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GERMAN DEVELOPMENT OF MODULATOR VALVES FOR RADAR APPLICATIONS

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B.I.O.S. Trip No. 2617

Reported by:-

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GERMAN DEVELOPMENT OF MODULATOR VALVES FOR RADAR APPLICATIONS

1. Introduction

The primary object of the trip was to investigate German valve technique as applied to radar pulse modulators. It was known that hard valves and thyratrons had been used in equipments operating at fairly low powers and that a valve similar to the British C.V.85 triggered spark gap had been produced but no information was available of the performance of these valves or of any development work in progress at the end of the War. It was therefore assumed that this field had not been covered by other investigators.

Since the personnel concerned with this work were not known it was necessary to interview a large number of people in order to locate the specialists. Gradually it became evident who were the required personalities and a number of them were finally located and interrogated but others, situated in the Russian Zone were inaccessible. A complete list of the persons located and, where possible, interviewed is given in Appendix I.

Appendix II gives a summary of valve characteristics obtained from documents which were evacuated. It also contains a list of documents which may be seen together with a translation in most cases, at the address given on the title page.

2. German applications of thyratrons to radar pulse modulators

2.1 General conclusions

The Germans seem to have made only preliminary steps in this art. The anode modulated transmitters that were in operational use employed either vacuum triodes, thyratrons, or trigatrons as the modulating device; no evidence could be found that peak powers exceeding 200 kw. had been achieved. However, they had need of high power modulators that were not cumbrous and were experimenting with both thyratrons and rotating spark gaps. By the end of the War, two sets with increased power were ready for production; one of these employed a high vacuum triode and had a peak power output of 1000 kw., the other used a helium filled thyratron and gave a peak power output of approximately 250 kw. They were distressed by the cost of the former equipment and were experimenting with rotary spark gaps as a replacement for the vacuum triode.

Turning to the gases used for filling the thyratrons, they quite early dismissed mercury because, without temperature control, they experienced very short lives and they did not believe that sufficiently simple temperature control systems could be devised. The potential advantages of hydrogen were appreciated, and indeed a fair amount of use had been made of it in contrast with its apparent neglect in England. However, they seem to have foundered on the very grave difficulties that attend the mass production of valves employing this filling, since the applications engineers expressed low opinions on their reliability and showed aversion to the idea of using them in their modulators.

Helium seems to have been the filling used for the radar thyratrons. This gas has not given good results, either in America or in England; the general experience being that the gas is lost rather rapidly by clean-up, so leading to premature failure. In view of these results, it is likely that the Germans also would have abandoned this gas had their experiments gone on longer. Particularly is this true if they had endeavoured to develop thyratrons for outputs exceeding 1,000 kw.; as it was, the greatest they achieved seems to have been 250 kw.

Unfortunately, the evidence for the above conclusions is not as complete as could be desired. Many of the men interrogated had no direct connection with the subject, and those that had were often without adequate records of their work. In addition, any generalisations about gas discharge devices can be misleading unless they are so hedged with qualification as to become almost unintelligible to the general reader. However, with these reservations, the foregoing represents the considered opinion of the Author.

2.2 Personalities

Dr. Mailandt of Telefunken, Hamburg, believed that any work carried out on large pulse thyratrons would have been done by AEG. He also thought that Herr Muth of Telefunken, Berlin, was an authority on apparatus that might employ such valves.

Dr. Hoffman of Siemens and Halske, Siemensstadt, Berlin, said that Drs. Jacobi, Steimmel, and Putzer did the thyratron development work for Siemens. Of the three, Putzer only was still in the Western Zone, However, Hoffman did not believe that thyratrons were used for powers greater than 200 kw. in operational equipments.

Dr. Kleen, a leading personality in electronics in Germany, suggested that the leading people on thyratrons were Dr. Aarens of AEG and Dr. Koch, also of AEG. He suggested Dr. Andrieu, Telefunken, Hanover, for modulator circuit work.

Dr. M. Nippold, AEG, Hohenzollern Damm, Berlin, knew the AEG staff well and said that, until his death in 1943, Dr. Glaser was in charge of thyratron developments. Incidentally, Dr. Glaser had an international reputation. When Glaser died, his work was taken over by one of his assistants. a Dr. Koch. The applications work on thyratrons was dealt with by Dr. Keitner until 1941, at which time Dr. Mohr took over. Nippold doubted whether thyratrons had been used as high power modulators at any stage during the War.

Drs. Bacher and Straub of Bosch, Seiden Strasse, Stuttgart, stated that the firm had done no development work at all on modulator valves. They had used argon filled thyratrons in ignition circuits for aircraft engines. These valves had been operated at 400 volts with a peak current of about 1 amp. and a conduction period of about 0.01 secs. A condenser was discharged through a transformer in series with the thyratron, so developing a secondary voltage of about 16,000 volts. The valve life was about 1,000 hours. They also stated that a Herr Grother, Bad Cannstadt, Buchenhalden Str, had developed a suitable hydrogen thyratron for this application.

Dr. Midius, Technische Hochschule, Munich, had worked with Prof. Schumann who had apparently worked on cold cathode valves before the War. Midius did not believe that Schemann had developed modulator valves during the War but he had done some fundamental work in connection with interrupting the current through a gas-filled valve. Some success had been achieved but the life of the control grid had been very short. Incidentally, these difficulties are well known with such valves used to break circuits. Midius believed that a Dr. Lumberger had also worked on thyratrons.

In the light of the above interrogations, the strong probability seemed to be that the important personalities for thyratron modulators are as follows:-

Valve development -	Messrs. Aarens and Koch of AEG.
	Messrs. Jacobi, Putzer, and Steimmel of Siemens.
Thyratron	Messrs. Muth and Andrieu of Telefunken
applications	- Messrs. Keitner and Siegenbein of AEG.

There is a distinct possibility that Dr. Mohr of AEG has importance in this connection but he was not located.

2.3 Modulator applications of thyratrons

Herr Muth is an eminent electrical engineer in the Telefunken organisation, and had held the responsibility for developing radar equipment. He stated that Telefunken apparatus had employed hard tubes and trigatrons only. Thyratrons were used in equipments made by Gema and Lorenz, but he knew of no case where they had been used to give powers greater than 200 kw. Telefunken were interested in higher powers and were experimenting with rotary spark gap modulators.

Professor Marx of Braunschweig had done the development work and powers of 1.5 megawatts had been achieved, but the gaps had not been incorporated into operational equipment.

Dr. Keitner had worked on stroboscopes for observing shell movement and stated that Dr. Koch had developed the thyratrons for this application while Dr. Hermann (Technische Physikalische Werkstatten, Sée-Strasse Reinigendorf, Berlin) had developed the light source. Dr. Siegenbein of AEG developed impulse generators for the transmitters. Prof. Marx had done a little work on spark gap impulse generators for the same application.

Dr. Keitner did not believe that any use had been made of thyratrons for producing high power pulses but suggested that a Dr. Werner should know of any radar applications. Werner was not located. Keitner had worked in association with Dr. Glaser on thyratrons and said that both AEG and Siemens had developed large thyratrons independently. Dr. Stainbeck (? Steimmel) developed the Siemens type but is now with the Russians. Keitner knew of no groups working on thyratrons other than those at AEG and Siemens. He confirmed that Koch did the thyratron development for AEG after Glaser died and mentioned that Prof. Marx had done a little work on rotary spark gap modulators. He recommended Dr. Siegenbein of AEG as a likely source of information on thyratron pulse modulators. Finally Dr. Keitner said that, prior to the War, they had developed a small hydrogen filled thyratron for short impulses (anode voltage of 500v. and a peak anode current of less than 1 amp.) These valves ran into serious cathode troubles and short life when attempts were made to produce them in quantity.

Dr. Siegenbein is an electrical engineer and had worked on radar equipment during the War. He said that the earlier sets were low powered (50 - 100 Kw) and employed trigatrons and thyratrons. They had developed two high power radar sets one of which employed a thyratron and had reached early production by the end of the War. The firm GEMA developed the transmitter and AEG the modulator. The modulator employed the S1/6 thyratron which had the following rating.

S1/6	- Helium filled thyratron made by AEG
Anode voltage	- 2000v.
Peak anode current	- 250 amps.
Fil. volt.	- 9v.
Fil. current	- 8 amps.
Pulse length	- 1 micro-second.
P.R.F.	- 500 per sec.
Life	- less than 1000 hours but not enough experience to be sure. However he had the impression that the life would not be good.

Apart from this set, Siegenbein mentioned another, made by Lorenz and named Hohentwiel. The modulator valve was the AEG thyratron S1/3, which had the following characteristics:

S1/3	- Helium filled thyratron
Anode voltage	- 2000v.
Peak anode current	- 30 amps.
Pulse length	- 1 micro-second.
P.R.F.	- 50 per sec.
Life	- 1000 hours.

Dr. Siegenbein knew that Dr. Koch had developed hydrogen filled thyratrons but said that they were not at a stage where equipment could be designed round them.

2.4 Thyratron valve development

Dr. Aaerens is working with Siegenbein at AEG Clausthal-Zellerfeld, they are trying to build up a small factory making gas-filled rectifiers. Aarens was responsible for thyratron development during the War. In the early stages he tried mercury filling but found it was necessary to control the mercury condensation temperature to lie between 40°C and 60°C. He formed the opinion that the apparatus required to do this would be too complicated and rejected mercury thyratrons on these grounds. It is interesting to recall that the experiments made at GEC Research Labs. in 1940 gave the same result, namely, that the condensation temperature must lie between 50°C and 60°C for good lives under pulse operation; however, GEC were able to develop simple means of temperature control. Aarens met the difficulty by developing helium filled thyratrons. He worked on two types, the S1/6 and the S1/3; the ratings of these valves are given above, in the account of Siegenbein's interrogation. These valves were designed for a maximum anode voltage of 2000 volts as attempts to work at higher anode voltages showed that the filling pressure had to be so reduced as to cause premature failure. The reduction of filling pressure may be presumed to be dictated to avoid a glow discharge from the anode to the low potential electrodes. They tried using gas reservoirs leaking into the discharge space via a capillary tube to overcome failures caused by loss of gas. They found this system prohibitively bulky and, in any case, useless unless the valve was in continuous use. These experiments have all the appearances of a very forlorn hope. However, at the ratings given above, the valves were reasonably satisfactory, although Dr. Aarens pointed out that there was not really enough service use to enable a good estimate to be made of the life. He said that failure took place by loss of the emissive coating from the cathode, and that large cathodes should be used so that life was adequate. However large cathodes were deprecated by the users on the score of overall size. Anodes were of graphite. He offered the opinion that mercury fillings demanded cathodes three times larger than did rare gas fillings. This is rather a curious point and the Author knows of no evidence in current English practice which supports it. It may be that the larger cathodes permit the mercury filled valves to work over a wider range of mercury pressures but, on this point, the shape and disposition of the cathode surfaces are of very great importance and statements about the total area are a little suspect until the cathode form has been specified.

Dr. Koch is now working at the AEG works at Belecke-Möhne. This factory is attempting to produce Selenium rectifiers and rectifying equipments, presumably for low voltage applications. During the War, Koch worked on dry rectifiers but he had also worked on hydrogen filled thyratrons for modulating stroboscopic flash tubes. Two types reached production, the S.83 and the S.86. The former operated at an anode voltage of 800 volts and a mean current of 3 amps. the peak anode current was several hundred amps and the repetition frequency was from 50 to 2000 per sec. The latter operated at the same anode voltage but at a mean current of 6 amps. The peak anode current was again several hundred amps and the repetition frequency from 50 to 2000 per sec. Koch gave a figure of several hundred hours for the life. Larger thyratrons were developed for range measurements using light pulses, presumably in the apparatus mentioned by Dr.Keitner. Koch was rather vague about the ratings of these valves, beyond that he knew that the light tube carried several thousand amps peak current and that a range of several thousand yards had been achieved, it is likely that he merely supplied valves to the applications engineers without asking many questions. He volunteered that the thyratrons for this work were about 24 inches long by 4 inches diameter, had nickel anodes with three grids closely spaced round the anode, a thermionic cathode of conventional pattern, and were filled with Helium and Argon to a few millimetres pressure. He apologised for his memory and explained that some time had elapsed since he had worked on the problem. It was arranged that he would supply to 'T' Force HQ all relevant information that could be found. Since no further information has been received it is assumed that he was unable to find his records.

In general discussion, Dr. Koch gave his opinion that good life in hydrogen thyratrons is entirely a matter of purity of materials and of saturating the electrodes with hydrogen. He had always introduced hydrogen into the valves through two palladium tubes in series, the second of which was electrically heated. They found that failure was always due to sputtering of the cathode material and that the most stubborn problem was to saturate the electrodes with hydrogen. They had found that helium was not as satisfactory a filling for these thyratrons as was hydrogen. With helium, the filling pressure had to be reduced to avoid a glow discharge between anode and grid; with this low pressure the current carrying capacity was reduced leaving the alternatives of either reducing the rating or permitting severe cathode bombardment. It will be noted that there is some confusion here, in that earlier it was stated that these valves were filled with a mixture of helium and argon whereas here, Koch is advocating hydrogen. It is not unlikely that the earlier samples had helium/argon fillings and that subsequent research had proved the value of hydrogen but that there had not been time to employ this result.

Dr. Putzer was the only available member of the Siemens thyratron group, Drs. Jacobi and Steimmel (? Steinback) both being with the Russians. Putzer was in hospital and evidently far from well. He had worked on mercury filled thyratrons for use as modulators and rectifiers until 1943 when his Laboratory was destroyed by fire. He endeavoured to use mercury thyratrons as modulators with anode voltages of 20,000 volts and at peak currents of 200 amps. Without control of the condensation temperature, lives were less than 200 hours. With the ambient temperature controlled at about 25°C, operation was improved but the life was still so short that the method was regarded as too expensive. The same valves used as conventional rectifiers had lives of 20,000 hours.

3. Development of high vacuum valves for pulse modulators

3.1 General Conclusions

The development of high vacuum valves was carried out mainly by the Telefunken organisation, but in the field of anode modulation it appeared that only very limited effort had been directed. Both AEG and Lorenz had valves in development but so far as could be ascertained no valves specially developed for the purpose had actually been put into production before the war ended.

3.2 Interrogation of Dr. Wiegend and Dr. Herrmann, Telefunken, Sickingenstrasse, Berlin

Dr. Wiegend is the Chief Technical Director of the Telefunken Valve Works.

Dr. Herrmann supplied information concerning the L.V.20 which was a copy of the American 715B but made on a pressed glass base. It had the following rating:-

Max. anode volts	15 K.V.
Peak cathode current	20 amps.
Anode dissipation	75 watts
Screen "	2 watts
Grid "	2 watts
Heater voltage	25.2 volts
" current	2.0 amps.

The cathode paste used consisted of sodium carbonate as it was found that the sputtering was less than with ammonium carbonate. The grids were gold plated to prevent secondary grid emission. The grid rods were of copper coated with nickel and the grid wires were of gold plated molybdenum.

The anode consisted of thorium or zirconium to prevent anode sputtering. A barium aluminium getter was used. Cathodes were aged over a period of 24 hours the H.T. voltage being gradually increased up to 18 KV.

Only about 400 valves had been made and it was believed that the war ended before they had been put into service. No information was available concerning the life of the valve. This appeared to be the only valve developed by Telefunken for pulsed operation.

Dr. Wiegend and Dr. Herrmann supplied information on the standard cathode techniques of Telefunken concerning the pastes in use.

1. Type E4F1 is used for spraying in fairly dry atmospheres and consists of:-

1.05 Kg. E4 Carbonates + 2400 c.c. Methyl Alcohol + 850 c.c. Collodium.

The E4 Carbonates are composed of:-

50% $Ba\,CO_3$ + 45% $Sr\,CO_3$ + 5% $Ca\,CO_3$

The ingredients of the Collodium are:-

1500g. Cellulose nitrate E950 + 5.5 litres solvent E13 + 5.5 litres Butyl acetate, giving about 12 litres of Collodium.

These materials are ball milled for 23 hours and give about 3.5 litres of spray paste.

2. Type E4F5 is used for Cataphoresis and consists of:-

400g. E4 Carbonates + 200 c.c. Methanol which are ball milled for 24 hours and to which are then added:-

300 c.c. acetone + 100 c.c. collodium.

The ingredients of the collodium are:-

1500g. Cellulose nitrate E950 + 5.5 litres solvent E13 + 5.5 litres Butyl acetate giving about 12 litres of collodium.

This produces about 0.7 litres of cataphoretic paste.

3. Type E4F6 is used for spraying in atmospheres with high moisture content and consists of:-

1.05 Kg. E4 Carbonates + 1500 c.c. Solvent E13 + 500 c.c. Butyl acetate + 500 c.c. Collodium solution.

The ingredients of the collodium are:-

1500g. cellulose nitrate E950 + 11 litres Butyl acetate giving about 12 litres of collodium.

These materials are ball milled for 23 hours and give about 2.7 litres of spray paste.

The E13 solvent is supplied by A.G. Farben and is a mixture of methyl and ethyl acetates.

It was stated that the type E4F1 paste gave trouble since the evaporation of the methanol produces condensation of moisture on the cathode.

The triple carbonates are precipitated from the mixed nitrate solution with ammonium carbonate, and this gave emissions as good as with sodium carbonate. The precipitates are filtered off by centrifuging, washed until free of ammonia and dried in an oven at 80°C for about 24 hours. The average particle size is 5μ.

For coating very fine wires (11μ), the wire is cleaned as for filaments of incandescent lamps by glowing in an atmosphere of Nitrogen and Oxygen at about 1300°C. The coating is applied cataphoretically either continuously or with interruptions.

Cathodes of nickel are used with 0.05 - 0.17% Mg, the optimum proportion being 0.07%. This gives improved emission for one hour only but is of considerable assistance in ageing. Nickel with 0.5% Al is used for strip filaments and this gives a real improvement in emission. More than 0.5% Al gives poorly adherent coatings. No improvement has been found using vacuum cast nickel.

3.3 <u>Interrogation of Dr. Siegenbein, AEG Clausthal - Zellerfeld</u>

One of the two high power radar sets in early production by the end of the War had utilised a thyratron as already described. The second set was to be made by the firm of ELAG in Kiel and was for naval use. The modulator was a thoriated tungsten cathode high vacuum triode driving a magnetron transmitter operating on 9 cms. The modulator valve was made by AEG and called the A.V.1012. Its characteristics were:-

Ea	15,000v.
Ia	60 amps (peak)
Fil. watts	1.2 Kw.

Anode watts	0.4 Kw.
Pulse length	1 micro-second
p.r.f.	500-1500 c.p.s.

It was intended to replace the A.V.1012 by the L.V.21 which was a further development of the valve with the inclusion of a screen grid. It was expected thereby to increase the anode voltage rating to 30 Kv. The first samples of this valve were available for test at the end of the War. Professor Marx was developing rotary spark gaps to reduce the cost of the equipment but did not complete the work.

3.4 Interrogation of Dr. Herriger, Lorenz, Esslingen

No work had been carried out on gas filled modulator valves, but a high vacuum valve the RL12T75 had been developed for pulse operation. The valve was on a pressed glass base and of 90 m.m. x 60 m.m. overall dimensions. It was constructed as a triode with two cathodes, two grids and two anodes, each pair being connected in parallel. The valve had an oxide coated cathode and was rated as follows:-

V_A	2.5 K.V. max.
I_A	9 amps peak
W_A	75 watts
Grid bias	-250 volts
" drive	+400 volts
Heater volts	12.6
" amps.	1.7

The valve was developed for use in the Wurzburg equipment but never reached production. Hohentwiel?

4. Triggered Spark Gaps (sealed)

4.1 General conclusions

As a result of enquiries at the leading valve firms it appeared evident that little work was carried out on this type of valve. Nowhere was there any evidence that more than two types had been under development, these being the LG201 and LG203. Although various personalities gave apparently conflicting information concerning the filling this was probably due to their having knowledge of certain stages of the development only.

During the interrogation of Dr. Moeller, of the Max Wien Institute it was learned that the triggered spark gaps had been developed by Osram, Berlin, in a department under Dr. Ewest. He believed the valves to have a filling of CO_2. It was subsequently established that Dr. Ewest had been in charge of a research group headed by Dr. Rompe and which was divided into two sections, one under Dr. Schulz who was concerned with triggered spark gaps and the other under Dr. Floriet who was responsible for fluorescent lamps.

Since the end of the war all the personalities concerned have left the Osram organisation, Dr. Ewest having retired, Dr. Römpe having joined a Russian Institute in Berlin and it was understood that Dr. Schulz was in the Russian Zone.

4.2 Interrogation of Dr. Römpe

Dr. Römpe was interviewed at the Kaiser Wilhelm Institute für Radiologie, Wilhelmstrasse, Berlin.

Dr. Römpe was able to quote only from memory. It was interesting to learn however that experiments had been carried out as early as 1940 on enclosed triggered gaps and a valve had been developed in 1941 but the work was abandoned, as it was not considered to have any applications, until a British equipment captured two years later contained a C.V.85. The design of the L.G.201 was then based on the C.V.85 and has similar characteristics. It was filled to a pressure of about one atmosphere with Argon and about 10% air. When operating with a 1 µsec pulse at 150 KW at 550 c.p.s. the life was 200 hours,
and at 1500 " " " " 60 hours.

It had been established that the short life was due to absorption of oxygen. No work had been done to improve the life as it was considered that high repetition rates were not possible by this method and all effort had been put into rotary spark gaps.

4.3 Interrogation of Dr. Ewest

Dr. Ewest was interviewed at his home in Lankewitz, Berlin.

Dr. Ewest was not familiar with the details of the development but undertook to obtain information concerning the filling of the LG203 from Dr. Schulz whom he considered to be the only man having the information.

The LG201 and LG203 were the only triggered spark gaps developed. The LG203 was filled to a pressure of 8 atmospheres, with 62.5% Argon, 17.5% Air and 20% Nitrogen. The filling was carried out by liquifying the argon by means of liquid nitrogen. Krypton filling had been tried but was abandoned as supplies of this were not as easily obtained as of argon with which the filling was also easier. The rating of the LG203 was as follows:-

Hold off voltage	16 KV.
Peak pulse current	125 amps.
Pulse length	0.5 µsecs.
Repetition rate	1500 c.p.s.

No reliable information concerning the life was obtained but the general impression given was that the life was poor.

5. Interrogations of other personalities

During the course of the investigation the following persons were also interrogated but were not themselves chiefly concerned with the subject under investigation.

5.1 Dr. Studemund, Herr Schlenke, Dr. te Gude
Phillips Valve Works. Stessman Strasse, Hamburg.

Phillips Valve Works are manufacturing a range of commercial valves and have little or no information of a detailed nature on high voltage pulse techniques. They have never worked on high power thyratrons, such work having been done entirely by AEG, Siemens and Telefunken. Concerning pulse techniques, Siemens and Hälske, Berlin, worked on a navigational beam, and other workers included Dr. G. Seibt of Seibt and Dipl. Ing. Gibel of Telefunken.

5.2 Dr. Fehr, C.H.F. Mueller, Roentgen Strasse, Hamburg

C.H.F. Mueller manufacture X-ray tubes and rectifiers for X-ray equipment. During the war they had manufactured two small thyratrons - the EC50 and AC50 but these valves had been designed by Phillips, Eindhoven before the war. They also manufacture large mercury vapour rectifiers.

5.3 Herr Andrieu, Telefunken, Göttingen Chaussée Hanover

Herr Andrieu had worked on the development of radar apparatus including the Mannheim and Berlin equipments. The Mannheim equipment employed a directly heated triode modulator LS300 having a thoriated cathode. It used an anode voltage of 6 KV and passed 20 amps peak current with a pulse length of 2 μsecs and a recurrence frequency of 3700 c.p.s. He believed that nitrogen had been tried as a filling for the LG201 valve used in the Berlin equipment.

5.4 Dr. Mailandt, Telefunken, Ferdinand Str. Hamburg

Dr. Mailandt explained that Telefunken had been organised during the war into four main groups working for:-

(1) Army (2) Navy (3) Air Force (4) Post Office.

Dr. Mailandt himself had been concerned mainly with the development of small valves for the Post Office and had only limited knowledge of the activities of the other groups. He was however able to give the following information concerning other personalities:-

Dr. Steimmel had been responsible for valve development at Telefunken which produced 90% of the German valves. He is now in charge of an Institute in the Ressian Zone.

Dr. Kotowsky was an aerial specialist and now works with Dr. Steimmel.

Professor Rukop had been manager of the Telefunken factory at Ulm. He and Dr. Steimmel probably initiated most the new ideas in valves at Telefunken.

Professor Moeller was head of the Max Wien Institute.

Dr. Döhler worked under Professor Moeller and had developed a spark transmitter for jamming.

Dr. Buschbeck was considered to be the most important man in Germany on short wave transmitters particularly in the range 12-100 metres.

Dr. Maas at the Telefunken factory at Dachau was mainly responsible for the design of the Berlin and Rotterdam equipments.

Professor Marx at the Brunswick Technical High School had been working on rotary spark gap modulators.

Professor Binder was a leading high voltage expert at the Dresden Technical High School.

5.5 <u>Professor Moeller, Sternwarte, Bergerdorf, Hamburg</u>

Professor Moeller was formerly head of the Max Wien Institute which was part of the Reichstelle für Hoch-Frequenz Forschung. His work had been on reflection measurements, radar camouflage, mine detectors, sound ranging of aircraft and location of moving targets using the Doppler effect. He believed that pulse techniques were first used in 1934 for measuring distances. Telefunken was mainly responsible for the later developments. He had been using Berlin and Rotterdam equipments for experiments to detect aircraft through 'window', but he had no special knowledge of the modulator valves which he believed to be filled with CO_2. He believed the valve was developed by Osram and in this connection mentioned Dr. Ewest. Concerning others who might have worked in this field he suggested Dr. Stutzer at Oberpfaffenhofen near Munich.

5.6 <u>Dr. Matthias and Dr. Engel, Siemens Reinige, Erlangen</u>

The firm made thyratrons before and during the war but are not manufacturing them now. Production had been carried out in the

Vienna factory. A list of the valve ratings and gas fillings was obtained.

5.7 Dr. Koelbl, Siemens and Halske, Nürnberg

This branch of the firm was mainly concerned with building apparatus. No valve development was carried out there. He stated that the Telefunken organisation carried out almost all valve development.

5.8 Dr. Herriger, Lorenz, Esslingen

Particulars were obtained of the RD12La velocity modulated oscillator valve which is being produced.

The RD12La is a coaxial line "Heil tube" type of oscillator, normally used in the single transit mode. It is tunable by the external line, over a range 20-25 cms and gives an output of 12 watts CW with an efficiency of 15%. Electronic tuning is possible by varying the resonator or anode voltages; about 30 volts change on the resonator produces 1 Mc/s change of frequency with negligible change of output power. The voltage supplies required are:-

Heater	12.6 volts
Resonator	500 volts above cathode
Anode	50 volts above resonator

A magnetic field of about 500 gauss across a gap of $2^3/4$" is required for focussing. The overall dimensions of the valve are approximately 6" long x 3" diameter. The connections are brought out at both ends of the cylindrical glass envelope through pressed-glass bases.

The RD12La was developed during the war and is now being used as the transmitter valve for an V.H.F. FM communications equipment called "Stuttgart".

Dr. Herriger expressed the opinion that the valve could probably be modified to operate satisfactorily down to 15 cms.

5.9 Dr. Renee Haefer, Max Wien Institute, Hamburg

Before the war Dr. Haefer worked at Siemens under Dr. Augustus Hertz on the problem of Field Emission and later on Magnetic Mines. In 1944 he joined the Max Wien Institute and under Professor Moeller had worked on various projects including cold cathode magnetrons and back heating in magnetrons. These projects had only just started when the war ended. Dr. Haefer's work was entirely on CW and he had no knowledge of pulse techniques, his interest being primarily in fundamental physical research.

On magnetron cathodes Dr. Haefer was experimenting with tantalum, oxidised and coated with a mixture of Alumina and Magnesia. Emission was of the order of 100 mA/sq.cm. The valves contained a mixture of Argon and Neon at a pressure of about 10^{-3} m.m. Hg.

5.10 Dr. Netheler, Eppendorfer Hospital, Hamburg

Dr. Netheler had been working on jamming problems using the Berlin equipment but he had no knowledge concerning the valves used. He was however able to give information concerning the whereabouts of other personalities.

5.11 Herr Siegfreid Schwarz, St. Georg Str. Hamburg

Herr Schwarz had been employed during the war on radar installation work for the German Navy. He had little detailed knowledge of the equipments, which he said were made by Telefunken and Gema.

5.12 Dr. W. Schwarz, Jaegerstrasse, Hamburg

Dr. Schwarz was a former member of the Ernst Lecher Institute. His main work had been on navigational aids for the Luftwaffe and in particular on "Epsilon". He stated he had no knowledge of modulator techniques but maintained there was another man of the same name at the Ernst Lecher Institute, and was believed to be at Bamberg.

5.13 Dr. Maier, Telefunken Berlin

Dr. Maier had been concerned with the development and manufacture of gas and vapour filled valves. He had knowledge of the RSQ15/40 thyratron which had a guaranteed life of 5000 hours and generally the actual life was considerably greater when operated under normal conditions. The polished carbon anodes in this and other valves are supplied to Telefunken by Schünk and Ebe of Giessen. The special carbon is known as electro-graphite type EL1400. In the early work on ignitrons silicon carbide igniters had been employed but were later replaced by one developed by I.G. Farben which had a better life. This one was believed to consist mainly of boron carbide.

5.14 Dr. Stockmeyer and Dr. Schnappanf, Schünk and Ebe, Giessen

The firm was concerned mainly with the production of carbon brushes. During the war anodes and grids made of graphite were produced for a number of valve firms. The method of production was as follows:-

(1) Cold pressing 12000 Kgs/sq.cm.) of normal carbon dust into cylinders, plates etc.

(2) Graphitizing in Acheson Furnace (10 hrs. heating up, 4 hrs. at 2500°C - 3000°C, 3 days cooling).

(3) Machining and polishing.

6. Conclusions

1. Only preliminary investigations have been carried out in the art of anode modulation, for which development appears to have been initiated at least partly as a result of the capture of British and American equipment. No evidence was available to indicate that any valves had been produced giving satisfactory lives at power outputs of more than 250 KW. Early experiments with thyratrons had been carried out both with hydrogen and helium fillings and the latter had been adopted as the more favourable, satisfactory valves having been produced. For higher powers, thyratrons and rotary spark gaps were the two lines of development which were to be persued.

2. Generally one gained the impression that there was little co-ordination between the various government institutes and the industrial research organisations working on similar projects, so that knowledge acquired was not disseminated to the best advantage. As a consequence of this no reliable information could be obtained concerning the performance of equipment in service. It is considered, however, that the field of the development of modulator valves has been adequately covered.

7. APPENDIX I

The following is a list of the persons located and interviewed where possible, together with a note to indicate their technical positions or the type of work with which they are familiar.

TELEFUNKEN

29, Ferdinand Str. Hamburg

Dr. Mailandt. Development of small valves for the Post Office.

76, Göttingen Chaussée Hanover

Dr. Andrieu. Radar circuits.

8, Max Str. Schöneberg Berlin

Herr Muth. Development of Radar Equipment.

Sickingen Str. Berlin

Dr. Günther-Wolf. Rectifier Engineer
Dr. Wiegend. Chief Technical Director
Dr. Herrmann. Expert on cathode techniques.
Dr. Maier. Manufacture of thyratrons and rectifiers.

5, Brünngarten Str. Dachau, Nr. Munich.

Dr. Vincentz, Herr Neuhausen, Dr. Rothe.

Telefunken Factory at Ulm

Professor Rukop. Manager.

A.E.G.

150, Hohenzollern Damm, Berlin

Dr. Nippold. Technical liaison engineer.
Dr. Keitner. Rectifier engineer of wide experience.
Dr. Mohr Circuit applications of thyratrons.
Dr. Maier. Thyratron production.

Belecke - Möhne

Dr. Kugler Managing director of Belecke-Möhne plant.
Dr. Koch Thyratron Research, Successor of Dr. Glaser who died in 1943.

Clausthal - Zellerfeld Harz.

Dr. Siegenbein. General Manager of factory developing gas filled rectifiers.
Dr. Aarens. Responsible for thyratron development.

SIEMENS AND HALSKE

Siemensstadt Berlin

Dr. Tamm. Chief of development labs. engaged on circuit work.
Ing. Buchwald. Assistant to Dr. Tamm.
Dr. Hoffman Electo-chemist. General liaison work.

Nürnberg

Dr. Koelbl. Manager of factory concerned entirely with assembling apparatus.

Siemens Reinige Erlangen

Dr. Matthias, Dr. Engel. Production of equipment.

Siemens. Rudolfstadt

Dr. Jacobi. Development of Siemens thyratrons
Dr. Steinbeck " " " "

Siemens, Vienna

Dr. Koenig. Valve Development.

PHILLIPS VALVE WORKS

Stessman Str. Hamburg

Dr. Studemund, Herr Schlenke, Dr. te Gude. Manufacture of standard commerical valves.

C.H.F. MUELLER

Roentgen Str. Hamburg

Dr. Fehr. Secretary to the firm.
Manufacture of X-ray tubes and rectifiers.

BOSCH

Seiden Str. Stuttgart.

Dr. Bacher, Dr. Straub, Aircraft apparatus.

TECHNICAL HIGH SCHOOL, MUNICH

Professor Schumann. Cold cathode valves.

KAISER WILHELM INSTITUTE für Radiologie

Wilhelmstrasse Berlin

Dr. Römpe, formerly of Osram. Valve development.
Dr. Buschbeck. A leading expert on short wave transmitters.

LORENZ

Necker Str. Esslingen

Dr. Herriger. Cm. valve development.

Technical High School, Dresden.

Professor Binder. High voltage expert.

MAX. WIEN INSTITUTE

Sternwarte. Bergerdorf. Hamburg.

Professor Moeller. Head of the Max. Wien Institute
Dr. Doehler. Pulse techniques and transmitters
Dr. Fack. " " " "
Dr. Haefer. Cold cathode magnetrons
Herr Buchmann. Radar camouflage.

FLUGFUNK FORSCHUNGS INSTITUTE

Oberpfaffenhofen, Nr. Munich.

Dr. Rindla. Knowledge of all personnel who formerly worked at the Institute.

Dr. Ewest, 30 Ahorn Str. Lankewitz, Berlin.
Formerly head of research dept. at Osram (Retired).
Herr Groether. Buchenhalden Str. Bad Cannstadt.
Small thyratrons when at Bosch.
Dr. Kleen. Telefunken. Valve research.
Dr. Netheler, Pav. 25, Eppendorfer Hospital, Hamburg.
Jamming problems.
Dr. Putzer. Development of mercury rectifiers for Siemens.
Dr. S. Schwarz, Gt.Georg Str. Hamburg.
Installation of radar equipment in the navy.
Dr. W. Schwarz, 15, Jeagerstrasse, Hamburg.
Pulse measurements at the Ernst Lecher Institute.
Dr. Stockmeyer and Dr. Schnappanf, Schünk and Ebe, Heuchelheim, Giessen. Manufacture of carbon brushes.

8. APPENDIX II

The following information concerning valves has been extracted from documents which were evacuated.

SIEMENS RECTIFIERS

Type	Heater Volts	Heater Current	Cathode Heating Direct or Indirect	Mean Current Amps.	Peak Current Amps.	Hold off Voltage	Gas Filling
Ste 350/02/03	3	1.1	D	0.2	0.3	350	Ar
1000/02/03	3	1.1	D	0.2	0.3	1000	Ar
1000/1/1.5	3	4	D	1	1.5	1000	Hg + Ar
1000/2/6	3	11.5	D	2	6	1000	Hg + Ar
3000/5/15	5.2	10	I	5	15	3000	Hg
3000/10/30	5.2	14.5	I	10	30	3000	Hg
1000/10/30	5.2	14.5	I	10	30	1000	Hg + Ar
1000/20/120	5.2	26	I	20	120	1000	Hg + Ar
15000/2/12	5	20	D	2	12	15000	Hg
15000/15/45	5	20	I	15	45	15000	Hg
Mst 1000/2/10	3	16	D	2	10	1000	Xe
1000/5/25	3	31	D	5	25	1000	Xe

Type	Min. Warming up Time	Max. Grid Voltage	Grid Stopper	Volt-drop	Temp. Range	Remarks
Ste 350/02/03	5 secs.	500	10-200K	18	Independent	
1000/02/03	5 "	500	10-200K	18	"	
1000/1/1.5	2 mins.	500	10-200K	15-20		
1000/2/6	4 mins.	500	10-200K	18		
3000/5/15	2 "	500	10-200K	18		
3000/10/30	3 "	500	10-200K	18		
1000/10/30	3 "	500	10-200K	18		
1000/20/120	5 "	500	10-200K	15-20		
15000/2/12	1 "	600	1-20K	15	15-35°C	
15000/15/45	10 "	600	1-20K	15	15-35°C	
Mst 1000/2/10	30 secs.	500	20-100K	15	-60-+100°C	Will operate up to 500 cycles. Min. anode current of 100 m.a. must be taken when heaters are switched on.
1000/5/25	30 "	275	20-35K	15	-60-+100°C	

A.E.G. GRID CONTROLLED RECTIFIERS

		Type SO.3/0.2	Type SO.7/0.2 He
Heater Voltage	(volts)	4	4
Heater Current	(amps.)	1.4	1.9
Max. Anode Voltage	(volts)	300	700
Min. " "	(")	25	
Voltage drop	(")	18	30
Max. Peak current	(M.A.)	250	200
Max. mean current	(")	100	• 100
Max. parallel condenser	(Cms.)	10,000	10,000
Max. mean charging current	(M.A.)	2	2
Max. frequency	(c.p.s.)	20,000	50,000
Max. frequency at 200 volts	(c.p.s.)	4,000	
Heating up time	(mins.)	2	3

Type S7.5/2.5d

Grid controlled high voltage rectifier for general rectifier applications.

Overall dimensions	195 mm. x 59 mm.
Temperature range	35°C to 15°C
Cathode directly heated	
Heater voltage	5 volts
Heater current	10 amps
Warming up time	1 min.
Max. peak anode current	2.5 amps
Voltage drop	10-20 volts
Max. anode voltage	7500 volts
Max. mean rectified current	0.8 amps
Peak control grid voltage	320 volts
" " " current	0.15 amp
Anode firing voltage for zero grid	100 volts

Type SO.8/2 i III

Grid controlled high voltage rectifier.

Overall dimensions	182 mm. x 80 mm.
Temperature range	+ 50°C to - 20°C
Cathode indirectly heated	
Heater Voltage	5 volts
Heater Current	5 amps
Warming up time	5 mins.
Max. peak anode current	2 amps.
Voltage drop	35-45 volts
Max. anode voltage	800 volts
Max. mean rectified current	0.7 amps
Max. control grid voltage	120 volts
" " " current	0.08 amps
Anode firing voltage for zero grid	40-120 volts

Type S1/0.2 i IIA

Grid controlled rare gas filled valve.

Overall dimensions	107 mm. x 45 mm.
Temperature range	+ 50°C to - 20°C
Cathode indirectly heated	
Heater voltage	4 volts .
Heater current	1.9 amps
Warming up time	0.5 min.
Max. peak anode current	0.2 amp
Voltage drop	22-35 volts
Max. anode voltage	1000 volts
Max. mean rectified current	0.07 amp
Max. control grid voltage	80 volts
Max. control grid current	0.01 amp
Anode firing voltage for zero grid	80 volts

Type S1/6 d M

Metal thyratron used for current control.

Overall dimensions	112 mm. x 61 mm.
Temperature range	100°C to -60°C
Heater voltage	3 volts
Heater current	12 amps
Warming up time	0.5 mins.
Max. peak anode current	10 amps
Voltage drop	15 volts (approx.)
Max. anode voltage	1000 volts
Max. mean rectified current	2 amps
Max. control grid voltage	250 volts
" " " current	0.05 amp
Anode firing voltage for zero grid	80 volts
Protective resistance for control grid	10K ohms

Type S1/15 d M

Metal thyratron with rare gas filling, used as a rectifier at low frequencies.

Overall dimensions	195 mm. x 65 mm.
Temperature range	100°C to -50°C
Heater voltage	3 volts
Heater current	30 amps
Warming up time	0.33 min.
Max. peak anode current	15 amps
Voltage drop	25 volts
Max. anode voltage	1000 volts
Max. mean rectified current	5 amps
Max. control grid voltage	250 volts
" " " current	0.1 amps
Anode firing voltage for zero grid	30-80 volts

Type S5/1 i

Grid controlled high voltage rectifier for general rectifier applications.

Overall dimensions	160 mm. x 60 mm.
Temperature range	35°C to 15°C
Cathode indirectly heated	
Heater voltage	4 volts
Heater current	3 amps
Warming up time	1 min.
Max. peak anode current	1 amp
Voltage drop	10-20 volts
Max. anode voltage	5000 volts
Max. mean rectified current	0.35 amps
Peak control grid voltage	320 volts
" " " current	0.06 amps

Type S0.35/0.35 d

Grid controlled rare gas valve (relay).

Overall dimensions	90 mm. x 42 mm.
Temperature range	60°C to -35°C
Cathode directly heated	
Heater voltage	2 volts
Heater current	2.5 amps
Warming up time	0.17 min.
Max. peak anode current	0.350 amp
Voltage drop	7-17 volts
Max. anode voltage	350 volts
Max. mean current	0.1 amp
Peak control grid voltage	80 volts
" " " current	0.02 amp
Anode firing voltage for zero grid	20-40 volts

Type S5/50 i

Grid controlled high voltage rectifier valve for general rectifier applications.

Overall dimensions	380 mm. x 150 mm.
Temperature range	30°C to 15°C
Cathode indirectly heated	
Heater voltage	5 volts
Heater current	20 amps
Warming up time	5 min.
Max. peak anode current	50 amps.
Voltage drop	10-20 volts
Max. anode voltage	5000 volts
Max. mean rectified current	16 amps
Peak control grid voltage	320 volts
" " " current	0.5 amp
Anode firing voltage with zero grid	100 volts

Type S5/100 i

Grid controlled high voltage rectifier valve for general rectifier applications

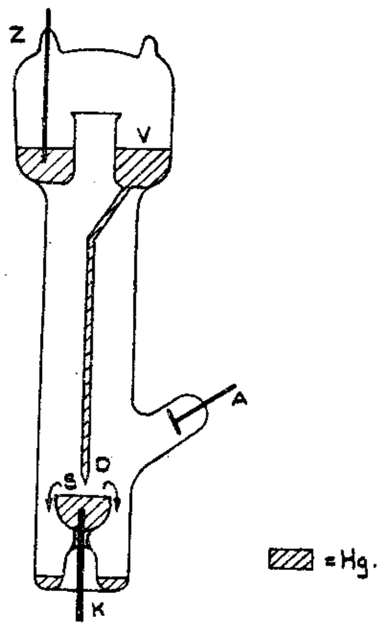
Overall dimensions	491 mm. x 180 mm.
Temperature range	30°C to 15°C
Cathode indirectly heater	
Heater voltage	5 volts
Heater current	36 amps
Warming up time	15 mins.
Max. peak anode current	100 amps
Voltage drop	15 volts
Max. anode voltage	5000 volts
Max. mean rectified current	35 amps
Peak control grid voltage	320 volts
" " " current	1 amp
Anode firing voltage for zero grid	50-120 volts

Type S7.5/0.6 d

Grid controlled high voltage rectifier for general rectifier applications.

Overall dimensions	131 mm. x 62 mm.
Temperature range	35°C to 15°C
Cathode directly heated	
Heater voltage	2.5 volts
Heater current	5 amps
Warming up time	1 min.
Max. peak anode current	0.6 amp
Voltage drop	15 volts
Max. anode voltage	7500 volts
Max. mean rectified current	0.2 amps
Peak control grid voltage	320 volts
" " " current	0.05 amps
Anode firing voltage for zero grid	20-200 volts

IGNITRON WITH A MERCURY JET IGNITER
(From a report by Dr. Maier, Telefunken, Berlin)



The diagram shows a sectional view of an experimental valve. A fine mercury jet, running from the reservoir V through a narrow tube, emerges at the orifice D. The distance that the mercury falls is such that a homogeneous jet S about 5 m.m. long is obtained. The jet S falls into the cathode cup, surplus mercury overflowing and collecting at the bottom. This ensures that the distance from the orifice to the cathode remains constant. The anode A is of graphite and is mounted at the side. The quantity of mercury is sufficient to permit continuous operation for one hour. When all the mercury has run out of the reservoir the valve must be tilted to return the mercury. It was proposed for the mercury to be automatically returned in a later design. For instance the valve could be made so that the mercury was evaporated by special heaters or by waste heat from the valve, and collected in a cooler. The valve was used with the same triggering circuits as normal ignitrons with rod igniters. This ignitron has the advantage that it is not subject to igniter disintegration.

Additional documents evacuated

1. Data sheet giving characteristics and diagram of L.V.20.
2. Report on gate switches by Dr. Karl Siebertz.
3. Diagram of stroboscope thyratron.
4. Diagram of small helium thyratron type TO.35/0.03 d and ignition characteristic.

These and other documents mentioned in this report have been lodged with. Technical Information & Documents unit., Board of Trade, 40. Cadogan Square, London. S.W.1. Applications to inspect these may be made to the above address quoting the following BIOS ref: BIOS/DOCS/2617/3375.