Supplement to the Bulletin of the British Vintage Wireless Society

This Supplement to the Bulletin is a new venture and it may be worth a word or two to explain what it is all about. It springs from the fact that from time to time we get articles which are too long or too specialised to be suitable for inclusion in the regular Bulletin series. These are often very interesting and it seems a pity not to be able to publish them, so we are starting these Supplements as a vehicle for such contributions. It is intended that a Supplement shall be issued at least once a year, or possibly more frequently if funds (and editorial effort) allow. We would be grateful for your reactions to this. Do you find the content interesting and have you suggestions for future issues? We would certainly welcome comments, critical or otherwise, so that we can know what you would like for the future. *Pat Leggatt & Bob Hawes*

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Metropolitan-Vickers

by Alan Douglas

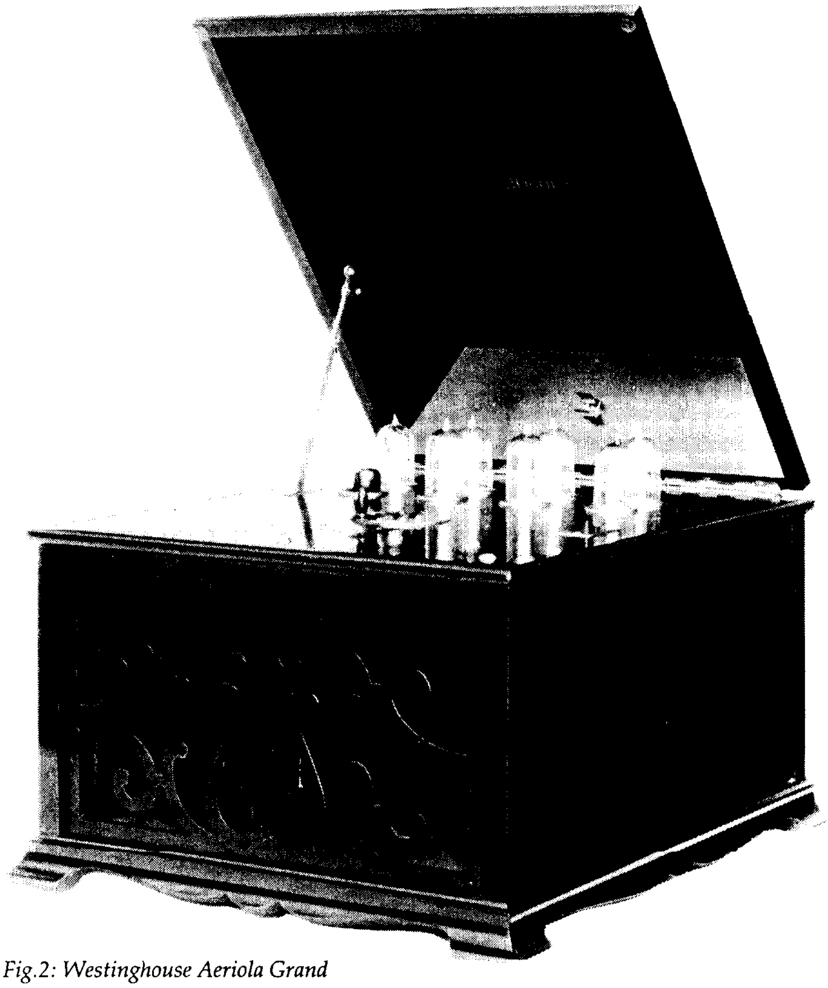

Fig.2: Westinghouse Aeriola Grand

One of the "Big Six": Metropolitan-Vickers and its Venture into Broadcast Receiver Manufacture, 1922-1928.

To understand Metro-Vick and its involvement with wireless, we must first look at the ties between some British and American electrical companies, and the start of American broadcasting.

In 1892 the Edison General Electric Company and the Thomson-Houston Company, the two largest electrical manufacturing concerns in America, merged to form the General Electric Company (GE): Thomson-Houston, smaller but better managed and financed, effectively swallowed Edison. In England, the General Electric Company (GEC) had already been in existence since 1889, so when American GE created a British subsidiary it had to take the Thomson-Houston name. Thus the two General Electric companies had no connection; and American GE's counterpart was actually the British Thomson-Houston Company (BTH).

The American Western Electric Company was a telephone supply company absorbed in 1882 by the American Bell Telephone Company as its manufacturing arm ('Western' because it was located in Chicago). A London branch office was opened in 1883. When IT&T bought Western Electric's international business in 1925, British Western Electric became Standard Telephones & Cables, Ltd. (STC) in October of that year.

In 1899 the American Westinghouse company founded a British subsidiary, the British Westinghouse Electrical & Manufacturing Co. Ltd. Westinghouse in the US had its share of financial problems – George Westinghouse, while a brilliant inventor and engineer, did not excel in corporate management. In spite of being the second-largest electrical manufacturing firm in the US, and General Electric's chief competitor, it barely avoided bankruptcy in 1908, and in the years following disposed of most of its overseas subsidiaries. British Westinghouse was sold in 1917 to a holding company (Electric Holdings Ltd) which was controlled by Metropolitan Carriage, Wagon & Finance Co. Ltd. and later, in 1918, jointly by Metropolitan and by Vickers Ltd. US Westinghouse sold all its Electric Holdings stock in 1919, although Westinghouse and Metropolitan-Vickers remained in close touch thereafter.

There is no doubt that Westinghouse did more than anyone else to popularise broadcasting, by establishing stations at East Pittsburg, Pennsylvania (KDKA); Newark, New Jersey (WJZ); East Springfield, Massachusetts (WBZ); and later Chicago, Illinois (KYW). Unlike most other stations which were run for publicity by newspapers or department stores, Westinghouse stations had a more specific purpose – to create a market for manufactured receivers, already designed and in production before KDKA went on the air in November 1920. GE, with a long lead in shipborne and commercial radio, was caught napping – if not snoring loudly – since it waited until October 1921 before constructing a station (WGY) and did not begin broadcast receiver design until December.

The Westinghouse receiver line in 1921 comprised four models; RA & DA, Aeriola Junior, Aeriola Senior, and the Aeriola Grand. The RA tuner and the DA detector amplifier (*Figure 1*), known as the RC when combined in one cabinet, had been designed in 1920 to be simple to use, but without much regard for cost.The Grand (*Figure 2*), available at the end of 1921, was very high-priced and few were ever sold.

Fig.1: RA tuner/DA detector amp.

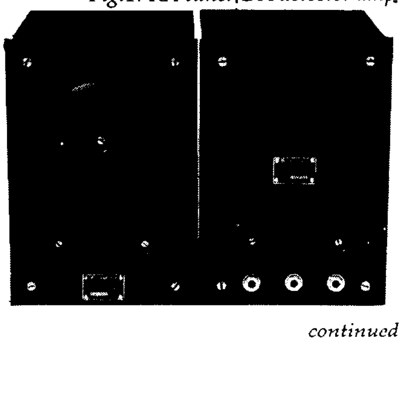

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Fig.3: Aeriola Junior crystal set

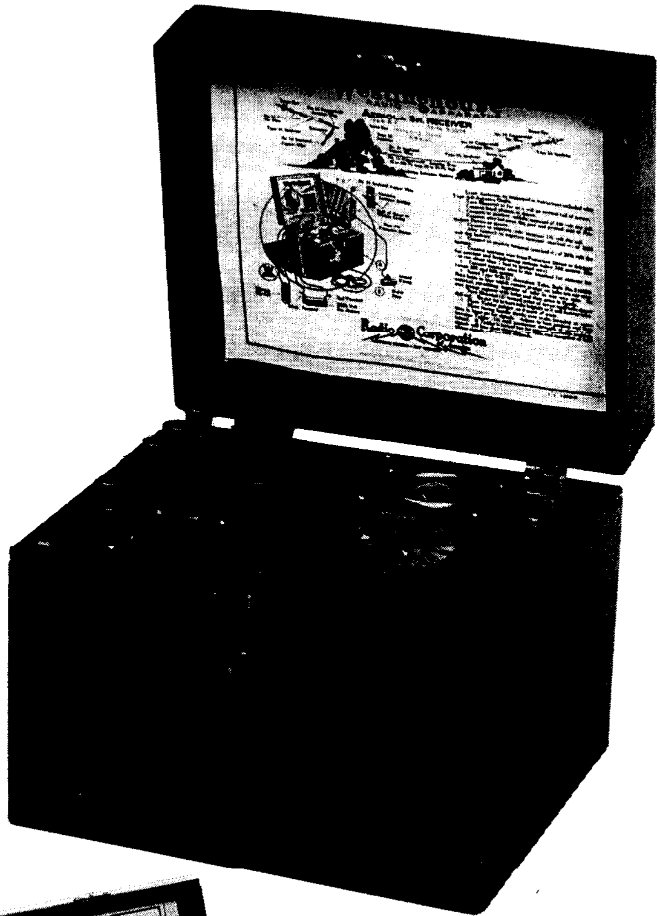
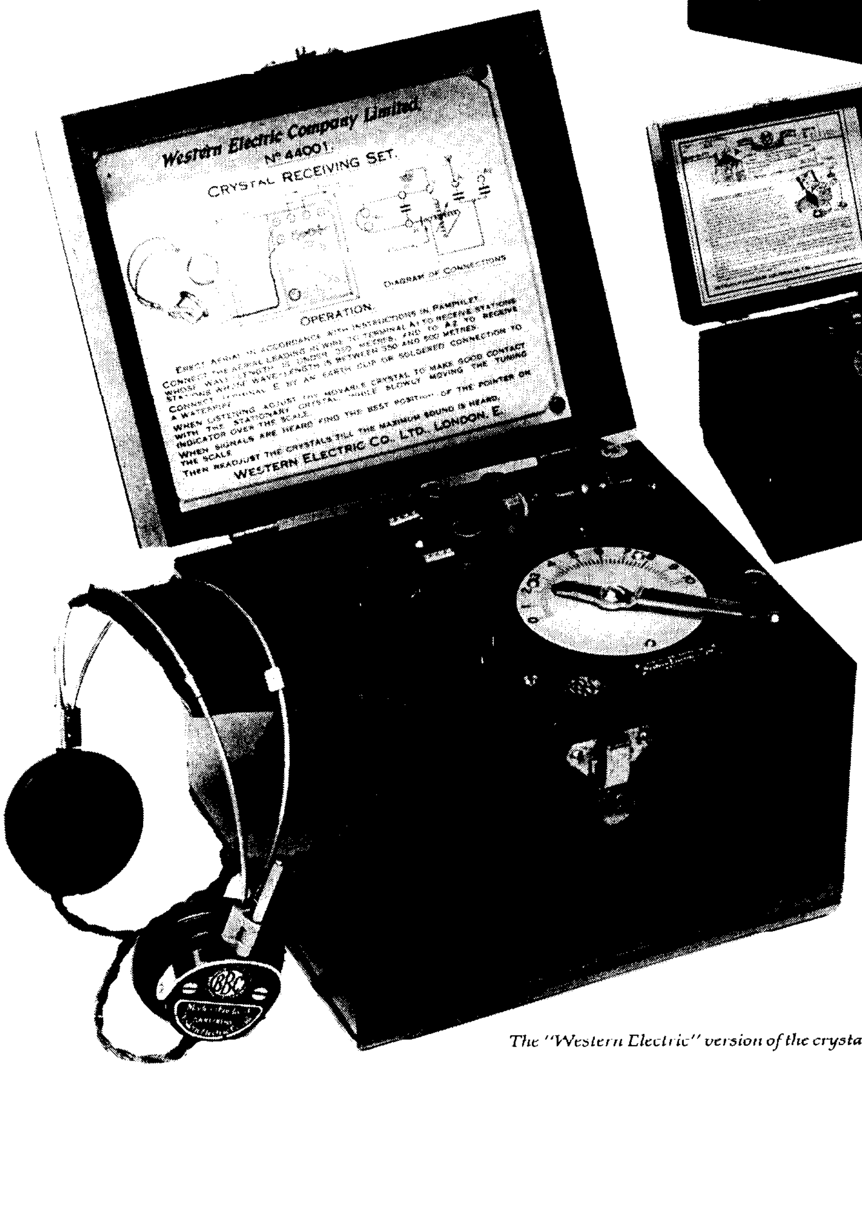


Fig.4: Aeriola Senior receiver



The "Western Electric" version of the crystal set

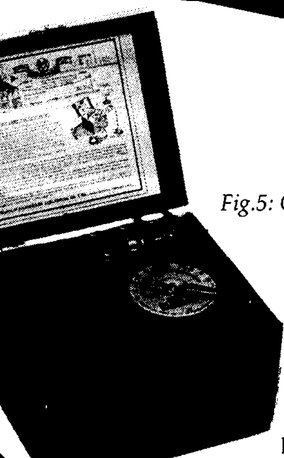


Fig.5: Cosmos C1 crystal set

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But the Aeriola Junior crystal set and the Aeriola Senior 1-valve set *(Figures 3 & 4)* were ideal – simple, efficient and designed with an eye on production costs. The Junior was so far ahead of the rival General Electric's designs that GE engineers used one as a laboratory standard while creating their own model (ER753, marketed in April 1922). Seniors, or other models with the same tuner design, were still being sold by RCA in 1926. When A.P.M.Fleming of Metro-Vick sought to get his company into broadcasting he naturally turned to Westinghouse who were so well experienced in station design and receiver manufacture. He undoubtedly obtained drawings of both the Junior and Senior in 1921, and the resulting Cosmos C1 crystal set *(Figure 5)* was virtually identical to the Aeriola Junior.

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1 and 2-valve LF amplifiers (A2 and A3) were also advertised, fitting neatly into the headphone compartment of the C1. Metro-Vick seems also to have supplied the C1 to the Æolian Co. Ltd, who sold it as "Aeriola Junior": Æolian also marketed larger models such as the 2-valve Cosmos VS1. It seems that the U.S. Æolian Company did not deal in radios; although station WJZ, after being transferred from Westinghouse to RCA and moved to New York City, was located in Æolian Hall.
British Western Electric also marketed its version of the Junior, not surprising since there were no American Western Electric models to copy. U.S. Western Electric was not licensed to make domestic receivers, having left that to GE and RCA when the cross-licensed "Radio Group" was created in 1920. Western Electric made receivers largely for monitoring at the several hundred broadcast stations it equipped; but Northern Electric did sell similar models for home use in Canada. Furthermore there were already ties between Western Electric and Westinghouse, as exemplified by the WD11 valve used in the Aeriola Senior, electrically identical to the Western Electric 215A Wecovalve which appeared a little later; however, no documentary evidence of this WD11/215A connection has so far been found.

It seems likely that A.P.M.Fleming would have put the Aeriola Senior into production along with the Junior; but around May 1922, when negotiations began with the Post Master General concerning the proposed British broadcasting company, it must have become clear that aerial reaction was to be prohibited – and reaction of course was what made the Senior so efficient. Evidently Metro-Vick engineers modified the Senior by removing the reaction and adding an HF stage, but retaining the original cabinet. This modified set (*Figure 6*) was exhibited in September 1922 but not widely advertised or sold. By March 1923 it had been superseded by a larger 2-valve model VR2, with two tuning controls a tuned intervalve transformer having been added. Carryovers from the older model (and from the original Aeriola Senior) were the use of variometers for tuning rather than variable condensers, offset tuning levers, and the use of silver-coloured dial plates: Westinghouse had a special department to make its own silvered brass nameplates and dials for the various works scattered around the USA; while Metro-Vick used aluminium.

Fig.6: Early Metro-Vick 2-valver

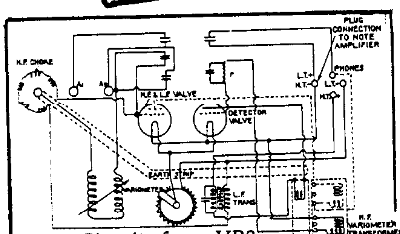
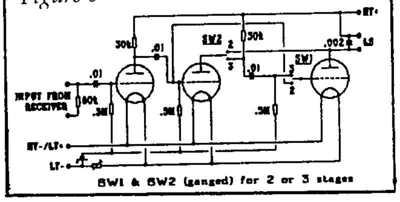


Fig.7: Circuit of new VR2

Figure 9



Although a November 1923 Modern Wireless advertisement illustrates the original VR2 model, the text describes a quite different VR2 (or VS1, VS2, VS3 when installed in a larger cabinet, with or without the A4 LF amplifier and loudspeaker). The new VR2 had different tuning knobs and an added reaction control, but the big change was inside – a reflex circuit using the first valve as both HF and LF amplifier (*Figure 7*). Reaction was allowed because it was applied to the detector stage, not to the aerial circuit. Together these changes must have improved the performance considerably.
A month later the VS4 made its appearance (*Figure 8*), a large set with frame aerial, three HF stages, carborundum detector and three LF stages: the three HF variometers were mechanically coupled so that tuning of all intervalve circuits could be effected with a single knob. While there is no direct evidence, the new VS1,2,3 & 4 range could well have been the work of Norman P. Hinton, who had resigned his Post Office position on May 30th 1923 and who began filing patent applications for Metro-Vick in June.

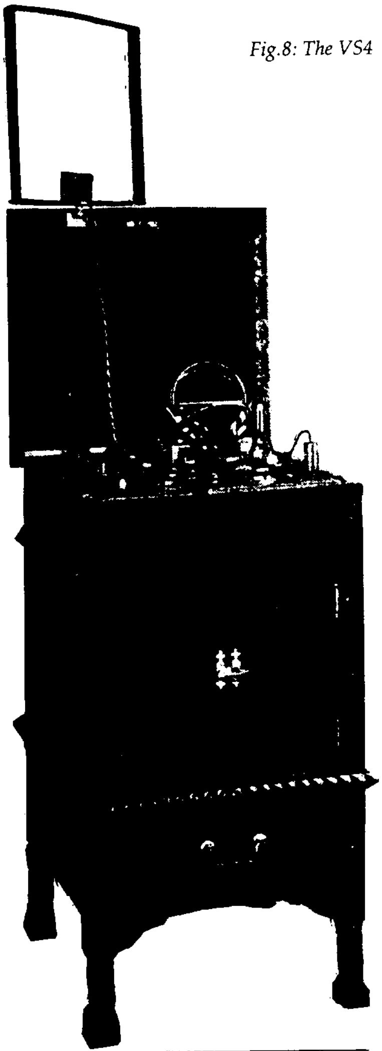
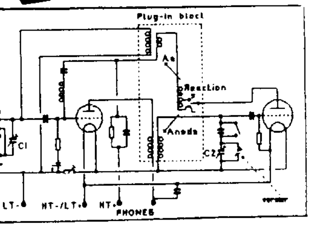


Fig.8: The VS4

Fig. 10



There is no doubt who designed the next series of models, based on the VR3 "Universal" tuner and A5 resistance-capacity coupled amplifier (*Figure 9*). The VR3 incorporated an ingenious dual reaction arrangement whereby a swinging coil could be moved into coupling with either the detector coil or the HF input coil, enabling reaction to be applied around the detector alone, or around both detector and HF stages for maximum sensitivity. Hinton secured both British and US patents for this system, as did W.J.Brown for his placement of both detector and HF stage coils in a single interchangeable box. To further complicate matters, the VR3 also embodied reflexing, in this case using R-C coupling without LF transformers. The circuit is shown in *Figure 10* and, amazingly, the whole box of tricks works quite well!

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Evidently the VR3 series did not entirely supplant the VR2, since in mid-1925 one large distributer, the East London Rubber Company, was offering both types, in a variety of cabinets. The old C1 crystal set was also there in the 1925/1926 catalogue and the Western Electric; but not, significantly, the 6-valve VS4 set which evidently had a short production life. In the United States, the final embodiment of the variometer-tuned Aeriola Senior was the Radiola III (*Figure 11*), introduced in February 1924 and sold for two years. Built by Westinghouse and sold through RCA, it looked totally unlike the average American set, with its horizontal panel and exposed WD11 valves; but this arrangement allowed simple mechanical design and a small cabinet. The cabinet, the one component that had to be bought in, was probably the most expensive part.

No doubt seeking economies, Metro-Vick entirely eliminated the wooden cabinet in its next model, the VR4 "Cruet" set (*shown in Figure 12*), building it instead on a circular moulded composition base. This was introduced at the NARMAT exhibition at the Albert Hall in September 1925, together with a matching crystal set, type C4 (*shown in Figure 13*). The Cosmos line for the 1925/1926 season comprised the two new models VR4 and C4, together with the existing VR3 series VS5, 6 & 7 (*Figures 14 & 15*). Cosmos was by now making a series of valves, the DE11 (September 1924), SP18 (March 1925), and A45 (May 1925): their sets generally used SP18s, Green Spot (higher gain) for HF and Red Spot (lower gain) for LF. Perhaps the close tolerances in the SP18 electrode assembly were at first difficult to hold under factory conditions, so Cosmos simply graded them after manufacture. A Blue Spot version for R-C coupled amplification appeared in June 1926, but this difference at least was intentional since the filament took 90mA rather than the 300mA consumption of the Green and Red Spot types.

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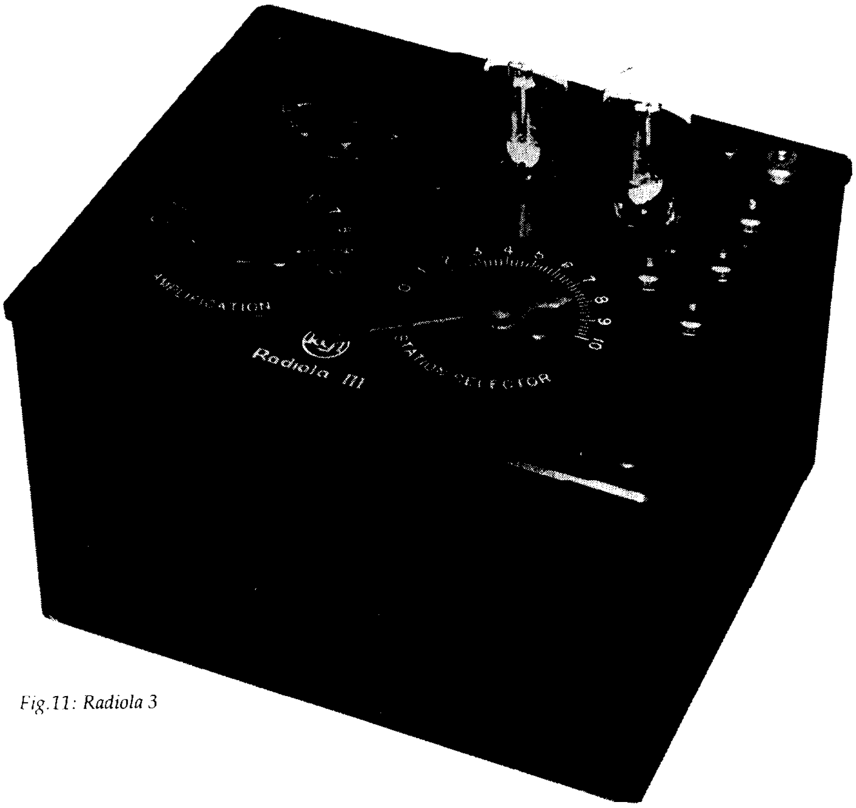
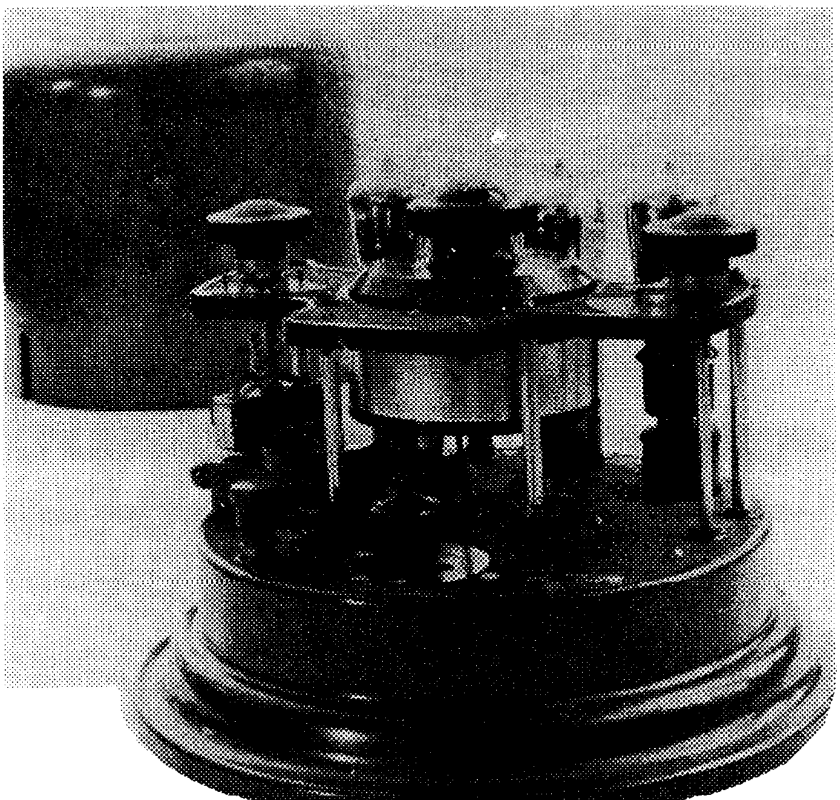


Fig.11: Radiola 3

Fig. 12 The VR4 "Baby Grand" known to collectors as the "Cruet Set"



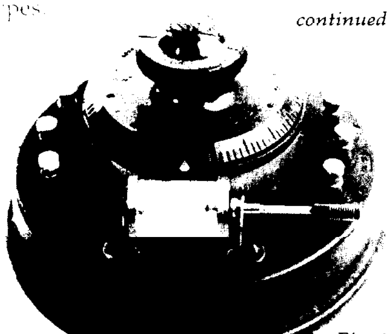


Fig. 13: The C4 Crystal set

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Metro-Vick apparently did not bring out any new wireless models in 1926, the Wireless World Olympia report mentioning only valves and components as new Cosmos items. By 1927 the old VR3 would have looked positively antiquated; so it had to be replaced and Hinton designed the Five which was exhibited at Olympia in September. This was very much like standard American practice of a 5-valve set with two HF stages, detector and two LF, tuned by three separate dials (though by this time the tuners on American models were usually linked to a single dial). Most of Metro-Vick's advertising was now for valves, components, and a variety of kits for home-construction including 3 and 4-valve versions. The following year, the Five was offered as a mains set; and factory-made Three and Four sets were advertised too , all using the new indirectly-heated valves produced by E.Yeoman Robinson, designer of Metro-Vick's "Short Path" series.

The International General Electric Co.(IGE), a subsidiary of American GE, bought control of Metropolitan-Vickers from Vickers Ltd in 1927, in accordance with a plan of F.Dudley Docker to form a single British electrical holding company: GE already controlled British Thomson-Houston. Rather than form an entirely new company, it was decided to use the existing structure of Metro-Vick and its subsidiary Metro-Vick Supplies. In January 1929, Metropolitan-Vickers Electrical Co. became Associated Electrical Industries Ltd and transferred its manufacturing activities to the Metro-Vick Supplies subsidiary, which in its turn took on the original name of the Metro-Vick parent company. AEI acquired most of the capital stock of BTH; Edison Swan; and Ferguson, Pailin Ltd: GE held a large interest but not the majority voting power.

At this point the way was clear for rationalisation of duplicated facilities within the group, which was done during the following year. The valve business of all three companies went to Edison Swan in August 1929 under the well-established Mazda name, while Metro-Vick's Wireless Department closed down completely.

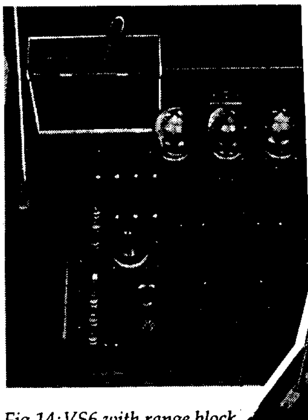

Fig.14: VS6 with range block

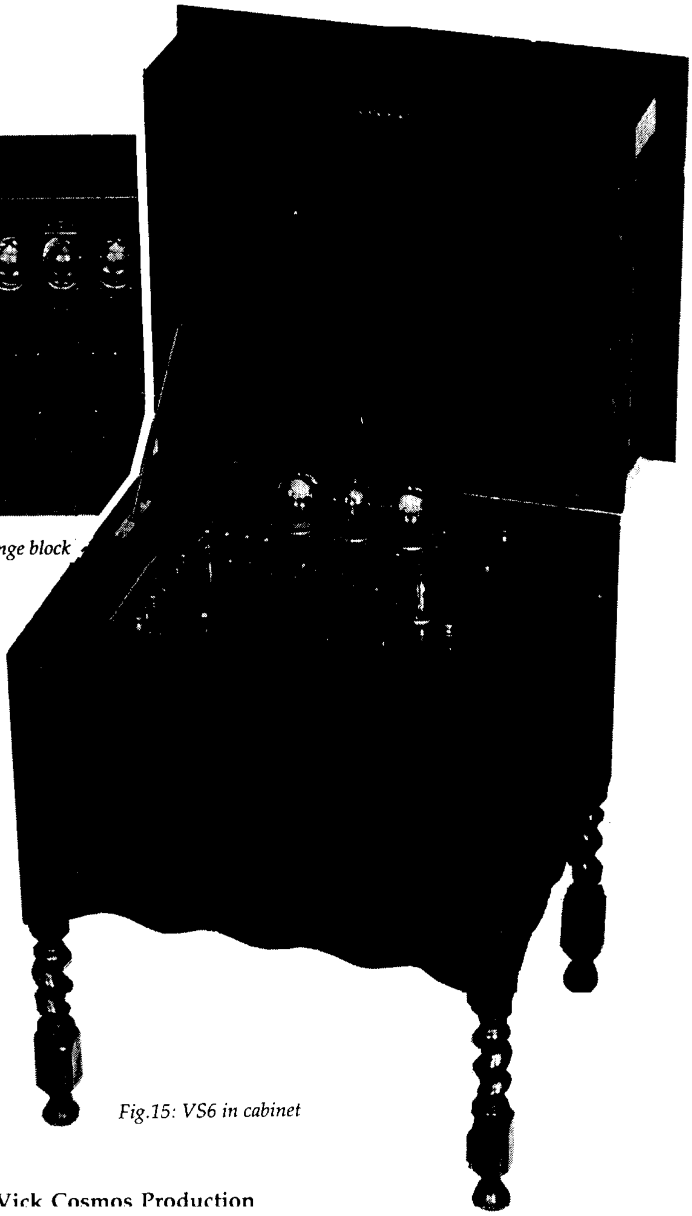

Fig.15: VS6 in cabinet

Metro-Vick Cosmos Production

Model	First advertised	Description
Crystal Sets		
C1	9/22	wooden box
C4	8/25	moulded composition case
Valve Sets		
—	9/22	2-valve, 1 tuning dial
VR2	3/23	2-valve, 2 tuning dials
VR2	11/23	same, with reaction & reflex circuit
VR3	9/24	2-valve 'universal' (plug-in coil box)
VR4	9/25	3-valve 'Cruet' set
Five	9/27	5-valve, 3-dial, battery-operated
Three	11/27	3-valve kit set, mains or battery
Four	1/28	4-valve kit set, mains or battery
Five	9/28	now mains-operated
Three	9/28	first advertised as factory-made
Four	9/28	first advertised as factory-made
Amplifiers		
—	9/22	companion to 2 valve set
A2	11/23	1-valve amp. for crystal set
A3	11/23	2-valve amp. for crystal set
A4	12/23	2-valve amp. for VR2, transformer coupled
A5	9/24	3-valve amp. for VR3, R-C coupled
Combination Sets		
VS1	3/23	VR2 in large table cabinet
VS1	12/23	new VR2 in large table cabinet
VS2	11/23	VR2 & A4 in large table cabinet
VS3	11/23	VR2 & A4 in console with loudspeaker
VS4	12/23	6-valve with frame aerial, table model or console
VS5	9/24	VR3 in table cabinet or console
VS6	9/24	VR3 & A5 in console with loudspeaker

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Radio! Radio! by Jonathan Hill.
Copy of 1925/26 East London Rubber Company catalogue, from Tudor Rees

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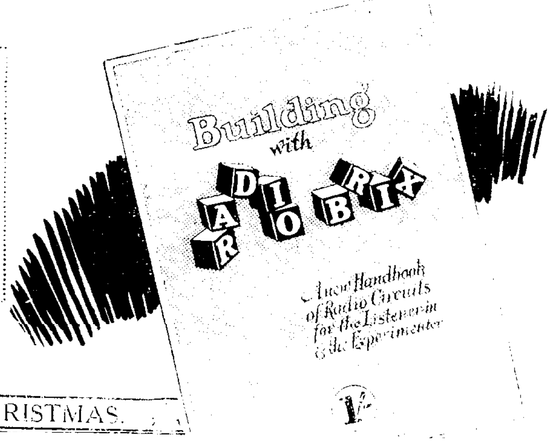


"COSMOS" RADIOPHONES AND "RADIOBRIX" FOR CHRISTMAS.

A review of early television in the UK

by Pat Leggatt

Establishment of Basic Principles.

The communication system requirements for television are not dissimilar in principle to those for radio, except perhaps that the necessity for a linear link is not so fundamental in the television case. The development of radio-frequency generation, transmission and reception techniques for sound broadcasting served, in general, for television transmission developments.

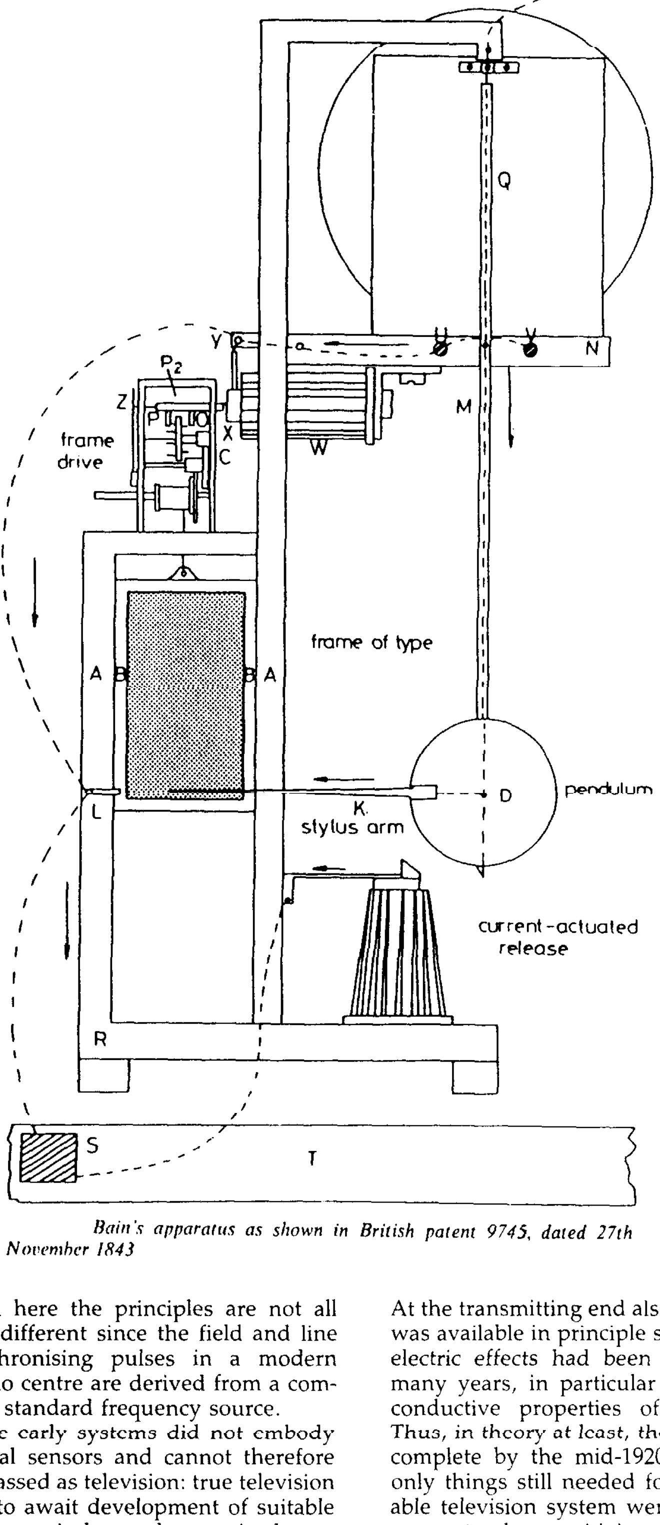
The early technological problems of television centred firstly on the conversion of data from a two-dimensional area object into a single serial data stream, and vice versa; and secondly on the required opto-electrical transmitting and receiving transducers. Solutions for the first category of problems were established as early as 1843 when Alexander Bain published his ideas for a facsimile system. This included simultaneous horizontal and vertical scanning of the object surface, together with measures for synchronising the receiver scanning with that of the transmitter. The transmitter transducer was based on electrical contact of a stylus, so the object surface had to be describable in terms of the presence or absence of electrical conductivity: printer's type-metal was an original application.

At the receiving end the electrical signals were passed to a stylus which was scanned over the area of a sheet of paper. The paper was moistened with a chemical solution which discoloured with the passage of current, thus reproducing an image of the original object surface.

At the transmitter and at the receiver, line scanning was controlled by pendulums, coupled to escapement mechanisms to provide frame scanning. A synchronising signal was arranged to delay the latched release of one pendulum if it got ahead of the other.

These scanning and synchronising principles were almost identical to those employed in television today, except that today's television receiver frame scan is initiated by separate synchronising signals rather than as a count-down from the line scanning.

Bain's facsimile apparatus



Bain's apparatus as shown in British patent 9745, dated 27th November 1843

Even here the principles are not all that different since the field and line synchronising pulses in a modern studio centre are derived from a common standard frequency source.

These early systems did not embody optical sensors and cannot therefore be classed as television: true television had to await development of suitable electro-optical transducers. At the receiving end some sort of solution became possible in the 1920's with the advent of valve amplifiers, in that the intensity of a neon discharge tube could fairly readily be modulated: the necessary scanning could be accomplished with the aid of Nipkow discs, or with oscillating or rotating mirrors.

At the transmitting end also a solution was available in principle since photo-electric effects had been known for many years, in particular the photo-conductive properties of selenium. Thus, in theory at least, the chain was complete by the mid-1920's and the only things still needed for a practicable television system were improvements to the sensitivity, colorimetry and speed of response of the camera transducer; development of scanning systems affording finer structure and higher picture repetition frequency; a transmission link of adequate bandwidth and phase response; and a larger, brighter display device. Yes, that was all!

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Mechanical versus Electronic Development

The cathode ray tube had been invented by Braun in 1897 and a number of workers saw the potentialities of an electronic approach to television. Rosing and Campbell-Swinton were notable proponents of this in 1911, but the technology did not then exist for their well-conceived ideas to be put into practice.
The field was left open therefore to development along mechanical lines. John Logie Baird commenced his work on television in 1923, giving the first successful demonstration of a complete system in October 1925. Similar work was being done at about the same time in America and Germany.
Mechanical scanning systems, although cumbersome, were adequate enough for the undemanding 30 lines/ 12½ pictures per second standards of this early television, and were indeed used for the BBC's regular experimental transmissions from 1929 to 1935. But a system for satisfactory public service required much higher picture definition and better movement portrayal, and the Baird system was finally pushed up to 240 lines/25 pictures per second. These in fact were the standards defined in the UK by the 1934 Selsdon Committee as the minimum acceptable for broadcasting, whereas they represented about the maximum which could be achieved by Baird's techniques. The situation was in some ways comparable to the early days of radio carrier generation, where the upper frequency limit of electromechanical alternators was soon reached and where further progress had to depend on electronic developments.

In fact there were two fundamental limitations in Baird's system. First, as already stated, there was the upper frequency limit of scanning systems depending on rotating discs or moving mirrors; and indeed Baird's 240 line installation at Alexandra Palace in 1936 included an electronically scanned device in the shape of the Farnsworth Image Dissector.
The second limitation of Baird's system lay in the lack of charge storage. Neither his "spotlight" (flying spot) camera nor the Image Dissector embodied storage mechanisms, the output signal arising only from the momentary exposure as the scanning aperture passed over each element of the scene. The flying spot camera was therefore very insensitive. The Image Dissector employed electron multiplication and was about ten times more sensitive as a result; but both types of camera required uncomfortably high lighting levels in the studio to produce tolerably noise-free pictures.

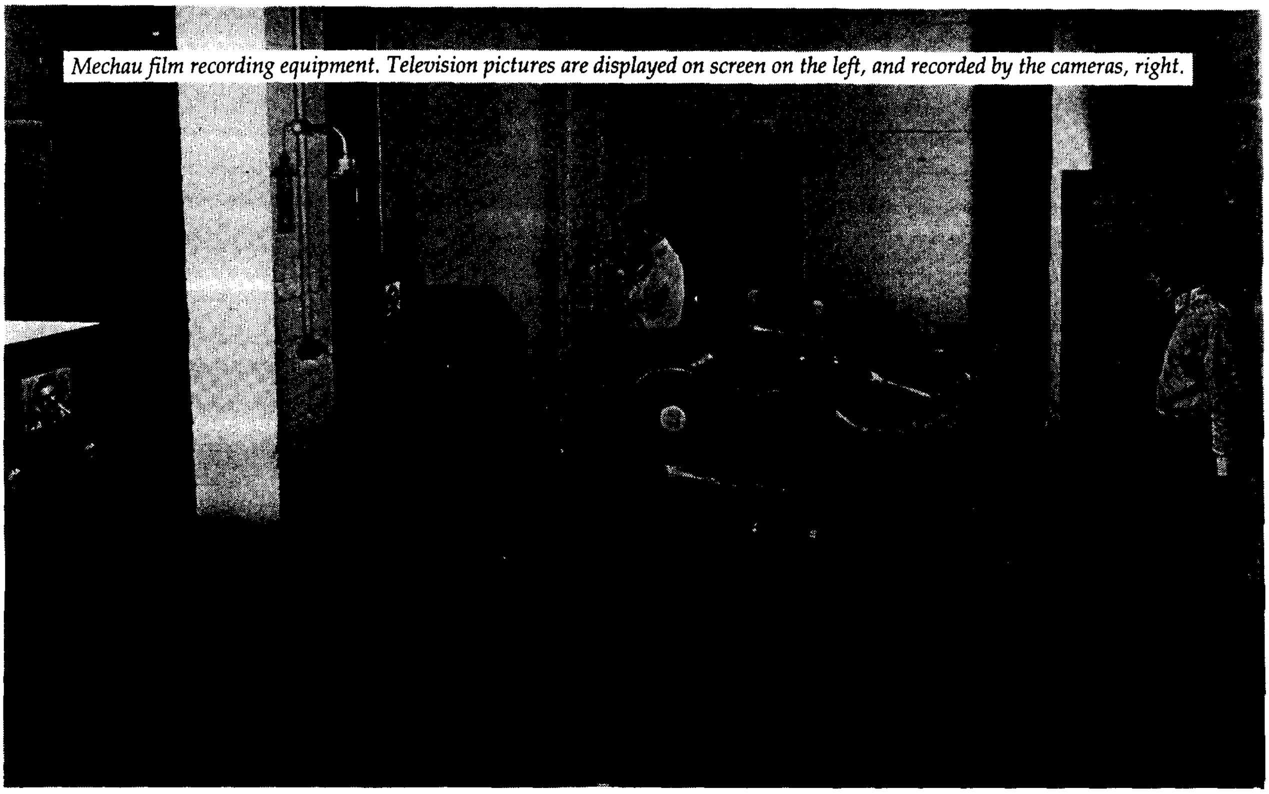

The new television control-room at 16, Portland Place, London

To overcome this basic lack of sensitivity Baird devised the intermediate film system, in which of course the emulsion surface is continuously exposed during the frame period and signal storage does therefore come into play. This did indeed offer reasonable sensitivity, but its immobility, bulk and high running cost were very evident disadvantages.
In contrast to Baird, EMI were working from 1931 on electronic television. Isaac Shoenberg, previously with Marconi's and the Columbia Graphophone Company, set up a team at Hayes including such figures as Blumlein, McGee, Lubszynski and Broadway; and in retrospect it seems inevitable that such an outstanding group should have achieved really notable success. Starting with transmission of films on 120 lines in 1932, EMI was ready by 1935 to match the 240 lines which represented the peak of the Baird system's development. But Shoenberg's team were not content simply to match their rival, and out of the blue they offered the Television Advisory Committee a remarkable leap to a 405 line/50 fields per second standard. This bold and imaginative decision by Shoenberg, triumphantly justified by the subsequent service which was finally closed only in 1984, set standards for television throughout the world in terms of picture definition and waveform techniques.

The success of the Marconi-EMI system depended of course on excellence in all parts of the chain. The cameras embodied McGee and Lubszynski's Emitron tube, similar in principle to the Zworykin Iconoscope developed in the United States, with electron-beam scanning of a photo-sensitive mosaic bringing the benefits of charge storage. The circuitry and waveform specification were largely due to Blumlein, much helped by EMI's access to the RCA interlacing patent. To Broadway goes credit for display cathode ray tube developments. And of course the association with Marconi's made available the necessary experience and skill for the wide-band VHF transmitter and aerial.
After a brief period during which the Baird and Marconi-EMI systems were transmitted in alternate weeks, the British television service was based exclusively on the all-electronic system from February 1937.

405-line television: the first three years

The original Emitron cameras were comparatively unsophisticated affairs. For example they had no viewfinders, although this was soon rectified by provision of an optical viewfinder with a second lens alongside the camera lens. The viewfinder picture was upside down, but nobody seemed to mind too much: at least the display was in colour, which is more than can be said of present day camera viewinders.
The Emitron was not a very good tube for telecine work (televising pictures from film) and indeed the quality of film reproduction was about the only aspect in which the Baird apparatus had been superior to the Marconi-EMI system. The spurious shading signals (tilt and bend) of the Emitron proved very difficult to correct in the film scanning application where abrupt changes of scene lighting balance could be expected: and because the



Mechau film recording equipment. Television pictures are displayed on screen on the left, and recorded by the cameras, right.

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telecine system involved a brief flash exposure during the scanning flyback period, the resulting large Emitron "photo pulse" proved troublesome. This latter difficulty was later removed by replacement of the intermittent-motion projector by a Mechau film transport in which successive tilting mirrors produced a stationary image from continuously moving film. The Emitron could therefore be exposed for the full television field period, avoiding the "photo pulse" and incidentally taking advantage of the tube's charge storage capabilities to reduce the required illumination.

Outside broadcasts were an early feature of the new television service, although at first the cameras could venture only into the grounds of Alexandra Palace to the maximum 1000 ft extent of their camera cables. Early in 1937 a balanced pair vision cable link was provided from central London to Alexandra Palace, and it was this that enabled the BBC to mount their first true outside broadcast. This was the Coronation of King George VI in May 1937 and it attracted the then huge audience of some 50,000 people. Soon after this the BBC acquired two mobile 3-camera O.B.vehicles and v.h.f radio links, enabling flexible coverage of all kinds of sporting and other events.

In those early days television was not regarded as the essential service it has now become. Odd though it seems to us today, the service closed down for three weeks in July 1937 to give the staff a holiday after the strenuous months of getting the service launched. The period 1936-1939 saw considerable development in the techniques and variety of programme making, but not much expansion of facilities apart from the O.B. units already mentioned. A notable technical advance was the introduction in 1937 of the Super Emitron, a camera tube of the image iconoscope type in which an image section with electron multiplication gave considerably improved sensitivity.

With war inevitable, the service was closed down on September 1st 1939, the last transmitted words being by chance those of Mickey Mouse "I tink I go home".

Post-war expansion

Towards the end of the war, consideration was given by the Government's Hankey Committee to the standards on which the television service should re-open. It was decided, for the sake of an early start, to retain 405 lines; and so it was that British television returned in June 1946, the first service in Europe to re-open. Included in the opening programme was the same Mickey Mouse cartoon that had ended transmissions in 1939; and on the following day there was major outside broadcast coverage of the Victory Parade.

An urgent post-war task was to spread coverage of television throughout the country. Four new high-power transmitters, all in VHF Band I, at Sutton Coldfield (Midlands), Holme Moss (Northern England), Kirk O'Shotts (South Scotland) and Wenvoe (South Wales) were completed by 1952, bringing 81% of the population within range. They were followed by five medium-power stations, giving 93.5% coverage by 1955. The original Alexandra Palace transmitter was replaced in 1956 by one of greater power at Crystal Palace. With additional low-power relay stations, final 405-line coverage of 99.5% was achieved by 1970.

On the programme origination front it was outside broadcast facilities that first received attention with improved CPS Emitron (orthicon) cameras in 1947; and zoom lenses in 1949, with only 2:1 range of focal length but still an important advance on lens turrets. More studios were acquired – Lime Grove in 1950, the Shepherds Bush Empire theatre in 1953 and the Riverside Studios in Hammersmith in 1956. The White City exhibition site was purchased in 1949 for a future Television Centre. A start was made on Regional television studios with a converted chapel in Manchester.

Studio equipment steadily improved, with the old Emitron camera tubes replaced successively by the CPS Emitron, image iconoscopes from EMI and Pye, and the 3" and 4½" image orthicons. Twin-lens flying spot telecine took over from Emitron tube types in 1949, and special effects systems such as inlay and overlay (equivalent to the cinema's travelling matte) offered new production opportunities.

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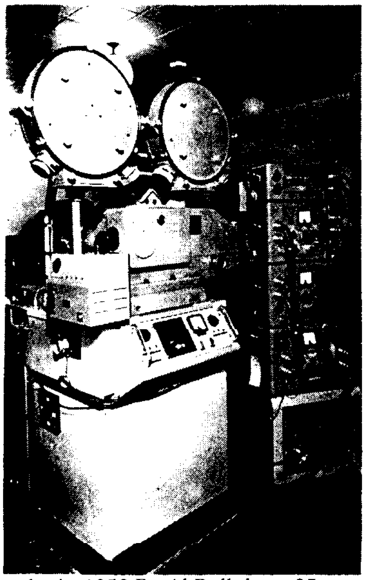

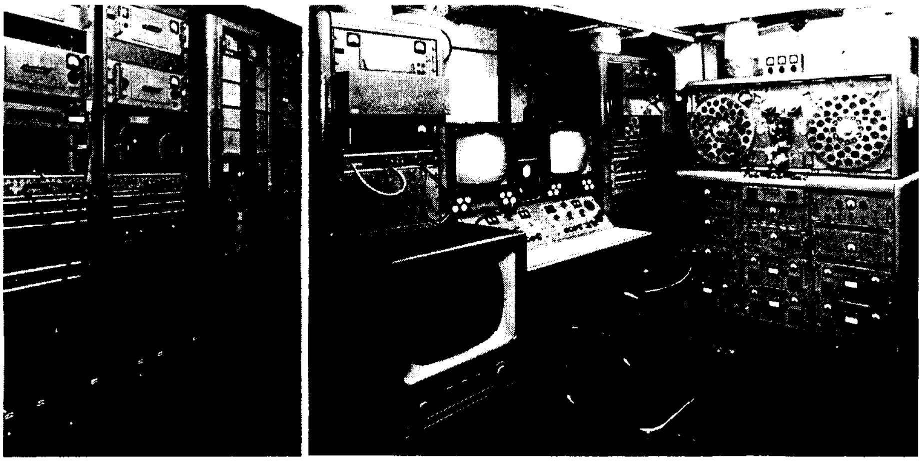

Right: the 1958 Vision Electronic Recording apparatus.

Left: the 1958 Rapid Pull-down 35mm Telerecoding equipment.

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Video Recording

A much needed development in this post-war era was some system for recording television pictures. In sound recording the only feasible approach is to make a replayable representation of the sound signal waveform. The same approach can be taken to video recording, but in this case there is an additional possibility in that a pictorial record of the television display can be made on film.

It was the waveform approach that was first adopted when gramophone disc recordings were made of the early 30-line television transmissions, quite practicable since the signal bandwidth was only a little over 10kHz. But for 405-line television with a bandwidth of 3MHz, waveform recording was not at first possible and picture recording on film was the only method employed until 1958. The first BBC film recordings were achieved in 1947 using the simplest possible approach with a conventional intermittent-motion film camera in front of the television screen. The film was run at 25 frames per second and the mechanism synchronised with the 25 pictures per second television display. Since time had to be allowed to pull the film down, only one of the two fields in each television picture period could be recorded and this resulted in a coarse recorded line structure giving rise to beat pattern problems on replay. A few years later this problem was much reduced by application of "spot wobble" to remove the line structure from the recorder display.

The problem of finding time to pull the film down was resolved in three different ways. Firstly the problem was avoided altogether by using the Mechau continuous-motion transport mechanism with tilting mirror compensation for film motion. In a second approach the missing television field was stored in the form of afterglow of a long-persistence display tube phosphor, thus presenting both fields simultaneously to the film. A third approach used fast pull-down mechanisms with the aim of completing the film movement during the television field blanking period: this proved possible with 16mm film, but 35mm film could not withstand the required accelerations and about 60 lost lines had to be recovered by display phosphor storage.

Having moved from the 1930's waveform recording to picture recording, the pendulum swung back to waveform recording in 1958. Improved magnetic tape materials and techniques made possible the brief appearance of the BBC's Vision Electronic Recording Apparatus (VERA) in which the video signal was frequency divided between two longitudinal tracks on 1/2 inch magnetic tape running at 200 inches/second: sound was recorded on a third track.

VERA was almost immediately eclipsed by the appearance of Ampex's VR1000 quadruplex VTR, transverse tracks being laid down on 2 inch tape by four rotating heads: the longitudinal tape speed was about 15 inches/second.

Although video recording on film had done yeoman service for ten years, it could not match the quality and operational convenience of the video tape recorder. The VTR revolutionised television production techniques and has continued as a vital tool throughout developments from 2" quadruplex to several new formats.

The Introduction of Colour

In principle the generation of colour television signals presents no great problem and indeed Baird demonstrated such a thing in the 1920's. For a simultaneous colour system (avoiding the movement portrayal problems of sequential methods) all that is needed is to build three monochrome cameras into one box, add three optical filters and a splitter prism, and the job is done. In practice much ingenious design has been necessary to achieve acceptable results; and the advent of the lead oxide vidicon (Plumbicon) camera tube and its relatives solved many of the problems of achieving three accurately matched picture signals.

More fundamental innovation was required to devise a compatible colour transmission system, with a luminance signal which existing black and white receivers could use without disturbance, and with the additional chrominance information accommodated within the existing channel bandwidth. The solution lay in frequency division multiplex, with the luminance signal remaining unaltered and two chrominance components modulated in quadrature on a subcarrier within the video band: the third colour component could be derived in the receiver by subtraction of the first two from the luminance signal. Interference between luminance and chrominance components was minimised, on static pictures at least, by choice of sub-carrier frequency to give frequency interleaving of luminance and chrominance signal harmonics.

The first system based on these principles was developed in the USA, largely by RCA, under the auspices of the National Television Systems Committee (NTSC) and received FCC approval for broadcast use in 1953. Later derivatives, PAL and SECAM, largely overcame the susceptibility of NTSC to phase distortions during transmission and reception. The price for this benefit was reduced vertical resolution in coloured areas, but this could be more easily accepted on the 625 line standards used by most of the countries adopting PAL or SECAM.

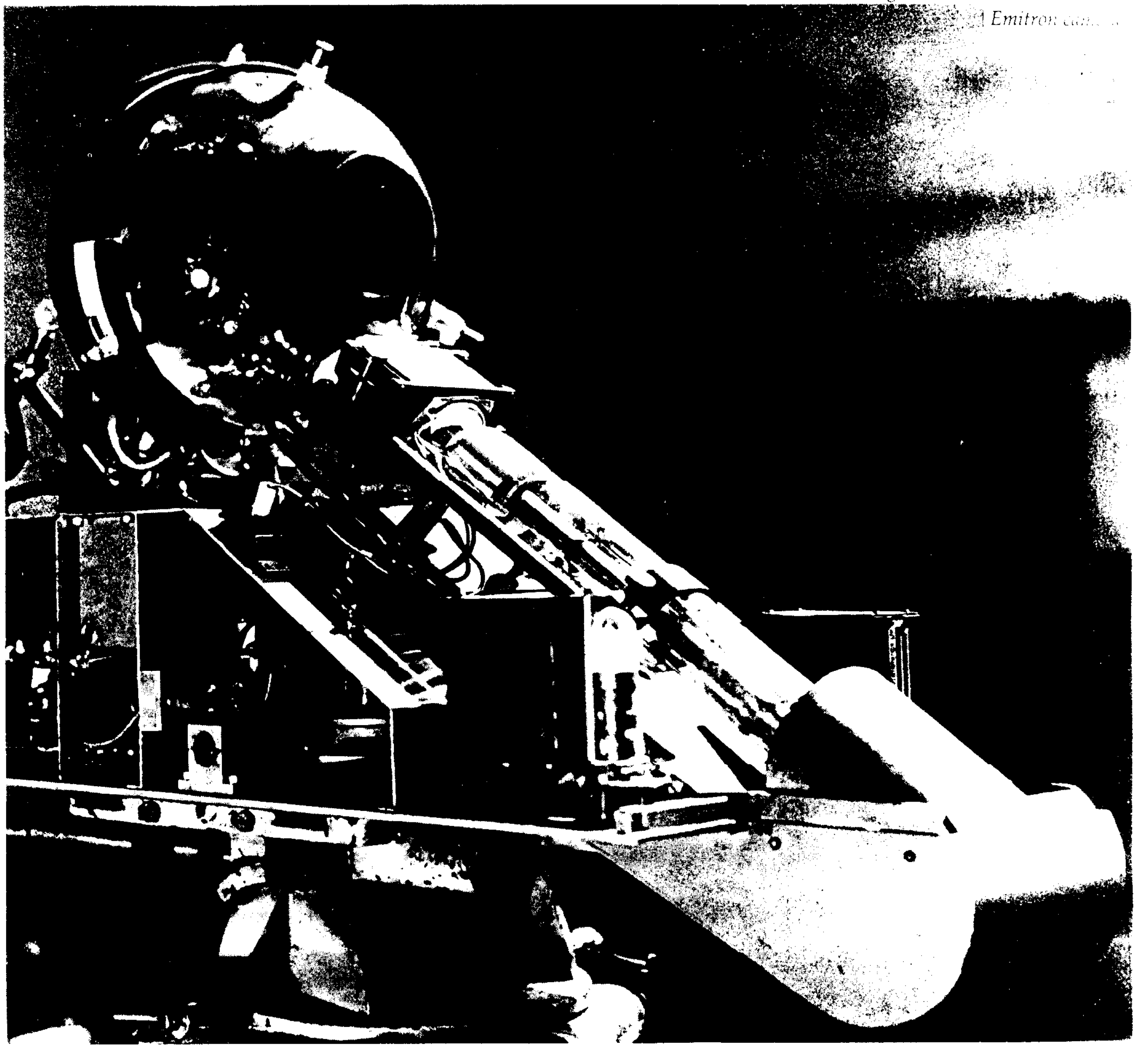
On the receiver display side, early equipment was based on the same techniques as were used for picture generation: images from three monochrome picture tubes, each with an appropriate colour filter, were optically superimposed into a composite colour display by means of a mirror system. The later shadow mask tube used the same principle, consisting in effect of three colour phosphor screens in one glass envelope: no additional optical superimposition is necessary since the human eye cannot resolve the individual red, green and blue elements of the matrix screen. The shadow mask technique, whereby each electron beam can stimulate only one set of red, green or blue phosphor elements deserves much credit as a landmark in the development of domestically practicable colour television.

European opinion was divided on the choice between the French SECAM and the German PAL colour coding systems. While France and some French-influenced countries stuck to SECAM, most European countries, including the UK, adopted PAL. It was decided that British colour television should be on 625 lines only and BBC2 commenced colour transmissions in 1967, the first colour service in Europe. BBC1 and ITV went into colour at the start of their 625-line services in 1969.

Conclusion

This review has taken us to within 20 years of the present day and and to go any further would perhaps invalidate the title reference to "early" television. In any case the more recent developments are no doubt sufficiently well-known to make further review unnecessary.

At the camera below Alexandra Palac[e] aerial is Douglas Birkinshaw



... Emitron ca...

The valve: Industrial aspects before 1925

by S. Wood

I interpret "Industrial Valve" to mean a valve or tube used by professionals. In the beginning, amateurs and professionals used the same valves since there was little choice. After about 1919 in Britain we can say, as a rough rule, that specialist valves were those over 5 watts in output or over 30/- in price! This account gives prime attention to the European line of development, mainly the efforts of Britain, France and Germany.

Professor Ambrose Fleming's diode of November 1904 was the first thermionic wireless valve and the first professional valve. Passing on to the 3-electrode valve, it is generally accepted that it was from Dr Lee deForest's grid Audion that the invaluable high-vacuum thermionic valve is descended.

I consider that the amplifying valve developed along two parallel paths, one starting from the Edison effect, through the German Wehnelt valve, the Fleming diode of 1904, deForest's 2-electrode Audion of 1906 and his better known grid Audion of October 1906 and January 1907, and culminating in the brilliant work of H.D.Arnold at Western Electric turning the fickle Audion into a superb new tool for the communications engineer and others. The finally developed end-product also benefitted from the much-publicised research carried out by Dr Irving Langmuir of U.S. General Electric on the high-vacuum tube.

The second of my two parallel paths starts, surprisingly, in Europe with Professor Ferdinand Braun's high-vacuum cathode ray tube of 1897, improved by Professor Zenneck and modified by Robert von Lieben, an Austrian, to become a high-vacuum cathode ray relay or amplifier, patented – believe it or not – on March 4th 1906 (German patent 179807). It had a concave oxide-coated cathode focussing the beam through a small aperture onto the inner of two concentric cylindrical anodes. Input speech currents passing through the field coils defocussed the beam, thus effectively 'modulating' (as we now say) the current to the same pattern in the high-potential anode circuit. Von Lieben had the determined ambition to create an amplifying device better than the mechanical relay – the sole (and desperate) expedient of that time. His patent of 1906 was the first in Europe, or indeed elsewhere, for a thermionic amplifier. This hard tube was not course satisfactory; it was about 14 inches (35 cm) long, it needed a high potential on the anode, the concave mirror cathode was difficult to manufacture, and a serious defect of the tube in operation was slow loss of the high vacuum giving 'blue glow' effects.

It is an unexpected paradox that the hard amplifying valve was patented before the soft!

Von Lieben was able to run a team on the project. Subsequent patents were in the names of the team, Lieben, Reisz and Strauss. This was just as well because von Lieben was very seriously ill, although with great spirit he still contributed to the task from time to time.

In their second attempt (UK patent 2111/11, March 1910), they abandoned the high vacuum and introduced ionisation into their cathode ray relay to increase the current and so enable the anode HT to be reduced.

They also inserted a diaphragm across the tube, and I am told that this would be the key patent from the legal point of view. Later that year their patent (German patent 249142, December 20th 1910) disclosed another new idea – electrostatic control by a 'grid' across the middle of the tube – but still with the soft vacuum. They described this patent as a supplement to their second one of March 1910.

The question of deForest's grid will arise in your minds. As far as I know the Lieben and deForest patents never came into direct legal conflict because the unfortunate deForest failed to pay the renewal fees on his European patents in January 1911, a failure that affected history. The Fleming diode then became the key patent in Europe and before any silly litigation could take place Godfrey Isaacs and Marconi came to a worldwide understanding on patents with Dr Ing. Hans von Bredow of the Telefunken Company: so the validity of the Lieben patents was never tested in European courts. However a Lieben patent was cited around 1911, presumably by the U.S. Patent Office, against Fritz Lowenstein, an American inventor, to prevent him claiming broad coverage on an Audion amplifier.

To return to the grid question, Gerald Tyne reminds us that in their third patent the Lieben team refer to the work of deForest and to his use of an 'auxiliary electrode' as a grid or sieve. So they knew of his work and they recognised the Audion as an amplifier, although by 1910 deForest himself had not yet been able to make it work as one. The Germans von Bronk and Schlömilch used an Audion successfully in an HF amplifier in September 1911 (German patent 271059).

The fourth Lieben patent (German patent 264554, October 1912) shows the Lieben relay in its final form, as it was used on certain long-distance circuits by the German Post Office in 1913. This form embodied a lamp-type filament construction with oxide coated platinum strip requiring 30V at 1.8A, and spiral aluminium anode at +220V. This tube was obviously ripe for further development, just as deForest's Audion was at that time. But the Lieben Relay carried vital German services from 1913 for some years in war, and permitted successful speech between the German Army Headquarters in the west (Coblenz) and in the east (Marienburg), a link of high strategic importance.

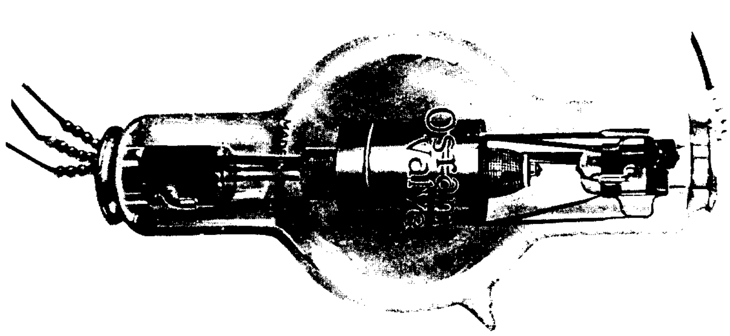
Likewise on the wireless side this same Lieben Relay, working in the oscillation mode, enabled Dr Alex. Meissner of Telefunken to create his feedback oscillator intentionally in April 1913. His patent (291604 from April 10th onwards) was considered the master patent for the oscillator in Europe and was never invalidated. Telefunken used this circuit as a heterodyne oscillator for transatlantic CW reception, as they converted their high-power spark transmitters at Nauen and Sayville N.Y. to CW alternators at about that time: this was a vital service for Germany from August 1914. There were also local R/T experiments.

Despite this remarkable record and much more, we must remember that the tube suffered some of the shortcomings common to most soft valves – instability and inconstancy from day to day largely due to temperature sensitivity; and noisy operation probably due to the mercury vapour used to produce internal ionisation. Steps were taken to hold the operating conditions more constant, but were not entirely successful. Claimed performance figures were 1000 to 3600 hours life, and current amplification factor of 33, or 20,000 using four tubes in cascade. The tube really began to show its paces in 1913, which was the year in which von Lieben died, like Hertz before him having had no time to reach his peak potential, but having fought to stay in the race.

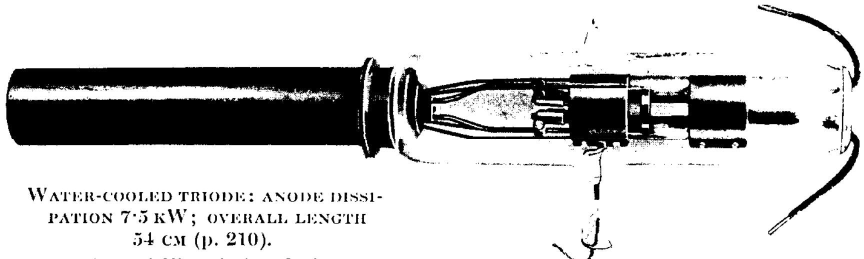
Von Lieben would have been pleased to learn how the thermionic valve in Europe went on from strength to strength, and to have read the testimonial of his old teacher Professor Nernst, eminent physicist and inventor, written in 1922 describing a demonstration in 1907 at which the output of the first type of cathode ray relay was "of extraordinarily intensified loudness and yet perfectly clear".

After a demonstration of the latest Lieben Relay model in August 1911, four leading German firms jointly purchased the Lieben patents on November 19th 1912. The four firms – AEG, Siemens & Halske, Felten & Guilleaume and Telefunken – formed the Lieben Konsortium and established a laboratory under the leadership of Eugen Reisz to improve the Lieben Relay and adapt it particularly to 2-way line communication. Unfortunately Reisz had little inclination to advance the development of a high-vacuum version on the lines of Langmuir's work: so in May 1914 Hans Bredow of Telefunken, aware of the way the wind was blowing, decided to create a laboratory at Telefunken and to put a very capable valve engineer in charge to produce high-vacuum devices. Development was then rapid and significant. The first high-vacuum Telefunken tubes were ready at the outbreak of war three months later (August 1914), type EVN 94 and a 2-stage amplifier EV 89 into which they neatly fitted. This was first designed as an interception amplifier, but was later used for many purposes including artillery receivers. I was astonished to find it forming a 7-page section in a 236-page German Field Manual on Instruction for Wireless Operators on Land, issued in April 1917: I could see no other valve equipment in the book. It is interesting to note the planar electrode construction of the valves, giving rather low performance but probably very stable and non-microphonic. Anode voltage was 95V, with 6V for filaments. A barretter (iron wire current stabilising resistor) was mandatory in filament circuits in all German WWI military equipment I have studied, giving the impression that omitting this was more likely to lead to the firing squad than was running away from the enemy!

Early Telefunken valves included a heterodyne oscillator EVN129 and an LF type EVN171: both these had planar electrodes. The EVN 171 was soon superseded by the EVN173 which embodied the concentric electrode assembly made popular by the French Valve in 1916. Major Rupert Stanley and others claim that the Germans copied Allied designs; and certainly they seemed to come to it rather late in the day, in 1917, although mentioning concentric cylindrical electrodes in their literature as early as 1914. Even the Lieben Relay of that time was modified to this form for use on civilian land lines; and the first German hard valve, made by Siemens & Halske according to Tyne, incorporated cylindrical electrodes. Yet Siemens' subsequent production of Tube Type A used planar electrodes as late as 1916. Their Type MC telephone



Glass transmitting triode: anode dissipation 200 W; bulb diam. 12 cm (p. 210).
(General Electric Co., Ltd.)



Water-cooled triode: anode dissipation 7·5 kW; overall length 54 cm (p. 210).
(General Electric Co., Ltd.)

repeater valve of 1917 goes part way with an inverted U-section anode. The Telefunken K6 valve of about 1917 is similar – indeed it resembles an original deForest Audion.

Subsequent valves from Telefunken, the RE11 and RE16, follow the French concentric pattern, but we are now into 1918 with the war nearing its end. About 1917/18 the Germans changed their system of valve designation from EVN and EVE to RE (receiving) and RS (transmitting or 'sending').

Also in their literature the Germans claim constantly that their high-vacuum developments were independent of Irving Langmuir's work in the U.S.A.: this must certainly be true for anything published in the States from 1916 onward. Rukop writes that Langmuir's 1914 publications reached them, but that nevertheless "one must work out such things for oneself in the laboratory". Due to wartime conditions, Langmuir's famous paper of May 1915 reached them very late and Rukop claimed that "we had to help ourselves the whole time with empirical design work". I would have thought there was some flow of information from U.S. General Electric to AEG in Germany through long-standing agreements; but no doubt, as Rukop writes, circumstances will have ended this flow even while the U.S. was still neutral and all commercial transactions would have ceased when the U.S. entered the war in April 1917. Meissner also, writing in 1922, complained at the delay in reports of Langmuir's early work reaching them in Berlin. However, with or without Langmuir's help, the Telefunken valve factory was making 1250 receiving valves (RE types) and some 110 transmitting (RS) types each day by the summer of 1918. Like the Allies, their wireless activities were reaching a peak in the last year of the war.

The English Valve

Delay in reacting to information can be due to slow recognition of its significance. For example the Audion reached Britain by 1907 and France two years later; but in both cases it seems to have been neglected for years, and its great potential went unrecognised in the United States too until 1911. True, many of the best workers were very busy on other aspects of wireless communication. France was rather slow to take up valve work, but in the UK Captain H.J.Round of the Marconi Company had been studying valves since early 1912 and had designed large glass diodes of a new construction. I have not yet found evidence of the use of these rectifiers in equipment, although Gerald Tyne mentions a 1922 MOV transmitter rectifier called the "ERECT" which is visually very similar.

Captain Round's important contribution came in 1913 with his TRIODE VALVE TYPE N and later TYPE C. Both these valves had a soft vacuum, oxide-coated filament, cylindrical mesh grid with closed top, and concentric anode. The concentric layout had first been used by von Baeyer, a

Berlin physicist, in 1908 in an ionisation measuring tube: Tyne remarks that if he had transposed the potentials on his device, he would have created a thermionic amplifier three years before anyone else! I do not think that Baeyer's arrangement influenced Round or Rukop, or any designer of concentric electrodes including the developers of the French valve. Professor G.W.Pierce, consultant to the U.S. Hammond Laboratories, suggested the concentric layout to Dr Langmuir in February 1913 as one of several proposals for "a proper triode design", but I would not think that these suggestions got through to European designers. Round closed the top of his grid cylinder to minimise electron bombardment of the glass envelope, since this could upset the valve performance.

It is difficult to distinguish between the Type N and the Type C valves if the inscription is worn off the glass, and the contemporary literature is of little help. Both types have 6V filaments consuming 2.5 amps. On samples in my possession the Type N has a very coarse grid mesh such that the thick lime-coated hairpin filament can be clearly seen; while the Type C grid mesh is very fine. The Type N is specified for the Marconi receiver type 27 (ca.1915) with 200 volts on the anode.

The Type C is used in the receiving circuit of Round's Wireless Telephone, which employed a Type TN (T for 'Transmitting') oscillator valve in the transmitter section: this, in 1913, was probably the first transmitting valve to be used in Europe. Round carried out tests of his Wireless Telephone between two Italian cruisers in the Mediterranean in March 1914, and he wrote "It was at once found that ridiculously small aerial currents, such as 0.2 amperes, were sufficient to enable speech to be transmitted 70km, this high efficiency being due to the absolutely silent and constant character of the oscillations produced and to the ability to magnify at the receiving end." (From the Marconi Year Book, 1915).

Round further describes how he introduced the oscillating valve (Type TN) to handle the power needed because the ordinary magnifying valve (Type C) was useless for this task due to filament failure. the Type TN at that time had a magnification of 3, "....but it will easily give current up to one ampere in the aerial without serious filament wear".

In the well-known Marconi receiver type 16, the valve is used only as an amplifier, rectification (detection) being provided by the carborundum crystal so dear to the Marconi Company. Round writes again "In addition.... a great improvement in the sensitivity of the arrangement is obtained by utilising a principle due to Mr C.S.Franklin. The circuit with the magnified energy in it is allowed to react back on the receiving aerial so that the whole system has an effective damping only slightly greater than zero. The result is an additional magnification, and the total result is that speech or spark signals, while quite inaudible with a crystal-receiver, are received strongly and with great selectivity due to the extremely low effective damping of the receiving system".

The brilliance of Franklin was momentarily illuminated by Professor D.G.Tucker of Birmingham when he wrote some time ago "It is interesting that Franklin is the only one of the inventors of feedback...... who mentions the effect of feedback in reducing the damping and sharpening the tuning".

In the above quotation from Captain Round he is describing normal positive feedback, not 'double magnification' which was a further development of the circuit involving return of the detected audio back to the aerial circuit to be further amplified by the HF valve.

A few final words on the Round Telephone Set: it was designed to put 0.6 amps into the aerial with 500V applied to the valve anode through a 3500Ω protective resistor. Round always used at least 2000Ω in series with the HT supply to his soft valves to prevent avalanche runaway in the event of some maladjustment or fault condition: excessive current through the valve made it behave like a thyratron, ionisation multiplying the current until the filament was destroyed. Being largely handmade in 1914/15, the valves were too expensive to lose unnecessarily.

Perhaps the most distinctive feature of the Type C valve is the small pip on the top of the envelope, containing a pellet of asbestos. In normal operation a Round valve gets harder with the passage of time, losing amplification as a consequence. Heating the asbestos pellet releases more gas into the interior of the valve, giving more ions and restoring the performance. The asbestos was normally heated by application of a lighted match; although in aircraft, where matches were discouraged, a small electrical heating coil was sometimes fitted round the glass pip.

The Type TN transmitting valve, although generally considered to be a soft type, was actually exhausted as effectively as the techniques of 1914 allowed and the construction of the valve permitted. The asbestos-filled pip was retained, but was really unnecessary and just an inheritance from its prototype, the receiving Type C. Some later Type TN valves had no pip.

It can be imagined that soft valves required highly skilled handling in practical operation, because of their sensitivity to variation of filament voltage, anode voltage, degree of vacuum and operating temperature. In 1915 Round wrote "The maximum practical magnification is given by a tube by careful adjustment of the vacuum, of the anode voltage and of the filament brilliancy. The magnification is extremely difficult to estimate, various measurements giving anything between 5 and 25 times for tubes constructed by the writer".

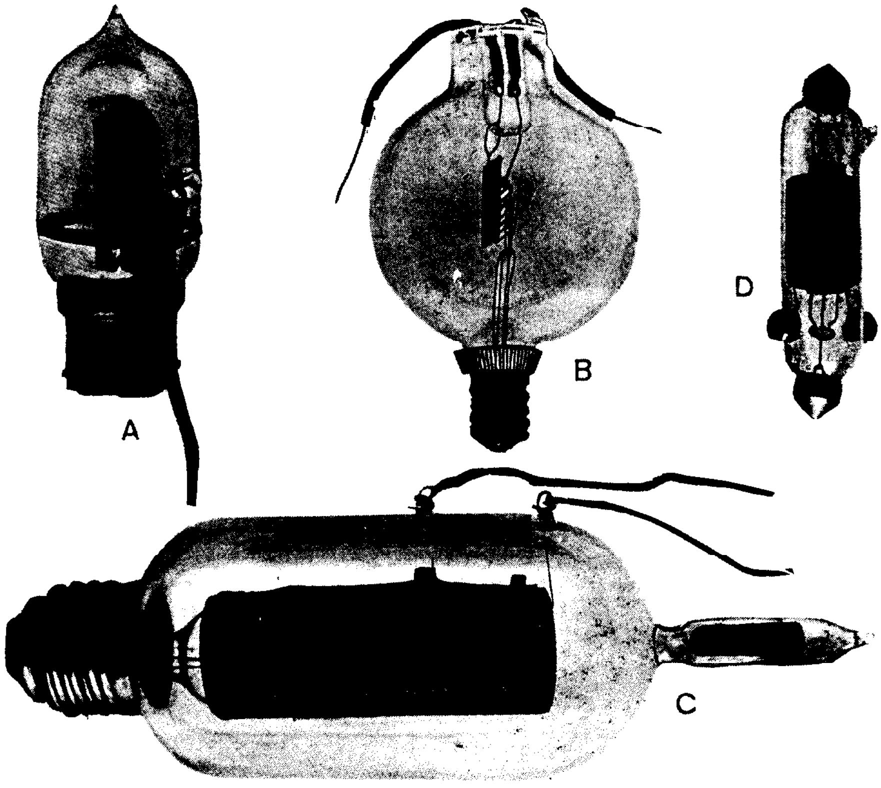
Everything seems so variable that it is remarkable that the early workers managed to achieve what they did with the Lieben valve, the Audion and the Round valves. When soft valves exhibit 'blue glow' it means that too much gas is present, or that anode voltage or current is too high. The valve is then on the point of failing due to ion bombardment of the filament leading to its disintegration. One operator stated that he could read morse signals visually from the blue glow radiating from a soft valve in a receiving station in Ireland. He did not say whether it was a Lieben Relay being tested or a Round valve in service: that would have been in 1913.

However much we may admire the ingenuity of the pioneers, the valves they created were very temperamental and generally unsuitable for military applications. Nevertheless the soft valve was the necessary precursor of the stable, reproducible and long-life hard valve that was to succeed it in Europe in 1916. But there *were* some soft valves with more predictable and stable characteristics. In the summer of 1916 R.C.Clinker, lamp works manager of BTH in Rugby (who were associated with U.S.General Electric), made copies of the deForest Audion for submission to the Royal Navy who had heterodyne receivers using American Audions and needed to secure their supplies in wartime. Some of these were high-vacuum and some were evacuated and then gas filled. They performed generally as well as the Audion but had much longer lives. The high-vacuum samples made by Clinker are claimed to be the first high-vacuum valves made in England – presumably Captain Round's Q valve was made a little later.

The Audion structure was abandoned in 1917 and a soft valve was deliberately developed similar in construction to the 'French' valve. This soft valve was called the Type R2 (or NR2 by the Navy) and was made by GEC in June 1917 at their Osram Lamp Works, and by others. The gas filling was originally nitrogen, but this seemed to disappear during operation of the valve and from September 1917 helium was substituted. These

helium-filled valves proved as constant in performance throughout their lives as high-vacuum types.
The anode voltage of the R2 soft valve was 20-40 volts and its final modification in the last year of the war , the Type R2A, required only 28-38 volts. It was made mostly by Osram and represented the final stage of soft valve development for Navy equipments, while another soft valve, RAF Type D, used as a detector in the Type 10 and Type XII equipments of the RAF, was the last soft valve designed for the British Forces. Mr B.S.Gossling, the source of my information on the soft series of R valves, ends by saying "Thus the reliable soft valve, the evolution of which began *before* that of the high-vacuum valve and finished later, attained reasonable perfection and equally reasonable obsolescence at very nearly the same moment".

The 'French' or R valve
Although some soft valves were made up to and beyond the end of the war, I consider that the arrival of the 'French' valve (known as the TM in France and as Type R in the British Army) on the battlefields of Europe in early 1916 marks the definitive entry of the hard valve into European equipment and likewise signals the demise of the soft wireless valve. Even the Round direction finders were changed over to hard valve amplification in 1917, much to the dismay of the operators who regretted the passing of their soft valves which could at times be coaxed into such high sensitivity.
In 1915 the French Army Wireless Service, known as **Telegraphie Militaire** or TM, under the superintendence of **Colonel Gustave Ferrié** (later General) studied the thermionic valve and developed a very practical form of hard valve with an electrode structure that lent itself readily to mass production and to robust service under normal military conditions: the valve also had an eminently practical 4-pin base that was used in Europe for some 50 years. **Ferrié**, a military scientist and wireless pioneer since the beginning of the century, instructed his team to study and make such a valve using the Audion as a starting point. A lamp factory at Lyon was put at their disposal for quantity production when they had arrived at the right design: the factory was Grammont's who made lamps under the Fotos name.
After an unsatisfactory beginning they succeeded, having completely redesigned the Audion, now of course a high-vacuum valve. Messrs **Peri** and **Biguet**, two members of the team, claimed the credit and obtained a very valuable patent for this construction in October 1915 (French patent 492657 of October 23rd). Three pages describe



Early valves: A. Fleming, B. DeForest "Audion", C. Marconi "N" triode, D. Marconi "Q"

the invention and the consequences were far reaching. Major Erskine-Murray, in charge of the wireless experimental section of the RAF at the end of the war, said in 1919 that he gave the French credit for having produced the valve which had been of most use during the war and also for producing standard types of amplifier. Major Rupert Stanley said of this valve that "it was marked by cheapness of construction and adaptability in action. Its use by the Allies became universal; it was much simpler than the Pliotron and owing to the excellence of the results obtained with it the valve became the standard for all wireless receiver and amplifier circuits in the equipment of the Allied Armies. Its design was copied not only by the Allies, but also by their opponents as soon as they captured examples". Although Stanley has been criticised for excessive enthusiasm for French developments, he was after all out there in the mud with them, dodging the shells; and furthermore, when the Americans arrived in France in 1917 they equipped themselves with French wireless and communications gear.
Returning to Grammont's Fotos factory, the demand became so great that it could not cope with it alone and another factory had to be brought into use, **CIE. Générale des Lampes** who made **"Métal"** lamps, and to distinguish between them they used the designations 'TM Fotos' and 'TM **Métal**".

On the valve itself, the concentric electrode assembly is fairly rigid with good clearances. It is not dissimilar to Dr Pierce's specification of sprung tungsten filament, nickel spiral grid, nickel cylinder anode, highest possible vacuum.
Captain Round, having used a wide-spaced concentric construction for his soft valves of 1913, now incorporated a very compact form in his first hard valve, the Type Q of 1916. This construction, in following types, survived through the 1920's.
Although a fine valve, the French type exhibited two defects. First it suffered from microphony, giving a ringing sound if tapped. Although this could be a useful means of checking that all was well, it was really a great disadvantage. Round tried to minimise it in his Q and V24 types by tensioning his linear filament with a spring.
Secondly, the input capacitance of the French valve was 15pfd, which gave rise to problems in multi-stage amplifier design. Quite apart from anode-grid capacitance feedback difficulties, the input shunt capacitance seriously reduced the gain of resistance-capacity coupled stages at wavelengths below 1000 metres: in some of Round's direction finding sets working on 200 metres, 22 valves had to be employed in cascade.
As already mentioned, all countries were slow to recognise the potential of the deForest Audion. Even Colonel Ferrié must be criticised on this score,

continued on next page

for he met the Audion when deForest visited Paris in August 1908 to transmit R/T from the Eiffel Tower; he made references to the Audion in several books; and he saw the Audion in operation in America in spring 1914. On his return, Ferrié ordered an Audion amplifier which was delivered in June, handed over to specialists for evaluation and disappeared into limbo! Then a fortunate chance brought several Audion triodes into his possession and it was one of these that started off the work at Lyon which led to the TM Fotos valve: the forgotten amplifier eventually turned up in a storage basement.

Once past this hiatus, the TM valve quickly went into full production and work proceeded on a multiplicity of LF and HF amplifiers, 2-stage to 8-stage receivers, transmitters, wavemeters and direction finders, all using the standard valves. Gerald Tyne says that over 100,000 TM valves were made during the war.

Several British firms took up manufacture of the French valve, under its British Army 'R' designation, including BTH, Ediswan and GEC-Osram. Some made modified versions to reduce microphony (BTH Type A); or to be suitable for transmitter applications (BTH Type B, 800 volts on the anode); and Royal Ediswan Type F, a fine looking valve used by the RAF. Using tungsten filaments, these lamp manufacturers employed their normal techniques to maximise production as quickly as possible. In 1917 when the production of Type R2 valves for the Navy required special diffusion pumps, they could not be provided for several months because all available facilities were being concentrated on the supply of R valves for the Army.

Meanwhile Captain Round, in solving his short-wave amplifier problem for direction finders, devised a special form of high-vacuum valve. It was inspired by the French valve, but he set out to eliminate as far as he could both the microphony and inter-electrode capacitance problems. The former was easily solved by compact rigid structure and a good spring tensioning the filament: the envelope was only 3" long and 9/16" in diameter, and the filament went straight down the centre of this cylindrical bulb. To reduce capacitance he separated the lead-out wires as far as possible, with filament connections at either end, and grid and anode connections brought out to the sides. This Q valve needed 4V at 0.3A for the filament and about 150V on the anode. It was used both as amplifier and detector initially.

Round's V24 valve of 1919 was the same size as the Q, with similar electrode structure and lead-out arrangements. The 5V filament consumed 0.75 amps and the rated anode supply was 20-50 volts. Amplification factor was 6 and the anode impedance 15-20kΩ. The V24 took over the amplifying role, with the Q valve being used only for detection. The Marconi Type 55 Amplifying Detector used six V24's in cascade, followed by a Q detector and was used in marine equipments until about 1925: there is a photograph of Marconi on his yacht Elettra in which V24 valves can be identified in his experimental equipment. I have come across V24's in boxes whose design indicates that they were still being sold in the early 1930's, presumably as replacements in solidly built apparatus which would not expire!

Still seeking to reduce inter-electrode capacitance, Round later developed the FE1, a four-electrode valve, of similar construction to the V24, but with a screening grid between the normal control grid and filament. But when this valve was incorporated in commercial Marconi marine equipment, the screen grid property was not used and it was advertised as a reflexed HF amplifier, detector and LF amplifier, all effected by the single valve. A smaller version of this valve, the FE2, followed soon after and I think this was the end of that style of valve construction, which suffered the disadvantage of requiring a special form of holder.

The R5 valve, developed at the Navy Signal School in Portsmouth, can be regarded as a rival to the V24. It was designed to have similar performance, but to be easier to manufacture, and it had the advantage of a filament capable of working from a 4 volt accumulator. The R5 embodied an envelope shape and lead-out arrangements similar to those of the V24, but with a larger diameter bulb and black moulded composition end-cap developed a short while earlier for the RAF by Captain Mullard. The same construction had been used for the RAF valve Type C (a high-vacuum type made in 1918 by GEC-Osram) and the RAF Type D which was a soft valve made by GEC-Osram and Ediswan. The R5 was a post-war valve, entering service around January 1919.

Reverting to civilian applications, one must pay brief tribute to the British Post Office for their part in valve development. In 1913 they had used some Round soft valves in telephone repeater amplifiers, but they recognised the advantages of hard valves and adapted the French TM design to their purposes. The resulting 'Valve, Amplifying No.1' at first included a tungsten helix as anode (possibly to facilitate de-gassing during manufacture), but soon reverted to the more usual nickel cylinder. The valve was used in the 'Repeater, Telephonic, No.2' with some 200V on the anode and filament supply of 4.7V at 0.75A. By 1923 they were employing a more conventional valve, still based on the TM type, made by GEC to Post Office Specification V.T.No.25. Later Western Electric/S.T.C. Types 101D/4101D and 102D/4102D were used, i.e. VT31 and VT32 respectively. S.T.C. were leading suppliers to the Post Office, as might be expected in view of their association with U.S. Western Electric who were pioneers and leaders in telephone transmission techniques.

So far I have considered mostly receiving valves, since the needs of the Services seemed to call for receiving valve development in early years: only later do we notice a demand for transmitting types. I think it is true to say that most of the Service Establishments in wartime Britain did yeoman service, not least H.M.Signal School (Navy) in Portsmouth and H.M.S.Vernon. Here they did remarkable work, pushing back the frontiers of knowledge under makeshift conditions, struggling to come to terms with new phenomena and always under pressure to produce the goods before the day was out. Putting the new-found knowledge into practice was a major task, as in the creation of their fine range of power valves T1 to T5 (six types plus two rectifiers) and associated circuits between early 1917 and 1919. As an example, the T4A transmitting valve was capable of converting 1kW of power to RF in an efficient circuit and, with others, served to meet requirements of the British Grand Fleet and other Naval centres. The basic development work was completed in only 4-5 months so that the first T1 valves could be delivered by Easter 1917. By 1919 some 5000 power valves had been supplied.

GEC-Osram gained so much experience in the manufacture of both large and small valves for the design authorities in the war years that they were well placed to play an important role in making valves after the war; and it is perhaps not surprising that the GEC and Marconi Companies agreed in 1919 to form a joint venture, the Marconi-Osram Valve Company, to take over the Osram valve factory. In 1920 the name was changed to M.O.Valve Company and during the 1920's they produced a wide range of valves of all types.

Other companies that had made valves before the war (A.C.Cossor and Edison Swan) or who had begun during the war (BTH and Metrovick), had also gained valuable experience and were well prepared to market useful ranges throughout the 1920's.

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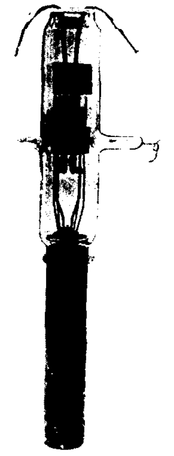
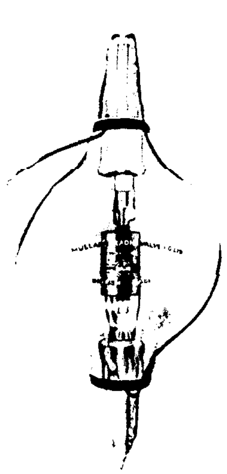
A new company joined those mentioned. Captain S.R.Mullard had worked on valve development and vacuum techniques for the Admiralty and had organised the design and production of valves for the Services at several Admiralty establishments. When released from war work in 1919, he began to manufacture receiving and transmitting valves on a small scale to meet Admiralty needs, and in 1920 he formed the Mullard Radio Valve Company. He was particularly associated with the silica valve, a high-power type used by the Admiralty both during and after the war. Silica valves could be repaired if their filaments failed and, since silica can stand higher temperatures than glass, a given size of silica valve can have a higher power rating. Mullard also made smaller receiving valves including the 'ORA' (Oscillates, Rectifies, Amplifies), his version of the R valve, which sold so well that he had to move to a larger factory. He continued to expand his range and in 1924 sold half his company shares to N.V.Philips of Holland who immediately rationalised the titles of his valves, using the prefix 'PM' throughout.

Turning to other companies, the Ediswan Type AR and its dull emitter equivalent ARDE are typical of early post-war receiving valves. Likewise the Cossor P1 and P2 bright emitters of 1922 were followed by their dull emitter equivalents P3 and P4. The odd one out was the Wecovalve or 'Peanut valve' based on U.S. Western Electric's 215A but made in England by the Mullard company: with an oxide-coated filament it needed only 0.2A from a single cell. In the field of post-war transmitting valves, the Marconi Company introduced a comprehensive range gradually over the years, first of air-cooled glass valves and then of water-cooled types of higher power. The first post-war transmitting valve was the MT1, three of which were used in the Ballybunion station in Ireland from where W.T.Ditcham spoke across the Atlantic to Louisburg, Nova Scotia in 1919. The next valve, the MT2 introduced in 1920, was rated at 5-6kW and a panel of nine of these was installed at the Clifden Transatlantic Marconi station in Ireland in 1920. Working on 5600 metres, 250 amps were delivered to the aerial with 18kV HT; whereas the Clifden spark transmitter with an input of 100kW gave only 100 amps aerial current. The valve panel input was 60kW plus 1.8kW filament supply. This valve transmitter carried all the telegraph traffic and was so satisfactory that the Canadian end also was similarly equipped.

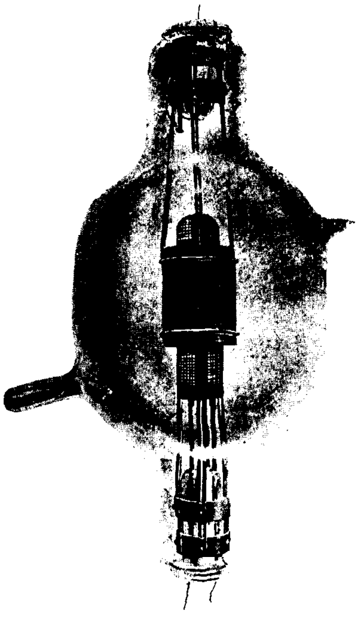


Marconi Water-cooled Transmitting Valve.

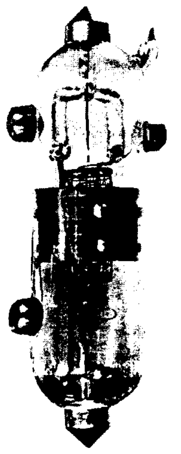
Marconi 3-electrode Valve.



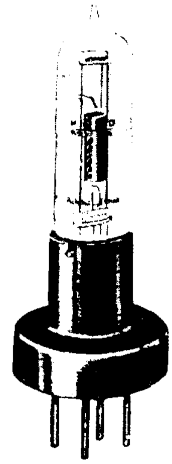
Mullard Transmitting Valve.



Marconi Valve MT7B, designed for use as a modulating valve in broadcast transmission. The design of the grid gives distortionless magnification.



Marconi 4-electrode Valve.



Mullard Dull Emitter Wecovalve.

In 1921 a larger panel of 56 MT2 valves was installed at Caernarvon (the most up-to-date Marconi station) which carried the main telegraph traffic direct to the United States. This panel delivered 160kW (320 amps) to the aerial. For both valve panels, efficiency was of the order of 75%. The MT2 valve had a tungsten filament, nickel mesh grid and lead glass envelope: it continued in use into the 1930's.

As the 'twenties proceeded, the powers and efficiencies of the valves and transmitters increased steadily. The next big station was a high-power long wave transatlantic telegraph station at Ongar in Essex, purpose-built to use valves from the outset. Then followed the 25kW Daventry long wave broadcast station of the BBC, using CAT1 (Cooled Anode Triode) water-cooled valves in 1925. Water-cooled valves had first been introduced in this country by the Post Office at Northolt using Western Electric types, and by Marconi's at their Caernarvon station using twelve CAT1's, both in 1924. The year 1926 saw the first of Marconi's famous Short Wave Beam stations; and also the equally famous Post Office 500kW VLF station at Rugby (GBR) using in the output stage a bank of 54 Western Electric VT26 water-cooled triodes in parallel. This was the culmination of the high-power long wave wireless station, apart from specialised defence installations at a later date. In less than two decades the thermionic valve had come a long way.

Acknowledgments
I am grateful for the assistance of Mr John Pool and Mr Roy Rodwell of Marconi Co. Publicity Unit, and Mr Aubrey Greenslade.
The works of Messrs. G.F.Tyne, B.S.Gossling and W.J.Picken have been valuable references.

deForest: Inventor of the Triode

by Bruce D. Roloson

Lee deForest was born in Council Bluffs, Iowa in 1873. However he grew up in Talladega, Alabama as the son of the president of a poor Negro college. Even when he was a young boy he had a desire to be a famous and wealthy inventor. As with most inventors whose lives were filled with trials, tribulations and conflicting stories, so would be the life of Lee deForest. Much of the confusion about deForest's inventions came from the stories that he himself told and retold. This is why finding the true story was at best difficult.

DeForest's first real opportunity to attain his goals of fame and fortune came when he was given a scholarship to Yale University by a wealthy distant relative. The scholarship stipulated that money be awarded to anyone named deForest to attend Yale. This was fortunate for Lee since his family was not wealthy and would not have been able to send him to a prestigious college like Yale. DeForest graduated from Yale's Sheffield Scientific School in 1896 and went on to receive his Ph.D. in 1899.

His idols were Nicholas Tesla and Thomas A. Edison, both coming from a poor background and both successful inventors. DeForest felt if they could succeed despite their lowly beginnings so could he. Lee felt that wireless was a way for him to follow in the footsteps of his idols.

He became interested in wireless while at Yale and studied the work of Hertz. He even did a thesis for his Ph.D. on the reflection of Hertzian waves on a transmission line.

After graduation deForest went to work for the Western Electric Corporation in Chicago. There he met Edwin H. Smythe (a fellow worker at W.E.) and Clarence Freeman, a professor at the Armour Institute of Chicago. Smythe was able to provide deForest with some financial and technical help with his experiments. Freeman was the inventor of a new transmitter using a capacitor discharge (Marx type) that increased the output voltage. DeForest was sure he could compete with Marconi (deForest's greatest challenger) if he had patent rights to a unique detector. It was to this end deForest and Smythe developed variations of liquid and paste detectors and applied for patents in 1900 and 1901. *"Responder"* was the

Dr. Lee DeForest

name that deForest used for many of his detectors in the early days, which makes it difficult to determine which one he speaks of in several of his stories.

It was one of these *"responders"* that deForest made into a receiver that he took to New York City to record the results of the America's Cup Yacht Race of 1901. At the age of 26 he was able to secure the backing of the Publisher's Press news organisation to supply the necessary finance. This was his big chance to make a name for himself, for he was competing with Marconi who was world-renowned. The results were not of the best for either of them, although deForest's equipment did prove to be as good as Marconi's. During the race, deForest was so disappointed with the performance of Freeman's transmitter because of frequent breakdowns that he threw it overboard. Several months after the race, deForest had gained enough of a reputation to to interest a Wall Street stock promoter, Abraham (Schwartz) White to finance him in his development of equipment to compete with Marconi. Because of his new relationship with White, Lee dissolved the partnership with Smythe and Freeman.

The American DeForest Wireless Telegraph Company was formed in February 1902 with deForest as vice-president and scientific director and holding one third of the stock. Over the next few years deForest was kept busy helping White promote his company stock. He helped to man a booth at the St Louis Exposition in 1904 to persuade people to invest in their company. For the first time in his life deForest had plenty of spending money and $1M in stock; he was now a millionaire. However, this lasted only about five years because of financial, legal and equipment problems. The *"responder"* proved to be unreliable and deForest had several complaints about patent infringements. In order to maintain his place in the market and keep the company's receivers running, he used a close variation of Reginald Fessenden's electrolytic detector. A court injunction stopped him using it any more, and without a good detector the company could not operate their stations commercially. One of the vice presidents of the company came up with a crystal detector which proved satisfactory; and with this White felt that they no longer needed deForest.

During this same period of time, deForest was working on the *Audion*, which also came in for its share of litigation. The Marconi Company was the holder of the Fleming patent for a two-element detector valve (that was filed in England in 1904, and in America in 1905) and was threatening action against deForest. It was for this reason that deForest was forced out of the American deForest Wireless Telegraph Company, retaining only the *Audion* patent and about $1000, half of which was taken by his lawyer.

Deforest was on his own once more with very little money. He felt that he needed a new direction in the wireless field so he decided to work on telephony, seeing this as a new way to make money and re-establish himself as a famous inventor. The Radio Telephony Company was started as a means to sell his new enterprise, but he was only able to sell his idea to a couple of his old Yale classmates who were stockbrokers. He had to perfect the radio telephone by using a novel detector; and this brings us to the story of the *Audion*.

The *Audion*

The *Audion* had its beginning in a most unusual way for a thermionic vacuum tube. To start with, the name "Audion" was given to a series of devices by C.D.Babcock, one of deForest's assistants. The name is a combination of the Latin verb *audire* (to hear) and the Greek derivative ion (to go): hence "Audion" is a way to hear electricity in motion.

In an article written by another of deForest's early assistants, John V.L.Hogan Jr, it is stated that there were six varieties of Audion. In order of development they were (1) the flame Audion; (2) the arc Audion; (3) the 2-element U-wing thermionic vacuum bulb; (4) the electrostatic type bulb; (5) the external magnetic control type; and (6) the grid type.

According to deForest, it all started from an accidental observation of the

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Welsbach burner (September 1900) that varied its flame as he transmitted with a spark set in the same room. He later found it was an audio effect, not electromagnetic or electrostatic, and this gave him the idea of using a flame as a detector.
The "Flame Detector", as deForest called it, was a bunsen burner with a metal electrode positioned in the flame at different points to make use of the ionised gas produced by the flame. The first of these experiments, in 1903, used only two platinum electrodes and so was of the basic detector type. The electrodes were placed opposite each other so that detection could occur in the flame. The circuit was a very simple one, a 6 to 18 volt B (boost) battery in series with a telephone receiver and the flame electrodes. The electrodes were connected with an antenna and earth ground in a tuned circuit. Deforest claims to have heard signals from distant wireless telegraph transmitters clearly with this device. By adding salts (such as common table salt) to the flame, he was able to reduce the resistance of the detector.
On February 2nd, 1905 deForest applied for the first of his U.S. patents for this detector, referred to in the application as "Oscillation Responsive Device".
He did not receive this patent until December 20th, 1910 (patent No.9792750). In four other patent applications dealing with various types of bunsen burner detectors, deForest added a third electrode as well as a static valve type (823402 issued June 12th 1906; 867876 October 8th 1907; 867877 October 8th 1907; 867878 February 11th 1908).
After these experiments, he realised that the flame detector was not suited to wireless work because of the potential fire hazard. He also tried using an electric arc, but found this too noisy to be of any practical value.
This brings us to the incandescent carbon filament as a source of ions for use in a detector. In one of deForest's first attempts he used two filaments in an enclosed lamp that was partially evacuated. He surmised that the residual gas was the conducting medium and that too high a vacuum would hamper the operation, an incorrect approach as we now know. In January 1906 he applied for a patent on an Oscillation Responsive Device with filament and a plate with a battery and telephone receiver in the plate circuit. On November 13th 1906 he was granted patent No. 836070.
This proved to be one of the most controversial patents in the history of wireless. It was the source of a lifelong feud between Lee deForest and J.A.Fleming, since Fleming had filed his British patent in November 1904 and the U.S.patent in April 1905.
As mentioned above, the deForest arrangement had a *telephone receiver and a battery in the plate side of the circuit*. It was these components that deForest contended provided a relay action,not that of a rectifier. This relay action was the result of what deForest calls a "trigger", a term from coherer technology where a wireless signal was said to trigger the coherer into action. Today we would refer to deForest's circuit as a "forward-biased diode thermionic rectifier".
On October 26th 1906, deForest presented a paper entitled "The Audion" before the American Institute of Electrical Engineers.. This was his first disclosure of the steps he had taken to develop the 2-element thermionic vacuum tube. He started from his observation of the Welsbach mantle, through his bunsen burner and finally to his thermionic vacuum experiments. In his paper he referred to Elster and Geitel, to whom he gave credit for their work on incandescent metals in a gas atmosphere and vacuum chamber. It is also interesting to note the reference to Fleming in this paper as follows:-
"I have arrived as yet at no completely satisfactory theory as to the exact means by which the high-frequency oscillations affect so markedly the behavior of an ionised gas. Fleming points out that when the cold plate of the Elster-Geitel tube is connected to the positive end of the filament, and the two put in a high-frequency oscillation circuit, only the positive half of the oscillation can pass from the plate to the filament across the gas. He uses this principle to rectify the Hertzian oscillation, and applies the unidirectional currents of the oscillations themselves to operate a sensitive galvanometer, or direct-current instrument, for quantitative measurements over very short distances.

When an independent external source of electromotive force is applied, in the manner I have described, the action becomes quite different. It then operates as a *relay* to the Hertzian energy instead of merely rectifying this energy so that it can be used directly to give the sense signal."
In deForest's terms, this action of the Audion as a relay "is tremendously more sensitive and available in practical wireless", as he so modestly puts it.
In this same paper, deForest also describes an enclosed Audion with a filament and plate being affected by electrostatic plates or electromagnetic coils external to the device. This is actually the most important part of the development of the triode Audion up to this point.
Later deForest states in his autobiography that "I was working on the grid Audion at the time I delivered my paper before the American Institute of Electrical Engineers in October 1906; however I was unable to say anything about it because I had not filed the patent.".
It is of interest to note that deForest had applied for a patent on October 25th 1906 (841387) for "Device for Amplifying Feeble Electrical Currents"; this was the first 3-electrode Audion patent. It showed an incandescent lamp with two plates or "wings", one on either side of the filament; this arrangement was not new, but the circuit was very novel. DeForest kept working with this arrangement of two parallel plates to find the optimum operating combination, so he tried positioning the "trigger wing" between the filament and the second cold electrode. The result of this experiment was the blocking of the flow of ions, so he reasoned that if the trigger wing had gaps or holes the ions would pass through. He therefore inserted a single length of wire bent back and forth to form a gridiron formation, from which the term "grid" was derived.
The first grid Audion was ordered by deForest on November 25th 1906 from H.W.McCandless & Co. of New York City. Three days after the order was placed, deForest was asked by his backers to resign his position as vice-president and scientific director of the American DeForest Wireless Telegraphy Company. As severance he received the rights to filed but not granted Audion patents (which his backers considered of little value) and $1000 of which half went to his lawyer.
Testing of the new grid Audion did not continue until late December 1906 when deForest was able to stabilise financial and legal problems. Testing was performed on December 31st 1906 by John V.L.Hogan Jr, a high school student, and was so successful that deForest instructed his patent attorney to file as soon as possible for a patent on the grid Audion and its basic receiving circuit. The filing date was January 29th 1907 and the patent was issued on February 18th (U.S. patent No. 879532).
The Brooklyn Institute of Arts and Sciences invited deForest to present a paper titled "The Wireless Transmission of Intelligence" on March 14th 1907; this was the first time that the "Grid Audion" was presented publicly. During this year deForest was able to form his new company, the Deforest Radio Telephone Company and a subsidiary Radio Telephone Company.
With these new companies deForest was marketing commercial, military

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and amateur wireless equipment using his new grid Audion as a detector. He was not meeting with much success until September 1907 when he was able to demonstrate his new Audion to the satisfaction of staff members of Admiral R.Evans of the U.S. Navy's Great White Fleet. This fleet was to sail round the world to enforce President Theodore Roosevelt's "Big Stick" policy. The admiral was so impressed with the results of the demonstration that he ordered all ships in his fleet to be equipped with deForest's Audion detector receivers. This order included receivers for sixteen battleships, six destroyers and two auxiliary ships. The opportunity was a great one; however the time available to manufacture, install and to train operators was very short. One unique problem was that the Navy insisted that the equipment be installed on deck of some of the battleships, which exposed it to the elements. The operation of the equipment was a mixture of success and failure, due to the varied training that the operators had received prior to the voyage. One of the success stories was that of "broadcasting" phonograph records from the U.S.S. Ohio to other ships of the fleet in the evenings during the voyage.

After this historic voyage, deForest was able to sell many of the grid Audions to the Navy for detectors. As the Navy used them they found that every tube was different from the next in operating characteristics, which meant changing the settings for filament, grid and 'wing' every time a filament burn-out necessitated changing a tube. If the operator had to change the settings in the middle of an important message, the message could be lost.

It was this kind of problem that prevented deForest's Audion from being the standard for the Navy. DeForest either did not know how to improve the Audion or did not care to perfect it. This meant that deForest lost many Navy orders for his detector.

He was given another chance by the Navy to show off his Audion, and in November 1912 a 3 stage amplifier was built to improve reception of distant signals. The first stage had an amplification factor of 4 and with two stages the factor increased to 10. This proved to be the limit, because when the third stage was added instability prevented any useful amplification. In December of 1913 the Navy ordered ten of the 2 stage amplifiers.

There was a need for an oscillator for reception with a heterodyne type circuit. In April 1914 deForest demonstrated a new circuit to the Navy using the Audion as an oscillator. This circuit was named the "Ultraudion" detector.

Let us now go back and look at some of the improvements to the Audion as it was developed to a mature state. As previously mentioned, the Audions were made by the McCandless Company of New York City, Henry Wallace McCandless being owner and manager. McCandless and his workshop superintendent Jacob C. Grogan actually made several improvements to the Audion and conducted a number of tests on them. One of the first changes was to modify the envelope shape from cylindrical to spherical, which helped with the mounting of the electrode components. Another change was incorporation of a dual filament, giving longer life and greatly assisting sales, to the Navy in particular.

A further improvement to the filament was the addition of tantalum to increase emission. This was done in several stages; first by McCandless who was trying to find a material for a low voltage (2V) filament for an automobile lamp. He was able to get a tantalum lamp from Germany and used the 110 volt filament cut into small pieces to form low voltage sections.

Unsupported tantalum proved to be a problem because it moved when heated and at times came into contact with other tube elements. About this time (1912) tungsten was coming into use, so McCandless tried this as a filament. Tungsten proved not to have the emission of tantalum, but it did offer mechanical stability and longer life. Accordingly McCandless tried to combine the advantages of both materials by wrapping a fine tantalum wire round a tungsten filament: this did work quite well but was a very difficult manufacturing process.

One customer for the Audions which McCandless sold over the counter was Dr Walter G. Hudson. In conversation with McCandless one day, Hudson came up with the idea of grinding the tantalum to a powder, mixing it with a binder and then coating the tungsten filament with the resultant paste. This was most successful in improving the operation of the Audion, and became known as the "Hudson" filament.

McCandless was also responsible for improving the pumps and process to achieve higher vacuum, a necessity with the higher plate (wing) voltages being used to increase amplification factors.

McCandless's assistant Grogan had the idea of making the Audion demountable, or constructed in double-ended form with grid and wing connections at the top, and filament at the other end so that it could be replaced and the tube re-evacuated. When Audions were placed on the market it was policy to require return of a burned-out tube before supplying a new one.

In 1909 deForest deduced that an increase in output would be obtained if a further grid and wing were added. McCandless made successful samples of this double wing Audion.

In mid-1912 deForest, with the aid of John Stone Stone, demonstrated the Audion amplification effect to engineers at the Western Electric Company. They were quite impressed, but felt that improvements could be made. DeForest left them the demonstration samples, and this was the beginning of tube development at Western Electric.

In 1914 deForest's problem with the Fleming patent came to a head. The Marconi Company filed suit against deForest for infringement, but deForest filed a countersuit claiming that the Marconi Company infringed the deForest patent: samples of the Marconi type D valve were used by deForest as evidence in his suit. Before the matter came to court, the Marconi Company confessed to infringement of the deForest patent. The eventual court decision held that deForest had infringed the Marconi patent; and Marconi's had confessed to infringement of deForest's, so that neither party was entitled to produce any 3-element tubes. This stalemate was temporarily resolved during World War I when deForest was granted immunity so that he could manufacture tubes for the Government; but resumed as the War came to an end.

In 1919 a West Coast manufacturer came up with the idea of cross-licensing of the Fleming and deForest patents: this was the beginning of the Moorhead Company.

During the War, deForest perfected the Audion and the associated circuitry. The Ultraudion was a feedback arrangement that improved reception of distant stations. DeForest also developed the "singer" type of tube for use as an oscillator, from which came the basic transmitting oscillator tube known as the "Oscillion".

In 1919 the Radio Corporation of America was formed, with consolidation of deForest, Fleming, Western Electric and General Electric vacuum tube patents. Henceforth RCA controlled all U.S. manufacture of tubes.

DeForest went back to an idea he had had in 1912, that of making talking moving pictures. He was able to perfect a system that he called Photofilm, which had its first showing in 1923. This proved one more disappointment because in 1926 a former assistant, Theodore Case, produced a more advanced system which put deForest out of the movie business and left him once again without money.

During the remainder of his life he worked on some minor inventions that provided a comfortable living for him and his third wife Marie.