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# The development of the British cavity magnetron and the role of E.C.S. Megaw at GEC

Abstract

The cavity magnetron was essential to build microwave radar sets during WWII. Historical sources agree attributing its conception to Randall and Boot at the Birmingham University. Unfortunately, none worried to explain the substantial differences between the Birmingham prototype, a six-cavity CW device, and the pulse eight-cavity E1189 brought to America by the Tizard Mission. The recent acquisition of the very early eight-cavity prototype, used by E.C.S. Megaw for test purposes at the GEC Research Laboratories in Wembley, made it possible to reconstruct the entire development of the British magnetron and the primary role he played. In a few weeks he managed to find in his E1189 magnetron the perfect synthesis between the structure devised by Randall and Boot and the most advanced solutions then available in England and worldwide.

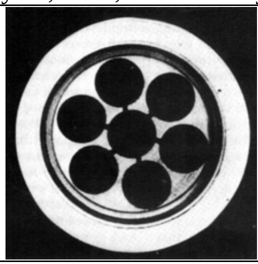
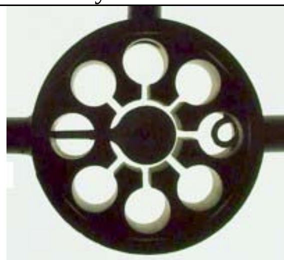
Il magnetron a cavità fu essenziale per costruire radar a microonde durante la seconda guerra mondiale. Le fonti storiche concordano nell'attribuirne la paternità a Randall e Boot dell'Università di Birmingham. Sfortunatamente, nessuno ha mai spiegato le differenze sostanziali tra il prototipo di Birmingham, un dispositivo CW a sei cavità, e l'E1189 ad otto cavità per funzionamento ad impulsi, portato in America dalla missione Tizard. La recente acquisizione del primo prototipo a otto cavità, usato da E.C.S. Megaw a scopo di test presso i Laboratori di Ricerca GEC di Wembley, ha permesso di ricostruire l'intero sviluppo del magnetron a cavità e il ruolo primario da lui svolto. In breve tempo egli riuscì a trovare nel suo magnetron E1189 la perfetta sintesi tra la struttura proposta da Randall e Boot e le soluzioni più avanzate disponibili allora in Inghilterra e nel mondo intero.

***Fig. 1 - This GEC 1189 C328 is the very early eight-cavity laboratory prototype, recently found and today preserved in the ase-museoedelpro collection. [*TM-01]***

Historical sources agree on attributing the cavity magnetron to Randall and Boot, two researchers at the University of Birmingham. A team led by Professor Oliphant, for the transmitter of a 10 cm radar or RDF system, was working on a klystron, the new vacuum tube devised at the Stanford University by the Varian brothers and based upon the cavity resonators theorized by Hansen. Due to the difficulties in obtaining linear electron beams dense enough to handle the required power, the two researchers were asked to integrate cavity resonators into a different structure (*11). The prototype conceived by Randall and Boot was not new for using cavities (*9), rather because the resonator copper block was at the same time the outer envelope, dramatically improving heat transfer to the outside. It started to oscillate on February 21, 1940, generating bursts of 400 W at 9.8 cm, about ten times the power obtainable then with Oliphant's klystrons. It was a water-cooled six-cavity magnetron, wax-sealed and operated in the field generated by a big 5-inch gap electromagnet. On April 10, Eric Megaw from GEC met Randall and Boot and proposed some solutions for sealing the device with thin end caps, so as to operate in a shorter air gap. On May 1st Randall, delegated by Oliphant, commissioned the GEC Research Center to build three evacuated prototypes: the GEC E1188 design led to the delivery of three samples on May 16, 1940. The resonators were provided by Birmingham and the tubes, which had no further follow-up, could operate into an air gap of ‘only’ 7 cm. So far the stories told by Callick (*1), Megaw (*15), the same Randall (*16) and others (*9,*11, *12).

We know that the magnetron brought to America by the Tizard Mission, the GEC E1189 No. 12, was remarkably different from the E1188. Until now it was seen as an evolution of the Birmingham prototype, if not the result of lucky coincidences during empirical experiments made by Megaw on his own initiative. Such reconstructions contrast with the information given by Callick, that the first samples of E1189 were tested on the bench as early as June 29, 1940, even on June

28 according to Paterson (*3), while the E1188 samples, delivered by GEC in May, were tested only in July. Birmingham would never have deliberated on variations before testing samples made to its own design.

| **GEC code** | **E1188** (Birmingham, sealed) | **E1189, revision C** (Megaw) |
|---|---|---|
| | | |
| Type | Continuous wave, 9,8 cm | Pulse, 9,8 cm |
| Anode | Six-cavity, Randall's design | Eight-cavity, Megaw's design |
| Magnet gap | 70 mm | 37,5 mm |
| Cooling | Water | Air |
| Cathode | Filamentary, tungsten | Oxide, indirect heating |
| Out power | 400 W at about 1.000 Oersted | 15 kW pulses at 1.050 Oersted |
| Samples | May 16, 1940, tested in July | 28 or 29 July 1940 |
| Resonating system (*16), [TM-01] |  |  |

***- Comparison between the Birmingham and the Megaw's magnetrons***

We know that the six-cavity E1189 prototype No. 1 had a thoriated tungsten filament, while the No. had 2 an oxide-coated cathode. All reconstructions then jump to the eight-cavity No. 12, the one brought to America by Bowen (*6). Nobody wonders when and where that variant came out and how many units were assembled. Stories of its appearance usually refer to the narration of the Tizard Mission left by Edward G. Bowen, who was directly involved in the development of airborne radar. In 'Radar Days' (*2) he exposes in a smooth and elegant way what happened on 7 October 1940, when the E1189 that he himself had picked up two months earlier at GEC was x-rayed at Bell, unveiling its eight-cavity internal structure. The accident aroused astonishment and suspicions, since documentation and drawings all referred to a six-cavity device. Bowen tells of his phone call to Megaw in England and of the confused reactions to the other end of the phone. He adds details about quantities and structures of the GEC prototypes, which were repeated by subsequent authors. But his book was written half a century after facts covered by utmost secrecy. Parts of his tale probably came from faded memories of people just hearing about the magnetron at GEC. The image one gets from reading is that no one knew how that experimental prototype ended up in America and that Bell finally decided to make copies of it, only due to the lucky circumstance of having seen that sample working fine on the bench. The confusion picture that emerges from Bowen's memories was viewed by some as a proof that his reconstruction was accurate. In fact, the dramatic 'Battle of Britain' took place in the summer of 1940, with a frantic English race for deploying every resource and every countermeasure, even if still experimental and untested.

For details on the magnetron development until 1940, readers can refer to the many publications on the subject (*9, *11). We will remember here that Eric Megaw was designing high frequency vacuum tubes at the GEC, Hirst Research Center in Wembley, since the early thirties. In 1933 he published an article on magnetrons in the Journal of the Institution of Electrical Engineers. In 1935 he had a dispute with Philips' Posthumus in a letter to Nature on extending the rotating cloud theory to the split-anode magnetron. He designed commercial and experimental magnetrons, as those in Fig. 2. He investigated the back-bombardment phenomenon, explaining how its emission could keep the tube oscillating, reducing or even removing the filament supply. In 1937, for an Admiralty secure communications system, Megaw developed the E880 four-segment magnetron, with thoriated-tungsten filament (*12), [*11]. We also know that he was personal friend of Henri Gutton of the SFR. In June 1939 in Paris they discussed the new SFR M16 magnetron, with oxide cathode. In May 1940 Maurice Ponte brought to him two M16 samples and their behavior on the test bench influenced the design of the second E1189 prototype, modified to accommodate the high emission oxide cathode (*1, *9).

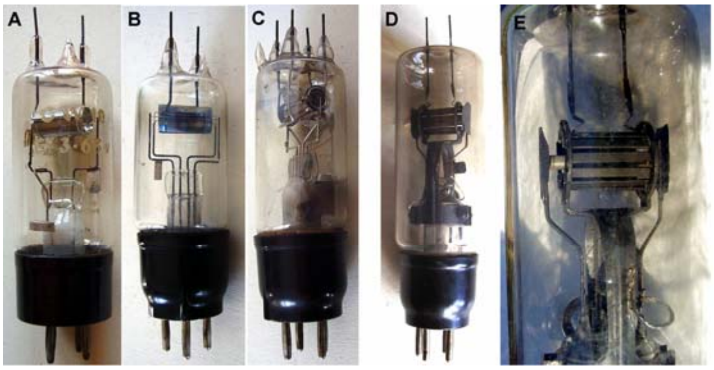



***Fig. 2 - Some Megaw's magnetrons. A) The CW10 split-anode, 1935-1936. B) A gridded experimental magnetron for investigatin direct modulation. C) A laboratory prototype of the E880/NT75 used in the early GEC ship-to-ship UHF communication system.. D and E) Two images of one of the CSF 12-segment samples specially adapted by Henri Gutton for Megaw and carried to him by Maurice Ponte on 9 May 1940.***

In November 1939, while Randall and Boot were designing their magnetron, GEC was working on a 25 cm AI prototype cm for the Air Ministry. Megaw with Coales of the H.M. Signal School obtainrd pulses in excess of 1 kW from the E881 four-segment CW power magnetron with thoriated-tungsten emitter. Few months later Megaw was asked to examine the prototype of his former colleague Randall (*11).

## The very early prototype of the GEC eight-cavity E1189, revision C

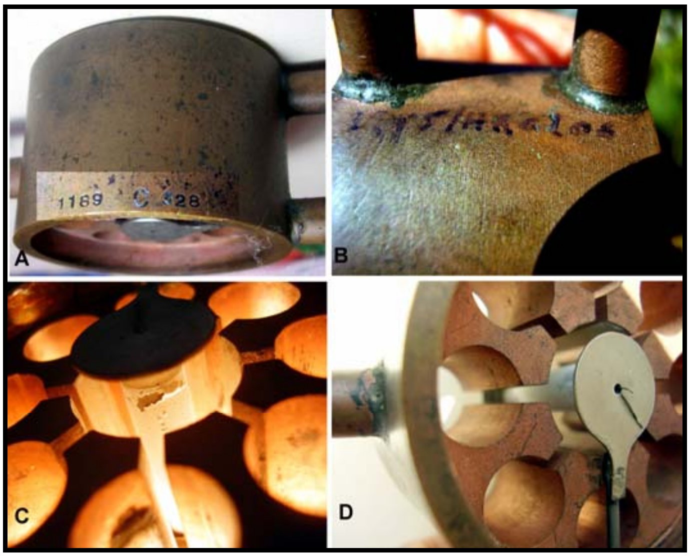



***Fig. 3 - Close-up views of our sample. A) The code 1189 C 328 is punched on the copper body. B) Characters HR210 are in the felt-tip writing. C) The partially detached oxide layer denotes heavy overloads or arcing. D) Heater wire is broken close to the welding to the end baffle. The oxide layer is very thin, so to expose the bare nickel surface.***

Our prototype was accidentally found in the UK in 2017. The presence of a small copper tube, soldered to the outer wall orthogonally to the filament spacers and to the coaxial output, was definitely unusual. The code 1189 C 328 was punched close to the edge. Except for the absence of the finned radiator and for the presence of the lateral copper tube, its design recalled that of the GEC E1189 given by Callick. On the outer wall some handwritten characters could be read, '... / HR210'. The oxide layer was somewhere thinned and elsewhere swollen or even peeled off, as if the device had been operated for a long while, even under extreme overloads and arcing. One end of the filament was broken at the welding to the end baffle. Traces of grease in the inner edges led to believe that the tube had been operated with removable caps, while connected to the vacuum pump. The lateral copper tube recalled the peephole encountered in literature to measure the cathode temperature of experimental power magnetrons, such as the LCW type described by Collins (*5). Back-bombardment raises the cathode temperature, hence its effect must be monitored and counteracted, reducing or even removing the filament voltage.

SECRET.

Not for circulation.

RESEARCH LABORATORIES OF THE GENERAL ELECTRIC COMPANY, LTD.

11th October, 1940.

Notes on Magnetron development programme (I).

E.Megaw.

1. Data on standard types.

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; $\lambda$ = 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; $\lambda$ = 10.0 cm.)

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

***Fig. 4 - Extract of the Megaw's internal report listing four eight-cavity E1189 made by 11 October, one failed with heater open after 210 hours (*14). The integral document also shows the many types investigated in about three months, from the end of June.***

Many signs indicated that the prototype had been used in the laboratory for severe tests, until the heater failure. To find out more, we started examining carefully the available documents of the time. Very relevant was the internal report of fig. 4, left by Megaw himself on the development of the early cavity magnetrons. It lists four eight-segment units, 'opt. H = 1050 g.'. <u>One of them had just operated 210 hours, before opening of the filament</u>. The document seems to contradict another paper written by Megaw in 1946 (*15), which only mentions two eight-cavity units, the No. 12 and the No. 13. The inconsistency could be explained, assuming that the second paper listed only the tubes completed with radiator, sealed and serialized. As said before, our prototype was never finished. It was clearly set up to operate only in the laboratory, continuously connected to the vacuum pump.

The diary of Sir Clifford Paterson (*3), at the time director of the Wembley Research Center, briefly provides us with facts and dates relating to the development of the magnetron at GEC and to its eight-cavity variant.

*May 1st*[86]

Randall from Birmingham came instead of Oliphant to get us to start quickly with replicas of three large magnetrons which Megaw thinks well of. Had to speak straight to Randall for Oliphant is an impatient person and expects first priority which we could not give him. I think Birmingham must have the main responsibility for the tubes or they will never be happy.

*June 28th*[104-105]

Randall coming on Friday re. high power magnetron. Megaw and Boyland have been making splendid progress with these. There are two types—Randall's and Megaw's—the former water-cooled and the latter air-cooled. At the moment Megaw's is on circuit and giving some 2 kW at the desired wavelength—but Randall's will follow in the next few days. Boyland's gold wire joint seems to be one of the chief features giving the striking success.

*July 1st*

Output from Megaw's 10 cm magnetron has risen to 4 or 5 kw and is still rising.

*July 17th*

The whole day at our two-monthly CVD meeting. A rather memorable occasion for we recorded (*a*) beam valve amplification at 50 cm, (*b*) Megaw's air-cooled low field magnetron, (*c*) Ramsay's mercury modulator, (*d*) two velocity modulation receiving tubes—one with resonator for 10 cm. General demand for specimens.

*August 6th*[113-114]

A crowd of people here from many establishments including Oliphant and Randall and Ellis. It is difficult for people to get on with urgent work when visitors are so frequent but it cannot be helped. Megaw's improved 10 cm magnetron with eight chambers appears up to expectations. Randall with Duke's assistance (we introduced him to Oliphant) has made a good copy of the air-cooled magnetron for 5 cm.

*August 7th*[115]

Schoenberg, Blumlein, Condliffe and Broadway with Bowen came for a thorough discussion of AI. It took a whole morning and until 3 o'clock. The general exchange of views and experience was helpful and the atmosphere of co-operation most encouraging.

***Fig. 5 - From the diary we learn that 'Megaw thinks well' of Randall's solution. As of June 28, there were two projects, one by Randall and another by Megaw. On August 6, the eight-cavity magnetron was shown to visitors, including Oliphant, Randall and Ellis. Randall and Duke, who had moved from GEC to Birmingham, had made a copy of the Megaw's design for 5 cm. On 7 August Bowen was in Wembley tobe briefed on the 10 cm AI. At the end he was allowed to pick out the best performing unit from a batch of E1189 previously tested by Megaw (*2): it was the No. 12.***

The chronology left by Paterson, along with what Megaw and other sources wrote, helps us date the key steps in the development of the E1189.

| **Summary of development phases of the E1189 magnetron** | |
|---|---|
| 10 April 1940 | Megaw is shown the Randall and Boot's prototype. |
| 1 May 1940 | The E1188 project starts, with resonators supplied by Birmingham. Soon later the E1189 low-profile project by Megaw takes off. |
| 9 May 1940 | Maurice Ponte of CSF brings two M16s with oxide-coated cathode to Megaw. After performance check, Megaw re-designs its second E1189. |
| 28 or 29 June 1940 | The two six-cavity E1189s start to operate, generating 1 kW pulses. In a few days the peak output power of the No. 2 rises to over 10 kW. |
| 8 July 1940 | The Tizard Mission is officially underway (*6). Almost certainly at that date Megaw had already decided to design the eight-cavity variant, to operate efficiently in the low magnetic field of a 6 lbs permanent magnet. |
| 17 July 1940 | At GEC the CVD committee discusses ***'the low-field Megaw magnetron'***. Samples of six and, whenever ready, of eight-cavity are then requested. |
| 31 July 1940 | Probably around this date the first eight-cavity E1189 - our sample - starts oscillating, continuously connected to the vacuum pump. |
| 1 August 1940 | Based on the worked hours, the second prototype starts oscillating. |
| 4 - 5 August | The two finished E1189s, No. 12 and 13, start running on the bench. |
| 6 August 1940 | ***'The Megaw's improved 10 cm magnetron with eight chambers appears up to expectations'***. It is the approval of the new eight-cavity design by that crowd of officials, including Oliphant, Ellis and Randall. The first prototype will continue an endurance test until the filament opens. |

| | |
|---|---|
| 7 August 1940 | Bowen and the key people involved in the 10cm AI radar discuss the details. At the end Bowen, chosen for the Tizard Mission, will select the best performing sample from the batch of E1189 previously tested by Megaw: it is the eight-cavity no. 12. The magnetron and the folder with the production documents of the six-cavity, the one approved until the day before, will be kept in the safe at the GEC until August 11, when Bowen is back to Wembley to pick them up. (*2) |
| 6 October 1940 | The E1189 No. 12 is powered at the Bell Laboratories in Whippany, generating 15 kW pulses in a field of 1100 gauss. The sample and drawings of the six-cavity type are left at Bell, who is asked for a small lot of evaluation and qualification copies. (*2, *4, *6) |
| 7, 8 October | X-ray of magnetron No. 12 unveils its eight-cavity structure. Bowen is recalled to Whippany. He phones Megaw, who appears puzzled: but that project had ended two months before and the perplexity felt by Bowen at the other end of the phone seems quite justifiable! |

The emerging picture shows the Megaw’s fundamental role in designing the cavity magnetron, the basic component of the microwave radar. Randall certainly devised a brilliant solution for a powerful generator, but his device was similar in performance to other contemporary types, even outclassed by the CSF M16. Possibly it would have just remained a laboratory curiosity without Megaw's contribution. In fact the now useless E1188 samples will be tested only in July, just a formal closure of the order. On the contrary, the E1189 project, attributed to Megaw by Paterson, best integrated Randall's solution with the emission capacity of the oxide cathode before tested by Gutton. The result was then perfected, recalculating in a very short time the geometries for eight-cavity, to increase its efficiency in the reduced field of a permanent magnet. Contrary to what is commonly believed, after Megaw's visit to Birmingham and the subsequent move to that site of the technologist Duke, the transfer of know-how was activated in the opposite direction, from GEC to Randall and Boot, allowing them to readily prepare a 5 cm copy of the Megaw’s E1189 (*3). It is evident that the eight-cavity low-field variant was authorized in the CVD meeting on 17 July. The whole project review was therefore carried out in a couple of weeks, relying upon the already tested six-cavity if it failed. Anyway our sample proves that the steps necessary to its characterization were all carried out. Then we understand the full meaning of the words written by Megaw in 1946 (*15) and the presence in our sample of the lateral copper tube, certainly what remains of a peephole to measure the cathode temperature with a pyrometer. He pointed out how he had roughly estimated its value on the second six-cavity sample, by measuring the resistance of the filament. Unfortunately, the new geometry had never been tried before and, furthermore, its cathode was indirectly heated. Megaw necessarily had to use pyrometric methods to accurately characterize his new tube.

The two valves were completed together and outputs of the order of 1 kW peak at 5–40 microsec, 50 pulses/sec, were initially obtained from both, using 1 000–1 100 oersted permanent magnets (29th June, 1940). The output at 6 microsec was independent of heater voltage down to zero with the oxide-cathode sample, and its success was regarded as completely established. An early mercury-vapour triode (E1191) modulator was used. The wavelength was near 9·8 cm for both valves. Within a fortnight peak outputs of about 10 kW had been measured in a water load with an input of about 8 kV, 8 A, 30 microsec, 50 pulses/sec; the field of about 1 400 oersteds was provided by an electromagnet. With higher inputs, powers estimated at over 15 kW were obtained, but with the large pulse length used persistent flash arcs occurred at this output. The cathode bombardment power was estimated by heater resistance change in No. 2 at 5–10% of the mean input, increasing appreciably as the load coupling was reduced. This agreed with some earlier measurements on glass magnetrons. Measurements of frequency variation with operating conditions were also made with encouraging results.

Eric Megaw, 1946

In our reconstruction there were still doubts about the fourth prototype listed by Megaw. Even this one was found: the image of figure 6 shows the second 1189 C328 prototype, absolutely identical to our sample. It comes from a page of an old GEC website, highlighting the products introduced in about one hundred years of activity. Then we have the two laboratory prototypes plus the two samples listed in the 1946 Megaw's paper, complete with radiator and caps and serialized as No. 12 and No. 13. According to Trevor Wright, who hosts the old GEC website, the second sample was preserved in the collection at the Marconi Research Center in Chelmsford [*P09]. Our sample comes from the today dispersed collection of the late Rodney Burman who anyway was not aware of its historic relevance.


***Fig. 6 - Cutout of the GEC page created around the early eighties about their cavity magnetron. It shows the eight cavities sample number 2, identical to our sample, so confirming our reconstruction [*P09].***

The fundamental role of Megaw in the development of the cavity magnetron is then evident. The story that emerges, even if less romantic than the one left by Bowen, shows him as the most experienced figure on the subject who, even thanks to the unlimited support of GEC, will transform the Randall and Boot's successful experiment into a readily usable powerful microwave generator, soon reproduced in hundreds of thousands copies and variants. It should be added that the E1189 No. 12, although made in great haste, was the result of careful planning and in-depth testing, when it began its journey to America in the Bowen's luggage.

Most likely the accompanying papers had been prepared in advance with drawings of the six-cavity E1189, the one approved until the evening of August 6. When the next day Bowen picked up the No. 12, the blueprints locked into a safe were not updated. But certainly the documentation handling was not in charge of Megaw.

**Subsequent developments of E1189 during the war**

For evaluation purposes, from November 1940 Bell hastily built a few copies with its developmental code 1259M, largely for the National Defense Research Committee (NDRC) and other research laboratories. A sample is preserved today in the collection at University of Birmingham. About sixty more copies were built in 1941 under the code D-160052 by the subsidiary Western Electric, which also put into production its own 25 kW peak variants, as **706A** to **706C** [*TM-ix].

The units manufactured in England from 1941 came with simpler four-fin radiator. Type E1189 was approved for naval use as NT98. In Canada the same tube was produced, as REL Type 3D, by the Bell related Northern Electric Co. It was used in the RX/C naval system and in the GL3C wheeled trailer (*7). There was also an Australian production, as NTA98, by Australian Standard Telephones and Cables, also related to Bell. A 9.1 cm variant, the E1198, was approved as CV38 for the Air Ministry. It was also manufactured in Canada as REL 3C.

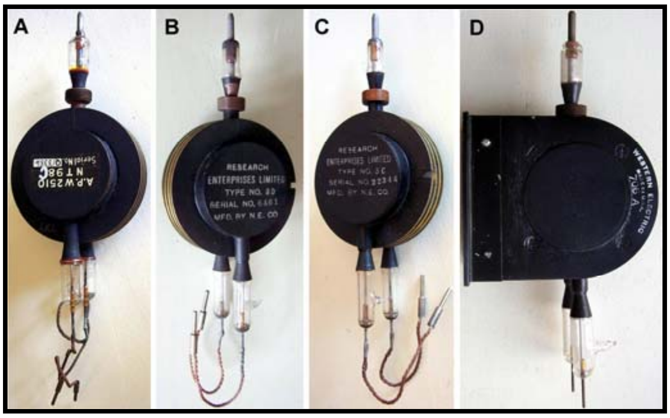



***Fig. 7 - A) The E1189, approved by the Admiralty as NT98. B) The same type was made in Canada by Northern Electric as REL 3D. C) The Air Ministry 9.1 cm variant, the CV38, was also manufactured in Canada as REL 3C. D) Western Electric in America designed its own strengthened variants, the 25 kW 706A-D, with four frequency selections, later replaced by the strapped types 706AY to GY.***

No need to list the countless types of cavity magnetron derived from E1189 and made in the war in America and England, and since 1944 also in Germany. We will only mention the major development lines among those proliferated from 1941, most of them retaining the basic design defined by Megaw.

**Pulse Power:** Since 1940 Megaw had obtained pulses of hundreds kilowatts (*14), but magnetron was unstable during transients. In July 1941, at Birmingham, Sayers devised the strapping technique, connecting the cavities according to patterns that prevented 'mode jumping'. Strapping removed limits to the power that could be obtained. Existing types were readily updated, with dramatic power increases. More powerful types were introduced, as soon as suitable modulators and T/R switches became available.

**Bands:** Early in 1941 Western Electric designed its first cavity magnetron operating at 700 MHz (*8), followed by other types in the S and in the L band, just beyond one gigahertz. At the end of 1941, early unstrapped samples operating at 3 cm, in the X band, were ready in England and America. Efficiency of the first types was low, but they allowed the early airborne equipment, such as the AN/APS-3, to be built and tested for operation [*P10]. Strapped types and even 'rising sun' types, operating at 24 GHz in the K band, followed shortly later.

**Frequencies:** initial specifications assigned a single frequency for each band but, to prevent interference between nearby sets, it was necessary to use a gradually increasing number of frequencies, introducing as many different codes for each basic type. To simplify inventory management, tunable magnetrons appeared, capable of replacing entire fixed-frequency families.

**Production Processes: A**lso production processes were soon improved. Early magnetrons were made by slow drilling the cavities in the heavy anode copper block, end caps being sealed with gold wires. Early in 1941 Western Electric opened in Chicago a special facility, equipped with long lines of drilling stations. Soon later Percy Spencer at Raytheon succeeded in growing anode blocks from thin metal sheets, by stacking copper discs, machine-punched to the proper shape, and then silver-brazing into hydrogen ovens enough discs to reach the wanted height. As a result, Raytheon was able to build 2,400 magnetrons per day (*10), compared to the approximately 2,000 units of E1189 manufactured by both BTH and GEC in 1941. Tizard's most optimistic predictions were far exceeded!

**Maintainability:** to simplify maintenance operations, 'packaged' magnetrons were introduced, with factory pre-installed magnet, so making their in field replacement fast and easy, no need for special instrumentation.

Figures 10 and 11 show images of some relevant magnetrons introduced between 1941 and 1942, plus samples of 'packaged' and ‘tunable’ types introduced before the end of the war. All the tubes can be accessed in magnetron pages of **ase-museoeselpro** [*TM-ix].

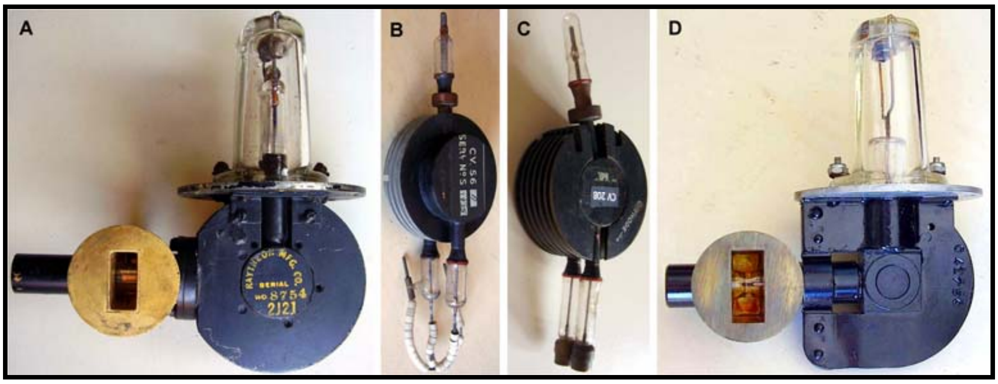



***Fig. 8 - A) 2J21 was the first 12-cavity X-band magnetron, jointly designed by MIT and Westinghouse. Built since 1941, it was used in the AN/APS-3 radar. B) The CV56 was delivered from 1941, adding straps to the E1189, power raised to 100 kW. C) With pulses of 25 kW, the BTH CV209 and the GEC CV208 were the early strapped British X-band types. D) The strapped 725A was designed by Bell to replace the 2J21 from the late 1942. Over than 250.000 units were made during the war, including about 92.000 units delivered to the Great Britain under the ‘Lend and Lease Act’.***

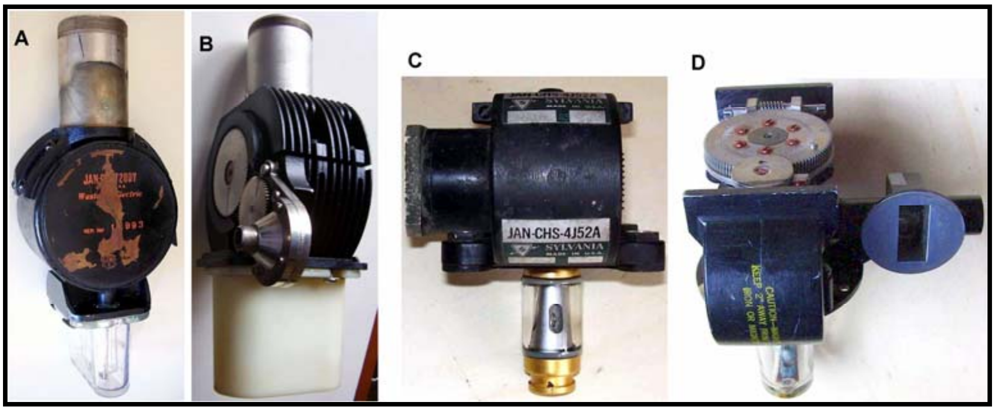



***Fig. 9 - Low-frequency, tunable and packaged types. A) The WE 728 family gave 400 kW from 900 to 970 MHz. B) The 5J26 could be tuned from 1.220 to 1.350 MHz, 600 kW peak pulses. C) The 4J52 ‘packaged’ X-band magnetron. It was supplied with factory assembled magnet, for easy in-field maintenance. D) Also the 2J51A was ‘packaged’, tunable over the entire X-band and fitted with magnetic shunts, to select the proper operating power range, so replacing several families of fixed magnetrons.***

**Acknowledgements**

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**External links to papers and sites**

[P01] - Boot - Randall - http://www.ase-museoedelpro.org/Museo_Edelpro/links/P-01.pdf
[P02[ - Megaw, 1940 - http://www.ase-museoedelpro.org/Museo_Edelpro/links/P-02.pdf
[P03] - Megaw, 1946 - http://www.ase-museoedelpro.org/Museo_Edelpro/links/P-03.pdf
[P04] - Fisk et al,, 1946 - http://www.ase-museoedelpro.org/Museo_Edelpro/links/P-04.pdf
[P05] - Y. Blanchard et al, 2013 - http://www.ase-museoedelpro.org/Museo_Edelpro/links/P-05.pdf
[P06] - M.J. Lazarus, 1986 - http://www.ase-museoedelpro.org/Museo_Edelpro/links/P-06.pdf
[P07] - Willshaw W.E., 1990 - http://www.ase-museoedelpro.org/Museo_Edelpro/links/P-07.pdf
[P09] - GEC site http://www.trevorwright.com/GEC/Archive/magtron.html
[P10] - Electronics, June 1948 - http://www.ase-museoedelpro.org/Museo_Edelpro/links/P-10.pdf
[P11] - Atti del Congresso Internazionale per il Cinquantesimo Anniversario della Scoperta Marconiana della Radio, Roma 1948

**External links to tubes of ase-museoedelpro collection**

[TM-01] - E1189 Prototype http://www.ase-museoedelpro.org/Museo_Edelpro/links/TM-01.pdf
[TM-ix] - Magnetron page http://www.ase-museoedelpro.org/Museo_Edelpro/links/TM-ix.pdf