"A" klystron only

Russell and Sigurd Varian, chairman and vice chairman of Varian Associates' board of directors, are another famous brother team important in aviation history. Just 35 years after Wilbur and Orville Wright's historical flight, the world's first klystron tube, invented and developed by the Varian brothers, operated successfully, thereby prefacing an exciting new chapter in aircraft control through electronics. The following story by Dr. Russell H. Varian, written expressly for MILITARY AUTOMATION, is a complete first-hand statement about the original work in the development of the klystron.

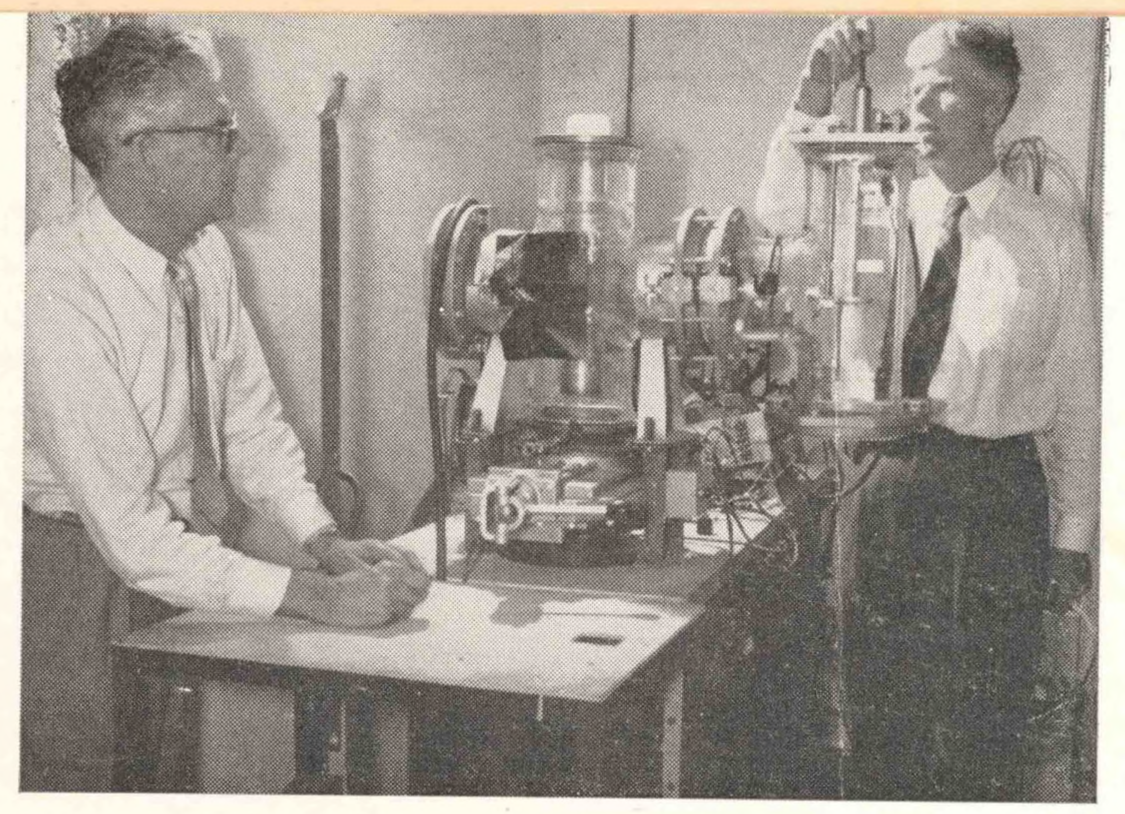

FIG. 1. THE VARIAN BROTHERS, Sigurd (left) and Russell (right) inspect experimental vacuum system in Varian Associates laboratory.

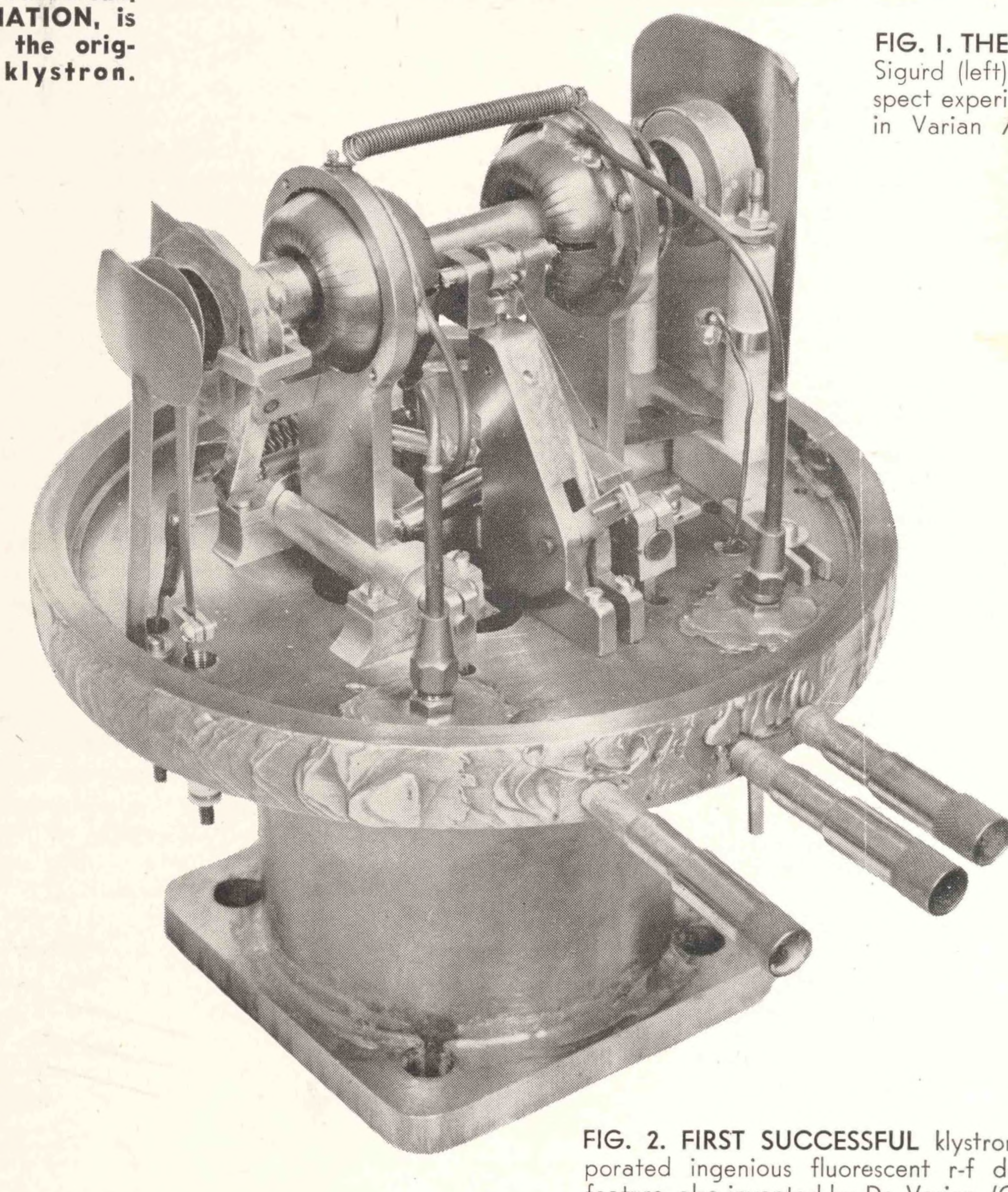

FIG. 2. FIRST SUCCESSFUL klystron incorporated ingenious fluorescent r-f detection feature, also invented by Dr. Varian. (Courtesy Microwave Laboratory Museum, Leland Stanford University.)

The *INVENTION* and *DEVELOPMENT* of The Klystron

Dr. RUSSELL H. VARIAN

THE ORIGIN of the klystron had its roots both in previous experience in television research and in activities in pure physics. From 1930 to 1933 I had been engaged in television research with Philo T. Farnsworth both in San Francisco and with Philco Corporation in Philadelphia. Previous to this time there had been an effort on the part of the faculty of the Stanford Physics Department to obtain a high voltage source of X-rays in the order of 2 million volts. This was prior to the financial crash of 1929. While money flowed rather easily at that time, it did not gush for scientific purposes and a budget of something like $35,000, which was estimated to be the cost of using the Ryan High Voltage Laboratory to generate X-rays, was completely unobtainable.

During my experience in television work I became

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—DAILY PALO ALTO TIMES, WEDNESDAY, SEPT. 4, 1957.

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acquainted with the frequency limitations of the then existing vacuum tubes. The general belief at that time was that the external resonant circuits were the primary limitation on performance.

After 1933 I returned to Stanford to continue work for a doctor's degree in physics. Dr. W. W. Hansen and I took it upon ourselves to try to find a cheaper method of getting high voltage X-rays than the one previously proposed. We investigated a large number of schemes, all of which looked interesting but too expensive, and finally Dr. Hansen proposed to use a concentric line resonator. Then the question was raised as to whether the concentric line resonator was really the most efficient form of resonator that could be designed.

About the time we had reached this point my brother Sigurd, who was then a pilot for Pan American Company in the Western Division running between Brownsville, Texas and the Canal Zone, had come to the conclusion that he would put into effect a tentative plan that we had had for a long time to set up our own laboratory. We set up a very modest

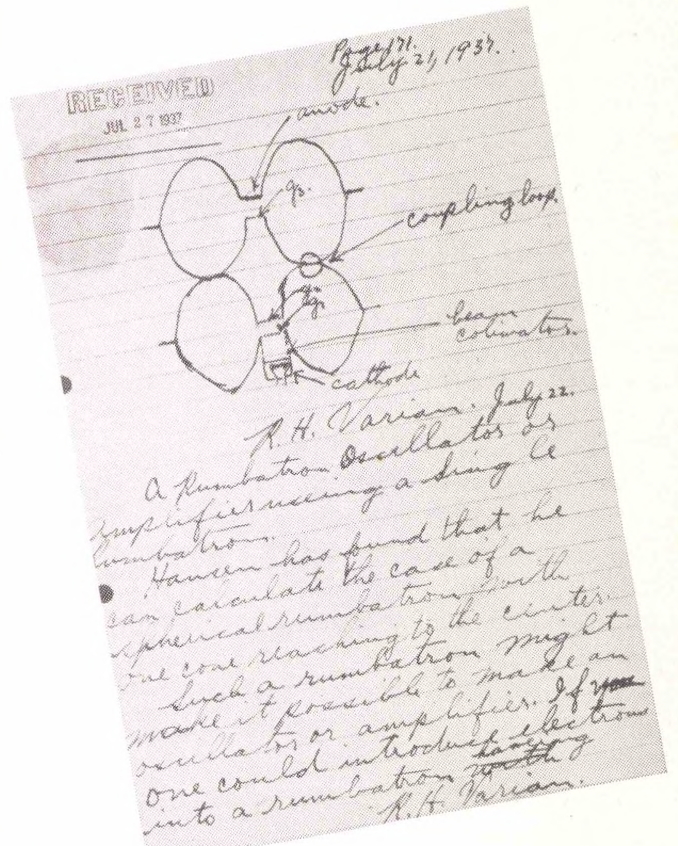

FIG. 3. PAGE from early notebook of Dr. Russell Varian. (Courtesy Sperry Gyroscope Co.)

laboratory at the old family home at Halcyon, California, and started on a project which we knew would provide a small steady income, if successful. This was to build a ruling engine to rule diffraction gratings. This was a mechanical problem that had never been satisfactorily solved. We worked for a considerable time on this project which proved to be much more difficult than at first anticipated.

Luftwaffe Inspired Radar

During the period of this work, Hitler's rapid rise to power took place and resulted in many discussions between my brother and myself concerning the great danger to the world in general. My brother had had a great deal of experience in blind flying with Pan American and was quite sure that he could locate a target and deliver a load of bombs either in bad weather or at night without giving the defenders even one shot at him by any of the existing defense methods. As time went on he became more and more alarmed about the striking power of Hitler's air force and this line of thought led naturally to ideas about what is now called radar, an aircraft locator that would be completely independent of visibility conditions.

As a physicist I knew that very short wave lengths would be required and the first major problem for providing such a defensive instrument was therefore, the production of the very short wave lengths or very high frequencies that were required to produce a satisfactory radar.

Our early thoughts on the subject of radar were, of course, guided by a knowledge of physical optics. The average radio man may know little about physical optics but it is something that every physicist is familiar with. As an example of how little knowledge of physical optics some radio people, and even patent examiners of years ago, had, I remember one patent that was cited against our application in which the applicant showed parabolic reflectors for reflecting beams of radio waves for locating airplanes using the wave lengths then available which were many times the diameter of the parabolic reflectors. To a person familiar with the principles of physical optics, it would be entirely obvious that such a system would form no beam at all.

Radar Patterned on Optics

The frequency required for radar was quite obvious to anyone familiar with physical optics because it had to be a wave length which was quite long compared to the diameter of cloud particles or rain drops, and quite short compared to the diameter of beam focusing and projecting equipment of a practical size for use. This inescapably put the required frequencies for radar into the microwave region. Given a source of radiation of the right wave length, any physicist would conclude that a parabolic reflector or some directional array of similar characteristic would constitute a practical means for locating targets in azimuth and elevation. Practical methods of getting range were not quite so obvious. Our early thoughts in determining range did not depend on the transmission of short pulses and measurement of the time delay of the return signal. At this time we had not realized the possibility for getting enormously high instantaneous power for extremely short intervals of time separated by relatively long gaps of silence. Our early radars were based on the determination of the doppler frequency of a moving object by heterodyning a part of the transmitted signal against the reflected signal.

We conceived a method of determining range which consisted of transmitting three or more slightly different frequencies and heterodyning them against the same frequencies derived from the transmitter. This system was capable of giving range information by comparison of the phase angle between the doppler note from the different heterodyne receivers. This type of ranging equipment was never built because of the appearance of the short-pulse-type radar systems. While our system constituted a possible method of measuring range, it has the great disadvantage that if two moving targets are present in the beam at the same time, ranges will be indicated that are not the true range of either target.

During the time when my brother and I were working at Halcyon, Dr. Hansen was continuing his work at Stanford on the question of the most efficient form of resonator. We were in frequent correspondence both concerning his work in resonators and our work on the ruling engine. The final result of Dr. Hansen's work was to obtain mathematical solutions for certain types of hollow resonators and to show that these were indeed much more efficient than the conventional types of concentric line resonators. My brother and I finally decided to abandon the ruling engine project and go to Stanford and start on the project of producing radar. I felt that Dr. Hansen's work was a good starting point for a high frequency source which could be used for radar.

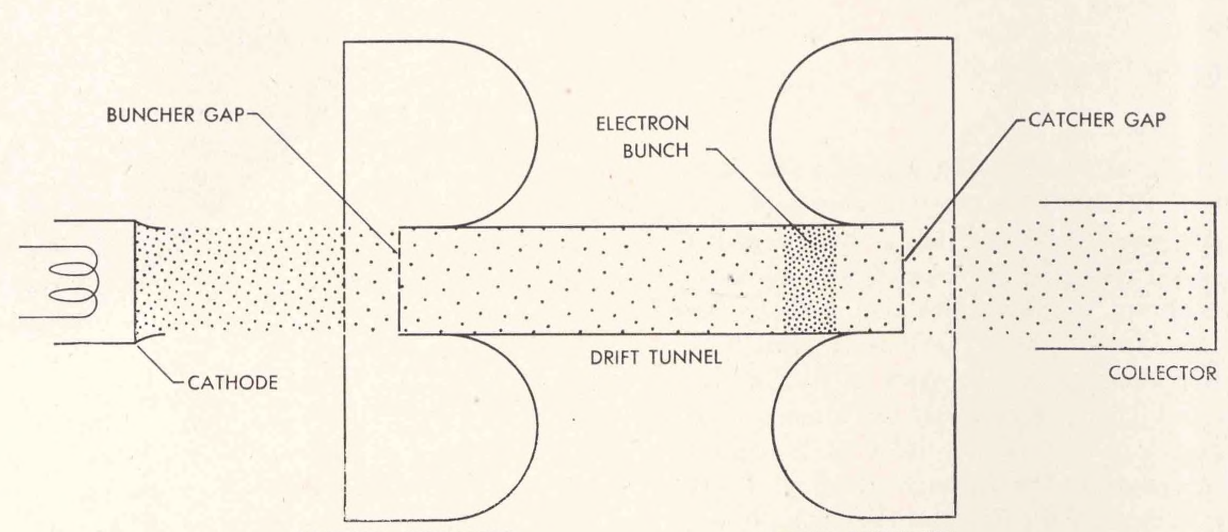

FIG. 4. PRINCIPLE of the klystron tube with two resonators. Electrons are produced by the cathode at left and accelerated toward collector at right. As they pass through the oscillating electric field of the first resonator, some of the electrons are speeded up and others slowed down. As the electrons proceed down the drift tube, the faster ones catch up with the slower, forming a bunch. When the bunch passes the second resonator, an oscillation is excited in it.

Classification An Inventor's Tool

After long discussions with Dr. Hansen I became very much aware of the fact that the resonant circuit requirement which the hollow resonator could meet was only one of two necessary conditions to achieve the frequencies that we were interested in. The other was a means of eliminating the troubles caused by the flight time of electrons in the ordinary grid-control-type of vacuum tube. This second requirement apparently required a new type of current control in a vacuum tube. We spent many hours thinking of all the types of controls that could be used. We very early arrived at one definite conclusion—that the cavity resonator must itself provide the electron control and that the electron control must be of a new type.

One day, after we had thought of a number of schemes, I was occupied in developing a classification for all the schemes we had thought of so that we could systematically investigate them all and not discover later that we had overlooked some of the most promising ones. In the process of developing this classification I suddenly thought of the velocity-grouping principle (Fig. 4). From a psychological viewpoint it is rather interesting that this attempt at classification actually produced the invention of the klystron. The velocity-grouping principle did not fit any of the schemes of classification that I had contrived and I rather think that the idea occurred to me because I was unconsciously attempting to test the validity of my classifications. Hence I thought up an exception to the classification which actually turned out to be the basic concept of the klystron.

There followed a very extensive series of discussions between Hansen and myself about the applicability of this new idea. After the first few discussions we had pretty well concluded that this new idea was the best of any that we had conceived, and the remainder of the discussions were related to the means for carrying it out.

RF Detected by Fluorescence

In the meantime my brother was impatient and needling us all the time so that he could get into the work by actually building something. Less than two or three weeks after the original idea, we had settled on a design that looked very much like the early klystrons. After deciding what kind of an oscillator to build, there was another important problem—if we built such an oscillator, and if it oscillated at times, how were we going to know that it oscillated? The general character of the original klystron was a two-resonator device which required tuning of one resonator to the frequency of the other and oscillations would not occur unless this was accomplished. How were we to know when this was accomplished?

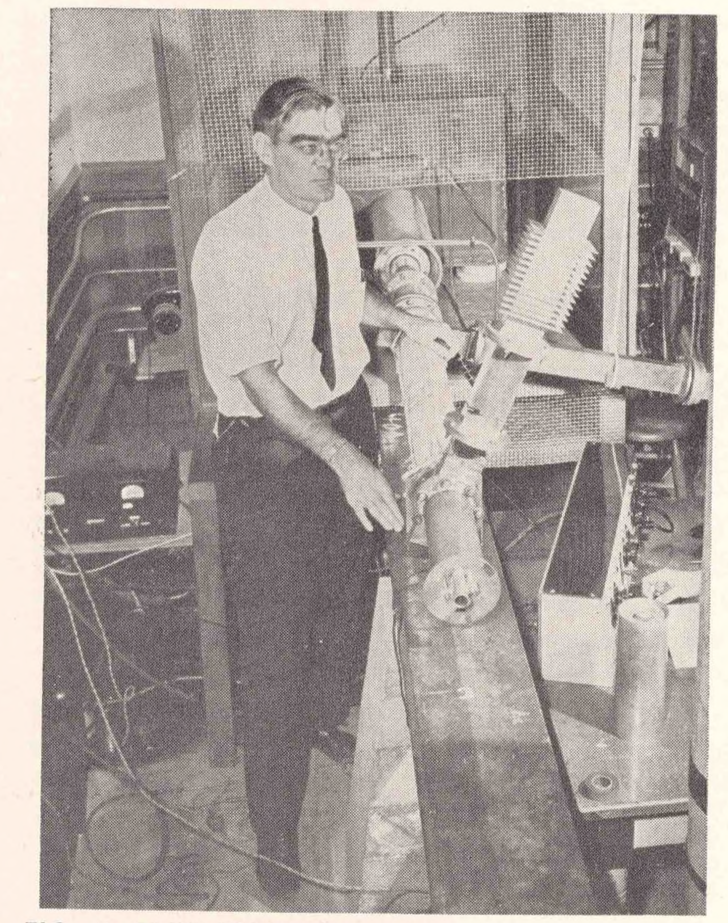

FIG. 5. THIS PHOTOGRAPH, taken in the Physics Dept. at Stanford University, shows the late Dr. W. W. Hansen just before the first linear accelerator operated for the first time. (Courtesy the San Francisco Examiner.)

None of the measuring instruments now available in the microwave region had been developed, and the only detectors we had that could be considered for the purpose were the old galena crystal detectors of early radio. We did not even know that these would function at all at microwave frequencies, and if they did function any meter that we could attach to them would be slow acting and the probability extremely high that we never would detect oscillations. I finally decided that we could allow a small part of the electron beam used to drive the klystron oscillator to pass through a hole in the last resonator and be deflected into the space beyond by a magnetic field so that it would land in a moderately small area on a fluorescent screen. This would provide a quick and sensitive detection system for any oscillations which occurred. As it turned out, this invention was probably about as important as the klystron invention itself, because without it we probably never would have discovered the oscillations although they would have been occasionally present. The first model we built produced some oscillations which my brother saw on the fluorescent screen, but the tuning mechanism was not capable of going smoothly through resonance and so we were never able to repeat the result. It was about the third model we built which gave reproduceable evidence of oscillation (Fig. 2).

Promotion Moves Slowly

At the beginning of the series of experiments, the university had made an agreement with us and provided the facilities and stock of the machine shop, plus $100 for purchased parts. At the time when we got conclusive proof that the klystron worked, we had spent about $50 of this $100 appropriation. This was probably the cheapest project ever completed in microwaves. About the time we had demonstrated the operability of the klystron, we had exhausted our own financial resources and very quickly had to hunt up some means of support. My brother made a trip to San Francisco and talked to people in all three branches of the military service. All three branches expressed mild interest in the idea but none showed signs of supplying support for further work at a near date. Sigurd also went and talked to the NACA office. They were interested, but were quite frank in saying that they had no one capable of making a judgment of the device. However, a few days later, we had a phone call from the CAA office and we found that a man in the CAA who was concerned with blind landing systems for airplanes had arrived and he was extremely interested in the idea. Also, there was a man from the Sperry Gyroscope Company at CAA who expressed interest in seeing the device and we were asked whether he could come along with the other men. We were somewhat afraid to disclose the device at this time to a commercial concern but we decided to take the risk since we had to have support rather quickly. The CAA people were quite sure they could get support for this project rather quickly and we were much encouraged. However, much government red tape intervened and it soon became apparent that although there was a great desire among some highly placed personnel in the CAA to support this project it would take a long time to get the money.

In the meantime, the Sperry Gyroscope Company saw in this device something that would supersede their military searchlights for air defense and therefore they offered to support the project. A klystron had been produced but it remained for others to complete the radar system we had contemplated. The project was supported for some time on the Pacific Coast by the Sperry Gyroscope Company but in the fall of 1940 they moved the whole operation to Garden City, Long Island, where we continued to develop the klystron and related equipment during the war.

British Make Rapid Development

When it became apparent that a new breakthrough had been made in the microwave field by the invention of the klystron, my brother and I, as well as the university, naturally were quite anxious to obtain publication. We wrote one letter to the Editor of the Journal of Applied Physics and later a more complete article by Drs. Hansen and Webster was published. We were a little uncertain about who would be helped most by these articles, but as later developments proved, the publication of these articles was a very important factor in winning the war since it was the British who immediately saw the significance and went to work under high pressure to produce klystrons. They had klystrons which were practical for operational use considerably before we in America had them and all of the earlier radars used by the American forces used klystrons which were copies

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of British models. On the other hand, the Germans did little or nothing about developing the klystron.

During the war there was a great deal of development of the klystron under forced draft. The 2K25, which is still used extensively, was developed by Bell Laboratories and the Western Electric Company and manufactured principally by Raytheon Manufacturing Company. The Sperry Gyroscope Company built a good deal of the radar equipment and many laboratory klystrons and much measuring equipment, but never did get into any volume production on klystrons during the war. Production models were soon frozen and not changed radically during the war.

High-Power Klystrons

During the war, Dr. Hansen and I tried hard to get work going on high power klystrons but the decision had been made to use magnetrons as power sources and to use klystrons only as local oscillators for receivers. This may have been a wise decision from a production viewpoint during the war, but it left a conviction in the minds of many people that was very hard to break. Magnetrons were considered to be power sources and klystrons were regarded merely as local oscillators.

Immediately after the war, Sperry Gyroscope Company, under government contract, developed some successful medium high power klystrons but they did not find their way into systems.

After the war Dr. Hansen returned to his position at Stanford University and started the development of a linear accelerator of electrons (Fig. 5). In this he was reverting again to the old quest for high voltage electrons and X-rays only now armed with a new tool, the old ambition of 2 or 3 million volts had been raised to the billion volt level. The work on the linear accelerator was supported by the Office of Naval Research and later also by the AEC and is now functioning in the field of pure physics to further solve the mysteries of the nuclei of atoms.

A by-product of this research was the development of super-power klystrons. It took this project in pure physics to break down the concept that a klystron was nothing but a low-power local oscillator device. This project proved that klystrons are far from being limited to low power devices and are in fact capable of greater power than magnetrons had ever produced. Now klystrons have invaded the high power field and are extensively used in the Continental Defense system as well as other applications.

There are now a very large number of klystron types ranging in power from milliwatts to megawatts including both pulsed and CW types and ranging in frequency from around 200 megacycles to above 30,000 megacycles, many of them available as production models. After many fluctuations in interest and arguments as to applicability the klystron has found its place as an accepted component in both military and commercial apparatus.

* * * * *

Articles to follow in this series will include a survey of modern Klystron tubes and applications, also tutorial articles on travelling wave tubes and backward wave tubes and their applications.

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