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Sandia Laboratories Technical Capabilities

Instrumentation and Data Systems

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Sandia Laboratories

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SANDIA LABORATORIES TECHNICAL CAPABILITIES

INSTRUMENTATION AND DATA SYSTEMS

ABSTRACT

This report characterizes the instrumentation and data systems capabilities at Sandia Laboratories. *Selected applications of these capabilities are presented* to illustrate the extent to which they can be applied in research and development programs.

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FOREWORD

Sandia Laboratories, a multiprogram laboratory of the Energy Research and Development Administration (ERDA), is located in Albuquerque, New Mexico, and Livermore, California, with a remote testing facility at Tonopah, Nevada. In fulfilling its responsibilities to ERDA in the fields of national security, energy, and other programs, Sandia has acquired extensive capabilities in research, development, testing, and evaluation, and has made numerous contributions in scientific and engineering fields. These technical capabilities are integrated by management for the definition and solution of scientific and engineering problems.

A series of reports has been written describing these capabilities and showing typical applications. The reader will find the capabilities summarized in a separate paper, or may choose any of the 17 separate reports, or, if he wishes a compendium, can find all the reports and the summary compiled in a single publication. Identifying numbers for the entire series are given below.

C. Donald Lundergan, Technical Editor
P. L. Mead, Publication Editor

TECHNICAL CAPABILITIES OF SANDIA LABORATORIES

Summary
(SAND74-0091)

Aerosciences	SAND74-0075	Instrumentation and Data Systems	SAND74-0083
Applied Mathematics	SAND74-0079	Materials and Processes	SAND74-007[illegible]
Biosciences	SAND74-0076	Measurement Standards	SAND74-0077
Computation Systems	SAND74-0080	Physical Sciences	SAND74-0074
Design Definition and Fabrication	SAND74-0084	Safety and Reliability Assurance	SAND74-0090
Earth Sciences	SAND74-0085	Systems Analysis	SAND74-0089
Electronics	SAND74-0086	Testing	SAND74-0088
Engineering Analysis	SAND74-0087	Auxiliary Capabilities	SAND74-0082
Explosives, Electrochemistry, and Electromechanisms	SAND74-0081	Environmental Health Information Sciences	

Compilation of
Sandia Laboratories Technical Capabilities
(SAND74-0092)

INSTRUMENTATION AND DATA SYSTEMS*

An extensive instrumentation and data-reduction activity is maintained. Many advanced designs now in development must operate in extreme environments such as those encountered in space, in high radiation fields, or under severe mechanical, thermal, and electromagnetic loads. The instrumentation activity provides instruments that will measure characteristics of the environments, measure responses and performance of materials and systems operating in them, and locate accurately the position of the systems in the environment. To fulfill these tasks, new instrumentation systems are developed and existing techniques modified. Instrumentation is fielded in conjunction with design and testing activities.

Data-processing and data-reduction are integral activities that provide test information in various forms, including charts, graphs, photos, movies, or special forms, depending upon needs.

Instrumentation and Data Systems
Professional Staff and Investment in Equipment

	Professional Staff	Investment in Equipment (in $1000)
Data Acquisition Systems	506	77,054
Transducers		
Communications		
On-board data storage		
Optical recording		
Tracking instrumentation		
Mobile and transportable		
Special Instrumentation	47	2,876
Meteorological		
Photometric		
Quality Assurance		
Radiation Analysis		
Data Reduction Systems	105	9,315
Magnetic		
Optical		

*Compiled September 1975

DATA ACQUISITION SYSTEMS

Data are acquired by subsystems that transform a property of a test item into a recognizable signal, transmit the signal, and receive and record the information for further analysis. The property to be measured is transformed by different kinds of transducers, depending upon objectives and ambient operating conditions. Data transmission from the test vehicle can be immediate or delayed, and transmission media can vary from space to substrata of the earth. Data storage is constrained by availability of power and space in telemetry applications. Optical data recording is concentrated on high-speed, short-duration phenomena.

Besides data-acquisition systems made up of subsystem modules for specific applications, there are tracking systems that remotely measure the dynamic motions of test objects, and both mobile and transportable instrumentation carriers are used in remote regions.

Transducers

The purpose of a transducer is to detect a measurable property and to transform its signal into a measurable form. Transducers are used to measure the test environment or the response of a component or system to that environment, or to control or monitor the function of a system. Some transducers are selected for their ability to survive and operate in severe mechanical environments in which high level short-duration forcing functions are produced. Others are selected because they operate properly in combined environments, e.g., severe thermal, radiation, and electromagnetic fields. The accuracy of a transducer is determined by the Primary Standards Laboratory.* (Items 1-7)**

Measured Parameters

- Force
- Heat flux
- Humidity
- Position and derivatives
  - Angular
  - Rectilinear
- Pressure
- Radiation levels and rates
  - Alpha
  - Beta
  - Gamma
  - Neutron
- Strain

Transducer Types

- Force balance
- Light sensitive diodes
- Magnetostrictive
- Piezoelectric
- Potentiometric
- Variable reluctance
- Variable resistance
  - Metallic
  - Semiconductor
- Thermocouples
- Linear variable differential transformers
- Linear velocity transformers

Capability for Primary Standard Calibration

- Acceleration
- Flow
- Humidity
- Length
- Mass
- Pressure
- Radiation sources
  - Alpha
  - Beta
  - Gamma
  - Neutron
- Temperature

Communications

Radio frequency (RF) communication systems transmit data or commands from or to remote instrumentation. RF systems are used for both atmospheric and underground communications. High reliability is emphasized in

*See "Measurement Standards," SAND74-0077.

**See Highlights below.

their design. These systems can be hardened against ionizing radiation of 10^{12} rad (Si)/sec and mechanical shock of 20,000 x gravity for 12.5 milliseconds (half sinewave). Most components are temperature-hardened to 150°C.

Hardwire communication systems provide capability for relatively nearby data measurements. Hardwire channels are simple and, over short distances, less costly than RF channels. They are usable in static as well as high-shock, high-velocity environments. Where distance permits, sensors on a rapidly accelerating test vehicle are connected directly to stationary data-recording systems by hardwire. Hardwire connections are extensively used where data must be collected before a damaging shock environment generated by the test reaches the cabling, as is characteristic of underground nuclear testing.

Combined hardwire and RF channels are useful in penetrometer research where an antenna remains on the surface as the penetrator executes its underground or underwater trajectory, connected by wire to the antenna. (Items 8,9)

Current Development Activities

- Impact velocity
- Radio transmission through earth
- Relay transmitter with message storage
- Space position of multiple objects

On-Board Data Storage

On-board storage makes it possible to retain data that cannot be transmitted in real time. On-board storage must function in and survive the same severe environments as other data-acquisition subsystems and also withstand the environments encountered by the carrier. Information packing density must accommodate the quantity of data to be stored in the space available. These storage units will collect data at a high rate and play it back at a lower rate. In other applications, readout awaits location or physical recovery of the on board storage unit. Suitable nonvolatile or low power volatile memories are sought, together with compatible logic and long-life power sources. Continual development is necessary to improve these parameters. Data capacity of typical units ranges from 14,000 to 500,000 bits. (Items 10-13)

Current Techniques

- In use
  - Volatile high-density memory
    - Integrated-circuit shift registers
  - Nonvolatile medium-density memory
    - Plated wire
    - Twistor
- Under investigation
  - Nonvolatile high-density memory
    - Bubble
    - Ferroelectric

Optical Recording

High-performance optical recording is used to obtain scientific data. For recording purposes, special-purpose cameras, processes, and techniques are developed as needed when commercial items are not available. Capabilities include capturing one pictorial dimension as a function of time to deal with high-velocity particles (streak camera), capturing a high resolution image of an object traveling at a very high velocity (image-motion camera), and capturing high-resolution images of short-duration events (image dissection camera, framing camera, and stroboscopic mode video systems). Where illumination can be controlled, high intensity light sources are developed to meet requirements of specific rise times, durations, and quench times (spark sources, gas discharge, and flash systems). Where illumination is low, image-intensification techniques are used to aid both video and film optical recording, an application is in magnification up to 15 power. Capability exists for aerial and underwater optical recording, on film and in video. Optical data can be recorded in all but the most adverse environments.

Equipment is being developed to increase realizable frame rates above the present capability of 20×10^6 frames per second so that better resolution can be obtained of high speed or short duration events. Computer analysis is being used to advance the state of the art in cameras, lens elements, and other optical system designs, and optical tracking situations are simulated to permit optimization of instrument application. (Items 14-15)

Current Techniques

- Holographic high-density data recording
- Framing camera
  - Rotating mirror (to 3×10^6 frames/sec)
  - Proximity focused (5×10^8 frames/sec)
- Image dissection camera (to over 1×10^7 frames/sec)
- High-intensity light sources
- Rotating-mirror streak-framing camera (100 mm/ms)

Current Applications

- Computer analysis
  - Lens design program (IBM 7090)
  - Optical tracking simulation
- Solar aureole, apparent radiated energy

DATA ACQUISITION SYSTEMS

Tracking Instrumentation Systems

Tracking a target to obtain trajectory and other engineering data is the purpose of several types of instruments, both mobile and fixed. Much of this instrumentation is at the Tonopah Test Range in Nevada; however, some is mobile for test support at various locations. Most of the capability is oriented to atmospheric trajectories obtained by radar, laser tracker, cinetheodolite, and Doppler systems. Computer analysis of test plans by optical-tracking simulation helps optimize the use of optical instrumentation. Other engineering information is obtained by telemetry ground stations or Newtonian telescopes which also track the target. Sandia develops or modifies tracking mounts and optical systems to meet the needs of the project. Underwater trajectories are traced by hydrophone networks. (Items 16-21).

Current Techniques

- Laser tracker
  - Control of remote tracker
  - Control of remote cameras
  - Control of target
  - Real-time position and velocity measurement
- Radar
  - Range measuring improvement

Mobile and Transportable Instrumentation Systems

Mobile instrumentation systems are essential to the investigation of interactions between systems and the atmosphere or the geomagnetic field. It has been necessary to measure in-situ parameters, inject tracer materials, and assess system performance over a wide range of altitudes and other test conditions. Tests are conducted where support facilities are minimal in such remote areas as the high seas, underwater to 1200 meters, multicanopied jungles, deserts, the Arctic ice cap, glaciers, islands, high altitude terrain, endoatmospheric regions above 15,000 meters, and subterranean regions. Instrumentation test beds include rocket payloads, artillery shells, earth penetrators, balloons, aircraft, trailers, and easily transportable systems that can be handled as baggage for shipment (Items 22-27)

• • • • • • *HIGHLIGHTS* • • • • • •

Item 1. *Tunable Dye Laser for Isotopic Atomic Spectroscopy*

Isotopic atomic spectroscopy is used as a diagnostic tool in transient conditions to measure trace constituents in vacuum tubes. They can be measured at such low concentrations as 10^6 atoms sampled. Experimental measurements of trace constituents in the atmosphere by remote monitoring, and isotopic trace-level determinations of the effluent of nuclear fuel-processing plants are under way.

A variety of pumped-dye lasers has been developed for these applications. Techniques for producing ultranarrowband tunable dye lasers have been established for different dyes, permitting operation over the visible spectrum (0.4 to 0.9 micron), which encompasses almost all atomic absorption lines. Techniques for precise wavelength measurement as well as stabilization of the laser oscillation frequency have been reduced to routine procedures.

Item 2. *Well-Logging*

A feasibility study has recently been undertaken to determine the possibility of using pulsed neutron sources for logging exploratory uranium bore-holes. This involves the measurement of epithermal neutron decay of the scintillator signal resulting from the detection of epithermal [energy >(1/40) eV] neutrons as a function of increasing time.

Item 3. *Instrumentation for In-Situ Fossil Fuel Processing*

Instrumentation and process controls are being developed for in-situ processing of coal, oil shale, and other fossil fuels. Recovery of energy from fossil fuels by in-situ processes generally involves burning a portion of a carbonaceous deposit in its natural underground location to provide heat for converting coal to gas and liquids, oil shale to oil and gas, and heavy oils and tar sands to pumpable oils.

DATA ACQUISITION SYSTEMS

Instrumentation sensors and measurement techniques are being evaluated in an in-situ coal-gasification experiment (Figure 1) and will be extended to in-situ oil shale processing. An objective is to develop techniques to monitor the burn front including the development of sensors capable of detecting the front from a considerable distance.

Sensors are being used on the surface and at various depths in 18 instrumentation wells near Hanna, Wyoming. Instrumentation includes thermocouple arrays, surface and subsurface resistivity probes, geophones, in-seam gas-sampling systems, and gages to measure tilt and displacement of the overburden near the coal seam.

Ready detection of the burn front is an important element in the in-situ gasification scheme since it will permit injection of air and oxygen at the right place and time, thus helping to maximize gas recovery.

The ultimate objective is to develop an integrated process-control system. This involves developing detailed diagnostic information on the chemical and physical mechanisms involved in combustion, sensors for monitoring all relevant combustion factors, and a computerized data-acquisition and analysis system.

Item 4. *Ablation Detector*

To permit determination of the amount of material ablated from reentry vehicles under various conditions, a nose cone is seeded with very small Ta^{182} gamma sources precisely positioned within the material along a line where erosion is expected.

During flight, as these sources are removed by aerothermal ablation or rain erosion, the gamma level is reduced. A gamma detector, positioned near the gamma sources, senses the removal of each source. The detector output voltage level corresponds to the intensity of the gamma flux and diminishes abruptly as each gamma source is removed. The resulting analog signal is processed and transmitted to the ground station where it is recorded in real time. When the known source positions, their removal time, and the rocket flight information are correlated, a material-removal history is obtained (Figure 2). The system has also been used to measure sidewall ablation on a heat shield.

Item 5. *Electro-Optic Accelerometer*

For determination of the decelerations of objects hitting concrete barriers at high velocities, commercial accelerometers are adequate but must be calibrated. Optical interferometry with electronic delay differentiation is used. Test accelerometers are subjected to a half sine wave of acceleration in the range from 10,000 to 100,000 x gravity peak, with time to the pulse peak from 60 to 1500 microseconds. These transient accelerations result from electromagnetic repulsion between a pulsed current in a drive coil and induced currents in the metallic driven element on which the accelerometer is mounted. The primary electro-optic accelerometer output is the maximum acceleration ±3 percent, determined as the average acceleration over a window of approximately 1 microsecond. The system also outputs the analog representation of the upper half of the acceleration pulse shape. The accelerometer is useful, for example, in weapon ground-burst applications and in evaluation of structural loading by tornado-driven objects.

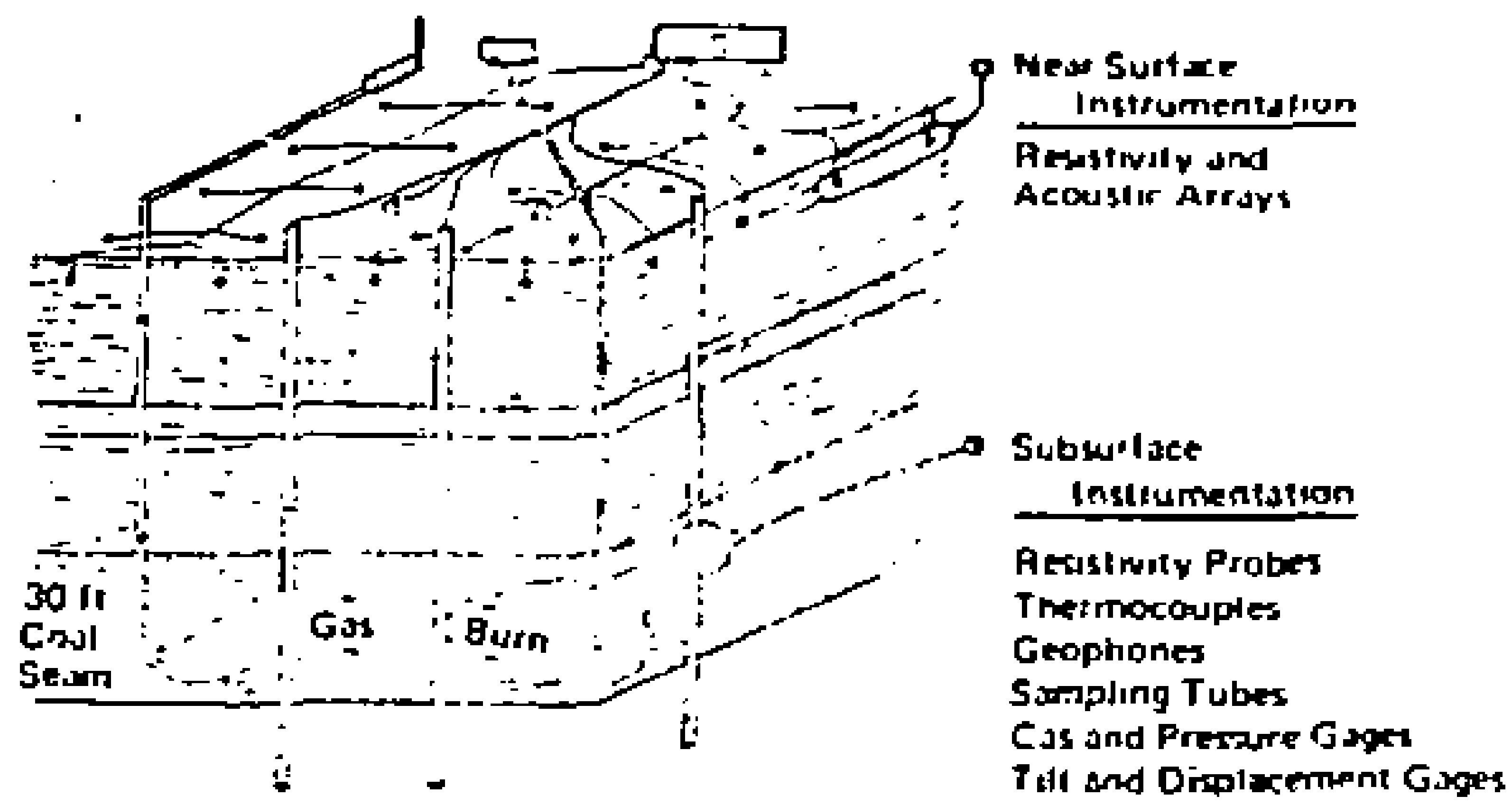

Figure 1. Instrumentation and process-control development for in-situ coal gasification

DATA ACQUISITION SYSTEMS

Figure 2 A nosetip after flying through rain clouds at 3200 meters/second

Item 6. *Pulsed Neutron Detector*

A device was required that would provide the health physicist a direct measurement (in REM—roentgen equivalent man) of single or multiple short bursts of neutrons. A detector was developed which provides a pulse counting system capable of being carried by one person. The equipment has been calibrated with pulses as short as 7×10^{-8} sec and has a sensitivity as low as 5×10^{-4} REM.

Item 7. *Radiation Dosimetry*

ERDA requires that employees likely to receive a radiation dose in any calendar quarter in excess of 10 percent of published standards must be radiation-monitored. A personnel radiation dosimetry program has been developed that provides this coverage for beta, x-ray, gamma, and neutron exposures over wide energy ranges and exposure levels.

The system used for routine (nonaccident) situations utilizes a thermoluminescent dosimeter that is automatically evaluated and identified. Its association with the user is done by computer as are data reducing, record keeping, and report generating functions.

Activation materials have been added to some dosimeters to extend the capability of the system when required. Doses may be measured from low environmental background levels of 10^{-2} REM to levels associated with severe accidents (10^4 to 10^6 REM).

Item 8. *High Shock Environment Telemetry Communication System*

Telemetry for artillery projectiles and earth penetrators (Figures 3 and 4) must function during and after exposure to high shock. Not only must the instrumentation operate during the severe environment, but the data must be recovered after the vehicle has penetrated as much as 50 meters of earth. Shock-hardened components have been developed out of which telemetry systems are fabricated to meet the requirements of a particular mission. Telemetry packages as small as 5 cm in diameter and 35 cm long are now possible. The number of time-multiplexed data channels ranges from 1 to 78. A typical system operates in environments of longitudinal shock of 16,000 x gravity peak with a duration of 12 milliseconds, angular acceleration of 325,000 radians/second^2 peak concurrent with angular velocity of 1700 radians/second; and temperatures from $-40°C$ to +[illegible]°C.

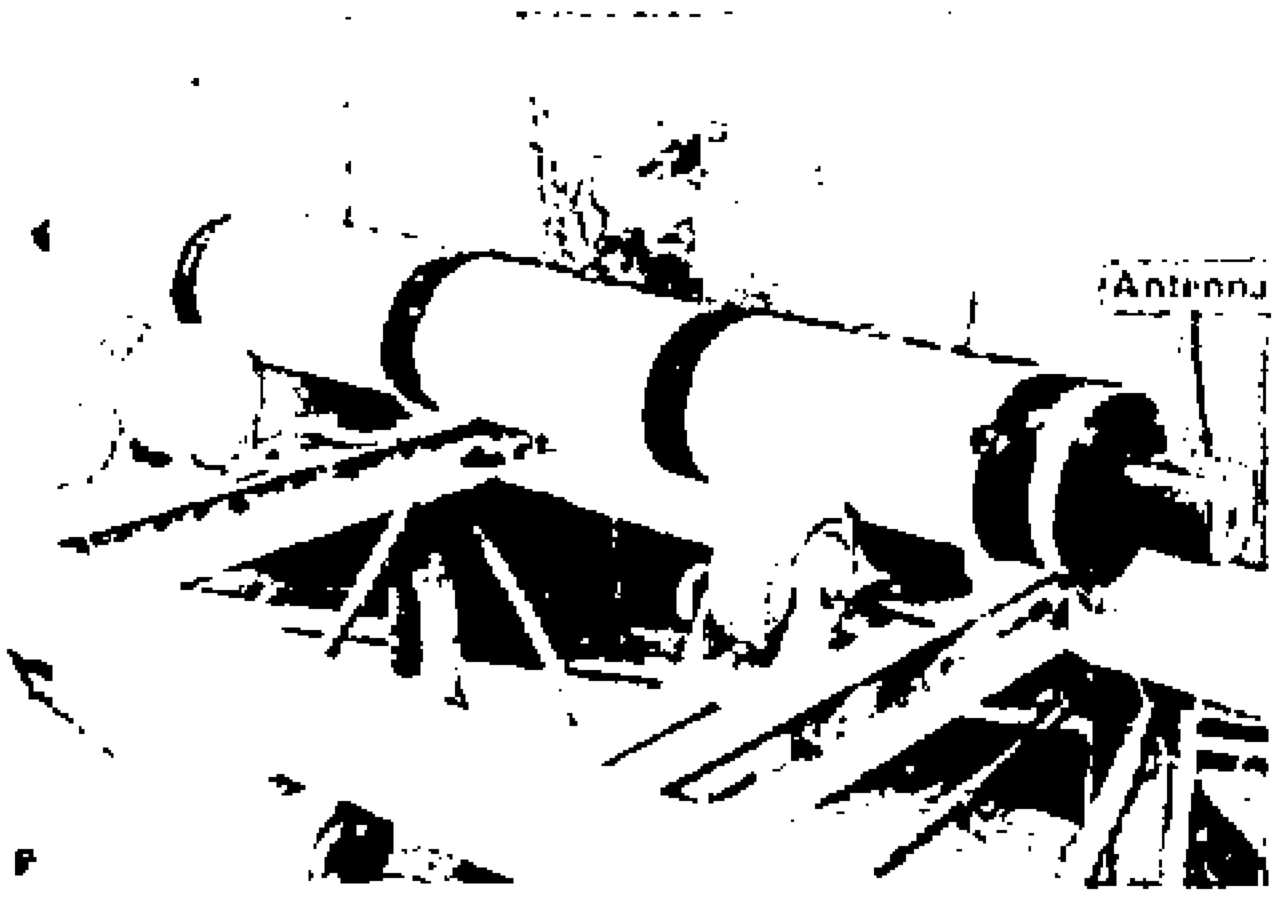

Figure 3. Penetrator with antenna

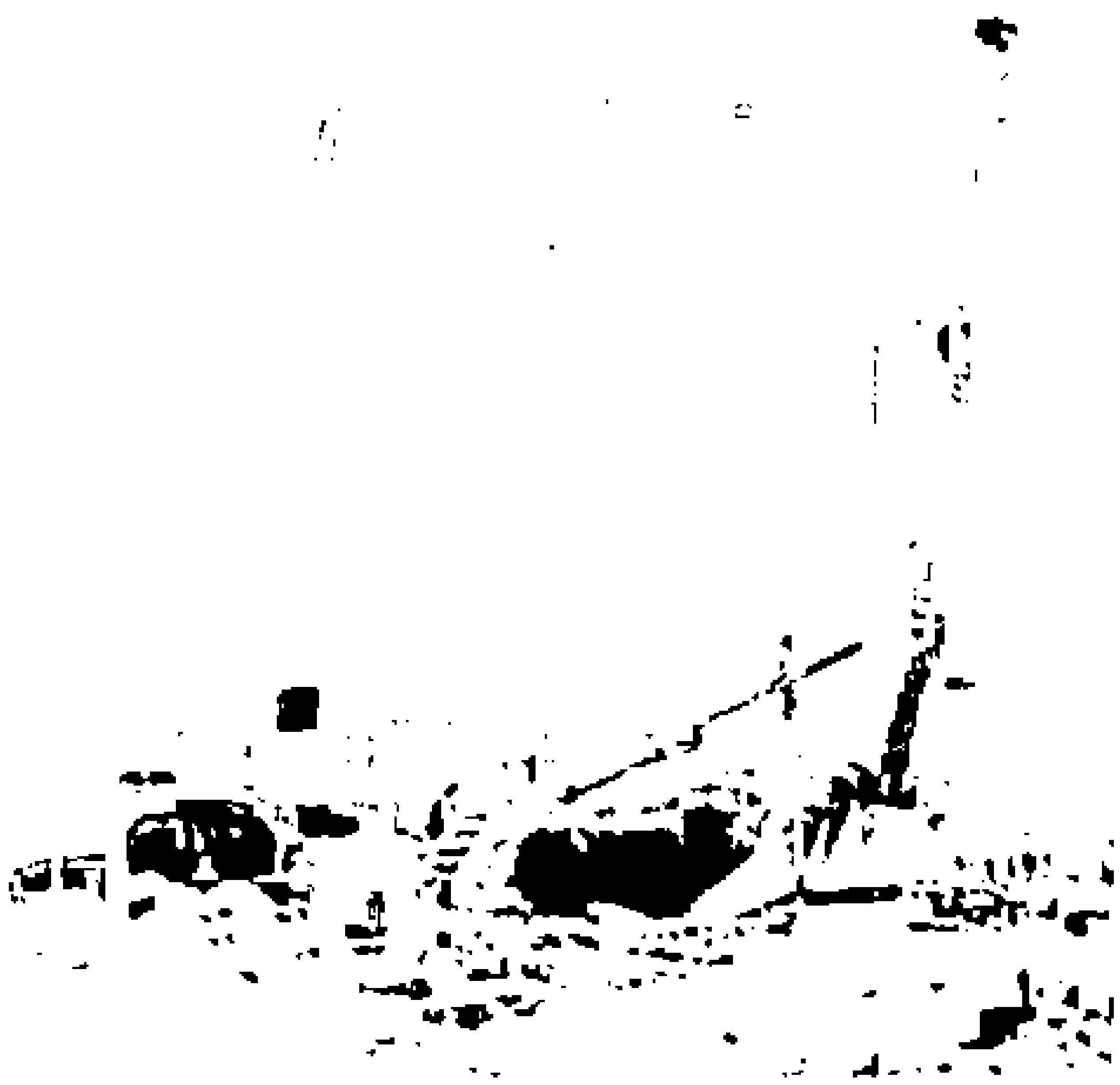

Figure 4. Gun used for earth penetrator testing

The capability has been developed to provide communication to the surface from a transmitter buried 50 meters in earth. Its application is prompt determination of stored data from penetrometer research vehicles without physical recovery (Figure 5). A companion downlink (surface-to-underground) is being developed that can both turn on a quiescent buried transmitter and turn it off again. The downlink will increase the amount of recoverable data or the number of times over an extended life that buried sensors can be interrogated. The chief downlink design constraint is 100 watts maximum transmitter power.

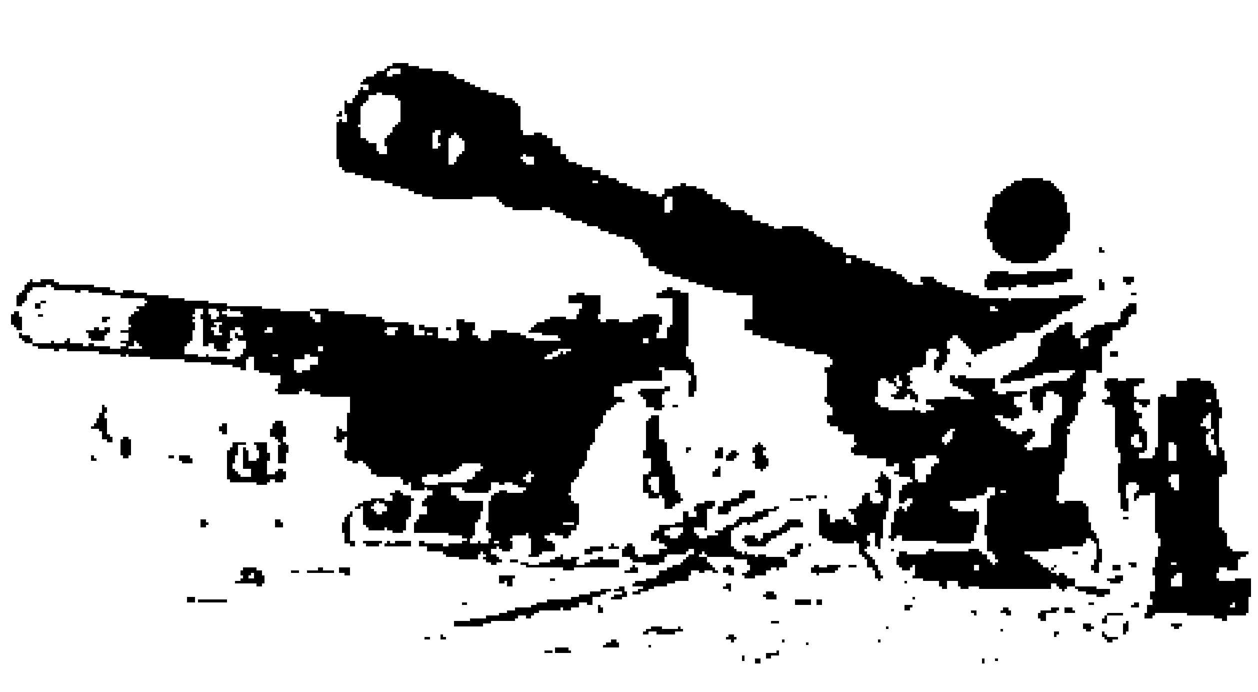

Figure 5. Artillery cannons for high-shock testing

For the uplink (underground-to-surface), a rate of 1000 bits per second with a rate of less than one error in 100 000 bits has been achieved from a depth of 52 meters using 10 watts in a pulse-code-modulated frequency modulation system operating at 10.5 kHz, a standard Inter-Range Instrumentation Group (IRIG) frequency. Transmission lasts from 30 to 40 minutes. The transmitter package is 10 cm in diameter. The design has been optimized for the range of soil conductivity found in the continental United States.

Item 9. *Remote Observation Post*

The U. S. Marines needed to obtain data about movement of enemy equipment and personnel at [illegible] locations where it would be extremely dangerous to [illegible] listening equipment manned. Sandia developed a system to collect, time-tag, and store data from numerous [illegible] seismic sensors and to retransmit the stored data [illegible] mand from a remote interrogating station. The system can discriminate between troop movements and vehicular traffic. Storage capacity is one-half million bits or approximately 45 thousand messages. Unattended operation for over one month is possible. The system is designed for one-man portability and [illegible] and can be [illegible] or airdrop installation.

Item 10. *155-mm Artillery Shell Application*

Several encoding and memory systems have been developed for use in the 155-mm artillery shell, where they must withstand 20,000 x gravity when the shell is fired. An in-barrel pulse-code-modulation data encoder contains 36,000 bits of memory and collects data for approximately 200 milliseconds while the shell is in free flight. High densities of data storage are obtained using integrated circuit shift registers as serial memories. 1024-bit registers are connected into chains which receive serial digital data. When the chain is filled, the output of the last register is connected to the input register and the data are recirculated. The system also collects in-flight data and transmits it in real time with the stored in-barrel data.

Item 11. *Bubble Memory Technology*

Bubble memory technology has been developed for use in penetrometers and other systems. In magnetic bubble memories, digital information is stored as cylindrical domains which exist in thin films of certain magnetic materials—for example one of the magnetic garnets. This technology takes advantage of the unique properties of nonvolatility and

DATA ACQUISITION SYSTEMS

radiation resistance possessed by such devices. These properties, in combination with low operating energy requirements, ruggedness, and very high bit packing density (10^6 to 10^8 bits/cm^2) allow magnetic bubble memories to overcome many of the problems of earlier memory systems. A nonvolatile memory can retain information after power ceases to be supplied to the unit and is advantageous for penetrometer on-board data systems. In this case, a limited power source means short operating life so that the possibility of a quiescent operating mode for a penetrometer data system allows some combination of longer useful life, increased data capacity, or greater functional flexibility. Radiation-resistant memories are required for closest-placement diagnostic data systems in deep [illegible] nuclear [illegible].

Item 12. *Self-Contained Environment-Measuring Systems*

To serve as backup for obtaining data from underground nuclear shots, self-contained environment-measuring systems have been developed. One of these is a plated-wire 196,000-bit random-access memory used in a digital recording system for a 55,000-g steel canister. A memory-controlled pulse-code-modulation encoder converts input analog data channels into a serial bit stream that is broken into 24-bit words and loaded into the plated-wire memory. The encoder can retrieve information from the memory and retransmit it, or the data can be retrieved by laboratory test equipment.

Another self-contained system is the piggyback "twistor" memory which, in its present configuration, is organized as 1024 words with 14 bits/word. Piggyback twistor is a type of magnetic memory where information is written into it electronically and will remain in memory indefinitely without any holding current required. The twistor memory and its 6-channel data-encoding electronics are contained in a steel canister 23 cm in diameter and 91 cm long which is buried near underground nuclear shots.

Other nonvolatile memories are being investigated, such as ferroelectric arrays that are low-power, small, radiation-hardened, and compatible with the voltage levels of digital integrated circuits.

Item 13. *Sea-Ice Penetrometer Telemetry System*

A penetrometer was developed for the U. S. Coast Guard to remotely measure the thickness of sea ice. Implant characteristics are shown in Figure 6. An accelerometer in the penetrator senses deceleration as it passes through the ice, and the data are transmitted in real time to a receiver in the aircraft used to drop the penetrator. Two integrations of the deceleration-versus-time curve give velocity and depth profiles (Figure 7). By noting penetration depth when deceleration approaches zero, indicating that the penetrator is entering the water below the ice, ice thickness is determined within 17 cm. Ice thicknesses of up to 3 meters can be measured.

Item 14. *Solar Aureole Radiation Measurement*

Solar photography systems have been developed, including processing chemistry for producing wide-latitude negatives, to directly photograph the sun and surrounding sky to quantitatively determine the apparent radiated energy of the solar aureole under various cloud conditions and sun positions (Figure 8). The data-reduction method uses sensitometry (a technique for measuring the density variation of photosensitive materials caused by their response to incident energy) to read the wide-latitude negatives, which may have a density variation of up to six orders of magnitude.

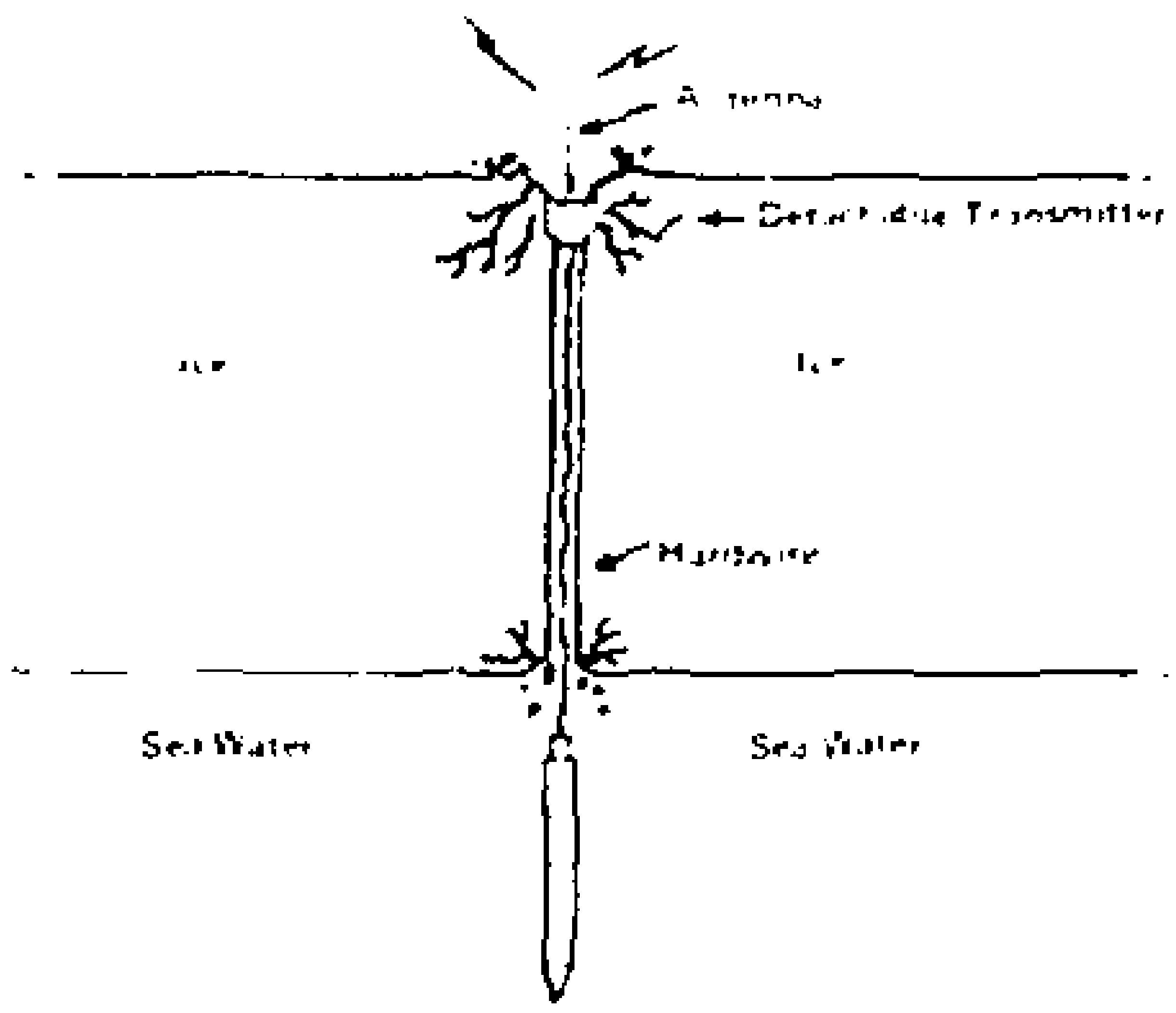

Figure 6 Sea ice penetrometer during penetration

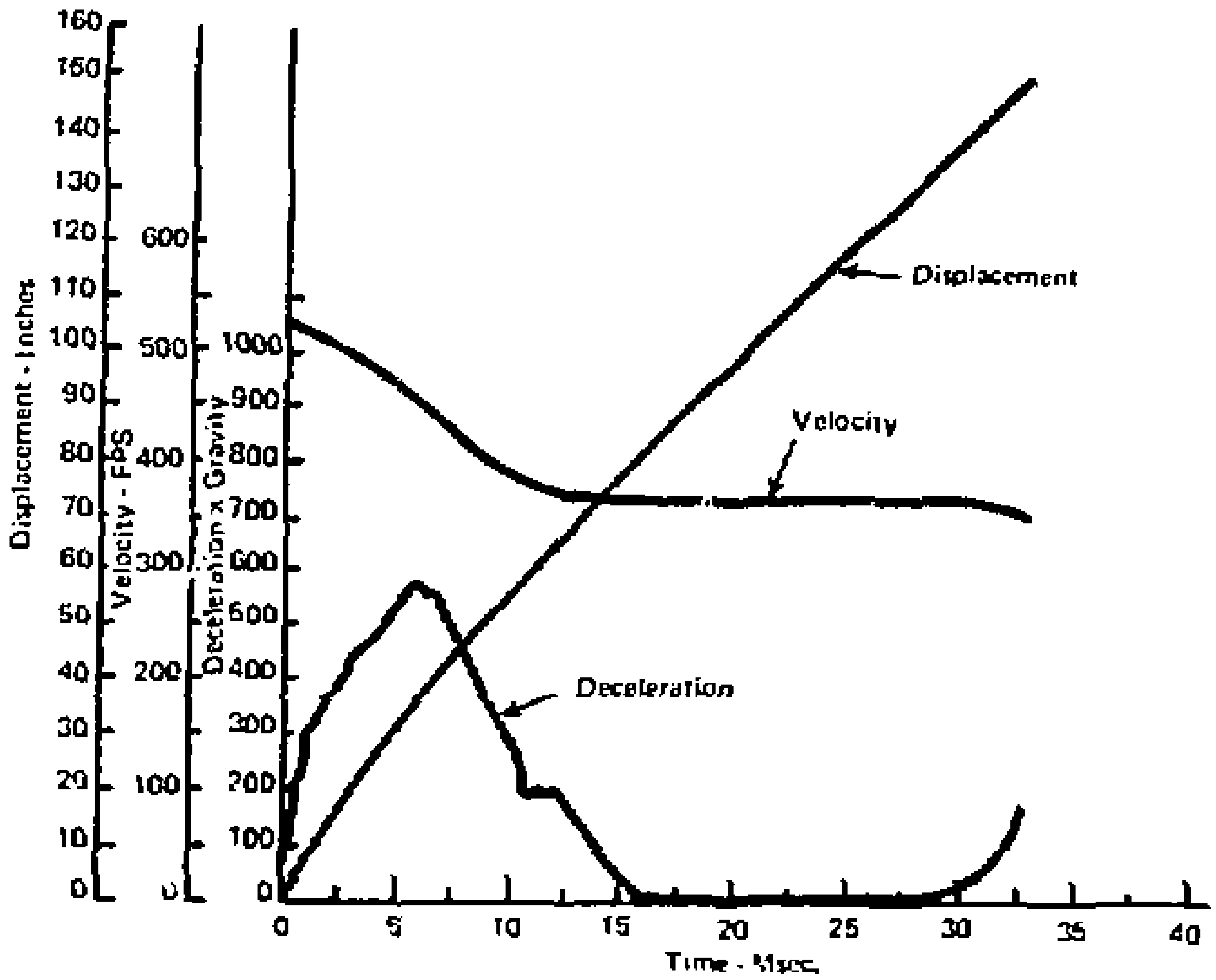

Figure 7. Typical plot for sea ice penetrometer

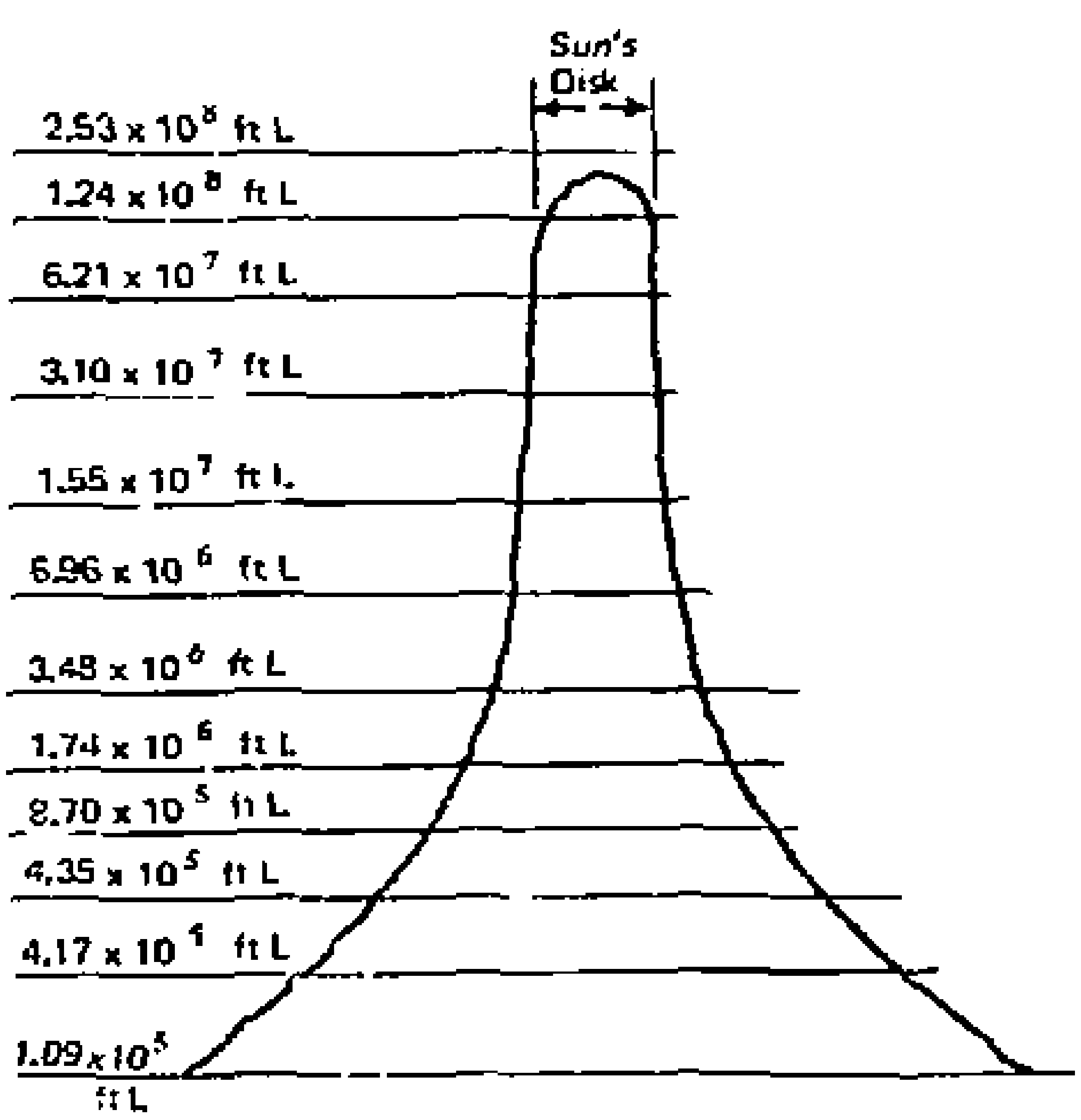

Figure 8. Analog plot and isodensity trace in foot-Lamberts (ft L) of . . . tograph of the sun taken on an overcas. . .

Item 15. *Holographic High-Density Data Recording on Reusable Media*

A method is being developed to achieve high-density data recording on an erasable, reusable medium. Holographic recording in the desired format at a repetition rate of up to 500 kHz using optical light guides has been demonstrated in the laboratory. Typical optical pulses are 10 to 50 nanoseconds in duration. Recording, erasing, and re-recording of holographic data on reusable thermoplastic materials has also been demonstrated in the laboratory. These techniques could be used where space is at a premium, as in a satellite.

Item 16. *Cinetheodolites*

A required characteristic of a class of shells or bombs is the consistency of the ballistic trajectory. To minimize the number of tests required to demonstrate this characteristic, an accurate trajectory-measuring system is necessary. Cinetheodolite tracking systems obtain such high-accuracy trajectory data. Tracking is manual after the target has been acquired by radar. Data, recorded on film, consist of the target image on which are superimposed cross hairs that locate the optical boresight axis and the numerical azimuth

DATA ACQUISITION SYSTEMS

and elevation of the mechanical boresight axis. A network of nine Contraves Model C cinetheodolites obtains trajectory information on targets requiring accuracies exceeding radar capability. The cinetheodolites are located along the main flight path at Tonopah Test Range. Three units are movable to any of several prepared pads to provide as nearly ideal geometry as possible for any given test. These movable units are equipped with radio-frequency communication and timing systems; the fixed units are linked to a land-line system. Frame rates available are 5, 10, and 20 pictures per second with either black and white or color film (Figure 9).

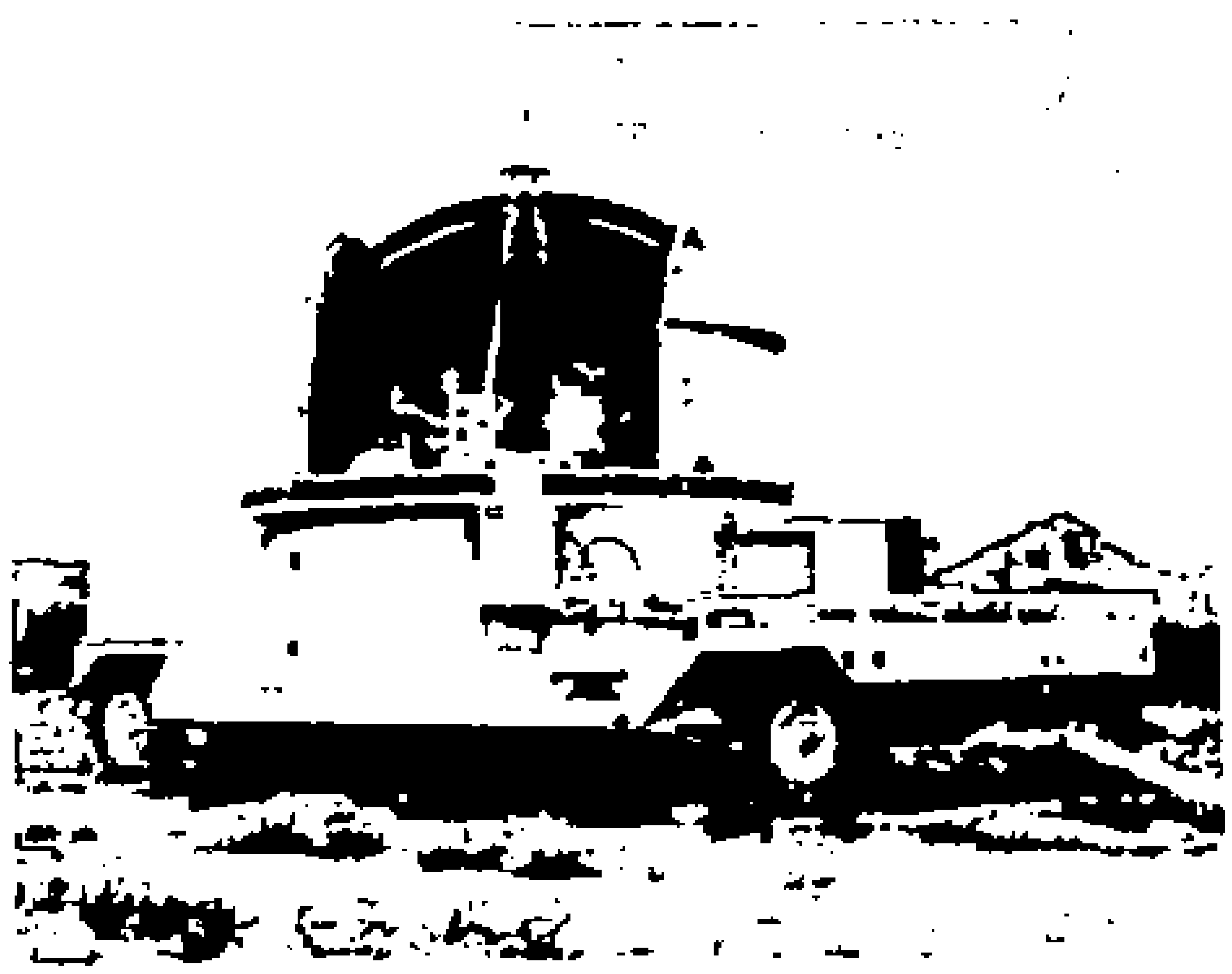

Figure 9. Mobile Contraves cinetheodolite

Item 17. *Laser Tracker*

The requirement for obtaining detailed pictures and accurate trajectory data on highly dynamic targets led to the development of a laser tracker (Figure 10). The laser illuminates the target, and the receiver optics projects the return spot on the optical receiver where it is centered. A shaft encoder on a gimballed mirror records azimuth and elevation angles. Range information is obtained by modulating the laser beam with a continuous-wave signal and measuring the phase shift.

The tracker is used to record trajectory data on rocket sleds and small free-flight missiles. Time-event photography of high-velocity flights occurs at rates as great as 400 frames per second on color film and 800 frames per second on black and white film. System resolution of trajectory information is 0.1 milliradian in both azimuth and elevation, and 0.75 meter in range. Tracking range extends to 6 kilometers for a "cooperative" target carrying 1000 square centimeters of Scotchlite, or to 12 kilometers if the target carries a glass corner-cube reflector. Slew rates and accelerations are 3.3 radians/sec and 2.0 radians/sec^2, respectively.

Item 18. *Radars at Tonopah Test Range*

Five radars at Tonopah Test Range provide target acquisition, trajectory data measurement, test-vehicle recovery data, and range safety (Figure 11). As target-acquisition systems, radars transfer their data to a system which calculates a parallax correction for all other tracking systems at the range having mounts that can be automatically driven. The mounts are driven with the corrected radar data until the target is acquired, after which a human operator takes over the tracking operation. Radar collects trajectory data for test analysis and evaluation only when target size and location preclude successful use of more accurate tracking systems (e.g., the cinetheodolites). When a test vehicle must be recovered, radar data are processed through a digital computer that provides an immediately available impact location.

Item 19. *Gun Projectile Doppler Radar Velocimeter*

To prove that gun-fired projectiles with nuclear warheads have the same ballistic properties as conventional projectiles, it is necessary to accurately measure the velocity of the shell as it emerges from the gun barrel. A Doppler radar was developed and has been successfully used to measure the average velocity of a gun-fired shell between the time it emerges from the gun barrel and the time muzzle blast arrives at the radar mounted at the rear of the gun (Figure 12). Measurement before blast arrival at the radar is a unique capability of the system.

The usual targets are shells having diameters from 155 to 203 millimeters. When the system is set to one of five apertures, each of which is approximately 150 m/sec wide, it will measure velocities from 150 to 1000 m/sec. Measurement uncertainty is 0.07 percent within 3-sigma limits. The Doppler radar velocimeter is more reliable than a dual streak-camera system, and precludes the time delays associated with film processing and reading. Another capability of the velocimeter is a diagnostic indication when coning of a shell occurs (obtained from fine structure in a trace of the return pulse).

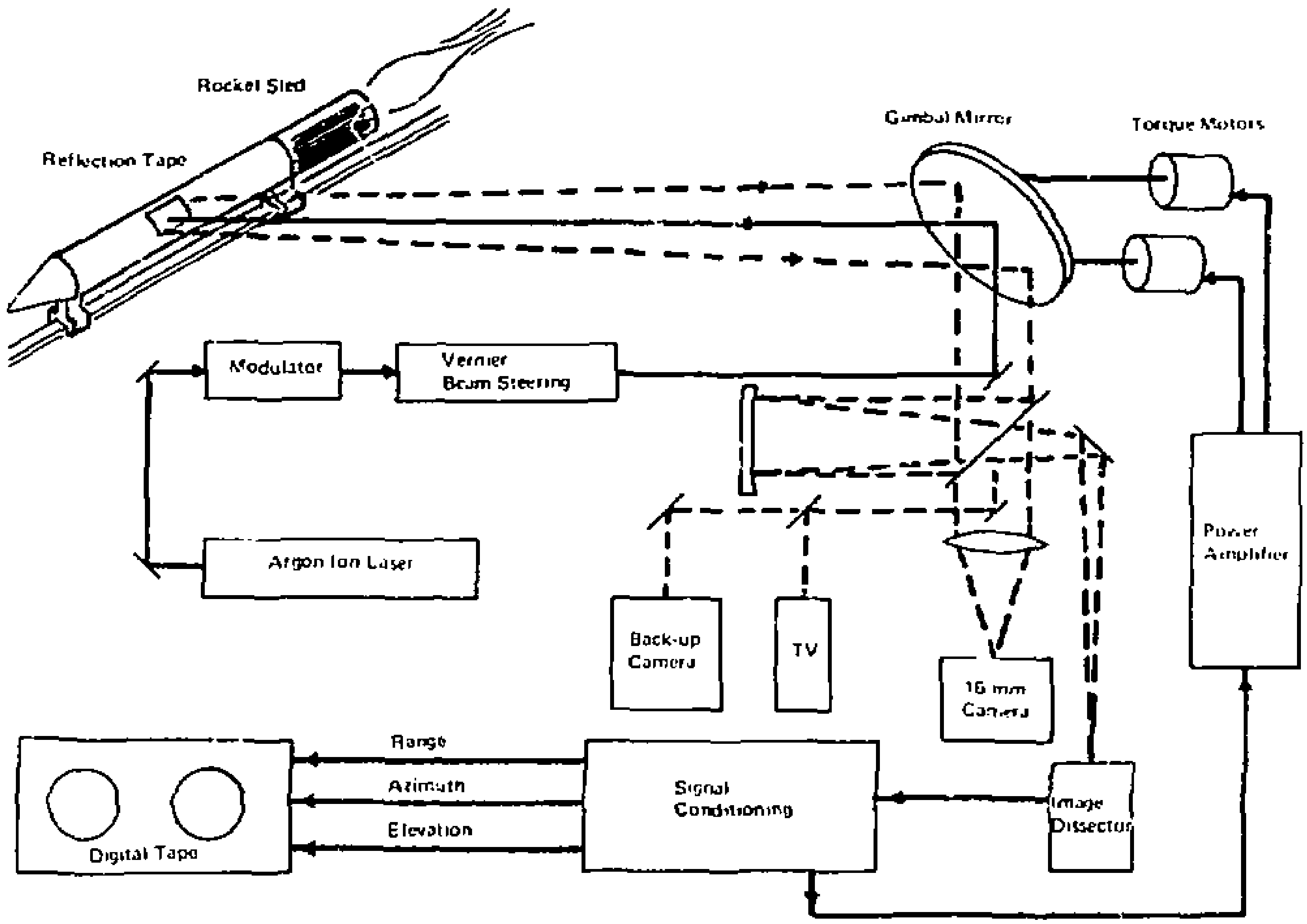

Figure 10. Laser tracker

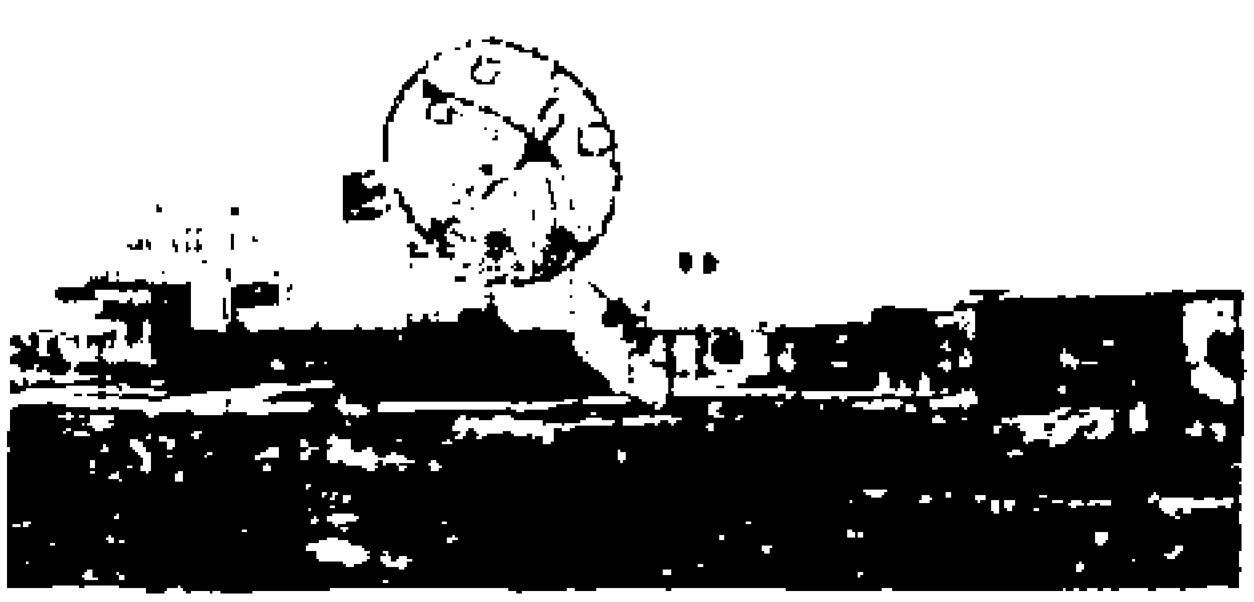

Figure 11. Instrumentation radar at Tonopah Test Range

Item 20. *Telemetry Ground Stations*

Telemetry ground stations receive and record data transmitted by telemetry systems aboard test vehicles. To obtain the best signal at the very-high and ultra-high frequencies transmitted, receiving antennas either are pointed in the general direction of the target or are placed on tracking mounts to follow its trajectory. Tonopah Test Range has three fixed and three trailer-mounted transportable telemetry ground stations to provide good coverage of all portions of the range. All stations have 1.5-MHz seven-track tape recorders, diversity combining S and L band receivers, and a common Inter-Range Instrumentation Group B time standard.

DATA ACQUISITION SYSTEMS

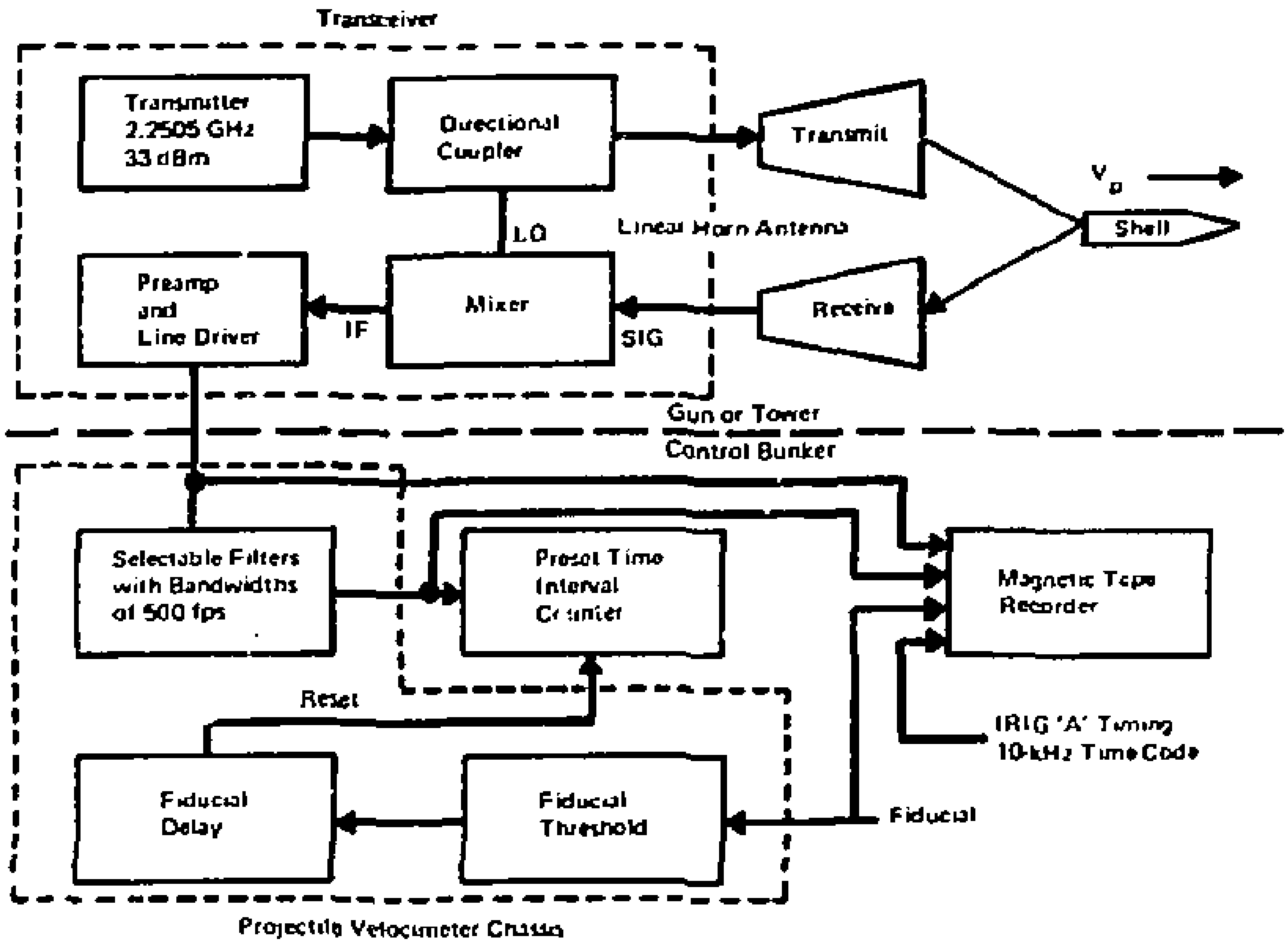

Figure 12. Block diagram of continuous-wave Doppler system

Item 21. *Optical Tracking*

Because on-board instrumentation cannot monitor everything that could malfunction during ballistic tests, Sandia has several tracking-telescope systems at the Tonopah Test Range and Barking Sands, Hawaii, to obtain event, attitude, and documentary photography. Eight of these systems have 40-cm-diameter primary mirrors with a focal length of 3 meters. One system has a 61-cm-diameter primary and a basic focal length of 3 meters that can be optically amplified to 6 meters. The tracking telescope *includes an automatic focus correction system for a* 1.5 to 90 km range to insure high quality photography. *The cameras use either 16, 35, or 70 mm film at rates to* 360 pictures per second. The telescopes are on various fixed and mobile tracking mounts that have azimuth and elevation slew rates and accelerations up to a maximum of 1.5 rad/sec and 1.5 rad/sec^2, respectively.

Item 22. *Airborne Instrumentation Platforms*

Studies of the earth's magnetic field require accurately pointed optical instruments at precisely located airborne positions almost anywhere in the world. Extensive scientific data-gathering systems have been developed for use on two ERDA-assigned NC-135 aircraft equipped with inertial navigation systems.

Magnetic-field tracing experiments require sensitive optical equipment such as intensified television, film *camera, and spectrographic systems to view both the* injection of barium into the earth's magnetic field and its *motion in the field. Continuous communications and* experiment coordination are provided by high-frequency radio and very-high-frequency satellite channels. The extremely important instrument-platform position are provided by dual inertial navigational systems, and in addition data are used by an on-board minicomputer to generate precise pointing angles for the optical instruments.

Flight position, and pointing parameters are recorded and available in digital format for in-flight processing, near real-time data reduction, and quick-look determination of mission results.

Item 23. *Long-Duration Stratospheric Composition Studies*

A series of cooperative experiments provides scientific data on the chemical composition of the stratosphere. At balloon float altitudes of 25 to 50 km, payloads weighing up to 200 kg gather data for 24 or more hours. In addition to providing overall payload design, integration, and engineering support, Sandia fields such scientific instruments as mass, ultraviolet, and infrared spectrometers, and special wind-drift measuring devices (Figure 13).

Figure 13. Instrumented balloon

Item 24. *Stellar X-Ray Experiment*

Low-energy x-radiation from two sources in the constellation Cassiopeia were studied in a stellar x-ray experiment. Sandia provided the rocket carrier system, telemetry, attitude control, and recovery system as well as range facilities and support.

Because x-rays are absorbed by the upper atmosphere, such studies must be done at altitudes above 100 km. A Terrier booster with a Sandhawk second stage carried the 33-cm-diameter, 330-cm-long, 193-kg payload to an apogee of 200 km.

The trajectory provided approximately 7 minutes above 100 km altitude, with 1-1/2 minutes allowed for maneuvering the payload to the proper pointing positions and 5-1/2 minutes for data taking.

Twenty-eight channels of frequency-modulated, multiplexed telemetry feeding two transmitters carried x-ray data, state-of-health information, and the position and rate information necessary for attitude control. The star camera provided the only on-board data storage. Star-field photographs taken at a rate of approximately one per second provided a means of resolving the pointing direction to within 0.0017 radian.

Item 25. *Rocket Capabilities*

Rockets are used as instrumentation platforms for high-altitude tests. In the following table are rocket systems that Sandia has modified or de loped.

Name	Payload Diameter (cm)	Payload Weight (kg)	Payload Apogee (km)
Nike Cajun	15	35	130
Nike Apache	15	35	170
Nike Tomahawk	23	57	325
Terrier Tomahawk	23	80	390
Sandhawk Tomahawk	23	75	540
Nike Tomahawk	30	115	175
Sandhawk	33	120	155
Terrier Sandhawk	33	95	420
Terrier Malemute	41	160	500
Terrier Sandhawk	43	350	125
Strypi IIR	79	800	280
Strypi IVR	79	400	600

DATA ACQUISITION SYSTEMS

The following systems are used for ablation and erosion studies.

Name	Payload Diameter (cm)	Payload Weight (kg)	Payload Experiment Velocity (m/sec)
Terrier Recruit	23	32	2640
Talos Terrier Recruit	23	32	3170
Strypi VII, 3-Stage	52	50	6130*
Strypi VII, 3-Stage	52	60	5910**

*At -25° reentry angle.
**At -35° reentry angle.

In-flight functions can be controlled by on-board programmers or by radio command. Parachute deceleration and recovery systems are available for both land and water impact (Figure 14).

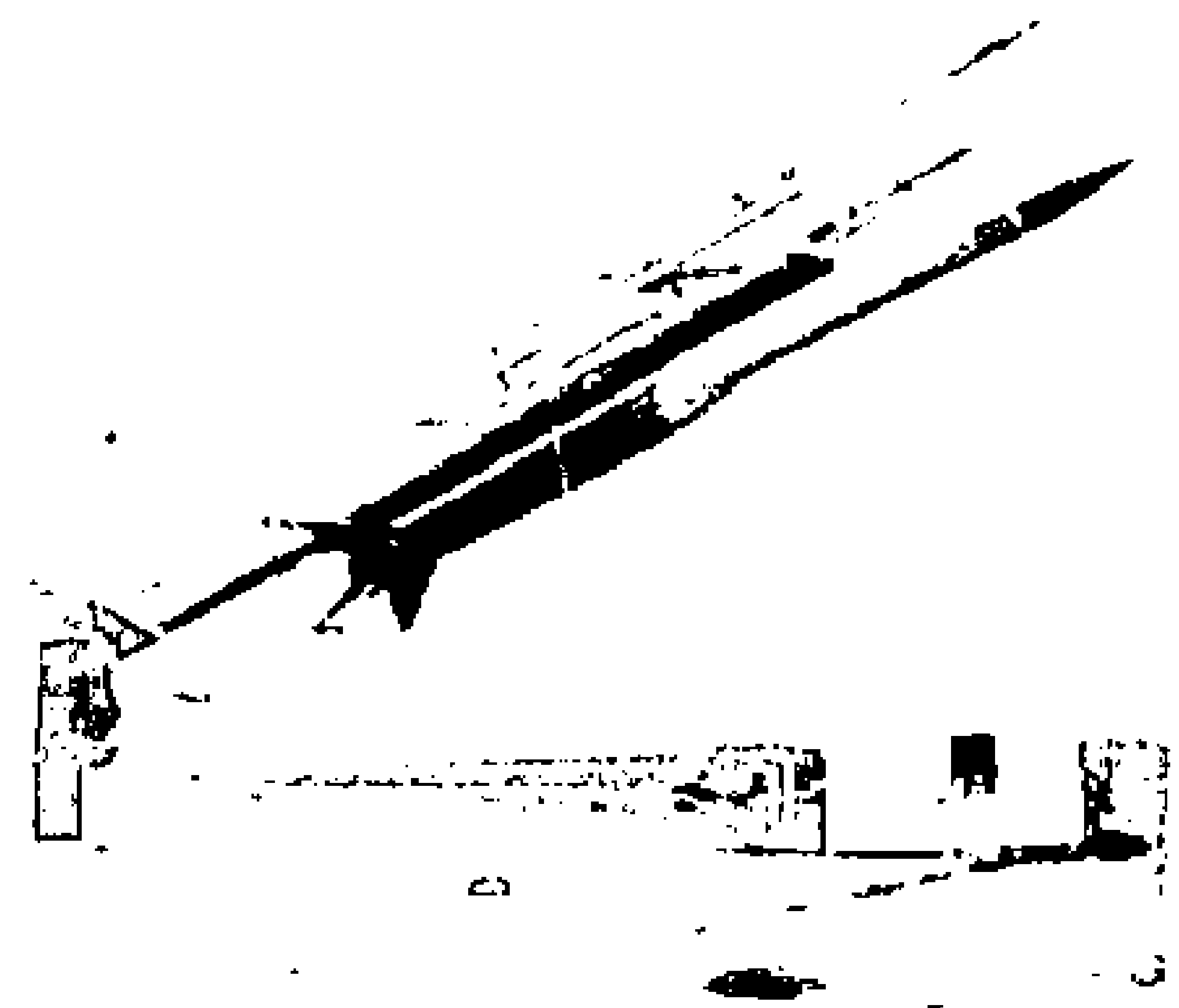

Figure 14. Talos-Terrier-Recruit rocket assembly used for rain erosion studies

Item 26. *Mobile Instrumentation*

Geological conditions, logistics, and economic considerations preclude having permanent instrumentation capabilities at all test locations. Instead, Sandia has more than 100 large mobile instrumentation trailers. Most of these are 3 meters wide by 12.2 meters long. Each trailer is a complete instrumentation system with its own Diesel power generators, air conditioning, control systems, and instrumentation. The instrumentation is mainly oscilloscope and magnetic tape recording. Tape channels are usually multiplexed and frequency-modulated to obtain maximum tape packing density, but each machine also has wide-band frequency modulation and direct-record options for higher-frequency response.

A capability also exists of fielding recording systems that are sufficiently compact and light to be transportable to any place in the world; a complete system was flown to Hawaii as excess baggage. Acquisition and transmitting systems consisting of both hardwire and radio-frequency standard IRIG voltage-controlled oscillators (about 150 channels) and 6-kHz carrier (about 100 channels) are available. The magnetic tape recording units can be packaged in a suitcase-size container.

Item 27. *Determination of Impact Velocity*

The velocity of test vehicles with respect to the earth is of primary importance for many tests. Such data are very difficult and expensive to obtain, especially at very remote locations, by conventional methods. The problem is solved inexpensively by recording in the drop aircraft, or another airborne platform, signal-strength variations from the vehicle's telemetry transmitter. Impact velocities are obtained very quickly by analyzing the frequency of the periodic reduction of radio-frequency signal strength ("nulls") which are caused by the effect of the multipaths of transmission and are detected by the telemetry receiver's automatic gain control circuitry (Figure 15). Experiments have proved that the vertical component of the impact velocity can be determined to within a 2-percent error.

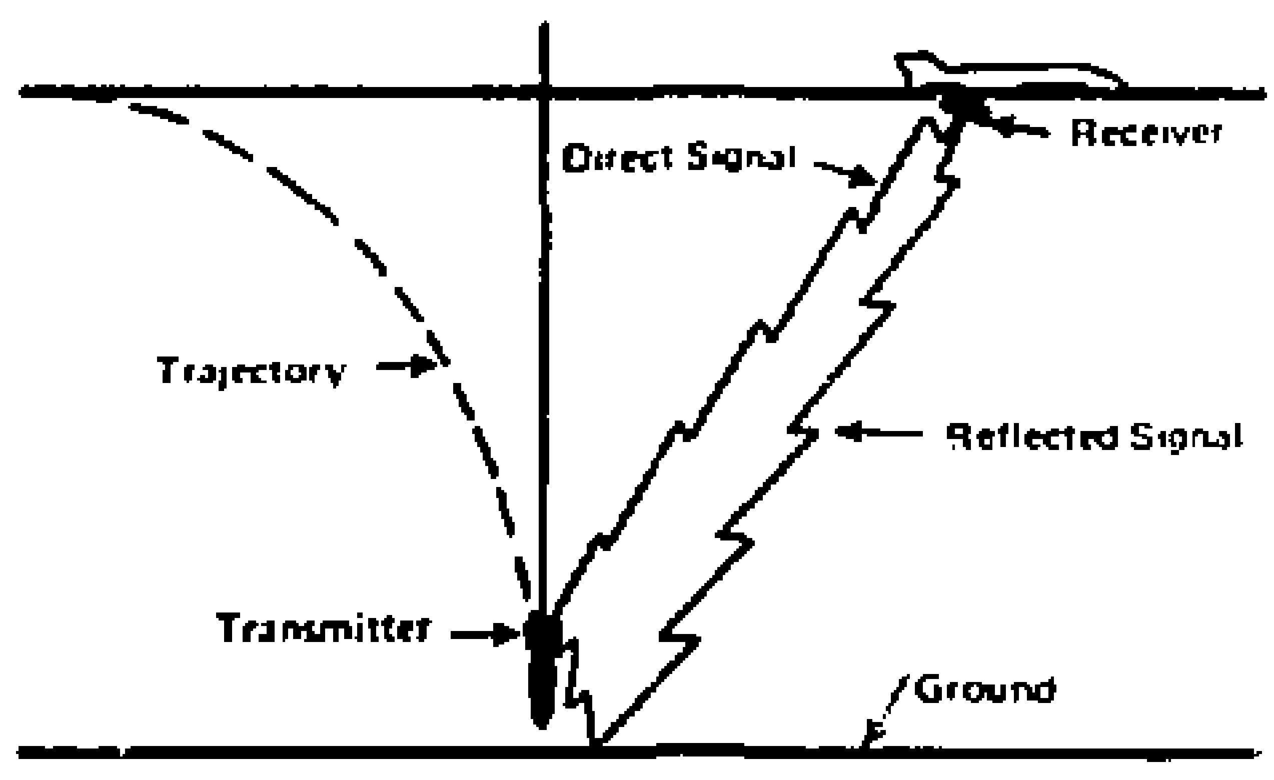

Figure 15. Signal multipath used to determine vertical velocity

SPECIAL INSTRUMENTATION FACILITIES

The development of data acquisition instrumentation for diverse activities such as meteorological, photometrics, quality assurance, and radiation analysis is provided by the special instrumentation activity.

Meteorological Instrumentation Facilities

Meteorological data are required for test safety, weather prediction, calculation of aeroballistic parameters, estimation of refraction effects on tracking instrumentation, and determination of rocket-launcher settings. Test safety involves calculation of potentially damage-causing shock-wave foci for explosive tests, and monitoring atmospheric electrostatic potential to warn of levels hazardous for explosives handling or for outdoor work in locations favorable for lightning strikes. Weather prediction makes it possible to avoid scheduling tests during adverse conditions for both test safety and suitability of atmospheric conditions for optical test instrumentation. Calculation of aeroballistic parameters requires knowledge of temperature, relative humidity, pressure, density, and winds as a function of altitude. This same information is used to estimate refraction corrections for optical and radio frequency instruments and to adjust rocket-launcher settings. Meteorological instrumentation systems have been developed for each principal testing location, each system tailored to the testing needs that predominate at the particular site. (Items 1-3)*

Photometric Instrumentation Facilities

Photometrics is a way of measuring properties that can be sensed in the optical spectrum from infrared through visible and into the ultraviolet. In most cases the phenomena are recorded on film or other photosensitive media for future analysis. Facilities for this work cover the fields of sensitometry, spectrophotometry, spectral radiometry, and time-resolved spectroscopy.

Facilities are available both in the laboratory and for field use to measure the photometric properties of various sources including optical recording materials. Spectrophotometry and spectral radiometry are conducted for both laboratory and field sources. Spectroscopy is applied to time-resolved photographic spectral studies of sources of low intrinsic radiance. Both cine and streak modes of operation are available.

*See Highlights below.

Spectrophotometry

Wavelength	0.185 to 3.0 microns
Modes:	Transmission
	Reflection
	Absorbance
	Percent concentration
Physical States:	Gas
	Liquid
	Solid
Readout	Chart recording
	Digital display
	Computer interface

Spectral Radiometry

Wavelength	0.2 to 1.1 microns
Response Time	10 nanoseconds
Readout:	Oscilloscope
Calibration	Black body source
	Irradiance standard
	Radiance standard

Spectroscopy

Wavelength:	Dependent upon photocathode response
Streak Rate:	1 to 100 nanoseconds per millimeter
Frame Rate	5×10^5 to 2×10^7 frames per second

Quality Assurance System-Test Equipment

To support the Quality Assurance activity in component and system testing, test equipment is designed, fabricated, and maintained for specific programs. This includes automated test beds that provide the environmental inputs necessary for system or component operation, and record critical system outputs as well as a variety of diagnostic information. The equipment is designed to test complete systems in simulated-use sequences. Real-time data are collected by hardwire in both digital and analog modes. Many systems are designed to meet a specific test requirement, e.g., for testing during system development to prove design intent; critical limited-life component testing, and testing in critical assembly areas.

SPECIAL INSTRUMENTATION FACILITIES

Test systems include: investigation of the operation of environment-sensing devices, failure-mode duplication testing, opto-electronic simultaneity instrumentation development testing, and performance tests of systems subjected to accidental or unusual environments. (Items 4-5)

System Test Equipment Capabilities

Environments and forcing functions
- Acceleration
- Adaption kit simulation
- Aircraft drop
- Altitude or depth
- Combined environments
- Linear or rotary force
- Impact
- Dynamic parachute deployment
- Radar target simulation
- Extreme temperature

Measurements
- Digitization, high-speed waveforms
- Energy
- Flow or mass rates of pressure systems
- Frequency
- Neutron flux
- Radio-frequency power, average and peak
- Simultaneity

Special tests
- Critical materials evaluations
- Live detonators
- Explosive activation and containment
- Life testing
- Spin rockets

Radiation Analysis Instrumentation Facilities

Data acquisition in the laboratory from samples collected in the field is a significant aspect of radiation analysis. Facilities include automated alpha spectrometry, a radiation counting laboratory for samples having picocurie activity, and a large variety of other apparatus. (Item 6)

• • • • • • *HIGHLIGHTS* • • • • • •

Item 1. *Albuquerque Lightning Early Warning and Meteorological System*

This system collects potential gradient and meteorological information from remote sites around the Sandia-Albuquerque area for the purpose of establishing safe operating conditions at sites where explosives are used, and displays the information for the operator at the control station. The information is also retransmitted to special displays at explosive-handling test sites for safety purposes. Data collection is over telephone lines and interrogated radio-frequency link. Retransmission is over telephone lines and radio-frequency output. The entire system is controlled by a central minicomputer. Operator output information is on a cathode-ray-tube display and long-term data storage is on cassette cartridges.

Item 2. *Tonopah Test Range Meteorological System*

At Tonopah Test Range the meteorological system uses a radar-directed L-band telemetry antenna to receive temperature and relative-humidity data from a radiosonde attached to a weather balloon. Meteorological and radar-tracking data are processed in real time for digital magnetic tape recording. The recorded data are then computer processed to provide a listing of altitude, temperature, relative humidity, pressure, density, and wind information, or they can be input directly into programs requiring meteorological data.

Item 3. *Kauai Test Range Meteorological Instrumentation*

Fixed and mobile lower and upper atmospheric wind-measurement systems are used to allow accurate rocket launcher settings. Meteorological balloons are tracked by modified Nike/Ajax radars; the current wind profile through which the rocket will fly is determined by computers and is considered in launcher-setting computations.

Item 4. *Detonator Simultaneity Testing*

Detonators and their firing systems are evaluated by measuring the simultaneity of detonator function time to within ± 2 nanoseconds. This measurement is made by using the light generated by the initial shock wave from each detonator (referred to as detonator breakout). The shock wave compresses the trapped air, causing it to emit light. This light pulse is sometimes enhanced by a thin coat of aluminum silicofluoride on the detonator surface. Bifurcated fiber optics transport the light pulse out of the explosive containment box to two separate photodiodes which convert the impulse into an electrical signal. The bifurcated fiber optics and two photodiodes provide measurement redundancy.

A multichannel measurement system is used to record the time interval from a common start signal (usually detonator current) to each detonator breakout signal.

Item 5. *Missile Environment Simulation*

Centrifuge simulation of a phase of flight profile of a current missile system proved to be a fixturing design challenge. Requirements of the profile were a 2-second period of +80 x gravity followed by a 2-second period of -40 x gravity, with a transition time of less than 200 milliseconds. Shock pulses during the transition were not to exceed 350 x gravity for more than 6 milliseconds or 100 x gravity for more than 10 milliseconds. Acceleration normal to the axis of the test unit was to be maintained at a constant 78 x gravity during the entire profile.

Fast transition is accomplished by pivoting the components about their axes at a predetermined point during the gravity profile. Radial forces acting on an adjustable counterweight set for a slight imbalance provide the energy for fixture rotation. The latching mechanism is released by a gas-driven cylinder and the shock at the end of rotation is mitigated by polymer material. Acceleration normal to the test unit is controlled by slowing the centrifuge during the critical time of rotation.

Test results proved that all design objectives were achieved. Time of transition is approximately 100 milliseconds and shock is reduced to less than 70 x gravity for 10 milliseconds.

Item 6. *Radiation Counting Laboratory*

A radiation-counting laboratory capable of counting radioactive samples in the picocurie range is maintained for health physics, environmental sampling, and tracer studies. The laboratory includes a selection of solid-state, proportional-chamber, Geiger-Mueller, and scintillation detectors in conjunction with a variety of instrumentation (pulse height and/or shape discriminators, single and multichannel analyzers, and multiscalers).

The samples are counted in the gross or spectrum mode, either individually or in automated counting systems, with immediate display or data storage, and with data reduction by computer if required.

A variety of low-background shields and coincidence networks is also available.

DATA REDUCTION SYSTEMS

Data reduction converts test data from the format and medium in which it was acquired *to a format and medium usable by the test requester either directly or for subsequent analysis.* Data coming into the reduction process are either recorded on magnetic tape or on a pictorial medium (film, photographic print, or chart paper) which requires optical processing. Output from data reduction can include oscillographic stripcharts or oscilloscope photos derived from data on magnetic tape, a digital magnetic tape in a standard format, and computer-generated plots of reduced data.

Magnetic Tape Processing

Magnetic tape processing begins with an oscillographic stripchart that allows a first assessment of test data as soon as possible after a test. Judgments are made on the basis of these "quick-look" data as to whether test objectives have been met. About half of all data channels require no processing beyond the quick-look stage. The other half, however, are usually converted to digital data for secondary processing by computers. This conversion involves editing and digitizing or pulse-modulation decommutation.

Three facilities are capable of processing analog or *digital data recorded on either analog or digital magnetic tape. The total tape-processing workload among the* three is approximately 50,000 data channels annually. A data channel is one data variable, usually from a single transducer. (Items 1-3)*

Optical Data Processing

Optical data processing transforms graphic into digital data to permit subsequent computer analysis. Capability exists to digitize a graphical trace recorded on a Polaroid print, stripchart, or frame of film, to track and digitize one point per frame for a sequence of frames photographed with a cinetheodolite; to obtain time tags for events pictorially recorded on film; and to scan an image, either transparent or opaque, to measure image density. (Items 4-5)

*See Highlights below.

* * * * * * *HIGHLIGHTS* * * * * * *

Item 1. *Oscilloscope Display Digitizer*

Two versions of an economical vidicon digitizer have been developed that use any commercial oscilloscope to digitize fast transient or repetitive waveforms at an effective sampling rate up to 25 gigahertz. One model is for laboratory operations and the other is portable for field operations.

Unique features include the ability to simultaneously photograph and digitize the trace, freeing the operator from having to precisely adjust the vertical trace position.

Light from a trace on the cathode ray tube of the oscilloscope is coupled to the target of the vidicon tube with a beam splitter and mirror. The vidicon tube converts the light image to an electrical signal which is sampled and converted to 500 nine-bit digital words. These are stored in a metal-oxide-semiconductor memory from which the data can be extracted and viewed on the display unit. The data can also be directed to a minicomputer or other peripheral device.

In addition to its portability, the field model has the advantage that the memory is compatible with either fast or slow peripheral devices. Calibration signals are digitized and analyzed by a computer, which then uses the calibration factors to properly scale the data in engineering units and to correct for vertical and horizontal nonlinearities. With prior calibration, the digitizer is accurate to ±0.4 percent of full scale.

Item 2. *User-Oriented Data Reduction System*

A new data-playback/data-reduction system has been developed that consists of a state-of-the-art automated telemetry "front-end" coupled to a Control Data 6400 computer. The system allows users to interact with their data via graphics CRT consoles and perform a wide variety of secondary processing. Users can receive high-quality electrostatic plots during any step of the process within minutes of the request. The user-oriented system allows much of today's analog processing to be converted to digital.

The automated telemetry front-end provides fast, error-free signal processing of raw data recorded on magnetic tape in the field, and will process pulse-modulation formats in addition to digitizing analog signals. Digital data are copied onto disk storage and are thus made available to a battery of some 60 interlinked program modules appropriate to the interpretation and analysis needs of the user.

In the batch mode, the user requests the predetermined set of sequenced programs necessary to complete his reduction process. Figure 1 is a schematic of the playback data-reduction facility.

Requested library programs and the parameters needed by the programs are placed on punch cards and run on a demand-priority basis. Output typically consists of graphical plots.

In the interactive graphic mode, the user enters processing requests at the graphics terminal and may interrupt the processing at any point to request plots in hard copy or on the terminal screen. Human judgment may override, change or supplement the calculations of the computer program. On the terminal screen, an engineer using a light pen may alter the data, then if desired any program module may be reexecuted.

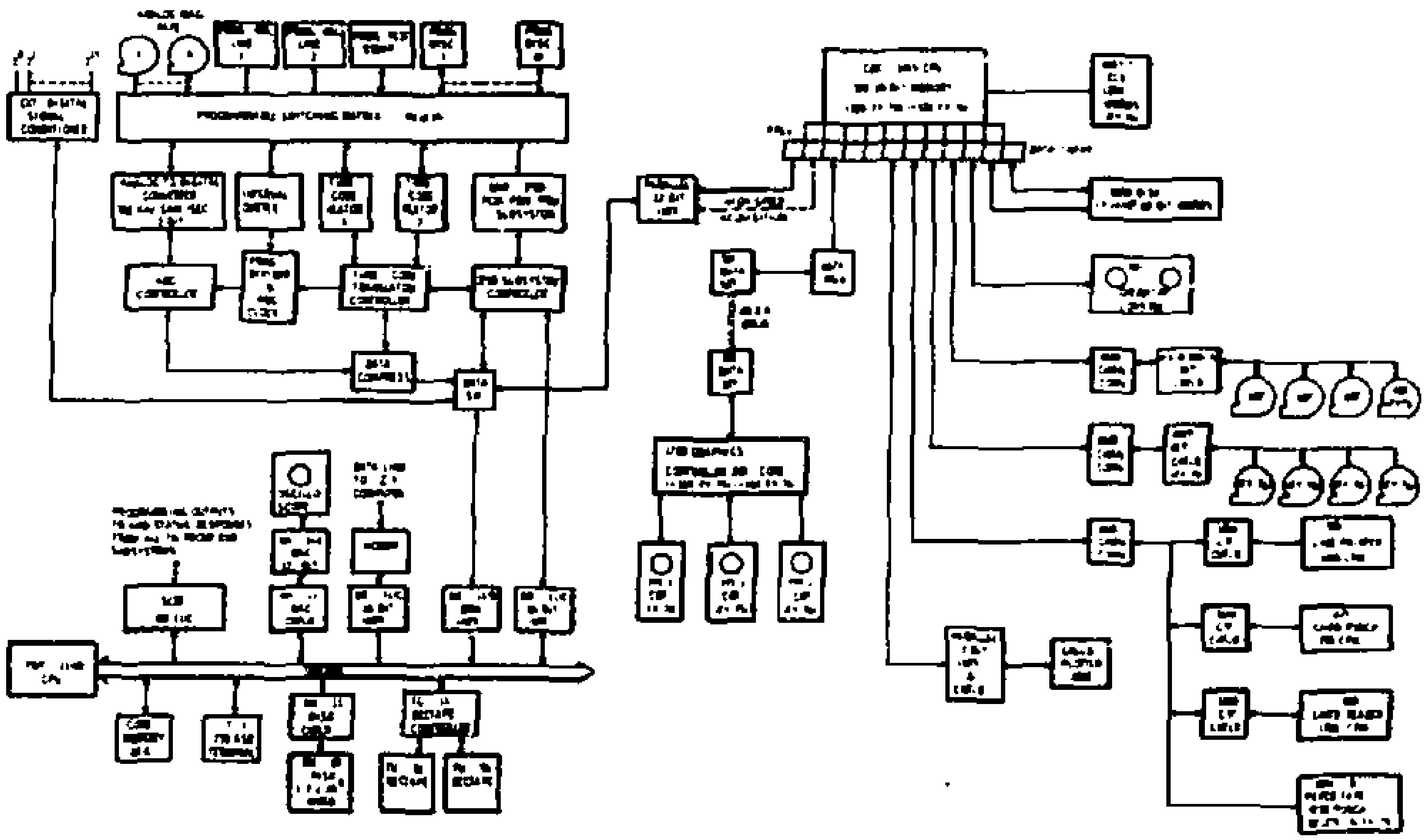

Figure 1. The CDC-6400 user-oriented data-reduction system

DATA REDUCTION SYSTEMS

Current Reduction Program Modules

- Calibration correction of raw data
- Conversion to engineering units
- Correlation functions
- Data entry, optical
- Data entry, radar
- Differentiation
- Filtering, digital
- Integration
- Pulse modulation decoding
- Reformatting of tape
- Shock spectrum calculation
- Statistical analyses

Item 3. *Data-Base Program for User-Oriented System*

A data-base gathering technique has been developed. A data base includes all information necessary to control the playback process, convert raw information to calibrated engineering units, and produce plots in the desired formats. Called Playback-Reduction User Network Editor (PRUNE), the technique uses Sandia's time-sharing computer system. The time-sharing terminal has two integral magnetic-tape cassettes that will record data-base information. The user inputs the required data-base parameters for a given test via the terminal in a fully conversational manner with the time-sharing computer. An editor identifies mistakes in data entry ranging from simple typographical errors to meaningless requests or formats. The partial or completed data base may be recorded on cassette at the user's terminal. At any future time, a partial or completed data base may be reentered into the time-sharing computer from the cassette for updating. The completed data base will be input to the user-oriented system through an identical terminal connected to a minicomputer in the telemetry front end.

Item 4. *Polaroid Print and Film Digitizing*

Data curves on a transparent or opaque medium may be digitized by three methods. First, on a Telereader, the image is projected onto a ground-glass screen on which the operator centers cross-hairs and presses a foot switch to produce a punched-card output. The second method uses an automatic print reader which is a computer-controlled scanner that tracks and digitizes a curve with operator assistance, producing a magnetic tape output. This is the faster and more generally used method. Film sizes of 16 and 35 mm as well as other data sizes to 28 cm x 28 cm can be accommodated.

A third method uses a sonic digitizer, a system where the operator holds a pen-like cursor and traces the curve to be digitized on a tablet with an X and Y array of microphones. The pen generates a spark that is acoustically coupled to the array, and X,Y coordinates are determined by acoustic propagation delay. Data output is on magnetic tape. Input data sizes to 50 cm x 50 cm can be accommodated.

Item 5. *Film Densitometers*

The automatic print reader may be used to measure film density of transparent images or brightness levels of opaque material that must be front-lighted. Better results are obtained with transparencies of 16 or 35-mm film because illumination of the film area is more nearly uniform. The system provides an output that is linear with respect to optical density. Addressable resolution of the system is 1:4000 with an optical resolution of 1:1000. Flexible operation is provided for selection of the area to be scanned and the spacing between the data points. Output is on 7-track, CDC-6400 compatible magnetic tape.