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REPORT OF CONFERENCE ON MICROWAVE MEASUREMENT TECHNIQUES AND VISITS TO OTHER LABORATORIES (SEPTEMBER 1961)

by

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I. CONFERENCE ON MICROWAVE MEASUREMENT TECHNIQUES (September 6-8, 1961)

The conference included the usual few dull papers, several interesting ones, and a couple of exciting moments. I do not propose to discuss or even mention all of the papers. The conference program includes extended summaries of the papers, which in many cases completely cover the subject.* A few papers, however, deserve particular attention.

1. S. B. Marsh and A. S. Wiltshire described equipment in which a resonant cavity was used to absorb the fundamental output of a signal source and noise measurements made at - 70 db within 1 kc of the carrier.

2. Charles Süsskind gave a fine presentation describing his recent work in measuring the changes of microwave properties of biological materials as a result of irradiation with high levels of rf power. He found detectable changes of real and imaginary parts of the dielectric constant at irradiation levels well below the "safe" level of 10 mw/cm^2. The measurement must be made at a much lower power level within milliseconds of the high-power irradiation and to an accuracy of $\pm$ 1%.

3. H. M. Altschuler gave a review paper entitled "The Precision Measurement of Microwave Networks."

*I have a copy of the program that I will make available to those who wish further information.

"The term 'precision measurement' as employed here implies a procedure of measurement and analysis as the result of which the limits of the errors, usually the maximum errors, associated with the measured quantities can be specified. While this definition does not necessitate that the measurement also is accurate, i.e. that these errors are small, this usually also follows. ... Precision measurements involve relatively large numbers of data points which must be averaged appropriately."

This definition favors measurements leading to a locus of points, preferably a circle.

4. Altschuler also gave a paper entitled "The Measurement of Arbitrary Linear Microwave Two-ports," in which he considered the general case of active as well as passive and nonreciprocal as well as reciprocal networks. In effect, the techniques involve plotting an impedance locus at each end of the network. The specific technique used a bridge in which the input and the reflection from each end are compared. It is an interesting analysis, although certainly not for common use.

5. J. K. Chamberlain and B. Easter, P. H. Hargrave and S. J. Robinson, and J. Brown and S. A. A. Ahmed described devices that automatically present and plot impedance loci. The techniques use three bolometer probes, seven hybrid junctions, and mechanical servo-systems, respectively.

6. H. E. M. Barlow pointed out that the Hall Effect in a semiconductor situated in an electromagnetic field is determined by a Poynting vector and is, therefore, a measure of the net power transmitted through the semiconductor.

"A very thin wafer of indium antimonide or indium arsenide is ... placed edge-on to the incident electromagnetic wave and picks up a pure displacement current.... ... the only wires attached to the crystal are those required for measuring the Hall e.m.f."

The device has been demonstrated to be workable, but it is not yet ready for commercial development.

7. L. Lewin and G. H. B. Thompson gave an interesting discussion of techniques for making measurements in microstrips, using Dechamps' technique for measuring radiation loss, attenuation, and isolation in a hybrid tee junction.

"Measurements in microstrip are in nothing like the same condition of accuracy or maturity as similar measurements in more orthodox transmission media. ... The utilization and understanding of microstrip would probably be revolutionized with the advent of a high-quality reliable plug-in reflectometer type of detector. Until then the design of high-quality well-matched low-radiation reliable transducers from existing media to microstrip needs to be high on the list of priorities. So, too, does the design of a first-class mechanical-cum-electrical joint."

8. Fred Crawford presented the paper, "A Method for the Measurement of Dispersion of Disc-loaded Waveguides," by I. Carswell, E. Feuchtwang, and H. J. Shaw. The audience appeared interested, and I believe the discussion might have been lively had one of the authors been present.

W. Culshaw could not attend the conference, so the 'Millimetre Wave Measurements' section was not as exciting as it might have been.

9. A. P. Anderson and J. Brown described "Some Simple Measuring Techniques Using a Crystal Doubler."

"The starting point of the programme was the suggestion that the crystal used to generate the harmonic could also be used as a detector. ... The basic arrangement used is ... a crystal excited by a c.w. oscillator at [8 millimeters]. The crystal output is a continuous wave at second-harmonic frequency and this is modulated by a phase modulator in the output waveguide. Any signal reflected back into the crystal is therefore phase-modulated and combines with the generator signal to produce amplitude modulation. This amplitude modulation is readily detected by an amplifier tuned to the modulation frequency."

A ferrite modulator was developed, and the components being tested were placed between the modulator and a calibrated movable short-circuit. The standing-wave ratios were found to be accurate to 2%, and the techniques were all carried out by using standard 8 mm components and two simple 4 mm components - the ferrite modulator and the calibrated short-circuit.

10. R. Hamer and R. J. Westcott reported on "Measurement of TE_{01}-mode Attenuation in Short Lengths of Circular Waveguide." The technique involved comparing the Q of a cavity formed by a length of the waveguide with the Q of a reference cavity. Q-factors of the order of 10^6 were measured. There seemed to be considerable disagreement, judging from the paper, discussion, and my observations, as to whether excess copper losses at 35 Gc and higher were due to roughness, surface hardening, or what. Hamer reported the curious result that a poor job of adding 0.0005-in. copper

plate actually decreased the loss from 1.42 to 1.25 times the theoretical loss. It was pointed out that the difference between theoretical and specified loss is a rapidly increasing function of frequency. The following explanation was proposed. A surface layer or film that has properties differing substantially from those of the bulk material begins to be of more importance than the surface roughness at such high frequencies that its electrical thickness becomes a significant fraction of the skin depth.

During one of the discussion periods, Oliner proposed a method of measuring dielectric constants relating to "Woods' Anomalies." The amplitude of the high-order reflection from a grating has a sharp dip at the frequency of angle of incidence, at which another reflection order just starts. In a grooved dielectric the dip occurs at a value that depends on the dielectric constant.

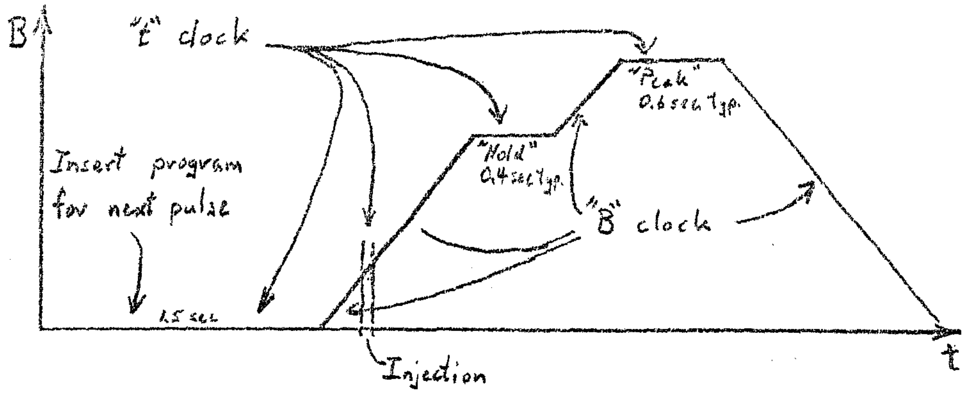
11. In the discussion of my paper, "A Perturbation Technique for Impedance Measurements," Joyce of Metro-Vickers claimed that they could make phase measurements with 1° accuracy by putting probes into holes in the side of their linear accelerator cavities and challenged me to do as well with my method. In the corridor, I challenged him to get 1° accuracy in a system requiring flexible cables. It seems likely that a precision of 2 or 3° is indeed doing quite well.

II. VISITS TO OTHER ACCELERATOR INSTALLATIONS

A. ARGONNE NATIONAL LABORATORY - ZGS MACHINE

I spent the morning chatting with Lloyd Lewis, said "Hello" to Dr. Crewe just before lunch, and lunched with Martin Foss and Len Goodman (never once mentioning magnets). It had rained the night before, and the resultant quagmire prevented walking near the ring.

Lewis has a nice timing system for programming pulses. For multiple beams they want a pulse somewhat like the one sketched below.



By using two "clocks," one counting a megacycle oscillator and the other counting (integrating) the output of a voltage-frequency converter looking at dB/dt from a sampling loop, Lewis can program any shape pulse (with several "holds" if desired) and can program successive pulses differently.

One 512-word (expandible to 1024) magnetic core memory for 36-bit words with nondestructive readout, one 16-bit (4 digit) comparator between clocks and instructions to determine when to perform next operation, one matrix with 128 outputs to feed controlled devices directly or to perform internal switching, a 10-bit word-counter and a few binary-switching elements comprise the entire computer. The computer has enormous versatility and occupies a little less than 12 cubic feet including all terminal strips for outside wires. The cycling time is under a microsecond except for serial readout to some external devices.

It is a very pretty scheme but would be of little use to us in its present form.

The control philosophy at Argonne originally called for all controls to be put in the one central location. The budget then forced them to put the controls for turn-on and test of each piece of equipment at "remote" locations ("local" to us). It was at this point assumed that only essential operating controls and information would come into the control center, but now it appears that almost all the signals will come into the control center anyhow.

Lewis feels that all essential operations should, in principle, be arranged so that one person could handle all the work. (His programmer certainly would help out in this respect.) However, he states that most of the electrical engineers on the project expect that the "Navy system" will be used. The engineer-in-charge will sit at a central desk, where he can observe the appropriate lights and meters and can receive reports from the subordinate operators, of which there might be a dozen. He will then bark out his orders to the appropriate operator.

Obviously, from the layout of the control center, it will take three or four people to handle the controls. The linear accelerator injector will use about 25 racks; the rest of the machine will use about 30, with perhaps 10-15 racks for the over-all summary information.

All signals are transmitted on individual wire-pairs or coax lines; A-D conversion is used only in the programmer for the field and rf system.

As in most synchrotrons, the magnet, the injector, and the vacuum system (I am not sure about the rf system) will each have a maintenance crew on station at all times. In general, it appears to be a more elementary approach than the one we hope to evolve.

B. BROOKHAVEN NATIONAL LABORATORY--AGS SYNCHROTRON

I talked to Ralph Kassner who showed me the machine. He is in charge of the instrumentation, and we spent a great deal of time discussing instrumentation philosophy. I was there the day Hurricane Esther went through, and although the Laboratory had not lost complete power, there had been a bad enough line-voltage drop to turn off the vacuum system. The system was being pumped down, and I presume that the vacuum was satisfactory well before I left the place. This served to emphasize that their vacuum system is not on emergency power. Only the public address system, the tunnel lights, personnel security circuits, water level indicators at the sump pumps, and hydrogen exhaust fans are on emergency power.

The main control room has no more equipment in it than Mark III. "There is no point in having information if you are not going to do anything about it." As an example, the synchrotron has 12 final amplifiers for the rf system, although the machine will work satisfactorily with only nine in operation. The operator is informed only if four or more amplifiers are not working and, even then, does not know which ones.

The control wiring is done entirely with direct wire circuits. They found that three-quarter mile was the break-even point between using channel-sharing equipment and using separate wires for each circuit.

There are no counting rooms in the place. The experimenters set up their read-out equipment immediately adjacent to their experimental area. (This was originally to have been in tents or temporary sheds outside the building, but the entire area where experimental equipment is likely to be installed finally has been closed in.) An electron machine, of course, would have to have readout equipment in a location remote from the target area.

C. HARWELL--AGS MACHINE

Everyone of importance at Harwell seemed to be out of town for a conference when I arrived. I talked to Trevor Hyman and N. D. West, former students of George Walker, who are working on the 14-Mev injector for the synchrotron. They have been very pleased with the electrostatic generator, which uses a rotating drum and grounded comb to provide 600 kv for the gun.

Originally, the Harwell control philosophy was to control everything at one central location. Budgeting restrictions forced them to put all controls at the equipment with the intent of providing remote control for essential items. At the moment remote controls seem to be provided for everything at the central location after all. This process, I gather, will now be limited only by the amount of space available at the central control. There appears to be no unified control philosophy for the machine.

D. ORSAY

I had but one day available for visiting Orsay and decided to go in spite of having just received the following letter from B. Milman,

> "I hope that you will be able to alter your schedule and arrange your visit to this lab at a slightly later date, since most of the people you want to meet will not be here on September 15th.
>
> "Dick Wilson has left Orsay a week ago. He will be at the Aix-en-Provence Conference, 13-20 September before returning to the States. Bill Gallagher leaves tomorrow for a visit of Russian Accelerators. He will be back here around September 20th. Burnod and Zyngier left today for the Brookhaven Accelerator Conference. Brunet goes on leave tomorrow. I am leaving on the 12th for Aix...."

I was shown around the laboratory by M. Le Francois, a French Canadian who had just arrived from Harvard, and M. Nguyen, from Viet Nam. The laboratory gives the impression that a large sum of money was made available for the buildings and proportionately less for the equipment, although I was assured that they find themselves pinched in each direction. The operation is totally different from any of the other accelerators I have visited, in that the machine was built, maintained, and operated by C.S.F. on a subcontract. C.S.F. is completely responsible for machine operation; the physicists are merely customers for the machine. In spite of our bad example at Stanford, they seem to have found themselves with an undersized end station. The construction of the machine is interesting but, generally speaking, it is merely different from, not particularly better than, Stanford's.

E. MEDICAL ACCELERATORS IN CHICAGO

I visited the Argonne Hospital and the Michael Reese Hospital in Chicago. Both hospitals are using their linear accelerators for the treatment of patients every morning and reserve the afternoons for maintenance, dosimetry calibrations, and other research. They have installed attractive treatment areas, feel that they have adequate support facilities, and are, in general, well pleased with the equipment.

At Argonne I talked to Lester Skaggs and L. H. Lanzl. Lanzl is the engineer-in-charge for the accelerator. Argonne has a magnet system that provides mechanical scanning of a dose area. (Two 45° magnets create a beam parallel to but displaced 18 in. from the accelerator axis. A 90° magnet may be moved parallel to the axis, providing z-scan. The entire magnet system may be rotated, providing θ-scan.) The beam is reasonably well-focused at the output. The scanning motors are programmed to trace an area according to a polystyrene cut-out of arbitrary shape, as determined for each treatment. The magnet system passes through a shielding wall in such a way that the accelerator may be warmed up with rf power while the patient is being prepared for treatment. A two-way intercom set and a remote-controlled panning TV monitor allow good observation of the patient during treatment.

At present, the energy is limited to 30 Mev by the modulator. The switch consists of two thyratrons in series; it will soon be rebuilt with three series thyratrons, and they then expect to get 45 Mev. One of their klystrons has a cracked input window, and one has no eyelet left for further cathode replacements. They will need major rework from us soon.

At Michael Reese Hospital I talked to Jacques Ovadia. His magnet system consists of one 45° magnet and one 135° magnet. The beam is defocused in the magnets and also by a scattering plate. The exposed area is defined by masks. The magnet system can be rotated to a convenient angle but is not moved during treatment. They are pleased with the results obtained by a further mask which has a pattern of holes such that roughly half of the patient's skin is irradiated where the beam enters, but the other half remains healthy. Apparently less skin damage is caused for the same internal dose.

Michael Reese has built a new laboratory and office area on the second floor of the accelerator building. Adequate shop space is now available. They are investigating the use of oxygen tracers (activated by the accelerator), thus continuing the tradition of their Radioisotope Laboratory. They have no klystron worries at the present.

III. VISITS CONCERNING INSTRUMENTATION AND MICROWAVES

A. PRD ELECTRONICS

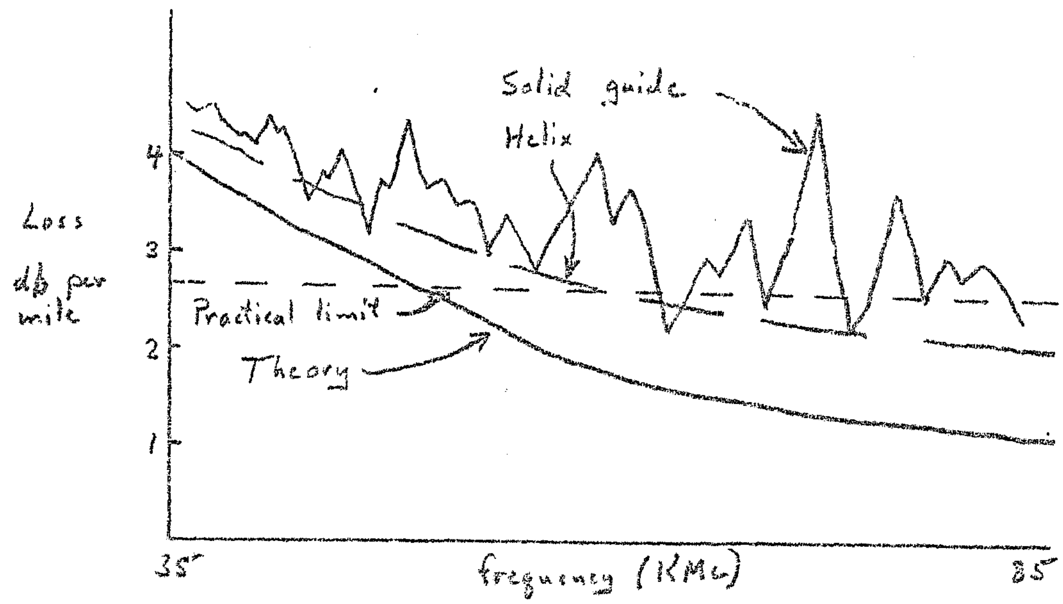
On September 19, 1961, I visited PRD Electronics to call on Louis Fisher, Chief Applications Engineer. While there I talked to several people, among whom were Paul Mariotti, Manager of Industrial Products; Harry Nelson, Director of Marketing; Bob Lebowitz, Manager of Microwave and Electronics Engineering Design; and Leo Nadler, Senior Project Engineer, working for Dr. Sam Hopfer, Manager of Research.

The talk was primarily a continuation of talks earlier this summer with Sam Hopfer, Louis Fisher, and Jerry Cyril, Manager of the West Coast Office. We discussed ways to monitor and measure rf power. In particular we discussed the block calorimeters, which are in the catalog line, and a new development, which is a calorimetric device with a reading time of on the order of 1 sec. It is based on an evaporated thermopile of antimony and bismuth on one-quarter-mil mylar, and is used in a coaxial mount.

The original motivation of our talks was the development of an extremely cheap device for monitoring power from the Project M klystrons. It is evident that PRD does not have the solution, and it is clear that we will have the problem of measuring power accurately for certain tests. Fisher suggested that I look into the possibility of creating an opportunity to test and use some of their calorimeters. I said I would certainly look into the possibility since we are scarcely satisfied with the absolute accuracy of any power measurements we have made to date.

B. BELL TELEPHONE LABORATORIES, HOLMDEL

At Holmdel I talked with Dr. Sharpless, C. A. Burrus, D. H. Ray and S. E. Miller. After a general chat about the status of Project M, we discussed some work with 2-in. diam waveguide at 50 kMc. They find that TE_{01} helix waveguide is approximately 10% more lossy than a solid waveguide with the same dimensional tolerances. In fact, the possible loss to reconversion is greater with the solid guide than the observed loss with the helix. (See sketch.) It turns out that a simple 90° mitered corner has a loss of about 0.25 db (in a 1/2-in. waveguide, the loss is 3 or 4 db), and it is possible to build an optical directional coupler consisting simply of a waveguide cross with a diagonal coupling mirror.



Loss in 2" dia TE_{01} waveguide

With this device, they have been able to create a low/high pass filter so that the very wide band waveguide can be coupled efficiently to narrower band transmitters and receivers. The transitions from dominant mode waveguide to circular waveguide are electroformed on a wax form that has been coated with Aquadag and the finest iron powder in a pure acid-copper solution. The iron, of course, is replaced by copper immediately upon immersion in the solution. The transition is made "dominant" inside. The wave passes through a helix made finer and then is tapered to the desired size transmission.

I talked to Burrus for a few minutes about millimeter wave detectors. He wondered if a balometer working at liquid nitrogen ambient temperatures would be more sensitive than the ones we have been using. They find that the crystal detectors have better sensitivity when the crystal is mounted on a waveguide of very low impedance. Sharpless has developed a new style wafer mount with grooves to make the active position thinner. He uses what he calls a "finline" to make all sorts of curious transitions and to control the polarization in the circular waveguide. I was shown an interesting measuring setup in the TE_{11} circular waveguide, in which some slightly elliptical pieces of tubing are used as one-quarter and one-half wave plates. The one-half section is mounted between two one-quarter sections and is rotated. The rotation provides a phase shift and when the device is properly adjusted the resulting phase modulation produces a pure frequency shift at about 150 cps. The output signal is then used as a local oscillator for making very sensitive, narrow-band measurements.

C. RCA, MOORESTOWN

I called on W. I. Smith in order to get an informal description on the instrumentation within and exterior to the modulators. I found nothing that had not been anticipated except, possibly, the requirement of about 1200 watts of heater power that should have 1% regulation. He claimed that a 5% adjustment might be possible as a temporary measure through the de-Q'ing system. The only fault alarm to be provided will be actuated by the cessation of klystron average current. He seemed to be very pleased with the progress they have made on the modulator development, particularly with the solid-state components in the power supply and triggering circuits.

D. SPERRY GYROSCOPE COMPANY, GREAT NECK

I spent the day on a very fine tour arranged by Tom Sege, although I met him only for one minute just before I left. I was more directly supervised by Barry Brown of the Tube Division

Neither Timms nor Striegl was available during my visit. I talked to a technician and found that they were running our klystron at 200 kv. The perveance is as expected, the gain is 43 db, and the efficiency is 30%. I found afterward that the tube had been running at 200 kv the day before solely because Lebacqz had sat at the control desk and pushed the tube up there.

I talked with Del Churchill, who has an X-band resonant ring that gives him 14 db gain with a 20-kw cw source. He has had very satisfactory performance with an adjustable directional coupler, made of 3 hybrid tees and a tuner. With 500 kw circulating in his ring, he wants fast shut-off protection in case of arcs. He uses a phototube that looks at the light collected by a quartz rod that is inserted into the side of the waveguide.

The rod has a roof-top prism that collects light from each direction in the waveguide. He can turn off his power supply within 5 μsec on the initiation of an arc. This device might be quite useful in our test stands.

John Romaine is working on an X-band, extended-interaction klystron that has 100-kw dc input and is to have 50% efficiency. His cavities are loaded with water-cooled bars (similar to the jungle jim structure). He cannot afford to lose even 1% of the beam in his structure for fear of melting it and is, therefore, using a device called a "profile monitor" for measuring temperature distribution. This device has 48 thermocouple inputs and a mercury throw switch that sweeps all the inputs at 20 cps and displays their outputs on a 17-in. scope face. The cost of the sampling and display unit is $3700. He has arranged the display beside a drawing of the tube so that he can correlate immediately the temperatures with the location of trouble. The device is commercially available, but at the moment I do not know who makes it. It might be of great use in our test stands and at the baking and processing stations. It might also be a useful display device for the Project M control console.

George White has been doing cold-test work with traveling wave structures and has built a rather interesting setup in which a perturbing bead in the test structure is used as one of the components of an analog computer. The circuit is adapted from that used for curve-tracing in an electrolytic tank and is used for computing electron orbits in a tube. He feels he can get rather good information on the shunt impedance and on the bunching that can be obtained in a given structure. I am afraid the method is not accurate enough for investigating the kind of bunching we want for the accelerator.

I talked with Peter Sferrazza of the Systems Division about some of our problems involved in phasing the accelerator. No conclusions were reached. He said he would let me know if he thought of any new ideas.

Frank Liebert showed me around the systems laboratory. I felt somewhat overwhelmed by the 12-in. wide waveguide that seemed to be running all over the place. The systems group has developed a rather pretty water load that uses a quarter-wave ceramic matching window and a section of circular waveguide filled with water. The water is injected into this section in such a way that it circulates rapidly, and the entire load has a length scarcely greater than its diameter. These loads have been built for all wavelength bands from L- to X-band. Such a device might prove useful to us.

The Sperry people seem to be very pleased with the hybrids and bends made by MDL. They make their own tuners for phase shifters and matching.

E. GENERAL TELEPHONE LABORATORY

I telephoned General Telephone Laboratory at Bayside and talked to Herman Dressel, who is working with Gerhard Weibel. At the Tri-Services Symposium on Millimeter Waves in 1957, Weibel had reported on a device to trap the plasma, pump it at one frequency and then increase its resonant frequency by increasing the magnetic field, so that it radiated at a higher frequency. The device is called the "tornadotron." It works from a pump frequency at S-band, and the output is from 75 to 300 kMc. A double stream pencil of charge is trapped in a combination of electric and magnetic fields. The magnetic field has a pulse form resembling one-half a sine wave with an amplitude of 100 kilogauss and a rise time of 2.5 μsec. They cannot yet measure the low output power, but they hope eventually to get kilowatts.

IV. ADDITIONAL VISITS

A. ENGINEERING ANNEX, OXFORD UNIVERSITY

I planned to call on Dr. Motz at Oxford but found that he was off in Munich, Strasburg. Dr. Motz is now a Professorial Fellow at St. Catherine's. I talked with Hugh Walsh, his assistant, and two of his students, John M. Free and M.E.B. Moffat. They have a number of projects underway. One is a linear accelerator with a 1-cm operating wavelength. They are designing an accelerator structure with ceramic-loading disks. It will be used for investigation of undulator characteristics. The accelerator that we sent from Stanford has just been retired. Its best performance was in multiplying the 10-cm operating wavelength to 8 mm. Apparently, shorter wavelengths than this could not be obtained. The performance of the undulator was quite satisfactor up to this wavelength. Another project, which apparently has just been shut down, was making use of electrons with a velocity 1000th of the velocity of light. This corresponds to 50-mv electrons. Unfortunately, my guides could not give me the complete story on this particular work.

A new engineering laboratory is being built, and there will be much more space available in a year or so.

I talked to George Walker on the way to Oxford. I got very little news of his present work, because he was full of plans for a "dust accelerator." This would be a machine built like a heavy ion accelerator, but accelerating very small dust particles of various materials to speeds of 5 to 50 meters/sec.

B. UNIVERSITY COLLEGE, LONDON

I called on Professor Barlow and discussed his microwave engineering course, which will be a full-time graduate level course. It will cover theory, circuits, devices, techniques, and applications at microwave frequencies. It is, at the same time, a more specialized and perhaps more complete course than is offered at Stanford. The department expects that its new graduate students will take this course before starting their research work. In this manner the students will, in principle, have learned all the microwaves they need to know before they start work. Three or four men carry almost the entire teaching and research load in the department.

I had hoped to talk further with John Brown, whom I met at the conference, but he had left for India for an extended stay. I took a tour of the laboratory with Geoffrey Sims. The laboratory is in a new nine-story building that is by no means completed, but the contractor started finishing the building from the top down. The elevators, of course, were put into service for the contractor's benefit, and so the microwave people have the top two floors of the building to themselves, although at the ground floor the flooring has not been laid. They are working on the properties of metals such as semi-conductor ferrites, the dielectrics, plasma physics and magneto hydrodynamics, Hall effect devices, and propagation of waves on surfaces and at TE_{01} waveguide. Sims is working on electron optics and tubes. He has a velocity spectrograph for measuring large signal effects in klystrons, but the equipment has been causing some trouble. Sims is also investigating a crossed-field device that he hopes will prove to be some form of Maxwell's demon to generate electricity from heat. Sims is also working on a form of traveling-wave tube that consists of drift tubes with external conductors for use at low frequencies. The group investigating circular waveguide work at 8 mm has developed a helix guide approximately 3/4-in. i.d. with 1/8-in. dielectric outside for voltage suppression. It is experimenting with a tube that has longitudinal grooves in the wall approximately 1 mm wide and 2 mm deep. The loss is claimed to be 0.9 db/meter with the grooves in contrast to 0.6 db/meter without the grooves, and is supposed to provide very good spurious mode suppression. This statement makes no sense to me, but this is a direct paraphrase of Sims' words and, unfortunately, there was not time for a good argument. I intend to find out more about this. There are surface waves along plane or simply-curved micarta sheets. The work is being done at 3 cm, and the instrumentation is admirably simple. Their work on the Hall-effect power meter and Hall-effect field properties was reported at the conference.