC converter due to the critical nature of this circuitry. Both static and dynamic testing were performed until considerable confidence was attained.

The complete system was statically tested in the air gun prior to actual flight in the 155 mm cannon. This preflight screening philosophy was intended to locate weak components before committing the system to an actual gun launch.

**Pre-Launch Check** Three control lines are available for pre-launch exercise of the system. One control line provides output selection while Four possible combinations the remaining two are used for memory control. of the memory control lines allow:

a. Clearing the memory.
b. Recirculating a main frame.
c. Shifting data with no recirculation.
d. Arming the system.

These four combinations allow complete system checking. First, the memory can be cleared (all logic 0 state) or the system can be forced to recirculate a main frame to check storage capability. Next the NRZ-L from the PCM encoder can be shifted through the MOS register to confirm real-time operation.

To conclude pre-launch check, the system is placed in the armed position which clears memory. The memory can only be loaded in this position when a preselected analog channel exceeds a programed threshold.

**System Testing** Two test firings leave been conducted employing the PCM/shift register memory systems. These test firings were conducted at Sandia Corporation’s Tonopah Test Range in Nevada. The projectile launch and data reception technique is depicted in figure 4.

The projectile containing the telemetry system is launched from a 155 mm rifled-barrel cannon at an elevation angle of 85°. The use of a high gain tracking antenna and fan beam fixed antenna provide for data reception during the projectile flights The fan beam antenna provides coverage during the lower portion of the trajectory with the high gain tracking antenna providing coverage during upper portion of projectile flights At an altitude of approximately 21,000 feet the projectile passes through a radar window and is tracked to impact to provide supplementary tracking data for the antenna and to aid in recovery. The spin stabilized projectile reaches an apogee of 10 miles in approximately 45 sec. A nose up attitude is maintained past apogee and a nose-mounted Parachute is deployed shortly after the projectile begins its base-first descent. Parachute retarded descent requires approximately 450 seconds from chute deployment and impact occurs base-first at a velocity of 80 ft/sec.

A block diagram of the projectile mounted telemetry system is shown in figure 5. During development testing, acceleration data from, each of three accelerometers were monitored as well as the +28v bus and the memory cycle initiate signal. System power during launch and flight is provided by an electric match initiated ammonia activated battery reported earlier(1). The L band transmitter is a single transistor, free-running voltage controlled oscillator that provides approximately 400 mW of output power. An internal 10 db pad is used to isolate the transmitter output from variations in load that can occur during projectile launch and subsequent flight. The antenna is an integral part of ogive and is a modification of the Halo antenna developed by Ballistic Research Laboratories(2). Since the ogive contains the parachute recovery system, the RF link is terminated when the parachute is deployed.

After the projectile has been inserted into the cannon and prior to launch, all modes of operation are exercised. This is accomplished through the use of an umbilical cable connected to the projectile through the muzzle of the cannon. After the cannon has been elevated and the internal battery has been activated, the control cable is extracted. The projectile is launched approximately 60 seconds after battery initiation.

**Test System Packaging** The 155 mm test projectile is shown in figure 6, with the internally mounted telemetry components shown in figure 7. the upper portion of the package contains the battery and the L band transmitter. Interconnection of this section to the lower section containing the remainder of the system is made via a terminal board and connector. Mechanical support of the components mounted in the lower assembly is achieved by tightly packing them in moist brown sugar. The entire lower assembly is then held under vacuum at a temperature of 130°F for 18 hours to remove the moisture from the sugar and cause the grains to adhere to each other. Figure 8 is a telemetry system packed in brown sugar that was launched with a setback acceleration of 12,500g’s.

**Test Results** The first full system test was conducted in January 1971 at ambient conditions and a launch acceleration of 12,500g’s. The L band RF link was maintained during first 10 sec of flight through the fan beam antenna coupled to a polarization diversity combining system. A transient signal, introduced when the umbilical was severed, prematurely loaded the memory causing the launch acceleration signature to be missed. However, the contents of the memory were read out properly during the projectile flight. Post-mortem of the system revealed the case of the reefing cutter used to sever the control cable was not sufficiently grounded and had introduced the transient signal. It was also determined the in-barrel multiplexer had failed during the projectile flight. Examination of the multiplexer chip revealed the flying leads used were longer than necessary and had shorted together during the flight of the spinning projectile.

The second test was conducted in February 1971 with the system preconditioned to -20°C and launch acceleration of 12,500g's. The memory was properly initiated during this test and the acceleration signature was stored in the shift register. This signature is shown in figure 9. The RF link was maintained on both the fan beam and the high gain tracking antennas through the majority of the flight.

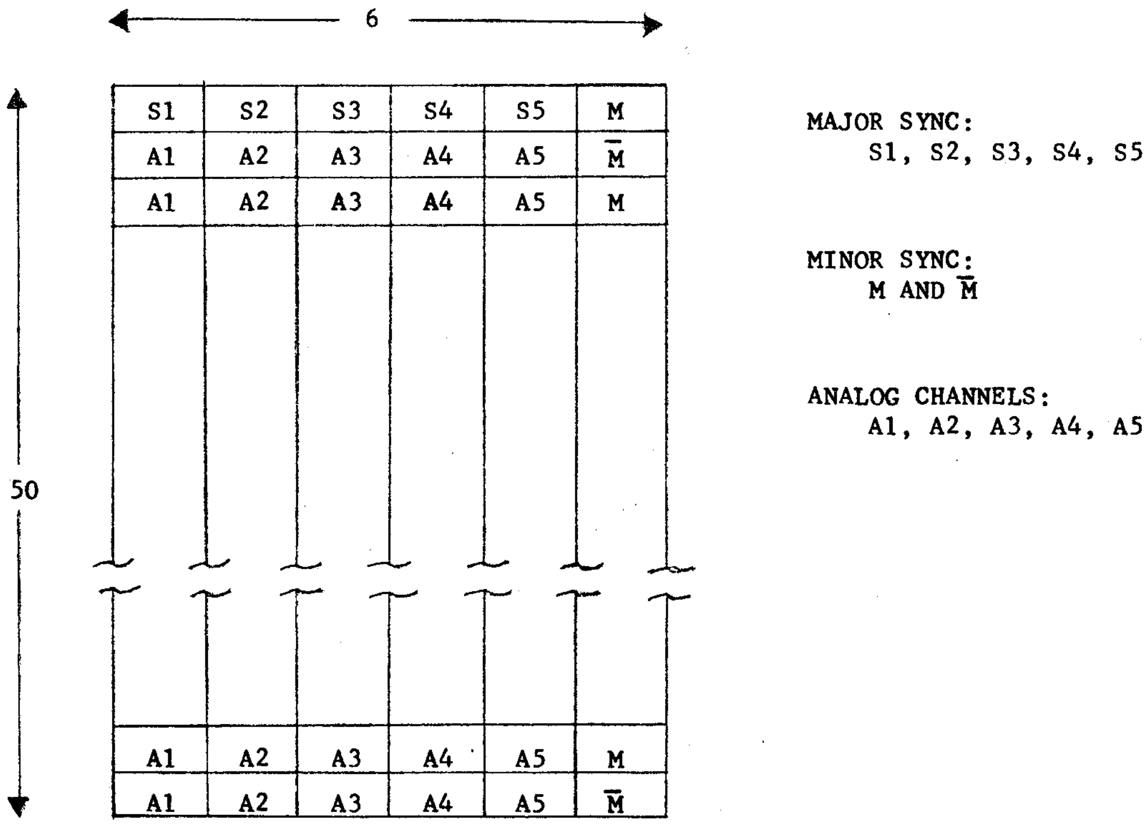
**Future Efforts** Based upon the results of the first two tests, two additional systems were fabricated. These systems will be tested in May 1971 at launch accelerations of 14,500g's and 16,500g's.

On future systems, the length of the flying leads will be carefully controlled by the multiplexer manufacturer to eliminate shorts induced by the centrifugal forces. In addition, a design change has been incorporated to reduce the readout rate of the memory. This reduced rate will allow the memory content to be read out on a VCO and thus allow the remainder of the baseband to be used for real-time data.

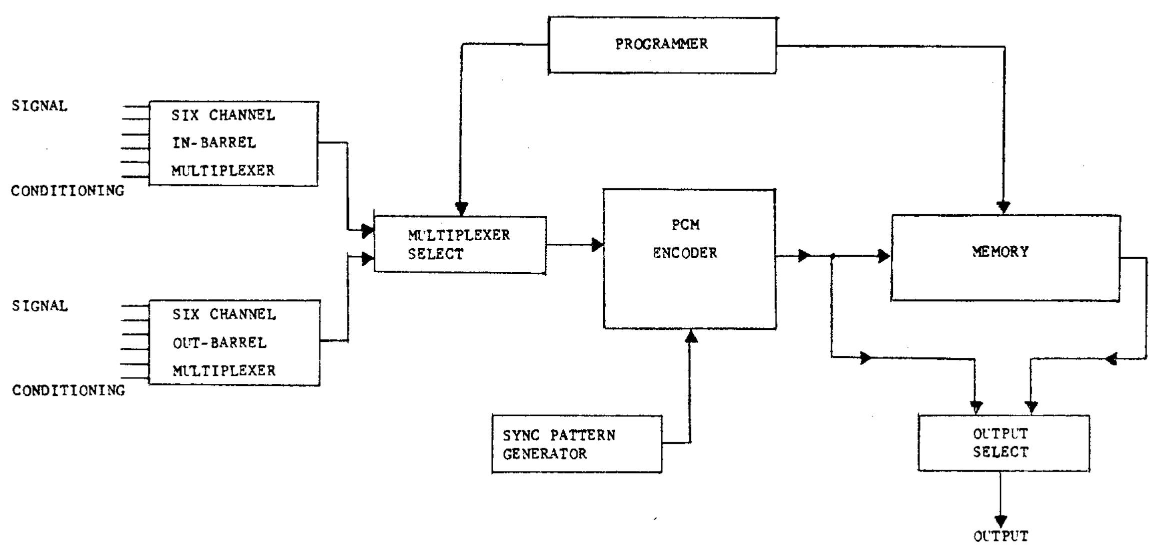
**References**


(1) R. Bentley, C. Ruttle, "A Projectile Telemetry System for In-Barrel Data", International Telemetering Conference Proceedings, Vol. VI, pp. 431-451 (1970)

(2) V. Richard, 14. Hadowanetz, "A Universal L-Band Telemeter for Use on Artillery Projectiles and Gun Launched Research Probes", International Telemetering Conference Proceedings, Vol. VI, pp. 402-430 (1970)




**PCM FORMAT**
**FIGURE 1**




**PCM BLOCK DIAGRAM**
**FIGURE 2**

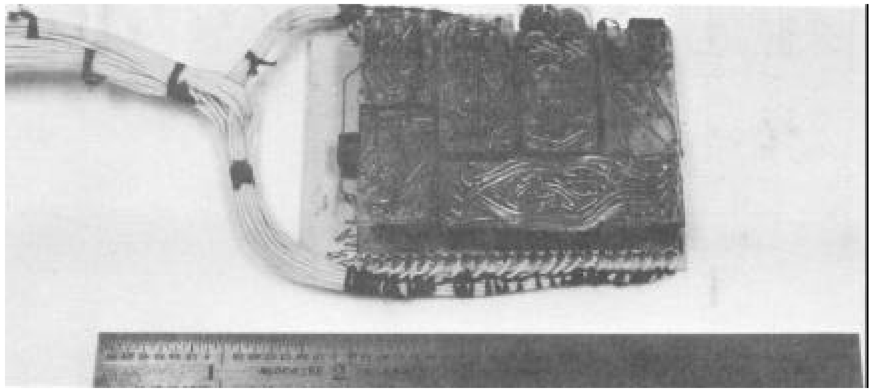


**Figure 3**

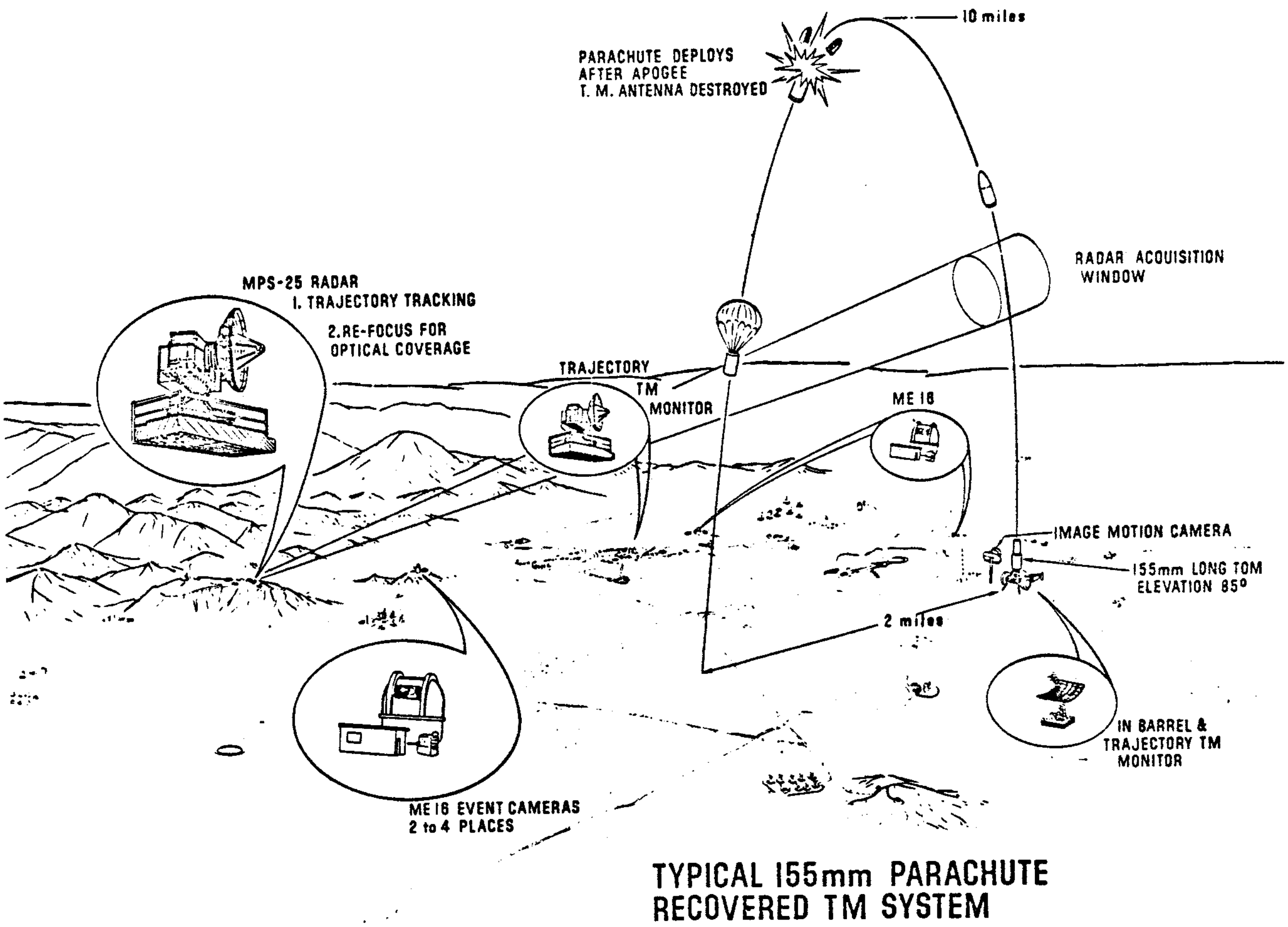
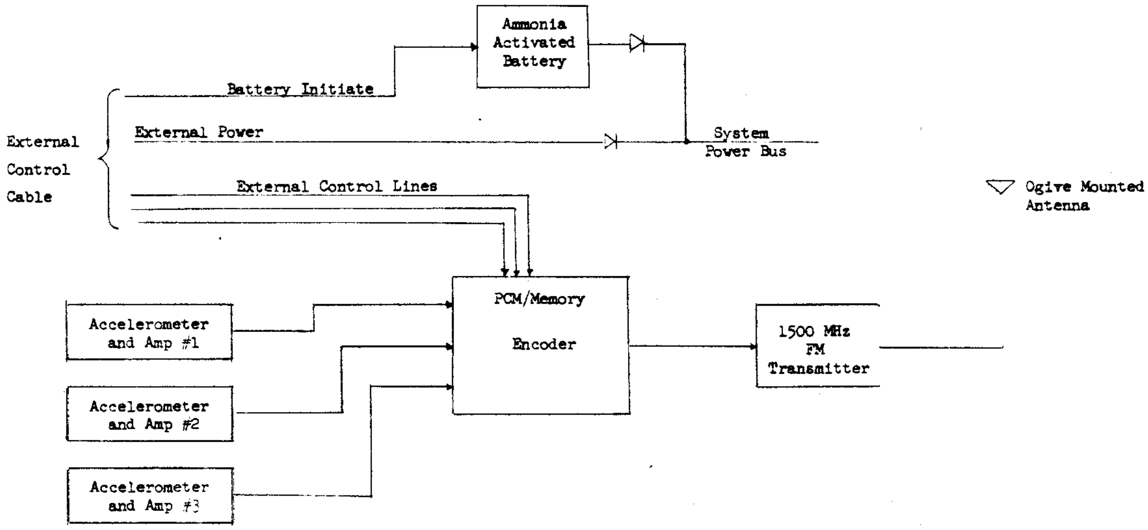



**Figure 4**




**System Test Configuration**
**Figure 5**

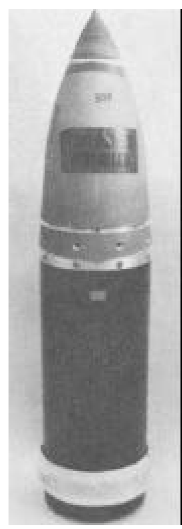


**Figure 6**

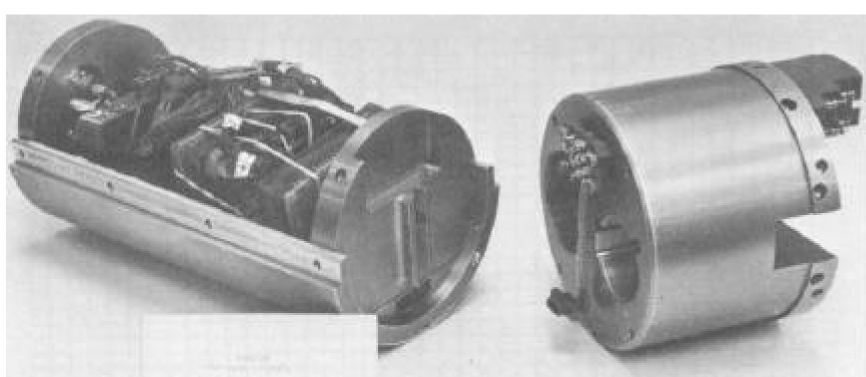


**Figure 7**

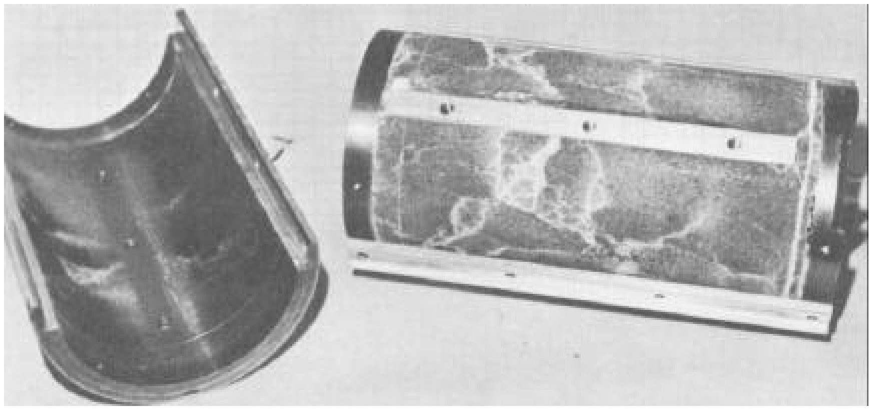


**Figure 8**

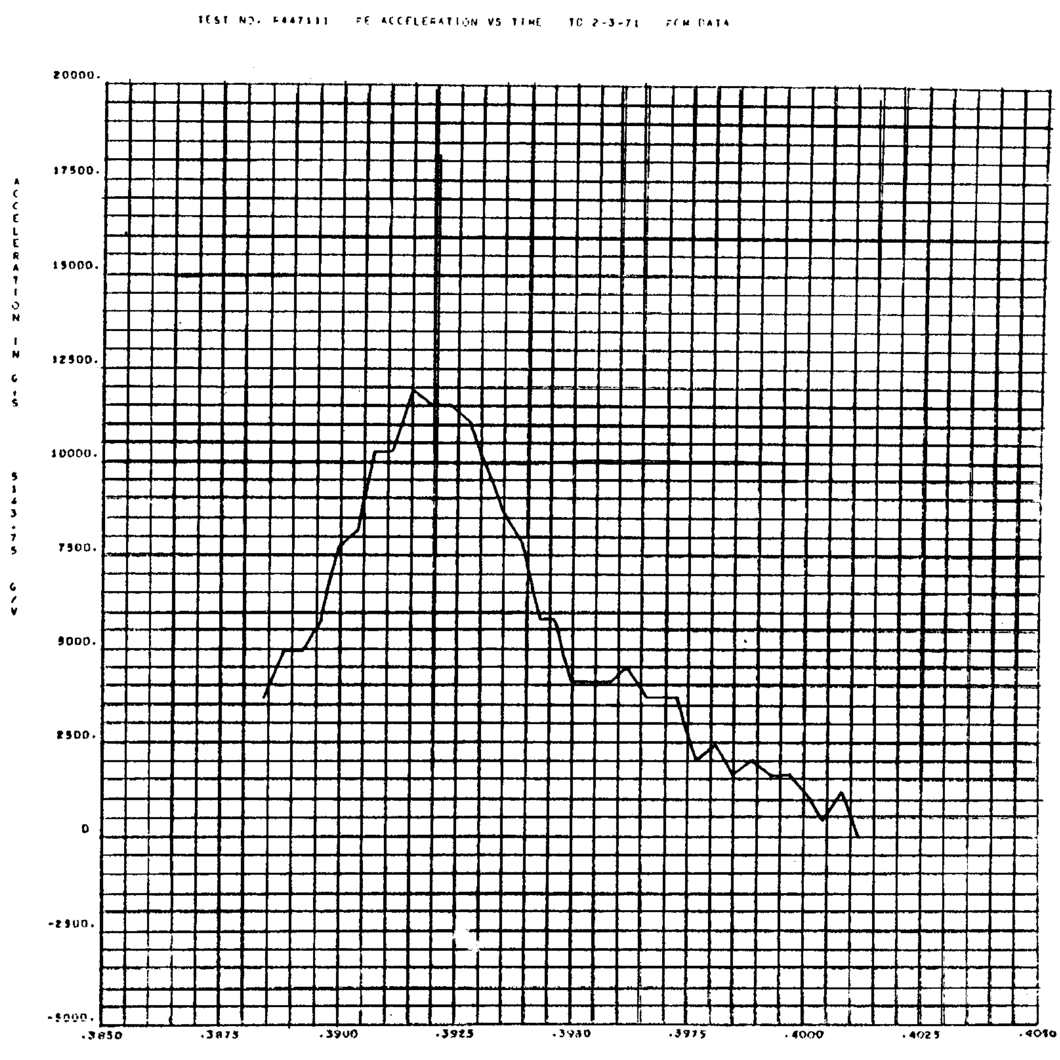



**Figure 9**