produce some stability and yet to retard ringing (too much stability). An obvious choice for the time constant of the exponential average (a first order low-pass digital filter) is the time constant of the band-pass filter in half periods. While a five-point arithmetic mean produces good results, this choice does not appear to be at all critical.

A typical control program is organized as follows:

1. INITIALIZE
2. DO ONE POINT
   a. AVERAGE
   b. COMPUTE BAND-PASS PARAMETERS
   c. INJECT SIGNAL VALUE
   d. PREFILTER
   e. BAND-PASS FILTER
   f. COMPUTE HALF PERIOD
   g. DEFINE OUTPUT
3. SEQUENCE

As an example consider a sine wave with a 5-point half period, $S_{hp} = 5$, plus white Gaussian noise with mean zero and variance (total average power) one. The noise power spectrum is thus flat between zero and the folding frequency. No prefilter is used. The signal-to-noise power ratio is $3/16$, that is, the signal is 7.3 db below the noise. Input amplitude, output amplitude, B_{chp}, and Q are plotted against time in Fig. 4. The filter moves from 10 to 5 points per half period and Q increases while the output becomes appropriately sinusoidal.

Conclusion

By combining the analog technique of filtering with the flexibility of digital computing we have been able to present an adaptive digital filter that could prove to be a useful new tool in the study of signals in noise.

We feel that the residual qualitativeness of our presentation may be more instructive to digital computer programmers than detrimental to engineers. It is, perhaps, as R. W. Hamming writes throughout his book,[5] "The purpose of computation is insight, not numbers."

[5] R. W. Hamming, *Numerical Methods for Scientists and Engineers,* McGraw-Hill Book Co., Inc., New York, 1962, pp. vii, 276, and 400.

Excerpts from the

REPORT of the DIRECTOR

of the Applied Physics Laboratory

July 1, 1963—June 30, 1964

TO THE PRESIDENT OF THE UNIVERSITY:

Technical Activities

Through its work during the last twenty years, the Laboratory has acquired a fundamental understanding of the characteristics and performance of three classes of Navy systems now in operational use. These are: (1) surface-launched, shipborne, anti-air warfare, guided missile systems, (2) fleet ballistic missile systems, and (3) satellite navigation systems. It is interesting to note that all of these systems have come into being within the fifteen years since the Korean War.

The surface-launched missile systems are based on Talos, Tartar, and Terrier missiles which were conceived and developed by the Laboratory and its associate contractors. The radars, computers, and other elements of the fire control and weapons direction equipment were developed for the Navy by industrial contractors. These systems are now deployed on 56 cruisers, frigates, and destroyers. The Tartar and Terrier missile systems are also installed on ships of the French, Italian, and Australian navies who chose them after studying the performances of the world's inventory of similar items.

The Laboratory's part in the development of the Fleet Ballistic Missile System has been very small, but it was asked to apply the test and evaluation techniques developed for use with its anti-aircraft systems to a thorough investigation of the design and performance, first of the Polaris prototype systems and subsystems and finally of the operational system itself.

The Satellite Navigation System

Photo by Udel Bros.

R. E. Gibson, Director

is a completely home-grown product. The Laboratory conceived the original design, demonstrated its performance with experimental spacecraft and an experimental tracking network, engineered the operational satellite, designed the operational tracking network, and indoctrinated Navy personnel in the fabrication and use of all the equipment.

To support the work on these three classes of systems, the Laboratory is carrying out a number of investigations which range from fundamental research through exploratory and advanced development to actual hardware evaluation. The problems in research, analysis, development, engineering, test, and evaluation connected with these systems and their support occupy the major portion of the Laboratory's effort.

From the recent results of supporting research work, two may be selected for mention here. The first is the experimental demonstration of thrust augmentation by the addition of air to the exhaust gases of solid fuel rockets. Since these gases are rich in fuel, further burning with consequent increase in thrust should be possible if a scoop can be fitted around the rocket nozzle to gather air from the atmosphere to mix with the exhaust. Experiments indicate that, in practice, this increase approaches the theoretical value and permits a specific-impulse gain far exceeding that found possible by changes in the composition of solid fuel propellants. The practical importance of these findings is potentially enormous.

The second is the new computing program developed for the Doppler tracking of satellites and the determination of position in the satellite geodesy program. Rework of all available observations has made possible the determination of the coefficients in the spherical harmonic expansion of the earth's gravitational field up to the eighth order. When these coefficients are used to express the value of the gravitational field in the equations relating the motion of the satellite to the observed Doppler frequency-time curves, an order of magnitude improvement in precision is realized.

The remaining portion of the Laboratory's technical work, although relatively small, is significant because of its future implications. It includes several assignments from the National Aeronautics and Space Administration, of which the most important by far is the conduct of the NASA Geodetic Program which goes under the code name of GEOS. This program involves the design and construction of special satellites, the collection of data, and the interpretation of results. At the request of the Bureau of Naval Weapons, the Laboratory is devoting increasing attention to problems in life support systems for advanced high speed aircraft, including the dynamics of seat-ejection systems, simulation of the effects of breathing on the atmosphere in closed cockpits, helmet design, and so forth. Although this work has definite applications in the technology of manned spacecraft, its immediate and high priority application is to Naval aircraft.

Approximately four per cent of the Laboratory's effort is devoted to fundamental research in the fields of chemical physics, chemistry, excitation mechanisms including lasers, electron physics, microwave physics, theoretical problems, plasma dynamics, and adaptive mechanisms. In the field of the chemical physics of flames, an outstanding series of experiments have recently yielded exciting results. Application of electron-spin-resonance concepts to the analysis of the contents of the reacting gases in a flame has permitted a determination of the concentration variations in time and space of unstable, short-lived, free radicals, thus providing an important but hitherto missing link in the understanding of the mechanisms of flame propagation.

SURFACE-LAUNCHED MISSILE SYSTEMS—Early in 1964, a major change took place in the course of the Laboratory's work on Naval surface-launched missile systems as a result of the termination of the Typhon program by the Secretary of Defense. The Typhon program consisted of long and medium range missiles and a brand-new radar and fire control system. For reasons of economy, plans to engineer and produce the long range missiles were cancelled in 1962, although a number of flight tests of the prototypes indicated that all the development objectives were being met. In the fall of 1963, concern was being expressed about the growing size and cost of ships required for fleet anti-air warfare, a subject intimately related to the number and missions of aircraft carriers. Since it was assumed that the Typhon system could only be installed on the larger ships, plans for its deployment were cancelled. Work on the remaining medium-range missile was stopped, and the knowledge and experience already gained were reoriented to other missile objectives. Plans for production of the radar and fire control systems were also cancelled, but it was decided to proceed with the installation of the prototype on the USS *Norton Sound* (AVM-1), a project more than halfway completed. The study of the prototype radar and fire control system in a realistic shipboard environment offers the possibility of evaluating the system's new techniques and of preserving for the Navy the technological advances made in the development of the Typhon system. This installation has progressed to the point where composite tests are being made and specific plans for evaluating the system are being formulated. The Laboratory is supporting the *Norton Sound* Engineer-

In this scene at the Maryland Shipbuilding and Drydock Co., Baltimore, the USS *Norton Sound* is shown during installation of the prototype radar and fire control system developed by APL for the Typhon missile system and fabricated by the Westinghouse Electric Corp. The photograph was made during the actual mating, with the upper structure of the ship, of the tower containing much of the associated electronics and radar mechanism.

ing Program with approximately forty engineers, most of whom are stationed at the shipyard while the remainder are investigating specific problems at the Advanced Radar Laboratory in Howard County.

The reorientation of the Typhon work was accompanied by an increase in effort in three other areas in the surface-launched missile field, namely: (a) improvement of the Terrier, Tartar, and Talos Systems, (b) improvement and consolidation of the Terrier and Tartar missiles—the Standardized Missile Program, and (c) the study of an Advanced Surface Missile System to replace Typhon.

As a result, the distribution of scientific and engineering manpower in this field is: *Norton Sound* Engineering and related work, 12%; Improvement of Terrier, Talos, and Tartar shipborne systems and their operation, 45%; Missile Development, 33%; Advanced Missile Systems, 10%.

Improvement of Existing Systems.—The Laboratory's share of the responsibility for the improvement of the Terrier, Talos, and Tartar shipborne systems is carried by the Fleet Systems Division, assisted by various R&D groups who accept investigations of specific problems. The first task undertaken by this Division, namely, the diagnosis of the engineering, procedural, and other defects that have detracted from the performance of the shipborne systems, has been essentially completed. Problems in various areas have been isolated, and solutions devised. A model, by which the effects of factors such as "mean time to failure" of equipment, mean time to diagnose and repair faults, and logistics and supply on the availability of the systems, has been developed and applied successfully. Complete digital simulations of the Terrier and Tartar fire control systems have been set up. At the Systems Evaluation Laboratory, a Terrier radar and computer have been in daily operation, and procedures for operation and maintenance have been checked under realistic conditions. The validity and accuracy of engineering improvements documentation have been checked, thus saving much time and lost motion at the shipyards. This facility is now concentrating on an experimental program. Much of this year's effort was devoted to assisting the Bureau of Naval Weapons in formulating a technical plan for the Terrier, Talos, and Tartar systems, and in providing documentation for the systems and subsystems. The Fleet Systems Division is now studying the deployed systems and their successors, largely through the investigation and application of digital techniques and study of environmental effects.

The area of *Missile Improvement* includes work on the performance improvement of Terrier and Tartar missiles in meeting certain important tactical requirements and the formulation of a technical plan for the development of retrofit kits for homing missiles. This program promises to be a fertile field for exploratory development and application. This area also covers the Standardized Missile Program, a contractor effort to exploit to the fullest the use of common components for Terrier and Tartar. The Laboratory initiated this concept several years ago. The staff of the Analysis Group has completed documents prescribing performance and compatibility requirements for systems and subsystems and controlling the parameters and signals at all interfaces. New guidance and control systems have been investigated theoretically and experimentally in "breadboard form." Preparations are being made for the evaluation of contractor-produced hardware at the Laboratory.

The Laboratory's efforts on the Advanced Missile System have been largely in the areas of defining the performance the system must have to meet probable enemy threats, applying the experience gained in the Typhon program to implement these performance requirements, and advising the Navy on the technical content of preliminary proposals by contractors.

Fleet Ballistic Missile System—The Laboratory's contributions to the Polaris System fall into two parts. The major part is the formulation of test and evaluation procedures for determining quantitatively the performance of the complete system, i.e., the missile and the submarine and its subsystems, first under controlled conditions at Cape Kennedy and then under tactical conditions. This evaluation function involves the devising of test procedures, analysis, interpretation, and documentation of the results. With the accelerated building program, the increasing number of Polaris submarines undergoing "shakedown" tests this year have placed a considerable load on the staff of the Polaris Division. The smaller part of the Laboratory's involvement in the Polaris program is in special studies that stem from the test results. An interesting application of control-system techniques is one example. The previously mentioned investigation of thrust augmentation is another.

Satellite Systems—This year has seen the successful culmination of the first major phase of the Laboratory's program to develop a navigation system based on precise observations of the Doppler frequency-time curves received from satellites transmitting highly stable radio frequency signals. After placing a number of fully equipped, gravity-gradient-stabilized satellites in orbit and testing the performance of the whole system (including the satellites, two types of ground receiving stations, and the computing and injection procedures), the Laboratory has been able to turn over the fabrication and prelaunch checkout of the satellite to the Navy Avionics Facility at Indianapolis and the tracking and injection operation to the Naval Astronautics Group at Point Mugu, California. The transfer has been made with a smoothness and efficiency that reflects great credit on the ability of the Naval agencies to assimilate a new system and on the ability of the Space Division to document their work and impart their experiences to others, a true teaching function appropriate to a university laboratory.

The navigational satellite (1961, Omicron-1) completed three years in orbit on June 29, 1964. It still functions as well as ever, if allowance is made for the inevitable deterioration of the solar cells owing to their bombardment by high energy particles.

With the transfer of the first operational system to the Navy, the Laboratory is concentrating on the design and construction of extremely reliable satellites. A thorough cost-effectiveness study has shown that, over the course of five years or more, achievement of a long-lived, reliable spacecraft pays off handsomely in the economical maintenance of an operating system.

The value of near-earth satellites as instruments for determining the shape of the earth and its gravitational field (geodesy) has received wide recognition. Experience with ANNA 1-B and the TRANET network of tracking stations controlled by the Laboratory has shown clearly that the Doppler tracking method yields data of excellent quality and in great quantity. Furthermore, the simplicity of the tracking stations permits wide geographic coverage, and the ease of data reduction permits rapid accumulation of data for interpretation. The National Satellite Geodetic Program is now under the sponsorship of the National Aeronautics and Space Administration. This agency has assigned to the Laboratory responsibility for geodetic work under the GEOS program. This program entails design and construction of the satellite, cooperation in the launching operations, prescription of orbits, satellite tracking, and reduction and interpretation of the data. To aid in the transition from Navy to NASA sponsorship, the Navy is funding the Laboratory to build a simple satellite equipped with stable oscillators to provide badly needed data from a low inclination orbit. This program goes under the code name of LIDOS. Research and exploratory development in space technology covers such items as: (a) investigation of the environment in which satellites operate by the use of satellites instrumented to measure radiation fluxes; (b) investigation of the effects of radiation on satellite components; (c) development of instruments for measuring the controlling satellite orientation; (d) continuing studies to refine the methods of measuring time and frequency; (e) studies of factors affecting the lifetime and reliability of satellite electronics; and (f) continuing research to improve the methods of computing orbits from Doppler measurements with particular attention to predicting orbits several months in the future.

Supporting Research and Exploratory Systems Analysis—The areas of supporting research which have been quite active during the past year include: extension of the performance of Laboratory-developed arc furnaces to produce very high pressures and temperatures in gases to simulate hypersonic flow; development of a new air-intake design and demonstration of supersonic combustion for a supersonic-combustion ramjet engine; development of a "gun tunnel" for producing experimental conditions of extremely high Mach number; development of methods for testing the behavior of materials under high temperature; development of microelectronic components and their applications in satellites and missile systems; investigation of monostatic and bistatic radar returns from the sea under varying wind conditions and the correlation of these returns with stereoscopic photographs of the sea surface (a cooperative project with Naval Research Laboratory); studies of optical data-processing systems using lasers; the design of adaptive mechanisms through the use of an automaton capable of surviving in a laboratory environment and the application of adaptive mechanisms to ship problems; and studies of advanced missile control systems and components.

Exploratory systems analyses that have been reported this year include: ALBIS, a study for the Advanced Research Projects Agency; SUBAD, an air-defense system for submarines; a system of self-defense for smaller ships; and a Landing Force Support Weapon System (LFSW). The last named system offers such promise that a program to explore the adequacy of available techniques in a series of test vehicle flights has been started.

Information Activities — Upwards of 60 formal regular technical reports and 290 informal reports, most of them classified, were prepared by the Reports Office to record the work of the Laboratory.

The formal and informal reports mentioned above form only a fraction of the total documentation issued by the Laboratory. For example, some 139 reports issued by the Polaris Division are not included. The preparation of documents and illustrations, including films, for presentations to the Navy, the Department of Defense, and other agencies has also become an important and time-consuming activity. Another example is the Handbook of Supersonic Aerodynamics, this year's publication being Volume 6, Section 17, on *Ducts, Nozzles, and Diffusers.*

Some 71 inventions were disclosed to the Department of the Navy, 30 patent applications were filed during the year, and 29 patents were granted. . . .

Members of the Laboratory staff published 76 papers in scientific journals or technical books. . . .

During the past year 83 staff members presented 98 papers before scientific, engineering, and lay societies of which 6 were given at meetings held abroad.

Chemical Propulsion Information Agency.—The Federal Government's increased emphasis on solving the problems in information exchange have resulted in the recent issue of a Department of Defense Instruction establishing a number of Centers for Analysis of Scientific and Technical Information. The Chemical Propulsion Information Agency, formerly the Solid Propellant Information Agency, which has been operated by the Laboratory for approximately sixteen years, has been designated as the Center for Chemical Propulsion Information. The principal increased responsibilities of the CPIA, as result of this directive, are the coverage of the world's literature in the field rather than only government-sponsored work, the publication of critical reviews on subjects in the field, and the periodic publication of lists of new and significant publications in the field, reflecting an evaluation of the published work. . . .

Administrative Operations

McCoy College Program at APL—For a number of years, both graduate and undergraduate scientific courses have been taught at the Laboratory through McCoy College. This year, a new educational program has been initiated. The University decided to expand the program at the Applied Physics Laboratory at Howard County to include a complete curriculum of study leading to the degree of Master of Science in Electrical Engineering and to open the program to all qualified applicants. The expanded program is scheduled to start in September 1964 with two courses each being offered in mathematics, physics, and electrical engineering. This represents a continuing and deepening involvement of the Laboratory in the educational and research missions of the University. . . .

R. E. Gibson
Director

ADDRESSES

The listing below comprises the principal recent addresses made by APL staff members to groups and organizations outside the Laboratory.

R. A. Freiberg, "Nuclear Radiation on Thin-Film-Microelectronics," *I.E.E.E. Tenth National Communications Symposium,* Rome, N. Y., Oct. 5, 1964.

S. D. Bruck, "Thermally Stable Synthetic and Pyrolytic Polymers," *Society of Plastic Engineers,* Baltimore-Washington Section, Baltimore, Oct. 13, 1964.

D. W. Fox, Lecture Series on "Bounds for Eigenvalues of Self-Adjoint Operators" (4 lectures), *University of Maryland, Computer Science Center,* Nov. 13 and 20, Dec. 4 and 11, 1964.

Jane Olmer, "A Practical Document-Data Retrieval System," *Data Processing Management Association,* Washington, D. C., Nov. 18, 1964.

R. R. Newton, "Measurements of the Doppler Shift in Satellite Transmissions and Their Use in Geometrical Geodesy" and "Characteristics of the GEOS-A Spacecraft," *Centre National d'Etudes Spatiales* and *L'Institut Geographique National,* Symposium on The Establishment of a European Geodetic Network by Artificial Satellites, Paris, France, Dec. 14–16, 1964.

R. McDowell, "Analog-to-Digital Data Conversion," *The Johns Hopkins University,* Computer Sciences Meeting, Dec. 17, 1964.

G. L. Weaver (APL) and C. H. Weaver (University of Maryland), "Speech Communication and Information Theory," *1964 Speech Association of America Convention,* Chicago, Dec. 27–30, 1964.

E. A. Bunt, "Plasma Arc Heating for Hypersonic Flight Simulation," *University of Delaware,* Department of Mechanical Engineering Seminar, Jan. 7, 1965.

D. J. Williams, "Temporal and Spatial Variations of Outer-Zone Electrons at 1100 KM," *NASA Goddard Space Flight Center,* Weekly Colloquium, Jan. 12, 1965.

R. E. Fischell, "The Scientific Uses of Earth Satellites," *U. S. Naval Propellant Plant,* Scientists and Engineers Club, Indian Head, Md., Jan. 13, 1965.

J. R. Apel and A. M. Stone, "Investigations of Growing Waves Excited in a Plasma by an Electron Stream," *A.I.A.A. Aerospace Sciences Meeting,* New York, Jan. 25–27, 1965.