Self-Contained High-G Wideband Telemetry System for the SADARM Program

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ABSTRACT

The Telemetry Section was tasked with the effort to develop two projectile/missile wideband telemeters in support of the Sense And Destroy ARMor (SADARM) Program. These telemeters were designed to withstand the complete operating environments of three carriers, namely the Multiple Launch Rocket System (MLRS), and both the 155mm and 8in guns. The development of these systems was based on gun proven designs and components, but additional design and qualification had to be conducted for the added features. A re-radiation (RERAD) system was also developed to enhance data acquisition in the field. The scope of this paper will include an electrical subsystem design analysis, mechanical design overview, system capabilities, qualification testing, test scenario configuration, and a brief discussion of the RF link analysis and RERAD system. The major advantages of these telemeters are the large amount of data throughput, the fact that the entire system is self-contained, and that they are qualified for use in extreme environments.

INTRODUCTION

The SADARM submunition is under development to increase the Army’s shoot-to-kill capabilities against armored vehicles and weapons. Employing the 155mm gun or the MLRS delivery systems, either two or six submunitions are deployed respectively. The 155mm carrier will induce a more severe environment including launch setback forces in excess of 15,000 G’s. The sequence of operation is as follows: upon expulsion from one of the carriers the submunition deploys a ram air inflated device to decelerate, despin, orient and stabilize the submunition; then a vortex ring parachute is deployed to further stabilize the submunition; the submunition then searches for a target beneath and fires a penetrator upon detection.

BACKGROUND

The basis for the designs was on previous work performed at ARDEC (1). Additional features made further design and qualification necessary. The two systems are designated as ARRT-74 and ARRT-84, one being for each SADARM prime contractor.

ELECTRICAL SUBSYSTEM DESIGN

The telemetry electronics are composed of standard as well as non-standard subcarrier oscillators capable of high frequency measurements, mixer amplifier, high pass filter and a crystal controlled 200 mw transmitter set to one of two S-band operating frequencies. Both systems employ FM/FM as well as PCM FM/FM modulation. One subcarrier channel from each of the ARRT-74 and ARRT-84 multiplex is dedicated to a PCM bit stream of either 40Kbps or 714Kbps respectively. Frequency modulation was chosen over PCM for two reasons. First, the high bit rate that would be required to support the data requirements (2-3Mbps), and second, the nonexistence of a high-g transmitter to meet the electrical and mechanical constraints imposed. Preemphasis was determined and set according to the summary of system parameters shown in Table I. A software program was written at ARDEC by the author to accelerate the time required to design the transmission system for threshold performance*.

The ARRT-74 operates from a 28 volt supply and consumes 270 mA while the ARRT-84 operates from an 18 volt supply and consumes 280 mA. Special frequency discriminators and low pass filters had to be designed for the high frequency channel of the ARRT-84 system.

Control Circuit

A unique control circuit was designed to turn the system on or off via the application of a negative or positive voltage pulse. This control voltage is isolated from the telemeter (TM) subcomponents and must be applied for a specific duration to prevent premature system initiation or shutdown during a test firing. The control circuit also controls the charging of the nickel-cadmium batteries which are used as TM system power during a mission. The batteries have an operational life of approximately 15 minutes between charges. The final function of the control circuit is to provide a system reset pulse which turns the system off when low battery voltage is detected. Without this function the batteries may not be capable of charging due to insufficient supply voltage. The control logic requires constant power to retain the on or off state otherwise it may randomly turn on the TM, draining

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*The determination of system parameters is beyond the scope of this paper. For further information see reference (2).

Table I SUMMARY OF SYSTEM PARAMETERS

ARRT-74 MODULATION STUDY

SYS CHAN	CNTR FREQ (Khz)	CHAN DEV (Khz)	DATA FREQ (Khz)	CHAN MOD IND	SYST DEV (Khz)	MOD IND	REL AMP
1	900	135	27	5	429	0.47	0
2	560	42	29	1.45	95	0.17	-8.9
3	448	16	3.2	5	73	0.16	-9.3
4	384	8	1.6	5	45	0.12	-12.2
5	352	8	1.6	5	41	0.12	-12.3
6	320	8	1.6	5	37	0.12	-12.3
7	288	8	1.6	5	33	0.11	-12.3
8	256	8	1.6	5	30	0.11	-12.2
9	224	8	1.6	5	26	0.12	-12.2
10	192	4	1.6	2.5	45	0.23	-6.2
11	176	4	1.6	2.5	41	0.23	-6.2
12	160	4	1.6	2.5	37	0.23	-6.3
13	144	4	1.6	2.5	33	0.23	-6.3
14	128	4	1.6	2.5	30	0.23	-6.2
15	112	4	1.6	2.5	26	0.23	-6.2
16	96	4	1.6	2.5	22	0.23	-6.3
17	80	4	1.6	2.5	18	0.22	-6.5
18	64	4	1.6	2.5	15	0.23	-6.2
19	48	4	1.6	2.5	11	0.23	-6.3
20	32	4	1.6	2.5	10	0.31	-3.7
21	16	2	0.4	5	10	0.63	2.4

PEAK TRANSMITTER DEVIATION ------------------------------> 1107 KHz
SELECTED IF BANDWIDTH ---------------------------------------> 4000 KHz
SYSTEM MODULATION INDEX ----------------------------------> 4.8
RECEIVER CARRIER TO NOISE RATIO ------------------------> 12 dB
DISCRIMINATOR OUTPUT SIGNAL TO NOISE RATIO -----> 40dB (except chan 2, 20dB)

ARRT-84 MODULATION STUDY

SYS CHAN	CNTR FREQ (Khz)	CHAN DEV (Khz)	DATA FREQ (KHZ)	CHAN MOD IND	SYST DEV (KHZ)	MOD IND	REL AMP
1	1216	285.76	350	0.82	720	0.59	0
2	448	16	6.4	2.5	186	0.41	-3.1
3	384	16	6.4	2.5	159	0.41	-3.1
4	320	16	6.4	2.5	133	0.41	-3.1
5	224	8	3.2	2.5	65.6	0.29	-6.1
6	192	8	3.2	2.5	56.2	0.29	-6.1
7	160	8	3.2	2.5	46.9	0.29	-6.1
8	128	8	3.2	2.5	37.5	0.29	-6.1
9	96	8	1.6	2.5	19.9	0.21	-9.1
10	80	4	1.6	2.5	16.6	0.21	-9.1
11	64	4	1.6	2.5	13.3	0.21	-9.1
12	48	4	1.6	2.5	10	0.21	-9.1
13	32	4	1.6	2.5	10	0.31	-5.6
14	16	2	0.4	5	10	0.63	0.46

PEAK TRANSMITTER DEVIATION -------------------------------> 1437 KHz
SELECTED IF BANDWIDTH ---> 4000 KHz
SYSTEM MODULATION INDEX ------------------------------------> 4.77
RECEIVER CARRIER TO NOISE RATIO --------------------------> 12 dB
DISCRIMINATOR OUTPUT SIGNAL TO NOISE RATIO -------> 40dB (except chan 1, 15dB)

current as the system attempts to charge. This was a major consideration in the design of the circuit because of the limited power source and long storage times prior to testing. The circuit employed however draws only μA's of current in the standby mode.

Heater Circuit

Prior to testing the entire flight vehicle is temperature conditioned for 48 hours. The TM's had to be designed with the severe operating temperatures of the SADARM submunition in mind, namely -34°C to +62°C. This proposed a problem for the nickel-cadmium power supply. If the batteries are discharged at very low temperatures, the effective internal resistance is increased significantly due to the reduced level of electrochemical activity, and if the drain rate is high the cells can sustain severe damage (3). The other problems cold temperatures pose to nickel-cadmium batteries is that the lower the cell temperature the lower the discharge voltage and capacity for discharge. These facts led to the development of a kapton insulated heating element and thermostat which would maintain the nickel-cadmium cells near room temperature and also survive the high shock environment. The amount of energy required to maintain the cells at room temperature was estimated from the following equation:

$$\text{Watts required to maintain heat} = \frac{k * A * T_{delta}}{3.412 * L} = \frac{1.742 * 0.0972 * 100}{3.412 * 0.15} = 33 \text{ Watts} \qquad (1)$$

Where: k = Coef. of Heat Trans. for potting material 1.742 (Btu/hr/°F/ft^2/inch)
L = Thickness of material (inches)
A = Surface area of heating element (1"X14" strip) 0.0972 (ft^2)
$T_{delta} = T_{ambient}(°F) - T_{low}(°F)$ or $70°F - (-30°F)$

This approximate wattage was increased by 30% for the first experimental verification. A test fixture was designed and fabricated and it was determined that 3 watts/in^2 was required to maintain the batteries at room temperature.

Microstrip Wraparound Antenna

Due to mechanical constraints a microstrip wraparound antenna was chosen for the systems. Limited surface area and obstructions required small and unequally spaced elements. These facts led the design to a circumferentially phased, cylindrical array of circularly-polarized elements. The resulting antenna radiation pattern was designed with it's energy concentrated from 0° to 90°, with 0° being along the fall line (see Figure 1). Limited in thickness to 0.040" including adhesive, two separate antennas had to be designed for each size submunition because not enough bandwidth could be attained to cover both operating frequencies. Extensive laboratory testing was performed and the maximum variation (maximum gain to minimum gain) at any given acquisition angle was determined to be 12dB. Field test results have confirmed that high quality data has been received while post test analysis of the antenna has shown that it sustained severe damage upon ejection. An analysis was conducted by the Aeromechanics Branch at ARDEC on the aerodynamic heating characteristics of the antenna in flight (4). The results of this report indicate that the antenna's radiating elements must survive and operate through peak temperatures at expulsion of 190°C worst case (stagnation air flow). While these results themselves can not be readily experimentally verified, the antennas were operated through extensive temperature testing and simulated temperature testing. The anechoic chamber used for testing could not be temperature conditioned to 190°C, therefore the VSWR was measured at the desired frequency of an individual element at various temperatures. The next characteristic to be determined was which frequencies produced corresponding VSWRs at each of the temperature measurements. The resulting frequencies were then used to measure the antennas in the anechoic chamber. The results of these tests indicate

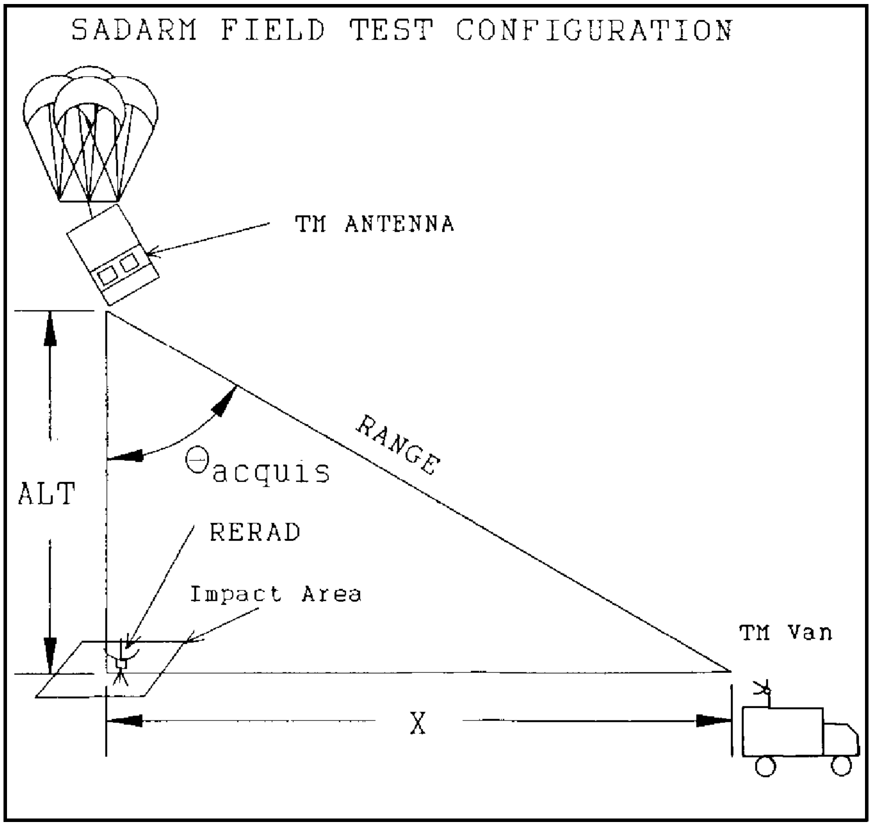


Figure 1

that at acquisition angles less than 60° the maximum variation is 16dB. The peak temperatures exist for only tenths of seconds after the expulsion event (see Figure 2) which correspond to small angles of acquisition. Figure 3 illustrates a worst case antenna radiation pattern which simulates 190°C at an acquisition angle of 50°. The simulation of 190°C at an acquisition angle of 10° has a maximum variation of only 5dB. Typically the lower the acquisition angle the lower the maximum variation.

MECHANICAL DESIGN OVERVIEW

These systems not only had extensive electrical requirements, but had severe operational and mechanical requirements as well. The size constraints can be seen from Figures 4 and 5. Within this envelope the telemeter had to meet the mass properties of the explosive. This was accomplished by designing the TM housing and associated hardware, including potting compounds, of different materials (i.e. different densities) to locate the centroid and meet the mass, first moments, moments of inertia and products of inertia as close as possible to the desired quantities. This task was accomplished through the extensive use of computer aided design software which reduced the iteration time interval. The system also had to be designed with the extreme environmental requirements in mind, namely the 15,000 g setback forces, 2,500 g sideload forces, and 1200 g set forward forces. Two different types of potting compounds were used in the TM. The electronics module was

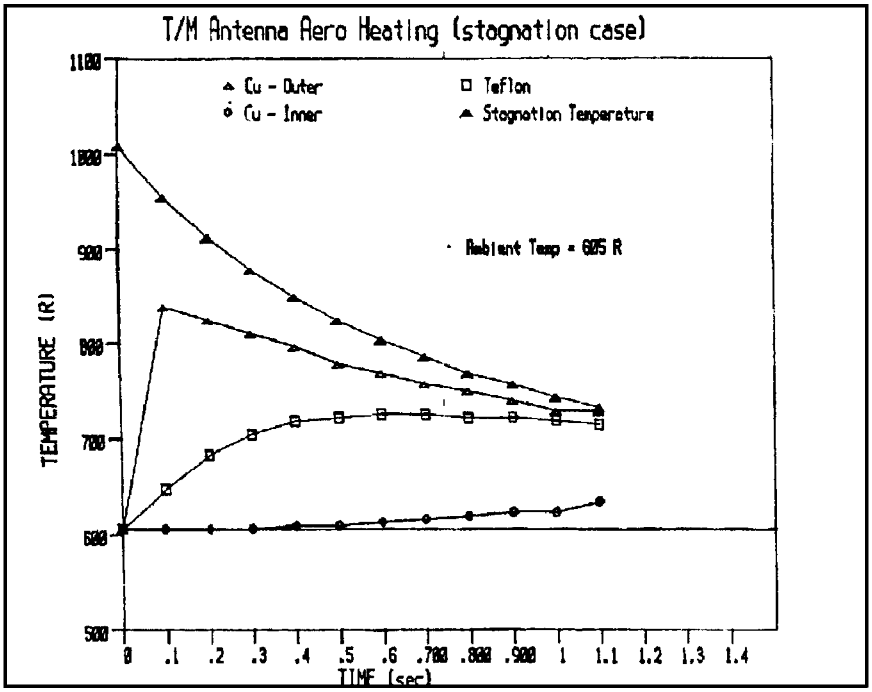


Figure 2

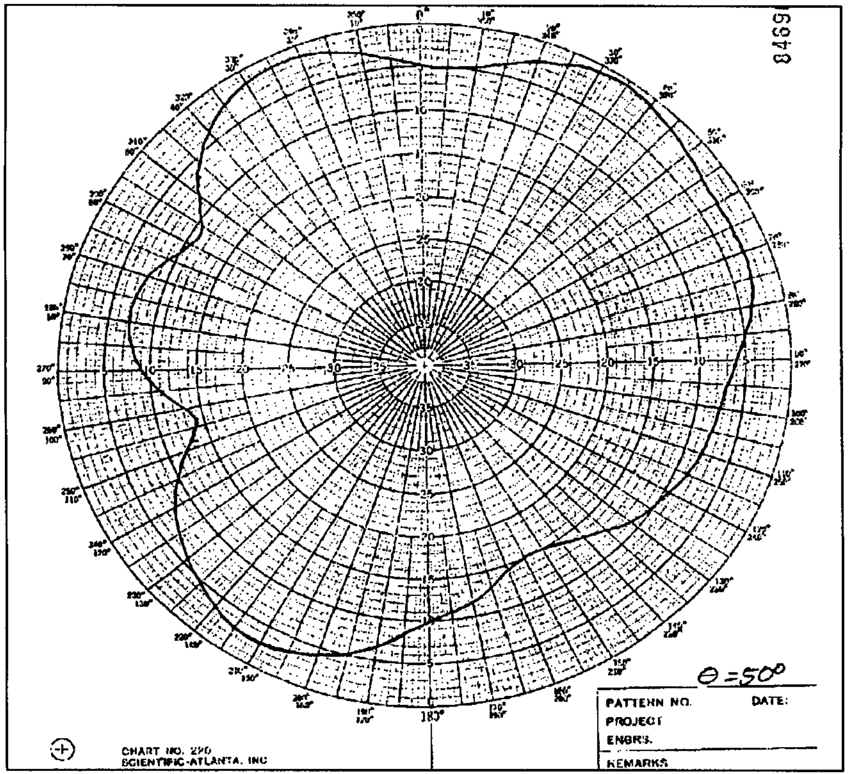


Figure 3

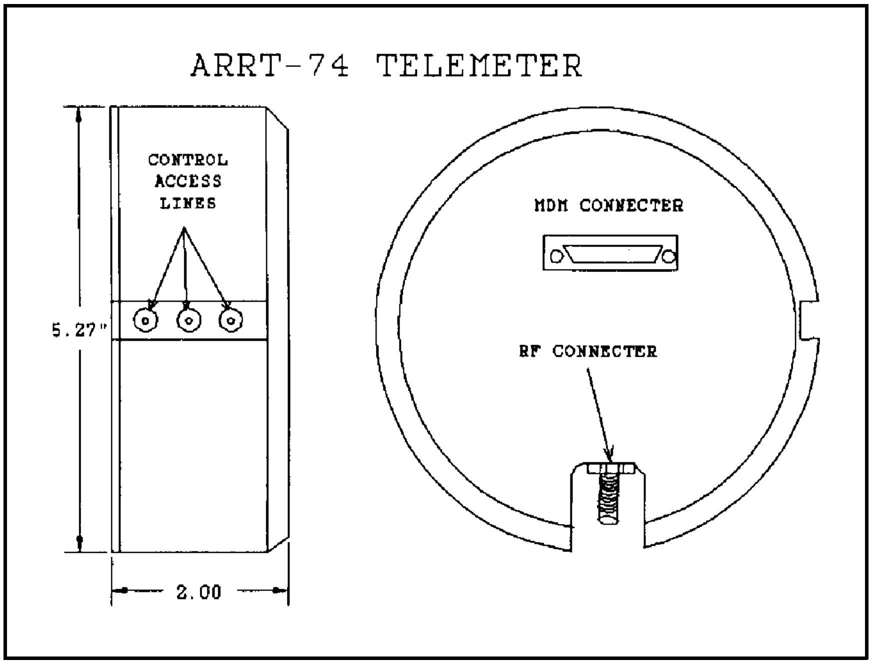


Figure 4

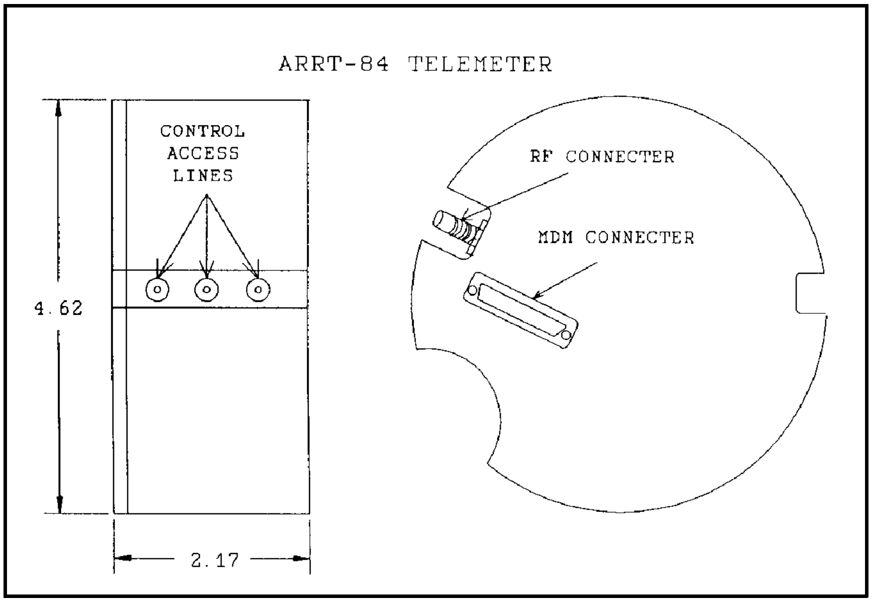


Figure 5

potted with foam and the battery module was potted with an epoxy resin. The foam was chosen for the electronics module to facilitate repairability in the event of failure during qualification testing and for its density. The epoxy resin was chosen for the battery module for its coefficient of heat transfer, density, and successfulness in the past. The ARRT-74 weighs approximately 3 3/4 pounds and the ARRT-84 weighs approximately 2 ½ pounds.

Gold Dot Umbilical System

A frictionless connection method for accessing the TM in the MLRS needed to be conceived. The Gold Dot Umbilical System was designed to meet this need. The system consists of a series of kapton insulated conductors terminated with gold dot pads. Corresponding pads from each umbilical are pressure fit together. When the pressure is released the pads disengage without inducing any forces on each other. This type of connection was needed to prevent any type of torque being induced on the submunition during expulsion which may have occurred if break wires had been employed. The system had to remain small and be capable of handling 2 amps in each conductor. The TM was designed to ignore shorts and voltage spikes on the access lines which may be produced upon connecter separation or ionized gases. The retainer strap which was used in the MLRS carrier to hold the submunitions in the bays was used to pressurize the gold dot connection. Upon expulsion the strap is fractured and subsequently releases the umbilical from the submunition.

QUALIFICATION TESTING

The first phase of the qualification program consists of performing an incoming inspection and testing of all subcomponents. The transmitters are fully checked out electrically and subsequently subjected to 15,000 g’s. They are then checked for any deviation of performance parameters. The second phase for the ARRT-74 consists of fabricating the electronics module, testing over temperature, and subjecting it to either 10,000 or 15,000 g’s depending on what test the system will be used for. The ARRT-84 TM is fully fabricated, tested over temperature, and subjected to the same number of g’s. The final phase consists of post high-g testing of the TMs and again testing over temperature. To obtain these levels of g-testing one of two facilities is used, either an air gun or rail gun which are both on site at U.S. ARDEC. Special fixtures and thinwall pistons for the rail gun and air gun also had to be designed. If a problem is found in a subcomponent at any point, it is replaced and the system is again rail or air gun tested and again tested over temperature.

RF LINK ANALYSIS

Standard range calculations were automated in a computer program written at ARDEC. The basic equation used is as follows:

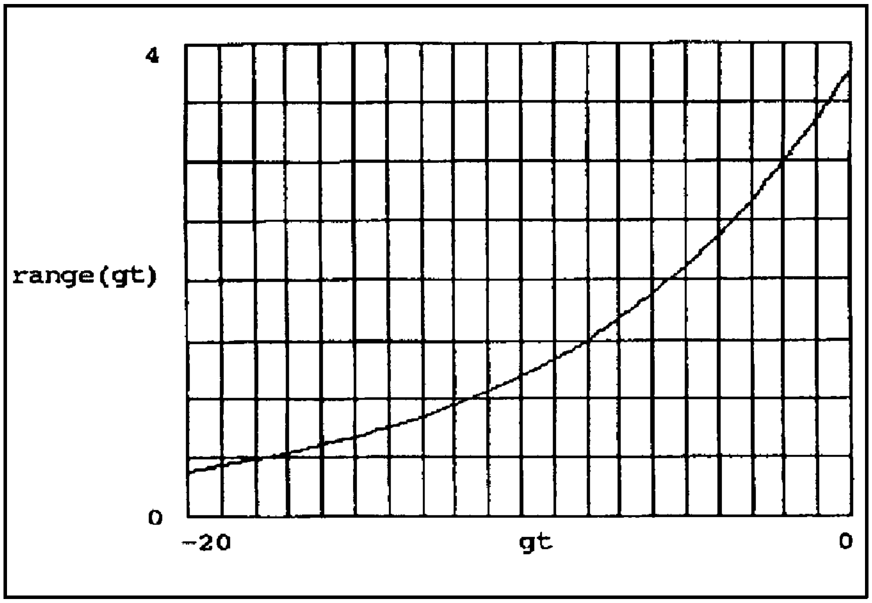
$$G(t) + G(r) = PL + R_N - P(t) + (S/N)_{rev} + L + SF \tag{2}$$

Where: R_N = equivalent noise input of receiver [-174+B(if)+NF] dBm
PL = Path loss (37+F+D) dBm
G(t) = gain of transmitting antenna NF = overall noise figure

G(r) = gain of receiving antenna
D = 20 log (distance in miles)
P(t) = power of transmitter
B(if) = 10 log (if bandwidth in Hz)
$(S/N)_{rev}$ = receiver threshold S/N ratio
F = 20 log (center freq. in MHZ)
SF = link margin (20dB for 99%rel.)
L = miscellaneous losses (10dB)

Note : All terms are power levels relative to 1mw into 50 ohms or 0dBm.

The maximum range at incremental acquisition angles was determined by using the worst case gain at the given angle and providing a 20dB link margin in order to obtain 99% reliability. Figure 6 depicts a graphic representation of the maximum range in miles as a function of transmitting antenna gain. A series of these graphs can be produced while varying other terms such as receiving antenna gain.



(This is a range plot of the TM in miles as a function of the transmitting antenna gain in dBi, given a 99% reliability according to Rayleight fading)

Figure 6

RERAD SYSTEM

This system needed to be developed due to the large safety area required around the impact area when testing the SADARM submunitions and the limited transmitting power of the TM. The systems operation is equivalent to an S-band video receiver coupled to a 2 Watt L-band transmitter. Specific input and output frequencies can be switch selected for multiple system operation. The system is battery powered and uses solar cells to prolong the operating life. The system can be operated for 10 hours continuously. This was necessary due to the limited access to the impact area prior to and in between test firings. The unit is placed off to one side of the impact area and has a spiral receiving antenna pointed upward to receive the S-band TM signal. The translated signal is then retransmitted L-band to one or both receiving vans depending on the type of test being conducted.

(This is a range plot of the TM in miles as a function of the transmitting antenna gain in dBi, given a 99% reliability according to Rayleigh fading)

CONCLUSION

To date one of these two modular designs, the ARRT-74, has been employed in actual field tests and has performed exceptionally. The ARRT-84 is scheduled for its first field test in July 1990. These telemeters demonstrate that for some applications wideband FM/FM systems are not only capable, but better suited to support systems requiring compact telemeters which demand the acquisition of large amounts of high frequency data and can operate through extreme environments. These and similar types of telemetry systems are being employed extensively in the development testing of many advanced weapon systems.

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