The development of E.1189 eight-cavity magnetron at GEC

All the sources on the story of multi-cavity magnetron actually talk of the six-cavity one, from the Boot and Randall early prototype, first operated in February 1940, to the E.1188 sealed-off design made at GEC by Megaw. Soon later E.1188 evolved in the two air-cooled E.1189 variants, No. 1 with spiral-wound filament and No. 2 with oxide-coated cathode, suitable for high-power pulsed operation. Peak power pulses in the order of 1 kW were obtained since the end of June 1940 at about 1040 oersted, the field of a standard 6 lb permanent magnet. Within a couple of weeks, power pulses in excess of 10 kW had been reached, increasing the field to about 1400 oersted in the pole pieces of an electromagnet. The design was only partially successful. The six-cavity magnetron with oxide-coated cathode was an outstanding source of 10 cm waves at that time, but it could never operate efficiently in a permanent magnet. Likely Megaw realized right away that the design had to be re-calculated for eight-cavity. From those early days of July, all sources are silent on the eight-slot design, until it suddenly appears about three months later, when the E.1189 No.12 is X-rayed in America. Where that 8-cavity sample sprung from? Not a word even by Megaw himself.

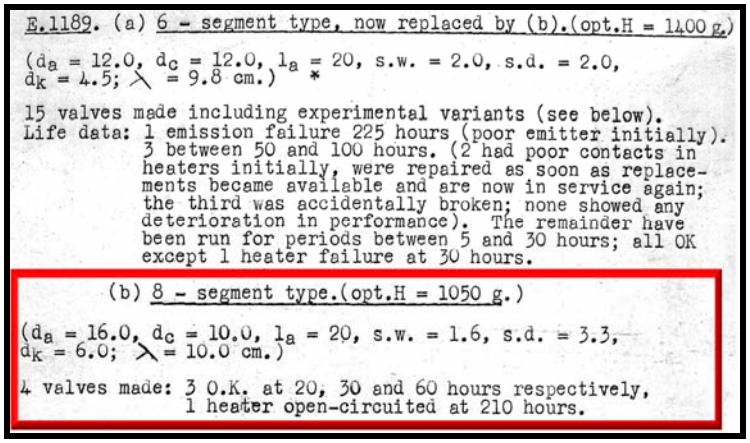
Bowen tells that on 7 August he attended the briefing on the magnetron construction before being allowed to select the best sample out of a batch of E.1189 units, tested by Megaw himself. He was briefed on the six-cavity design, since he was not aware of eight-cavity variants until 7 October, when his sample was X-rayed at Bell. Bowen tells of his phone call to Megaw 'At first he was vague, and disbelieving - he was obviously as puzzled as I was.'. Then Bowen tells what he was led to believe, that is the No.12 sample was just an odd experimental unit, built in the same batch of the six-cavity ones and that just by chance had performed on the test jig better than the others. This is not true. Fisk in his article (5) tells that the magnetron was operated at about 1100 gauss, giving pulses in excess of 15 kW. The experiment at Bell was arranged with the right parameters for the eight-slot: somewhere, likely on the test label of that unit, operating values were then correctly indicated. What really happened before Bowen left GEC with his precious luggage?

Paterson in his diary reports: '**6 August - A crowd of visitors at GEC, including Oliphant, Randall and Ellis. The Megaw's improved 10 cm magnetron with eight chambers appears up to expectations'.** In other words, the eight-slot review, still experimental until that morning, had been approved to replace the six-slot design. After the meeting only Megaw was aware that the sample No.12 was eight-slot: GEC employees had access to production documents of the six-slot E.1189. Likely that morning of August 7 Megaw was too relaxed to think of warning his employees and even Bowen that the No.12 was built to the latest design review, still in process to be filed. Due to a small lapse, on 7 August Bowen was briefed on the six-slot magnetron and later, on 11 August, he was given blueprints and production details of the six-slot design with a sample of the latest eight-slot E.1189.

The story told so far does not help to understand where the eight-slot design came from. The recent accidental finding of an E.1189 prototype, likely coming from a British Marconi warehouse, sheds new light on what really happened at GEC in the days before August 6.

Fig.1 - E.1189 eight-slot prototype recently found. Believed to be the very early of the four samples listed by Megaw in his secret report and built at GEC in the Summer 1940. First operated around 30 July.

Carefully reading today the available documents, the whole story becomes clear. It tells of a true miracle performed by Megaw and his team, designing the new eight-slot magnetron and then manufacturing, testing and characterizing a couple of laboratory prototypes, while assembling two complete units, all in about a couple of weeks. The Megaw's internal report on developmental magnetrons dated 11 October (*2) lists four units made of E.1189, 8-segment type, 1050 gauss. Three were still good after respectively 20, 30 and 60 hours of operation. The fourth unit worked for 210 hours, until opening of its heater. Official story tells that the E.1189 No.12 was the very first eight-slot experimental magnetron made at GEC, hence these samples were hastily assumed as built sometime later for unknown reasons. Actually Megaw in his 1946 paper (*4) writes of two sealed samples, No.12 and 13, performance curves being reported for the last one.


E.1189. (a) 6 - segment type, now replaced by (b).(opt.H = 1400 g.)

(d_a = 12.0, d_c = 12.0, l_a = 20, s.w. = 2.0, s.d. = 2.0, d_k = 4.5; λ = 9.8 cm.) *

15 valves made including experimental variants (see below).
Life data: 1 emission failure 225 hours (poor emitter initially). 3 between 50 and 100 hours. (2 had poor contacts in heaters initially, were repaired as soon as replacements became available and are now in service again; the third was accidentally broken; none showed any deterioration in performance). The remainder have been run for periods between 5 and 30 hours; all OK except 1 heater failure at 30 hours.

(b) 8 - segment type.(opt.H = 1050 g.)

(d_a = 16.0, d_c = 10.0, l_a = 20, s.w. = 1.6, s.d. = 3.3, d_k = 6.0; λ = 10.0 cm.)

4 valves made: 3 O.K. at 20, 30 and 60 hours respectively, 1 heater open-circuited at 210 hours.

Fig. 2 - Samples of E.1189 built at the date of 11 October 1940, from the Megaw's secret internal report.

Moving to our E.1189 prototype, we note that it does not have usual finish, finned radiator, black paint and gold-sealed caps, as it was assembled in a hurry. The GEC experimental code 1189 is punched on the copper anode. There are traces of sealing grease into the anode cylinder, as the unit was continuously pumped in a laboratory test jig. It also shows a marker writing containing '210HR'. Cathode oxide shows signs of heavy usage and one heater end is broken near the welding to its end baffle. Few doubts it is just the fourth eight-slot E.1189 listed by Megaw.

Now let us observe the close relation between some key dates of the Tizard Mission and the development of the magnetron at GEC. On 8 July, few days that after the successful tests on the second E.1189 sample, Lord Lothian, British ambassador in Washington, submits a direct appeal to Roosevelt: 'The British Government have informed me ... that they would greatly appreciate an immediate and general interchange of secret technical information with the United States, particularly in the ultra short wave radio field. ...'. London was ready to send a small group of British military officers and civilian scientists to the United States 'to give you the full details of any equipment or devices in which you are interested without in any way pressing you beforehand to give specific undertakings on your side". The appeal concluded 'for our part, we are probably more anxious to be permitted to employ the full resources of the radio industry in this country [the United States] with a view to obtaining the greatest power possible for the emission of ultra short waves than anything else.' On 11 July Roosevelt accepted the British proposal. Likely the encouraging tests on E.1189 had given the green light to the mission that Tizard was planning for a long time. From the acceptance of the British proposal, everything had to be carefully prepared to send a working sample of magnetron to America. It was the most valuable secret that the British could offer to gain the unconditional help of America, the very purpose of the mission itself.

New samples were to be made since, according to Megaw, the E.1189 sample No.2 had been stressed up to flashing arcs during tests. The Paterson's diary reports that in the meeting with CVD on 17 July the discussion dealt with a new '**air-cooled low field magnetron**', obviously the eight-slot one, followed by '**General demand for specimens**'. Eight-slot magnetron could be the best

microwave source if ready; in the meanwhile the six-slot type was an acceptable compromise. In that meeting the decision was taken of building a small batch of the 6-cavity E.1198 for the most urgent needs, including the Tizard Mission, while trying the venture with the 8-cavity variant proposed by Megaw. The sample that Bowen was to bring to America had to be produced in volume there, as it really was with REL 3D. Then the plan of Megaw looks obvious. He launched a rush production of four eight-slot anode blocks and matched cathode subassemblies. Two samples were partially assembled in a hurry, no radiator, no end caps, and operated on the bench as soon as each of them was ready. In the meanwhile two complete units were being assembled, so to be ready for the test bench shortly before August 6. Looking at the worked time of the three still good, 20, 30 and 60 hours, we must assume that tests were interrupted all together at a given date. Assuming they were left running about 10 hours per day and tests were all interrupted in the presence of Oliphant, Randall and Ellis towards the end of August 6, we can conclude that each unit started working approximately on 5, 4 and 1 August, respectively. Likely the last two units, operated for 30 and 20 hours, were the E.1189 No 12, brought to America by Bowen, and No. 13. The fourth sample, also used in the endurance test until opening of the heater, certainly was the first unit to operate while continuously pumped, just completed with anode block and cathode subassembly. We can assume that it started oscillating since July 30, or 31 at worst, so giving Megaw the full confidence in the design while other units, including the No.12, were in process to be assembled.

The recent discovery of the E.1189 prototype, jointly with the Megaw's internal report, his 1946 paper on the magnetron development and the diary of Sir Paterson contributed to clarify the story of the British eight-cavity magnetron development. It was not the result of mistakes, confusion and lucky coincidences. On the contrary, as other British achievements, it was the result of carefully planned and coordinated work of a brilliant person, Megaw, and his team. They succeeded in a true miracle, designing, building, testing and fully characterizing the new magnetron in a couple of weeks or so, while manufacturing a backup batch of the previous type.

Development steps at GEC of the eight-cavity E.1189 magnetron	
29 June 1940	Six-cavity E.1189 No.1 and soon later the No.2, with oxide-coated cathode, start operating at about 1000 oersted, giving 1 kW pulses. In a few days, using an electro-magnet to increase the field to 1400 oersted, output power will raise to more than 10 kW.
8 July	The Tizard Mission starts officially, based upon the early successful operation of the E.1189 No.2. Three days later America accepts the British proposal. Likely at that date Megaw had already realized that the design had to be changed to eight-cavity.
17 July	Paterson writes that in a meeting with CVD, part of the discussion deals with the 'Megaw's air-cooled low field magnetron'. There is a 'general demand for specimens'. This is the official start for Megaw to launch his eight-cavity design review of the E.1189.
30 July	Likely the first prototype of the eight-slot E.1189 starts operating while continuously pumped.
1 August	The second eight-slot laboratory prototype starts operating around this date.
4 August	The third eight-slot E.1189 is sealed and starts running on the test bench. It is the No.12.
5 August	The fourth unit of the four listed by Megaw, the E.1189 No.13, starts running.
6 August	From the Paterson's diary: 'A crowd of visitors at GEC, including Oliphant, Randall and Ellis. The Megaw's improved 10 cm magnetron with eight chambers appears up to expectations'. Sir Paterson takes the picture of the official approval of the eight-slot E.1189 review, based upon the successful tests on the four samples. Tests are stopped all together once the decision is taken.
7 August	Bowen is briefed on the construction details of the six-slot E.1189. Then he is allowed to select the best performing sample in a batch tested by Megaw. It is the No.12. Megaw forgot to warn the briefer and the same Bowen that the sample is eight-slot. Likely he was too busy arranging further tests on his latest magnetron, the endurance test on the very early eight-slot prototype and the complete performance characterization on the sample No. 13.
11 August	Bowen is again at GEC to pick his sample and the envelope with the blueprints of the E.1189. The No.12 leaves GEC and begins its travel to America.

References

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5. **The Magnetron as Generator of Centimeter Waves, Fisk et al, BSTJ April 1949**
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