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MISSILE PLUME TEMPERATURE SENSOR AND ARCAS ROCKET VLF/LF PAYLOAD

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Transverse Electric
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VLF/LF Receiver

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The report describes two separate types of instrumentation packages. The first relates to a requirement for measuring missile plume temperatures. A low weight, low volume projectile has been designed and fabricated to include a fine tungsten wire resistance thermometer. The variation in resistance as the projectile transverses the plume at ground level after vehicle ascent is telemetered at 1680 MHz to a ground receiver.

The second system describes a VLF/LF experiment package for inclusion in —

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an Arcas payload. Transverse Electric and Transverse Magnetic components propagated through the upper atmosphere in the 20 KHz to 60 KHz range are detected, processed and retransmitted to the ground at 1680 MHz. The transmission to the ground is achieved by a quadrupole antenna system consisting of four 1/4 λ stubs. The entire payload weight is approximately 8.5 lbs. and will achieve a peak altitude in excess of 70 Km.

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I. INTRODUCTION

Under Air Force Contract F19628-74-C-0052 Epsilon Laboratories has developed and delivered two rocket related instruments; one of which is to be used to determine missile exhaust plume temperatures and the other to monitor TE and TM components of low frequency electromagnetic fields in the altitude range of 0 to 70 Km. The first instrument, the plume temperature-sensing package, was designed to measure the temperatures of rocket exhaust near ground level during the early ascent phase of the rocket. The instrument uses a tungsten wire resistance element to measure exhaust temperatures between ambient and 1300° K. A prototype instrument was built and tested. At the completion of the tests the unit was delivered to the Air Force.

The second development resulted in the fabrication of four flight qualified miniaturized receiver/telemetry payloads which are designed for launch by an Arcas rocket motor.

Two receivers are provided in each payload in order to separately monitor the transverse electric and transverse magnetic components of VLF/LF electro-magnetic fields in the range of 5 to 5000 uv/meter. The receiver outputs are frequency multiplexed and, using an FM/FM L-band telemetry system, are transmitted to a GMD receiver at the ground station.

The development efforts required to design, fabricate, test and deliver the two classes of instruments along with some of the problems encountered and the results obtained are discussed separately in the following two sections.

II. ROCKET PLUME TEMPERATURE-SENSING PACKAGE

A. Discussion of Development Efforts

The prototype rocket plume temperature-sensing package is a lightweight fast response temperature-sensing package specifically designed for use as a probe which will obtain temperature distributions of missile plumes in the near earth portions of their trajectories. The sensor package can either be catapulted into or fired through the missile plumes in order to make the required measurements. A short range telemetry system is used to transmit the temperature readings of the instrument to a nearby receiver. A photograph of the prototype temperature-sensing package is shown in Figure 1.

A knowledge of plume temperature in both the spatial and temporal dimensions enables an assessment to be made of whether or not a lightning hazard exists both with respect to the missile itself and also to the launch area below. Such an assessment is important for launches which must be performed in the presence of high atmospheric electric fields such as those which would prevail during thunderstorm conditions. The relationship between lightning hazard and plume temperature results from the dependence of plume conductivity on the degree of ionization of the plume gases, which, in turn depends on plume temperature.

The specification for the temperature-sensing package require that the instrument be capable of measuring the radial temperature profile of the exhaust plume between ambient temperature and 1300°K to an accuracy of ±50°K and to a spatial resolution of 0.1 meter or better. The package should be designed to complete a 20 meter profile in 1 second or less and the temperature data is to be telemetered to a receiving station located approximately 1000 feet from the launch site. The requirement of providing a 0.1 meter resolution and also covering the 20 meter profile in one second or less results in a time resolution requirement for the temperature sensor of 5 msec. A study of available temperature sensors which could have this fast response time and also be capable of measuring temperatures up to 1300°K limited the choice of sensors to fine resistance wires made from materials such as Tungsten or Platinum.

The sensor selected for the instrument is a fine tungsten wire approximately 1 mil in diameter. The tungsten wire approach was chosen because it represents the best overall compromise when one considers strength, temperature range, accuracy and response time requirements. A preliminary design was completed and tests were begun during November and December 1973.

The basic approach used in the system design was that temperature changes in the sensing element result in resistance changes which in turn would be converted to frequency changes in an associated audio frequency oscillator circuit. The audio oscillator output was formed into short pulses which in turn modulated an L-band transmitter. The L-band transmitter output was applied to a matching section which provided outputs to a 4 element turnstile antenna system.

PLUME TEMPERATURE PROBE

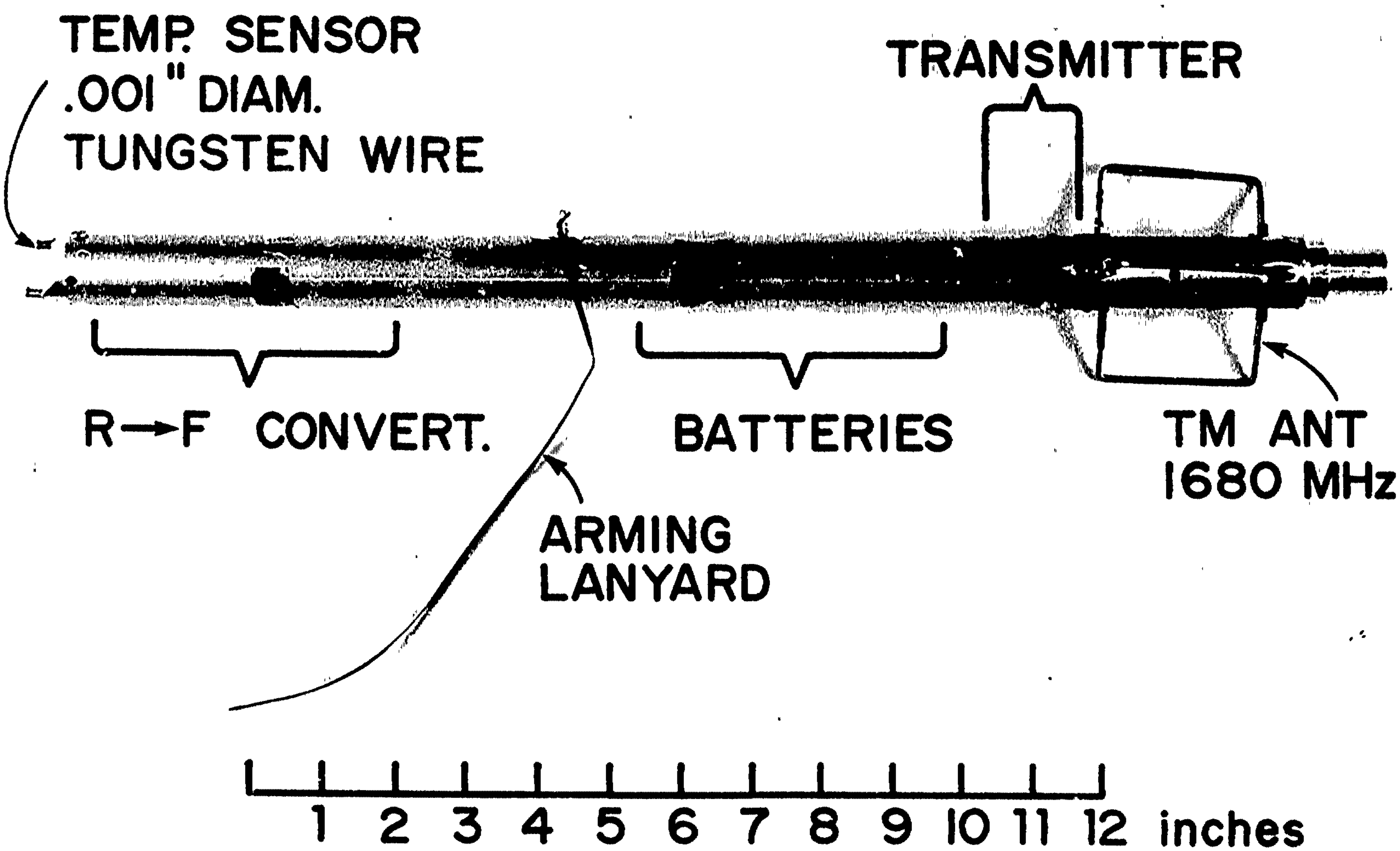


Figure 1

A prototype instrument was built and subjected to a series of tests during which it was found that the resistance-to-frequency converter was susceptible to interference by the 1680 MHz oscillator signals. The interference was a consequence of the non-optimum location of the component elements of the sensor system. The location of components in the initial assembly of the system was in turn dictated by operational and aerodynamic considerations. The antenna had been located in the front portion of the payload in order that the following two desirable objectives would be met.

1. Any protruding components such as antennas should be located as far forward as possible in order to simplify launch operation with either cross-bow or cylindrical launchers.
2. It should be possible to operate the antenna during pre-launch operation with no detuning from nearby metallic objects such as launch tubes in order that a "lock" condition could be established at the receiver before launch.

The battery pack which powers both the L-band oscillator and the resistance to frequency converter circuit had been placed next to the antenna in order to bring the center of gravity as far forward as possible. The resistance to frequency converter had been placed next in line in order to be as close as possible to the sensor located in the nose of the sensor package. The oscillator had been located at the extreme rear of the payload.

The above compromises resulted in the requirement for having not only the R-F cable but also many signal and power leads passing through the very sensitive resistance to frequency converter circuitry portion of the payload. As a consequence of the small diameter of the package, there was insufficient room to properly shield or electrically decouple the various signal and power leads to prevent interference from residual 1680 MHz signals which were present on these wires. A one inch diameter was used in the design because it was desirable to minimize the launch energy requirement.

After considerable time was spent trying to reposition and/or electrically bypass the signal and power leads, it was finally decided to rearrange the component locations in the payload to that shown in Figure 1 in order to minimize interference problems discussed above. Although the new layout somewhat compromises the location of the center of gravity and the antenna configuration, it was felt that the change was necessary to ensure that the required improvement in the electrical performance of the system would be met.

A test run of the system was made using internal battery power and a dummy load in place of the antenna. The system operated for approximately 45 minutes.

Later, a temperature test was made between the limits of +20°C and +50°C and it was found that the equivalent error in temperature under these conditions would be less than 10°C. Under actual flight conditions the temperature variations which will be experienced within the package will be considerably less than the 30° range used for temperature test.

A simple telemetry test was made by taking the instrument and measuring the L-band signal level as a function of distance from a receiver consisting of a dipole antenna coupled to a low sensitivity detector. The signal level which was received at a range of 100 meters corresponded to a field strength of 2500 microvolts per meter.

The GMD receiver has a sensitivity which is many times that of the detector used above; so that the range of operation of the system should be well beyond the required 1000 feet.

An additional change to the system incorporated shortly before delivery consisted of the substitution of a simplified 3 element loop antenna system for the 4 element turnstile antenna used in the initial design. The loop configuration provides a more rigid structure than the probe antenna elements used in the turnstile antenna and should therefore be better able to withstand the anticipated plume environment. A secondary benefit from the loop antenna approach is the elimination of the relatively complex distribution harness which had to be used in the turnstile antenna system to obtain the quadrature phase relationships.

In the final antenna system configuration the three loop elements are equally spaced in azimuth (120°) and are located the same axial distance from the aft end of the payload structure. The loop elements are all fed in phase by a common symmetric feed bus so that the magnetic field lines of the radiated RF signal form closed loops, approximately circular and contained in planes perpendicular to the axis of the package. The magnetic component of the radiated signal will be a maximum in directions perpendicular to the axis of the payload and in a plane which passes approximately through the center point of each loop. The electric component of the radiated RF signal likewise will be maximum in the same directions. However, the electric field lines which correspond to the direction of maximum radiation will be pointing approximately parallel to the axis of the sensor package.

The prototype temperature-sensing package was delivered to the Air Force in February 1974 after the final tests were completed at Epsilon Laboratories.

B. Discussion of System and Circuit Design Details

Figure 2 illustrates the basic design of the rocket plume temperature-sensing package in block diagram form. As can be seen from the figure, the probe system consists of the following major elements:

1) A resistance temperature sensing element consisting of a 1 mil tungsten wire.

2) A resistance to frequency converter circuit.

3) A pulse forming multivibrator circuit MV1.

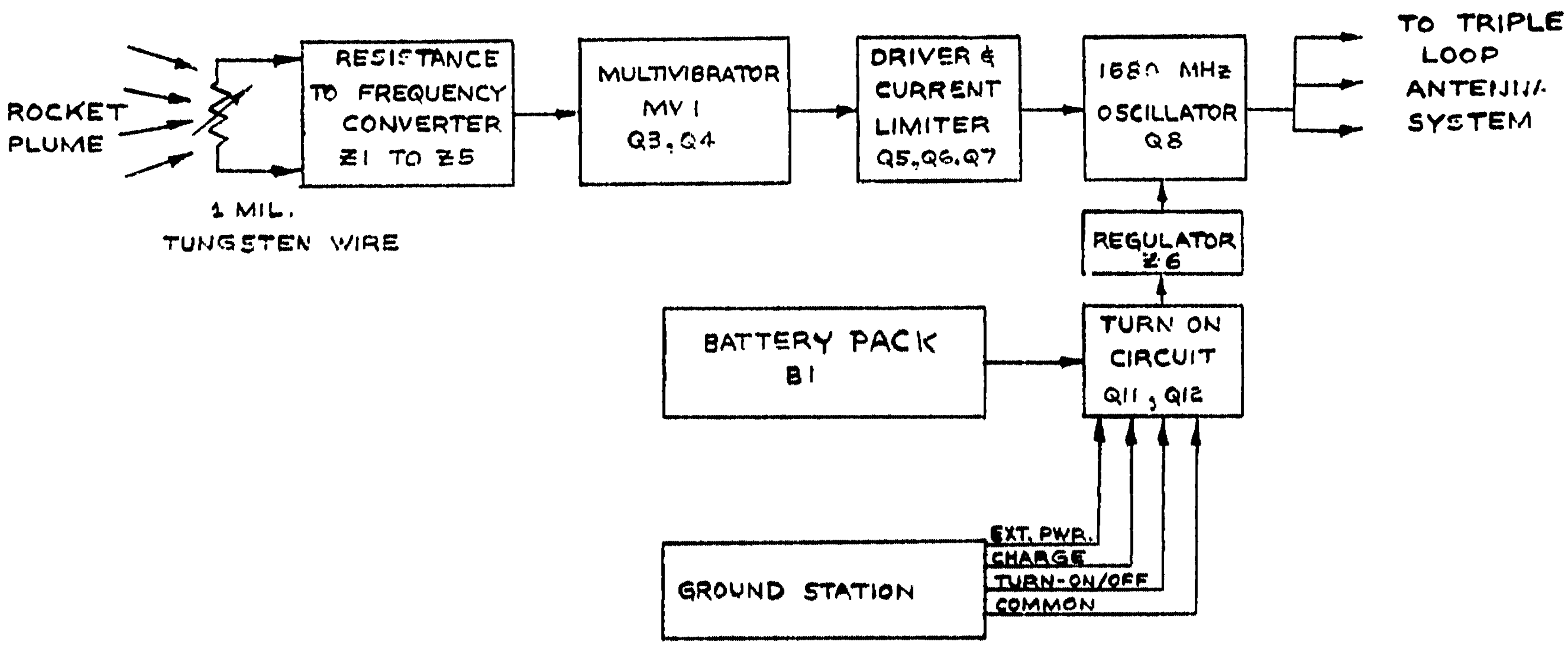


FIGURE 2.
SYSTEM BLOCK DIAGRAM

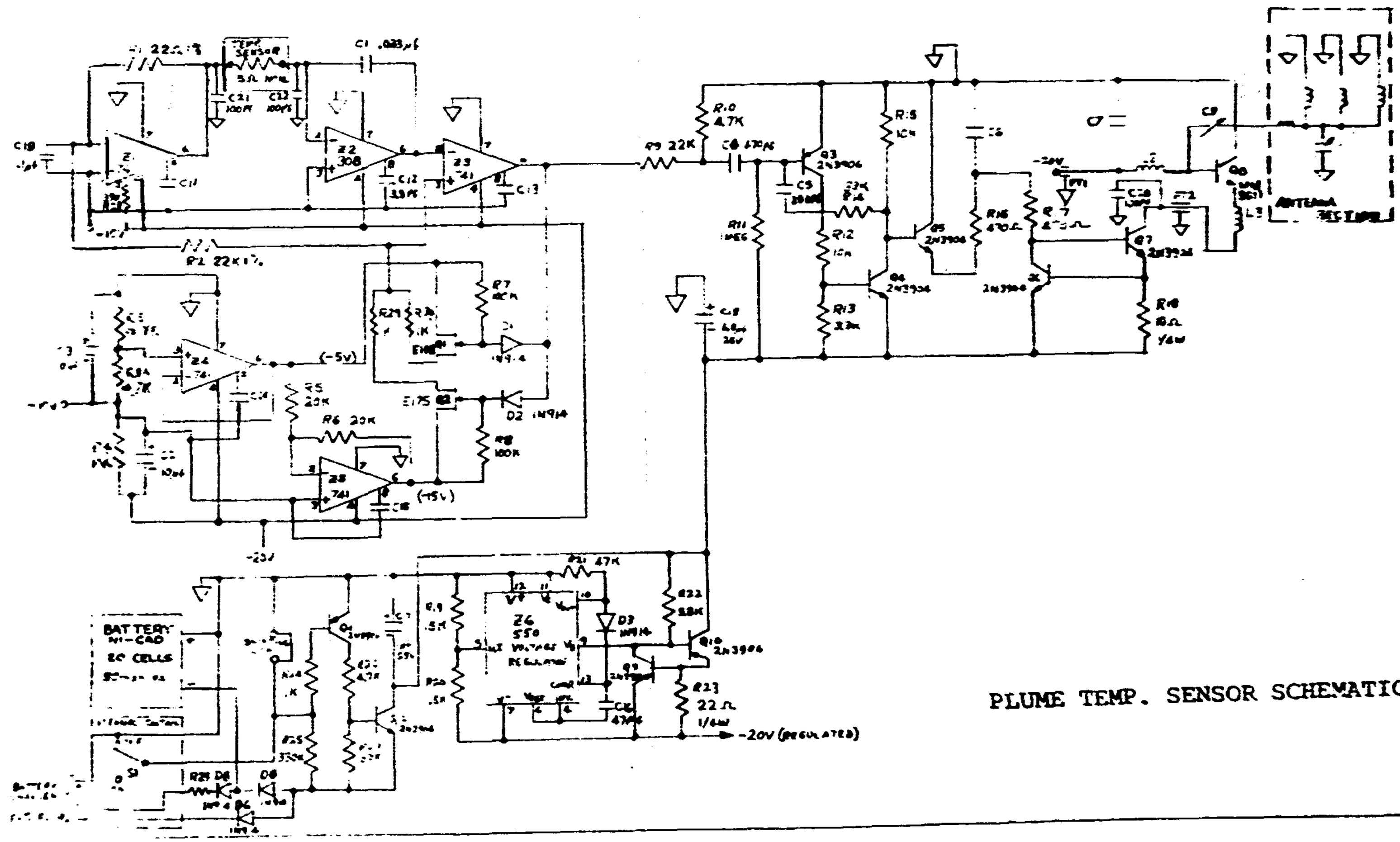
4) A driver and current limiter circuit which is used to pulse the oscillator.

5) An L-band oscillator operating at a nominal frequency of 1680 MHz.

6) A triple loop symmetric antenna system which is used to relay the output of the sensor system to a nearby receiver.

7) An internal battery source.

These elements are shown in more detail in the schematic diagram shown in Figure 3. The location of the component elements of the temperature sensor package is indicated in Figure 4. A detailed discussion of the operation of each of the above elements is contained in the equipment information report "Rocket Plume Temperature-sensing Package" previously prepared and submitted to the Air Force under the present program.



PLUME TEMP. SENSOR SCHEMATIC

Figure 3

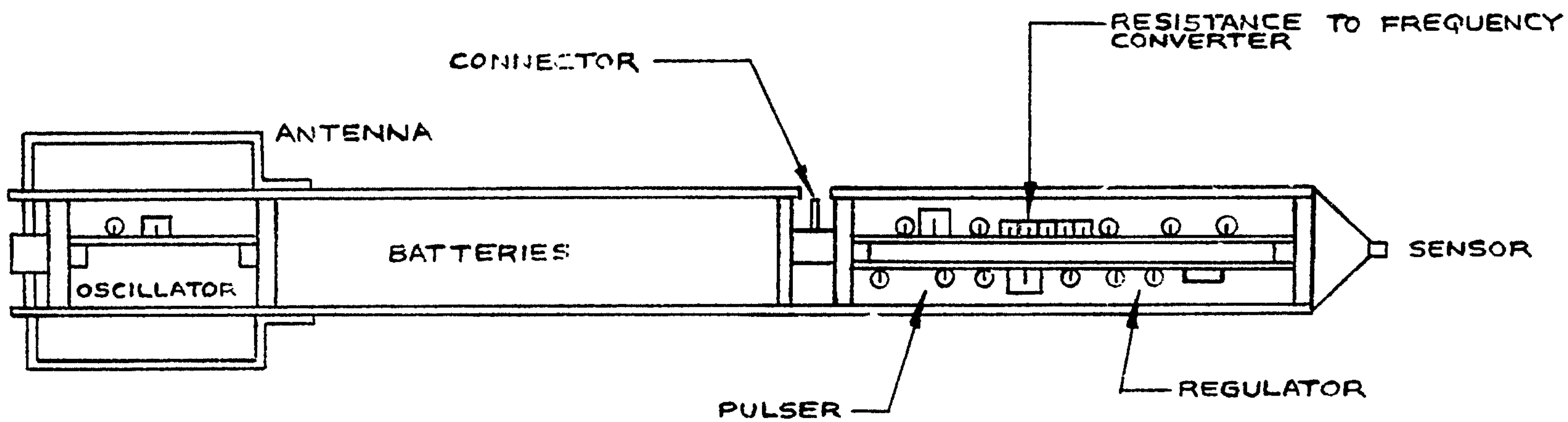


FIGURE 4.
COMPONENT LAYOUT FOR THE PROTOTYPE ROCKET PLUME TEMPERATURE-SENSING PACKAGE

III. MINIATURE ROCKET PROBE

A. Introduction

The measurement of transverse electric (TE) and transverse magnetic (TM) components of VLF/LF electromagnetic signals for altitudes up to about 70,000 feet has been performed routinely using sensor packages released from high altitude balloons. The present development represents an initial effort directed to the extension of these measurements into the ionospheric D-region (approximately 70 Km) using an Arcas vehicle to transport the sensors. Epsilon Laboratories has delivered four flight qualified rocket probe sensors as the end item of this development effort. The following portion of this report provides a detailed discussion of some of the design approaches considered problem areas encountered and the final system design employed.

B. Program Development Efforts

During the initial period of the design, which was begun during the early part of 1974, several meetings were held with cognizant AFCRL technical personnel in order to develop the design criteria for the Rocket Probe Sensor system. Using these design criteria as a basis, Epsilon Laboratories developed the detailed design of a Probe Sensor package which could be used to obtain the required measurements of both the transverse electric and the transverse magnetic components of electromagnetic fields in the VLF/LF region of the radio spectrum.

On May 20, 1974 a design report of the system was submitted which consisted of the standard Arcas parachute configuration in which the payload would be boosted to an altitude of about 70 Km. At the approximate apogee point the parachute would automatically be deployed and thereby control the descent rate of the sensor system. Transmission of signals would occur both during the ascent and the descent portions of the flight with the primary emphasis being given to the more controlled descent portions.

Several meetings were held between Epsilon Laboratories and the contract monitor after the design evaluation report in order to review the design and redirect the program along a mutually acceptable direction.

During the technical discussions the relative advantages of a parachute descent system were weighed against the simpler more reliable configuration in which the parachute was eliminated. The advantages of the parachute system included 1) a more predictable attitude during the measurement, and 2) the capability of using an on-board transponder system to enable the tracking GMD4 receiver to determine slant range. The slant range information together with the aximuth and elevation outputs of the GMD receiver system would have enabled a determination of altitude to be made.

The disadvantages were rather numerous and included 1) a long descent time characteristic which could have resulted in serious compromise to the performance of the system because of the exposure to low temperatures, 2) excessive battery requirements because of the resulting longer operating time, 3) added complexity as a result of the parachute and transponding requirement thereby increasing the chance of mission failure, 4) possible distortion of the electromagnetic VLF/LF field by the Gentex parachute which is 50% aluminized, and 5) reduced space availability for the sensor components as a result of the volume occupied by the parachute and transponder.

The advantages of the non-parachute configuration were that 1) higher reliability would result as a consequence of reduced system complexity, 2) a more precise performance of the electronic circuitry would be ensured by the reduced extremes of temperature variations made possible by the shorter mission time, 3) simpler yet reasonably precise altitude determination would be provided using a simple barometric sensing device and the "free fall" equations to determine altitude versus time, 4) the battery requirements would be less demanding, 5) tracking requirements would be less demanding, and finally, 6) more telemetry capacity for the experiment would result as a consequence of the elimination of the transponder.

The disadvantage of the non-parachute configuration was that the control of and the determination of the attitude of the ferrite loop magnetic sensing elements could prove to be less acceptable than for the parachute configuration. As a result of discussions with the contract monitor in which the relative merits of several approaches were reviewed the following decisions were mutually arrived at:

a) The parachute configuration would be eliminated from the experiment because of its degrading effect on the local TE and TM ambient field. Instead, the desired vertical attitude would be achieved using a high "QE" attitude at launch and altitude would be obtained using the closure of a barometric switch preset for a predetermined altitude together with the ballistic equations for an object under the influence of gravity alone.

b) The VLF/LF antenna system would be located in the nose cone section of the payload and would be designed to be as large as was feasible in order to optimize sensitivity.

c) Provisions would be built into the wide band amplifier for tuning; alternatively, a notch filter option could also be considered.

d) The electronics package of the system would occupy the parachute canister.

e) A trap would be considered to eliminate possible interference from the 68.9 KHz station at Thule, Greenland.

f) A slot or stub antenna design would be investigated for possible use in place of the existing Arcas 1680 MHz antenna system.

Based upon the above design decisions the original parachute design was abandoned and a new design effort was initiated. The revised system made use of the more reliable approach in which the entire measurement would take place primarily in the ascent portion of the trajectory during which the attitude of the sensor can be predicted with more certainty.

Before beginning with the actual fabrication of the payload, a number of discussions were held with government, university and industrial personnel who either were currently associated with Arcas rocket programs or who had recent operational experience with Arcas vehicle performance characteristics and who also may have had a knowledge of performance characteristics and availability of accessory telemetry components such as L-band transmitters and antenna systems. As a consequence of these discussions it appeared that even with the use of a high "QE" launch setting, a precise quasi-vertical orientation of the rocket payload could not be absolutely guaranteed. However, the use of excess thrust such as that provided by a Super Arcas rocket could considerably reduce the amount of coning which would take place in the altitude of interest (the first 70 Km of altitude). Because of the above possible uncertainties both in the determination of and in the control of Arcas attitude it was decided that it would be prudent to incorporate a solar aspect sensor in the payload to provide supplementary attitude information which would be useful during the post flight data reduction effort.

It was also discovered that standard solid state transmitters for the "sonde" class of experiments were not readily available as off-the-shelf items. Most of the available transmitters seemed to be either of the special order types such as the one developed by Ball Brothers or vacuum tube types such as one of the RCA models or the VIZ sonde transmitter. The VIZ unit is reputed to be quite reliable and provides more than adequate output power (300 mw). However, VIZ could not guarantee that frequency modulation of up to 2 MHz could be accomplished with their transmitter.

After a considerable search effort was expended a solid state transmitter produced by RCA was located and purchased. The transmitter was tested and found to be acceptable with respect to frequency modulation and power output capability. The final design of the rocket probe sensor is shown in Figure 5.

The major elements of the system are 1) two orthogonal loop antennas, two associated amplifier channels A1/A2, A3/A4, subcarrier oscillators VCO #1 and VCO #2, linear mixer Z3, aspect sensor AS1, FM transmitters Z4 and a four element turnstile antenna system.

In the final design the TE component is monitored by a 10 inch long ferrite loop antenna located in the nose cone area of the payload. The antenna is broadly tuned to accept VLF/LF signals in the frequency range of 20 KHz to 60 KHz. The output of the TE antenna is amplified first by a low noise preamplifier, A1, contained in a shielded enclosure and secondly by an AGC amplifier, A2, designed to minimize the possibility of signal overload. The output of A2 is used to frequency modulate subcarrier oscillator VCO #1 over a frequency range of 500 to 740 Hz.

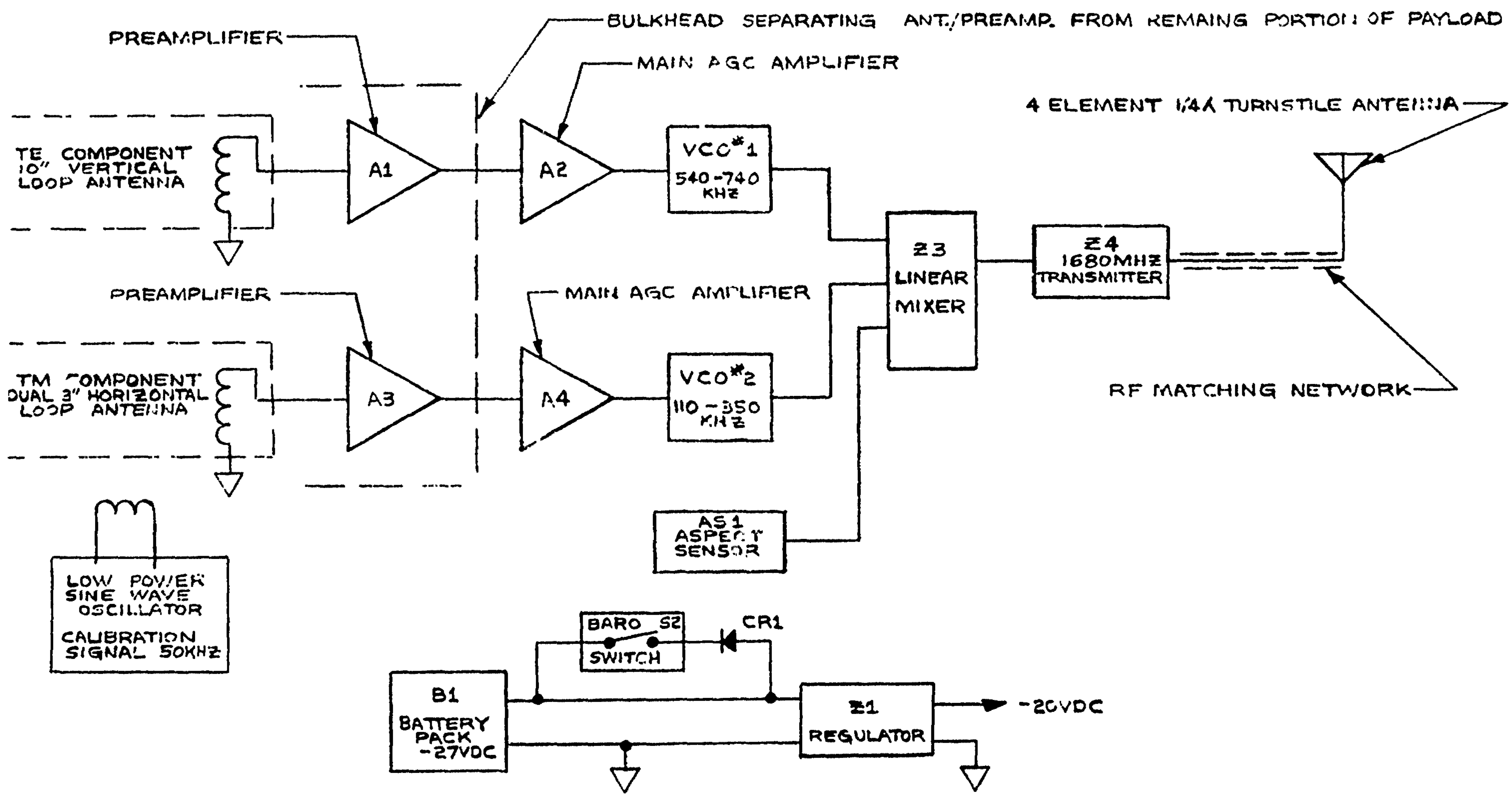


FIGURE 5.
SYSTEM BLOCK DIAGRAM MINIATURIZED
TE ROCKET PROBE SENSOR

The monitoring of the TM component is accomplished in a similar manner using amplifiers A3, A4 and VCO #2. Because of the restricted geometry in the nose cone area the TM antenna was fabricated using two parallel 3 inch ferrite elements located on each side of the center portion of the TE antenna. System symmetry was maintained to the maximum extent possible in order to avoid field distortions which could introduce TE signal components into the TM antenna or TM signal components into the TE antenna. The frequency range for VCO #2 is 110 KHz to 350 KHz.

The outputs of VCO #1 and VCO #2 are linearly added together in Mixer Z3 the output of which is used to frequency modulate oscillator Z4 which consists of the RCA Model S507V1 L-band transmitter module.

Calibration for the two signal channels is obtained using a low power 50 KHz sine wave oscillator to introduce a reference a-c magnetic field into the TM and TE antenna loops. Because this level is stable and of known value it conveniently provides a known reference which can be used to compensate both for gain changes in the amplifier channels and for modulation sensitivity changes in the subcarrier oscillators.

Power to the system is provided by a 27 volt primary battery which has sufficient capacity to operate a payload for about one hour. An output regulator Z1 is used to obtain the stable 20V d-c output which is used to power the various system components shown in the figure.

Switch S2 shown in the figure provides both a backup "turn on" feature and also is used to introduce a momentary disturbance into the operation of the calibration oscillator so that the reference altitudes of 70,000 feet on the upleg and 57,000 feet on the downleg portion of the flight can be identified during the post flight data reduction analysis.

The identification of these two points together with the use of the ballistic equations of motion enables a determination to be made of the altitude profile of those portions of flight which are of interest.

Because the sensor will be used to monitor the TE and TM components of VLF/LF electromagnetic fields as a function of altitude it is necessary that not only altitude as a function of time be available for the post flight analysis but also data on rocket aspect with respect to local vertical. In order to aid in the determination of this latter parameter, a solar aspect sensor, AS1, in the figure has been incorporated into the payload. The output of AS1 is pulse-like in nature and has spectral components which can extend up to a few kilohertz. This output requires no intermediate conditioning and is therefore applied directly to the FM transmitter via mixer Z3. Further details of the miniature rocket probe sensor are contained in the equipment information report "Miniaturized T.E. Rocket Probe Sensor" recently submitted to the Air Force under the present program.

When the testing program was concluded the units were delivered to the Air Force.

The following specification data summarizes the performance characteristics of the miniature VLF/LF rocket probe sensors which were delivered.

Frequency range of receiver:	20 KHz to 60 KHz for both the TM and TE channels
Antenna:	A single 10" ferrite loop antenna for the TE mode channel and two 3" ferrite loop antennas for the TM mode channel
VCO Frequency Range:	110 to 350 KHz for the TM mode channel 520 to 760 KHz for the TE mode channel
Transmitter Frequency:	1680 MHz
Battery Power:	-27 VDC
Calibration Oscillator Frequency:	50 KHz
Weight of Payload:	8.5 pounds

Complete schematics of the VLF/LF payload are available in the Equipment Information Report dated September 1975.