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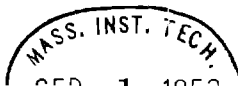
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Foreword

Linked to man's age-old propensity for waging war has been his tendency to boast of his warlike accomplishments. In the ancient sculptures of the Euphrates Valley and the colorful friezes of Egyptian tombs we can see the warriors of prehistory marching to battle and can surmise something of their weapons, their tactics, and their equipment. Herodotus, the father of history, earned his title for his story of the Greco-Persian wars; and the epic verse of Homer has preserved forever the legendary battles of Troy, preceding in time the century-long struggles of the Peloponnesian wars. Later, Julius Caesar recorded for us not modestly, but with revealing detail, the story of his Gallic conquests. The men of the North first recorded the sturdy heritage of the Anglo-Saxon in the epic story of Beowulf. The wars which ravaged Europe during the dark ages were preserved in history in the cloisters, last refuge of the written word. In modern times, the chronicles of war have lost the epic touch and become the handbooks for future warriors. Every general has read his Clausewitz, and every admiral his Mahan.

World War II brought with it the responsibility for a new kind of documentation. Technological progress in weapons and devices of warfare was of such transcendent importance that it influenced the turn of events at almost every point. Science was organized for war in a way that it had never been organized before. It therefore became a matter of major importance to record processes and achievements of technology in such a way that future generations might benefit to the fullest by the trials, errors, and successes of the experimenters.

The late President Roosevelt, with an appreciation of the historical significance of current happenings, directed that each agency of the Federal government should write the history of its wartime accomplishments. In the case of the Office of Scientific Research and Development, the mere chronology of its undertakings and accomplishments would not have sufficed to aid the researchers of the future in dealing with related problems. The Office of Scientific Research and Development, therefore, has left behind it full documentation in the form of summary technical reports covering the programs of the technical divi-

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Boston, Dec. 1945.

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sions of the National Defense Research Committee; a technical monograph series dealing with special aspects of its program—of which this Radiation Laboratory Series is a part; and a detailed history by field of endeavor, including that of the Committee on Medical Research, expanding the popular history by James Phinney Baxter, III, *Scientists against Time*, which won the Pulitzer prize for history for 1946. It is hoped that this attempt at full documentation, made though it was by busy scientists amid all the pressures of war and postwar adjustments, will contribute substantially to the soundness of our present program of military research and development and will prevent the retracing of old ground and the exploration of unfruitful paths, already explored to no avail. For one of the principal functions of the scientist's notebook is to record his failures as well as his successes in order that others may not duplicate his efforts in vain.

I am particularly happy to contribute these few words to this, the concluding volume in the series of 28 volumes which comprise the technical details of radar. It is gratifying to observe that not all the efforts of scientific warfare were directed to the creation of lethal devices whose sole objective is destruction. Radar, which is the ear-catching word coined to describe the processes of radio detection and ranging, was one of the greatest tools of the recent war, but it also has vast usefulness in the postwar world and its powers are happily extensible to many problems of modern navigation.

Early warning radar can look into 300,000 cubic miles of space. It is as efficient on a moonless night as on the brightest day, and the obscuring effects of storms and fogs, which have beset navigators from earliest times, hold no problems for it. It not only revealed the hiding places of the enemy's ships and planes, but it identified our own planes in darkness and in battle and guided many a flyer back to the safety of his own base. Now an instrument which can accomplish such wonders is necessarily a complex mechanism. Although its development spreads over the two decades of the twenties and thirties, the period of greatest progress occurred during the war under the impetus of strategic and tactical needs. It is the technological achievements of these years which the present series records.

Back of the efforts of the Radiation Laboratory lie the perceptive observations of A. Hoyt Taylor and Leo C. Young of the United States Navy Department, who in 1922 were quick to grasp the implications of interference in the signals caused by a steamer passing on the Potomac.

Three years later, Gregory Breit and Merle A. Tuve of the Carnegie Institution developed a short-pulse technique for measuring the height of the reflecting layers in the ionosphere. This was the first true radar, for radar is in essence the method of locating objects in space by propa-

gating a beam of short pulses of electromagnetic energy and measuring the time between the pulse and its echo at the sending station. In the decade of the thirties, the British advanced the art to the point where they were able to throw up around their island a lifeline of radar surveillance stations and so made possible the defense of Britain against the superior numbers of the Luftwaffe.

To tell the full story of the United States radar program would necessarily be to tell, also, the story of the Office of Scientific Research and Development under whose cognizance the work of the Radiation Laboratory of the Massachusetts Institute of Technology was done. For large though it was, both in dollar volume and in achievement, the Radiation Laboratory contract was but one of the many research and development contracts through which the OSRD made its contributions to the winning of the war. One would find, too, that applications of radar extended in an important way to other phases of the OSRD program such as fire control, submarine detection, and wave propagation. To tell such a story fully would be in effect to recapitulate tasks which have already been adequately done. It is suggested, therefore, that the reader who finds the present series of interest and who cares to explore the background against which the radar story developed, may do so through the medium of the historical series which has been made available to the public at large and through the summary reports which are available through official channels to authorized persons.

The individual authors of the volumes of the Radiation Laboratory Series and the over-all editor, Dr. Louis Ridenour, are to be commended for the immense amount of additional work and research they have performed above and beyond their technical accomplishments in thus recording in such detail the achievements in the Laboratory.

VANNEVAR BUSH

WASHINGTON, D.C.

February, 1953

Establishment of the Radiation Laboratory

By Karl T. Compton

One of the first steps taken by the members of the National Defense Research Committee after its appointment in June, 1940, was a preliminary breakdown of the fields of activity into four main categories dealing respectively with ordnance, chemistry, communications, and physics. Drs. Tolman, Conant, Jewett, and Compton were respectively given the initial cognizance over these areas.

Through the Army and Navy members of NDRC there were next received lists of all of the research and development projects currently being carried on by the Services, each with a brief description and an estimate of priority. This list was distributed among the four divisions of the National Defense Research Committee and provided the starting point for its thinking and its activities.

To Section 1 of Division D was assigned the problem of detection devices. Since it was clear that the art of electronics would play a very important part in practically all detection devices, it was to someone versed in that art, and who at the same time had demonstrated a high degree of imagination and administrative skill, that we turned to head this division. This person was Dr. Alfred L. Loomis of Tuxedo Park, New York.

Early in the 1920's Dr. Loomis had established his own private research laboratory in Tuxedo Park, to which he had invited visiting scientists to cooperate with him or to carry on their own independent research work. In this laboratory, shortly before the war, there had been completed important exploratory investigations on the subject of brain waves, and Dr. Loomis had decided that the time had come to pass on his equipment and techniques to medical schools and hospitals where the applications and further scientific investigations could more effectively be carried on. For over a year he had been studying various scientific fields with a view to deciding what general line he should select next for the major activity of his laboratory. After consultation and visits to university and industrial laboratories he had decided on the field of microwaves and had begun to assemble equipment and a small staff of collaborators. Thus Dr.

Loomis' selection was a "natural" to head this original detection section of NDRC.

A second fortunate coincidence bearing on the ultimate selection of Massachusetts Institute of Technology as the place for the Radiation Laboratory was the fact that its Electrical Engineering Department had for a couple of years been carrying on a microwave development for the blind landing of airplanes, under the sponsorship of the Sperry Gyroscope Company in the interests of the Air Force of the Army. This development, using a 40-cm wavelength and an oscillating tube of the newly developed klystron type, had reached the stage of successful flight tests at Wright Field by the time NDRC was established. Thus there was at M.I.T. a small group actively working in the microwave field.

The other principal centers of microwave interest in the United States at that time were the Bell, General Electric, Westinghouse, and RCA Laboratories, and Stanford University, in all of which the interest had been principally centered on the development of oscillating tubes capable of producing appreciable power in the wavelength range of roughly 50 cm or less.

One of our first moves was for Dr. Loomis and me to visit research and development establishments of the Army and Navy where work in the detection field was in progress. Our first visit was to the Naval Research Laboratory where for the first time we saw radar in the laboratory and in operation. Rear Admiral Harold G. Bowen as Chief of the Naval Research Laboratory gave us every opportunity to see what that laboratory had done and to learn its future plans, and gave us every encouragement to enter this field to supplement the NRL activities. On this visit we also examined the status of the submarine-detection techniques which were principally "Asdic," an engineered improvement over the underwater supersonic detector which had been developed by Professor Langevin in France during World War I.

Our next visit was to the Signal Corps laboratories at Fort Monmouth, New Jersey, where we saw two Army versions of radar, one for detection and the other for fire control. Here the Commanding Officer was Colonel (later Major General) Roger B. Colton, the warmth of whose welcome rose many degrees when he learned that our organization might have a considerable amount of money to devote to further research and development in this field. We learned from him of the great struggle against economy through which the Signal Corps had finally succeeded in carrying the radar development to its then operating stage.

Finally, Dr. Loomis and I visited the Army maneuvers in the fall of 1940 in the northern New York State region of Ogdensburg where for the first time the Army version of radar was tested as a part of an early-warning network against "enemy" aircraft. Here we first saw the early-

warning reporting center with its complicated array of charts, plotting boards, and communication networks. Radar was so secret at that time that even generals of the Army were not permitted to approach the radar equipment unless they were directly concerned with its operation.

As a result of these visits Dr. Loomis decided that the work of his Committee on Detection Devices should concentrate initially on the field of microwave radar. Since the Army and Navy were working at the longer wavelengths, this decision avoided a duplication of effort. Since the airplane and the submarine appeared to be the two most important things to be detected in the type of mobile warfare which might be expected, and since detection of submerged submarines by supersonic devices was already an established art in the Navy, this decision to start out by concentrating on applications of microwaves for detection was a happy one. As the work developed, it soon became evident that the opportunities for the application of microwaves were so numerous and so important that this committee actually never expanded its field of activity outside of the microwave range, except for the development of the long-range navigation system, Loran, which involved something of the same techniques and principles. Consequently this initial section, D-1, on detection devices soon became the Microwave Division of NDRC.

An enormous lift to the developments in this field was provided through a visit of the British Scientific Mission headed by Sir Henry Tizard in the fall of 1940. Accompanied by Dr. Cockcroft and other British scientists, this Tizard mission brought to the United States the full story of research and development for military applications which had been carried on by the British up to that time. Among the material brought to America by the Tizard mission was a "cavity magnetron" of a type which had been invented in England by Dr. Oliphant and which was capable of delivering power at microwave frequencies far in excess of any of the tubes which had thus far been developed in America. This cavity magnetron, as further improved, became the heart of microwave radar. Small as it was in size, it has been called "the most important piece of cargo ever to cross the Atlantic Ocean."

Another valuable gift from Great Britain was Dr. E. G. Bowen, a British physicist and communications engineer who had worked with Sir Robert Watson-Watt in the development of Britain's first version of radar, and who also had had flying experience and was keenly interested in the problems of detection of enemy aircraft—especially the development of radar, which could be mounted in a pursuit plane and used to detect and home on the enemy bombers. Dr. Bowen also had the vision of microwave radar, with its enormous advantages over the longer wave radar, provided sufficient output power could be secured. Dr. Bowen was immediately attached to the Microwave Committee and it was as a

result of a series of discussions between Dr. Bowen and Dr. Loomis that the decision was reached to make the first radar-system objective of NDRC the development of a 10-cm AI (Air Interceptor) radar equipment. The initial tentative specifications were drawn up and the next move was to organize a laboratory, under some contractor, to carry out the work.

The selection of the site and the contractor for the Radiation Laboratory came about in this way. It was immediately realized that a laboratory for the development of radar must be close to an important air field in order that experiments with and on aircraft could be carried out, and should also be near the seashore in order that similar experiments could be carried out on the detection of ships. The first idea was to locate the laboratory at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. When this laboratory was visited, however, it was found that another NDRC project had already become established there, and it was felt that the remaining space available in the laboratories of this organization was inadequate for the future expansion of that other project, together with the new microwave work.

Negotiations were then undertaken with the Army to use one of its hangars on Bolling Field as a radar laboratory. Since this solution seemed feasible, a contract was prepared for submission to the NDRC, providing for the operation of this contract through the Carnegie Institution of Washington as contractor, with the work to be carried on at Bolling Field.

When I arrived in Washington to attend the meeting at which this proposal was to be submitted, I found, through Drs. Bush and Loomis, that the hopes for this solution had been completely dashed by a decision just transmitted from the Army to the effect that further plans for the use of Bolling Field made its use by NDRC impracticable. Another solution had to be found in a hurry. Bush and Loomis had one to propose. They asked me to find out whether the Massachusetts Institute of Technology could immediately make available 11,000 sq ft of floor space and could secure the use of the National Guard Hangar at the East Boston Airport, adjacent to the Boston Harbor. The idea was that the research and development could be done in the laboratories of M.I.T. and the experiments on aircraft or naval ships could be carried out with installations in this National Guard Hangar. I immediately called up M.I.T.'s Vice-President, Dr. J. Rhyne Killian, Jr., and asked him to explore the situation and report back immediately. Within a few hours he reported that the desired arrangements could be made, and thus this proposal went before NDRC and resulted in the initial contract with M.I.T., establishing what soon came to be called the "Radiation Laboratory." The failure of the first two plans was a blessing in disguise, for neither of those

locations in Washington would have permitted the unexpectedly large and rapid growth of the radar project.

Because of the background of microwave work carried out by the M.I.T. Electrical Engineering Department in its cooperation with the Sperry Gyroscope Company and the Army, this contract, which was made through the Division of Industrial Cooperation of M.I.T., was originally under the general supervision of M.I.T.'s Electrical Engineering Department. This was a convenient arrangement also because Dr. Edward L. Bowles, who was secretary of the NDRC Microwave Committee, had been in charge of the electrical engineering group working on the microwave blind-landing problem. However, it was agreed from the beginning that the prosecution of the radar program would require the importation of a great deal of outside talent—physicists, electrical engineers, and many others—and that as soon as possible this laboratory should be set up in as autonomous a manner as possible, with a maximum degree of freedom and responsibility for initiating and carrying out its program. It had of course to be responsible to M.I.T., since M.I.T. had the contract responsibility, and it had to be responsible to NDRC. But within these limits of financial responsibility and over-all direction it is certainly true that the great success of this laboratory was in no small measure due to the opportunity afforded its staff to accept responsibility and to take initiative.

The next most important problem facing the laboratory was its selection of personnel, and to aid in this selection Professor Ernest O. Lawrence of the University of California, who at about that same time was made a member of the Microwave Committee of NDRC,¹ was called in to assist the Microwave Committee and M.I.T. in the initial selection of personnel. This was a most fortunate choice and Professor Lawrence naturally turned to his many associates and disciples in the cyclotron field, because the circuits of a cyclotron, like those of radar, involve the pulsing of large amounts of high-frequency electric power. Thus the initial members of the high-powered team were selected, with the really inspired choice of the two top executives of the laboratory, Dr. Lee A. DuBridge as Director and Dr. F. Wheeler Loomis as Associate Director.

The operations and accomplishments of this Radiation Laboratory have been well and adequately described elsewhere and I shall not attempt to duplicate these statements. However, I should like to say something

¹ The first membership of the Microwave Committee consisted of Alfred L. Loomis, Chairman, Edward L. Bowles, Secretary, Ralph Bown, Hugh Willis. In July, 1945, it consisted of A. L. Loomis, Chief, J. R. Loofbrouow, Secretary, W. R. G. Baker, Ralph Bown, L. A. DuBridge, Melville Eastham, J. A. Hutcheson, L. F. Jones, M. J. Kelly, E. O. Lawrence, I. I. Rabi, C. G. Suits, F. E. Terman, A. T. Waterman, Warren Weaver, H. H. Willis.

about the relationship of the Massachusetts Institute of Technology to this radar project.

Until the Radiation Laboratory was so strongly established that it could do its own recruiting, M.I.T. had the responsibility of selecting the first staff, as described above. Then it had the responsibility of making the arrangements with scientists and engineers from other institutions, and particularly it had the job of negotiating with their home institutions the leaves of absence for these scientists. At that time the United States was not yet at war. The duration of this preparedness effort was uncertain. Consequently the leaves of absence were negotiated for a period of one year.

M.I.T. had to take the financial responsibility for the members of the staff thus recruited, as well as for the purchases and subcontracts. This financial responsibility involved two difficult factors, one of delay and the other of risk. The delay was incurred because of the time required to assemble vouchers and have them cleared through the Government Accounting Office, and for this reason M.I.T. was continuously out of pocket by amounts which ultimately ran into several million dollars. The payments of course came through eventually, but in the meantime M.I.T.'s endowment fund had been reduced by a sizable portion.

The risk involved was of two types. The regulations of government purchasing were such as frequently to require considerable time for competitive bids or other established procedures. The exigencies of the situation, however, required speed. M.I.T. from the beginning adopted the policy that it would permit no consideration of convenience or financial safety or any other consideration to stand in the way of doing what had to be done as promptly as possible for the winning of the war. Consequently, there were some purchases made for which reimbursement was not allowed, but the largest item of financial risk was in the reappointment of the scientists on leave of absence for their second year of duty, which came about in the following manner.

It was the end of June, 1941, before Congress voted the appropriation to continue the work of OSRD in the following fiscal year. However, M.I.T. could not wait this long to re-engage the staff of the Radiation Laboratory for the following year, because the personal financial risk to the individuals would have been too great, and also because the institutions which had loaned them to M.I.T. were demanding, as early as March or April, definite information as to whether the leave of absence of their scientists should be continued in the following academic year. In order to meet this situation the Executive Committee of M.I.T. agreed to underwrite the staff appointments for the following year to the extent of a half million dollars. This, however, was only about half enough to handle the situation, and I secured permission from Dr. Bush to describe

the problem to John D. Rockefeller, Jr., who immediately agreed to underwrite another half million dollars, and thus the staff of the Radiation Laboratory was saved from disintegration at this critical period between the first and second years of its operation.

I have mentioned M.I.T.'s responsibility in the radar program by acting as contractor and banker and by following the basic principle that nothing within its power should be allowed to interfere with doing what needed to be done to help win the war. There were other contributions, however, which were also significant for the work of NDRC and of its other contractors. Because M.I.T. was the first large contractor of NDRC, and probably also because it had previously, over a number of years, given a good deal of thought to the appropriate conditions under which research and development work should be carried on for outside agencies in an educational institution, M.I.T. became the "guinea pig" for working out a wide variety of contractual policies having to do with the repayment of overhead expenses, the establishment of salary and wage scales, the handling of patentable inventions, the advancement of funds to meet contractual obligations, and many other factors. Notably helpful in such negotiations and agreements were Vice-President J. Rhyne Killian, Jr., Director Nathaniel M. Sage of the Division of Industrial Cooperation, and Phillips Ketchum, legal counsel of M.I.T. Their services on such matters were not only of great advantage to the Office of Scientific Research and Development and its other contractors, but they also relieved the research and development staff of the Radiation Laboratory from as much troublesome business detail work as possible.

In conclusion I should say a word with reference to the relations between the Radiation Laboratory and our allies of the United Kingdom. I have already mentioned the Tizard mission and the valuable services of Dr. E. G. Bowen. I should also mention Dr. Denis M. Robinson, who arrived shortly after Dr. Bowen and teamed up with him in contributing to the work of the Laboratory, at the same time taking general oversight of the design and production of certain types of radar equipment in which the United Kingdom was particularly interested. There was also a continual stream of research workers from Canada, Australia, and New Zealand, together with additional scientists from England, who stayed in the Laboratory for longer or shorter periods and contributed both to the productivity of the Laboratory and to the coordination of its work with the efforts of our allies.

Particularly important in our cooperation with the United Kingdom was the work of two parallel committees, one the United States Joint Chiefs of Staff's Committee on Radar, and the other a parallel committee of the British Radar Board which, under Professor G. P. Thomson and Sir Robert Watson-Watt, was charged with the development of the

United Kingdom's program in radar. I served with Dr. Lee DuBridge and Dr. Alfred Loomis as civilian members of this United States committee, and Dr. I. I. Rabi served as the committee's chief analyst. I believe that one of the "claims to fame" of this committee is the fact that in early 1943 it selected, as a means for focussing its thought on practical issues, the conception of a landing operation carried across the Atlantic Ocean from the United States to the north coast of Africa, making a landing and establishing a beach-head, and later a base, in Africa, then moving armies across North Africa with parallel fleet movements in the Mediterranean, and finally crossing the Mediterranean to Italy and working up through Italy into the backdoor of Germany. At every stage in this hypothetical process, of whose actual conception as a military plan we had no information, our committee attempted to analyze each movement and hazard, to see whether radar could advantageously be used and whether it was better than any other method of handling the situation. Then, if radar appeared to be indicated for any purpose in this whole series of operations, we asked the question: Is the radar already available for this use, or does a new type of radar have to be developed and, if so, what are its specifications and what is the priority?

In this way the American Program of Research and Development in Radar came to be established and actually went into operation in the various civilian and military radar agencies of the country while the discussions were going on, because of the presence of representatives of these important agencies at our committee meetings.

Organization of the Radiation Laboratory

By Lee A. DuBridge

The story of the growth, the activities, and the accomplishments of the Radiation Laboratory of the Massachusetts Institute of Technology cannot easily be condensed into a few short pages. Its operations were so complex and far reaching that an entire book would be required to describe them. Such a book has, indeed, been written by Dr. Henry Guerlac, who was brought to the Radiation Laboratory for the purpose of compiling its history. Unfortunately, no mechanism for the publication of this extensive and important document is now available. Various brief accounts of the Laboratory have appeared, however, the most complete being that which constitutes Chap. 9 of *Scientists against Time* by James Phinney Baxter, III (Little, Brown, and Company, 1946). The material covered therein, relating particularly to the role played by microwave radar in the war effort, need not be repeated here.

The technical work of the Radiation Laboratory is a still longer story. This 28-volume Radiation Laboratory Series is an attempt to tell the essential features of this work, and, in addition, to compile from the work of all the radar laboratories in the allied countries a reasonably complete account of the status of technical developments related to radar as they stood at the end of World War II.

This present summary is intended primarily as a background for those who are interested in the kind of organization which produced this technical series. It will concentrate on the functioning of the Laboratory itself rather than on its accomplishments in providing new military weapons.

History

The Radiation Laboratory as an organization dates from Nov. 10, 1940. On this date a group of about 15 physicists assembled at the Massachusetts Institute of Technology in Cambridge, following weeks of preliminary planning and recruiting by the NDRC Microwave Committee, as described in Dr. Compton's article in this volume. Drs. Karl T. Compton, Alfred L. Loomis, and Edward L. Bowles, representing the Microwave Committee, presented to this group the NDRC plans for the

establishment of a laboratory to be devoted to the development of microwave-radio-detection techniques and their application to the problems of warfare. The initial project which the Microwave Committee had agreed to undertake at the request of the British, namely, the development of microwave-detection equipment for use in night fighters, was outlined in broad terms by Dr. Loomis and a week later in more detail by Dr. E. G. Bowen, the representative of the British effort in this field. A preliminary laboratory organization designed to undertake this project was agreed upon at the Nov. 10 meeting and the embryonic laboratory group proceeded to prepare the quarters which had been assigned to it in Building 4 of M.I.T., to become familiar with the technical problems involved, and to recruit additional members for the staff.

The Microwave Committee had agreed that the new laboratory should be recruited largely from the ranks of the physicists of the country. This was partly because British experience in this direction had already proved highly successful; partly because the electrical and radio engineers were already being drawn into industrial laboratories to man their expanding war programs, while the physicists as a group had not yet been drawn into war work. Also the field of microwaves was at that time an almost unexplored area in which few engineers had been trained. Since it depended on the basic principles of physics, it seemed that physicists would be well equipped by previous training and experience to undertake its development.

The three laboratory rooms initially assigned to this new group almost at once became a beehive of activity. Equipment was ordered and assembled, components previously ordered by the Microwave Committee soon began to arrive, and new recruits to the staff came in at an average rate of about one per day. By Jan. 1, 1941, most of the men who were to be the key leaders of the Laboratory throughout its five years of activity had been assembled.

By mid-January a crude laboratory model of a microwave radar set was in actual operation in a shack on the roof of Building 6. By March a set was being successfully flown in a B-18 aircraft provided by the Army. A few weeks later, in May, a model for an airborne AI set was turned over to the Bell Telephone Laboratories which had received an Army order for its further development and production. The SCR-520, and later the vastly improved and widely used SCR-720, resulted from this project.

Following this initial "blitz" effort the Laboratory group really settled down to work. It was now evident that microwave radar was feasible and had many potentially important applications. It was also clear that the microwave art was in the very early stage of development and a large effort was still ahead.

Two other projects initially decided upon by the Microwave Committee were also under way. One was the design of a precision anti-aircraft fire-control radar and the other a long-range radio navigational system, later called Loran, which was the only major nonmicrowave project the Laboratory ever undertook.

The initial AI project itself turned out to be less important in the war than a whole host of other projects which grew directly out of it. These included radar equipment for detecting surface vessels and submarines, for firing of guns and rockets, for blind bombing, for harbor surveillance, and for general navigation of both ships and aircraft. A variety of sets serving each of these functions were developed in sequence as improved techniques came along and as it became necessary to meet the special demands of different types of Army and Navy aircraft.

The fire-control project, also off to an early start, eventually led to one of the most successful of all Radiation Laboratory equipments, the SCR-584, which proved adaptable to many uses and which gave rise to many other radar sets for ground and ship applications.

The Loran equipment developed by the Laboratory eventually provided a radio navigational system which covered a large proportion of the air and sea traffic lanes of the world.

At the time of Pearl Harbor, Dec. 7, 1941, the Laboratory had grown to a staff of over 400 and was just moving from its outgrown quarters in the main M.I.T. building into a new permanent building. It was at work on many of these projects and had made important improvements in all microwave components and techniques.

The entrance of the United States into the war enormously accelerated the Laboratory's activity and its rate of recruiting. It expanded into additional buildings, of which some were rented in nearby Cambridge, and others were temporary structures built on the M.I.T. campus. By the end of the war the Laboratory had a staff numbering just under 4,000 individuals, it occupied a half million square feet of space in buildings on or near the M.I.T. campus, and had groups spread in a dozen field stations throughout the world, including a branch laboratory in Malvern, England, and another in Paris, France. By this time it had undertaken and had fully or partially completed work on some 100 different models of radar equipment for use on land, on sea, and in the air. Over a billion and a half dollars' worth of equipment, which had its inception at the Radiation Laboratory, had been produced, and another billion dollars' worth was on order when the war ended. This equipment saw service in every fighting area and was supplemented by a substantial amount of equipment manufactured directly in the Laboratory and in the Research Construction Company model shop that reached the field before production lines were delivering it in quantity.

As the end of the war approached, the desirability of writing a systematic account of the technical developments in the field of radar became apparent and the Office of Publications, under the direction of Dr. L. N. Ridenour, was established in the Laboratory. At the end of the war, as projects were terminated, the Office of Publications acquired a large staff which remained at work for an additional six to nine months, during which period the bulk of the manuscript for the Radiation Laboratory Series was completed.

The Functions of the Radiation Laboratory

The Radiation Laboratory has often been referred to as a research laboratory. As a matter of fact, research, in the true sense, was only a small, though vital, part of its activities. A complete list of its functions would go something like this:

1. Research on microwave equipment and techniques
2. Component development and engineering
3. System design, engineering, and test
4. Collaboration with the manufacturers on design of production equipment
5. Coordination of military tactics with equipment design
6. Field trials of pilot-model equipment
7. Operational trials, often under actual battle conditions
8. Assisting military services in introducing new equipment into operational use, modifying it to meet new operational requirements, and assisting in the training of operation and maintenance personnel
9. Reporting field experience and problems back to the Laboratory for guidance in future design
10. Manufacture of small quantities of new equipment for immediate use in the field
11. Collaboration with all other research and development agencies in this country and abroad, seeking and rendering assistance in all of the foregoing areas

During the early days of the Laboratory the first three functions naturally occupied the major portion of the attention. As time went on, and equipment got into the field, the other items on this list occupied a larger and larger fraction of the Laboratory's effort.

This article would be entirely too long if we attempted to give a complete account of all the above functions. It would, however, be desirable to say a few words about several of the more important items.

Research Activities

All the important activities of the Laboratory, other than the early ones in which the experience of the British and of other United States

laboratories was copied, depended upon two things: (a) research which uncovered basically new microwave and electronic techniques, and (b) imaginative thinking on the adaptation of these techniques to tactical problems.

The research activities of the Laboratory did not get under way during the early rather hectic days of investigating whether a microwave radar could be made to work at all. Indeed, it was always a struggle to give proper emphasis to long-range research problems in the face of pressure to get equipment completed for immediate operational use. Nevertheless, some research got under way at quite an early stage, and the efforts grew steadily in magnitude, proving in the end extremely productive.

Shortly after the first 10-cm magnetrons, copied from British designs, were delivered by the Bell Telephone Laboratories, research was undertaken to develop a magnetron which would operate at a wavelength of 3 cm. As early as the spring of 1941 such a magnetron was actually operating as a result of the combined efforts of the Radiation Laboratory magnetron group and the model shop of the Raytheon Manufacturing Company. This success initiated a considerable effort aimed toward the development of other 3-cm equipment, and eventually some of the best and most important sets developed by the Laboratory operated at this wavelength.

Later the extension of magnetron and radio-frequency techniques to wavelengths in the range of 1 cm was undertaken. This endeavor encountered very serious and difficult problems, most of which were eventually solved, and equipment operating at 1 cm actually was getting into production at the end of the war. In this program the Columbia Radiation Laboratory played a most important role, partly because it was purposely isolated from the press of equipment-development problems at the M.I.T. Radiation Laboratory itself. The research groups of both laboratories operated under the inspiring leadership of Dr. I. I. Rabi.

The problems involved in extending radio techniques into ever higher frequency ranges led to research in many areas aimed at a better understanding of high-frequency phenomena. As a result, the radar equipment designed toward the end of the war incorporated apparatus and techniques which made the early sets look very crude and inefficient, as indeed they were. Research on the theory of propagation of electromagnetic waves in waveguides and in free space, on the "optics" of microwave-antenna design, on the basic theory of component and system operation and performance, and indeed, on every subject discussed in this 28-volume Radiation Laboratory Series eventually paid large dividends in better understanding of radio and microwave technology and in marked improvements in the performance and adaptability of microwave

radar sets. Possibly never before in history has a new technology advanced so rapidly on so wide a front as in this area.

Component Development

The activities of the research division, aimed at discovering new phenomena or at a better understanding of old ones, merged imperceptibly into activities aimed at the development of new components. The two largest divisions of the Laboratory were devoted to this work. Magnetrons, pulsers, antennas, indicators, receivers, together with all the vacuum tubes, condensers, waveguide elements, transformers, and the dozens of other parts all had to be developed, improved, tested, adapted to new types of sets, and engineered for mass production. The work of the many component development groups not only continually improved the performance and the reliability of radar equipment but also, through new ideas originating there, opened up new possibilities in the design of sets for new tactical purposes.

The separation in the Laboratory organization of equipment development from component development made possible more concentrated attention on the latter as well as a degree of standardization which was essential for economy of effort and production.

It must be remembered that parts, tubes, and equipment for radar, especially microwave radar, simply did not exist in 1940. Though many standard radio parts could readily be adapted to radar, many others had to be developed and put into manufacture. These covered an amazing variety of devices, from shock mounts to huge antenna structures, from detector crystals to hydrogen-filled thyratrons, from i-f amplifiers to microsecond timing circuits, and literally hundreds of additional items.

It is the work which was involved in component development which occupies the bulk of these volumes, and even much of this work is omitted for lack of space.

System Development

It was the task of the several system divisions to keep in touch with tactical problems on the one hand, and the status of technical developments of components on the other, and then to design and build the best possible radar systems to meet operational needs. Sometimes these operational needs could be stated in precise terms by military agencies; frequently, however, equipment was evolved to meet possible operational requirements before the need for such equipment or the possibility of obtaining it was realized by the Army or Navy. It was not the practice of the Laboratory to wait for official requests for new equipment but rather, by studying the progress of the war, to attempt to visualize such needs in advance. In fact, strenuous "selling" was often required to

convince some military agencies of the need, or the feasibility, or the possibilities of new radar sets.

If the research and component development divisions made radar possible and practical, the system development divisions made it usable, valuable, and adaptable to new needs. Since all groups in the Laboratory kept in close contact with each other, with other laboratories and agencies, and with the problems of war, a cooperative effort was possible which multiplied the effectiveness of the whole Laboratory manyfold. It is this spirit of friendly cooperation which now stands forth in my own mind as the most essential feature of the Laboratory's operations.

Relation to Other Agencies

Although the Radiation Laboratory grew to be probably the largest single radar laboratory either in this country or in England, it would be a mistake to assume that it was the predominant source of radar and electronic research and development. The radar effort of the Allies went forward on a very large scale at a host of research, development, and manufacturing centers, and it was characterized by extensive collaboration, on both a national and an international scale.

The Radiation Laboratory itself was founded on the basis of information brought to this country by the British, and it depended heavily, particularly during its early years, upon British experience, both operational and technical. The AI project, which occupied such a large share of the Laboratory's attention in the first months of its existence, was itself visualized as an effort to help the Royal Air Force in its night-fighter problem. The British magnetron developments and the British concepts of airborne microwave radar were brought to the Laboratory by Drs. E. G. Bowen and D. M. Robinson, and by a large volume of correspondence and reports exchanged between the two countries. The British ideas were the guiding influence of the initial group of physicists who had, for the most part, never before heard of microwaves or of the detection of aircraft by radio.

Throughout the history of the Radiation Laboratory the contact with the British laboratories and the British services was extremely close and cordial. Many representatives from British laboratories visited the Radiation Laboratory and other laboratories of this country repeatedly, and often for extended periods. As early as 1941 a Radiation Laboratory representative, Dr. K. T. Bainbridge, made an extended visit to England to secure a better view of British developments and problems. He served as the vanguard of a host of Laboratory travelers who went to England, and later to the continent, and who sent or brought back a most complete story of technical developments and operational problems. The British Branch of the Radiation Laboratory (BBRL) was established

on the grounds of the largest British radar laboratory, the Telecommunications Research Establishment, in Malvern, England, in 1943. Though much of the effort of this laboratory was devoted to rendering help to the United States forces in Europe, a major result of its activity was the still closer liaison between British and American radar scientists and engineers.

The importance of the contacts between the two countries was dramatically illustrated as early as June, 1941, when an early model of the Radiation Laboratory's AI equipment was installed in an airplane supplied by the Royal Canadian Air Force and sent to England, accompanied by Dr. D. R. Corson, for technical and operational trials.

These trials showed the American equipment to be inferior in performance to the British equipment as far as the receiver techniques were concerned, but also showed that the American transmitter equipment was more powerful than the British. By combining the best features of British and American sets, a set which outperformed either was put together.

It would require many pages even to list the other examples of a fruitful outcome of British and American collaboration. The British laboratories were a continual source of new ideas and new techniques which were generously shared with the Americans and which were promptly incorporated into American practice. The Radiation Laboratory only hoped that by the time the war was ended its own contributions, particularly in the field of radar engineering, had eventually made the exchange an even one.

The Radiation Laboratory also owed much to, and collaborated extensively with, other American agencies. Before the Radiation Laboratory was started, the U.S. Naval Research Laboratory and the U.S. Signal Corps Laboratories already had practical radar equipment in production. Though these and other military laboratories concentrated largely on longer wavelength radar equipment, while the Radiation Laboratory devoted most of its attention to microwaves, the collaboration with these laboratories became very extensive and mutually valuable.

The design and engineering of radar components and sets eventually involved literally hundreds of manufacturing companies, many of which either had or acquired important research and engineering activities. With all these the Radiation Laboratory kept in closest contact and each of them contributed in many important ways to the development of the art.

Special mention should be made of the large and very important contributions of the Bell Telephone Laboratories and the Western Electric Company in research, development, design, engineering, and production. The contribution of the Bell Laboratories in magnetron development,

vacuum-tube development, development of receiver and antenna techniques, and many other fields was particularly important to the whole United States effort. The Radiation Laboratory borrowed generously from the work of these laboratories as well as from the work of the research laboratories of the General Electric Company, the Westinghouse Electric and Manufacturing Company, and a host of others. The above companies, together with the Philco Radio Company and the Raytheon Manufacturing Company, were the chief producers of microwave radar, and close collaboration with them on development and engineering problems often greatly expedited production schedules.

Finally, it must never be forgotten that the Radiation Laboratory was an integral part of the program of the National Defense Research Committee and the Office of Scientific Research and Development, and it was at the same time a part of the Massachusetts Institute of Technology. It was the NDRC-OSRD organization which set the basic policies and provided the framework of organization and funds within which all its separate units operated. The Radar Committee (initially dubbed the Microwave Committee) was an agent of NDRC in administering these policies and programs in the radar field. This Committee served in a sense as the Board of Trustees of the Laboratory. To this Committee, and especially to its genial and far-sighted chairman, A. L. Loomis, the Radiation Laboratory owed as much as a child owes to its parents for wise guidance and control combined with wisdom and confidence in allowing necessary freedom of action.

To M.I.T. the Radiation Laboratory owed all its physical facilities and its framework of operation. The Laboratory was a part of the M.I.T. organization, though a large and somewhat separated part to be sure. But the Laboratory could not have existed except as a part of some such organization and it was fortunate indeed to be a part of M.I.T. The flexibility of its administrative organization, the kindly and wise leadership of President Compton and Vice-President (now President) Killian were vital factors in the Laboratory's operation and success.

In conclusion, I wish to pay a personal tribute to the men and women of the Laboratory itself. They constituted a superb group, certainly one of the finest ever assembled. Only in a time of national crisis would it have been possible to assemble such a magnificent array of talent. The task of the Director was made a simple one by the loyalty, intelligence, and cooperative spirit of this splendid group of people.

Preparation of the Radiation Laboratory Series

By Louis N. Ridenour

With the publication of this Series Index, the Radiation Laboratory Series is complete. It has seemed appropriate to include in this volume some short historical accounts of the work which gave rise to the Series. Dr. Vannevar Bush, wartime Director of the Office of Scientific Research and Development, the parent organization of the Radiation Laboratory, has contributed a Foreword for this volume which replaces the Foreword by Dr. L. A. DuBridge that appears in the other volumes of the Series.

Dr. Karl T. Compton, who led the Division of the National Defense Research Committee that established the Radiation Laboratory, has given an account of the Laboratory's founding. Dr. DuBridge, Director of the Radiation Laboratory during its 62 months of existence, has written a very brief account of its organization, its growth, and its work. Here follows a short sketch of how the Series was prepared for publication.

Dr. I. I. Rabi, then Associate Director of the Radiation Laboratory, proposed the original idea for the Series in the fall of 1944, when it began to appear that the war in Europe was nearing its end. Preliminary outlines for the work were made at that time, contemplating only the preparation of books dealing with the basic microwave theory and techniques which had been developed during the wartime work on radar. Work on the planning of the Series was laid aside when the bitter fighting of the winter of 1944-1945 in Europe made it clear that the war was not yet over.

Work was resumed in the late spring of 1945. The Editor-in-Chief of the Radiation Laboratory Office of Publications was appointed in May of that year, and actual work began about June 1, 1945. Progress was slow at first, since most of the Laboratory's staff members were understandably more concerned with the further prosecution of their technical work than with the preparation of reports on work already done. During the early days of the Office of Publications, invaluable help and encouragement were offered by Dr. George B. Collins, who became Deputy Editor-in-Chief; by Charles Newton, who, as Production Manager, handled all the

technical matters concerned with typing, drafting, photography, and the processing of manuscript and illustrations; and by Dr. George E. Valley, who was the first Radiation Laboratory staff member to join the Office of Publications.

At the outset of the work of preparing the Series, it was necessary to proceed in two general directions. Outlines for the various volumes had to be worked out, authors and editors chosen and induced to undertake the work, drafting and typing facilities set up, and the actual task of writing begun. This, although difficult, was a relatively straightforward job. The second part of the work—that of making the formal arrangements for the publication of the Series—was far more troublesome, mainly because no pattern existed for what was being attempted.

Since the Radiation Laboratory had been maintained by contract with the OSRD, an agency of the Federal government, it was necessary to obtain the approval of the Government Printing Office for the arrangements made to publish the Series. With the help of Dr. John E. Burckhard, then Chairman of the OSRD Committee on Publications, and of Dr. Carroll L. Wilson, then assistant to Dr. Bush, discussions with the Government Printing Office were undertaken. It was determined by the GPO that publication of the Series would be accomplished most expeditiously if the job were handled by a commercial publisher.

The leading technical publishers of the country were then approached to learn their interest in publishing the Series. The McGraw-Hill Book Company, represented in these initial negotiations by James S. Thompson, then President of the company, showed a keen interest in the project from the very beginning. Proposals were ultimately submitted by three publishers, and that of the McGraw-Hill Book Company proved to be the one most favorable to the government.

Contractual arrangements for the publication of the Series had to include the Massachusetts Institute of Technology as "author" of the manuscripts, since the Institute was the contractor maintaining the Radiation Laboratory. This presented new problems, for the actual authors of the manuscripts for which the Institute was asked to become contractually responsible were in fact hundreds of individuals, each with his own postwar problems of relocation and readjustment. Nothing beyond the good faith of the author could be relied on as a guarantee of satisfactory completion of the work.

Negotiations for publishing the Series could readily have collapsed completely at this point, but the energetic efforts of Dr. James R. Killian, Jr., then Vice-President (now President) of the Massachusetts Institute of Technology, and of Curtis G. Benjamin, then Vice-President (now President) of the McGraw-Hill Book Company, surmounted every obstacle. A contract for the publication of the Series was finally signed

on Nov. 14, 1945, largely as a result of the vigor, good faith, and generous cooperation of Benjamin and Killian.

Until the end of 1945, the work of the Office of Publications was budgeted as a part of the operation of the Radiation Laboratory, but that laboratory formally ended its existence at the close of the year. Estimates of the additional cost of preparing the manuscripts and illustrations for the Series came to \$500,000, and this sum was set aside by OSRD to provide for the independent existence of the Office of Publications during the first six months of 1946, in which time it was estimated that the work could be finished. In recognition of the fact that the costs of preparing the Series had been met from the Federal treasury, the contract with McGraw-Hill for the publication of the Series provided that the usual authors' royalties be returned to the treasury of the United States. Up to January, 1953, the sum of \$132,367 had already been returned to the government in the form of royalties on the Series. There appears to be a possibility that the entire direct costs of preparing the manuscripts and illustrations of the Series will eventually be returned to the government in the form of royalties. The publisher assumed all the substantial costs of composing, printing, and binding the volumes. In the public interest, the contract with the publisher also provides that McGraw-Hill will hold its copyright on each volume of the Series for only ten years following the date of publication.

The mechanical task of preparing in six months the manuscripts and illustrations for 27 technical volumes was as formidable as the literary task of writing and editing them. Preliminary estimates, which turned out to be surprisingly accurate, indicated that about a ton and a half of copy paper would be used, that about 75 typists would be needed, at the peak of activity, to prepare the various drafts of the manuscripts, and that about 100 draftsmen would be required to prepare the line drawings illustrating the Series. Substantial photographic facilities were needed to prepare the prints used for half-tone illustrations. Charles Newton managed all these arrangements, and supervised the photographic service which he had previously operated for the Radiation Laboratory. Mary Dolbeare was in charge of the typing center, Vernon Josephson of the drafting room.

By the end of 1945, the preparation of outlines for the work as a whole had been substantially completed, and actual writing was well under way. To the volumes on basic techniques that had been planned earlier there were added several books on systems problems, such as Vols. 1, 2, 3, and 4; and books on specialized techniques, such as Vol. 27. Every effort was made to achieve a maximum of technical and stylistic uniformity, with a minimum of confusing shifts in notation, abbreviations, and the like. Dr. Leon Linford headed the group that was responsible for setting

the technical standards of style; he was greatly assisted by Monica Stevens, who was assigned by the McGraw-Hill Book Company to the Office of Publications as an expert on style. Whatever uniformity is observable in the books of the Series was very largely conferred upon them by the efforts of Elizabeth Gile, now Editor-in-Chief of the McGraw-Hill Book Company, Miss Stevens, and Dr. Linford and his group, who went so far as to prepare a Style Manual for the use of authors and editors, there being no suitable technical manual in existence.

By no means all the technical information reported in the Series originated in the work of the Radiation Laboratory. As the brief histories in this Index volume attest, the very notion of establishing the Radiation Laboratory was a result of the British invention of the multi-cavity magnetron and the disclosure of this capital device to representatives of the United States. For early leadership in the field and for many important advances in radar, the free world is deeply indebted to the Telecommunications Research Establishment and the other British radar laboratories. The recent Royal Commission award to Sir Robert Watson-Watt, the acknowledged father of radar, has come as welcome news to those of us who took part in the wartime radar development program. In order to make sure that British work would be adequately reported in the Series, the Office of Publications secured the assignment to the editorial staff of Dr. B. V. Bowden, then of the British Air Commission in Washington. Dr. Bowden was of great help in securing British documents, in making sure that important British work was not overlooked, and in taking part in the actual writing.

Apart from the Radiation Laboratory, the main centers of radar development in this country were the technical laboratories of the Army and the Navy, and the development laboratories of the principal electrical manufacturers, the most important by far being Bell Telephone Laboratories. Liaison offices were maintained at the Radiation Laboratory by the Army, the Navy, and the Army Air Forces; there were also groups of engineers from most of the important manufacturers. This made it possible to include in the Series the principal results obtained elsewhere in the country. In addition, Dr. M. J. Kelly, then Executive Vice-President (now President) of Bell Telephone Laboratories, was kind enough to arrange for members of Bell Laboratories to review and comment on manuscripts of the Series prior to publication; this was very helpful in correcting errors both of omission and of commission.

Before the publication of any volume of the Series, two sorts of clearance of the manuscript and illustrations had to be secured. Despite the extensive declassification of technical material at the end of 1945, formal security clearance had to be obtained. This was managed in two steps. At the time the outlines for the volumes were being settled, they were

discussed with a joint Army-Navy-AAF security committee especially appointed for this purpose, and all outline entries of dubious clearance status were either eliminated or else determined to cover unclassified material. When the manuscripts were in hand, this same committee studied them to determine compliance with the original judgments on security. Thanks largely to the effective work of this Service group, the usually troublesome task of security clearance was accomplished with a minimum of difficulty. Members of the special security panel were Commanders J. E. Boyd, W. C. Hilgedick, and C. A. Smith, Lieutenant Commander J. Weber, Major Max Hall, Captain Hugh Winter (Army), Lieutenant J. A. Rexroth (Navy), and W. J. Brown, of the Signal Corps.

The other clearance required before publication involved a review of the manuscripts to ensure that they did not jeopardize the integrity of government-held patents, for example, by making inaccurate statements about dates or sources of invention. Captain R. A. Lavender, the principal patent advisor to the OSRD, was helpful in setting up the mechanism for reviewing the manuscripts from the patent standpoint. Most of the actual work of review was accomplished by John C. Batchelor, who was uniformly patient and helpful.

Much of the work of securing the formal clearance of the completed Series manuscripts came after the dissolution of the Office of Publications, and consequently fell on the late Dr. J. R. Loofbourow and J. L. Danforth, of the OSRD liaison office at M.I.T., and on Dr. Eugene W. Scott, J. H. Sole, and the late Cleveland Norcross, of the Washington staff of OSRD. Their effective help in this undertaking is gratefully acknowledged.

For those Radiation Laboratory staff members who remained with the Office of Publications after the termination of the Radiation Laboratory, doing so often represented a substantial sacrifice in terms of postponing or foregoing academic fellowships, professorial appointments, or industrial jobs. After the close of the Office of Publications, there was still much work to be done in "spare" time, without any additional compensation except the reward inherent in a job well done. At best, there were proofs to be corrected; in many instances, there were substantial tasks of writing and editing still to do. All this work was ultimately done, and the Series is complete.

During the active life of the Radiation Laboratory's Office of Publications, it was planned that Dr. Leon Linford should prepare the general index volume for the Series. Unavoidable delays in the completion of the last few manuscripts, however, delayed the appearance of the Index very considerably. Meanwhile, Dr. Linford became so busy with his professional duties that he was unable to invest the substantial amount of time necessary to prepare an adequate index. Fortunately for the Series, Keith Henney, of the McGraw-Hill Publishing Company, very gen-

erously agreed to undertake the difficult task of preparing a unified Index for the entire Radiation Laboratory Series. He has carried out this job with vigor, skill, and success, and all users of the Series are permanently in his debt.

Those of us who helped prepare the Series sincerely hope that it is worthy of the dedication Dr. DuBridge has given it—"to the unnamed hundreds and thousands of . . . scientists, engineers, and others who actually carried on the research, development, and engineering work the results of which are herein described."

Editor's Introduction

The best person to make a book index is the author. He knows what is in his book, why it is there, and where a reader is likely to look for it. But it would be impossible to get the 53 authors whose names appear on the jackets of the 27 volumes of the Radiation Laboratory Series to compile the final volume—the master index—even if they could agree upon an index style!

This editor, therefore, assumed a job which at first sight seemed quite simple. But closer look made it apparent that an index of the individual indexes would not be very useful; and still closer scrutiny indicated that the final index could not be made by merely shuffling the entries in the 27 volume indexes. These individual indexes are not uniform in magnitude, style, or in any other parameter. Some have author's names and others do not. Some indexes are sparse; others are voluminous. And in the individual index an entry without qualification, "amplifier," for example, might be all that was necessary, but when included in the master index such an entry would be virtually worthless.

The editor took a bold step. He eliminated all authors' names. He eliminated all company and laboratory names unless the item referred to has real meaning at this date. Many entries were eliminated because time has negated their importance. Other entries which contribute little or no information have been dropped—the mere mention of a 6SA7 tube, for example.

Qualifying adjectives have been added to many thousands of entries which now appear in the individual volume indexes without qualification. In this way the reader has a better and quicker chance to find what he wants. Every attempt has been made to bring together matters which naturally belong together—beacons, for example, are collected and not scattered; antennas, for whatever purpose, are found under "antenna."

Some of the larger individual indexes have been streamlined; and in many cases the slender indexes have been built up when the editor found material which a present-day reader would want.

The editor cannot end this preface without saying something about the 15,476 pages of the 27 volumes themselves. Throughout the job of making this index it was a constant temptation to read paragraphs,

chapters, or whole books to learn more about matters which are still so current and so important that the books might have been written yesterday instead of from three to eight years ago. There is an amazing amount of information in this library, much of which is currently being applied to many scientific and engineering jobs which have no relation whatever to radar.

May the reader find this index useful in locating what he wants when he wants it; and may he remember that the Radiation Laboratory Series exists only because of the vision of men like Bush, DuBridge, and Ridenour and because of their unconquerable determination in forcing the contents of these 27 volumes out into the open where all can read and learn.

KEITH HENNEY

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