MECHANICAL DESIGN CONSIDERATIONS FOR A PROJECTILE TM[1]

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Summary The mechanical packaging necessary to protect electronic packages from the gun firing accelerations is the key to a successful telemetry system. All components and wires must be given structural support, usually by the use of potting materials. Where the accelerations come from and two successful packaging methods are described.

Introduction The design of a projectile telemetry package which will either survive or operate during a gun firing is more of a mechanical packaging job than it is an electronic design job. For this reason, Mr. Bentley thought it would be appropriate for a lowly mechanical engineer to address this distinguished assembly of "electronickers."

The acceleration environment that a projectile sees in a gun firing is extremely severe, but electronic packages can be built which not only survive but which can operate successfully during these accelerations. The army did the first work in this area with Harry Diamond Labs, and The Ballistic Research Labs leading the way. Sandia Laboratories became involved when we needed to obtain data upon projectiles while they were still within the gun tube, as well as after exiting from the tube. After five years of hard knocks, we feel we know haw to design a package to oper-ate in this environment, and this paper attempts to pass on the major pointers that we have learned the hard way.

The Gun Firing Environment Today we shall only talk about the projectile accelerations, since they present by far the most severe problems to the designer. We shall first discuss how the accelerations are produced, give an example of typical acceleration levels, and then discuss haw to protect the electronic components from these accelerations.

When a gun is fired there are four short duration accelerations and one long duration acceleration of interest: the setback and spinup accelerations caused by the gas pressure on the base of the projectile, the balloting or slap of the projectile in the gun tube, the unloading shock as the projectile exits from the tube, and the radial acceleration due to the spin velocity of the projectile. Some people also consider the ramming shock, but we will only consider the accelerations after the gun is fired.

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The setback, or launch acceleration, is the primary force which has been considered by the designer. This is a long duration shock compared to the natural frequency of the shell structure, and so the response is essentially that of a static load. When you use a cartridge gun instead of a powder bag gun, you have superimposed the shock due to the impact of the cartridge closure plug on the base of the projectile. This is a short-duration shock which causes ringing of the structure at its natural frequency while it is stressed by the setback acceleration. This is analogous to the water impact shock NOL has worried about for years and for which they developed the two-phase air gun shock test.

The balloting of the shell in the gun tube is the second acceleration of interest. In general, the importance of this acceleration decreases as the length over diameter ratio of the projectile increases. In our applications these have been relatively low and caused little trouble.

The unloading or muzzle exit shock is the third acceleration of concern. This is not an externally applied acceleration but rather an internal rebound due to the rapid removal of the setback acceleration as the projectile exits from the gun. This loading is often overlooked in design, and since the effect is that if a negative acceleration (opposite direction) it quite often causes trouble.

The spin of the projectile causes two additional accelerations of interest: the angular, or “spin up,” acceleration and the radial or centrifugal acceleration. The angular acceleration and set-back acceleration are directly proportional, with the ratio between them being determined by the rifling in the gun tube. In our experience, this angular acceleration has caused little trouble. The final acceleration is the radial, or centrifugal, which is produced by the spin velocity of the projectile, and is the only acceleration which continues throughout the flight of the projectile. The twist ratio of the rifling determines the ratio of spin velocity to muzzle velocity and the peak of this acceleration occurs at muzzle exit. The easiest way to minimuze this acceleration is to keep the component on the centerline of the projectile, and for this reason centerline space is at a premium. Our experience indicates that other space is what will be available for telemetry systems.

Typical design accelerations for a 155mm projectile are as follows:

Setback acceleration	16,000g peak	12nm duration
Spinup acceleration	700g/in. of radius	
Radial acceleration	9,000g/in. of radius	
Balloting acceleration	300g lateral	
Set Forward	1,000g	

Of these, the setback and radial are the most significant.

Protecting electronic components from acceleration requires that some structure be provided which will support the forces generated by the acceleration, but which will not interfere with the electrical circuitry. Semi-flexible potting--this mans hard but not brittle--is the best approach for small components, and has been used on complete TM system . We feel that a whole system should not be potted in one block unless there are many identical system to be fabricated, or they are to be expended in each test, or the contained components are so cheap that the additional design required for a modular approach is uneconomical. The problem with semi-flexible potting is that once installed it is hard to remove without damage to the components. Normally, if something goes wrong with a potted package, the whole package is thrown away as unusable. The module approach allows only a part of the system to be discarded and replaced, and on complex, expensive system saves money.

A temporary potting which can be removed at will does away with the necessity of the more complex design of the module approach. We have been unable to find a universal temporary potting which has good rigidity, high dielectric constant, ease of application and ease of removal. We have investigated this field rather extensively, and have used several techniques which can be helpful, the use of brown sugar being the most versatile. We have used this successfully in projectile telemetry packages, and with proper care, it can simplify the TM mechanical design considerably.

Selection of Components Allied to the module approach is the problem of selecting electronic components that will survive the gun launch environment. Commercial packages, if available, would be desirable. Unfortunately, we have only found transmitters, voltage-controlled oscilators and batteries that can be used in their original packages, and even then a great deal of care must be taken in their mounting. As a result, we have taken a procedure from the Ballistic Research Laboratory and pre-shock every component and module before committing it to a firing. We use an air gun delivering a 10,000g, 3ms pulse for our pretest, and find this has increased the reliability of our systems greatly. This is an application where the brown sugar temporary potting is very helpful, allowing odd-shaped components to be fired in a standard canister (Figure 1). Certain components are electrically monitored during this shock, but the Majority are checked before and after the test for changes and failure. Obviously, the reliability of a telemetry package can be no better than ts components, and this is how we insure the reliability of the components.

In most of our projectile telemetry packages we plan on recovery and reuse of the package. Since the next test will probably differ from this test, we not design versatility into the package. Again, the modular design allows this greater flexibility, since only a portion of the system must be changed. The most versatile of modular assembly techniques we have developed is what we will call the wiring harness technique. A more sophisticated, less versatile, but more compact method we will call the wire cage technique.

The Wiring Harness In this method, many of the electronic components are repackaged into standardized module shapes to fit into a predetermined package structure. By having all of these circuits in the same size package with a standardized connector, many different telemetry system can be built in the same housing, and so the system has a good versatility.

The module shape chosen has been a right circular cylinder. The outside of the cylinder is formed of thin-wall fiber tubing, with a phenolic header at one end supporting a connector. After the circuit for the module is assembled inside this module, the cavity is potted with a send-flexible material such as Scotchcast 8. The module is then trimmed to length in a lathe.

Non-conductive materials are used in these module cases to prevent electrical grounding problems with the solid aluminum case. The case contains round, flat bottomed holes to receive and support the modules. A smaller diameter hole in the flat bottom allows the connector to protrude through to mate with a connector on the wiring harness plate. Dowell pins in the phenolic header mate with holes in the structure to position the module and to take any forces tending to rotate the module. The module is held into its cavity by a threaded cap screwed into the housing. Between this cap and the module is a keyed washer which prevents the torque applied in screwing in the cap from being transmitted to the module. For details of typical module mounting see Figure 2.

The wiring harness plate supports the mating connectors of the modules, the interconnecting Wiring, and connectors for electrical access to the outside world, Figure 3. A versatile mounting for the connector incorporating sore solder terminals and allowing other wires from the connector to be routed directly to other connector mountings, make the interconnecting wiring easier to installs All interconnecting wiring is made with hard wires supported on this harness plate and epoxied In place to prevent movement, (Figures 4 and 5). This greatly simplifies the cabling and wiring problem and gives the method its name.

The structural housing In this method is a complex machining job and only a limited number of standard-sized, round holes may be drilled into a given sized cylinder. The metal in the rest of the housing adds weight and often is lowly stressed. The structure itself, therefore, is not efficiently designed from a structural standpoint, but the resulting package is an efficient and versatile telemetry system.

The Wire Cage Space is saved in this method by the elimination of the unused volume between modules in the wiring harness method and by simplification of the connectors and interconnecting wiring. To make this simplification, more restrictions are placed on the design of the component modules, and these modules become more expensive. Again, almost all components must be repackaged into a standard shape.

Each module starts out with a printed circuit board on which the electronic components are mounted. These are round PC boards and all interconnections with other boards are made through terminals around the circumference of the board. These terminals are round grommets (miniature spring socket AMP, Part No. 3-331272-5, through which solid .025" berylium copper wires are pressed perpendicular to the PC board. This imposes the restriction that the interconnection terminal on the next board must be in the same position to allow this wire to be inserted. This restriction adds to the complexity in the design of the PC boards.

After the electronic components have been mounted on the PC boards, thin fiber rings are bonded to the top and bottom of each board outside all components and inside the terminals. These rings are filled with 20#/cu.ft. foam plastic and then machined to give a smooth top and bottom surface, (Figure 6). The modules are then ready to be stacked on top of each other and the interconnections made by inserting the wires down through the terminals. When viewed in this state, the modules seem to be surrounded by a cage of wires, and hence the name, (Figure 7). These wires may be continuous from top to bottom, or may only go between two adjacent modules. To prevent slippage of the wires under acceleration, the wires may be soldered in the terminals, the wires deformed to prevent slippage in the sockets, or the bottom of the wires supported by a plastic plate. The insertion of the wires is made easier by the use of a sewing thimble on the finger when making the interconnections.

These modules mist be designed to carry the load of the stack in compression through the foam potting. Additional compression paths through the module can be designed in, but this makes the layout of the PC board more complex and should be avoided unless really necessary. The whole assembly is then mounted in a housing which interfaces with the carrier vehicle.

Non-conductive anodize on housing parts has worked very well to allow the use of un-insulated wires in the interconnecting circuitry. Cable access into the package is fixed and cable routing to the package can be a problem, especially if interfacing requirements change.

The elimination of connectors between modules allows much closer stacking of components than in any other method. A module can be redesigned and the system modified, but there are more restrictions in this method than in the other methods. Individual electronic components can be replaced by digging out the foam and then patching the modules, so some repair of modules is possible. This is a sophisticated, complex packing method, which gives the minimum volume and weight, but costs more than other methods, and therefore should be used only when really needed.

Supporting Interconnecting Wires The most common failure mode for a TM package fired from a gun is to have an interconnecting wire break. We protect the individual components with potting, but the interconnecting wires and cables are harder to protect. This is especially true when the wires run parallel to the direction of acceleration. The copper wire must act as a tensile member to carry the load of the wire and its insulation, and since copper is a weak but heavymetal, the wires often break.

As a rule of thumb, for wires running parallel to the acceleration direction, if the acceleration in "g" times the length of the wire in inches exceeds 56,000, some intermediate support is necessary.

$$L \times g = 56{,}000 \qquad L = \text{Unsupported length of wire in inches}$$

or

$$L = \frac{56{,}000}{g} \qquad g = \text{Acceleration in "g"}$$

This simple formula is based on a breaking strength of copper of 36,000 psi, a density of copper of 0.322 lbs/cu.in., and a factor of safety of 2. The factor of safety should take care of the weight of the insulation on the wire in most cases. The second form of the formula shows how often intermediate supports are needed.

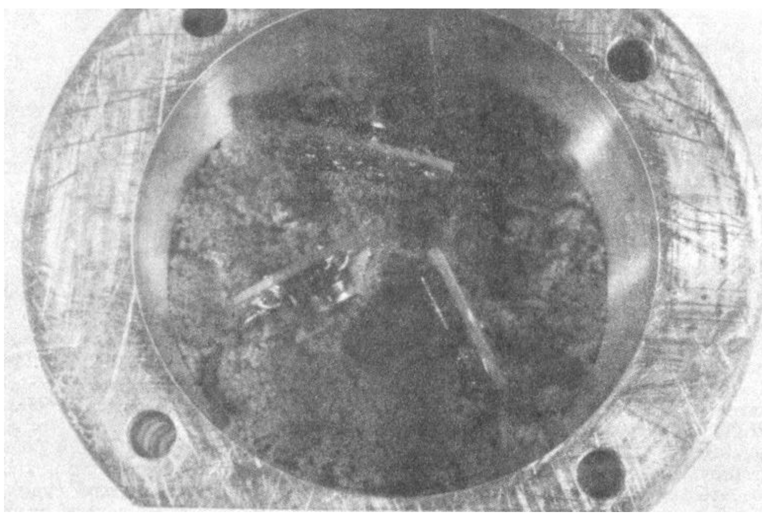
For support it is not enough to bond the insulation of a wire to the surface, since the bond between the copper wire and its insulation is weak, and we have experienced cases where the conductor has broken and slid r1git out of the insulation. <u>Don't let yourself be caught in this trap!</u>

A sinple way of transferring the load to the center conductor is to tie a knot in the wire, (Figure 8). You can then fasten the insulation of the wire and be assured that the conductor will remain with it. On more rigid wires or cables, it my be necessary to bend the cable into a serpentine shape, fastening each section which runs transverse to the direction of acceleration. This is not as sure a method of transferring the load from the center conductor, and so the bends should be closer together than the formula predicts, normally twice as close.

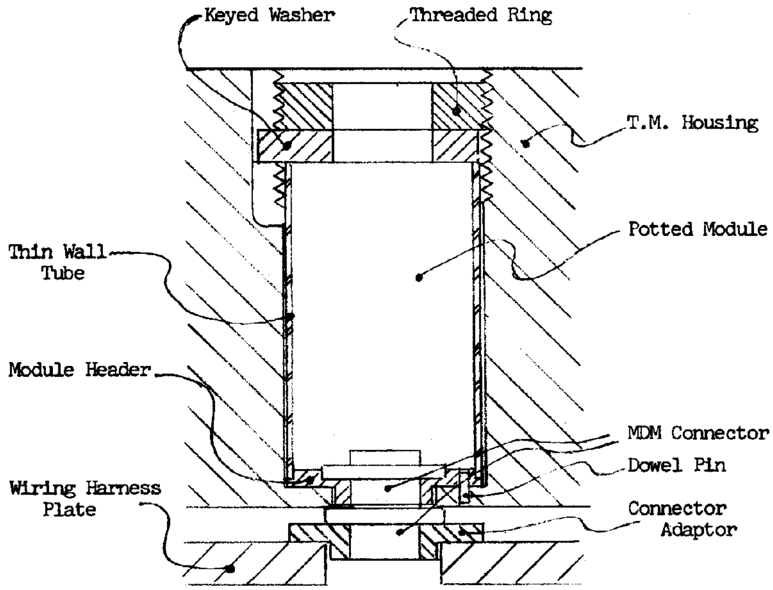
Wires running transverse to the direction of acceleration need support for the same reasons, but this can usually be accomplished by allowing the acceleration to press them against a flat plate. If the cable must run on the opposite side of a plate or along a plate which has an axis parallel to the acceleration direction, the cable needs to be securely fastened either by,bonding or tiedowns.

The 56,000 constant is large enough that these techniques need only be worried about when large accelerations are expected, but this fact makes it easy to overlook the case where it is needed and will almost guarantee a package failure if it is overlooked.

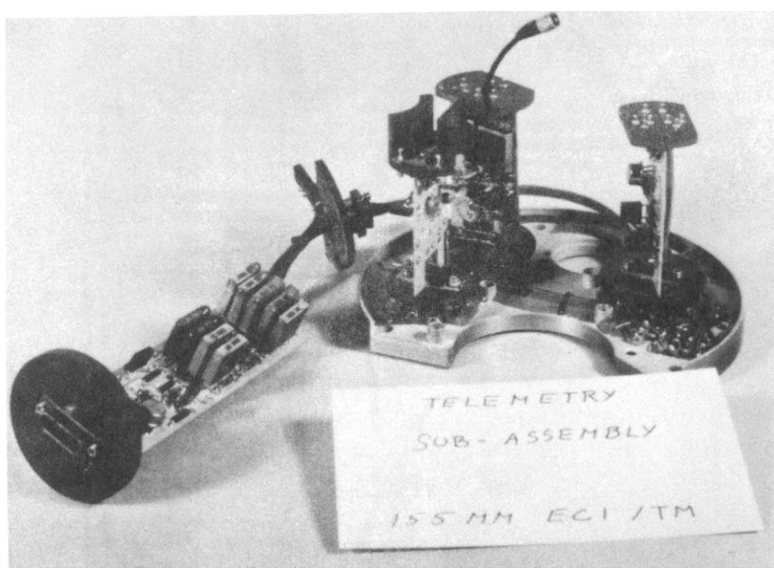
Conclusion The primary rule in hardening telemetry packages for a gun environment is that all electronic parts must be given structural support. In most cases, a seid-flexible potting compound such as Scotch Cast 8, or a medium density foam, will give this support. The most commn failure is the breaking of interconnecting wires during accelerations, and so particular care must be given to supporting these wires. Following these sinple cautions will eliminate 90% of the problems associated with the survivability of electronic packages in a gun environment.



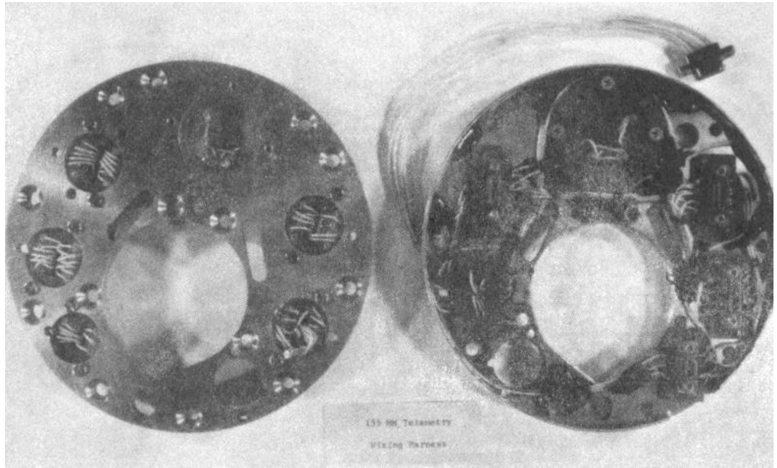
155mm TELEMEIRY BROWN SUGAR POTTING
Figure 1



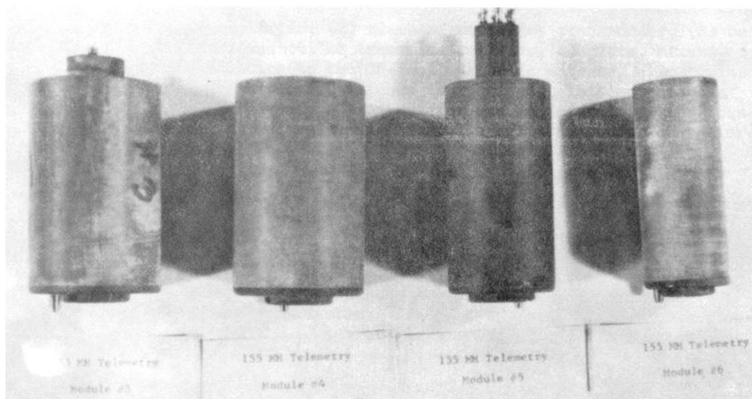
TYPICAL WIRING HARNESS MODULE
Figure 2



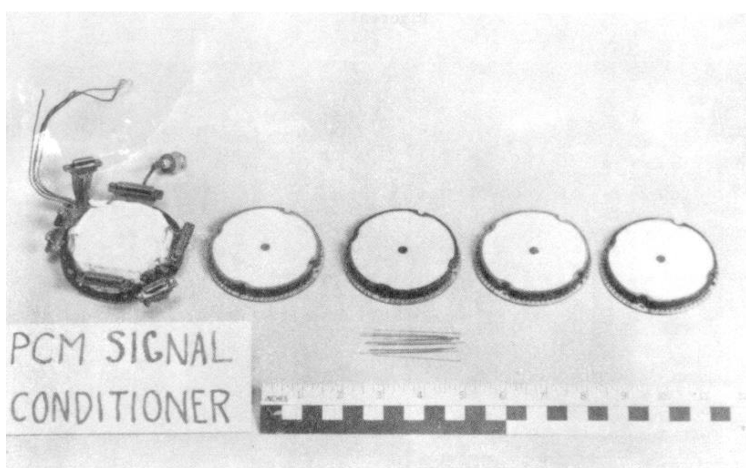
155mm TELEMETRY SUB-ASSEMBLY
Figure 3



155mm TELEMETRY WIRING HARNESS
Figure 4

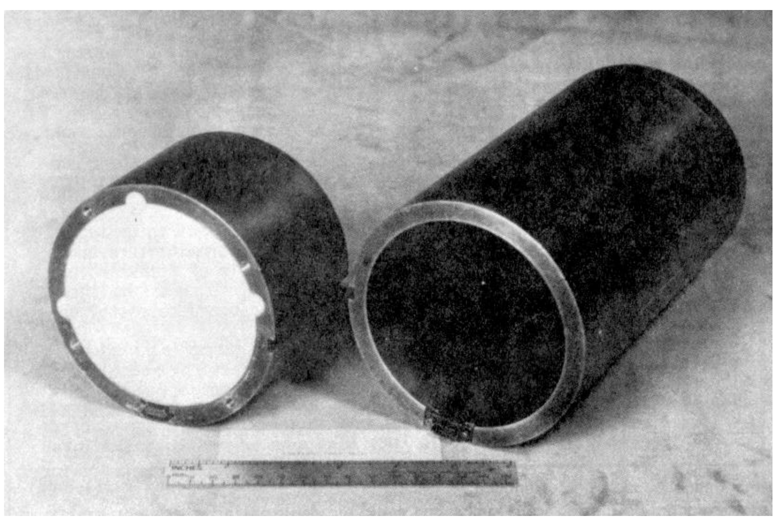


155mm TELEMETRY MODULES
Figure 5



155mm PCM SIGNAL CONDITIONER SUB-ASSEMBLIES
Figure 6

15mm PCM SIGNAL CONDITIONER
Figure 7



155mm WIRE SUPPORT MECHANISM
Figure 8