A UNIVERSAL L-BAND TELEMETER FOR USE ON ARTILLERY PROJECTILES AND GUN LAUNCHED RESEARCH PROBES

VICTOR W. RICHARD
Ballistic Research Laboratories
U. S. Army Aberdeen Research & Development Center
Aberdeen Proving Ground, Maryland

WASCO HADOWANETZ
Atomic Ammunition Development Laboratory
Picatinny Arsenal, New Jersey.

Summary A UHF (1520 MHz) telemetry system for use with artillery proL jectiles and gun launched research probes is described. The feasibility of a universal telemeter (UTM) is demonstrated which is based on the use of modular plug-in components available to meet a variety of instrumentation requirements, including ogive and rear mounting, thus, eliminating the need for the development of a special projectile telemetry unit for each application of in-flight projectile performance monitoring or gun probe experiment. The special, ruggedized components and techniques for pre-flight high acceleration testing are described. The components described include: broadband, omnidirectional antennas for ogive and base mounting in projectiles; a high gain, all polarization, fan beam receiving antenna; stabilized, high efficiency UHF transmitters; miniaturized voltage controlled oscillators; 8 and 16 channel commutators; button cell and g-activated reserve cell batteries; shock resistant, electrically compatible radome and encapsulating materials; modular assembly cases; and ogive and base mounted telemeter test projectiles.

The physical and electrical characteristics of the components of the telemetry system are presented, along with laboratory and field performance data obtained from firing standard, 155 mm, spinning projectiles, including the reception of signals while the projectile is in the gun barrel.

Introduction The development of a universal telemeter has been a serious goal borne out of the desire to avoid future, “crash” telemetry development programs carried on concurrently with projectile development. Concurrent telemeter and projectile development has caused several undesirable problems in the past. First, the evaluation of projectile component behavior in flight produced ambiguities when the telemetery system characteristics had not been thoroughly determined beforehand. Secondly, telemetry problems were not adequately pursued when projectile development schedules were pressing. Each of these detrimental conditions have been experienced periodically in projectile development programs. The solution to these problems has been obtained by the development of a UHF universal telemeter.

The success of the UHF universal telemeter concept is due largely to that fact that UHF antennas can be designed to be small, efficient, omnidirectional and relatively independent of the projectile configuration, allowing considerable versatility which is lacking at VHF. Telemeter versatility is essential in relieving the projectile designer of unnecessary extraneous constraints. It also allows for frugality in testing. For instance, early in the engineering design phase, when component proof-testing is predominant, a capability of ogive mounting allows the use of an inexpensive test shell. Later, when ogive mounted fuzes are tested, costs can be reduced if the same type of ogive telemeter components can be employed in a base mounted or centrally mounted telemeter. Another decided advantage in a versatile telemeter design is that it can be utilized in any projectile caliber to be considered, thus, essentially precluding the need for continuing large-scale telemeter development programs.

The universal concept has been questioned due to the wide variety of possible telemetry requirements. Therefore, it is argued, telemeters must be tailored to each specific projectile. This is not necessary if IRIG Telemetry Standards (now converted into MIL-STD-442B, Aerospace Telemetry Standards) are followed. Among other guidelines, this standard specifies limits of electrical input characteristics. If these limits are converted into System/TM interface requirements, the system developer can be delegated the responsibility for conditioning his test points to the proper levels in order to insure that electrical compatibility is maintained. To insure that mechanical compatibility is maintained, the configuration and attachment method should be resolved for the smallest caliber round being considered and testing should be conducted at the most severe anticipated firing environments. An axial location of the universal telemeter allows the use of normal, straightforward, design procedures in providing for ballistic stability in each test round. Recently formulated computer programs aid substantially in arriving at suitable test projectile designs.

The basic round used for this program was the 155 mm projectile. With some minor engineering changes of the present UTM, use can be extended down to the 90 mm shell. With the rapid advancements in microcircuit technology it is conceivable that, in the near future, one design will be applicable to all calibers from 20 mm upward. When this state-of-the-art is achieved, integrating the UTM with each projectile system would be seriously considered as the most economical design.

System Description A ruggedized, UHF, FM/FM telemetry system, shown in Figure 1, has been @fesigned to serve widely diversified requirements of gun probe experiments and artillery projectile in-flight performance monitoring. Examples of information that can be telemetered include switch closures, acceleration, vibration, pressure, temperature, strain gage output, battery voltage, battery noise, pitch, yaw, spin, slant range, solar cell output, and Langmuir probe collector current. In order to meet a variety of instrumentation requirements, the major components of the projectile telemetry unit have been designed as cylindrical modular units which can be conveniently interconnected with plug-in connectors, see Figures 2 and 3.

Loop fed slot and scimitar type omnidirectional antennas have been developed for ogive and base mounting on projectiles. A modified meteorological balloon sonde tracking parabolic antenna and a high gain, all polarization, fan beam receiving antenna that does not require tracking, have been used. The basic criteria for the design of stable, high efficiency, miniaturized, low cost UHF telemetry transmitters ruggedized to withstand 50,000-g's have been determined and many types of commercial transmitters have been evaluated. Commercially available, miniaturized voltage controlled oscillators, and 8 and 16 channel commutators are used. Standard, silver oxide, hearing aid type button cell battery packs have been used successfully. Acceleration activated, reserve batteries are also available. Shock resistant, electrically compatible insulating materials and encapsulants, were used for the UHF circuits and the antenna radomes. The modular concept of design, using threaded cylindrical steel cases with separation disks to support the components and facilitate connector mounting was used and proven to be very satisfactory and versatile.

The parameters of a UHF system are given in Table I for telemetry up to 50 miles range. These parameter values have been verified by flight tests with 155 mm projectiles as feasible for a UHF projectile telemetry system using components currently available. For short range and in-barrel telemetry, much less transmitter power (1 to 10 MW) and antenna gain (0 to 6 db) are required.

TABLE I
UHF TELEMETRY SYSTEM PARAMETERS

Transmitter Power, nominal	100 MW	
Trans. Freq. Peak Deviation	±250 kHz	
Subcarrier Frequencies, typical	22, 40, 70 kHz	
Commutator (# Segments k Frame/ Rate/Sec)	8 x 5	
Transmitting Antenna Gain	0 db/isotropic	
Receiving Antenna Type	GMD parabola	Fan Beam
Receiving Antenna Gain	26 db	15 db
Receiving Ant. Beam (Az x El)	7° pencil	10° x 50°
Polarization	Linear	RHC, LHC, Linear

Receiving Noise Figure	4.5 db	4.5 db
RF bandwidth	3 MHz	3 MHz
IF andwidth	500 kHz	500 kHz
Video bandwidth	100 kHz	100 kHz
Data filtering bandwidth	6.6, 12, 21 kHz	6.6,12, 21 kHz
Data signal-to-noise, minimum at 80,000 feet	40 db	29 db

Component Development Particular emphasis has been placed on the-design of transmitters and the projectile antennas, since designs with acceptable performance were not available at the initiation of the development of a ruggedized UHF telemeter. Following is a description of the special components.

a) Transmitter specifications for UHF telemetry from projectiles are very difficult to meet with compact, low cost designs. Figure 4 shows a number of methods of generating UHF signals in the band of 1435 to 2300 MHz at the several hundred milliwatt level. However, not all of these circuits are practical for projectile telemetry because they cannot meet the basic criteria of ruggedness, small size, high stability, good efficiency, or low cost. Our studies have shown that one of the most difficult criteria to meet is that of good frequency stability versus load impedance while maintaining a reasonable efficiency i.e. $\geq$ 15%.

A useful test technique to check for frequency pulling (frequency change with load impedance change), pushing (frequency change with supply voltage change), hopping (an abrupt frequency change), and squegging (a self biasing to cutoff mode) is to use a calibrated mismatch load connected through a variable length coaxial line, directional coupler, and signal sampling tee to the transmitter, as shown in Figure 5. The variable length coaxial line must have a constant characteristic impedance and must have an adjustment length of at least one-half wavelength in order to present to the transmitter all possible load impedance combinations of resistance, capacitance, and inductance for a specified load VSWR (voltage standing wave ratio).

Some transmitters which are highly optimized for maximum efficiency while loaded with a 50 ohm wattmeter will display a frequency hop and/or squegg mode when loaded with even a slight mismatch, such as 1.5:1 VSWR, a situation easily encountered with a flight antenna. The frequency hop phenomena, which occurs in some transmitters at certain load impedances is serious if it happens during flight since the automatic frequency control in the receiver will lose the signal. To further compound the difficulty, the operator will not know which direction to tune to recover the signal and considerable time may be required to find the signal.

All of these forms of frequency instability are functions of output coupling, relative Q of the output circuit and the antenna, oscillator feedback magnitude and phase, bias network time constant, and the basic method of generating the UHF signal. The theory of oscillator squeggi ‘ ng, frequency hop and pulling under conditions of changing load impedance is very complex, particularly for the case of the UHF-transistor oscillator where stray capacitances and lead inductances are major elements of the circuit; therefore, the final design optimization is usually done by a cut-and-try method that requires considerable ingenuity and dexterity in simultaneously adjusting the circuit for maximum efficienty, power output, and frequency stability and reliable starting over a wide range of load impedances, supply voltages, and temperatures.

Typical pulling figure data for various basic types of transmitters are shown in Figure 6. The simple, fundamental oscillator type of transmitter has a very large pulling figure, often accompanied by frequency hops and squegging, see curve (1), Figure 6. Curve (2) shows the performance of a low frequency oscillator i.e. 400 to 800 MHz, and a diode multiplier. The performance of this circuit is fair, with somewhat excessive pulling and a tendency to squegg. A low frequency oscillator with enhanced harmonic output performs well, see curve (3), however, the circuits are critical to adjust and difficult to reproduce. A fundamental oscillator whose output is lightly coupled through a high-Q circuit has a fair pulling figure, see curve (4), however, the resulting overall efficiency is then very low. Excellent performance is obtained with a fundamental oscillator and buffer amplifier transmitter, curve (5), the pulling is very low and the efficiency exceptionally high. Excellent performance is also obtained when using an isolator with a fundamental oscillator, curve (6). The extra space, weight, and cost of the isolator is a disadvantage, however, the overall transmitter circuitry is very simple and more easily ruggedized.

In order to properly evaluate the frequency stability of a transmitter, its pulling figure must be normalized with respect to efficiency. For example, a transmitter that has a large pulling figure but is highly efficient can be stabilized by the simple expedient of an attenuator pad and be as good or better than a lower efficiency, more stable transmitter. Figure 7 shows the pulling figure of the same transmitters shown in Figure 6 but plotted with respect to efficiency. The inherent superiority of the oscillator-amplifier and oscillator-isolator types of transmitters is clearly shown.

Overall performance factors which are important in evaluating a transmitter are given in Table II. The “acceptable” values of performance listed are a compromise between those desired and those expected to be technically feasible in the near future. The power levels are for telemetry over long ranges, i.e. So to 100 miles. For in-barrel and short range telemetry, power levels of 1 to 10 milliwatts are adequate. It is encouraging to report that improvements in transmitter frequency stability by an order of magnitude and improvements in efficiency by factors of 2 to 3 were made during this project by careful choice and optimization. Also the feasibility of using an isolator under high-g conditions was demonstrated, which makes possible a very simple, stable and efficient transmitter.

TABLE II
SPECIFICATIONS FOR UHF HIGH-G TELEMETRY TRANSMITTERS, NON-CRYSTAL CONTROLLED

Performance Factor	Specifications Desired	Acceptable for Current Use
Supply Voltage	≦ 15 volts	20 volts max.
Supply Current	≦ 75 Ma	100 Mz max.
Efficiency	≧ 25%	10% min.
Power Output	≧ 280 MW	200 MW min.
Frequency Change vs:		
Temperature, 0+50°C	≦ 1 MHz	3 MHz max.
Voltage	≦ 0.1 MHz/volt	0.5 MHz/ volt max.
Time after cold turn-on to one second	≦ 0.25 MHz	0.5 MHz max.
40,000 g shock and 30,000 RPM spin	≦ 0.5 MHz	1 MHz max.
Initial setting accuracy	≦ 0.5 MHz	1 MHz max.
Pulling figure:		
1.5:1 VSWR	≦ ± 0.25 MHz	± 1 MHz max.
3:1 VSWR	≦ ± 1 MHz	± 3 MHz max.
5:1 VSWR	≦ ± 2 MHz	± 4 MHz max.
Squegging Point:		
VSWR	≧ 10:1 VSWR	5:1 VSWR min.
Supply voltage	≦ 5 volts	10 volts max.
Frequency hop VSWR	≧ 10:1 VSWR	5:1 VSWR min.
Modulation sensitivity	≧ 500 kHz/volt	125 kHz/volt min.
Modulation impedance	≧ 5000 ohms	1000 ohms min.
Start voltage	≦ 10 volts	10 volts max.
Diameter	1.495 in.	$1.495^{+.000}_{-.005}$ in.
Height	≦ 0.5 in.	0.875 in. max.
Construction	Integrated circuit	Printed circuit
Weight	≦ 60 grams	60 grams max.

Two major problems in the optimum design of ruggedized UHF transmitters are the lack of strong, low dielectric constant encapsulants and the lack of compact, low cost crystal controlled transmitter circuits.

The low loss encapsulants currently available that have sufficient strength to be useable up to 50,000-g's, such as Emerson & Cumings Stycast 35DS, have a dielectric constant of about two. Although this is not a large value for a dielectric, it has been observed that surrounding a UHF oscillator or amplifier circuit such a dielectric will change the frequency several hundred megacycles, and of more importance, often markedly reduce the efficiency and stability because of changes in capacitive feedback and mutual coupling between circuit elements. An encapsulant is needed which has a dielectric constant less than 2, preferably less than 1.5, a maximum dissipation factor of 0.005, a minimum compressive strength of 2500 psi, voids less than 1/32-inch in diameter, and a maximum pouring viscosity of 10,000 centipoises.

A tuning technique that has been used very successfully to account for the effect of the encapsulant is to fill the transmitter chassis with a dielectric powder which simulates the electrical properties of the encapsulant and adjust the circuit for optimum performance. The powder is then removed and the encapsulant applied.

The use of crystal controlled transmitters will ensure the rapid acquisition of the signal after firing. The frequency change observed on twenty five non-crystal controlled transmitters tested at g-levels between 15,000 and 20,000-g's has been an average of 1.5 MHz, with occasional peak shifts of 4 MHz and many of them with only about 1/2 MHz shifts. Because the use of narrower receiver bandwidths will be feasible when crystal controlled transmitters are used, the transmitter power and antenna gain requirements will be reduced. Ruggedized quartz crystals are available but sufficient circuit work has not yet been done to achieve a low cost, field tested transmitter. A low cost, miniaturized, crystal controlled transmitter for projectile telemetry is a most urgently needed component at this time.

b) Projectile antennas of two types, a balanced Scimitar and a loop fed slot, have been developed. Emphasis was placed on the design of antennas with radiation as near isotropic as possible for use on projectiles with diameters ranging from 2 to 8 inches and lengths from 1.5 to 5 feet.

Figure 8 shows the Scimitar antenna mounted at the front of a projectile and protected by a plastic nose cone. The plastic is PPO, (poly-phenylene oxide) a strong, high-temperature resistant material that has very low loss.

The Scimitar antenna consists basically of a double, balanced, scimitar shaped element which radiates simultaneously in a balanced loop mode polarized in the plane of the

Scimitar and in an unbalanced loop mode polarized in the plane of the base of the Scimitar. The dimensions and configuration of the Scimitar have been chosen to equalize the magnitude of each radiation mode. The radiation patterns of the Scimitar mounted in the nose of a 155 mm projectile are shown in Figure 9.

It should be emphasized that the near-isotropic radiating properties of this antenna can only be fully realized at the receiving site by the use of polarization diversity, i.e., separate vertically and horizontally polarized or clockwise and counterclockwise circularly polarized receiving channels. However, the use of a single, circularly polarized receiving antenna provides near-isotropic reception, with nulls at only two directions 45 degrees from the axis of the projectile where the polarization will be of opposite sense of rotation. The output of a linearly polarized receiving antenna will have two deep nulls per revolution of the projectile when receiving off the tail or nose, which will provide good spin rate data. The output of a linearly polarized antenna receiving off the side of the projectile will be a complex waveform with two or four nulls per revolution.

The Scimitar is matched with an 1/8-inch wide strip transmission line which is connected at a point on one of the Scimitar arms that presents 50 ohms at the other end of the stripline. Solid copper outer jacketed coaxial cable, 0.085-inches O.D. is used. The cable shield is attached to one side of the Scimitar to form a balun feed to maintain electrical balance. The Scimitar dimensions are chosen for self-resonance at the desired frequency when in the PPO radome; for 1520 MHz, the height is 1-3/16 inches, the base width is 1.5 inches, and the center hole is 7/8-inch in diameter.

A Scimitar has also been developed for mounting on the base of a projectile. The electrical properties and physical configuration of this antenna are similar to the front-mounted Scimitar except that the plastic housing is a hemisphere filled with an encapsulant. Figure 10 shows the Scimitar antenna configuration for mounting on the base of a 155 mm projectile. The plastic dome is made of PPO. It was necessary to fill the PPO hemisphere with a strong dielectric to withstand the chamber pressure during firing. Emerson & Cumings 35DS casting resin was found to be satisfactory for mechanical support in test firings conducted by Picatinny Arsenal personnel [1]. This resin has sufficiently low loss and low dielectric constant to not seriously affect the antenna. However, because of the dielectric loading of the 35DS, the Scimitar size had to be reduced by 15 percent to maintain resonance at 1520 MHz. The same technique for tuning the Scimitar in a dielectric was used as described for tuning transmitters, where the hemisphere was first filled with a powder with a dielectric constant of two and the Scimitar inserted and adjusted for resonance and impedance match, then the powder was removed and the encapsulant applied.

The loop fed slot antenna configuration, termed the “Halo” antenna, is shown in Figures 11 and 12 for mounting on the base of the projectile. The Halo antenna consists of a wire wrapped around a dielectric cylinder that is bounded by two circular metal surfaces which form a parallel plate cavity. The 1520 MHz Halo mounted on the 155 mm projectile uses a cavity formed by a metal plate 2-1/8 inches in diameter spaced one inch from the base of the projectile. The cavity is filled with an epoxy fiberglas cylinder which serves both as a strong spacer and for dielectric loading to reduce the outer diameter of the antenna. The antenna wire is wrapped in a groove around the dielectric cylinder. The loop thus formed is connected to the inner conductor and the shield of the coaxial cable at the loop gap. The diameter of the dielectric cylinder is 1.9 inches, making the length of the wire wrapped around the cylinder 5.9 inches, (0.77 wavelengths long physically but approximately one wavelength long electrically at 1520 MHz because of the dielectric loading of the cylinder). A teflon-fiberglas shell is placed over the cylinder for thermal protection. A 3/4-inch diameter steel bolt is run through the center of the antenna to secure it to the projectile base.

A very simple and rugged matching technique has been developed for controlling the resonant frequency and broadbanding the impedance of the Halo. The matching device consists of a thin, rectangular strip of metal attached to the Halo wire near the feed gap. The width, length, and position of this tab relative to the feed gap is adjusted to obtain the desired center frequency and bandwidth. This tab acts as a short section of reduced characteristic impedance transmission line in series with the Halo wire and as a shunt reactance at the feed point. The combined effect is to greatly broaden the impedance bandwidth of the Halo and to present a constant and very low VSWR over a large portion of the bandpass. The VSWR versus frequency for a Halo with a matching tab is shown in Figure 13, the bandwidth is 1000 MHz at the 2:1 VSWR points.

The current and voltage standing wave around the Halo has two maxima and two minima. In the region of the current maxima, the antenna radiates as a loop with the polarization parallel to the wire, while at the voltage maxima, it radiates as a slot antenna with the polarization perpendicular to the wire. These two radiation components are almost equal in magnitude as shown in Figure 14, providing omnidirectional coverage without any deep nulls if polarization diversity is used for reception.

In addition to the Scimitar and the Halo antenna, several other configurations were investigated but were not developed to the ruggedized flight model stage. The configurations considered consisted of the following:

1) Flush logarithmic spiral
2) Flush slot
3) Flush helix in cavity
4) Flush loop in cavity
5) Stub for body feed
6) Unbalanced loop for body feed
7) Wrap-around quadraloop for body feed

Sketches of proposed configurations of these antennas are shown in Figure 15. Antennas (a) through (d) in Figure 15 (the spiral, slot, helix and loop) can be designed to be flush with the base surface, or protrude at most about 1/2-inch in the form of a thick, flat plastic attached to the projectile base. This plate would be made of a strong, high temperature resistant, non-charring dielectric such as a teflon-fiberglas laminate. These antennas produce a broad, strong radiation lobe off the rear, have some radiation off the side, but are weak off the nose. The spiral and helix antennas are circularly polarized, and, therefore, provide continuous, null-free data as the projectile spins, a good feature for telemetry but poor for spin rate measurement. The slot and loop are linearly polarized and, therefore, good for spin data.

Antennas (e) through (g) (the stub, unbalanced loop, and wrap-around quadraloop) are body feed antennas, i.e. they excite currents along the projectile body, resulting in a radiation pattern that has a deep null off the nose and tail and has a multilobed radiation pattern off the side of the projectile. The shape of the pattern is a function of the length and diameter of the projectile. In general, there are as many lobes as there are half-wavelengths of body length, i.e., a 155 mm projectile which is 24 inches long would have a 6 lobed radiation pattern at 1520 MHz. The strongest lobe will be directed away from the end of the projectile that is being fed by the antenna. Antennas (e) through (g) are linearly polarized but do not give deep spin nulls because the radiation is rotationally symmetric around the projectile body. Best continuous reception from body feed antennas is obtained with the receiving antenna located off to the side of the plane of the trajectory rather than at the gun site, as is the case for all of the other antennas described.

c) <u>Voltage controlled oscillators</u> available commercially to IRIG standards have been used successfully to 50,000-g's. They are available in "hockey puck" and "half hockey puck" form, 1.5 inches in diameter by 0.5 inch thick.

d) <u>Commutators</u>, available commercially, with 8 or 16 channels at a frame rate of 5 per second have been used. They are available in hocky puck form, 1.5 inches in diameter by 0.6 inch thick for 8 channels and 1-3/16 inch thick for 16 channels.

e) <u>Batteries</u> are available in a wide variety of sizes and capacities that are useable for projectile telemetry. Standard, nickel cadmium button cells have been used successfully in sizes of 50, 100, and 250 Ma-hr and in stacks up to 15 cells for 20 volts. The commercially assembled stacks usually have to be vacuum encapsulated to fill the voids between the cells. For reliable use of the large cells at 50,000-g's it has been found necessary to buy them as separate cells and spot weld them together with 0.006 inch thick stainless steel strips 1/4-inch wide. The commercially assembled 250 Ma-hr cell stacks usually have a connecting strip that is too weak to withstand 50,000g's.

Silver oxide button cells have been used very successfully in sizes of 105 and 165 Ma-hr. The commercially available, 105 Ma-hr, S-41 cells in seven cell, 9.5 volt stacks have been found to be a very convenient, low cost, and reliable battery. They may be used as purchased for spinning projectile telemetry up to 20,000-g's. Four stacks used in a series-parallel connection will provide 19 volts at 100 milliamperes for an hour. Higher acceleration applications require that the seven cell stacks be vacuum potted in a strong encapsulant such as E&C Stycast 1090SI, because, as purchased, they often have voids in the potting. Although not rated as a rechargeable battery, the silver oxide cells can be recharged at about one milliampere.

The development of a reserve battery, based upon the standard NC36 design, was undertaken in order to provide for an initial UTM capability equivalent to that of the existing VHF telemeters. The new battery, called the NC71j. retains the chemical system of the NC36 i.e., lead, lead-dioxide electrodes with an electrolyte consisting of fluorboric acid--and the dependency upon shock and spin for activation and in-flight operation. The electrolyte is stored in a glass ampule and, upon gun launching setback, is dispersed throughout the cells. Figure 16 is an early conceptual illustration of this battery. The NC71 is 1-1/2 inches in diameter and 1-5/8 inches long, excluding the connector prongs.

The glass ampule requires a minimum of approximately 1000-g's for breakage and a minimum spin rate of approximately 60 rps to fill the plates sufficiently to provide threshold power. These limiting conditions are approached when firing at zone 1 in cold regions. Low temperatures also tend to reduce reliability due to their inhibiting effect on fluoroboric acid.

The initial goal for the NC71 was to provide a nominal 180 Ma at 28 volts for 2 minutes in addition to a 5 volt reference tap-off. An early laboratory test demonstrated the feasibility of approaching this goal. Later flight testing confirmed that the NC71 can deliver at least 100 Ma for 2 minutes.

At the outset of the UTM program, a battery utilizing liquid ammonia appeared to be highly desirable due to its reputed operation at temperatures as low as -65°F. An additional encouraging factor was its high power-tovolume ratio. A program was undertaken to develop a battery capable of operation across the range of anticipated gun environments - from low-g, no-spin to high-g, high-spin. Figure 17 is an early conceptual illustration of this battery, model NH_3 .

The NH_3 battery proper is longer than the NC71 (2.375 vs 1.6 inches) mostly due to the addition of an inert pressurized gas. The pressurized gas enhances rapid activation at low g's and at low or no-spin conditions. A plunger capable of puncturing the diaphragm at low g's enters the battery proper and allows the cells to be force-filled with liquid ammonia electrolyte. The goal for this first UTM prototype is to provide 300 Ma at 28 volts for more than 3 minutes.

f) <u>Acceleration activated switches</u> consisting simply of a brass slug and a fuze clip holder have been extremely reliable. A switch encased in a plastic case 3/8 x 3/8 x 7/8 inches has been designed by the Harry Diamond Laboratories.

g) <u>Modular cases</u> consisting of steel, cylindrical sections threaded at each end are used, These cases can be screwed together to form a flight package of the desired length, depending upon the requirements of the test. The case modules are 1-1/2 inches inside diameter and 2-5/32 inches outside diameter, threaded at each end. The end with the inside thread has a recessed shoulder to support a bulkhead disk through which the prongs of the interconnecting plus pass.

Plastics and Encapsulants In previous portions of this paper, effects of plastics on tr; smitter and antenna designs were reported. The following discussion provides additional background and supplementary information considered in the selection of acceptable radome and encapsulating materials.

While developing fuzes the Harry Diamond Laboratories found that a relatively new plastic, poly-phenylene oxide (PPO), was the most promising material capable of meeting projectile radome requirements. It possessed good electrical properties required for use with UHF transmitters, it could survive gun launch shocks, and it could withstand the aerodynamic heating in high velocity flights. Therefore, PPO was selected for initial ogive configurations of the UTM. Later a continuing literature search disclosed several alternate radome materials: Polysulfone, Noryl-3, and Polyimide. Table III is a comparison of these and other materials considered.

Tests of both PPO and Polysulfone under high acceleration were successful. Also, no discernible difference in antenna patterns was detected when utilizing radomes of either material; though only PPO designs were flight tested. Noryl-3 and Polyimide also appear to be attractive. However, the latter has been tentatively dropped from further consideration due to the proprietary nature of its manufacturing techniques. Recently, PPO has also become less attractive since the manufacturer will fill only special military orders. For future radomes Noryl-3 (probably glass-filled for strength) will be evaluated further.

The base-mount Scimitar antenna also uses PPO as the radome material. In addition to the other characteristics required for the ogival configuration, the base design required reinforcement in order to withstand breech pressures up to 50,000 psi. To provide this added strength, an encapsulating material was wought which possessed high compressive strength, low dissipation at UHF, and chemical inertness when placed in

TABLE III
RADOME PLASTICS

	PPO	PPO w/30% Glass	Polysulfone	Noryl-3	Noryl-3 w/30% Glass	Polyimide
Impact Strength (ft-lb/in, 1/2 in bar)	1.7	1.8	1.3	3.8	1.7	0.8-1.1
Tensile Strength (psi x 10^3)	11.0	18.0	10.2	9.6	17.0	5-14
Elongation (%)	20-40	4-6	50-100	20-30	4-6	6-7
Heat Dist. Temp. (°F, 264 psi)	345	360	345	265	310	680
Heat Resistance (Continuous °F)	250	--	300	--	--	--
Dielectric Constant (60 Hz)	2.58	2.97	2.82	2.64	2.93	3.5
Dielectric Strength (volts/mil, 1/8 in)	400-500	1050 (1/32 in)	425	550	1020 (1/32 in)	400
Dissipation Factor (60 Hz)	.00035	.0009	.0008 - .0056	.0004	.0009	--
Flammability (in/ min)	Self Extinguishing	Self Extinguishing	Self Extinguishing	Self Extinguishing	Self Extinguishing	Self Extinguishing

contact with radome materials. One material, E&C Stycast 36DD looked promising due to its low dielectric constant, but was discarded due to its low strength. Selected for investigation instead was the stronger Stycast 36D.

Considerable difficulty was encountered in the potting of Stycast 36D in a PPO dome. In a postmortem investigation it was found that a chemical reaction was experienced during potting. An x-ray examination uncovered the existence of a boundary layer, from 1/16 to 1/811 thick, containing an abundant amount of gaseous voids which might cause failures under elevated breech pressures. The high strength, E&C Stycast 35DS was next selected for investigation even though it had a higher dielectric constant. It also attacked PPO (but not as drastically), causing a relatively small gaseous boundary layer. It was found that this boundary layer was reduced considerably by pre-brush-coating the PPO dome interior surface with 35DS, allowing this coating to cure, then filling the dome with the same 35DS. Successful testing in guns at Picatinny Arsenal and at Wallops Island, Virginia, lent credence to the validity of this procedure.

Another deficiency found in the initial potting procedure was that pressure feeding of 35DS into the dome produced gas voids and bubbles, which were deemed detrimental to survival at high breech pressures. Subsequently, this method was replaced by the simple gravity feed method (plus vibration) which resulted in successful tests as indicated above. Table IV lists comparative characteristics of the several encapsulants studied.

Preflight Testing Testing of components to determine whether they will withstand the acceleration of experienced while in the gun barrel ideally requires exact simulation of the magnitude, duration, and variation of acceleration with time. The acceleration pulse shape of several guns is shown in Figure 18.

A method of high-g testing used very successfully at the Ballistic Research Laboratories for a number of years consists of mounting the component in a 5-inch diameter slug and firing it from a short barrel gun into lead blocks. The component is stressed as the slug penetrates into the lead. Peak deceleration magnitudes up to 70,000-g’s are obtainable by this technique. A very small amount of propellant is required so the setback acceleration in the gun barrel is only several thousand g’s. The amplitude, duration and waveform of the deceleration pulse is determined by the velocity and weight of the slug and the angle and shape of the slug nose.cone. Experimental and theoretical studies of the relationship between these parameters have been made [2]. The test slug with the various nose cones used is shown in Figure 19, and the lead block after impact is shown in Figure 20. The lead impact g-pulse has a rise time that is shorter than in the gun, which means that components are subjected to stronger high frequency components of acceleration; also, the pulse is narrower for a given g-load than most guns provide. However, a spectral analysis of the energy content of the lead test g-pulse indicates that, by a suitable over-test, the energy distribution of an actual firing can be satisfactorily simulated. In practice, good correlation has been obtained between high-g lead tests and actual firings.

TABLE IV
ENCAPSULATING PLASTICS

	Stycast 36D	Stycast 36DD	Stycast 35DS
Service Temperature	-70° to +150°C	-70° to +150°C	-65° to +300°F
Specific Gravity	0.98	0.57	0.7
Flexural Strength (psi)	>10,000	1,700	--
Axial Strength (psi)	6,000	1,500	5,000
Water Absorption (% in 24 hours)	0.05	<0.1	--
Dielectric Strength (volts/mil)	>500	>300	--
Volume Resistivity (ohm-cm)	$>10^{15}$	$>10^{14}$	--
Dielectric Constant ($60-10^{10}$ hz)	2.45	1.7	1.9
Dissipation Factor ($60-10^{10}$ hz)	<.0007	<.0009	<.001

A convenient method of supporting components, particularly irregular shaped assemblies, for high-g testing has been developed which consists of packing the item tightly in a strong container filled with soapstone powder. The powder is tamped tightly around the item and the cover then screwed on to further compress the powder. Figure 21 shows a container developed for this purpose. The inner wall is tapered to ease removal of the compressed powder after firing. Up to 25,000-g's, the powder falls off readily from the sample; at 50,000-g's, it compacts very firmly but can be chipped away easily. This is a much cleaner and quicker technique than encapsulating a component for high-g testing and then dissolving the encapsulant to retrieve the component for inspection and electrical testing.

Ground Receiving Antennas A complete UHF telemetry ground station has been developed which uses a high gain, pencil beam tracking antenna and a high gain, fan beam fixed antenna. The tracking antenna is a modified GMD (Ground Meteorological Detector) seven-foot diameter, parabolic antenna, originally developed for tracking balloon borne radiosondes at frequencies between 1600 and 1700 MHz. The VSWR of this antenna is satisfactory for reception between 1400 and 1850 MHz.

The GMD antenna is a conically scanned tracking antenna with a vertically polarized, 7-degree, pencil beam. The tracking motors are activated by a 34 Hz error signal derived from an AM detector in the receiver. For tracking a projectile, the antenna is located behind the gun and pointed toward a place along the trajectory where the slew rate will not be in excess of the tracking motor's capabilities. The scanning motor is turned on after the gun is fired at a time when the projectile is estimated to be in the acquisition volume of the antenna. The GMD antenna system will track with an accuracy of about one-half degree. The gain of this antenna over isotropic is 26 db at 1520 MHz.

In applications where data are required immediately after emergence of the projectile from the gun barrel, or, where the complexity or possible uncertainty of acquiring the signal with a narrow beamwidth tracking antenna is undesirable, a fixed antenna is preferred. However, at UHF when using fractional watt transmitters for long range telemetry, appreciable gain is required in the receiving antenna but a narrow pencil beamwidth is often too small to provide data throughout a trajectory. The fan beam antenna, narrow in the azimuth plane and wide in the elevation plane, is a unique solution to this problem, since projectiles normally fly with little or no deviation in azimuth. A fan beam antenna has been developed for UHF telemetry, see Figure 22. The design of this antenna is based on the "Casshorn" (Cassegrain-folded horn) principle [3]. The antenna design is unique in that it provides all polarizations, i.e., vertical, horizontal, right- and left-circular simultaneously, and a low VSWR for the low and high UHF TM bands, with continuous operation from 1400 to 2200 MHz. At 1520 MHz the beam is 10 by 50 degrees wide at 3 db down, giving 15 db gain.

UTM Flight Tests and Applications A total of twenty one flight tests have been conducted with 1520 MHz telemetry units made up of the type of components described in this paper.

The two test projectiles employed in gun firing tests were modifications of the standard M101, 155 mm projectile inert loaded to 95 pounds. Initial testing was conducted in the basic ogive test vehicle (Figure 23). A reinforced base design (Figure 12) was developed as an inexpensive base-mount test vehicle.

A standard, 155 mm, M2 gun was used. Type M19, Zone 7, 29-1/2 pound propellant charges were used giving a chamber pressure of 50,000 psi, peak acceleration of 18,000-g's, muzzle velocity of 2820 feet per second, and spin rate of 220 rps. The long range firings were made at a 60-degree elevation angle, giving a peak altitude of about 40,000 feet and an impact range of 75K feet. Tests while the projectile was in the barrel or close to the barrel were made with the gun fired horizontally through the BRL Transonic Range which is instrumented for high accuracy velocity measurements.

Only three telemeters failed to function out of the twenty one fired. One unit that failed to transmit used a developmental liquid reserve battery as the power source for the transmitter. It is suspected that this battery failed to activate properly.

Two other rounds in which the telemeter was powered by a developmental battery, the NH_3, had erratic transmission, suspected to be improper battery operation. All'telemeters subsequently used a separate silver oxide button cell battery pack.

The second telemeter that failed used a base-mounted Halo antenna of a new design that had not been adequately high-g tested prior to firing it. The joint between the coaxial cable and the connector is suspected to have failed. Subsequent high-g tests and actual firings using an improved cable to connector joint on the Halo were successful.

The cause of the failure of the third telemeter is not known. It was a normal, ogive-mounted Scimitar antenna type of unit that operated successfully for 18 other firings, giving a reliability of 95%.

Particularly noteworthy was the successful reception of signals from all five of the UTM units fired with the gun horizontal. Strong signals were received from the projectile while it was still in the gun barrel and, when the transmitter was turned on prior to firing, signals were received without interruption during the firing. Thus, indicating the feasibility of in-barrel telemetry with the UTM unit.

Several programs exist or are pending at Picatinny Arsenal to which the UTM effort can be readily applied. These involve investigations of projectile yaw and vibration; investigations of component failures; and post production quality assurance testing. Also, interest has been expressed in the possible in-barrel application, based upon recent successful RF monitoring before, during and after firing.

Conclusions The feasibility of the “Universal Telemeter (UTM)” concept has been demonstrated, including the versatility and convenience of using modular hardware with interconnecting plug-in connectors for ogive and base mounted applications, thus, eliminating the need for special telemeters for each application.

A UHF telemetry system for projectiles has been successfully developed with feasibility demonstrated for in-barrel and long range applications. The basic criteria for designing and evaluating the components of a telemetry system that must withstand high accelerations have been determined quantitatively in considerable detail. The most significant progress has been made in the design and performance evaluation of ruggedized UHF transmitters and omnidirectional projectile antennas.

A very high percentage of successful telemetry performance was achieved, 18 out of 21, which confirms the high quality of component designs and corroborates the adequacy of the pre-flight, high-g, lead block impact testing technique.

The feasibility of utilizing a low-cost, base-mount test shell which can survive high breech pressures (-50,000 psi) has been successfully demonstrated.

The feasibility of utilizing a standard silver oxide cell battery pack and a liquid reserve energizer to power the basic UTM prototype has been successfully demonstrated. However, further flight evaluation of the liquid reserve energizers is necessary in order to adequately define their characteristics and reliability. The NC71 battery will allow operation of the UTM down to temperatures approaching -40°F, though at reduced reliability.

References

[1] A. Magnecz, "155 mm Test Shell for Use With Base Mounted Telemetry Units," Picatinny Arsenal Report SMUPA-TK-1072, September 1969.

[2] S. Marks, J. Pilcher, F. Brandon, "The Development of a High Acceleration Testing Technique for the Electronic Instrumentation of HARP Projectile Systems," BRL Memo Report 1738, March 1966, AD 635 782.

[3] "Broadband Primary Feed Assembly and Casshorn Antenna," Technical Proposal #M-2994, 9 December 1963, Aero Geo Astro Corporation, Edsall and Lincolnia Roads, Alexandria, Virginia.

Bibliography

[1] V.W. Richard, "Development of a UHF Telemetry System for Projectiles," BRL Report 1486, July 1970.

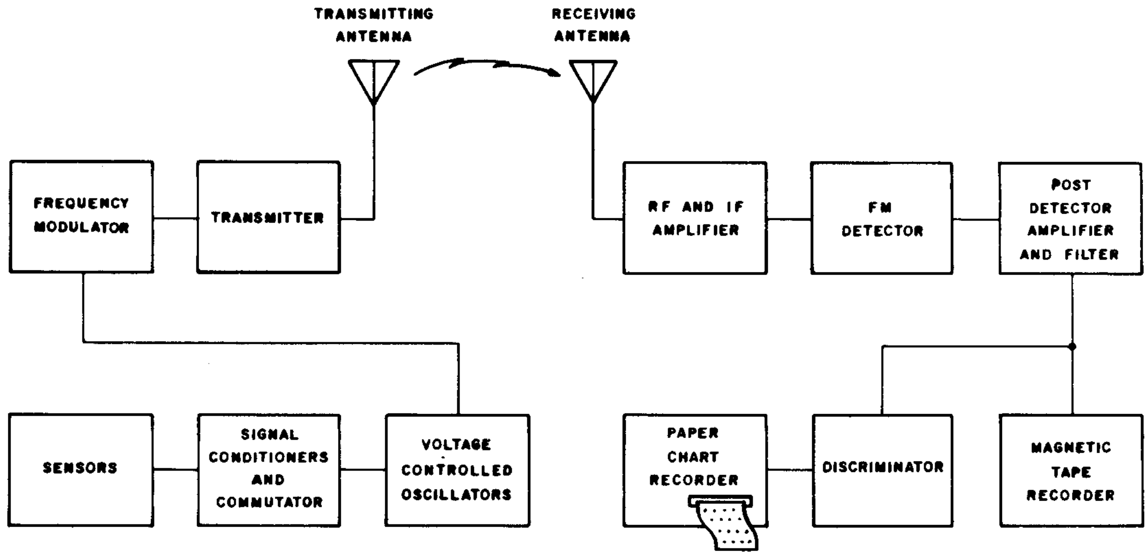


Fig. 1 - FM FM Projectile Telemetry System

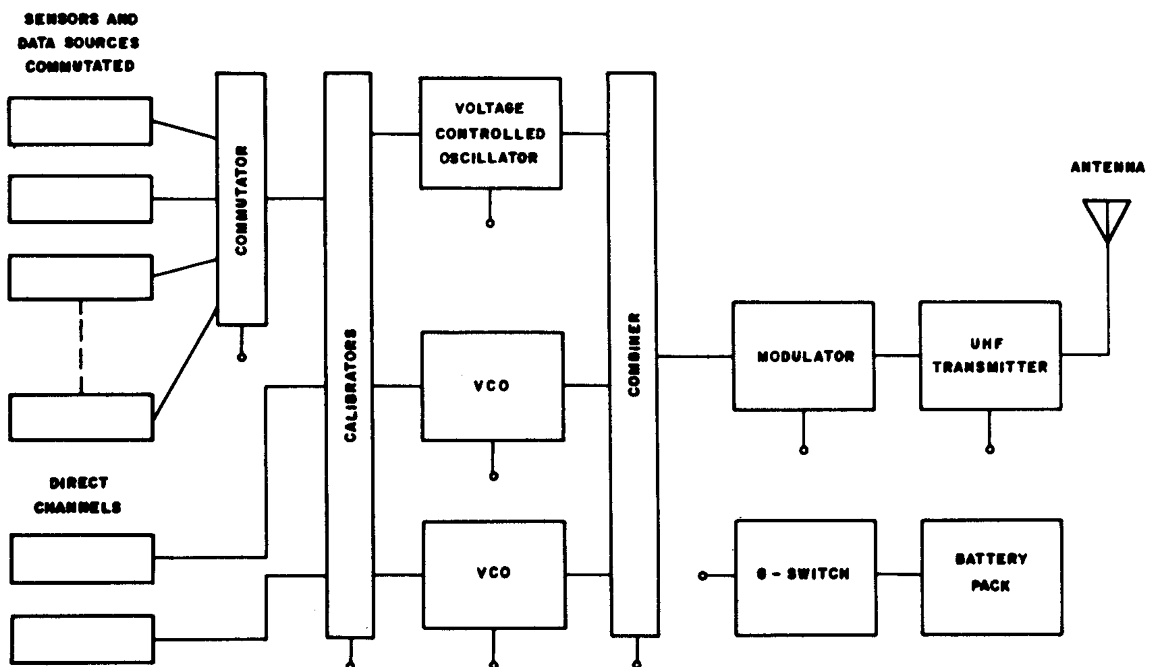


Fig. 2 - Projectile Telemeter Block Diagram

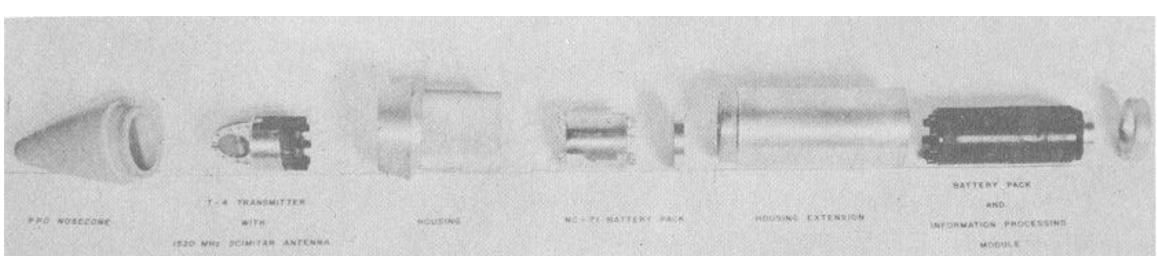


Fig. 3 - Projectile Telemeter Components

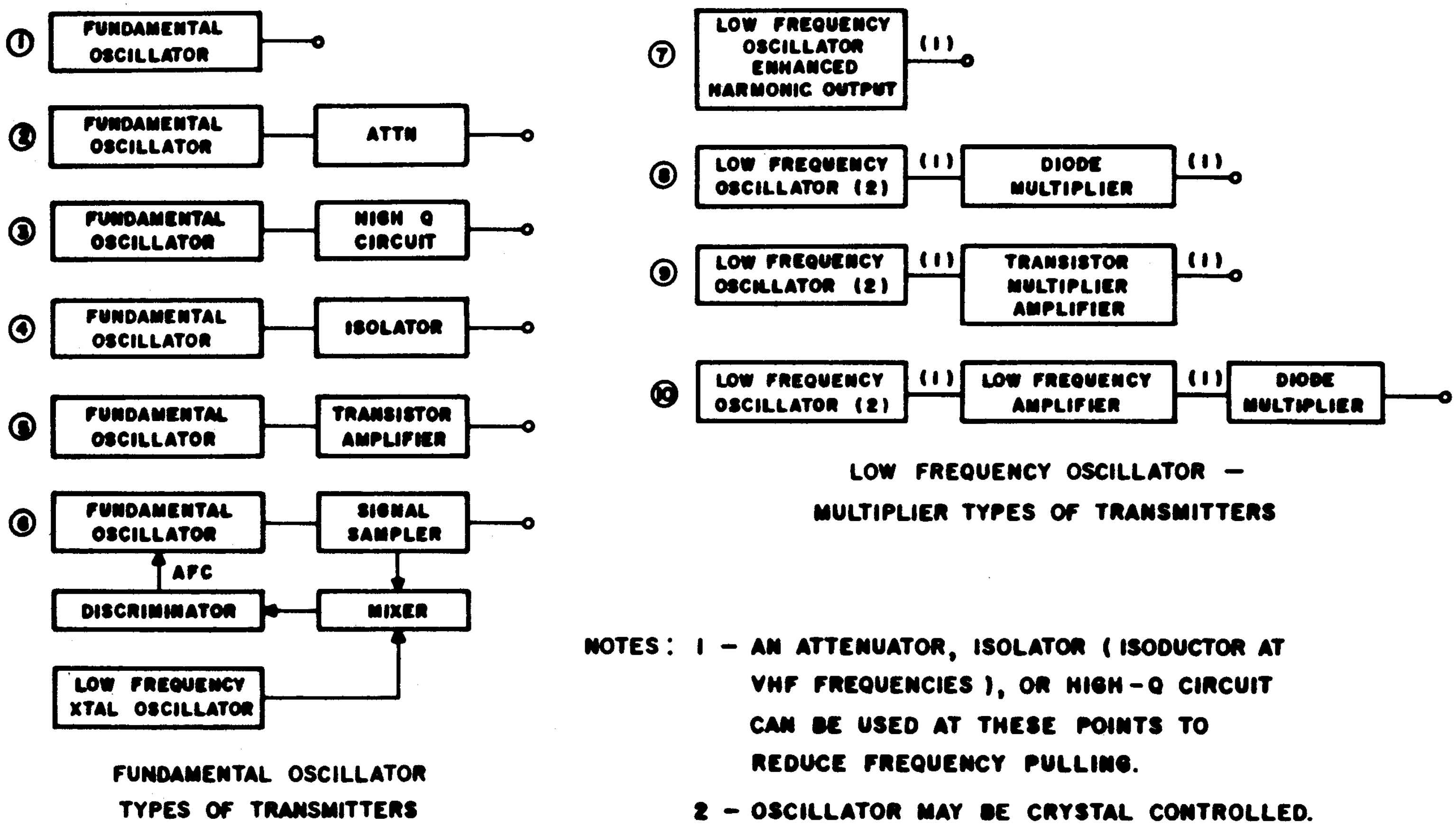


Fig. 4 - Methods of Generating UHF Signals

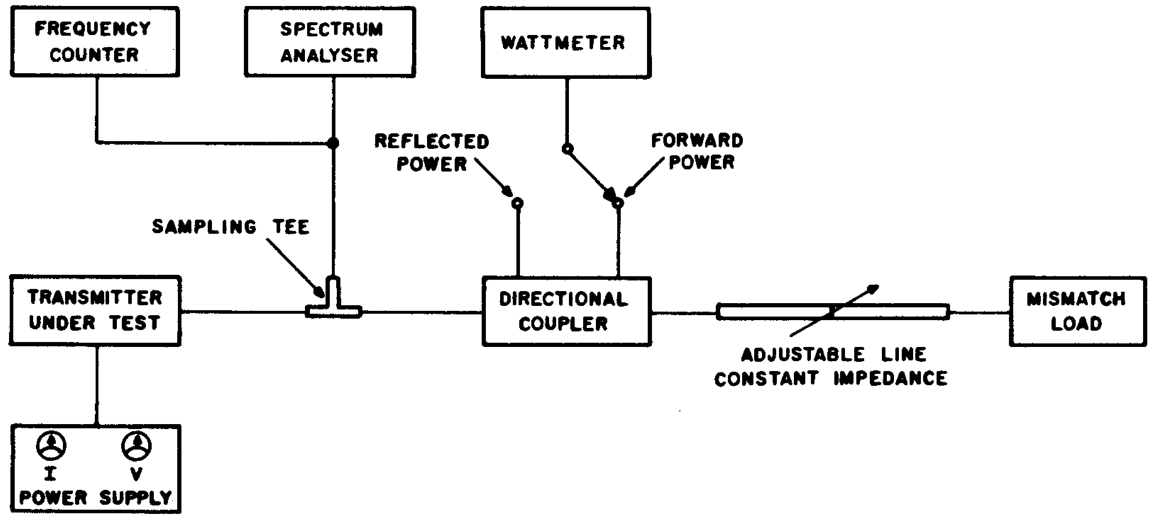


Fig. 5 - Pulling Figure measurement Test Setup

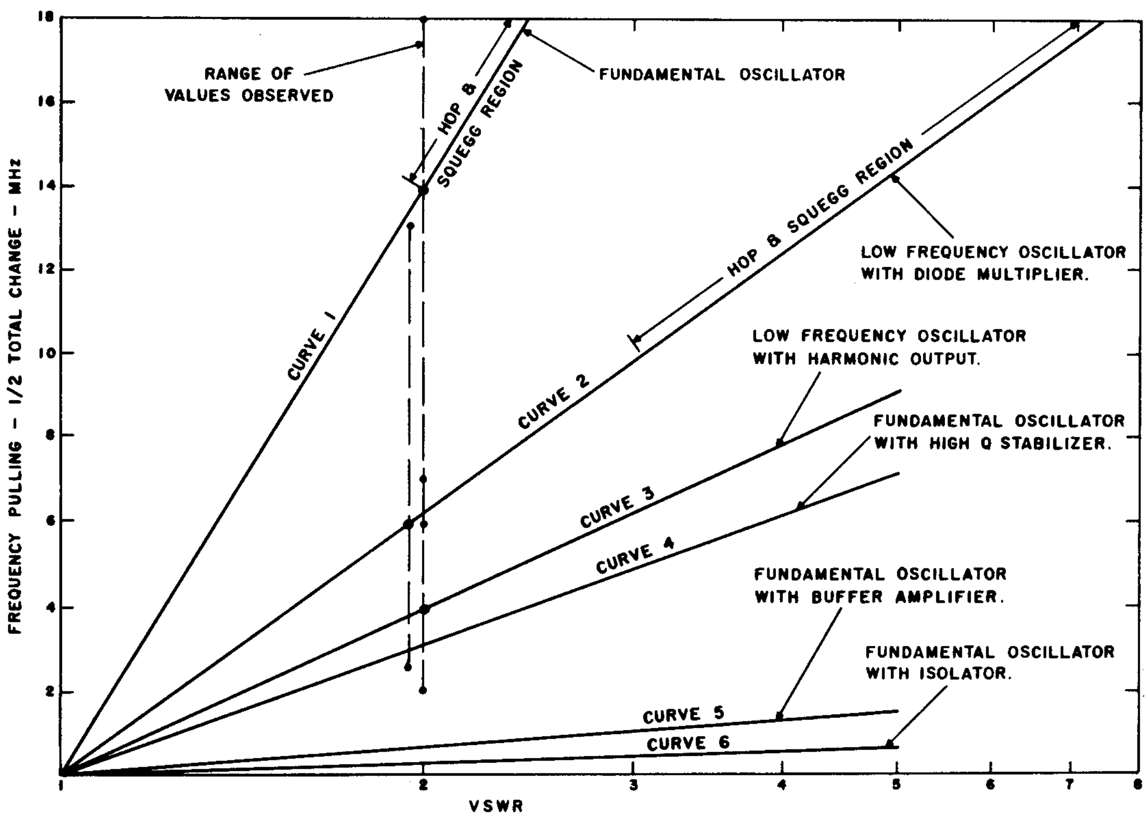


Fig. 6 - Pulling Figure of Various Types of UHF Transmitters

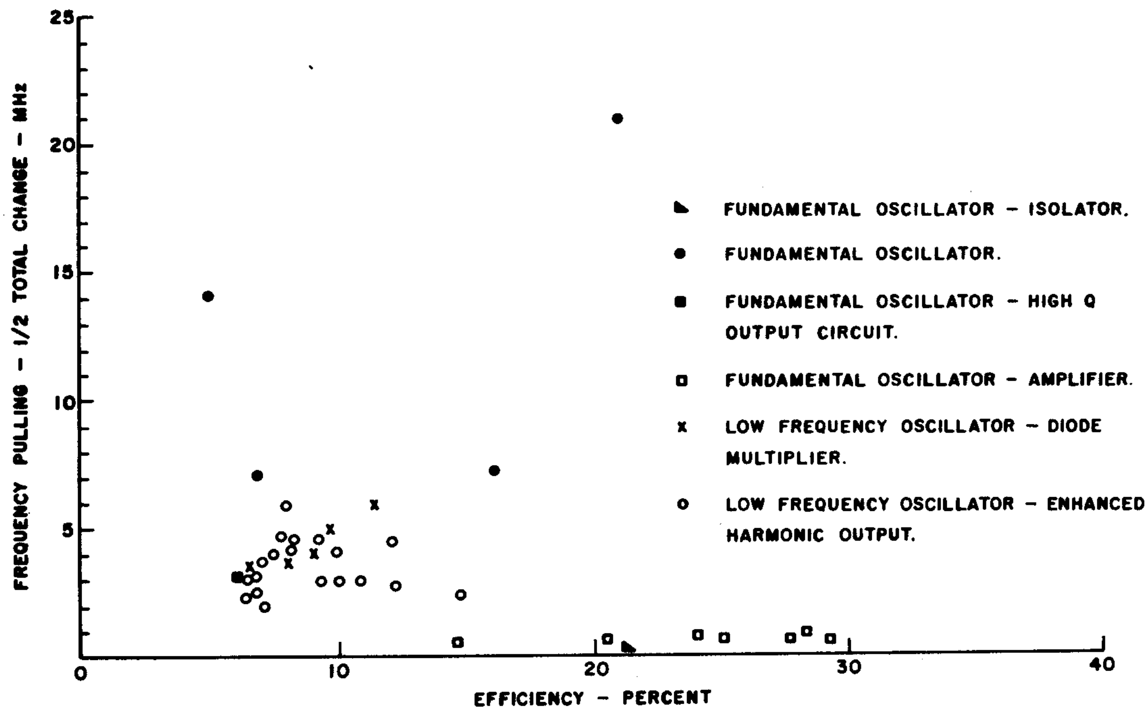


Fig. 7 - Pulling Figure Versus Efficiency of UHF Transmitters

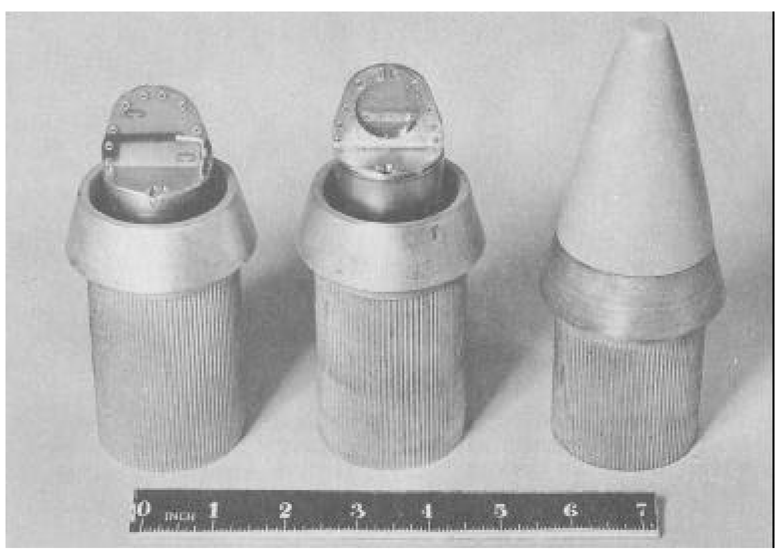
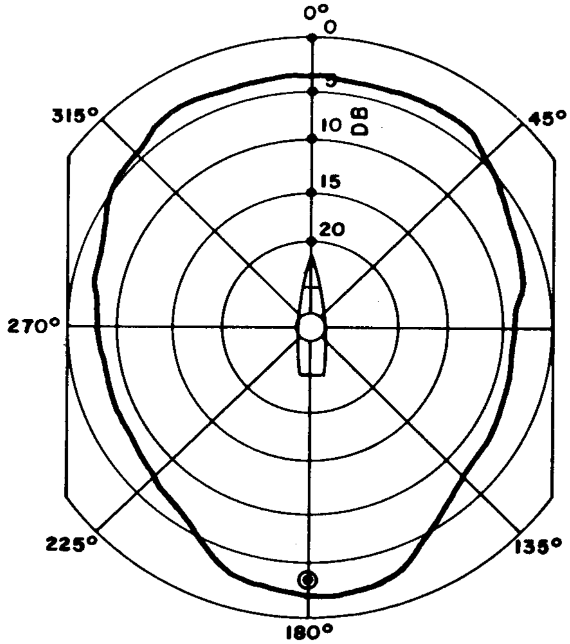
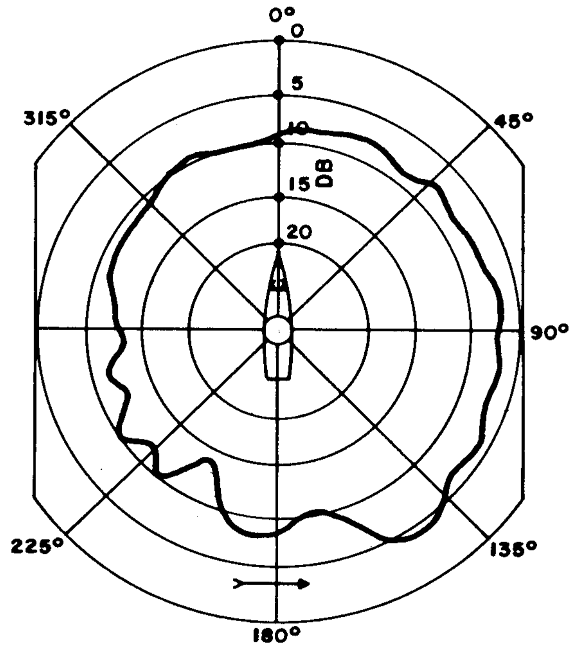


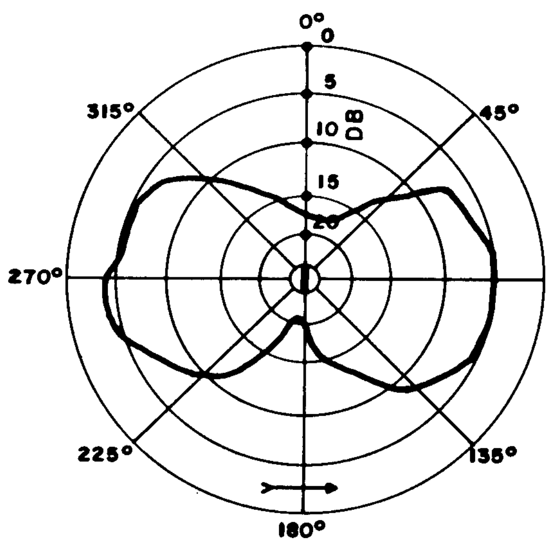
Fig. 8 - 1520 MHz Scimitar Antenna, Front Mounting



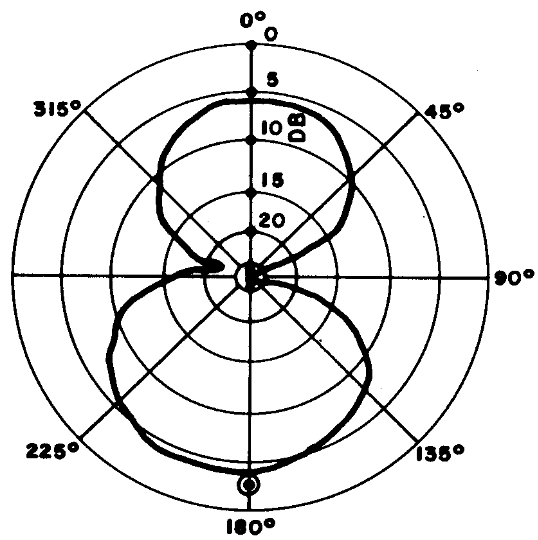
POLARIZATION PERPENDICULAR TO PROJECTILE LONGITUDINAL AXIS. PATTERN IN PLANE PERPENDICULAR TO PLANE OF SCIMITAR.



POLARIZATION PARALLEL TO PROJECTILE LONGITUDINAL AXIS. PATTERN IN PLANE OF SCIMITAR.



POLARIZATION PERPENDICULAR TO PROJECTILE LONGITUDINAL AXIS. PATTERN AROUND PROJECTILE LONGITUDINAL AXIS.



POLARIZATION PARALLEL TO PROJECTILE LONGITUDINAL AXIS. PATTERN AROUND PROJECTILE LONGITUDINAL AXIS.

Fig. 9 - 1520 MHz Scimitar Radiation Pattern

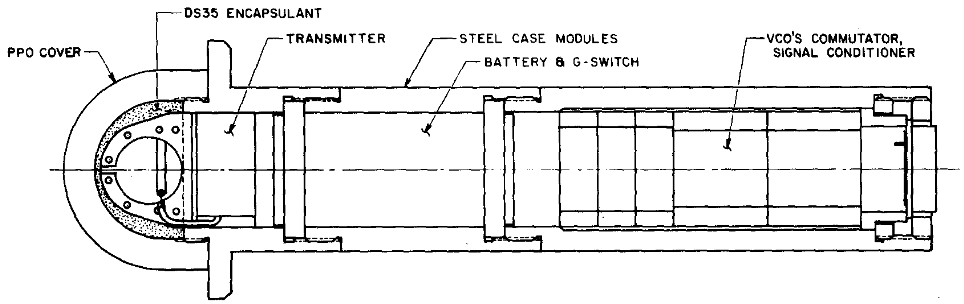


Fig. 10 - 1520 Scimitar Antenna in Base Mounted TM

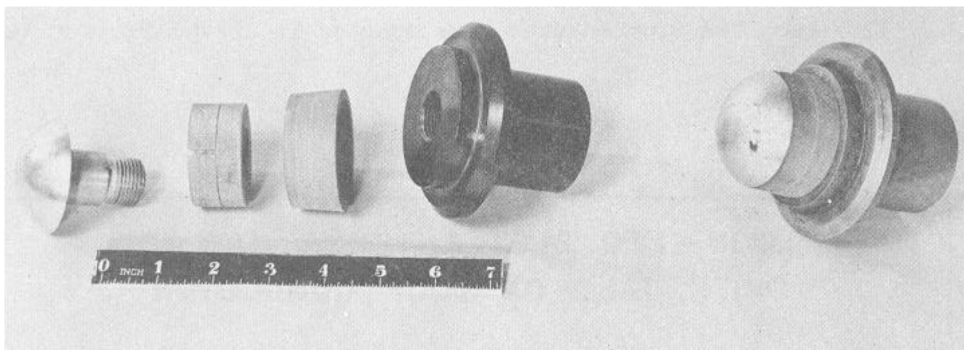


Fig. 11 - 1520 MHz Loop Fed Slot Antenna for Base Mounting

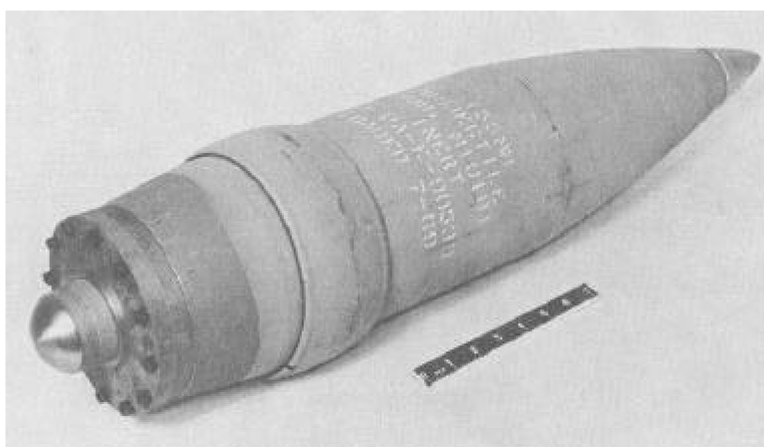


Fig. 12 - Loop Fed Slot Antenna Base Mounted in 155 Mm Projectile

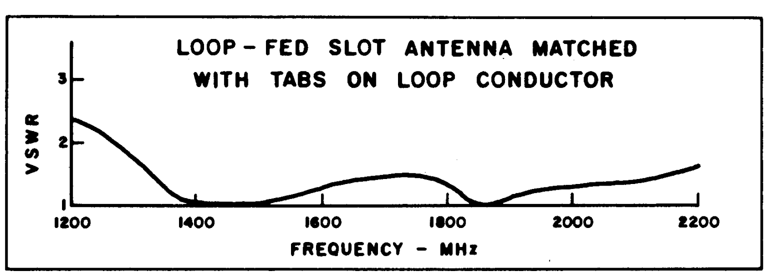
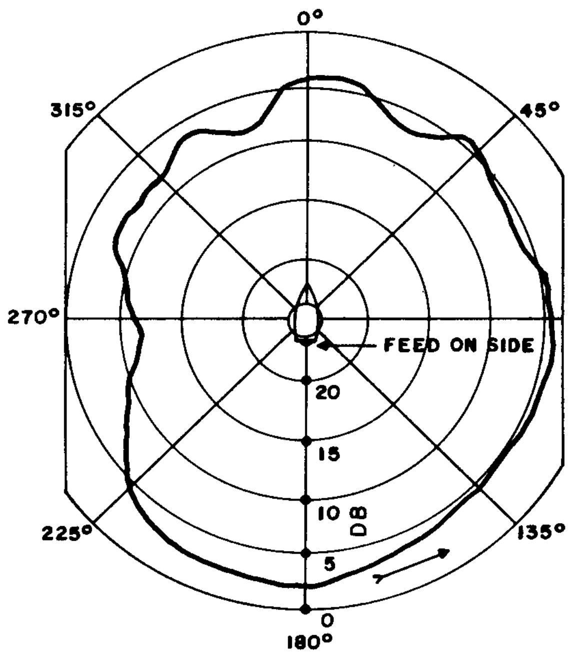
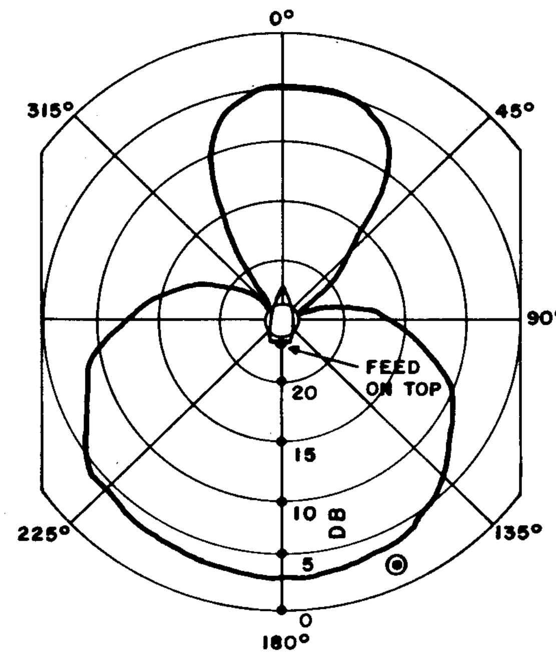


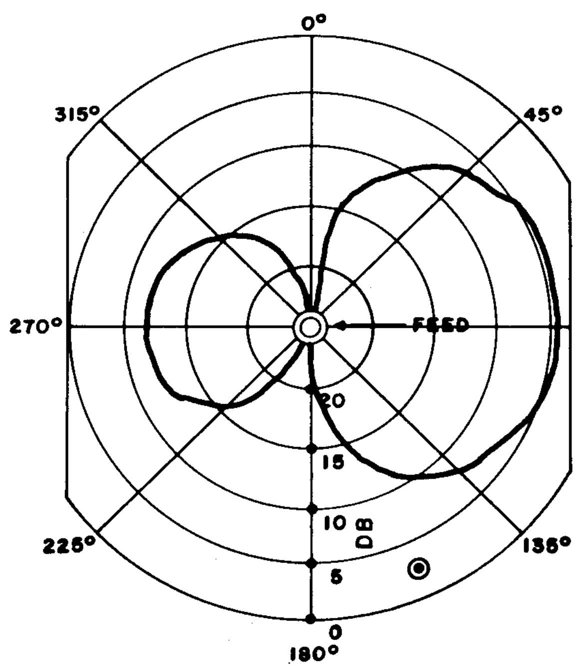
Fig. 13 - VSWR of Loop Fed Slot Antenna



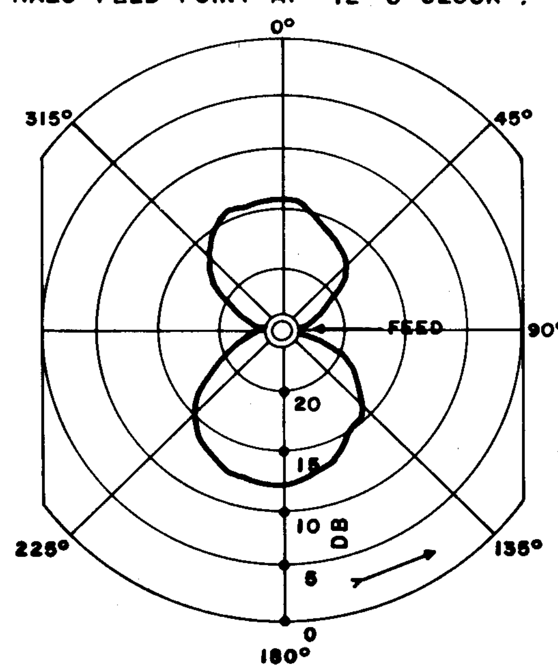
POLARIZATION IN PLANE OF
PROJECTILE LONGITUDINAL AXIS.
HALO FEED POINT AT "3-O'CLOCK".



POLARIZATION IN PLANE PERPENDICULAR
TO PROJECTILE LONGITUDINAL AXIS.
HALO FEED POINT AT "12-O'CLOCK".



POLARIZATION PARALLEL TO
PROJECTILE LONGITUDINAL AXIS.
ROLL PATTERN.



POLARIZATION PERPENDICULAR
TO PROJECTILE LONGITUDINAL AXIS.
ROLL PATTERN.

Fig. 14 - 1520 MHz Loop Fed Slot Radiation Patterns

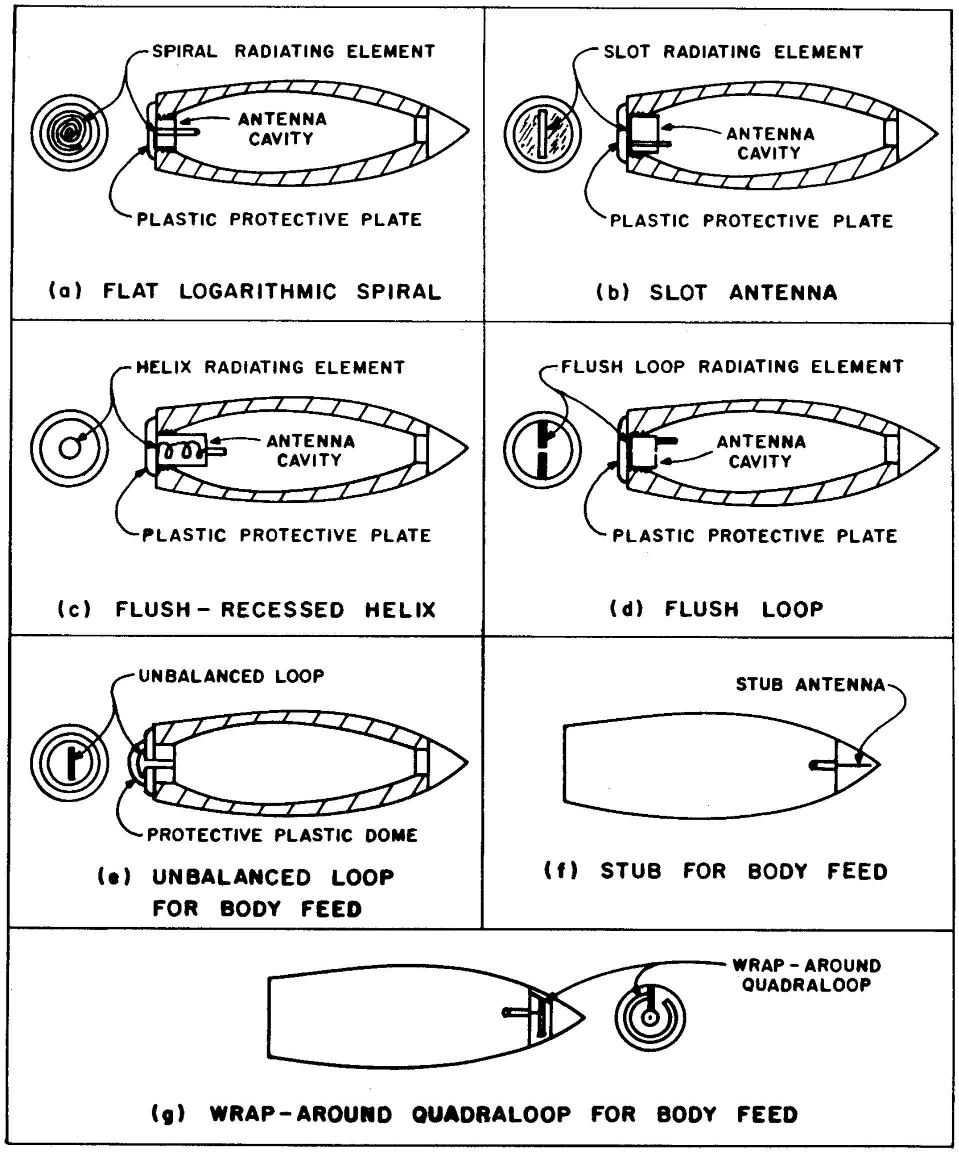


Fig. 15 - UHF TM Antennas for Projectiles

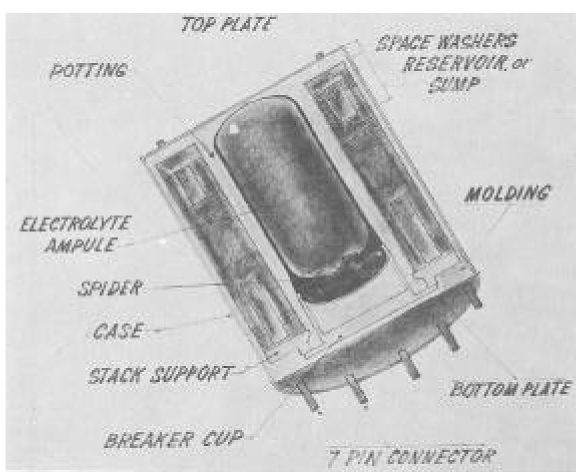


Fig. 16 - NC71 G-Activated Reserve Battery

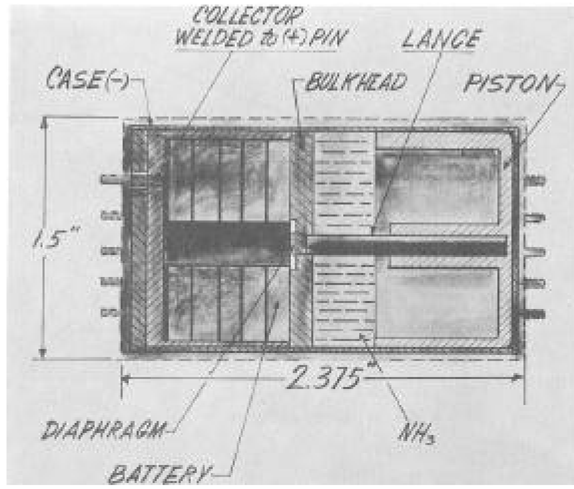


Fig. 17 - NH_3 Liquid Ammonia Reserve Battery

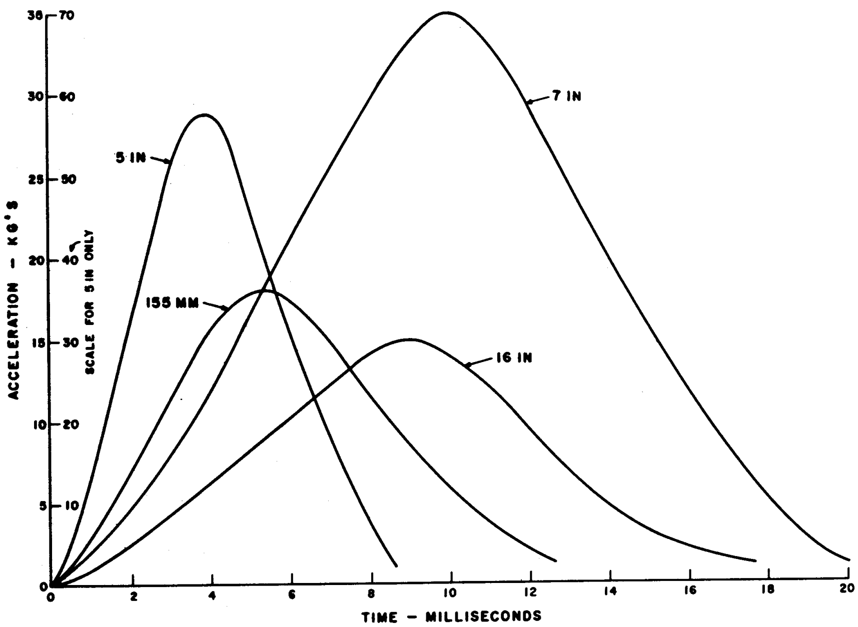


Fig. 18 - Acceleration Pulse of 155 MM, 5-, 7-, and 16-Inch Guns

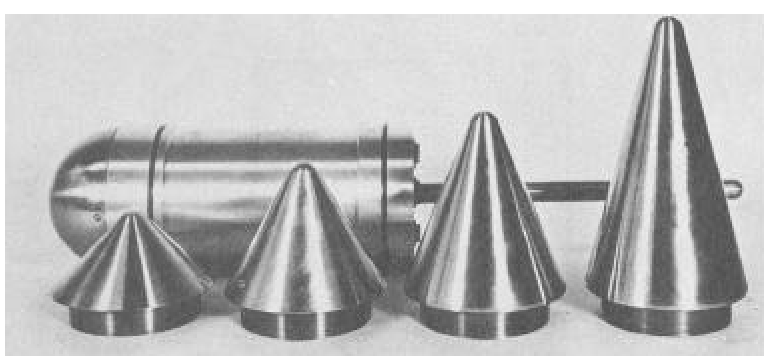


Fig. 19 - High-G Test Slug with Nose Cones

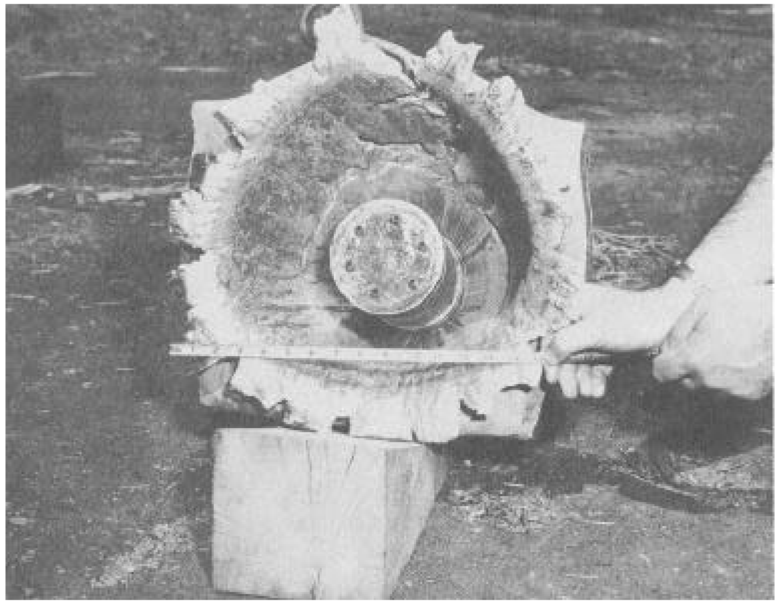


Fig. 20 - High-G Lead Test Block Impact

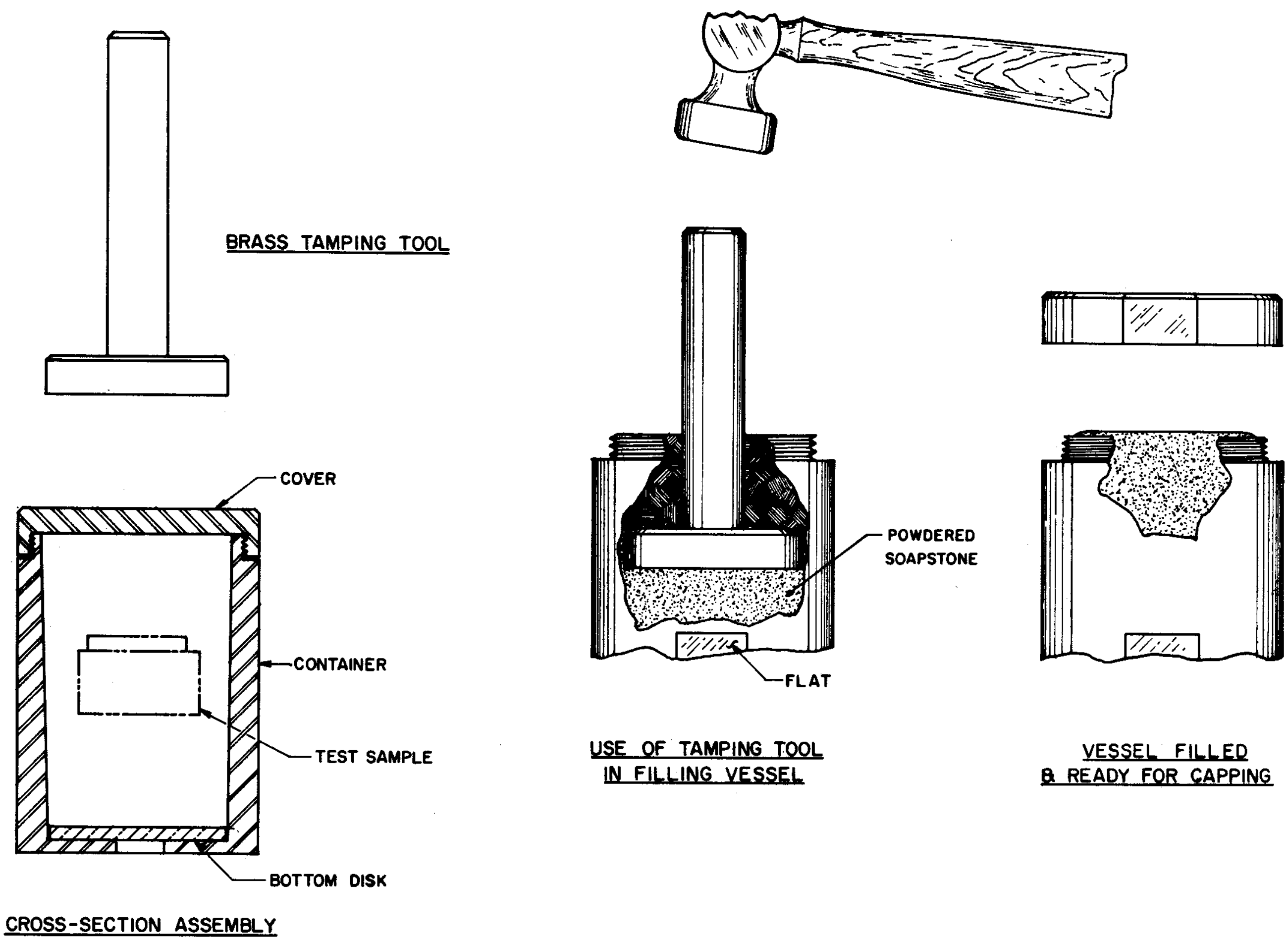


Fig. 21 - Soapstone High-G Test Container

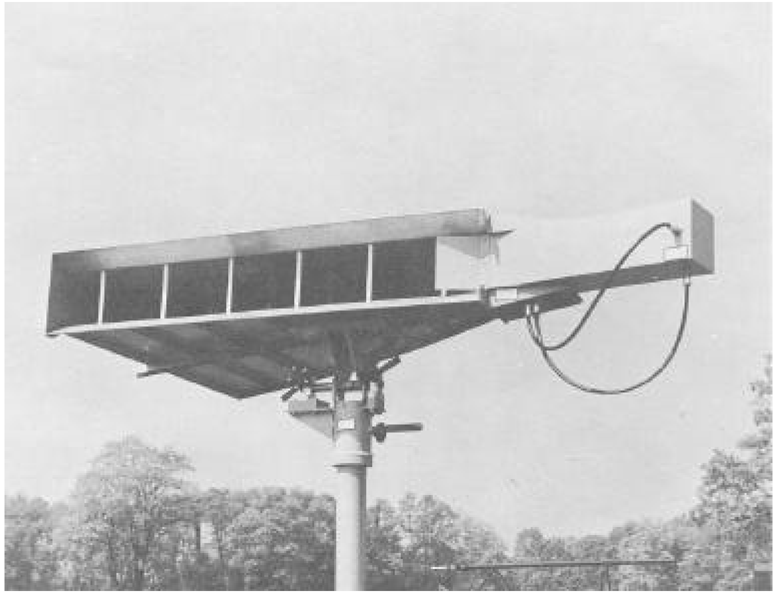


Fig. 22 - Fan Beam Antenna

Fig. 23 - UHF TM in Ogive of a55 Mm Projectile