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FREDERICK EMMONS TERMAN

1900—1982

A Biographical Memoir by
O.G. VILLARD, JR.

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FREDERICK EMMONS TERMAN—author, teacher, mentor, university administrator and maker of policy par excellence—was beyond any reasonable doubt responsible for the concentration of economic accomplishment in what has come to be known as California's Silicon Valley, as well as for important innovations in engineering. Son of National Academy of Sciences member the late Lewis Madison Terman, Frederick Terman achieved perhaps as distinguished a reputation for his work in electronics and education as his father—who was credited with development and widespread adoption of the IQ test—had in psychology and education.

Like his father, the younger Terman was gifted with remarkable energy and clearly defined goals. He achieved a lifetime of accomplishment in spite of a setback caused by severe illness (tuberculosis) contracted in 1924. His distinctions included the Presidential Medal for Merit; the IRE (now IEEE) Founder's Award; and Stanford's highest, the Uncommon Man Award. He was a founding member of the National Academy of Engineering. Perhaps more than any other individual since the university's start, he left his mark on Stanford University. Terman served successively as electrical engineering department head, dean of engineering, and provost. His approach to support of graduate education had the effect of winning Stanford University a nationwide reputation, and the approach has been adopted by many other institutions. At one point Stanford, which prior to the war was scarcely known nationally, was graduating more Ph.D.s in electrical engineering than MIT.

Terman married in 1928 and fathered three children. Born in 1900, he passed away peacefully in his sleep in 1982.

Frederick Terman had a profound influence on the lives of many others, as well as on his profession, his technical specialty, his university, and indeed his country, as his many awards and prizes make clear. To accomplish all this required phenomenal concentration. If there was a single theme that characterized his life and may in some measure explain his success, it would be his ability to take advantage of opportunities (for example, maintaining contact with former students of unusual skill, keeping in touch with friends in industry, etc.) This theme will appear frequently in this memoir.

The Terman family moved to Stanford University in 1912 and settled in a home on the farm-like campus where Fred grew up. The senior Terman was inventor and co-developer of the Stanford Binet intelligence (or IQ) test, which was widely used in World War I for screening recruits. As part of his research on measuring IQs, he identified a number of individuals having exceptionally high scores, and presumably exceptional intelligence. One of these proved to be his son Frederick. At the time very little of a scientific nature was known about such gifted individuals—in particular it could not be said whether the high intelligence was a help or a hindrance. A study was organized to follow their careers as long as possible. Interim reports (understandably) aroused considerable interest. A finding of one such study was that those with exceptional IQ did considerably better than average career-wise and in their personal lives. This circumstance may well have had an influence in forming Fred Terman's personal philosophy concerning the importance to any organization of truly gifted individuals, who with their followers could be said to form "steeples of excellence."

Since his father believed in progressive education, the younger Terman did not begin his formal schooling until age nine. He graduated from Stanford in 1920 with a major in chemistry. He then switched his field to electrical engineering, receiving a master's degree in 1922. He went to MIT for his doctorate, where he was a student of Academy member Vannevar Bush, another choice that surely helped later. Upon completing his degree in 1924 he was offered an instructorship at MIT, but before he could begin it, he fell victim to a severe form of tuberculosis, which sent him to bed for a year and very nearly took his life. During a protracted convalescence at Palo Alto, he nevertheless managed to teach electrical engineering on a part-time basis in 1925 at Stanford. He then decided to stay on at Stanford and accept a full-time appointment in electrical engineering. During the same period he began work on his first textbook on radio engineering, which was designed to be an improvement on the then leading text in this field authored by Columbia's J. H. Morecroft. The Morecroft text reflected a strong program in radio engineering at Columbia University. For example, its faculty included such well-known early contributors to the art as Edwin H. Armstrong, credited among other things with the invention of FM. Although Stanford had had for several years a distinguished program in electric power engineering under Academy member Harris J. Ryan, there was no formal instruction in radio (or what we now call electronics) until Terman came along. Thus, the decision to compete with Morecroft must have required courage.

Since there were no resources available for building a new program in radio engineering at privately supported Stanford University, Terman had to use every possible source of funds. First were the royalties on textbooks, and in this Terman was successful from the start. In addition, he found that even though it might not be particularly strong, a viable individual patent in a particular field could nevertheless have appreciable value to a company already holding a group of patents in that field. For a second income source, Terman found it possible—at least in the early days—to make patentable improvements to existing inventions, claiming that almost anyone could do it, and that a rate of one or two saleable inventions per month is not unusual. By his own admission, young Fred was not a distinguished inventor like the University of California's Ernest Lawrence, whom he greatly admired. Terman had a remarkable ability to understand complex material and to present it in books, articles, and teaching in such a way that his readers found it easy to grasp. His well-respected textbooks brought in a steady stream of income, much of which he plowed back to support educational enterprise at Stanford. His radio engineering texts were at one time the second most valuable book property of the McGraw-Hill Book Company, being exceeded in popularity only by a standard treatise on engineering drawing.

Terman's own inventions and contributions to the state of the art can be better understood by recalling that in his early days the way vacuum tubes amplified was poorly understood. For example, it was not clear whether residual gas inside the bulb improved results or made them worse. By showing that the tube represented a problem in electrostatics and by deriving a simple but effective equivalent circuit, Terman and his colleagues made the tube amplify so effectively that there was in effect more gain available than needed for the minimum functions. The extra gain could then be used to achieve results not previously contemplated (for example, negative feedback in amplifiers). Since vacuum tubes were costly, a great deal of effort was devoted in those days to cutting down the number needed to perform a given task. One thrust of Terman's work showed not only how to get maximum gain from a given set of tubes, but also what interesting things could be done once that gain was available. Preparation of Terman's textbooks and patent disclosures required visits to manufacturing concerns to establish the state of the art in areas of interest.

When Terman returned to Stanford University in 1946 as dean of engineering, he applied his wartime reputation and experience to augmenting the university's income by encouraging research for the U.S. government, which reimbursed its contractors generously. His success with building the engineering department then led to his appointment as provost, where he was instrumental in building other departments as well.

The success of Terman's books (which had a profound effect on his reputation in electrical engineering) may be traced in part to his choice of subject matter. During the late 1930s most electrical engineering texts were dominated by needs and attitudes of the by then reasonably mature and in some respects standardized electric power industry. Communication, if mentioned at all, was subservient to electric power engineering. Terman's texts reversed this order; radio came first and a-c analysis as needed. In Terman's books mathematical analysis was used when needed and appropriate, and design information was also given. Mathematical derivations primarily for their own sake were avoided. This sometimes gave his texts a deceptively simple appearance, however readers looking for rigor in the mathematical discussions were never disappointed.

Another characteristic of Terman's texts was that they addressed themselves to the user's needs. He always undertook to find out whether a particular design approach described in published literature was actually favored in practice. He would take the trouble to contact the chief engineers of important radio companies to find out which device or approach was widely used. To compensate his informants for their trouble he kept them in touch with the abler Stanford engineering degree candidates. In this way he acted as a sort of one-man employment agency.

In planning his own teaching career at Stanford, Terman must have been influenced by his experience at MIT, where students supplemented theoretical work on campus with practical experience in industry. At Stanford the only such industry contact was incidental to faculty consulting. While arrangements of this sort augmented professors' salaries, they did little to improve the quality of university instruction in the subject field. Financial support was particularly important if students were to be attracted to a privately supported university in those post-depression years. Since there were only a few local manufacturers interested in or able to pay for research at Stanford, it was natural if not inevitable to explore other possibilities, such as the U.S. government.

Still another source of support used in attracting able students was acquisition of discarded equipment from firms contacted by Terman for information needed in his textbooks; he was very skilled at securing gifts of nonstandard but nevertheless entirely workable apparatus.

This activity required that Terman keep in touch with defense research circles in Washington, D.C. It is possible that these contacts—plus those resulting from his textbooks—had more than a little to do with his appointment in 1942 as director of a newly established civilian counter-radar laboratory, a counterpart of the pro-radar MIT Radiation Laboratory in Cambridge, Mass. The new organization was called the Radio Research Laboratory (RRL) and was assigned a very high security level by the military services. This caused some puzzlement at the time, because hardly anybody knew what radar was, much less radar countermeasures.

A further factor making Terman a particularly happy choice was his wide circle of acquaintanceships among radio engineers resulting from his, by then, widely read textbooks plus his professional work for the Institute of Radio Engineers (IRE). (He was the first national president of that organization from west of the Mississippi River.) A complicating factor in staffing RRL was caused by the great many physicists who had already signed up for the radar and atomic bomb efforts; it was expressly forbidden to approach anyone already spoken for.

Located at Harvard University, by the end of the war the RRL staff had grown to about 800 persons. The group included a few atomic physicists, whose mysterious disappearance as the end of the war approached gave rise to some inevitable conjectures. There were also two world-famous astronomers, as well as a remarkable group of radio engineers, many of whom were recruited from prominent industrial laboratories (such as radio broadcasting), which for one reason or another had not previously become involved in war work.

The extent of Terman's previous administrative experience can be surmised from his being head of the Stanford electrical engineering department, which in those days consisted of some five faculty members. At the first official cocktail party he and his wife gave after establishment of the Cambridge laboratory, the Termans found it prudent to seek how-to-give-a-party advice from an eastern U.S. student couple of their acquaintance. There had been no need to acquire this recondite skill at Stanford, because the university's founding grant strictly forbade alcoholic beverages both on campus and in neighboring Palo Alto. Faculty-student socializing at Stanford had traditionally been done at dessert parties.

Radar countermeasures (in case the reader is wondering) consist basically of active jammers (i.e., interfering signal sources), passive reflectors or jammers (also known as "window" and "chaff"), and search receivers for locating the radar to be jammed. Like standard communication sets, these devices were often needed in quantity. In the case of "window" as many as several hundred packages might be required per plane.

In using these devices, enemy counteraction frequently had to be taken into account. For example, given advance warning, the Germans could, to some extent, mitigate the effect of the jammers by changing the operating frequency of their radars. Anticipating this action and providing for it in advance was an important part of jammer design. Getting the right number of jammers to the places where they were needed, and at the right time, was a logistics problem that proved taxing to normal military supply procedures. Civilian assistance proved helpful. Seeing to it that the jamming transmitters were used in the proper fashion was an additional challenge. (For example, jammers do no good if they are tuned to the wrong radio frequency.) Terman's laboratory had the task of finding out which jammers would be important and in what quantities and locations, so they could be manufactured sufficiently far in advance to get to their destinations through the standard military supply channels. It is generally conceded that Terman's group did an outstanding job of dealing with these challenges by following his advice of "keeping your eye on the ball."

One of the sources of undesirable delay was the well-known tendency for able engineers to make a workable device even better. Research engineers tend to build prototype devices, which, however elegant they may have seemed to the designer, could not be manufactured in the available time. It is better to have an inelegant but workable solution delivered on time than a more refined solution that could not be delivered until too late. To speed the supply process RRL followed MIT's example in establishing a transition office whose purpose was to speed up the passage of equipment through prototype design and construction, field test, production design and test, manufacturing, instruction book preparation, packing, field shipment, and finally, user training.

The transition office reported directly to the director, and its job was not considered complete until sufficient of the desired "black boxes" were not only performing in the field as planned, but were producing the desired effect. Other requirements for the black boxes included minimizing space and weight, making adjustment straightforward, and having the device rugged enough to operate under severe accelerations at unconscionably high altitudes for those times. Many problems of an unusual nature both psychological and technical were encountered, and in most instances, innovative solutions were found. Terman took an active role in supervising the work, dropping in on the various groups (as he did with university students in the laboratory) and making useful suggestions. He believed in the hands-on approach. He was especially good at avoiding related activities, which, however interesting they may have been, did not bring RRL perceptibly closer to its fundamental goal.

As as example of Terman's ability to take advantage of opportunities, one might cite his good fortune in having acquired a wartime home next door to a senior member of the Harvard business staff (William H. Claflin). Chats over the backyard fence on weekends seem to have yielded invaluable insights and information concerning Harvard University customs and practices. An occasional conflict between university customs and military requirements took place. An example of an unexpected situation was the fire accidentally set in the black cloth used to disguise the operating wavelength of a high power jammer called TUBA. Since the antenna was located on the roof, and the firemen had no security clearances to enter the laboratory, they could not get to the fire by conventional access means.

Terman often expressed his gratitude for Claflin's advice and assistance. One of the best indicators of the effectiveness of an organization is whether it stimulates imitation, and RRL qualified on that score. Various military laboratories held both the technical and administrative program of RRL in considerable respect.

Terman's success as director of RRL led to his receipt of various high prestige offers, but both during the war and later he remained intensely loyal to Stanford. He was appointed head of the electrical engineering department during the war, and accepted the post of engineering dean shortly thereafter.

The year 1942 must have been incredibly busy. In addition to assuming directorship of a rather sizeable organization put together at wartime speed, Terman also completed his *Radio Engineers' Handbook*, a volume particularly remarkable because of the coherence of presentation made possible by sole authorship.

Throughout his life, Terman showed great ingenuity in taking advantage of opportunities. His decision to write a series of textbooks intended for a wide audience—rather than specialists—led him to visit regularly a variety of companies in the radio manufacturing field. These visits, whose primary purpose was to inform him of contemporary practices, also helped him identify job opportunities for his students, especially during the depression years. In addition, he could frequently arrange for gifts of equipment to the university—obsolete, perhaps, but nonetheless of value for instructional purposes.

As another example, he published a textbook on measurements in radio engineering, which was in large measure based on experience derived from a measurements laboratory he and his students built as part of the Stanford instructional facility. The book was particularly attractive in its day because of the direct hands-on experience it represented.

Terman also used his students to catch typographical errors in his texts. This was both great fun and part of the instructional process. Some of his books went through several editions, and in this way they were considerably improved each time.

Terman must have received help formally or informally from his psychologist father. Certainly, his procedure of seeking out above-average students, rather than selecting at random from an entire applicant group, suggests that. (Mrs. Terman was a student of Fred Terman's father.)

It is interesting that in the selection process for new appointments the younger Terman did not exclusively rely on IQ scores. While this was useful information, he felt it was important to look at the components of the score, or at the student's detailed academic record. Sometimes, otherwise very able students are turned off by unexciting courses. The trick is to watch for high grades in difficult subjects. A low IQ score in a given subject—or overall—did not necessarily signal a lack of ability.

Another indicator of ability used by F. E. Terman in a manner unusual for his time was extracurricular activity. He found that the most effective individuals were those who, after completing their course work, had time left to do things on the outside, such as athletics, hobbies, or business.

Terman's acquaintance with Vannevar Bush must have had an influence—direct or indirect—on his choice as director of the Radio Research Laboratory at Harvard University. It can be said that the younger Terman had little experience in running a large organization. The professionals among its staff included such specialists as physicists and astronomers, as well as radio engineers with years of industrial experience. In the course of its work the laboratory interacted with a large number of military users, some of whom did not feel particularly pleased to have assistance from a civilian organization. RRL was the lead laboratory of Division 15 of the National Defense Research Committee (NDRC), which in turn was an agency of the Office of Scientific Research and Development (OSRD). OSRD's role in the U.S. war effort was to decide in each instance whether a piece of science-based equipment to aid the military could be developed; to develop it and show that it was indeed useful; and finally, to persuade the military to adopt and use it. The last item was as difficult as it was important, because several of the armed services especially toward the latter part of the war had laboratories of their own in which developments parallel to those of the NDRC were being carried out. While some military service individuals generously aided and accepted the NDRC, others, by insisting on the superiority of their own special approaches, were a source of strain and even programmatic delays.

In spite of—or perhaps because of—wartime pressures, defusing these situations required great tact and skill. Terman deserves credit for his choice of A. Earl Cullum, Jr., as associate director. Cullum was given responsibility for RRL's external relations. A consulting radio engineer having extraordinary tact and originality in human relations and consensus building, Cullum had a number of years of experience in the ways of officialdom in Washington, D.C. He was a happy choice, and the team of Terman and Cullum proved very effective.

One reason for its effectiveness was what Terman called "keeping one's eye on the ball." This might be defined as deciding at any given time on the most important objectives and moving toward them in spite of the most plausible distractions, and there was never a shortage. It could be said that the technological problems faced by the laboratory were in some respects not as challenging as the human problems, many of which required great ingenuity to solve.

A troublesome item, at least initially, was finding out exactly what countermeasures were needed in a given situation. This required determining what enemy radars might be planned for use, what their characteristics were, and how they were currently being used—all highly sensitive information not normally shared by the military with civilians. One of the first steps taken by NDRC was to devise improved search receivers and procedures for acquiring intelligence of the type needed by RRL. In this connection, invaluable assistance was received from the U.S. Allies, particularly the British. The U.S. mission differed sufficiently (e.g., daylight versus nighttime bombing) to justify an independent search effort.

Later, receivers were initially used to give threat indication and for checking jammer frequency coverage. Next came devising the transmitting electronic jammers themselves plus the passive arrangement code-named "window" and "chaff." This consisted of thin strips of tinfoil a few inches in length. Several of these would create, in falling to the ground, a radar echo equivalent to that of a bomber. These were ejected from the plane to create electronic clouds in which the plane could hide—at least temporarily—to evade ground-based, fire-control radar or airborne fighter attack.

Although the British were among the first to experiment with chaff, Terman made a major contribution to its practicality by arranging for L. J. Chu of MIT (a specialist in electromagnetic theory) to do a complete theoretical analysis so that the design could be optimized. This plus important mechanical innovations made by RRL staff saved, over time, hundreds of tons of aluminum and made any given plane's complement of chaff very much more effective.

Development of the needed electronic jammers called for solution of a large number of individual problems, such as high voltage equipment that could operate at high altitudes without pressurization. Engineers who had spent their civilian careers combating noise suddenly found themselves engaged in trying to produce (and utilize) noise in spectacularly large amounts. Many of the initial RRL devices used the existing state of the art, but methods for generating random noise or energy sources of extremely high RF power required novel approaches.

A most difficult problem was seeing to it that working jammers were not only developed but were also engineered for volume production. It was found necessary to monitor every step of the way from factory to field operation, since roadblocks could and frequently did develop as a result of the sheer size and bulk of the military procurement process. Fortunately, when differences of opinion developed and when it was absolutely necessary, civilians could bypass the military chain of command and straighten out mix-ups that might otherwise have been very troublesome. Of course, this required great tact.

The need for speed in development, procurement, and deployment of military apparatus was never more keenly felt than in the case of radar countermeasures whose use depended on the enemy's disposition and utilization of his radars. In addition, the relative need for some countermeasures depended both on our own frequently changing deployments and the impact on them of enemy activity. The successful use of radar countermeasures by our forces during the Second World War depended in no small measure on the skillful direction of Terman's RRL effort. That effort extended far beyond the walls of the laboratory at Harvard. The military was assisted at every step of the way; for obvious reasons, this assistance had to be low key and largely anonymous, but it was effective.

Terman's personnel challenges were both internal and external to the organization. Inside the laboratory, there was a large staff, many of whom had headed successful industrial laboratories of considerable size. It was unavoidable that laboratory leaders did not see eye to eye on all issues of importance. One of Terman's policies helped him avoid or settle a number of conflicts. In the case of untried individuals, he always waited for signs of natural leadership to emerge before appointing that person to a position of importance. In the end it was Terman's reputation, to which his textbooks greatly contributed, that saw him over the rough spots.

Terman's outside challenges included a few persons and organizations already to some extent in the radar countermeasures field, who understandably felt threatened by the activity at Harvard. This required tact on the part of Terman and Cullum. By including all concerned (even rivals) in the planning and decision-making process in what came to be called "smoke-filled sessions," working at cross purposes was avoided to a considerable extent.

Terman had a remarkable ability to persuade others to adopt the fresh viewpoints he introduced on many issues. This was especially noticeable when he was building up

Stanford University. (For example, see R. S. Lowen, *Creating the Cold War University*, Berkeley, Calif.: University of California Press, 1997.) He used mathematically based arguments when appropriate. If adequate information on a particular issue was unavailable, Terman would arrange to collect it. When at all possible, he would base his value judgments on quantitative considerations, such as classroom attendance, costs of preparing teaching materials, etc. As might be expected, the mathematical approach (for example, the amount of research money a certain department had either spent or brought in during the last year) had the effect of upsetting some of those affected, particularly in the humanities, since some faculty members were unaccustomed to such procedures and in some cases understandably felt threatened. Terman was very skilled in dealing with these reactions. He could foresee them and would come to meetings well prepared with counter arguments. Terman was quite insistent on advance preparation, which was known as "doing one's homework." This procedure caused Terman to be (understandably and perhaps unavoidably) unpopular in certain circles. However, for the most part his proposals represented win-win situations. Once the initial shock wore off, the new procedures usually went smoothly. In preparing his own proposals as provost, Terman took maximum advantage of his own and his father's familiarity both with the campus and the likes and dislikes of the faculty. It is probably fair to say that throughout his life, Terman's enthusiasts and supporters considerably outnumbered his detractors in terms of true influence.

In the postwar years, an important consideration in winning over non-defense sponsors was the generosity of the funding made available when sponsors followed the Defense Department example. It was a pleasant surprise that other parts of the government (such as the U.S. Army Corps of

Engineers) adopted the same generous contracting procedures as those used by the Defense Department when the relatively penurious approach followed by the National Science Foundation was a clear alternative. That Terman so clearly foresaw the generous alternative that was selected is to his credit, since the possibility was by no means obvious at the time.

The success of Terman's wartime radar countermeasures program was not unnoticed by the large backlog of students (and their advisors) in search of university degrees under the GI Bill. Electrical engineering was particularly attractive because of its clear-cut civilian applications. In making appointments, Terman followed his philosophy of strengthening specialties (such as semiconductor devices), which led to additional applications. In addition, to attract attention he made certain landmark appointments of well-known individuals, such as the late William Shockley, co-inventor of the transistor. As a result, there was little difficulty in finding outstanding students—or research support, for that matter. The principal objections at the university to Terman's proposed program of appointments were the faculty members and others who objected to military-sponsored research on general principles; those who felt that support by the government would destroy the unique financial independence of the university; and those who felt that research having a military component was more like development and not sufficiently theoretical for an institution of Stanford's analytical skills.

To these objections some negative perceptions of certain sponsors would normally have to be added. However, Terman's wartime reputation for being friendly and helpful to sponsors and for holding meetings at which information was exchanged on an equal footing overcame them.

Stanford had traditionally followed an appointment procedure whereby each department or area was assigned a fraction of the funds available, and the final decision was made by the department. It was necessary for Terman to circumvent this tradition, which he did by pointing out that if outside financial help could be found for one half of an individual's time, the fraction to be borne by the department would permit two appointments instead of one for the same total amount. By this and other means Terman built up electrical engineering and then the rest of the School of Engineering.

Terman perceived that from the university's point of view a number of useful ends could be served by continuing work for the U.S. government after V-J Day. Of course, strictly military research was expected to taper off postwar to some extent, and it did, but never to the vanishing point. Successful wartime development of the atom bomb conferred great prestige on physicists and on academic research generally. Prior to the war, such research had a reputation for producing results that were interesting but for the most part impractical. The war had shown clearly how academic and government scientists could work together to produce useful, tangible results in a timely fashion. Aided by low-cost air travel, postwar inter-institutional cooperation produced excellent results.

From the sponsor's point of view, to be responsible for an important research program was a great feather in the cap. Provided that the work outcome was successful, the more costly the research the greater the resulting prestige.

From the individual faculty member's point of view, government sponsorship conferred many advantages, not the least of which was independence. From the university admissions point of view, it meant that offers could be made to more and better faculty. A given department budget could be stretched to an extent otherwise infeasible.

However, from the standpoint of the university administrator, direct support of the individual faculty member could be a disadvantage, particularly when the objectives of the faculty member did not coincide with those of the administration. On balance, however, outside support was advantageous in that it could be used to raise the quality of the faculty, thereby making a given department more attractive from the standpoint of all concerned.

Terman can be said to have made major contributions in many directions during his lifetime. His contributions to the state of the electronic arts were a consequence of his textbooks in which he clarified his subject to the point where many readers, who might not otherwise have done so, were encouraged to take up and use electronic devices in their work. His books were translated into a number of foreign languages. This took place even in the Soviet Union during the height of the Cold War.

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