Staff Report

Twenty Years of Microwave Activity at Harry Diamond Laboratories

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The Harry Diamond Laboratories had its beginnings in the early 1940's as the Ordnance Development Division of the National Bureau of Standards (NBS). A group of experienced researchers, engineers, and technicians was formed to develop fuzes for non-rotating projectiles, with technical direction of the program given to Harry Diamond, outstanding engineer and administrator. Major accomplishment of the group was the development of the radio Doppler proximity fuse, described by the War Department, at that time, as "second in importance to the atomic bomb."

In 1953, the Ordnance Development Division was transferred from the Department of Commerce to the Department of the Army, and activated as R&D installation under the Chief of Ordnance. It was renamed the Diamond Ordnance Fuze Laboratories (DOFL). This move recognized the very heavy involvement of the facility with the Department of Defense. In 1962, DOFL was renamed the Harry Diamond Laboratories (HDL) and assigned a broadened mission as one of the five corporate laboratories of the newly formed US Army Materiel Command.

HDL's principal facility is in Washington, D.C., and it has a number of remote test and research facilities located in nearby Virginia and Maryland. Occupation of completely new facilities in Adelphi, Maryland will commence in January 1974. The new location will ultimately provide 555,400 sq. ft. with construction scheduled for completion by the end of 1975.

CURRENT ACTIVITIES/SUPPORT

While the initial charter of the organization directed all of its efforts into weapons fuzing, its current activities (including proximity fuzing) range through a wide variety of interests. Among the more important fields covered are:

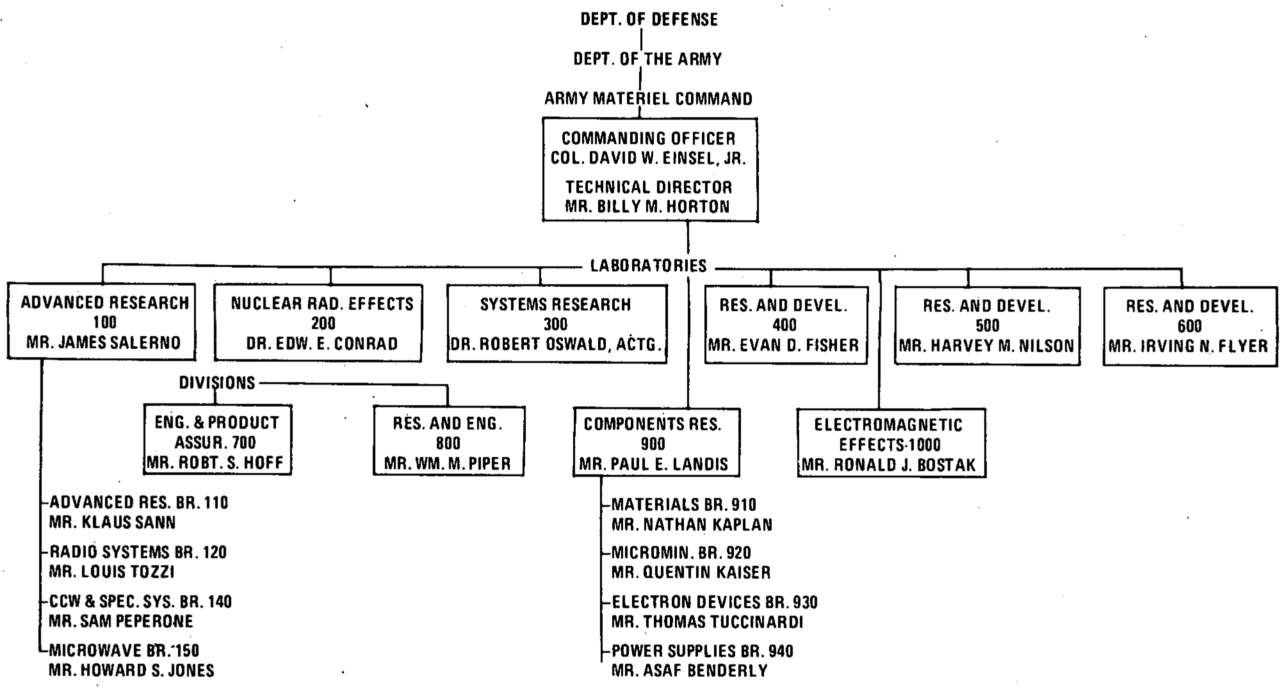
1. **Nuclear Weapons Effects** — HDL pioneered in the field of transient radiation effects (TREE) in the internal and external electromagnetic pulse (EMP) effects on electronics. Presently, it is the lead laboratory in this area for the Army Materiel Command and co-ordinates all AMC activities in this field. To harden electronic components for tactical and strategic systems, HDL maintains nuclear, X-ray, gamma, and electromagnetic pulse simulators that are used by many elements of DOD.

2. **Advanced Radar Techniques** — Present emphasis is upon advanced-radar techniques for target detection and signature analysis for a wide range of environment. The technique of combining coherent radar signals in phase and in quadrature to obtain the direction of the target's movement was conceived and developed by HDL for the purpose of detecting moving targets in a cluttered environment.

3. **Fluidics** — Since the invention of the first family of fluid devices at HDL in 1960, it has been the lead laboratory for AMC on the application of fluidics.

4. **Instrumentation** — the task of recovering information from in-flight artillery shells and missiles has led to a highly-refined capability to apply ruggedized, miniaturized electronic devices by HDL. An early recognition of this capability was the 1957 micro-miniaturization award won by HDL for the application of photo-lithographic techniques to transistor production.

The Laboratories have a complement of approximately 1500 personnel led by 500 engineers and scientists, who are principally electronic and mechanical engineers and



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physicists. Approximately one-quarter of the present professional staff was recruited from HDL's annual program involving the employment of approximately 50 undergraduates during summer months. This program originated by the Bureau of Standards has been in force for at least 20 years of HDL, and its success has prompted its adoption by most of the other Army laboratories.

Total expenditures approximated $63,000,000 in fiscal 1973, of which about one-third was devoted to contract and procurement awards, approximately 60% of these on sole-source basis.

HDL presently is organized into eight laboratories and two engineering divisions reporting directly to the Technical Directory of the Laboratory. The microwave activities center in the Advanced Research Laboratory (Code 100) and the Components Research Laboratory (Code 900).

BACKGROUND

The Advanced Research Laboratory, headed by James Salerno, is an outgrowth of the activity which originally researched and developed microwave components and systems for military weapons from 1953 on. Employing an engineering team originally part of NBS, the activity developed the first microwave ferrite devices, *e.g.*, NBS magnetic attenuator, Reggia-Spencer phase shifter, and broadband microwave switch, partly assisted by Microwave Associates under contract. Another pioneer effort was development of antennas for various types of missile systems. They also encouraged development of klystrons and magnetrons by providing new circuit designs.

Primary concern in antenna design was efficiency and physical conformation to the weapon systems involved – forcing compactness, light-weight, and reduced costs. As a result, investment-casting methods for fabrication were evolved which were applied also to microwave components; industry immediately followed this lead.

Basic research work was performed in the Microwave Branch on ferrite and diode phase shifters and amplitude modulators. Other firsts emanating from the original workers at DOFL included use of coiled wave guide for delay lines, development of microminiaturization techniques, application of dielectric-loading techniques to small-antenna design, introduction of antennas into the radome structures to conserve space and offer protection from the environment, and development of ablative materials for missile nose cones.

From all this activity and innovative efforts has come many patents, awarded to numerous HDL personnel. Averaged over the past 10 years, the rate of patent activity approaches 50 per year, which represents 15% of all those granted personnel of the US Department of the Army and 3% of all patents assigned the US Government; and this is accomplished by a working force of 1% of the scientific work force of the Army!

OUTSIDE ACTIVITIES

A close relationship has always been maintained with industry and educational institutes. Recently, Westinghouse was assisted in development of an Air Force tactical lightweight radar antenna operating at 130°C for periods of one hour. HDL acts as consultant on many military contracts and to the US Air Force. Other typical, important coordinated activities have included development of TR and ATR tubes at Sylvania and Bomac, klystrons at Varian, and diode waveguide switches at Philco.

The work in microwave solid-state devices has included development of pulsed TRAPPAT oscillators in the UHF and F (3-4 GHz) bands. Contracts for analytical work by the University of Michigan ($30-35k for 1 year) and ex-

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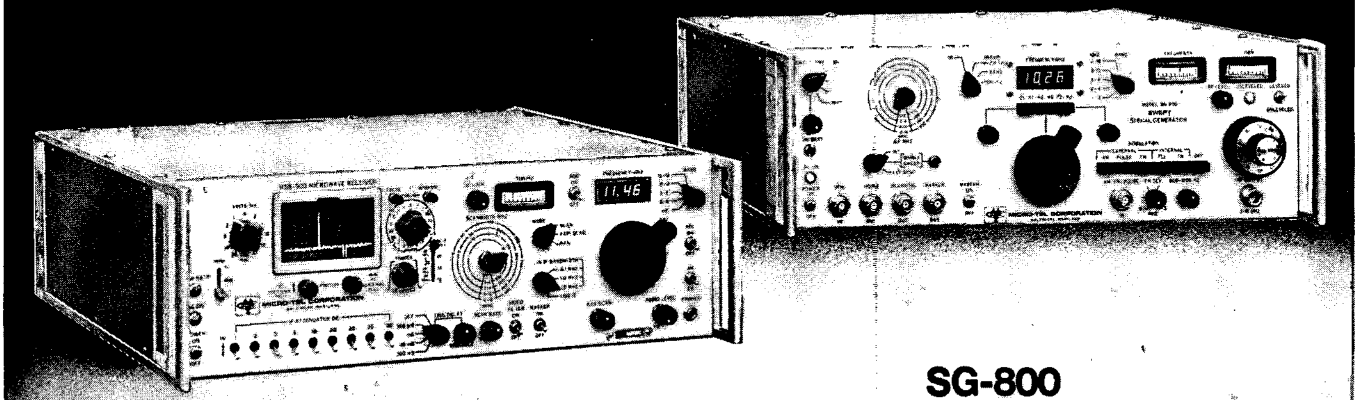
Generate Receive Measure 0.1 to 18 GHz



SG-800 Swept Signal Generator

- Swept, CW, FM, AM Pulse
- Replaces six signal generators
- Single RF output
- Calibrated Output Attenuator: 99 dB
- Internal Leveling
- —70 dB harmonic output

MSR-903 Microwave Receiver

- Noise Figure: 20 dB max.
- Bandwidth: .1 to 20 MHz
- Image Rejections: 70 dB min.
- Spurious, Int.: –110 dBm max.
- LO Radiation: – 80 dBm max.
- AM and FM Demodulators

and for both . . .

- Removable-Remotable RF Assembly
- No plug-ins
- Very low RFI
- Battery operation
- Programmable
- Synthesizer/Counter available winter 1973

Both receiver and generator are completely self-contained with single knob band selection. Both are available with full crossbanding. The receiver can also be supplied with simultaneous display of all bands on a multi-channel storage oscilloscope or, at lower cost, a sequential scan displayed on a similar oscilloscope.

Both units are in production and available for immediate demonstration.

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perimental work by RCA-Princeton ($50-60k for 1½ years) have resulted in some positive contributions: RCA's development of a solid-state F-band device providing a 200-watt peak power, 1% duty factor, and 18% efficiency that combines a TRAPPAT source with a pulse modulator, and combines two output diodes in one package. A modified computer model of the TRAPPAT diode, developed by the University of Michigan, requires only 10% of the computer time originally required by previous models, and provides good agreement with experimental results. Present objectives of the TRAPPAT program are 350 watts peak-power output, 2% duty factor, and 20% efficiency. The leading-edge jitter of the RF pulse remains a major problem in this development. For high duty-cycle applications the University of Michigan has been exploring two types of junctions, an N^+PP^+ complementary and a P^+NN^+ device. The former has resulted in better performance.

IN-HOUSE ACTIVITIES

Advanced Research Laboratory

H. Gerlach, of the Advanced Research Branch, monitors an Army Electronic Command (ECOM) Production Engineering Measure (PEM) contract with Hughes Aircraft ($200k-2 years) involving TRAPATT's, oscillator circuits, and small-sized pulse modulators, predominantly in UHF and F-bands, and another contract with TRW involving microwave power transistors. Present gain-bandwidth product is 3 GHz, with output of 20 watts CW at 2 GHz, 10 watts at 3 GHz, and 2.5 watts at 3.5 GHz, and respective efficiencies of 45%, 35%, and 25%.

A monitored PEM contract with TRW, ended July 1973, has produced microwave transistors producing 20 watts at 2 GHz with 45% efficiency, capable of 10 watts output at 3 GHz. Work will continue at HDL in attempts to increase power levels. Another important path of development is modulators for pulsed sources.

Development work in the area of pulsed transistors (0.5-2 GHz), involving Microwave Semiconductor, TRW, and Power Hybrids devices, has resulted in Power Hybrid oscillators producing 120 watts at 600 MHz with 50% efficiency and 1% duty factor. Duty factors can be increased to 5%. The oscillator source is jitter free and is capable of 12 nanosecond risetimes.

An experiment involving push-pull transistors producing 200 watts (peak) at 1% duty factor and 33% efficiency is presently underway. Microwave power transistor large signal characteristics are investigated, utilizing computer simulation, with operation at 2 GHz forecast. Triodes from General Electric and Eimac have been incorporated into oscillator circuits operating to 4 GHz with high efficiency in small packages. IMPATT diodes operating in X-band have also been fitted into small pulsed doppler systems applications, at low cost and with good FM/AM noise characteristics.

Microwave Branch

The Microwave Branch, headed by Howard S. Jones, Jr., conducts research and development on microwave systems and components for military applications and provides consulting service to HDL's development programs. This effort includes design, fabrication, and evaluation of small antennas in various types of waveguide systems (rectangular waveguide, stripline, microstrip, etc.) used in the frequency range from 200 MHz to 18 GHz. Examples of the antenna research effort include electrically small VHF antennas, dielectric-rod radiators, copper-plated dielectric foam horn antennas, base-mounted reentry vehicle antennas, and conformal dielectric-loaded circumferential-slot antennas. Emphasis on the antenna program is directed toward improved efficiency, low-cost, light weight, and simplifying fabrication techniques.

Present activities of the above microwave program also include investigations of ferrimagnetic, ferroelectric and piezoelectric material properties and their applications for designing high peak-power phase shifters (both analog and digital types), low-power limiters and microwave switches; electronic scanning techniques for antenna phased arrays; design and fabrication of hybrid integrated circuits in both microstrip and slot transmission lines; and semiconductor device applications for high speed switching and phase shifters.

Components Research Laboratory

In the Microminiaturization Branch, attention is being given to performance of surface acoustic-wave amplifiers and devices from outside sources. Development work continues on personnel detection devices utilizing both pulse and CW propagation via electrets (polarized dielectrics).

Another effort includes bulk-wave devices employing thin-film ZnO sputtered transducers. In-house fabrication and evaluation facilities permit sophisticated control of processing experimental models of acoustic delay lines.

A PEM contract with Teledyne MEC ($269k-2 years) for microwave acoustic delay lines (2-3.5 GHz), sponsored by ECOM, is monitored by HDL. Correlation between MEC and HDL test results has been good even after shock testing by HDL's air-gun. Stored samples of the bulk-wave devices show no signs of deterioration after 9000 hours at temperatures of 90° C.

Under development are surface acoustic wave devices at Teledyne, for operation at 1-1.5 GHz. Difficulties have been encountered in producing masks (0.8-micron line widths are required) for 1.0 GHz, but production presently is underway. There remain, however, severe production problems using surface-wave techniques including (a) fragile masks, (b) inadequate yields, (c) mask lifetime, (d) possible restricted input levels. Alternate fabrication methods were considered — grating array and over-tone — the latter was chosen. Present models, air-gun tested from 14k to 19k g_m with impact time of 1 millisecond, proved to be mostly satisfactory.

Development of surface acoustic-wave convolvers for signal processing in which two signals are presented at opposite ends of a central section to yield a sum frequency for ECM purposes, is a project for FY 1974.

Matching bulk acoustic-wave devices to nominal 50-ohm inputs has presented a design problem reduced, somewhat, by connecting the individual transducer elements in series, to the extent that matching impedances is made possible.

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