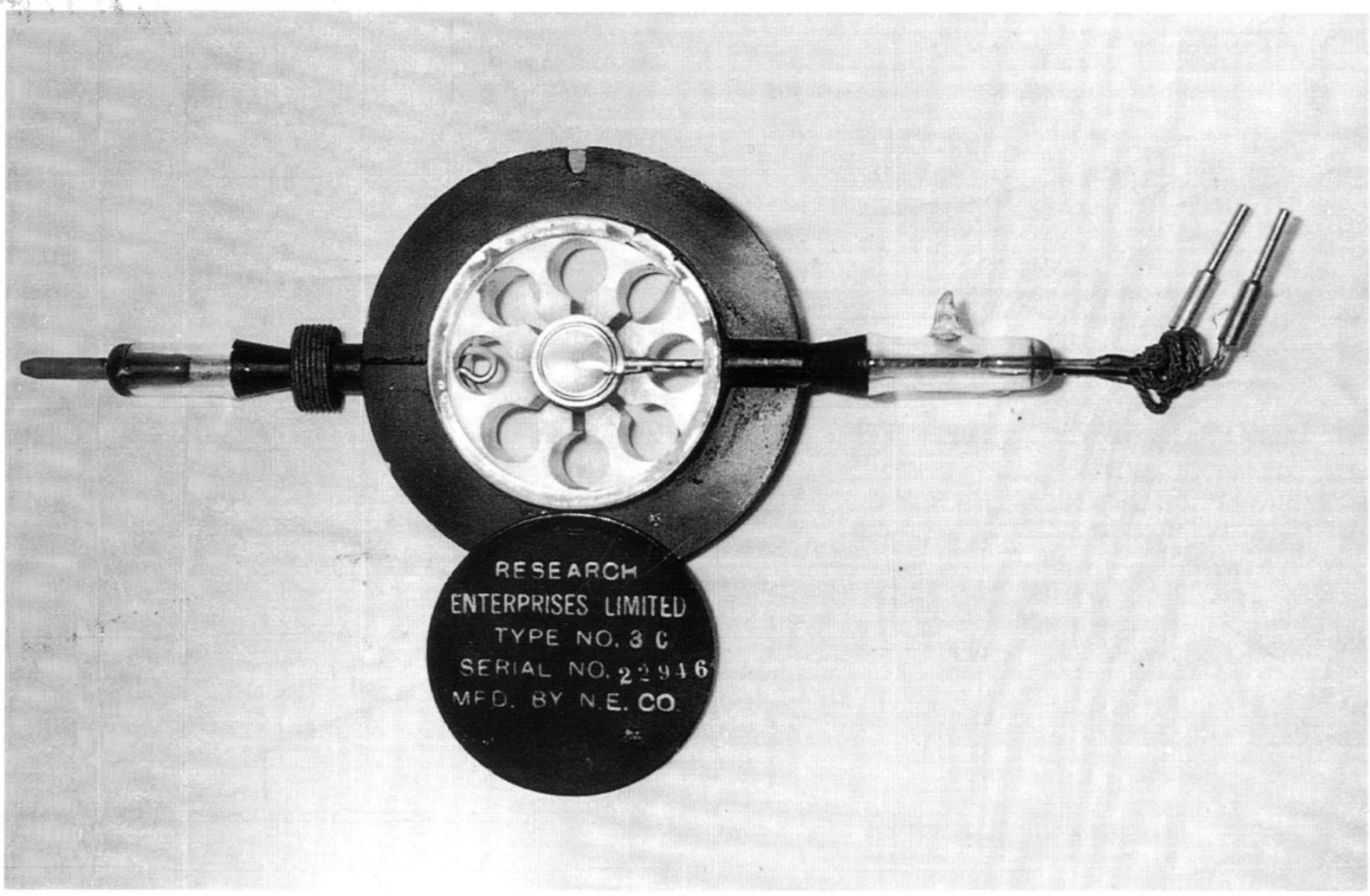
MICROWAVES 9A

The Applications of RF. Microwave and Millimetre Wave Technologies

HISTORIC VALVE EXHIBIT

Catalogue



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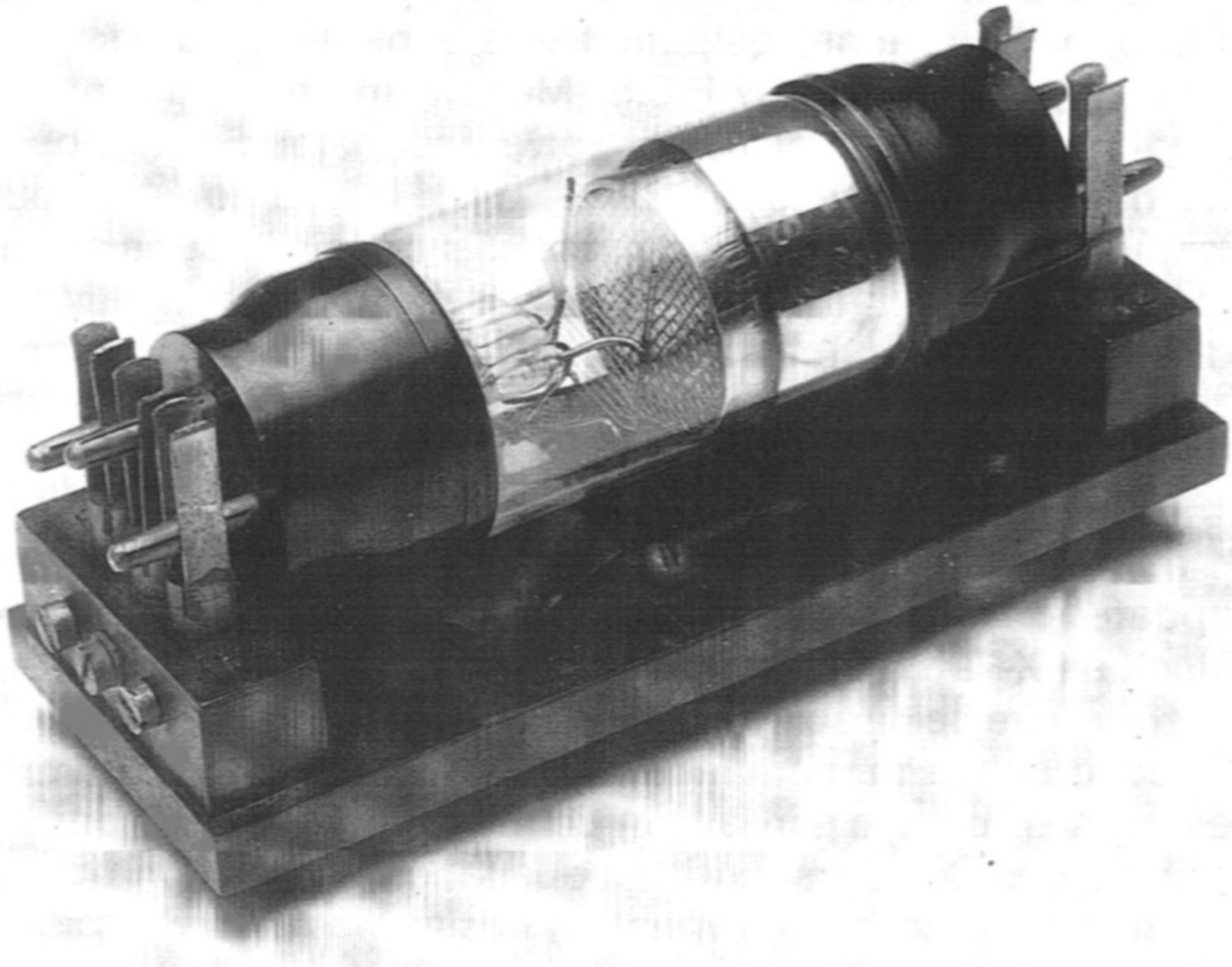
Front cover caption: 8 resonator unstrapped S band cavity magnatron type 3C, made in Canada by Northern Electric as a direct copy of the E1189

HISTORIC VALVE EXHIBIT

INTRODUCTION



MARCONI / OSRAM SCREENED GRID VALVE TYPE 8625

The purpose of this display is to show the development of the valve (vacuum tube) especially as applied to radar and microwave technology. Although the use of valves was originally applied to radio communications, the invention of the diode detector by Fleming in 1902 and its subsequent improvement by the addition of a grid by Lee deForest in 1906, set in motion a train of events that within the next 30 to 40 years led to the development of a number of devices with specific microwave applications.

Typical of these were the Resonant Cavity Magnetron and the Klystron. The principal of the Magnetron, namely a cylindrical diode in which the electron motion is influenced by both electric and magnetic fields, had first been demonstrated by Hull in the United States during the late 1920's. Whilst it was realised that potentially this valve was capable of generating extremely high frequency oscillations, its modes of operation were not well understood and the performance and efficiency achieved poor.

It was the incorporation of resonant cavities within the cylindrical anode block which turned a laboratory curiosity into a useable generator of high power microwave energy. Although this work is generally credited to John Randall and Harry Boot of Birmingham University, Post War research has shown that similar types of Resonant Cavity Magnetron were demonstrated in Japan in 1939, 6 to 12 months prior to the Birmingham valve and even earlier in the Soviet Union in 1937.

The conversion of the Birmingham Magnetron into a practical valve that could be incorporated into military radar equipment was achieved in the surprisingly short space of time of only 4 months by E.C.S. Megaw and his team at the GEC Hirst Research Laboratories in Wembley. Their valve designated E1189, operated with a permanent magnet and gave approximately 10kW of pulsed power output at 9.6 cms wavelength. It was found however, that peak efficiency could not be achieved with the magnetic field available from the permanent magnet and consequently the design was recalculated for an 8 resonator anode as opposed to the 6 resonators of the Birmingham valve.

The first of the 8 resonator valves, E1189 Serial No.12 was sent to the USA and Canada with the Tizard mission in September 1940. Unfortunately nobody had thought to update the drawings with the result that when the engineers at Bell Laboratories took an X-Ray photo of the valve whose performance had so impressed them, they felt they were being somewhat misled. However after the error was cleared up work proceeded apace to manufacture 30 more valves as exact copies of the E1189 in their possession and similarly in Canada the valve was copied by Northern Electric as the type 3D. Comparison with the Japanese Magnetron type M312 makes it clear how much more practical the Wembley design was and why this valve became the prototype for many of the Magnetrons used during World War II.

Because of the breakthrough that the Resonant Cavity Magnetron represented in terms of generation of high pulsed power microwave energy there was considerable reluctance amongst the Allies to utilise Magnetron powered radar equipment in aircraft operating over enemy territory, in case the secret was compromised. Attempts were made to fit the Magnetron with an explosive destructor but during a test on board a captured Ju88 at Farnborough an 11ft diameter hole was blown in the side of the fuselage and a scientist not previously acquainted with the Magnetron was able to reconstruct it in a couple of days from the pieces that remained.

In order to overcome the problem it was suggested that the Klystron be used as the power source for airborne radar as the design of this valve had been published prior to the commencement of World War II. However, with one notable exception, the EMI PK150, none of the other Klystrons were capable of generating sufficient power and even the PK150 was soon left behind as Magnetron performance improved. As a result by January 1943 permission was granted for aircraft fitted with Magnetron powered H2S radar to operate over Germany and German held territory. In February of that year the Germans recovered an almost undamaged H2S radar from a Stirling bomber that had been shot down near Rotterdam. The equipment was taken to the

Telefunken works in Berlin and set to work and the Germans were amazed by the progress that had been achieved by Allied radar during the past 3 years.
A few weeks later the Telefunken works were completely destroyed in a bombing raid but by this time more equipment had been recovered from other crashed Allied aircraft and the Germans who had by this time called the equipment the "Rotterdam Gerat" were able to assess its performance and start work on suitable countermeasures. In addition by June 1943 they had succeeded in manufacturing their LMS10 Magnetron which was a direct copy of the CV64 used in the H2S radar, although the LMS10 never actually worked as well as the CV64.

With regard to the Klystron, this valve which makes use of the principle of velocity modulation of the electron beam, had been invented by the Varian brothers in the United States in 1938. In spite of considerable research effort it proved impossible to generate sufficient power with this device for it to be used in microwave radar transmitters. It did however, turn out to be an extremely useful local oscillator in microwave superheterodyne receivers. As far as the UK was concerned the initial development was carried out by Sutton and his team at the Naval Signal School in Bristol. The valve they developed which was a Reflex Klystron became known as the Sutton tube, the earliest examples of which, the NR89 and 10E/501 required in excess of1700 volts for correct operation.

The design of this valve was rapidly improved, resulting in lower operating voltage requirements and as the CV67 became the standard local oscillator valve in many British designed 10cm radar systems. The CV67 was still further improved resulting in even lower voltage requirements, smaller size and operation at 3cm (X Band).

The most successful receiver Klystron was that developed in the USA by Pierce and Shepherd. This all metal valve designed for X Band operation was first put into production by Western Electric in 1943 and given the type number 723. Subsequently known as the 723A/B or 2K25 it became the world wide standard local oscillator valve in virtually all X Band radars until superseded by solid state devices.

Although there are a number of other microwave thermionic devices such as Cross Field Amplifiers, Carcinotrons or Backward Wave Oscillators, Gyratrons etc. The majority of these were invented after the end of World War II and therefore cannot fall into the category of being historic. The one exception is the Travelling Wave Tube (TWT), the principle of which was invented by Kompfner in 1944. The first practical TWTs came too late to be of any use during World War II, but since then the TWT has been developed to a point where there are many thousands of these tubes currently in use in microwave systems. For broad band or high power amplification even to_days solid state units cannot compete with the TWT.

THE EXHIBITS

EARLY VALVES

FLEMING TYPE DIODE. c.1905
A thermionic diode with a loop type filament and cylindrical anode. Similar to the type used by Fleming as a detector of spark transmissions and incorporated by Marconi into early receiving apparatus.

DeFOREST AUDION TRIODE. c.1914
The first three electrode valve, based on deForest's patent filed in 1907 and granted one year later. Manufactured by H.W. McCandless & Co. in New York, this particular specimen is a double wing audion, having plates and grids either side of the filaments. These filaments are known as Hudson filaments which consist of tantalum wire wrapped round the tungsten filament wire to increase its emissivity.

WHITE SOFT VALVE. c.1915
Designed and manufactured in Cambridge under the direction of Sir J.J. Thomson. Fitted with a standard bayonet cap base, the grid being connected to the metal shell. The valve has a large envelope so that the residual gas pressure did not vary excessively during operation. Used in the British Signals Experimental Establishment MkIII amplifier.

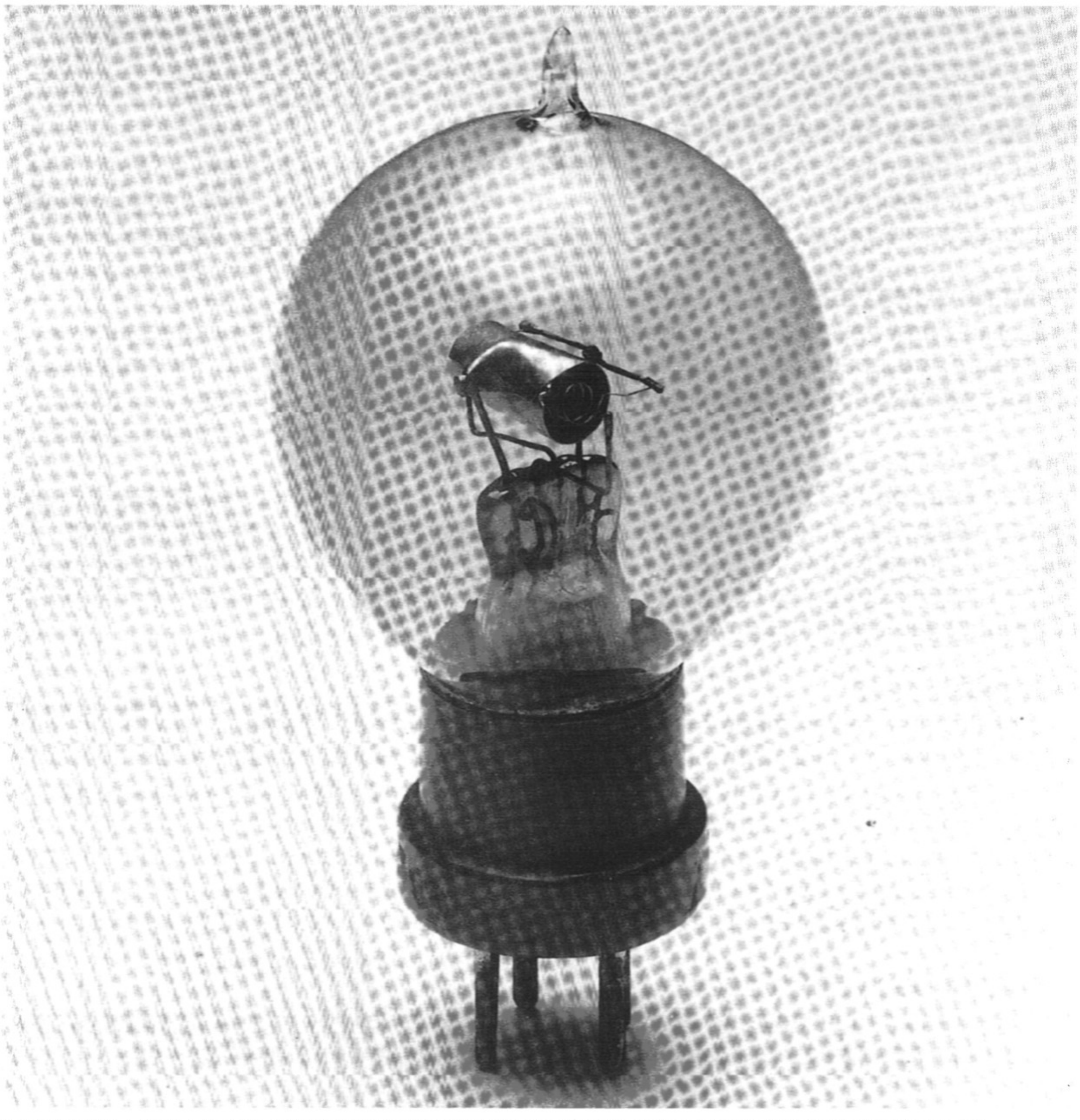
MARCONI ROUND TYPE "N". c.1916
Developed by Captain Round of Marconi's Wireless Telegraph Company and manufactured by Osram, this was a "soft" valve which relies on a small amount of residual gas for its correct operation. The top pip contains a small piece of asbestos which if heated, for example with a match, will release some gas thereby allowing the operator to control the performance of the valve. Fitted with a standard Edison screw base.

MARCONI ROUND TYPE "T". c.1916
A transmitting valve also designed by Captain Round, having three filaments normally operated in series at a current of 4 Amps. The anode is close to the glass so that maximum cooling could be effected by immersing the valve in oil. The bayonet cap base is merely used for mounting as the filament connections are brought out by wires round the periphery.

MARCONI TYPE "Q". c.1917
A low capacitance triode specifically recommended for detector applications. Another Captain Round design made for Marconi's at the Osram Lamp Works, this valve has its anode and grid connections brought out on opposite sides of the glass envelope to minimise the stray capacity. Valves of this type of construction were in use by the Royal Navy up to the outbreak of World War II.

WESTERN ELECTRIC VT2. c.1917
Developed from a telephone repeater tube as a small transmitting valve for the US Army Signal Corps. Also used by the US Navy under the designation CW931. This valve is typical of the design that was used by Western Electric up to the mid 1930's.

FOTOS TM (R TYPE). c.1917
Manufactured by E.C.& A.Grammont in Lyon from about 1915 onwards, this valve was the first high vacuum type to be made in Europe and was the forerunner of the much used "R" valve and also the first valve to use what later became the standard European 4 pin base. The designation TM over which some controversy exists, is reputed to stand for "Telegraphie Militaire".



FRENCH "R: VALVE, C 1917 FIRST EUROPEAN PRODUCED HARD VACUUM VALVE, MADE ETS FOTOS, GRAMMONT IN LYON

SIEMENS & HALSKE TYPE "A". c.1917
A German manufactured valve originally designed as a telephone repeater tube, but pressed into service by the German Military during World War I. Valves of this type were also manufactured by Siemens and were used mainly in low frequency amplifiers designed to eavesdrop on Allied telephone conversations by amplifying small earth return currents.

MOORHEAD "R". c.1918
By this time the supply of valves required for the War effort had become extremely difficult. Accordingly the US Government suspended all patent litigation and allowed a number of "pirate" valve manufacturers to make valves under contract to the British Armed Forces. One such was Otis B. Moorhead in San Francisco who made several types of "R" valves. This particular specimen is interesting in that it has a vertical electrode assembly rather than the more usual horizontal.

RADIOFOTOS GRAMMONT TM75. c.1918
A transmitting triode manufactured in France about the time of the end of World War I. The anode dissipation is believed to be in the region of 75 Watts. The anode and grid connections are brought out separately in an attempt to reduce stray capacity.

SIEMENS SCHOTTKY SS1. c.1918
One of the first valves to have more than one grid. The object of the inner grid was to neutralise the space charge in the vicinity of the filament so that the valve could operate with a lower H.T. voltage, thereby saving weight on H.T. batteries.

MOV "R" TYPE. c.1922
A direct copy of the Fotos TM used during World War I. Manufactured by the Marconi Osram Valve Co. which had been formed in 1921 as a joint venture between the Marconi Company and the Osram Lamp Works. The reddish colour of the glass is due to the presence of phosphorous which was used as a getter to remove the last traces of residual gas within the envelope.

MOV DER. c.1922
One of the first valves made in the UK with a "dull emitter" filament. Up to this time valves had been made with pure tungsten filaments which needed to be heated to white heat in order to emit an adequate supply of electrons. However, by adding certain oxides to the filament material it was found possible to achieve adequate emission at much lower temperatures. Although it still makes use of the "R" type electrode assembly the required heating power has been reduced by a factor of about 6 times. This valve in various guises continued to be made until the late 1930's.

DeFOREST OSCILLION. c.1924
A triode transmitting valve made by the DeForest Company in the USA. Valves of this type would have been used in early broadcast transmitters and for ship to shore communications.

MOV KL1. KELLOGG 401. COSMOS AC RED SPOT> c.1926
Three of the first valves from the UK and USA to be made successfully with indirectly heated cathodes. This feature enabled the valves to be heated using alternating current without inducing hum into the circuits. As AC mains was starting to become more common, this was a very important development. The unusual construction of the AC Red Spot and 401 was so that they could be used as direct replacements for battery valves in radio sets.

LOEWE 3NF. c.1927
Made by Loewe Radio of Germany. This valve could claim to be the world's first integrated circuit! The envelope contains two amplifier triodes and an audio output triode plus all the interstage coupling capacitors and resistors, which are sealed in separate glass vials to prevent their outgassing destroying the vacuum. The valve enabled a complete receiver to be built using only an external tuned circuit and achieved a useful saving on tax which at the time was calculated on the number of valves in a radio set.

MOV S625. c.1927
The first 4 electrode valve designed specifically for Radio Frequency amplification. Although valves with 2 grids had been made as long ago as 1918, in all previous designs the extra grid had been used to neutralise the space charge and allow the valve to operate at much lower anode voltages. In the S625 the extra grid acted as a screen between the input grid circuit and the output anode circuit. Hence the name screened grid valve. The double ended form of construction was to enable the valve to be placed through a metal screen within the receiver.

PHILIPS PENTODE. c.1930
The screened grid or tetrode valve suffered from the defect that under certain conditions of anode and screen voltage it would exhibit a negative resistance characteristic. This problem was overcome by the addition of a third coarse mesh grid between the screen and anode. This valve which was introduced by Philips became known as the Pentode and became the standard configuration for radio frequency and audio output valves for many years.

MOV PX25. c.1932
A large Audio output triode with a 4 Volt directly heated cathode. Anode dissipation is 25 Watts and a pair of these valves in push¬pull can deliver in excess of 20 Watts of output. Although designed more than 60 years ago they are now very much in demand for modern hi_fi amplifiers as it is believed in certain circles that valves, especially triodes give the ultimate distortion free performance, with the added benefit compared with semiconductors that they can be seen to be working.

RCA 6L6G, RCA 807. c.1936
Another way of overcoming the negative resistance characteristic of the tetrode was developed by RCA. This was known as the beam tetrode. In this valve the electrons are formed into beams by ensuring the alignment of the wires of the control and

screen grids, in addition beam forming plates at cathode potential ensure that the electron beams are directed at the anode. The first production examples of these valves were the 6L6G and 807, the 807 in particular being designed as a high frequency transmitting valve capable of operating at full ratings up to 60MHz.

LATER VALVE DEVELOPMENT 1930-1950

The 1930's saw a rapid growth in the number of types and complexity of valves being introduced. This in turn increased the number of connections required and led to the introduction of several new bases. At the same time there was an increasing trend towards miniaturisation as new techniques in metal to glass sealing enabled valves to be made with the leadout wires used directly as pins. This part of the display shows a selection of valves typical of types that were developed over the period and is divided by country of origin, USA, UK and Europe.

USA

1. 4 pin UV base.
2. 4 pin UX base.
3. 5 pin UX base.
4. 6 & 7 pin UX bases.
5. Metal octal, 8 pin base.
6. "G" & "GT" octal 8 pin bases.
7. Loctal all glass 8 pin base.
8. 7 pin button base.
9. 9 pin button base.
10. 12 pin "Compactron".

UK

1. 4 pin base.
2. 4 pin base large
3. 5 pin base.
4. 7 pin base.
5. 9 pin base.
6. Mazda octal 8 pin base.
7. 3 pin B3A.
8. Wire ended.

EUROPEAN

1. 5 pin side contact.
2. 8 pin side contact.
3. European octal (Philips)
4. German "Y" base.
5. 9 pin all glass. EF50.
6. German standard receiving valve, RV12P2000.
7. A selection of other German World War II types.

The remainder of the HISTORIC VALVE DISPLAY is devoted to valves that were designed and developed specifically with VHF, UHF or microwave applications in mind. In addition there are a number of valves which whilst not designed for radio frequency applications, were used in radar systems, for example modulators and high voltage rectifiers.

CONVENTIONAL VALVES

Until new types of valves such as the Magnetron and Klystron were introduced considerable effort was devoted to improving the R.F. performance of conventional triodes and pentodes to the point where they could offer acceptable gain and noise figures in the case of receiving valves and useful output power in the case of transmitting valves. The exhibit shows some of the results of these efforts.

RECEIVING VALVES

ACORNS.
In 1935 RCA introduced their range of acorn valves which whilst difficult to manufacture gave useful performance up to 500MHz. This improvement was achieved by the use of small electrode assemblies, thereby reducing stray capacitance and low lead inductance due to the very short lead out wires. These valves were subsequently copied in many other countries, including the UK, Holland, Germany, Japan and France. The display block shows several examples of these.

RCA VT128. c.1938
Using the same constructional methods as for the acorn valves, RCA introduced an "Orbital Beam Hexode" as a very high gain high frequency amplifier, the idea being that the electron multiplication caused by the secondary cathodes would enable the valve have much greater gain than a normal pentode. Unfortunately the electron multiplication also gave rise to a lot of extra random noise so the valve was never a great success. However it was used as the second R.F. stage in the receiver type BC404-C of the SCR270 radar which operated at 106MHz and actually detected the Japanese aircraft on their way to attack Pearl Harbour.

MOV CV52. c.1941
A UHF triode designed for use as the local oscillator in the British UHF/microwave ELINT receiver type R1294. This receiver covered 500-3000MHz, but the CV52 would only oscillate to 1000MHz, so the higher frequencies were covered by using harmonic mixing.

STC CV82. c.1941
As metal to glass sealing techniques improved it became possible to manufacture valves with the electrode connections brought out around the entire circumference of the glass envelope. These valves were known as "disc seal" or "planar" triodes of

CV15 MOV.
A conduction cooled version of the VT90 "Micropup". Used in 200MHz radar transmitters where the provision of cooling air was not practicable.

NT99/CV92.
Another valve based on the "Micropup" design but somewhat larger. A pair of these valves were used in a naval radar transmitter at 600MHz to generate up to 100kW peak output. The valve was also manufactured under licence in the USA by National Union as the 4C27.

CV240 MOV.
The largest of the "Micropup" type valves. Obviously capable of extremely high pulse output power but the frequency response must have been compromised by the large physical dimensions. It is not known in what application, if any, the valve was used.

NT57T MOV. c.1938
The NT57T is a silica envelope triode that was developed by HM Signal School specifically for use in pulsed radar transmitters. The suffix "T" indicates that the valve is fitted with a thoriated tungsten filament. Because of its good high frequency performance and high power handling capability it was chosen as the output valve for the initial CH radar transmitters being developed at Orfordness which operated at 25MHz. Other silica envelope valves were used in early Naval radars such as the type 79Y (43MHz) and type 281 (90MHz).

EHT RECTIFIER No1 MOV. c.1937
A large high voltage half wave rectifier that was used to provide the output stage high voltage in CH radar transmitters. Ratings were 25 milliamps current at 65KV peak inverse voltage. The valve is fitted with an Edison screw base and anti-corona bushings at each end.

VT58 MOV. c.1940
A large cooled anode triode developed from a range of broadcast transmitter valves using the same design technology. A pair of these valves were used in the transmitter of the gun laying radar GL1 MkII. The valve was also made under licence in the USA by Westinghouse as WL533.

CV315 STC.
A VHF transmitter output valve capable of full ratings up to 120MHz. A pair of these valves were used in the output stage of the RAF T1131 ground to air transmitter which maintained communication with fighters during the Battle of Britain. Valves using a similar form of construction were made in the USA, Germany and Japan.

AMERICAN

15E EIMAC. c.1937
A small all glass triode with a thoriated tungsten filament designed for pulse operation. American radar transmitter design made use of the ring oscillator concept and by using six of these valves in a ring circuit an output power of 50kW peak was achieved at 600MHz.

100Th EIMAC. c.1936
This valve was originally designed for amateur service but was likewise pressed into radar applications. A ring of six of these valves were used in the US Navy radar type CXAM at 500MHz.

VT127 EIMAC. c.1939
Developed from the 100Th specifically for pulsed operation in radar transmitters, with anode voltages up to 15KV. These valves were used in the US Signal Corps SCR270 radar.

VT158 EIMAC. c.1942
Also known as a Zahl tube after its designer it comprises four 75T electrode structures in parallel and plate and grid tuned circuits all within the vacuum envelope. The tube is capable of delivering up to 200KW peak pulse at 600MHz and a single valve was used in the transmitter of the TPS3 transportable air defence radar.

VT191 GENERAL ELECTRIC. c.1940
This valve was originally designed by Philips in Holland, as the TB04/8. Also made in the USA by Tung_Sol and Western Electric as the 316A, in the UK by STC as 4316A, in Germany as the TS1 and in Japan. Used in the early American IFF set type ABA1.

388A WESTERN ELECTRIC. c.1942
Developed from the original Samuel design for use in airborne jamming equipment. A pair of these valves were used in the APT2 (Carpet) jammer producing 5 Watts of noise modulated output tunable over the frequency range 450-720MHz.

GERMAN

TS1a GEMA. c.1941
A mirror image of the TS1, which in turn had been copied from the Philips TB04/8. The object of making a valve as a mirror image was that it enabled a push-pull oscillator to be made without upsetting the symmetry of the tuned circuits.

TS6 GEMA.
This unusually shaped valve was designed to be used in the "Seetakt" Naval and land based radar. A pair of TS6 in an oscillator circuit produced 15kW pulse at 375MHz.

The presence of German radar was first detected by the identification of a "Seetakt" antenna on the mast of the pocket battleship Graf Spee after she had been scuttled in Montevideo harbour in December 1939. This valve was also made under licence by Fivre in Italy.

TS41 GEMA. c.1939
A pair of these valves were used in the transmitter of the "Freya" air defence radar at 125MHz. This was the first German radar positively identified by the British during World War II. Its signals were picked up using a Hallicrafters S27 receiver and the installation was subsequently photographed, which finally laid to rest the myth that Britain was the only country that possessed radar.

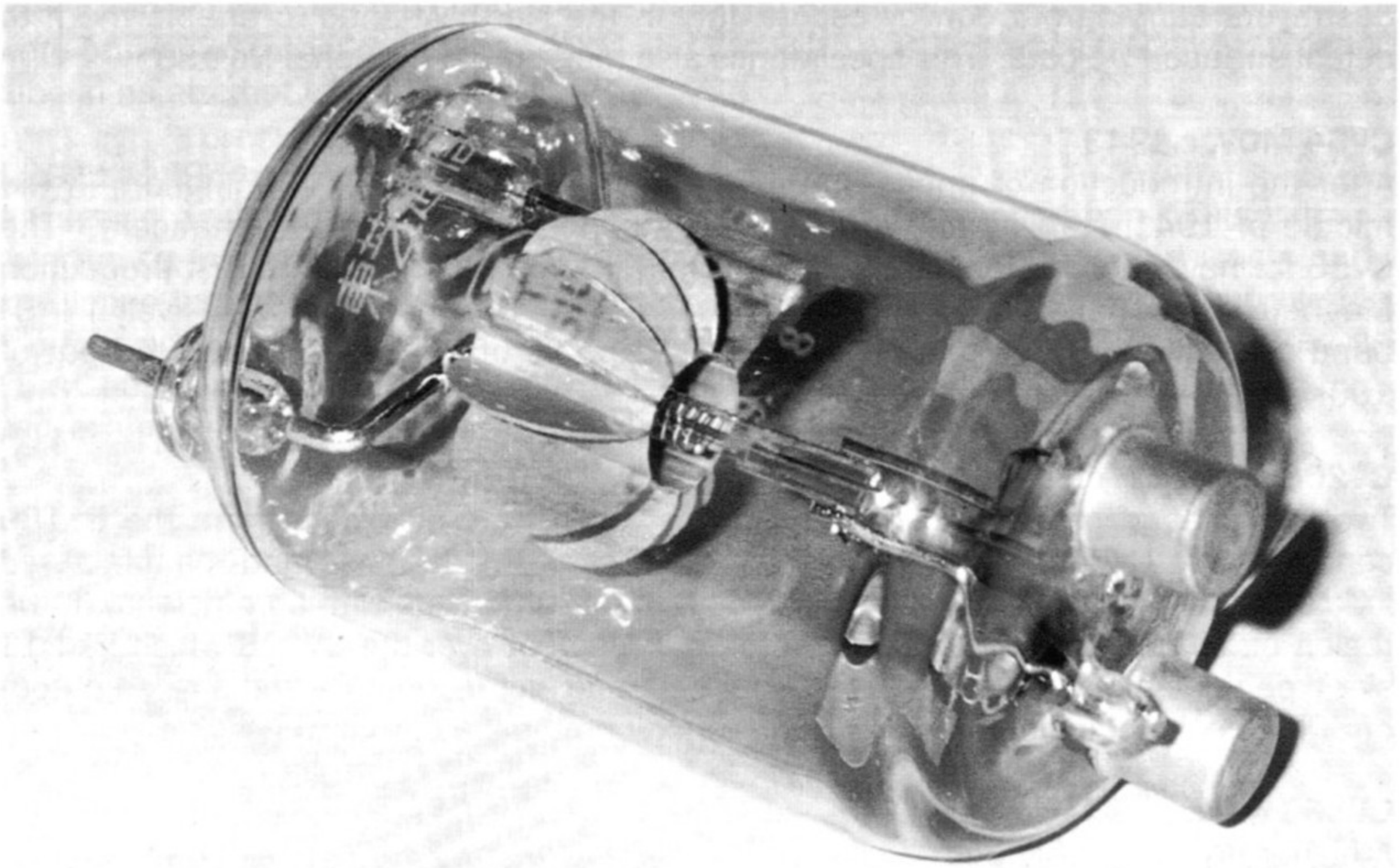
RD12Tf LORENZ. c. 1944
One of the best performance UHF pulsed triodes of its time. A pair in push-pull generated 50kW peak at 53.6cms when used in the FuMG39l Kurmark fire control radar. A pair of these valves was also used in the transmitter of the FuG200 Hohentweil German ASV radar operating at 550MHz.

LS180 TELEFUNKEN.
Manufactured from 1940 onwards this was the transmitter valve of the famous Wurzburg flak and searchlight control radar. The valve generated about 25kW peak at 50cms at a prf of 3750 and duty factor of 8%. An example of the valve was captured during the Bruneval raid in February 1942 and the evaluation of the transmitter enabled the Allies to develop suitable countermeasures which were used to great effect later in the War.

TS60/14 GEMA. c.1942
A high power all glass triode using "ship in a bottle" construction techniques. The design appears to be an improved version of the TS6 but it is not known whether this valve was used in later versions of the Seetakt radar. The filament current rating of 75 Amps would seem to indicate a power capability for a pair of these valves of about 20kW peak at 375MHz.

JAPAN

T310. c1944
This valve is believed to be a UHF pulse triode designed for radar transmitter applications. Because of certain similarities with the German LS180 q.v. it is possible that the T310 may have been developed from this valve. It is known that in the latter stages of World War II a complete Wurzburg radar was shipped from Germany to Japan by submarine and the T310 could well have been the outcome of this co-operation. Unfortunately the filament of this valve is damaged so it has not been possible to assess its performance.



JAPANESE RADAR TRANSMITTING TRIODE TYPE T310

MAGNETRONS

CW11 MOV. c.1938
A split anode Magnetron capable of generating about 5 Watts CW at 150MHz. Valves of this type were used in early experiments to generate RF power at microwave frequencies but suffered from low efficiency and unpredictable performance.

3C,3D NORTHERN ELECTRIC. c.1941
These valves are direct copies of the E1189 taken to the USA and Canada by the Tizard mission in September 1940. As can be seen from the open example of the 3C, the anode is not strapped and as a result these valves were fairly unstable in operation and only gave an efficiency in the region of 15 to 20 percent. Also included in the exhibit is an example of the permanent magnet that was used with these valves.

NT98 MOV. c.1941
This rather damaged example of the NT98 was used in the Naval radar type 271, which was the first operational centimetric radar and was fitted to Royal Navy

destroyers carrying out convoy escort duty in the North Atlantic to enable them to detect surfaced U-Boats. This specimen is also marked E1189 Serial No.183.

CV64 MOV. c.1943
After the introduction of anode strapping, invented by Sayers in Birmingham in the middle of 1941, stability and efficiency of Magnetrons improved dramatically. The CV56 for naval applications and the CV64 for airborne radar were the first production Magnetrons to make use of this technique. The CV64 was used extensively in "S" band version of ASV, AI and H2S and was capable of delivering a peak output of 100kW with an efficiency of 50 percent.

CV208, CV2111. c.1943
Two examples of early "X" band Magnetrons which were developed from the E1189 concept. The CV208 was the first really successful UK designed and manufactured "X" band Magnetron. It was capable of delivering 25kW peak with an efficiency in the region of 20 percent which was a useful improvement over the CV108 which had 12 slot type resonators. The CV2111 has 14 hole and slot resonators and a rated output of 30kW peak. In addition the design now incorporates the output waveguide.

CV356 MOV. c.1944
A higher power preplumbed "X" band Magnetron rated at 200kW peak power with an efficiency of 35 percent. Comparison with the CV208 will show how rapidly the performance of "X" band Magnetrons was improved over a period of about one year. It is not known if this valve was ever used operationally.

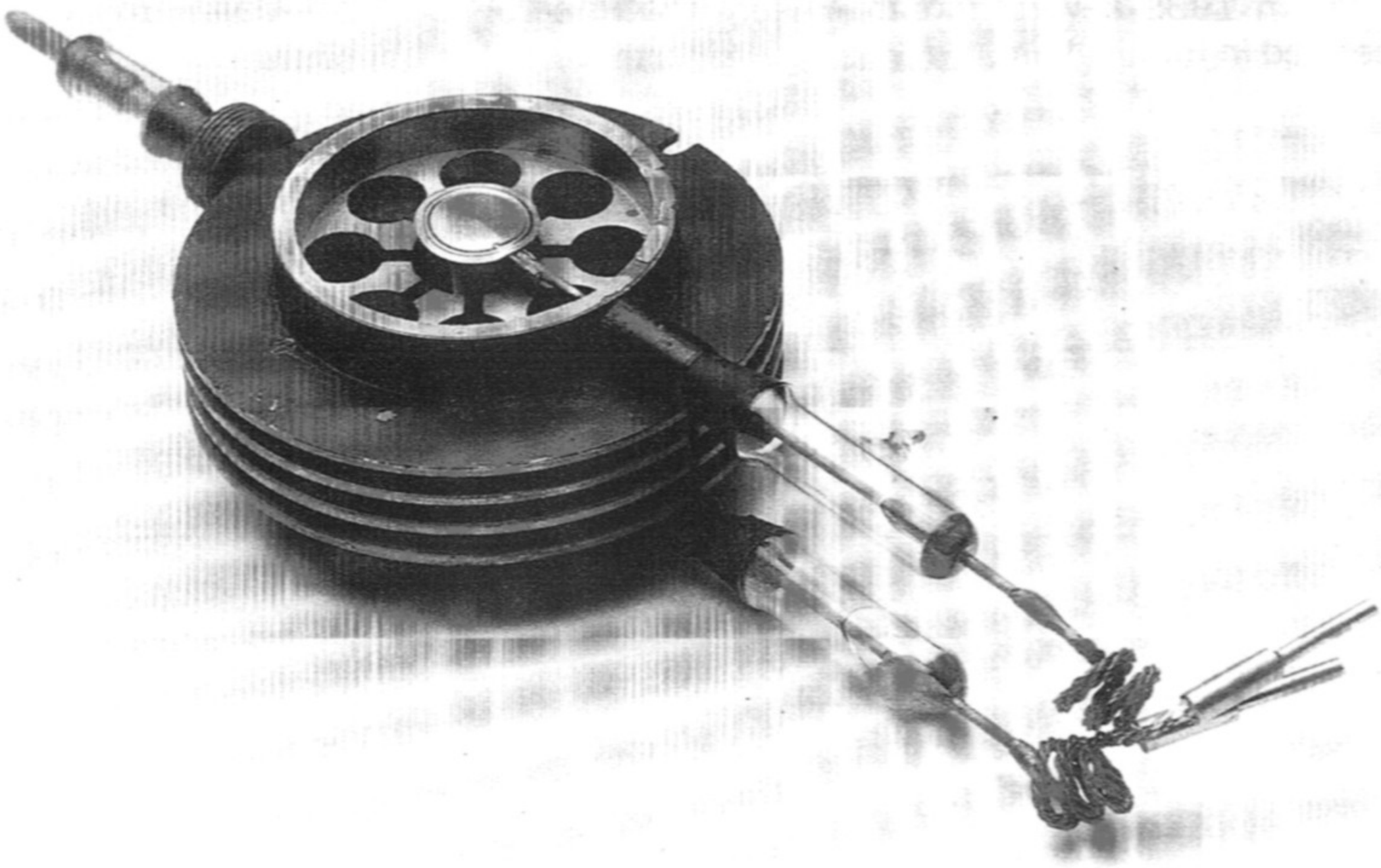
2J50 RAYTHEON. c. 1944
An American designed and manufactured "X" band device used extensively in US airborne radar equipment during the latter part of World War II. Comparison with the CV208 and CV2111 shows the significant difference in construction method between the UK and US designs. The American design lends itself well to mass production techniques and this valve and the Western Electric equivalent 725A were made in very large quantities.

CV79/CV89 MOV.
These are interdigitated Magnetrons that were designed as low power oscillators at 6GHz. Their principal use was in the transmitter and local oscillator of the wireless set No.10 which was the first pulse width modulated microwave communications system and was used to maintain contact between Montgomery's Headquarters and England after the D Day landings.

LMS10 c.1943/4
The German copy of the CV64 recovered from the crashed Stirling bomber at Rotterdam in February 1943. The discovery of the "S" band H2S equipment came as a great shock to the Germans who believed that Allied radar technology was far behind their own. However by June of that year they had reproduced the CV64 in the shape of the LMS10 and which with an electromagnet was used in their own designed AI radar

"Berlin" in 1944. One major difference from the British valve was that the end plates were brazed on rather than gold sealed and the valve was, therefore fitted with a getter tube in an attempt to hold the vacuum.

LMS11. c.1944
A German designed resonant cavity Magnetron for 5.1cms operation. This valve is referred to in the minutes of the Rotterdam committee meetings and was clearly developed independently although the slot resonator design is similar to that used in the first operational British "X" band Magnetron CV108. Output power is stated as 15kW peak but there is no evidence that the valve was ever used in any radar system. This example is probably unique.



NORTHERN ELECTRIC TYPE 3C, UNSTRAPPED 8 RESONATOR CAVITY MASNETRON, BASED ON E1189

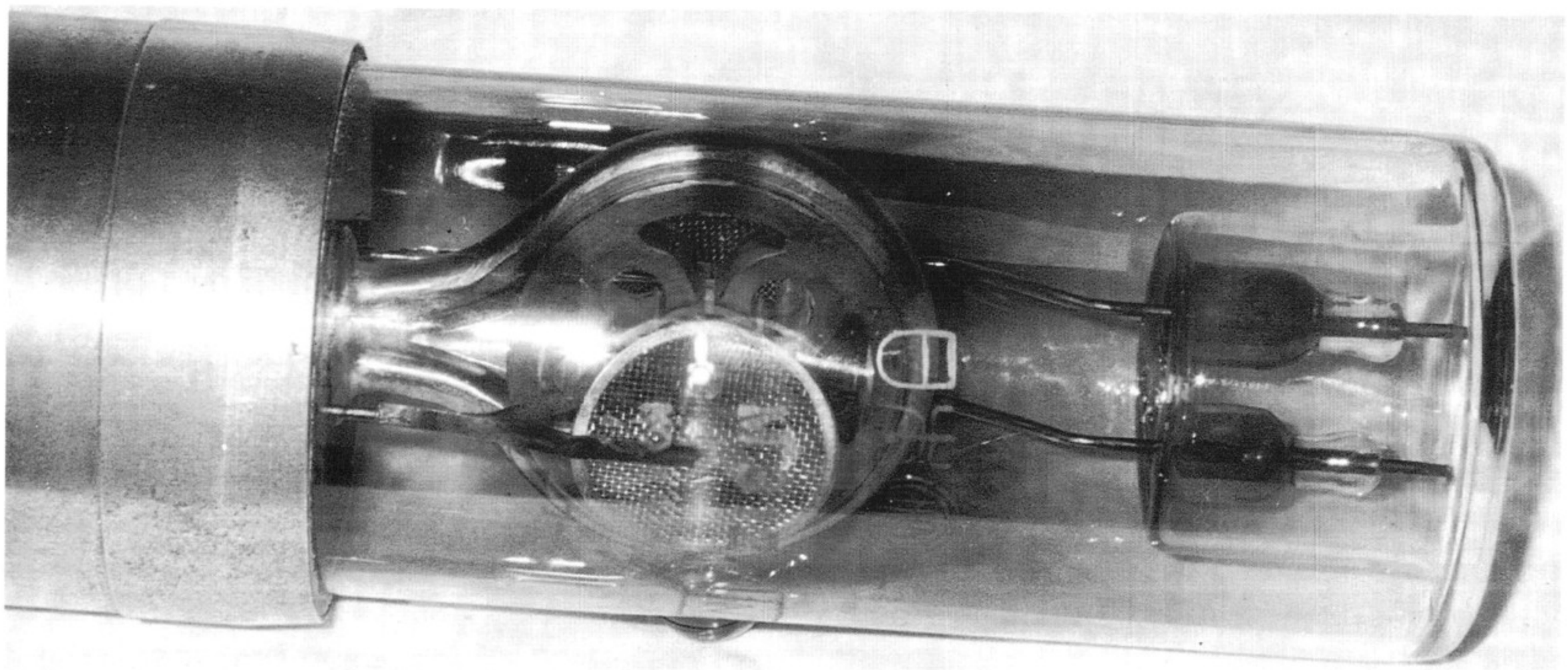
RD2Md2 TELEFUNKEN. c.1944
An interdigitated local oscillator Magnetron developed for use in the German "Korfu" and "Naxos" microwave ELINT receivers. Once the Germans realised the Allies were using centimetric radar a major effort was undertaken to develop receivers which could detect the H2S and ASV radar transmissions.

5J29, 5J30 GE.
Two American water cooled split anode Magnetrons designed for CW operation in high powered jammers. The 5J29 operated over 450-780MHz and both valves could

deliver 150 Watts output. The 5J30 was designed for lower frequency operation down to 150MHz and was used in the TDY-1 jammer which continued in service up to the mid 1950's. Filament current for both valves is in the region of 30 Amps.

MN119 STELANO.
A modern "L" band mechanically tuned Magnetron of current Soviet manufacture. Believed to be capable of about 1.5MW peak output. This valve was "liberated" from the spares kit of a Russian air defence radar after the fall of the Berlin wall. The tuning mechanism is motor driven and enables the radar to be operated in a frequency agile mode.

M312 JAPAN RADIO CORPORATION. c.1942
This valve is probably the "star exhibit" because of its rarity and historical background. The M312 is a Japanese manufactured 10cm resonant cavity Magnetron with an output power of about 6kW peak pulse. The prototype of this valve, the M3, was tested in 1939 several months before the Randall and Boot Magnetron was first operated in Birmingham.



JAPANESE RESONANT CAVITY MAGNERON, TYPE M312, THE DESIGN OF WHICH PREDATES THE RANDALL & BOOT INVENTION BY SEVERAL MONTHS, 6KW OUTPUT @ 3Ghz

Although this example is a production valve (about 8,000 were made), it shows considerable deficiencies compared with the GEC E1189. There are only 4 cavities instead of 8, it uses a thoriated tungsten filament as opposed to an oxide coated cathode, thereby limiting the secondary emission and hence the pulse output power, the anode requires water cooling and most significantly the output power is coupled via two capacitive tabs in the inductive portion of the cavities and then taken out to a 2cms spaced transmission line which undoubtedly results in large radiated losses at the 10cm wavelength. This is confirmed by the fact that the type 22 radar in which

this valve was used was only rated at 2.5kW output power.
The example on display may well be the only remaining specimen of this valve outside Japan.

The copper deposits on the inside of the glass envelope indicate that the valve has had a number of hours of use. Even though the filament is intact, in view of the rarity of the valve it was not felt prudent to attempt to operate it at full ratings. However, the filament has been run at about 30% of the normal 10V @ 19.5A and this seems to confirm the integrity of the vacuum.

According to an article published in the May 1946 issue of Electronics other key characteristics were as follows:-

Anode Volts	11 kV
Anode Current	2 Amps (peak)
Anode dissipation	2 kW (average)
Magnetic field	1000 gauss
Input power	22 kW (peak)
Efficiency	30 %
Wavelength	9.875 cms

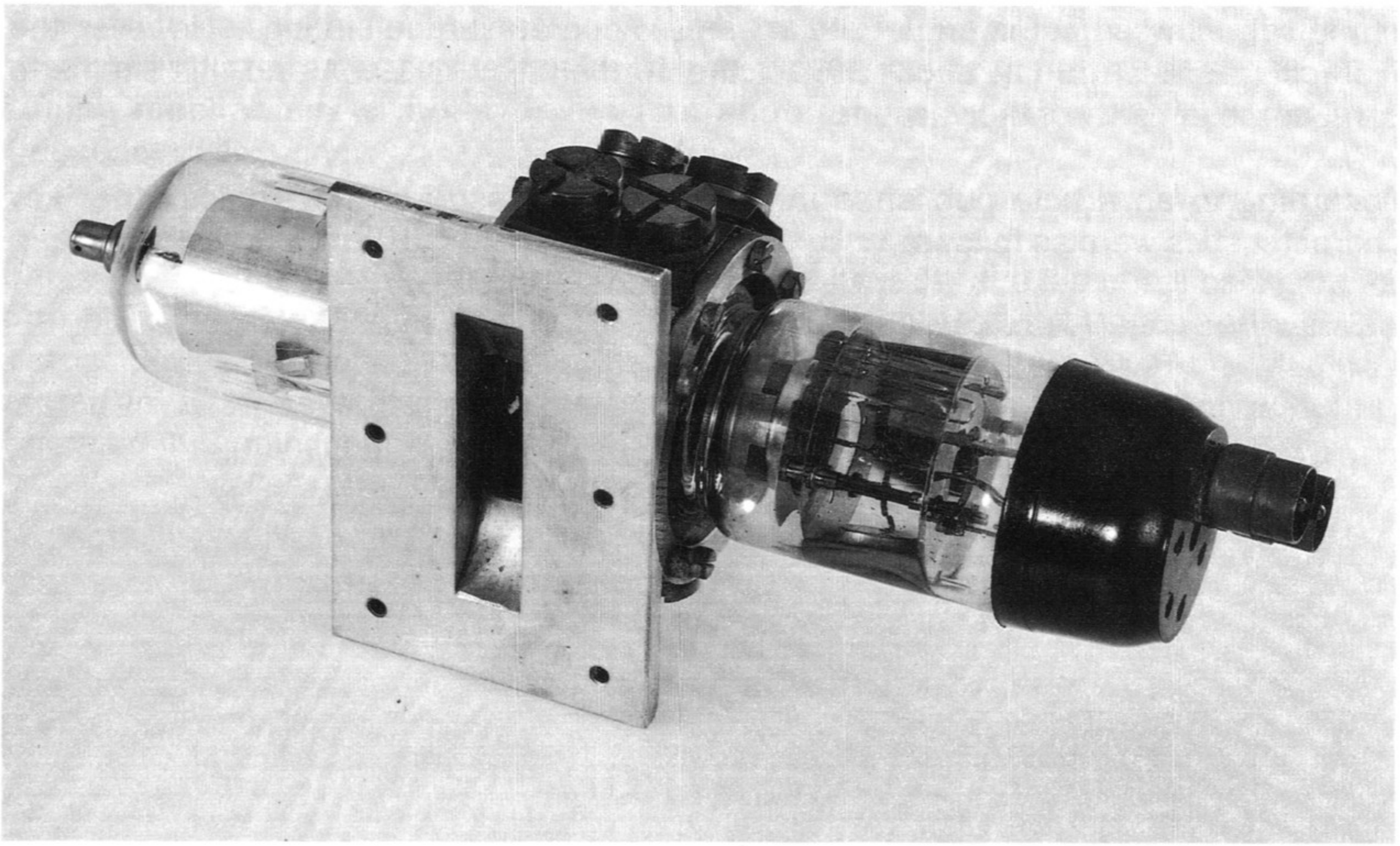
KLYSTRON

AM Ref 10E/501 c.1941
The first reflex klystron to be manufactured from the design developed by Sutton and his team at HM Signal School at Bristol. Power output was a few tens of milliwatts at 10cms and the valve in its Naval version NR89 was used in the type 271 radar. The Air Ministry version was used in early marks of centimetric ASV. The valve is easily distinguished from later versions because of its long drift space and hemispherical reflector. Manufactured by both EMI and E.K. Cole, the example without its resonator clearly shows the differences versus the later version CV67.

CV67 EMI c.1943
After two redesigns the CV67 was evolved from the original Sutton tube and became the standard receiver fit for British "S" band radar equipment. Although the operating voltage was still high (1400 Volts), the power output was increased to 300mW and the frequency stability with supply voltage variations much improved. However tuning was still effected mechanically.

CV150 EMI c.1943
Developed by EMI as the PK150 this valve was an attempt to develop the Klystron to a point where it could deliver sufficient power to be used in a radar transmitter. Although the performance, 15kW out at 10-12 percent efficiency was comparable with

early unstrapped "S" band Magnetrons, Magnetrons were by this time providing powers up to a few 100kW and efficiencies in excess of 50 percent. However work on the CV150 had continued in the hope that it could be used in equipment being flown over Germany so that the secret of the cavity Magnetron would not be compromised. Production of the valve ceased in June 1944.



CV150, THE WORLDS FIRST HIGH POWER KLYSTRON DEVELOPED BY EMI AS AN "S" RADAR TRANSMITTING TO AVOID THE NEED OF FLYING MAGNETRON EQUIPPED AIRCRAFT OVER GERMANY.

KRN2 EMI. c.1942
Type approved as CV87 this valve was the first production 3.0cms "X" band reflex Klystron in the UK. Used in the early versions of AIX and H2X it overcame the problems of losses in the glass envelope at 10GHz by making use of a harmonic resonator, which had first been proposed by Blumlein. Unfortunately the complex tuning mechanism was difficult to manufacture and the valve was quickly superseded by the CV129.

WL417A WESTINGHOUSE.
A mechanically tuned reflex Klystron with flexible copper bellows between top and bottom of the tube. The tube has two outputs and was used as the local oscillator in the SCR584 "S" band radar. The SCR584 was the first auto follow gun laying radar and played a significant role in helping to defeat the V1 attacks on London.

723A/B WESTERN ELECTRIC. c.1943
An all metal "X" band reflex Klystron designed by Shepherd and Pierce in the USA.

Capable of both mechanical and electrical tuning this valve became the preferred "X" band local oscillator for all 3cms receivers for many years. The valve fitted into a special international octal base with pin 4 removed and the output was coupled via a probe directly into the waveguide. Apart from Western Electric it was made by many companies in the USA and also in other countries including the UK and USSR.

CV129 EMI. c.1943
At the same time as the 723A was being developed in the USA, EMI had simplified the design of the KRN2 to ease the manufacturing problems. This valve type approved as CV129 was used in a number of UK designed 3cms radars until supplies of the 723A became readily available. Whilst mechanically much simpler than the KRN2 it still required 1600 Volts for correct operation which was undesirable in airborne equipment.

RK707B RAYTHEON. c.1945
An octal based external cavity reflex Klystron for local oscillator applications. By changing the resonator and reflector voltage it was possible to operate this valve over a wide frequency range. The specified performance is 110mW output from 1200-3750MHz.

TRANSMIT RECEIVE (T/R) CELLS

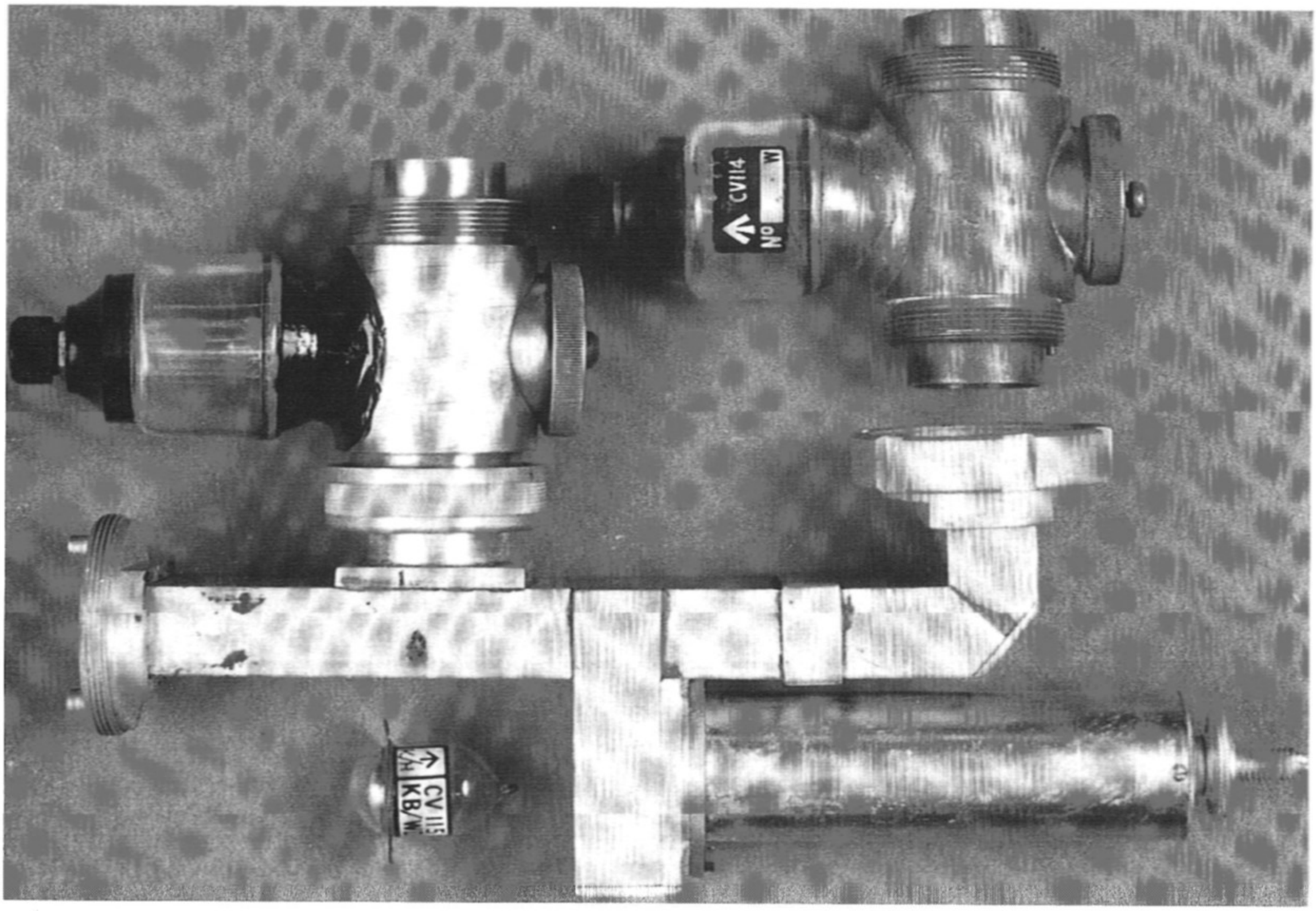
Early Radar systems used separate aerials for transmission and reception. However once the advantages of using a common aerial for both became apparent it was essential to devise a method by which the sensitive receiver could be protected from the high power transmitter pulse. Initially this was achieved in metric radar systems using spark gaps and quarter wavelength lines, but when centimetric radar was developed it became necessary to find better methods of isolating the receiver as the silicon mixer diodes were susceptible to damage by very small amounts of RF energy breakthrough.

VI507 GEC/MOV. c.1941
A spark gap type T/R cell designed for use in 1.5 metre radar systems. The initial design contained argon at 400mm Hg pressure and a small quantity of mercury and could withstand 25kW peak for several hundred hours. The recovery time was of the order of 100 microseconds. The design was subsequently modified by the addition of 5% oxygen to the argon, which reduced the recovery time to 10 microseconds at the expense of a slight increase in transmitter breakthrough.

1960 RCA. c.1941
An American designed spark gap type T/R cell with a performance similar to that of the VI507. Was used in a number of USA metric radar systems.

JAPANESE. c.1942
A Japanese manufactured spark gap T/R cell. Presumed to have been used in several Japanese metric radar systems.

CV43 E.K.COLE. c.1942
The first gaseous T/R cell developed specifically for use in centimetric radar systems. Known as the "Soft Sutton tube" the CV43 made use of the resonator and glass body of the NR89 Klystron. The tube was filled with a mixture of argon and water vapour at 6mm Hg pressure and had a life of a few hundred hours. The tube was fitted with a small keep alive electrode which facilitated the initiation of the discharge. It was used in AI MkVIII and H2S.



"X" BAND WAVEGUIDE MOUNTED T/R CELL TYPE CV114 AND AT/R CELL TYPE CV115

CV114 GEC. c.1942
Originally designed by Skinner and Ward at TRE the CV114 was the first "X" band T/R cell and was externally tunable via a flexible copper bellows. The cell was fitted with lead glass windows for coupling to circular waveguide. Insertion loss was in the region of 3dB. It was used in AIX and H2X.

LG76 TELEFUNKEN. c.1944
When the Germans recovered the H2S equipment from the crashed Stirling bomber in Rotterdam early in 1943, as well as discovering the cavity Magnetron they also found the CV43 T/R cell. The LG76 is virtually a direct copy of CV43 and was used in the "Berlin" 10cms AI radar.

CV115 GEC. c.1942
Known as an anti T/R or TB cell, the purpose of this device was to reduce the amount

of received signal lost in the transmitter between pulses. Because it did not contribute to the protection of the mixer crystal the TB cell was not required to switch quickly and therefore the keep alive electrode could be dispensed with and inherently the device could be much simpler. The CV115 was designed in conjunction with TRE and type approved in 1943.

721A SYLVANIA. c.1944
A gaseous "S" band T/R cell designed to be fitted into an external cavity. This device was used as the T/R cell in the SCR584 auto follow radar and provided approximately 70dB of attenuation to the transmitted pulse deionisation time is less than 1 microsecond.

WL1B24 WESTINGHOUSE. c.1943
A gaseous "X" band T/R cell of similar design to the British CV114.

CV193 E.K.COLE. c.1943
A waveguide slot coupled "S" band T/R cell. As transmitter powers increased to more than 50kW peak it was found that flashover problems occurred with the loop coupled resonator type T/R cells like the CV43. In order to overcome this difficulty the slot coupling method which allowed the unit to be bolted directly to the side of the waveguide was devised at ASE. The CV 193 was capable of handling powers up to 200kW.

CV6073. c.1950
An "X" band waveguide inserted T/R cell. This particular device has three gaps internally to reduce leakage to a minimum. Although this cell has a keep alive electrode a number of "X" band waveguide T/R cells contained a low energy radioactive source to provide the initial ionisation and assist rapid turn on.

MODULATORS

A radar system generally requires the transmission of a short high power pulse of RF energy on a regularly repetitive basis. In a few systems this is achieved by allowing the transmitter oscillator to be "self pulsed", but in the majority of cases a high power modulator is needed. These modulators in the early days of radar fell into three main categories namely, hard valve, thyratron and triggered spark gap in association with a delay line. This section of the exhibit shows examples of all three types.

CV57 GEC/MOV c.1942
A hard valve beam tetrode capable of handling 5 Amps at 10KV. A pair of these valves in parallel were used initially to modulate the CV64 Magnetron in early version of Al MkVIII. Using two cathodes the design was based on that of the classic audio valve the KT66.

RK-715B RAYTHEON. c.1943
An American designed hard valve modulator tetrode. Rated at 12KV and 15 Amps peak anode current, the valve was used in a number of modulation systems for the medium power Magnetrons available at the time. An improved version the 715C with an anode voltage rating of 17.5KV was introduced about 1 year later and was manufactured by several companies in the USA and UK.

304H HEINTZ AND KAUFMAN. c.1940
A VHF triode actually designed as a transmitting valve but pressed into service as a radar modulator. Eight of a similar valve the 304TL were used in parallel as the modulator in the SCR268 200MHz radar. The valve is shown in its original shipping cradle.

GMN-90 RUSSIAN.
A high power all glass modulator tetrode believed to be from the same radar system as the MN119 tunable Magnetron q.v. Although its specification is not known examination of the internal structure would seem to indicate a peak power rating in the region of 20-25KV at 100Amps.

RS391 TELEFUNKEN.
1943 A German modulator tetrode a pair of which were used in the Freya 125 MHz air defence radar. Radar output power was approximately 20kW so the handling capability of each RS391 is likely to have been of a similar level.

CV22 BTH. c.1941
A mercury vapour thyratron capable of handling 50 Amps at 20KV. However the mercury thyratron suffered from the disadvantage that due to the slow deionisation time, typically greater than 1 millisecond it was not possible to use it at pulse rates greater than 500pps. Nevertheless the CV22 was used as the modulator in Naval radars 271Q and 291 and also in the Army GL3 system.

CV85 METROPOLITAN VICKERS. c.1942
The first of the triggered spark gap or "trigatron" devices it contains a mixture of argon and oxygen gas at several atmospheres pressure. Used in conjunction with a delay line the CV85 could generate pulses of up to 160kW peak. The valve was part of the modulator type 64 which was used in early versions of "S" band AI and H2S. The valve is fitted with a protective sock to prevent damage or injury should it explode due to its high internal pressure. Later developments of the valve (CV125) gave powers up to 500kW.

THE HISTORIC VALVE DISPLAY

All the valves on display in the historic exhibit at M94 Wembley form part of the private collection of Rod Burman, Managing Director of Pascall Microwave Ltd.

This collection has been assembled over a number of years and apart from a few exceptions covers the period 1905-1950. At present it totals more than 2000 different valves divided into the following five categories.

Early Valves (before 1931)

Unusual Thirties Valves

Transmitting Valves

CV Valves

German World War II Valves

The majority of valve collectors tend to concentrate on early valves which are becoming increasingly difficult to acquire. However, because of the rapid development of thermionics in the 1930's and especially the War years this period provides a particularly rich source of interesting valve types, not the least in areas associated with radar and microwave technology.

Unfortunately once semiconductors took over the role of active devices in electronic systems valves were rapidly consigned to the rubbish tip and it is only recently that their historic importance has become more widely appreciated. For example, the GEC E1188 which was the intermediate Magnetron between the Randall and Boot Birmingham prototype and Megaw's successful E1189, although reasonably well documented is believed not to have survived even though several were made.

Consequently, if any of the visitors to M94 who have enjoyed seeing the historic valve display know of early or interesting valve developments that have not yet been discarded and are seeking a "good home" please contact:-

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Pascall Microwave Ltd.
Saxon House, Downside
Sunbury-on-Thames
Middlesex, TW16 6RY.
Tel. 0181 979 0123
Fax. 01932 782402

If examples are not already in the collection they will gladly be added.

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