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An Automatic Position Detector for Handheld NDE Probes

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Handheld nondestructive evaluation (NDE) probes are widely used in the aerospace community. Data acquired manually are less reliable than data acquired by automatic methods. The use of handheld NDE probes could be significantly facilitated by a versatile device designed to remotely sense the spatial position of the probe each time a data point is acquired. Such a device, which will be referred to as an automatic position locator (APL), is currently under development and will be described in this report.

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PREFACE

The authors would like to thank R. L. Corbin, whose wealth of electronic knowledge was evidenced through many helpful discussions throughout the development of the automatic position locator circuitry. The authors also thank Dr. E. Johnson, whose excellent technical advice and encouragement was extremely helpful in the completion of this project.

CONTENTS

FIGURES

I. INTRODUCTION

Handheld nondestructive evaluation (NDE) probes are widely used in the aerospace community. This is especially true when data must be taken in the field, when a sample exhibits a complicated geometry, or when there is insufficient time to build an automated scanning apparatus. Data acquired manually is less reliable than data acquired by automatic methods. With the former technique, there is no assurance that the entire sample has been scanned, since a hardcopy image of the sample is not produced. The use of handheld NDE probes could be significantly facilitated by a versatile device designed to remotely sense the spatial position of the probe each time a data point is acquired. Such a device, which will be referred to as an automatic position locator (APL), is currently under development and will be described in this report.

II. THEORY OF OPERATION

The components that constitute the APL are depicted in Fig. 1. An ultrasonic transducer is mounted on the back side of the NDE probe. This transducer propagates

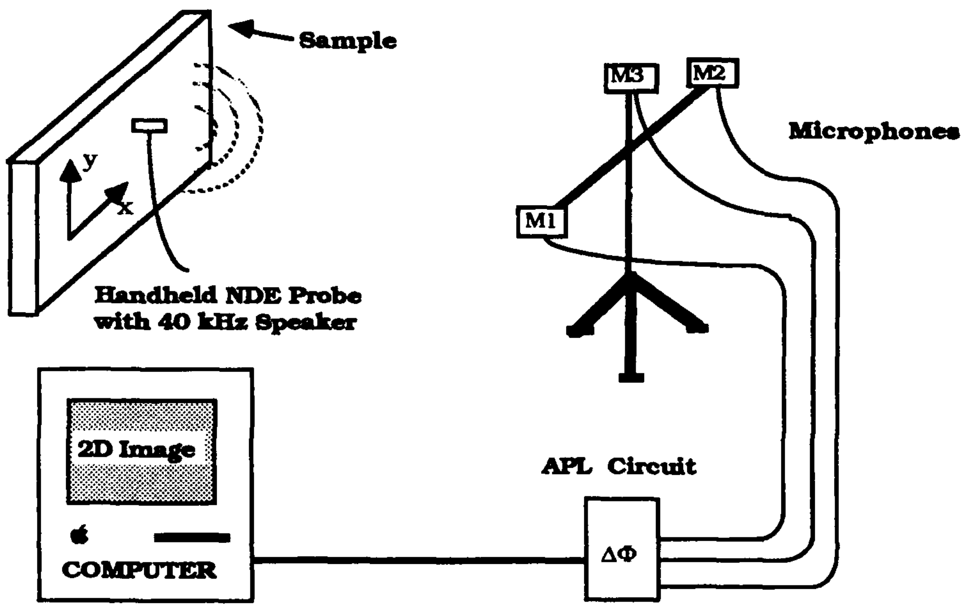

Fig. 1. Components That Constitute the APL

40 kHz sound waves in the opposite direction of the surface being scanned. This acoustic signal is then detected by three microphones (labeled M1, M2, and M3), which are attached to a stand several meters from the probe. The geometry associated with M1 and M2 is depicted in Fig. 2. The microphones are separated by a line of length 2L, which runs parallel to the sample surface at a distance R. The origin is defined by the intersection of the sample surface and the perpendicular bisector of the line between M1 and M2 in the plane of this figure. The probe is located at x. The difference in phase between the signal detected by M1 and that detected by M2 is given by the expression

$$\Delta\Phi_{12} = \frac{2\pi}{\lambda}\left[\sqrt{R^2 + (L + x)^2} - \sqrt{R^2 + (L - x)^2}\right] \qquad (1)$$

where λ is the 40 kHz wavelength in air ($\approx$ 0.83 cm). If one arranges the APL so that $x << L$, Eq. (1) reduces to

$$\Delta\Phi_{12} \approx \frac{4\pi x}{\lambda\sqrt{(R/L)^2 + 1}} \tag{2}$$

where $\Delta\Phi_{12}$ is directly proportional to x. Note that the wavelength is such that $\Delta\Phi_{12}$ may include multiple cycles of the ultrasound. Expressions similar to Eqs. (1) and (2) relate the phase difference between M1 and M3 to the y coordinate of the probe. The phases of the signal detected at each microphone can therefore be compared to determine the position of the probe relative to a fixed point on the sample surface. This comparison is performed by a circuit in the APL, which then digitizes the result for input into a Macintosh II computer. This circuit will be discussed subsequently. Software has been developed that permits the display of a grid overlaying a portion of the sample being scanned. As the probe is moved, the computer fills in each section of the grid with a color indicating the amplitude of the associated NDE signal. The result is a two-dimensional image, which can be inspected immediately and then stored for future use.

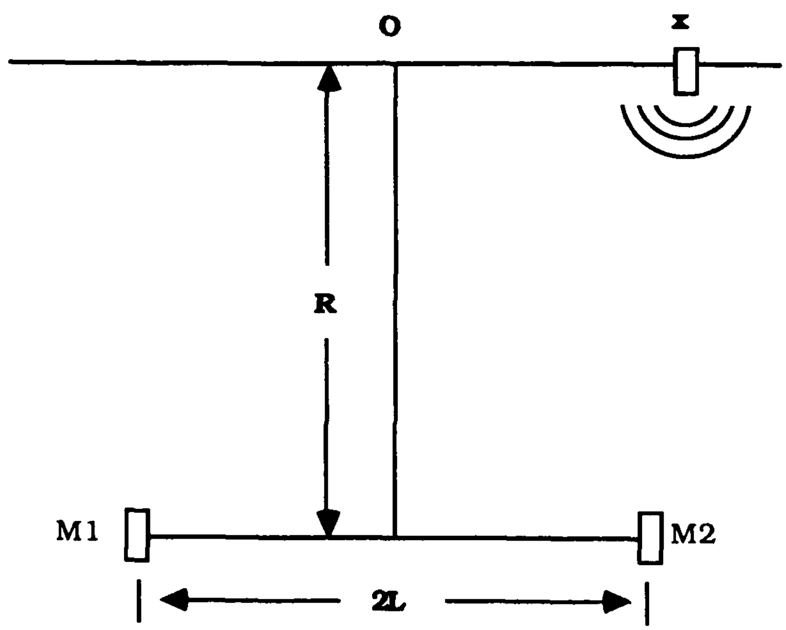

Fig. 2. A Top View of the Geometry Associated with the Microphones M1 and M2

III. CIRCUIT DESCRIPTION

A block diagram of the APL circuit is depicted in Fig. 3. The circuit contains a 40 kHz driver, which outputs to the transducer on the handheld NDE probe, and three receivers, which get their input from M1, M2, and M3 (see Fig. 1). The received signals pass through a 60 dB amplification stage, a 40 kHz bandpass filter, and then a phase locked loop (PLL) for final noise suppression. The synthesized 40 kHz square wave PLL outputs from M1 and M2 are then fed into the inputs of an up/down counter. These signals differ in phase because the positions of M1 and M2 are different with respect to the transducer. The counter outputs binary coded decimal (BCD) information, which indicates the phase difference between the two signals. This difference may consist of more than one complete cycle. The BCD signal is then channeled into the digital-to-analog (D/A) converter, where each complete cycle adds a 10 mV step to the output. When the difference is not an integral number of complete cycles, one of the BCD bits flickers, resulting in a 40 kHz pulsed output, as depicted in Fig. 4a. The pulse width is proportional to the phase difference (see Figs. 4a-4c). Consequently, when this pulsed output is passed through a low pass filter, a direct current (dc) signal is achieved, which interpolates between the 10 mV steps. This signal is then sent to a scaling amplifier and is digitized for input into a Macintosh II computer, which calculates the x position of the probe. The y position of the probe is determined in an identical fashion through comparison of the signals detected by M1 and M3.

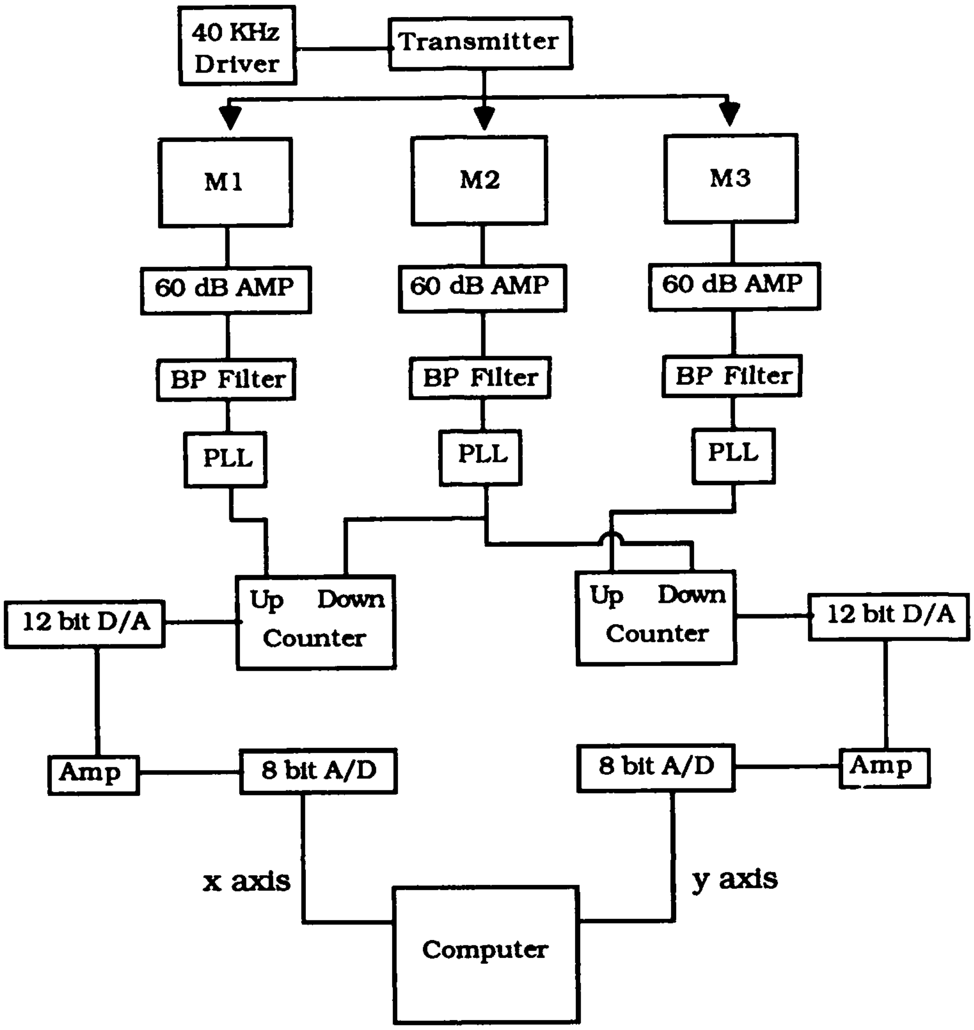

Fig. 3. APL Circuit Block Diagram

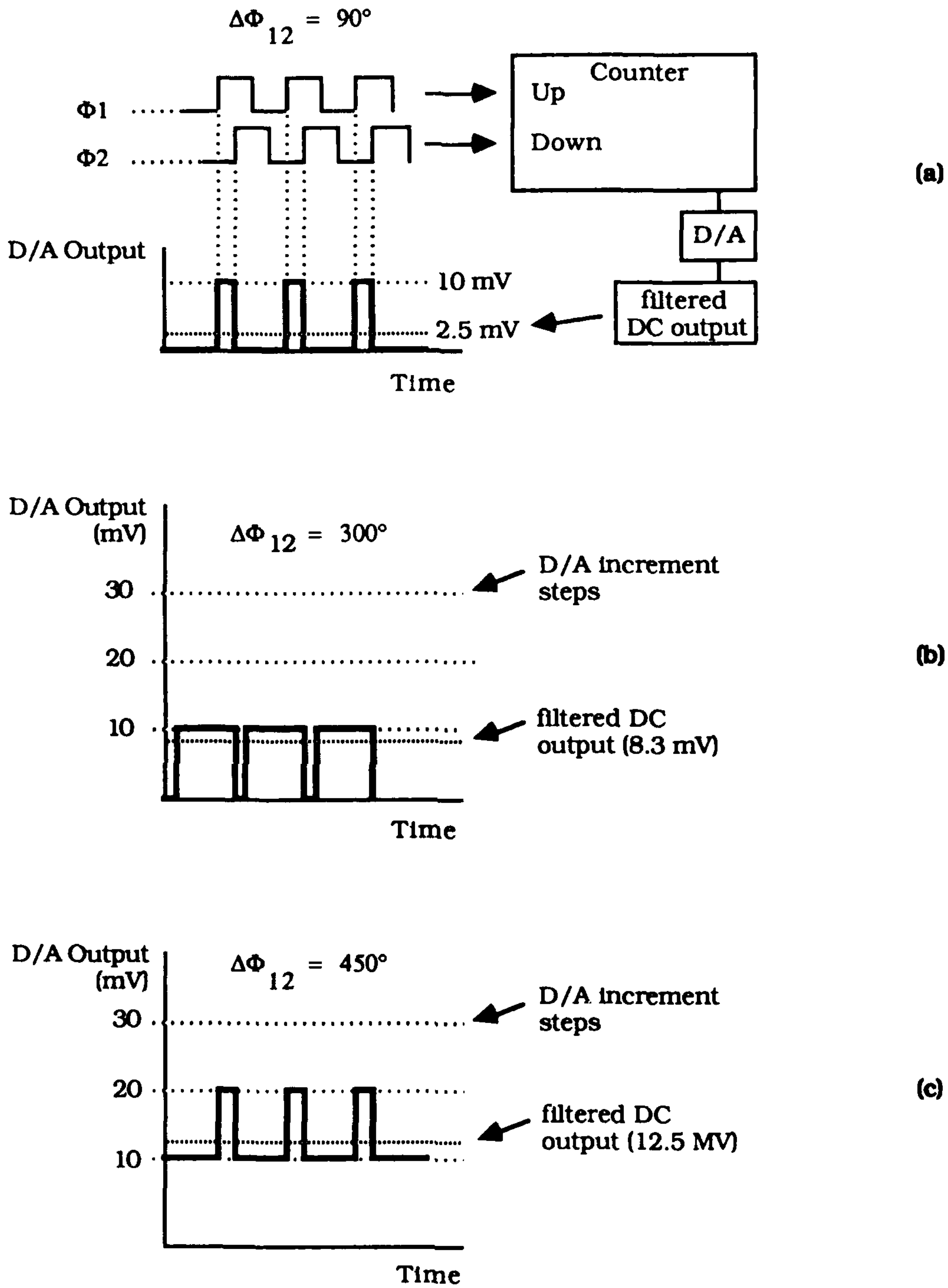

Fig. 4. Changes That Occur in the D/A Output as $\Delta\Phi_{12}$ Is Varied from 90 to 450°

IV. SAMPLE MEASUREMENTS

The microphones and transmitter were arranged according to the geometry depicted in Fig. 2, with $2L = R = 30$ cm. The APL output voltage was then measured as a function of x, the transmitter distance from the origin. The results are plotted as circles in Fig. 5. As predicted by Eq. (2), the curve is linear for $x << L$. Deviations from linearity in this region are such that one would expect the APL to exhibit a spatial resolution of 1 mm or less. On the basis of Eq. (2), as long as R and L are increased proportionately, this resolution should be maintained

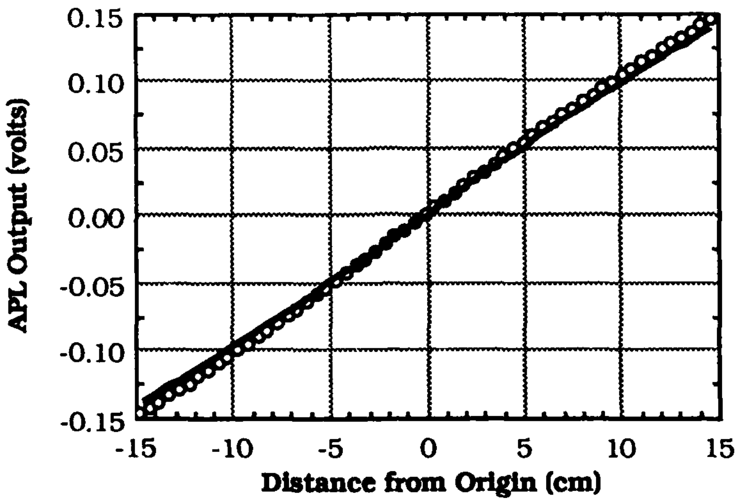

Fig. 5. APL Output as a Function of Distance from the Origin. The coordinate system is defined in Fig. 2. Experimental data are represented by open circles. The solid line is a theoretical curve.

until R becomes too large for accurate detection of the 40 kHz signal. Successful tests were performed in the laboratory for values of R as large as 4.5 m. For comparison, a theoretical plot of $\Delta\Phi_{12}$ [given by Eq. (1) multiplied by an appropriate amplification factor] is also included in this figure (solid line). Differences between the theoretical and experimental curves could possibly be traced to peculiarities in the directional response of the microphone and speakers.

To test the utility of the APL for an actual scan, a test sample was prepared. The sample consisted of a 0.5 in. thick brass plate containing three blind holes of diameters 0.125, 0.250, and 0.375 in., respectively. In addition, a 0.375 in. end mill was used to cut a blind rectangular channel along the border of the plate. A 20 MHz ultrasonic transducer was then used with the APL to scan the face of the plate opposite the holes and the rectangular channel. The results of this scan are depicted in Fig. 6.

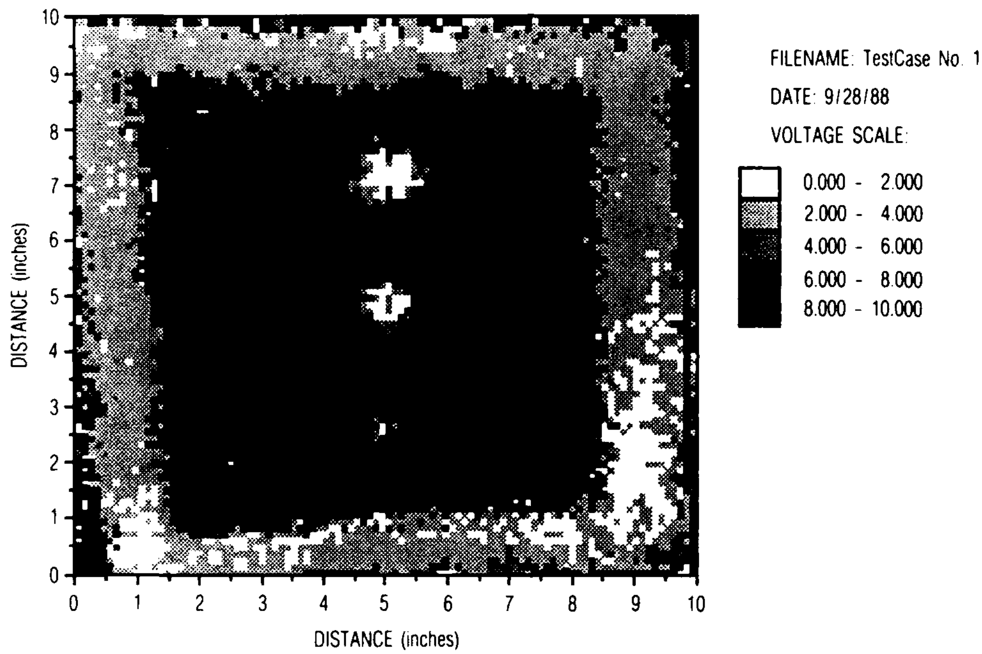

Fig. 6. Computer Image Resulting from an Ultrasonic Scan of the Test Samples, as Described in the Text

V. DISCUSSION

One condition for optimum performance of the APL is that the medium (the air that transmits the sound) between the transmitter and each of the three microphones should be uniform. Variations within the medium due to factors such as wind currents or thermal gradients could result in sound velocity changes, leading to improper phase measurements. Tests performed in the laboratory indicate that the effects of thermal gradients are much more severe than those of wind currents. A thermal gradient, for example, might exist in an enclosed room. In such a case, however, the microphones could be positioned appropriately to avoid this problem. The APL is also adversely affected by sources of stray 40 kHz noise. Such noise was found to accompany the jingling of a set of door keys on a ring. Finally, the APL keeps track of the transmitter's location with respect to a reference position on the sample being scanned. Any interruption of the sound path between the transmitter and the microphones (by an operator's hand, for instance) could result in a reference loss. The APL must then be referenced again before the scan can continue.

The basic operating principle by which the APL detects positional changes is similar to that of a device called the Headmaster, which is currently marketed by the Personics Corporation.[1] The Headmaster is a device designed to interface with the mouse or joystick port of a computer in order to control the position of the cursor. The device includes a headset, which is worn by the computer operator, and an ultrasonic transmitter, which is set on top of the computer display. The transmitter propagates sound that is picked up by three microphones in the headset. The sound waves are compared for phase changes. The phase changes are converted by a circuit into position data, which is used by the computer to control the cursor.

Another device, the model GP-8-3D sonic digitizer, marketed by Science Accessories Corporation (SAC),[2] was developed for the same purpose as the APL. This device differs distinctively from the APL in that time-of-flight (TOF) measurements of sonic pulses determine the position of a transmitter on a handheld probe. The continuous wave (CW) phase comparison technique of the APL has several advantages over the TOF technique of the sonic

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[1]U. S. Patent 4682159, assigned to Personics Corporation, Concord, MA.

[2]U. S. Patents 3626483 and 8631719, assigned to Science Accessories Corporation, Southport, CT.

digitizer. First, to produce the necessary TOF sonic pulses, the sonic digitizer uses a stylus that emits a spark. Such a spark would preclude the use of this device for some applications, such as the scanning of solid rocket motors. Second, the rate of data acquisition is limited by the TOF of the pulse, whereas, in principle, the APL could accumulate data at a rate of 40 kHz. Third, because the APL relies upon relative phase changes to compute positional information, it may be less sensitive than the sonic digitizer to some thermal gradients.

In conclusion, the APL is still in its development stage. On the basis of the data presented here, however, it appears likely that this device will be useful for acquiring NDE data with handheld probes.

LABORATORY OPERATIONS

The Aerospace Corporation functions as an "architect-engineer" for national security projects, specializing in advanced military space systems. Providing research support, the corporation's Laboratory Operations conducts experimental and theoretical investigations that focus on the application of scientific and technical advances to such systems. Vital to the success of these investigations is the technical staff's wide-ranging expertise and its ability to stay current with new developments. This expertise is enhanced by a research program aimed at dealing with the many problems associated with rapidly evolving space systems. Contributing their capabilities to the research effort are these individual laboratories:

Aerophysics Laboratory: Launch vehicle and reentry fluid mechanics, heat transfer and flight dynamics; chemical and electric propulsion, propellant chemistry, chemical dynamics, environmental chemistry, trace detection; spacecraft structural mechanics, contamination, thermal and structural control; high temperature thermomechanics, gas kinetics and radiation; cw and pulsed chemical and excimer laser development including chemical kinetics, spectroscopy, optical resonators, beam control, atmospheric propagation, laser effects and countermeasures.

Chemistry and Physics Laboratory: Atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions and radiative signatures of missile plumes, sensor out-of-field-of-view rejection, applied laser spectroscopy, laser chemistry, laser optoelectronics, solar cell physics, battery electrochemistry, space vacuum and radiation effects on materials, lubrication and surface phenomena, thermionic emission, photosensitive materials and detectors, atomic frequency standards, and environmental chemistry.

Computer Science Laboratory: Program verification, program translation, performance-sensitive system design, distributed architectures for spaceborne computers, fault-tolerant computer systems, artificial intelligence, microelectronics applications, communication protocols, and computer security.

Electronics Research Laboratory: Microelectronics, solid-state device physics, compound semiconductors, radiation hardening; electro-optics, quantum electronics, solid-state lasers, optical propagation and communications; microwave semiconductor devices, microwave/millimeter wave measurements, diagnostics and radiometry, microwave/millimeter wave thermionic devices; atomic time and frequency standards; antennas, rf systems, electromagnetic propagation phenomena, space communication systems.

Materials Sciences Laboratory: Development of new materials: metals, alloys, ceramics, polymers and their composites, and new forms of carbon; nondestructive evaluation, component failure analysis and reliability; fracture mechanics and stress corrosion; analysis and evaluation of materials at cryogenic and elevated temperatures as well as in space and enemy-induced environments.

Space Sciences Laboratory: Magnetospheric, auroral and cosmic ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; effects of solar activity, magnetic storms and nuclear explosions on the earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation.