APPLICATIONS OF RECOVERABLE DIGITAL MEMORY TELEMETERS IN ARTILLERY PROJECTILES

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ABSTRACT

As fuzes and guidance systems become more sophisticated, the use of artillery projectile TM's is increasing. In some applications where data requirements are simple in nature and limited in volume, and where there is a high probability of successful hardware recovery, the use of micropower digital memory systems is more desirable than the conventional, more costly RF system.

Digital Memory TM systems, their capabilities and limitations, design considerations, and field and laboratory test results are presented. Some of the extreme environments and shock resistant packaging techniques are also discussed.

INTRODUCTION

The rapid advancements in electronics have brought about highly sophisticated artillery projectile fuze and guidance systems, including expensive microcomputer and laser guidance devices which render the conventional statistical proof testing (e.g., firing large lots) financially impractical. As the cost of the projectiles increases, the use of telemetry to acquire quantitative performance data has become increasingly necessary so that the maximum amount of data can be obtained from each firing test. Furthermore, while the statistical approach provides only an estimate of the quality of a given lot, the telemeter can frequently pinpoint or infer the cause of an anomality or failure. Usually, the quantity and frequency content of the data requirements is large, and the use of an RF telemeter is necessary because of its large data band width. However, when there is only interest in limited event-type functions, such as sequence and time of switch closures or detonator actuations, a recoverable memory telemeter can be considered.

The memory telemeter is a micropower, digital electronic storage device. It acquires and stores the data in its memory, which is interrogated after recovery of the projectile. A typical multifunction telemeter may contain charge amplifiers, signal conditioner, flash converter, clock, control logic and storage. Typically, the power is switched on for the duration of the date acquisition period. After that time, only the memory device is powered, which consumes approximately 10 microwatts per 2K x 8 bits of storage. The activated TM may draw 10 - 50 ma. at 10 V for the duration of the flight, typically 30 to 60 seconds. Using 150 mah batteries, data retention varies between 1 - 15 days, depending upon the storage volume.

Packaging of the telemeter to survive the firing and impact in a form so that it can be recovered and interrogated is of paramount importance. First of all, it has to conform to the available mounting volume and form factor within the projectile. Performance of components is affected by their location and mounting direction. For instance, batteries should be located near the longitudinal axis to minimize the migration of the electrolyte as a result of spin. The telemeter must be sturdy enough to survive the environmental forces while its weight must be kept to the minimum.

Support of components in a high-g electronic assembly is achieved by either simple mechanical structures and extensive use of potting materials, or by more complex mechanical mounting and minimized use of potting. The mounting methodology is determined by such tradeoffs as available size and weight, estimated need for repair, need for rework or changing of measurement parameters after fabrication; planned re-use of a system requiring, as a minimum, battery replacement; and cost of components. This latter factor frequently is the overriding factor in deciding whether to make a whole assembly “throw-away” or repairable if testing discloses a fault. A recoverable memory pack may use relatively inexpensive components, but, because of its inherent sturdiness, may be reusable if the batteries can be replaced. Therefore, a removable battery assembly can be designed.

High density, hard but resilient potting compounds have been used successfully for potting high-g electronic assemblies. One was found to be easy to work with and offered variable control over the hardness and resiliency of the final cured compound.

Tests have been performed on a light-weight hard foam compound which offered the property of filtering the high frequency harmonics of the shocks to protect high resonant frequency electronic components as well as continuous control of the foam cell density. The foam was tested successfully in set-back environments up to 20,000 g’s. However, it failed to support dense components such as the batteries at higher g levels. A high density, hard but resilient compound was found to provide the best overall protection against shock.

In comparison with the RF telemeters, the memory telemeter has the following advantages and limitations:

Advantages:

1. Simplicity

2. Reduced volume and weight

3. Logistics simple

4. No transmitter or antenna required

5. Faster deliveries

6. Data is secure

7. Lower cost

A typical memory TM is a basic, micropower digital device. Due to the lower power consumption, the size and weight of the battery pack is considerably smaller than that of an RF telemeter. The data is retained in the memory until recovery and interrogation is achieved by the use of a lightweight, hand-carried interrogator. In comparison, the RF telemeter has to be monitored continuously from ground stations, usually at least two heavily equipped mobile units, with a minimum of two operators each. The memory telemeter does not use a costly transmitter nor antenna system. The overall result is lower cost and faster delivery.

Limitations:

1. Limited data volume

2. Limited frequency response

3. More stringent packaging required to permit recovery

4. Applications limited to those where recovery is possible

As data is acquired, it continuously fills up the available storage space. Although responses up to 50 KHz can be attained, the fast scanning rate fills up the memory faster and shortens the duration of coverage. There is a trade-off between frequency response and time duration of coverage for a given memory size. The test round and the TM within must be recovered for interrogation. Target areas such as water, mud and fields covered with heavy vegetation or rocky terrain should be avoided if possible.

Following are discussions of three memory type telemeters. Specific requirements, environments, and some unique approaches are also discussed.

TELEMETER "A"

This telemetry concept was proposed for use in acceptance testing of a projectile time fuze. The arming and firing fuze functions occur sequentially at pre-set times. A dud will occur if either function fails. Since either or both functions may not occur at the set time in the trajectory, but could be forced to occur at ground impact (still a dud), determining the times of events in the event of a dud was impossible without instrumentation. The following requirements were placed on the instrumentation: (1) measure and register the times of occurrence of the two functions within the first 35 seconds of flight, including possible inbore or premature functioning. (2) the package will screw onto the fuze and fit into the initiator charge cavity. (3) total package weight should be less than 1 lb. (4) data must be retained for a minimum of two days. (5) the telemeter must survive setback and ground impact, with forces estimated in excess of 30,000 g. (6) the TM should be reusable for a minimum of 20 tests.

A digital memory telemeter was designed and successfully tested for conceptual soundness. The telemeter (Figures 1 and 2) measures 2 1/8" dia. by 3 1/2" long and weighs approximately 3/4 lb.

The basic circuitry is comprised of level detectors, clock and counters. All integrated circuits are type B micropower CMOS devices. The RC clock rate was tested for deviation due to expected temperature and voltage variations and was found to be better than 2%.

The power is supplied by 150 mah, rechargeable NiCad button cells. Access to the circuitry is accomplished by a Cannon Type MDM connector. All telemeter components had been previously qualified for the expected environment.

Three prototype telemeters were fabricated using discrete integrated circuits and other components and custom hand wiring in lieu of printed circuits. Following functional laboratory testing and temperature cycling, the telemeters were successfully tested in the rail gun at 12,500 g's setback. The first unit contained a diode whose performance was marginal during environmental testing; therefore, this unit was designated as a spare during field tests.

Firing tests were conducted with the following results: 1. The metal housing and TM/fuze interface fractured at ground impact in each round (Figure 3). The telemeters then broke loose into the shell cavity. 2. The TM with the unreliable diode failed. Post mortem test indicated that the diode in question fractured, but the remainder of the circuitry was still functioning when the diode was bi-passed. 3. The other two telemeters were functioning properly after recovery, and the times of events in the memories correlated closely with the fuze preset times. The deviations from the preset times were within fuze tolerances.

This field test proved that the telemeter's electronic design concept satisfied the requirements, and the packaging technique adequately protected the circuitry from the setback and impact shock forces.

The mechanical housing wall thickness had been minimized to reduce weight. The housing is being redesigned to increase its strength.

TELEMETER "B"

Telemeter B was developed to measure and record several operational events in a projectile. These included the sensing of some voltage thresholds, the velocity of internally moving parts, total flight time, and other event times of occurrence. The telemeter design uses CMOS micropower integrated circuits and consists of a 1 MHz clock, control logic, comparators, dividers, counters and shift registers. A g-switch is used to sense set-back and start the clock. Flight time is obtained by dividing the clock output and feeding a counter. Knowing the frequency, the contents of the counter will be directly proportional to the elapsed time with a resolution of 10 milliseconds. The velocity of the internally moving objects is measured by monitoring the functioning of breakwire sensors positioned at precisely spaced distances along the path of the moving objects. The sensor outputs are fed into the control logic, which, on command, feed the clock pulse train into counters. This data is stored in the counters and, during interrogation, is transferred to the shift registers and clocked out serially. In effect, each counter contains the time which elapsed while the object moved from one sensor to the next. Knowing the distance and time, the average velocity can be easily computed. The average acceleration can then be calculated. Finally, the voltage thresholds were monitored by comparators made of CMOS buffers.

The telemeter was contracted for hybridization and fabrication. The first model, shown in Figure 4, was successfully tested in the air gun at 20,000 g's and in a gun firing of an inert projectile at a setback of 10,000 g's. These preliminary tests were nonfunctional, e.g., the storage registers were preloaded with data, which was retained unaltered during the tests. Next, the TM was tested in a full function test round in which it was subjected to an estimated shock of 300,000 g's. This configuration did not survive the environment. The housing deformed, causing substrate and wire fractures. At this point, several corrective measures were taken to increase package strength. The housing was reinforced, and a 3/4" thick steel base plate was added so that the forces would be more evenly distributed on the whole unit (Figure 5). In addition, a W shaped bracket shown in Figure 6 was mounted between the shell and TM package. This bracket was designed to limit the inertial shock to 18,000 g's, based on the weight of the telemeter and the estimated total energy output of the impact shock. The aluminum W bracket, when subjected to the compression, deforms and reduces the low frequency harmonics of the shock, which otherwise would be transferred to the instrumentation package. The performance of the bracket is mechanically analogous to that of the reference diode in electronics. Redundant memory and backup battery packs were also added.

Two prototype housings were fabricated and potted without electronics. They were then successfully tested for mechanical survival and the proper functioning of the W bracket. The housing did not deform and the bracket was compressed but not fractured, indicating proper operation. Three telemeters were built for two full function ground tests. The first unit measured and registered the proper voltage threshold data, which was confirmed by hardwired instrumentation. All other registers contained zeros. The second round was monitored by two telemeters. One telemeter was mounted inside the test projectile and subjected to the full shock environment. The second was mounted on a stationary stand and not subject to any adverse environment. Both TM's were connected to the same breakwire sensors (inputs). The voltage threshold measurements were not connected to the second TM. The results were that the telemeter mounted on the stand contained all velocity information. The telemeter mounted in the test vehicle contained all zeros (no input state) except for one word of velocity data which concurred with the data acquired by the telemeter on the stand. It was concluded that the high frequency shock penetrated the package and altered the state of the IC's (e.g., an unconditional reset) by acting on the stray capacitances inherent in CMOS circuitry. A 1/4" soft padding of Stycast 2741 was applied between the base plate and the metal assembly containing the substrate with the circuitry (Figure 7), in an attempt to attenuate the high frequency harmonics of the shock. Two telemeters were modified, preloaded with calibration data and field tested for data retention capabilities. Both units retained all data.

Four telemeters were modified to add the pads full function firing test. Two additional units, using discrete components and custom wiring techniques, (Figure 8) were also fabricated. Full function firing tests were conducted. The modified, hybridized telemeter was fired first. The entire package disintegrated upon ground impact. Apparently the shock absorbing W bracket failed to hold at impact; it fractured and the TM was driven forward against the interior of the ogive (nose cone), falling apart in the process. A second round was fired with a discrete component telemeter mounted in the ogive, and a large void in front of the TM was filled with high density foam. The ground impact again separated the W bracket from the round and, while the foam provided some cushioning, the TM still hit and fractured the ogive. The telemeter was noticeably deformed, its memory holding some numbers, but they could not be related to the expected data. The module was then tested with the signal simulator and was found completely functional. It is not certain at this time whether the impact shock (TM vs. ogive) or malfunctioning of the break wire sensors caused the failure. Since the number of preflight tests was very few due to availability of test projectiles, the parameters of the physical environments are unknown. The simulation of the forces would require the use of explosive propellant, which is both elaborate and costly. The problem causing test failures is mechanical in nature, and rectification without a costly test program may not be feasible. It is uncertain at this time whether this program will be continued.

TELEMETER “C”

In the past, the “reverse ballistic” method was frequently used to acquire data on impact fuze functions during impact. This method consisted of firing simulated targets at a stationary fuze. This approach greatly simplifies instrumentation of the fuze; however, there are considerable problems involved with firing “soft” targets at a prescribed velocity while maintaining target integrity. In addition, this technique does not necessarily result in a true impact environment simulation, and, therefore, the actual gun firing approach may be considered. The instrumentation of fuzes in actual gun environments requires some special design considerations. First and foremost is the need to assure ballistic integrity of the round. Although this does not entirely preclude the use of RF telemetry, some modification would have to be made to the projectile to accommodate the antenna. In instances where no changes can be made to the fuze, a costly “wrap-around” antenna configuration must be affixed to the shell body. The cost per test round is usually very high.

Telemeter “C” is a self-contained, solid state, micropower, memory telemeter that was designed to provide a cost-effective method for acquiring fuze function data in actual gun environments. Because the entire telemetry package can be placed inside the round and requires no modification to the fuze itself, it does not impede the true ballistic flight of the test vehicle. The telemeter is also designed to be reusable and therefore significantly reduces the cost of each test. Figure 9 shows this telemeter attached to a fuze. The design criteria for telemeter “C” required that it record, retain and subsequently display the function time and g force versus time curve resulting from target impact and penetration. The telemeter consists of two modules that total 10 inches long by 1.9 inches in diameter. The upper module (Figure 10) contains the memory and its associated support and timing circuitry. It was fabricated using thick film hybridization technology which reduces circuit volume and provides the means to accurately trim all resistor values. A 15 pin Cannon MDM connector on the side of the package provides for signal simulation, test monitoring and access to data.

This module also contains both an ionization detector and a custom piezoelectric accelerometer and charge amplifier. The ionization detector senses the functioning of the fuze by detecting the ionized gasses created by the detonator, since ionized air provides a low resistance path between two conductors. The accelerometer, provides dual outputs of different sensitivities. Figure 13 shows the two outputs due to the same setback shock. Both traces are the same scale, the upper trace showing the higher sensitivity output. The lower module (Figure 11) contains twelve 100 MA hour button Ni-Cad batteries. The use of a separate module for the batteries facilitates re-use of the telemeter. The simplified block diagram (Figure 12), shows the operation of the telemeter circuitry. At setback, a longitudinally oriented g-switch activates a master system reset and starts the 1 MHz system clock. The circuit is held in reset for a 250 millisecond duration, after which sampling of the deceleration g levels begins. The time interval generator, in conjunction with the decoder, generates the appropriate scanning intervals for the data encoder. The detonation time counter is activated at a deceleration level of 50 g's. It is disabled when the functioning of the fuze is sensed by the ionization detector. This information is encoded with the deceleration data and transferred serially along with a sixteen bit syncronization "word" (not shown) to the memory. An event counter (not shown) records and controls the sequential operation of the entire system. At completion of data acquisition, the memory is switched to a recirculate mode which insures the retention of data during the balance of the projectile penetration and subsequent recovery and interrogation of the unit.

Telemeter "C" adds several novel design approaches to the use of memory telemeters for the instrumentation of projectile flight up to target impact and penetration. The frequency of sampling at deceleration is governed by logic control, with emphasis on the lower leading edge of the acceleration versus time curve. (Hence the use of dual accerometer outputs). The logic control also preserves selected data acquired prior to the 50 g deceleration level. The ionization counter, which gives the fuze function time referenced to the 50 g level, has provisions for acquiring data should the fuze function prior to this deceleration level.

Telemeter "C" has been qualified in the ARRADCOM air-gun to levels in excess of 12 Kg's.

The piezoelectric accelerometer module has been qualified in actual gun firings. The Ni-Cad batteries used have been qualified in several other ARRADCOM telemetry systems. Initial firing tests of the entire telemetry assembly are expected some time during late1982.

CONCLUSION

This paper has presented memory telemeter concepts and their application to projectile instrumentation; advantages in gathering narrow bandwidth or event type data, and the packaging difficulties inherent to a system that must be recovered after experiencing an extremely harsh shock environment. Presently, there is only limited performance data available. Two of the three telemeter designs have been field tested. Telemeter “A” performed well under very adverse conditions and shows great promise. The environment for telemeter ‘B” may be too severe for survival. Telemeter “C” has not been field tested to date, but based on preliminary testing data, appears promising.

With the compression of more digital functions on a VLSI chip, the increasing density of RAM devices, and the advent of flash A/D converters, the future of memory telemeters looks very promising. The bandwidth, and data channels will make the memory telemeter increasingly attractive for many projectile instrumentation applications.

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They also expressed their appreciation to Cathy Cinelli, Agnes Blich and Louis Lesaski for timely and accurate clerical assistance.

TELEMETER "A"
HOUSING AND INTERFACE

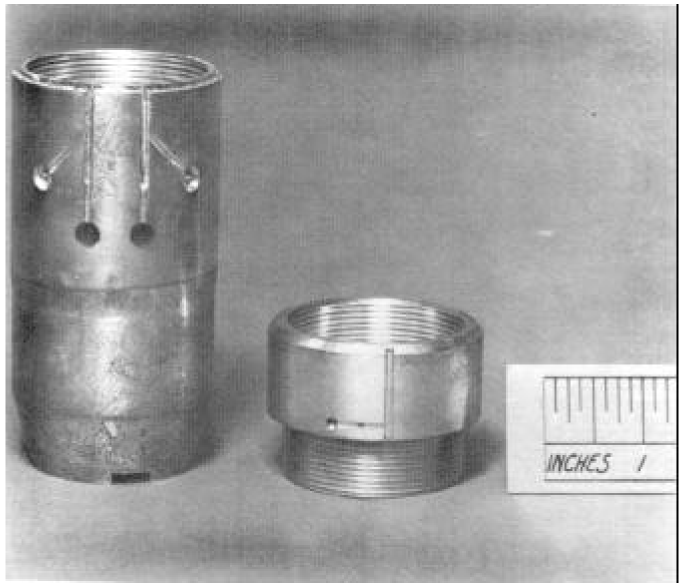

FIG. 1

TELEMETER "A" ASSEMBLY

FIG. 2

TELEMETER "A"
METALWORK FRACTURE

FIG. 3

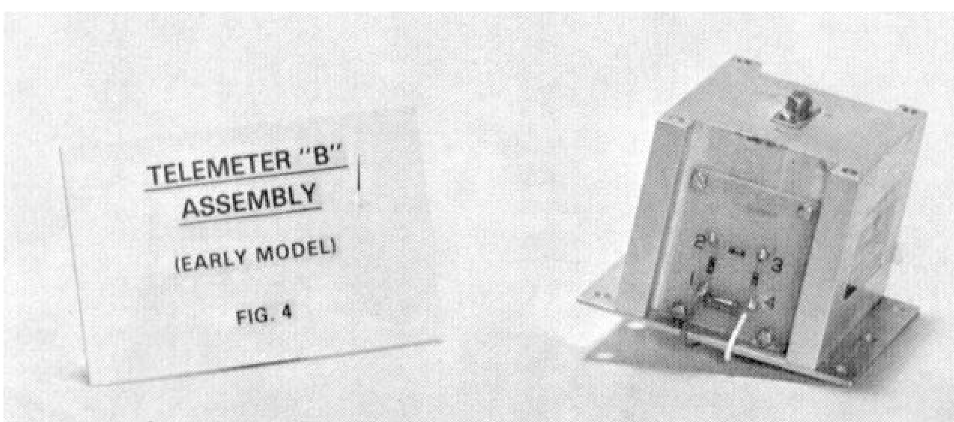

Figure 4

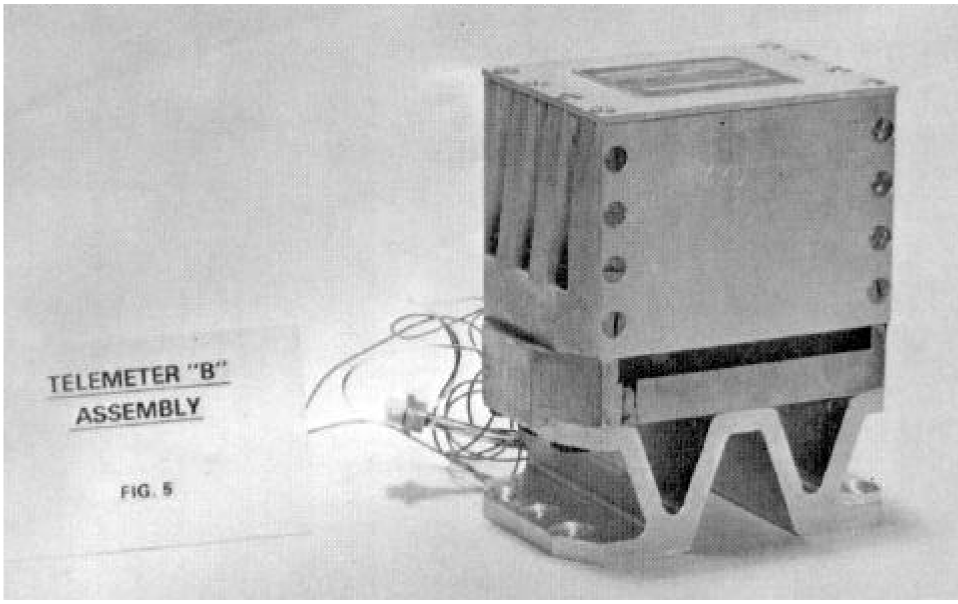

Figure 5

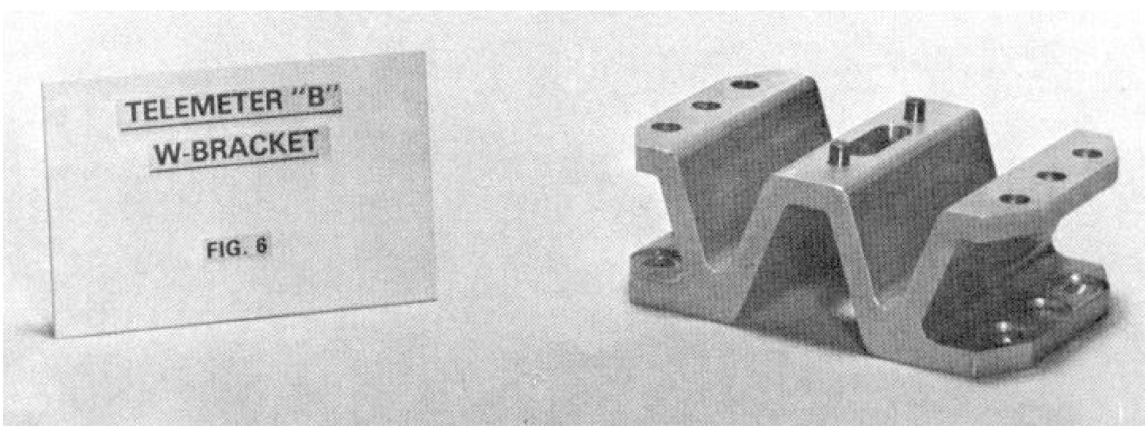

Figure 6

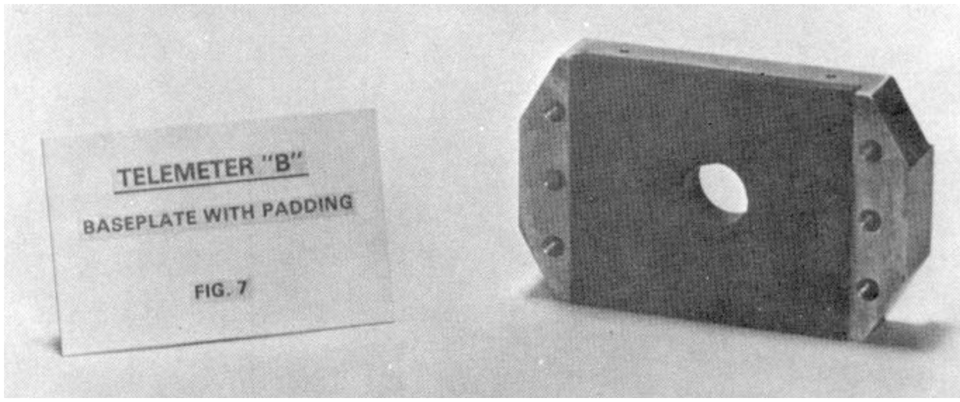

Figure 7

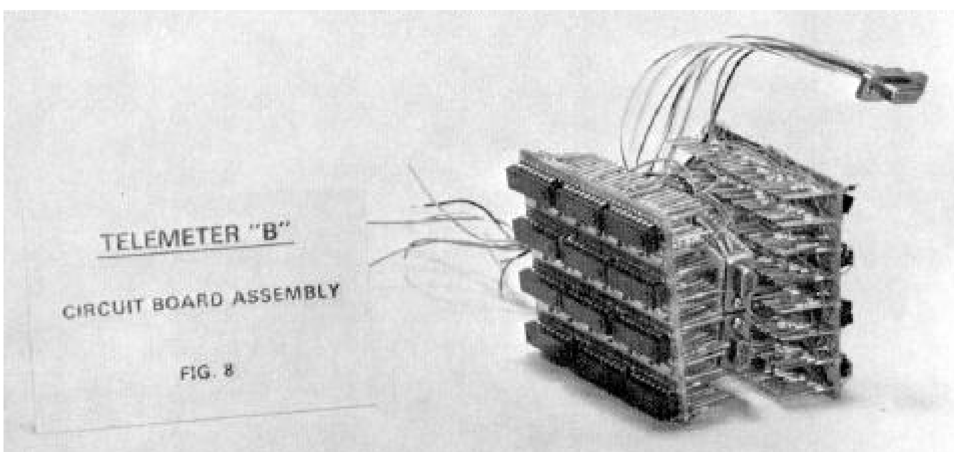

Figure 8

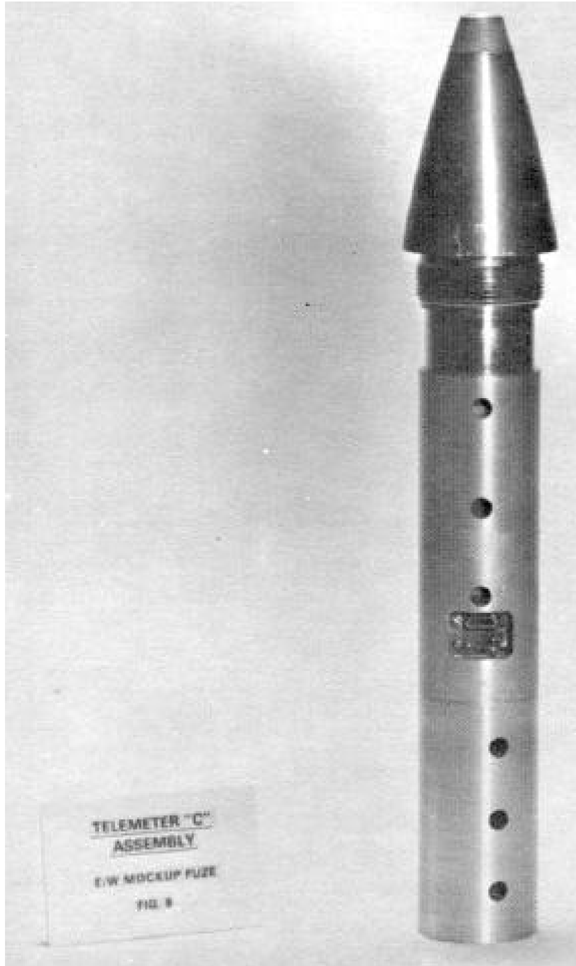

Figure 9

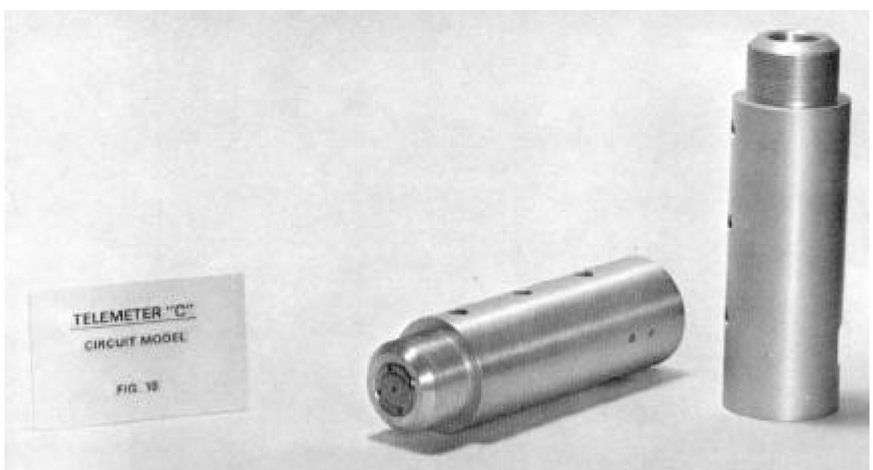

Figure 10

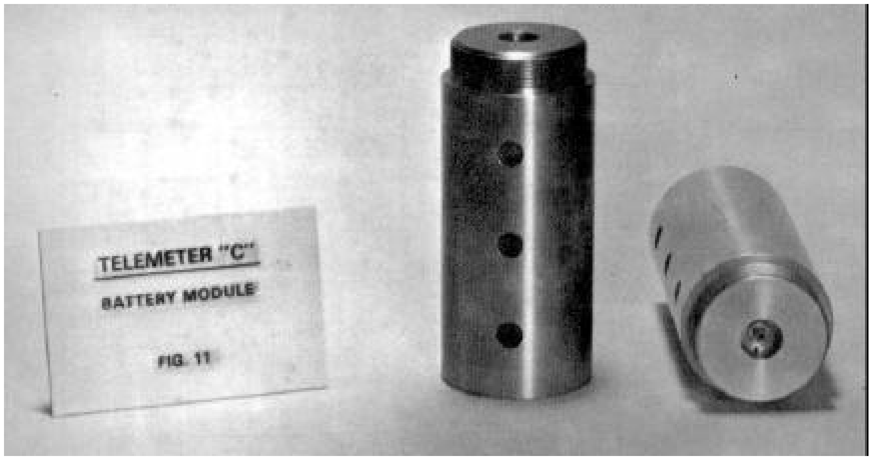

Figure 11

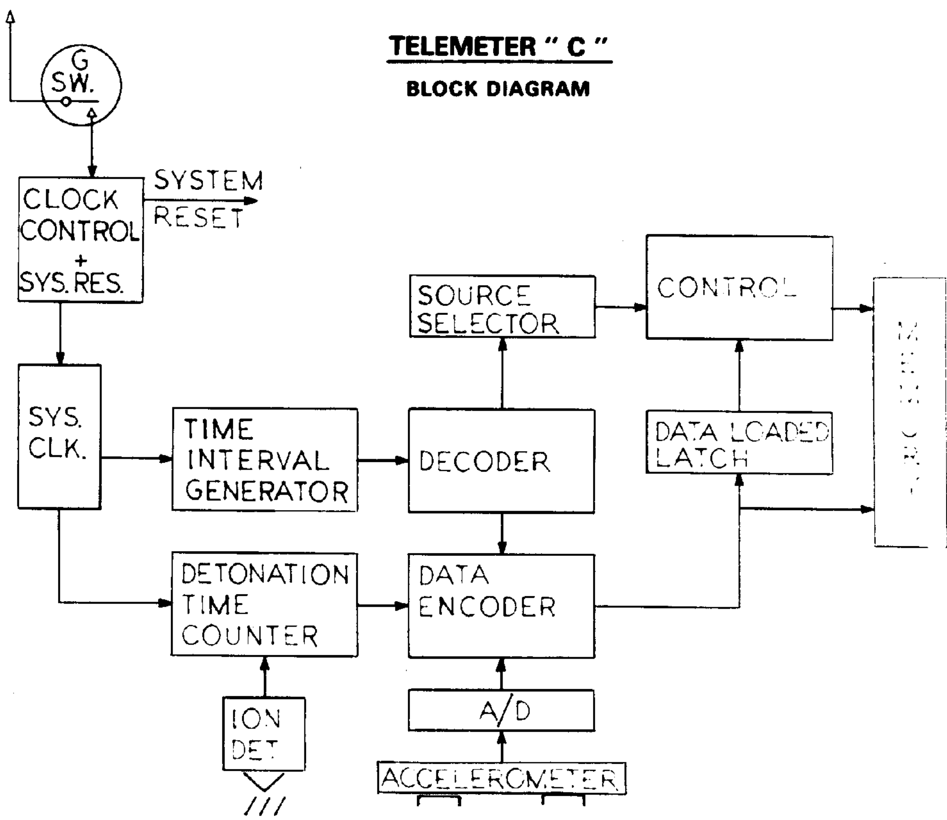

FIG. 12

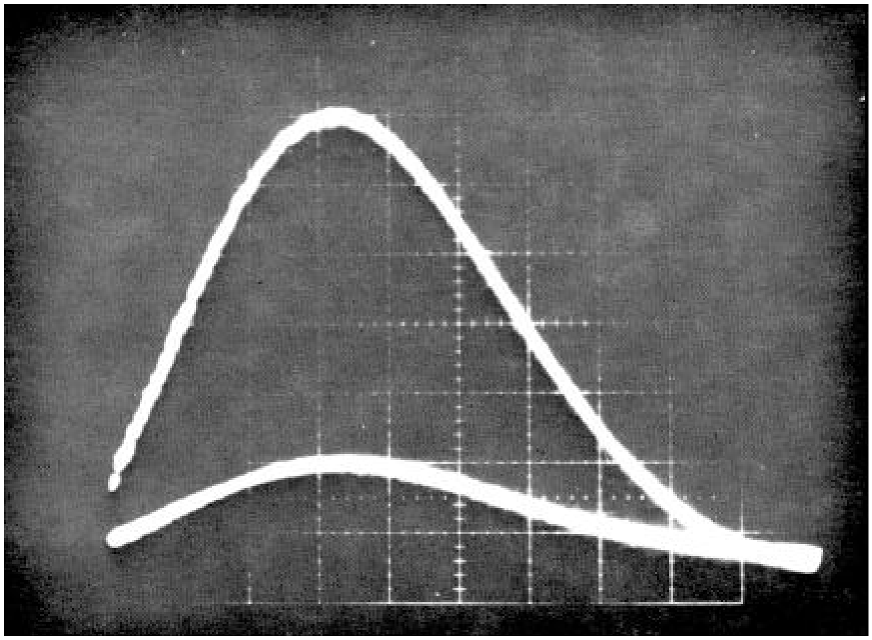

Figure 13
TELEMETER "C"
TYPICAL ACCELEROMETER OUTPUTS