UHF TELEMETRY SYSTEM DEVELOPMENT AT WHITE SANDS MISSILE RANGE

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Summary This paper describes UHF telemetry system development at White Sands Missile Range (WSMR), New Mexico, to achieve the telemetry operation change from VHF to UBF. Component and subsystem development is discussed. Results of the S-band equipment testing using the L-20 light aircraft, the F-100F jet fighter, POGO missile, and ATHENA re-entry vehicles are presented. Comparative analysis of missileborne telemetry data transmitted through both the standard VHF and the developmental S-band links are made.

Introduction The first directive calling for a shift of telemetry operations from VHF to UHF was issued by the Joint Chiefs of Staff Electronic Communications Board (JCEC) in 1958. This directive also established the 44 one-half MHz channels for the interim period to 1 January 1970. The directive also indicated that telemetry services in the 216 to 225 NHz band would be permitted on a noninterference basis after 1 January 1970. In February 1965, the Military Communications-Electronics Board (MCEB) of the Joint Chiefs of Staff directed (Directive M 92-65) the Military Services to shift their telemetering operations from the existing VHF (225 to 260 MHz) band to the UHF (1435 to 1535 MHz and 2200 to 2300 MHz) band by 1 January 1970. Fortunately, most Missile Ranges had been anticipating such a move.

In 1960, a plan for the orderly implementation of microwave telemetry by the January 1970 deadline was presented at the National Telemetering Conference by R. C. Barto[1]. In January 1961, the Navy Bureau of Weapons sponsored a survey--"Design Objectives for Telemetry RF Transmission Links for the Period 1960 - 1970."[2] Additional plans for microwave telemetry implementation were formulated for several Army and Navy test ranges[3] by G. F. Bigelow, T. B. Jackson, and R. T. Merriam. The WSNR UHF telemetry system development is based on these plans.

Technological Problems in the VHF to UHF Telemetry Conversion The VHF to UHF telemetry conversion presents theoretical as well as equipment development problems. Since the equivalent transmission loss between isotropic transmitting and receiving sources at 2200 MHz is 20 db greater than that at 220 MHz (the loss for 1450

MHz is 16.4 db), higher-gain antennas are used to compensate for the loss. Because the higher-gain microwave antenna is highly directional, reasonably accurate pointing is required to receive the signal. An automatic servo-driven antenna is the only practical solution to this tracking requirement. This adds a complex automatic tracking subsystem to the telemetry system. In addition, the servo response of automatic tracking systems places a limitation on the antenna tracking rate. Narrow beamwidth tracking system presents considerable difficulty in initially acquiring the target and a formidable task in target reacquisition should the system lose track during an operation.

The missileborne telemetry package may consist of standard telemetry multiplexing and encoding components with the exception of the S-band transmitter and its antennas. UHF transmitters available thus far are larger in size and weight than the standard VHF transmitters. UHF transmitter DC-to-RF efficiency is less than that of a VHF transmitter. Also, the UHF transmitter stability is a problem when used with narrow IF bandwidth receivers. The size of the S-band missileborne antennas can be reduced due to the shorter S-band wavelength, but the ratio of the S-band antenna wavelength to the missile diameter is also reduced. This reduction often presents considerable difficulties for the antenna designer to achieve smooth and omnidirectional antenna patterns.

Radio frequency propagation at the UHF region normally does not encounter special problems in atmospheric absorption and interference from natural noise sources. However, multipath propagation during missile lift-off and tracking of a target at low aspect angle may cause problems for the automatic tracking system. The fact that doppler frequency shift in S-band is 10 times as large as that in VHF may pose additional data demodulation problems in UHF telemetry systems.

The noise figure of an S-band telemetry receiver is about 5 db greater than the noise figure of the standard VHF receivers. Low noise preamplifiers such as parametric, tunnel diode, TWT, or transistorized amplifiers are used ahead of the telemetry receivers to reduce the overall system noise figure. However, this addition of the preamplifier increases system complexity and decreases its reliability. Most of these preamplifiers also have limited input dynamic ranges. These are the fundamental considerations for the development of the UHF telemetry system.

Development of UHF Telemetry System at WSMR The WSMR S-band telemetry subsystem development program was initiated in 1958. The development program was designed to provide sufficient hardware to investigate the problem areas in the missileborne transmitters, airborne antennas ‘ and automatic tracking antennas. Some of these subsystems were procured from industry and some were developed in-house. Off-the-shelf components from industry were purchased for evaluation whenever they were available. To reduce cost, some S-band radar equipment was modified for these tests where they were technically feasible. The details of our various subsystem developments are discussed below.

Missileborne Transmitter During 1959, a development contract for three S-band transmitters was awarded to Spectralab Co. A 12 watt S-band FM transmitter was developed with nearly 10 percent efficiency. (See Table I, UHF Telemetry Transmitter Characteristics, for additional details). These transmitters met most design goals, but they generated excessive incidental frequency modulation (IFM) under adverse environment. Also, long term frequency stability became a problem. Nevertheless, this development demonstrated the feasibility of producing an operable S-band transmitter from BF components available at that time.

In 1963, a cost-sharing development contract was awarded to Microdot for three S-band transmitters. The Microdot S-band Telemetry Transmitter[4] Model 2436, consists of power supply, RF exciter-modulator, and power amplifier modules. The transmitter was especially designed to minimize IFM under adverse environment. At 10 g sinusoidal vibration, induced IFM was below 12 kHz peak-to-peak. These transmitters operated satisfactorily for several months and then the transmitter output power gradually decreased as testing continued. Also, heat dissipation in the power amplifier module became a problem. Two separate planar triodes failed during laboratory testing. Due to the lack of an operational transmitter, this prototype S-band transmitter was used for the first UHF missile flight test. The transmitter failed after the first 30 seconds of the missile flight. Additional results will be discussed under the first POGO missile flight test.

In late 1965, Monitor Electronics delivered a solid-state transmitter, Monitor Model 2250P3FMT under an open-competitive, fixed-price contract. The transmitter exhibited excellent frequency stability (0.002 percent) and low IFM (3 kHz peak). The-transmitter was certified to meet the spectrum occupancy criteria of IRIG Document 106-65. This transmitter achieved all the government design objectives. It has twice been flight tested aboard a POGO missile and is scheduled for a third POGO flight test in the near future. The transmitter developed an air leak in its case causing it to fail after about 12 minutes of the first missile flight. It was returned to the manufacturer and sealed by an improved technique. This transmitter was again used during 17 February 1967 missile flight test, which was a complete success.

Monitor Electronics delivered one L-band and two additional S-band transmitters to WSNR under a separate contract. The L-band transmitter met all the government design objectives and was certified to operate under IRIG 106-65. The two S-band transmitters are Monitor Model 2250P2FW. They are similar to Model 2250P3FMT but about 40 percent smaller in size. They complied with most of the government technical requirements. However, optimum tuning of the output power is difficult to achieve under load due to the high Q of the three varactor multiplier stages. A circulator with proper termination was used to provide approximately 50 db isolation between the load and the transmitter output. This solved the problem. Another contract for two L-band transmitters was awarded to Monitor Electronics in June 1967.

Conic Corp. delivered two S-band transmitters, Model CTM-UHF-3, to WSMR in late 1966. These transmitters have been evaluated and meet all the manufacturers' specifications. However, it has recently been discovered that one of the transmitters decreases its output abruptly from 2.8 to 2.0 watts when the outside temperature is changed from 52 to 53 degrees centigrade. On the other hand, little variation was found in the second unit in performance as a function of aging or temperature. This second unit is on loan to Air Force Cambridge Research Laboratories for an Aerobee S-band telemetry flight test.

Microcom delivered two S-band transmitters, Model T-40, to WSMR in June 1967. This was the first time that UHF telemetry transmitters were delivered to WSMR ahead of schedule. Bench test results correlated well with the test data supplied by the manufacturer. Simulated environmental tests are scheduled in the near future. WSMR has a contract with Microcom. for one additional S-band and one L-band transmitter.

A contract for five S-band telemetry transmitters was awarded to Dorsett Electronics in 1966. These transmitters are scheduled to be delivered in August 1967.

Presently, transmitters are being produced by manufacturers -who have engineers and technicians with specialized skills. One could anticipate that mass production of S-band telemetry transmitters may remain a problem for some time. Transmitter warm-up time and frequency stability requirements in accordance with IRIG 106-66 my be a problem for most transmitter manufacturers. We do not know of any transmitter which has been certified in accordance with the requirements of IRIG 106-66. This document is interpreted to require a warm-up time of one second. This is most difficult to achieve with present transmitters. A transmitter warm-up of five to ten seconds may be realistic for most anticipated range needs.

There has been considerable discussion on the existing IRIG frequency stability. This is another parameter which is difficult to achieve in UHF transmitter production. Many telemetry manufacturers, range telemetry users, and R & D personnel believe that a transmitter with 0.003 percent frequency stability is sufficient for S-band telemetry operation. A frequency stability of 0.003 percent appears adequate for the interim, based on the hardware available and our limited UHF telemetry system testing in the last few years. However, the final standard on stability should not be made until a thorough investigation on the effect of transmitter frequency stability due to doppler shift, data receiver bandwidth, tracking receiver bandwidth, receiver frequency stability, transmitter deviation, and other related factors are determined.

To sum up the UHF telemetry transmitter development, we believe that the telemetry manufacturers have performed an outstanding task in spite of the lack of demand for a large quantity of transmitters.

Airborne Antennas Missileborne antennas remain relatively unexplored, and is perhaps the most challenging UHF telemetry system problem. Missile Ranges have sponsored few developments because each antenna system must be tailored to a particular missile, since each missile has different physical and aerodynamic characteristics. It is difficult to design a universal UHF antenna system. WSW has participated in three antenna developments.

In 1964, two S-band quadraloop antennas were designed in-house at WSMR for a nine-inch diameter POGO missile. They were mounted 180 degrees apart and were fed 180 degrees out of phase from a 3 db power divider. The antenna system had a 5 MHz bandwidth with a VSWR of about 1-5 to 1. The system operated satisfactorily during a missile flight, but had a radiation pattern which was far from optimum.

In early 1965, the Physical Science Laboratory of New Mexico State University designed a UHF and VHF telemetry antenna system for the POGO missile[5]. The UHF antenna consists of a pair of folded Valentine antennas fed in phase. These antennas operate on the equiangular principle of the conventional folded dipole. The antenna dimensions, patterns, and impedance are relatively independent of frequency, provided the inner antenna curve exceeds a quarter wavelength at the lowest operating frequency. The VSWR of the system was less than 1.5 for the frequency range of 2200 to 2300 MHz. Maximum gain over an isotropic antenna is 4 db. The system handles 10 watts of continuous power at 115,000 feet MSL. It performed well during two POGO missile flight tests.

In 1966, a contract[6] was awarded to Dorne and Margolin, Inc., Chatsworth, California, to develop “flush-mounted” antennas to operate at VHF (221.5 MHz) and UHF (1485.5 and 2250.5 MHz) on a POGO missile, an L-20 aircraft, and an F-100F jet fighter. The antenna design provides maximum radiated signal fore and aft with minima in the missile transverse plane. Design of each antenna was based on the contractor’s standard shallow cavity antenna. Maximum gain of the S- and L-band antenna systems is 3 db above an isotropic source. The VHF antenna system gain is 3 db below an isotropic source. The S- and L-band antenna systems’ bandwidth is 4 MHz and the VHF bandwidth is 1 MHz. Each antenna will handle eight watts of continuous power at an altitide in excess of 115,000 feet MSL.

Telemetry Automatic Tracking Antennas. -Automatic tracking systems are a modified SCR-584 radar, a modified T9 radar, and a commercially-developed TELTRAC system. The three tracking systems are capable of S-band telemetry reception and conical-scan tracking techniques. The SCR-584 and the TELTRAC are also capable of L-band operations. Detailed automatic tracking antenna characteristics are given in Table II.

In June 1961, WSMR awarded a contract to Dalmo-Victor Co., Belmont, California, to convert an SCR-584 radar[7], for UHF telemetry operation. The system was delivered to WSMR in 1962. It has been modified several times as improved telemetry components became available and has operated satisfactorily during the last two years.

The T9 telemetry tracker consists of an antenna and feed developed by Temec, Inc., and a modified T9 radar servo, and an S-band receiving subsystem 4eveloped by the government. The initial modification was completed in 1964[8], and was up-dated in 1965. The system has performed reliably for the last 18 months.

The TELTRAC[9] antenna system -was manufactured by Canoga Electronics Co., Chatsworth, California, to WSMR specifications (WSMR TDP-739). The RF system, with the exception of the antenna, was supplied to the contractor as GFE. The system has operated satisfactorily since its delivery. A measurement system was installed in the tracker to provide instantaneous system noise figure measurement prior to each tracking operation.

R & D UHF Telemetry System Flight Tests The purpose of UHF telemetry system tests is to demonstrate the operation of the system and to investigate potential UHF telemetry problem areas. Tests have been conducted with an L-20 aircraft, an F-100F jet fighter, and a POGO missile. We have also attempted to track an ATHENA re-entry vehicle which had an onboard transmitter.

The purpose of the L-20 aircraft flight test was to determine the maximum dynamic tracking velocities of the tracking antennas and to observe multipath propagation phenomena. The L-20 aircraft was flown in flight patterns which required maximum tracker servo system response. The T9 and TELTRAC systems tracked the aircraft satisfactorily when it war. flying at 100 knots at a distance of about 100 feet. At this distance it is difficult to estimate airborne antenna pattern effects and the propagation phenomena. However, the estimated maximum dynamic tracking rate in azimuthl correlated well with the static tracking rates. Additional tracking testsio were conducted at aircraft altitudes of 2,000, 5,000, and 8,000 feet above the terrain. Tests results indicate that we can estimate signal level based upon the radio line of sight, to within 10 db. As expected, a greater effect of multipath and fading occurred as the aircraft was farthest from the tracking antennas. Large short-term variations occurred when the aircraft was near the radio horizon and above a mountain range.

Three F-100F jet fighterhigh altitude tests were conducted during the last two years. Test results were not totally conclusive because of problems in logistics, transmitters, and airborne antenna radiation patterns. We expect to solve these problems within several months and resume the tests.

Three POGO missile flight tests were conducted to determine the operational capability of the newly developed S-band telemetry system. The POGO is a nine-inch diameter missile. The missile is launched at an angle of 85 degrees from horizon. The solid propellant booster burns for five seconds and a maximum velocity of 3,400 feet per second at six seconds. The missile reaches a maximum altitude of 120,000 feet in 75 seconds after which a parachute is deployed.

The first LW telemetry system was flight-tested with a POGO missile in May 1964. Good quality S-band telemetry data was received for the first 30 seconds and excellent VHF data was received for 102 seconds. Telemetered data indicated that the S-band transmitter failed after 30 seconds. The T9 was the only operational tracker at that time. It operated satisfactorily until the transmitter failed.

The second POGO missile test[11] was conducted on 16 June 1966. The T9 tracked the missile and received satisfactory data for six minutes 28 seconds after which the UHF signal was lost. UHF transmitter power was measured and telemetered over the VHF telemetry link which confirmed the loss of UHF power at that time. The UHF power was off for about 12 minutes, then returned to its original value. The T9 reacquired the missile shortly after the UHF power returned and tracked the POGO to impact. As the missile ascended, the SCR-584 antenna moved downward and hit the lower limit Stop 3.5 seconds after launch. Ten seconds after launch the antenna elevation angle was increased manually until the missile was reacquired at 35 seconds after launch, and the tracker returned to automatic mode. The SCR-584 then tracked the missile until the UHF transmitter failed. It reacquired the missile shortly after UHF power returned.

A 480 Hz oscillator was part of the POGO telemetry package. During the flight, the reference-oscillator distortion was measured and found to be less than 2.0 percent from both the VHF and UHF links.

The POGO was recovered and the telemetry package was undamaged. To investigate the UHF telemetry failure during the flight test, the package was placed in an altitude chamber to simulate the missile flight environment. The UHF transmitter repeatedly failed at 44,000 feet, but operated satisfactorily below 40,000 feet. 'It was concluded that a slow leek caused the UHF transmitter failure at high altitudes.

The third POGO missile flight test was conducted 17 February 1967. The UHF and VHF receiving systems were located about five miles from the launch site. All three UHF tracking systems locked on the missile prior to lift-off. During missile lift-off, all three tracking systems were erratic and had a tendency to track downward. The TELTRAC system was switched from automatic mode to optical slave mode for five seconds to prevent the antenna from hitting its lower limit switch. Aside from the problems at launch, the TELTRAC automatically tracked the missile to impact. The missile flight lasted 770 seconds. No attempt was made to manually or slave-control the SCR-584 and T9 antennas. They tracked the missile through the entire flight. UHF and VHF telemetry date obtained from this flight were comparable–1.0 to 1.2 percent total distortion of the 480 Hz reference-oscillator transmitted through a 22 kHz IRIG subcarrier. However, a greater number of signal dropouts occurred in the UHF links than in the VHF links. These dropouts were expected since the UHF link was operating within 10 db of the system threshold.

In February 1967, an attempt was made to track a 60 milliwatt S-band beacon aboard an ATHENA re-entry vehicle with the SCR-584, T9, and TELTRAC tracking systems. (The ATHENA missile is a re-entry vehicle which is launched from Green River, Utah, to impact at WS@R.) Tracking was unsuccessful because the missileborne beacon drifted 1 MHz.

A second attempt to track an ATHENA S-band beacon[12] occurred 4 may 1967. The beacon was a one-watt Conic S-band telemetry transmitter. The TELTRAC initially received signal at T plus 95 seconds and automatically tracked' the missile to impact. The SCR-584 received signal at T plus 8 seconds and automatically tracked the missile to impact, except for two momentary losses of signals. However, tracking was reacquired each time -with the aid of radar chain link data. The T9 received signal at T plus 260 seconds and tracked the missile to impact. The T9 operation was hampered because the antenna does not have a position indicator for pointing, nor does it have an input for radar chain data. Nevertheless, the overall tracking mission was considered a success since the ATHENA Project personnel did not expect the trackers to receive signals until T plus 120 seconds. Unfortunately, the missile did not reach re-entry velocity to cause transmission blackout. Additional S-band ATHENA tests are scheduled for the near future.

Conclusion Results of the tests have demonstrated that the WSMR developmental S-band system is capable of good quality telemetry data transmission, but the reliability is still significantly less than VHF. Limited support (using experimental R & D prototype) has been provided to range users with reasonable success. Nevertheless, full scale UHF telemetry operation at WSMR is far from being achieved. Little work has been done at L-band. Considerable operational experience and system integration, in addition to better solutions to certain technical problems, will be required to insure reliable UHF telemetry operation.

During the next two years we will continue to improve the performance characteristics of the existing UHF telemetry system as improved telemetry components become available. We will use the existing UHF system to further investigate potential problems such as multipath, fading, automatic tracking during the missile-launch phase, doppler shift, optimum AGC loop, initial target acquisition, reacquisition of target after loss of automatic tracking, and continuous tracking of re-entry vehicles. We believe that reliable UHF telemetry operation cannot be attained until the phenomena and characteristics of these problems can be adequately defined and methods developed to overcome these effects.

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TABLE I
UHF TELEMETRY TRANSMITTER CHARACTERISTICS

Manufacturer		Spectralab	Microdot	Monitor Elec.	Conic Corp.	Microcom
Model		2406	2436	2250P3-FMT	CTM-UHF-3	T-40
Year Procured		1960	1963	1965	1966	1967
Size (in.)	L. W. H.	11-1/4 7-1/4 4-1/4	9-3/4 6 6	11-3/4 6-3/4 1-3/4	5-5/8 4-5/8 1-3/8	3-1/2 2-3/8 1-1/2
Volume (cu. in.)		350	110	100	36	12.5
Weight (lbs)		16	8	2.2	1.9	0.75
Input Pwr. (watts)		125	50	35	52	35
Output Pwr. (watts)		12	5	2.0	3.0	4.3
Efficiency (percent)		9.6	10.0	5.7	5.8	12.3
Frequency Stability (percent)		0.005	0.005	0.002	0.002	0.003
Modulation (Hz)		50-100k	6-600k	5-500k	DC-1M	DC-200k
Components Used		Mostly tubes	Hybrid	Solid state	Solid state	Solid state
Construction		Single unit	Modular	Single unit	Single unit	Single unit
Deviation (1Hz)		125k	500k	500k	1.2M	1.2M
Deviation Linearity		1%	2%	2%	2%	1.25%
Approximate Cost		$30,000	$23,000	$5,000	$8,000	$5,000

TABLE II
TELEMETRY AUTOMATIC TRACKING ANTENNA CHARACTERISTICS*

Antenna		SCR-584	T9	TELTRAC
Date		1962	1964	1966
Frequency Range		1435 to 1535 MHz 2200 to 2300 MHz	2200 to 2300 MHz	1435 to 1535 MHz 2200 to 2300 MHz
System Noise Figure		7.5 db	7 db	6 db
Antenna Size		10 foot parabolic	6 foot parabolic	6 foot parabolic
Reflector Gain		33 db	28 db	28 db
Antenna Beamwidth		3.3°	4.5°	4.5°
Polarization		Right or left hand circular	Right hand circular	Right hand circular
Cross-Over Level		1 db	1 db	1 db
Side Lobe Level		-17 db	-24 db	-20 db
Scan Rate		30 Hz	30 Hz	30 Hz
Preselector Filter		Melab Mod. F-114	Rantec RS205	Telonic Engineering TTF2250-5-5EE
Loss		0.5 db	0.5 db	0.5 db
Preamplifiers		Watkins-Johnson TWT WJ-269	International Micro. Corp. ACR-2250-15	Aertech Tunnel Diode, Amplifier Model T5411
Gain		30 db	20 db	20 db
Noise Figure		5.5 db	4.5 db	4 db
Post Amplifier Filters		Sage 22023CA337	None	Telonic Engr. TTR-2250-5-5EE
Loss		2 db	None	0.5 db
Receiver		Defense Electronics TR-711, Telemetry Receiver with S-band RF Head	Defense Electronics TR-711 Direct Reception at 2200 to 2300 MHz	Defense Electronics TR-711, Direct Reception or Mixer Down-Conversion
Servo System		SCR-584 Radar Vacuum Tube	T9 Radar, Vacuum Tube	Mostly solid-state
Tracking Velocities	AZ	77°/sec	150°/sec	80°/sec
	EL	30°/sec	50°/sec	40°/sec
Tracking Mode		Manual Slave Automatic	Manual Slave Automatic	Manual Slave Automatic

*with reference to S-band.