SUMMARY OF MAGNETRON DEVELOPMENT

Origins of the magnetron

The name magnetron was coined at GE Schenectady New York and arose out of the work being done by Albert W. Hull in 1921 on the use of magnetic fields to control the current in a vacuum tube in an attempt to circumvent the triode patents of Lee de Forest. ‘Magnetron’ has been referred to as a “Greco/Schenectady” word.

Hull’s magnetron was a coaxial diode with an axial magnetic field and an early example of such a device was the UV212.

About the same time Zacek in Prague, working on a similar device noted oscillations under certain conditions of anode voltage and magnetic field.

In 1925 a Hull magnetron was found to be capable of generating quite high output at 20 KHz in the dynatron mode.

Also starting in 1924 and continuing into the 1930’s work was done on split anode magnetrons in an attempt to generate higher frequency oscillations. As well as Hull in the USA, Okabe in Japan and Posthumus at Philips in Holland did much more work on these devices. Split anode and multi-segment anode magnetrons were also being developed in the UK by GEC Wembley, SFR in France and Telefunken in Germany.

At Brown Boveri, in Switzerland in the late 1930’s, Dr. Fritz Ludi developed a single cavity resonator magnetron which he called a TURBATOR. This valve was able to generate 15W CW at 15cms and a later version was capable of generating 10KW under pulse conditions.

Whilst the development of split anode and multi-segment anode magnetrons for generating microwave oscillations is a fascinating subject in itself, the purpose of this gathering is to examine the development of Resonant Cavity Magnetrons, RCM’s.

Resonant Cavity Magnetrons

Although it is generally accepted that the high power RCM was developed (invented) by Randall & Boot at Birmingham University in 1940, there were several RCM patents in existence prior to that date.

A.L. Samuel of I.T.T. filed a patent for 2 cavity and 4 cavity RCM's as early as December 1934 and this patent was granted 2 years later. It is not known whether Samuel ever produced any working devices.

Hans Erich Hollmann of Telefunken in Germany filed a patent for a 4 cavity RCM in November 1935 and was subsequently granted US patent No. 2123728 for this device in 1938. Also in Germany there appears to have been another patent for 4 cavity and 8 cavity RCM's filed by Dr. Wilhelm Engbert in November 1938 and granted in July 1942. There also exists a picture of an 8 cm 4 cavity RCM made by Lorenz and dated 1938.

In Leningrad in the USSR during 1936 and 1937 considerable work was done by N.F. Alekseev and D.D. Malairov on 2, 4 and 8 cavity RCM's. This information was first published in the Russian Journal of Technical Physics in April 1940 and was subsequently translated by I.B. Bensen and published in the "Proceedings of the I.R.E." in March 1944.

Their magnetron appears to have been of a demountable design and amongst the data quoted is a claim of a CW output of 300 Watts at 9.0 cms with an efficiency of 20%. Like a lot of Soviet research of the period, nothing much was heard of what was done with the results. A paper to be presented at this conference will shed some more light on this interesting development.

In Japan in 1929, K. Okabe succeeded in generating oscillations at a wavelength of approximately 5.6 cms using a slotted anode magnetron. This success triggered a vast amount of research in the 1930's on magnetrons using a variety of anode shapes and structures. The majority of this work was unknown in the West until a paper given in London in April 1947 by Dr. Nakajima of Japan Radio Corporation. However, in about 1940 this research resulted in the development of the M312 water cooled 4 cavity RCM which generated about 400 Watts at 9.6 cm. Under pulse conditions the output was about 6 KW and the valve was used operationally in the type 22 radar fitted to a few capital ships and submarines. Later during WWII the Japanese produced an "all metal" magnetron, not unlike the UK design, but little is known of its performance.

UK RCM Development

Mark Oliphant's group at Birmingham University was set up in the latter part of 1939 with the main remit of producing a high power generator of centimetre waves which it was known would be required for the creation of effective airborne AI and ASV radar. It is surprising that in view of the amount of RCM information in the public domain that no initial effort was put into evaluating magnetron performance as a means of achieving this objective. Instead most work was concentrated on increasing the power of the klystron which had been invented by the Varian brothers in 1938.

John Randall and Harry Boot joined the Birmingham group several weeks after it was first set up. They had spent some time at the Ventnor long wave (CH) radar station assessing radar systems in general. When they joined the Birmingham group most of the interesting projects had already been allocated and they were given the task of evaluating Barkhausen–Kurz oscillators which they soon concluded would not yield the sort of power levels being sought.

Accordingly they decided to investigate the magnetron approach and constructed their prototype with a 6 resonator copper block anode. John Randall claimed he had no previous magnetron knowledge, although in a letter written in 1984 shortly before his death he acknowledges that they were aware of the magnetron due to the previous work at GEC, Germany and the USA. However Randall's work prior to joining the group had been research into phosphors for fluorescent lamps so his comment in the same letter that the idea of a cavity resonator came to him as a result of reading a copy of an English translation of Hertz's "Electric Waves" seems entirely believable.

Due to the lack of equipment at Birmingham, before the prototype magnetron could be tested the team had to make their own high voltage rectifiers, borrow a high voltage transformer from the Admiralty and make use of an old Biot electromagnet to provide the magnetic field. Finally on the 21st February 1940 all was ready and the prototype magnetron was powered up for the first time whilst still "on the pump".

They were surprised to see streams of high frequency radiation emitted from the output probe and successively higher powered car headlamp bulbs were being burnt out when connected as a load. They had difficulty in believing the RF output was in the microwave region. The next day the wavelength was measured using Lecher wires and the wavelength was found to be 9.8 cms and the power output estimated at 400 Watts CW.

The significant difference between the Randall & Boot RCM and those previously patented was that all the others (barring perhaps the Russian one) had their anode system inside a glass envelope containing a vacuum whereas the Birmingham valve had its vacuum system inside the anode structure. Not only did this allow for much more efficient cooling of the anode system and therefore higher dissipation, but in general it allowed for a smaller air gap in the magnetic path.

The Birmingham prototype was passed to E.C.S. Megaw's group at GEC Wembley and they very soon produced a pre-production design the E1188. This device still had a filamentary cathode and was therefore not ideal for pulse operation.

About this time (May 1940) some examples of the French M16 16 cms multi-segment anode magnetron, which had been developed for the collision avoidance radar fitted to the liner Normandie, were brought to Wembley by M. Maurice Ponte of SFR. One of these M16 had an indirectly heated oxide coated cathode and this was incorporated within a revised E1188 design and designated E1189.

The initial samples of the E1189 still used the 6 resonator anode block which had been drilled using the chamber of a Colt revolver as the drilling jig. However examples No. 11 and 12 had the number of resonators increased to 8 in order to maximise the efficiency of the valve with the magnetic field provided by the then available permanent magnet, E1189 also incorporated cooling fins to enable the device to be air rather than water cooled. Sample No.12 was taken to the USA by E. Bowen with the Tizard mission and upon testing at Bell Labs produced 10 times the power at 5 times the frequency of the best performing American triodes. A certain amount of confusion arose as the drawings taken by Bowen still showed the 6 resonator anode but an X-Ray picture taken at Bell Labs revealed the presence of 8 resonators.

The E1189 or its Navy equivalent NT98 was used in the Naval radar type 271 which was the Allies first operational centimetric radar.

The early RCM's like the E1189 were prone to mode jumping (frequency instability) under pulse conditions and the problem was solved in by means of strapping together alternate segments a process invented by Sayers in 1942. Strapping also considerably increased the magnetron's efficiency.

German RCM development during WWII

In spite of the amount of RCM data in the public domain at the outset of WWII, the Allies were extremely worried about the possibility of UK designed RCM falling into German hands. It was not until 1943 that aircraft fitted with magnetron powered radar were permitted to fly over enemy territory.

In February 1943 a Stirling bomber carrying magnetron powered 10 cms H2S equipment crashed near Rotterdam and the Germans acquired a virtually complete H2S system, which they named the 'Rotterdam Gerat'. They were amazed at the progress that had been made by Allied radar, especially the RCM, which is somewhat surprising in view of their own experience with RCM's.

They went on to develop the LMS10 which was an almost exact copy of the CV64 used in the Rotterdam Gerat and subsequently went on to develop a 5 cm slot resonator magnetron type LMS11.

Fortunately for the Allies the capture of the centimetric radar secrets by the Germans came too late to have any significant effect on the outcome of the war.

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