Tricks of the Trade

Dave Porter G4OYX

Recently, the author was pleased to receive correspondence from fellow VMARS member Gerald Stancey G3MCK; he asked whether it would be possible to feature information specifically on Droitwich–Long Wave. In reply, the author said "of course", however, after having had a little more time to think about it decided that a better approach would be to widen the scope and offer a piece on the history of the engineering of the UK LF broadcast sites and services. With the imminent, proposed closure of the LF service in June 2025 it seems very pertinent to research the subject.

The LF centenary

In 2025 it will be over 100 years that there has been a BBC presence on LF. Indeed, the ToTT feature in the August 2024 issue of *Signal* **[1]** included two paragraphs detailing the very early days of LF as follows:

From the early beginnings at of the BBC in 1922 with the relatively low power MF sites serving the main conurbations, Daventry, 5XX was on the air on LF on 1600 m 187.5 kHz, starting service at 25 kW on July 27th, 1925 making an LF presence to date of just over ***99 years****. 5XX was later on 187 kHz, then in 1929 to 193 kHz and finally in January 1934 to 200 kHz.*

Droitwich was the high power successor to Daventry and, in 2024, celebrated 90 years of continuous service on LF having come on the air on October 7th, 1934, though it should be mentioned that daytime tests were carried out on 200 kHz from Thursday, September 6th, 1934 with Daventry 5XX obligingly scheduled off for the test periods.

Reminiscences

No doubt like many in VMARS, the author has fond memories of first listening to the 1500 m service, starting in the very early 1960s and enduring the seemingly endless repetition of the playing of "Nellie the Elephant" by Mandy Miller followed by yet another outing for "There's a Hole in my Bucket" by Harry Belafonte and Odetta on Children's Favourites with Uncle Mac.

In those days there was no notion of from where, or how, or by what it was broadcast. The same ignorance was present for the author's father's early morning Home Service "Today" programme, with Jack de Manio, best received in Nottinghamshire on 434 m, 692 kHz though, by the mid-1960's, this transmission from Moorside Edge did have an unwelcome accompaniment of East Germany co-channel in the background in the hours of darkness during the winter.

These reception habits changed during 1965 when the author discovered the Pop Pirates and then wondered just how all these transmissions were achieved as having never seen before the photographs of a transmitting site or passed one; these were a revelation.

The BBC LF story

There are, essentially, six distinct periods and time lines to consider.

1. The Daventry service which ceased in 1934. As described in **[1]**.
2. Specifically, the Droitwich site (more correctly called Wychbold).
3. The wartime rearrangements and additions.
4. Post-War to 1962.
5. The mid-sixties.
6. The mid-eighties to the present day.

The engineering at Daventry was alluded to in **[1]** but with no reference to the antenna or transmitter. Two 500-foot stayed lattice masts spaced 800 feet apart supported a Tee aerial comprising a cage of ten copper wires grouped around six-feet diameter aluminium hoops.

The earth system used consisted of a number of zinc plates packed around with quantities of crushed carbon that were placed in the ground on the perimeter within a two-hundred feet radius of the aerial feeder hut. They were connected to the earth point of the transmitter by overhead copper wire conductors supported on short poles.

This earthing arrangement was changed for the Regional stations that followed where a copper wire earth mat was buried about 12 inches deep, the 12 SWG wires, normally to the perimeter of the site, were spaced typically at 5° or 10° intervals. The author can only recall hearing about one other BBC station, Start Point, where the first part of the earth mat was above the ground for a short distance and was supported on short poles.

In the USA, another school of thought was to use metal sheets, copper in their case, not zinc, right around and under the antenna tuning hut (ATH) and attach the radial No. 12 AWG copper wires to those, then out to the perimeter.

The Daventry transmitter, known by its callsign 5XX, was of the choke modulated type with several low power stages up to the final RF amplifier which consisted of four CAT1 valves in parallel. CAM1 valves were used in the modulator.

DC motor generator sets were used for the filaments and grid bias. The 10 kV EHT was from thermionic rectifiers type CAR2; these derived their anode supply from transformers with primary windings fed at 1500 V and 300 Hz from motor alternators. All the MG sets were powered from the public electricity supply (with no diesel reserve) taking about 300 kW on load.

With Daventry becoming the HF transmitter site for the Empire Service from 1933 onwards, the BBC had selected the site at Wychbold, some four miles north of Droitwich Spa, in 1932 as the best they could find for the necessary high-power replacement for Daventry. It provided far better coverage in the Midlands for the MF Home Service outlet and for almost the whole country on LF, 1500 m, 200 kHz.

Known universally as "Droitwich" and marked for many, many years thereafter on millions of radio dials, this site on a saltwater sub-soil has proven its worth ever since.

The official transfer of the LF service to Wychbold also included the callsign and the new 150 kW transmitter was thus called 5XX. The same resulted with the ex-Daventry 5GB service, where its new 50 kW transmitter at Droitwich from March 1935 was also annotated 5GB. This was, in later years, rather confusing as will become evident later.

Luckily, all the later high power MF stations had transmitters annotated T1, T2, T3, *etc*, except at Brookmans Park in 1929 where the first three were BP1, BP2 and BP3 but, by the mid-1950's even they were re-badged on the front panels to T1, T2, *etc*. It all went wrong again, though, after November 23rd, 1978.

5XX at "Droitwich-Longwave"

This Marconi transmitter was state-of-the-art in 1933 and used a series modulator rather than the Heising (choke) modulation system previously employed. Until recently, the author had always assumed that the series modulation was carried out on the final RF stage, however, on visiting the 90th anniversary exhibition in October 2024 at the Droitwich Heritage and Information Centre there was an exhibit of the final stage circuit of the transmitter. It comprised six-off CAT14 valves (four in service and two switchable spares) in a parallel/push-pull arrangement and it was not series modulated; it was a Class B linear amplifier. The series modulation occurred in the driver (the penultimate RF stage); unfortunately, there was no circuit diagram of that actual configuration. Much was made at the time in the technical press of the exacting requirement that the filament generator supplying the modulator valve(s) was 20 kV above earth and, as such, had to be supported on insulators with an insulated drive coupler to the motor.

CAT14 to the rescue

It was necessary to use valves capable of dissipating about 120 kW; none were immediately available when the transmitter was designed but the M-O Valve Co came to the rescue with the CAT14, requiring an anode potential of about 20 kV.

The valve data for the CAT14 are shown as **Figure 1**. As the valve has tungsten filaments, the DC supply required is 32.5 V at 460 A. Also of interest is the maximum anode dissipation, Pa at 150 kW. With the valve being used in Class B linear operation for telephony, note that the maximum recommended Pout for one valve is 67 kW with an anode dissipation of 146 kW, so just under the manufacturer's design maximum. With four valves in the 5XX transmitter, for an RF power output of say, 160 kW, to allow for output circuit losses against the 150 kW specification, each CAT14 would have to deliver a comfortable 40 kW on plain carrier. Accordingly, there was a degree of headroom and that was made use of after 1939 when the transmitter was run at 200 kW output in wartime service.

A suitable EHT supply was also a problem as it was required to provide 30 A at up to 20 kV. The solution was found in a continuously pumped, steel tank mercury arc rectifier, MAR. Teething troubles with the British Thomson-Houston Co. MAR were experienced with 'backfires' and the consequent tripping of the supply. At one stage, the problem was so severe that a thermionic rectifier was installed whilst modifications were made to the MAR.

As with the previous four Regional MF sites, there was no public electricity supply to the station when it was first commissioned; it took until mid-1940 before the mains arrived. Four, six-cylinder English Electric 750 bhp diesel sets were installed, each delivering 470 kVA, 415 V three-phase AC. Three of these could supply the station at 100% of full load, making the fourth set available for scheduled and emergency maintenance.

It was necessary to produce a good response characteristic from the single wire Tee antenna of 7/0.161-inch steel-cored aluminium cable, which had an asymmetrical impedance characteristic at the driving point. A transducer was designed which was essentially a set of π-networks in series, one in each leg of the balanced 550 Ω Zo feeder. The use of the transducer preserved the fidelity of the signal allowing a flat audio response to ±9 kHz. The driving-point response and transducer have previously been described in *Signal* **[3]**. This necessary technique was repeated on all future LF installations.

Wartime broadcasting arrangements

The 5XX 200 kHz 150 kW and the 5GB 1013 kHz 50 kW services continued until 1st September 1939 when, after announcements, listeners were advised of the up-coming wartime arrangements. The LF service was closed down immediately and two synchronised groups, each of four transmitter sites, were set up and on the air from precisely 2015 that night. They comprised, for the northern stations 767 kHz, 391 m and for the southern group, including as far north as Moorside Edge, 668 kHz, 449 m. It is important to remember that the LF/MF services were, at that time, and had been for the previous 28 years, the only domestic outputs from the BBC, save for the three-or-so-year excursion into 405-line TV from Alexandra Palace. HF services had also been expanding and, by the middle of 1940, there were 15 senders available for Empire and Overseas Service use.

Prospective plans, propaganda and power

The German authorities had started to use the Reichsender, not just solely on HF but on LF for propaganda purposes and no doubt this concentrated the minds of the UK Government and the BBC. As a consequence for the then newly-introduced BBC European Service transmissions, a synchronised group was set up in autumn 1939 on 1149 kHz, comprising Brookmans Park (BP), Moorside Edge (ME), Washford (WA) and Westerglen (WST). Broadcasting during the hours of darkness, these were on the regular ex-domestic service vertically polarised antennas. Droitwich joined the group on October 7th, 1939 with 5XX, now wave-changed to MF and at 200 kW.

CAT 14 and 14 C/NOV. 1957

Triodes *Types CAT14 and CAT14C*

(HF AMPLIFIERS)

General. Water-cooled anode transmitting triodes, fitted with tungsten filaments, these valves are suitable for use as high frequency amplifiers at frequencies up to 10 Mc/s.

They are designed for use in communication or RF heating equipments.

The two valves are identical except for filament lead cooling, the CAT14C having air-cooled leads and the CAT14 water-cooled leads.

Cooling. The anode forms part of the valve envelope and is designed for cooling by water circulated in direct contact with the envelope. The rated flow should not be less than 40 gallons per minute. The temperature of the cooling water at the outlet must not be greater than 150°F (65°C).

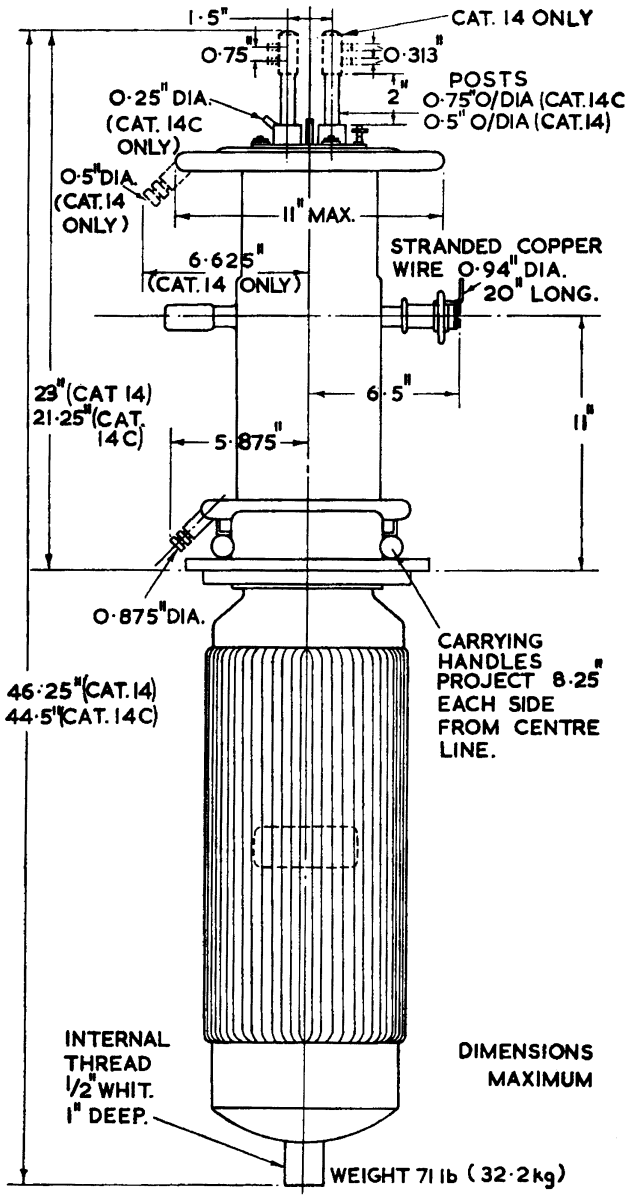
Each external valve filament lead of the CAT14 requires a water flow of 400 cc. per minute. The temperature of the cooling water must not exceed 122°F (50°C) at the outlet.

Each internal filament lead of the CAT14C requires a flow of air of approximately 8 cu. ft. per minute at a pressure equal to 5 in. water gauge.

The air flow to the anode seal cooling ring should be 4 cu. ft. per minute at a pressure equal to 4 in. water gauge.

All cooling supplies must be started before the application of any supply voltages, and must continue for at least 2 minutes after the removal of all supply voltages.

Filament Starting. The cold resistance of the filament is of the order of 0·0057 Ω. The filament current must never exceed 500 A at any time during the switching-on period. If the valve is operated for periods greater than 15 minutes without anode current flowing, the filament voltage must be reduced to one-half its normal value during the standby period.



MARCONI'S WIRELESS TELEGRAPH COMPANY LIMITED

Marconi House, Chelmsford. Telephone: Chelmsford 3221. Telex: 1953. Telegrams: Expanse Chelmsford Telex

Figure 1a. Page 1 of CAT14 Valve Data courtesy Frank Philipse [2]

HT Switching. It is not permissible to apply directly HT voltage in excess of one-third the maximum rated anode voltage. At higher voltages the HT should be either gradually increased from a low value or three-position switching should be employed.

Mounting. The valve must be completely supported by its water jacket, which should be capable of adjustment so that the axis of the valve is truly vertical. Rigid connections must be made to the anode only.

Seasoning. Whenever a new valve is put into service, or when a valve has been idle for periods of approximately 2 months, it must be seasoned by operating for at least one hour at half the normal anode voltage and current. The anode voltage should then be increased slowly to normal value.

APPROXIMATE DATA

V_f	32·5	V*
I_f	460	A
V_a	20	kV
p_a	150	kW
p_{gl}	8	kW
$I_{gl\ (pk)}$	30	A
μ (taken at V_a 15 kV, V_{gl} −100 V)	45	
r_a (taken at V_a 15 kV, V_{gl} −100 V)	900	
g_m (taken at V_a 15 kV, V_{gl} −100 V)	50	mA/V
$c_{a\text{-}gl}$	52	pF
$c_{a\text{-}k}$	4·5	pF
$c_{gl\text{-}k}$	100	pF

*Each valve is marked with the filament voltage to give 100 A emission at 90% saturation.

Typical Operation

(1) HF POWER AMPLIFIER AND OSCILLATOR. CLASS C TELEGRAPHY

(*Unmodulated, one valve, key down conditions*)

V_a		15	18	20	kV
I_a		18·8	18·8	18·8	A
V_{gl}		−950	−1,030	−1,070	V
I_{gl}	(a)	4·3	4·3	4·2	A
$v_{gl\ (pk)}$		2,650	2,730	2,770	V
P_{dr}	(a)	11·5	11·6	11·6	kW
Z_a		400	490	550	Ω
p_a		74	80	104	kW
P_{out}		209	258	272	kW

(2) HF POWER AMPLIFIER AND OSCILLATOR. CLASS C.

(*Anode modulated, one valve, carrier conditions, permissible modulation 100%*)

V_a		10	15	kV
I_a		9·6	9·8	A
V_{gl}		−895	−1,120	V
I_{gl}	(a)	1·9	1·8	A
$v_{gl\ (pk)}$		1,845	2,070	V
P_{dr}	(a) (b)	3·5	3·8	kW
Z_a		435	716	Ω
p_a		32	39	kW
P_{out}		64	108	kW

(3) HF POWER AMPLIFIER. CLASS B TELEPHONY

(*One valve, carrier conditions, permissible modulation 100%*)

V_a		10	15	kV
I_a		10·6	10·6	A
V_{gl}		−330	−440	V
$v_{gl\ (pk)}$		890	940	V
P_{dr}	(a) (b)	5·4	5·6	kW
Z_a		330	480	Ω
p_a		114	146	kW
P_{out}		46	67	kW

The figures quoted above are only applicable when operating at frequencies up to 3 Mc/s. At higher frequencies the anode voltage must be reduced according to the following table:

f (Mc/s)	3	5	10
% $V_{a(max)}$	100	80	60

NOTES

(a) Subject to wide variation. The figures given are approximate only.

(b) At crest of audio cycle with 100% modulation.

Figure 1b. Page 2 of CAT14 Valve Data courtesy Frank Philipse [2]

By February 17th, 1940 an innovative, horizontally-polarised antenna system was installed for 5XX on 1149 kHz that had been tested previously at Start Point on 977 kHz and proved. Droitwich at 200 kW was now able to operate independently and not as part of a synchronised group; as with horizontally polarised radiation it was rendered useless for DF purposes by enemy aircraft or ships. 1149 kHz from BP, ME, WA and WST was then closed down.

When France fell in June 1940, there was a need for a very high power MF transmitter for broadcasting to enemy-occupied countries. This led to the construction of a station

capable of an unmodulated output of 400 kW. As time and facilities were not available for the design of an entirely new single transmitter, it was decided to operate in parallel, two up-rated 150 kW Class B modulated transmitters that were already under construction at MWT.

With the rapid increase of HF plant and the construction of more sites, under a new coding system of “Overseas Service Extensions, OSE” it was decreed that the 400 kW MF installation would be at Droitwich as “OSE 6”. It already had the masts and, more importantly, the mast-height needed to accommodate the revised MF/LF antenna. As the 200 kHz service had been re-introduced there in February 1941 for overseas services at 200 kW from the 5XX transmitter (now wave-changed back to LF) that too had to be accommodated on the masts.

To prevent Droitwich LF being used for enemy DF, ‘spoiler transmitters’ had been set up, including one at Brookmans Park where 200 kHz at 15 kW was radiated from one of the 200-foot base-insulated towers.

Droitwich antenna changes

The already proven 150 kW λ/2 Krauss antenna was reconfigured as shown in **Figure 2**. It consisted now of an array formed of two horizontal λ/2 Krauss dipoles fed in phase and spaced λ/2 vertically for 1149 kHz, 261 m giving a horizontally-polarised signal with no upward radiation.

The energising arrangements were such that the upper dipole, together with its vertical transmission line, was used as a Tee antenna for simultaneously radiating the 200 kHz 200 kW service. The total amount of RF power on plain carrier into the array was thus 600 kW. The resulting voltage at the top of the antenna was the arithmetic sum of the peak voltages, including 100% modulation of both services and represented up to 100 kV peak. At times both services radiated the same programme and, to avoid unnecessarily high peak voltages on the upper dipole, the MF transmitter was fed with programme of opposite phase to that on the LF service.

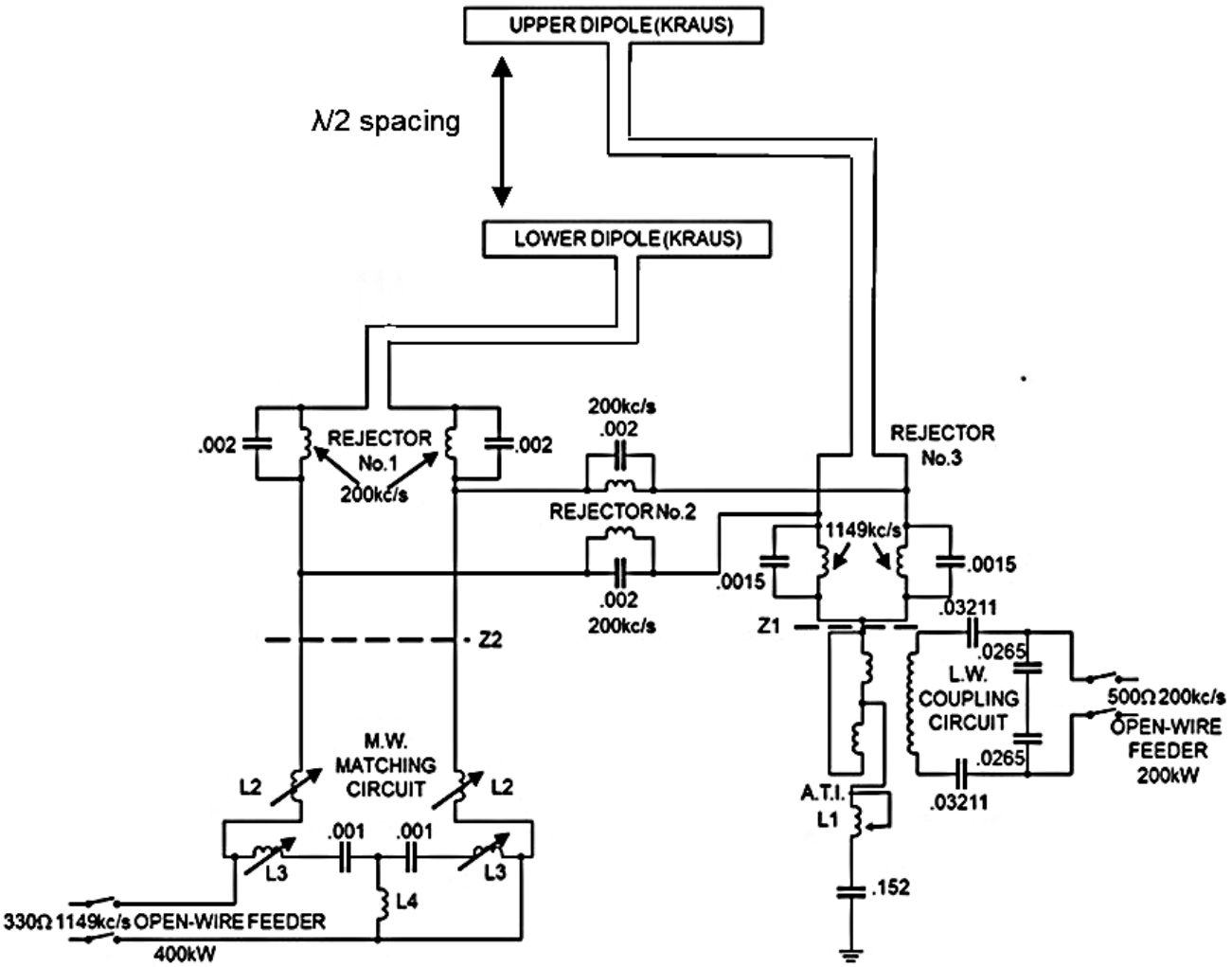


Figure 2. Arrangement of the Droitwich dual frequency antenna

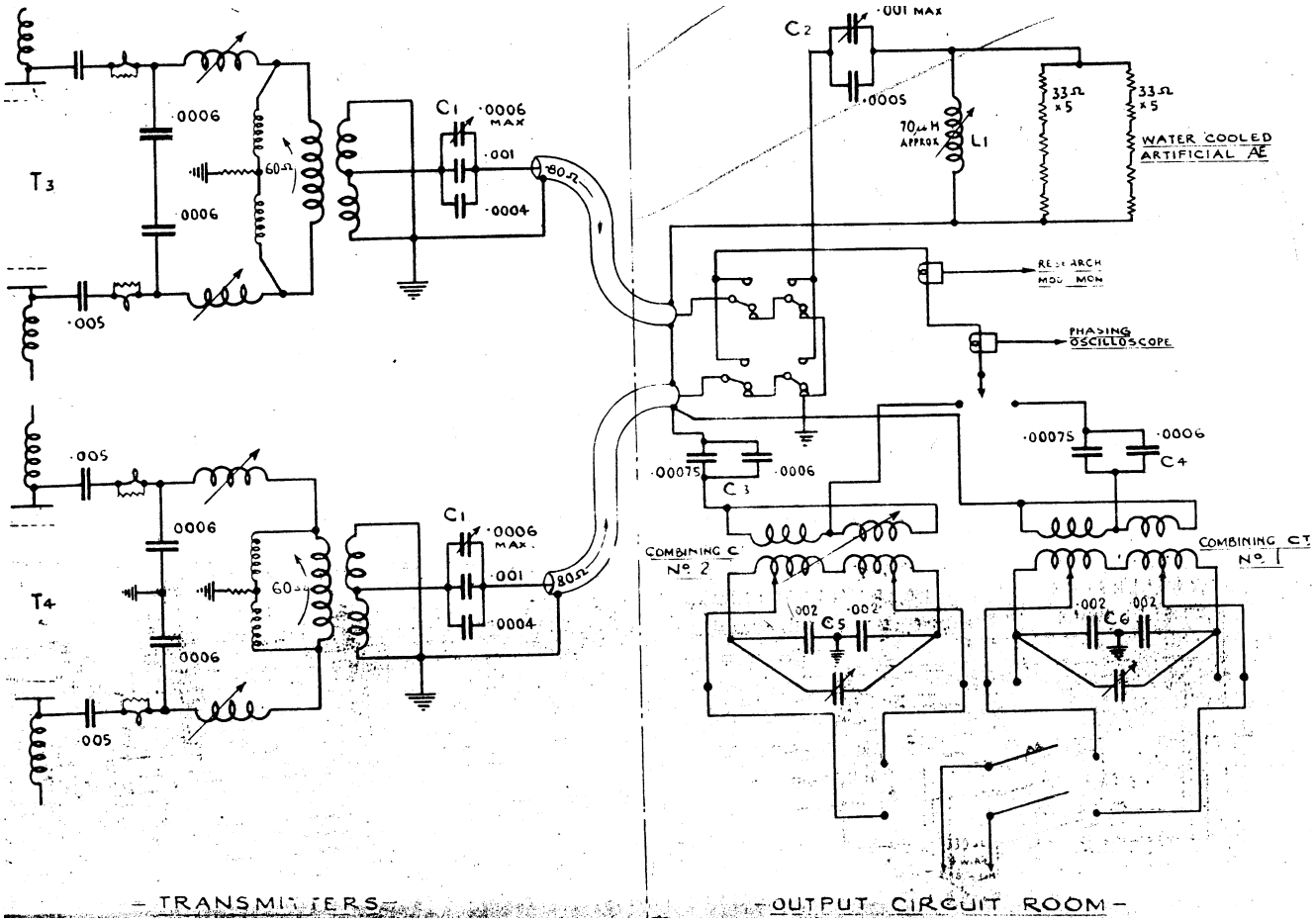


Figure 3 Original drawing of (BBC SD&ID SD45E-509) HPMW Station: output circuits

Overseas Station Extension 6, *aka* "Ozzie 6", *aka* HPMW

OSE 6 was in an austere, purpose-built, extension across the antenna field from the original building at Wychbold. Access was again easy from the main A38 and GPO cables had easy passage to the site, just as to the main building in 1934. Brookmans Park was similarly well provided for in 1929, being adjacent to the A1 Great North Road and with GPO Trunks passing the door.)

In typical Droitwich-speak at the time, neither the official designation OSE 6 nor the Ozzie 6 moniker were used; it was called High Power Medium Wave, abbreviated to Droitwich H.P.M.W. or just HPMW.

The two MWT Class B-modulated transmitters, now labelled T4A and T4B, were installed together with pumped MARs for the 14 kV EHT. Although these transmitters were nominally rated at 150 kW they were capable of 200 kW provided that a slight increase in audio distortion at high modulation levels could be tolerated.

T4A and T4B were paralleled in operation and this was the first time this technique had been used. The paralleling circuit had been devised and is shown as **Figures 3**; this has been described previously in *Signal* **[4] [5]**.

This paralleling arrangement was significant for both the BBC and the author, as will be detailed later.

HPMW came on the air on February 12th, 1941 (**Figure 4**) and operated on a sliding-schedule of transmission times from 15 minutes after sunset until 15 minutes before sunrise. The transmitters, being of the latest design, could accommodate quick wave-changes. Initially, a pair of M-OV CAT14 triodes were used in the RF PA and the CAT20 in the push-pull modulator but, later, the up-rated CAT17 were used in the RF PA. These valves and their even later, thoriated-tungsten filament cousins, the CAT27 (RF) and CAT30 (Mod), were to be a mainstay of the BBC LF/MF and HF MWT transmitters for many years thereafter.

A pair of CAT17 in the RF PA in Class C will generate 200 kW output on MF and LF at 14 kV EHT and, for the Class B modulation requirement of about 150 kW at 100% modulation, a pair of CAT20 in push-pull will suffice.

For HF, as typically used in the MWT SWB-18, a pair of CAT27 are sufficient to 15 MHz at 100 kW, 87 kW at 21 MHz and 72 kW at 26 MHz with an EHT of 10.5 kV.

An RF-friendly alternative to a conventional damp course?

Because of the combined 600 kW or so of power, other complications arose and emphasised the necessity for exceedingly low-loss earth connections in the ATH. Certain earth leads from the tuning components were connected originally to the earth system by taking two copper strips through each of the four walls of the ATH. When the 400 kW of 1149 kHz was added, the concrete footings of the ATH building became excessively hot, apparently due to dielectric or conduction losses or both.

Additional connected leads were taken through the wall at intervals of 12-inch centres. This action resulted in an almost total disappearance of the heating. At all subsequent sites, the earth connection was effected by laying a continuous sheet of copper in the courses of the brickwork a few inches above the ground, the copper projecting an inch or so each side of the wall; this was deemed to be satisfactory as the building's damp-course and connections were made from this to the outside radial earth system typically of 72 x 12 SWG buried wires.

With the declining threat of the enemy using HPMW for DF after autumn 1943, the complex array was replaced by an American Lease-Lend Blaw-Knox 350' mast radiator and HPMW used that at 400 kW on 1149 kHz, vertically polarised from December 19th, 1943.

OSE 5: Ottringham, near Hull

Charged with the success of the HPMW installation, the plans for a super-power LF and MF station were executed and OSE5 was built at Ottringham near Hull. It came on the air on February 12th, 1943.

Four MWT Type 1247 150 kW/200 kW transmitters were installed in separate, heavily-protected surface buildings with an underground control room and were able to be combined to give up to 800 kW on LF. However, only 600 kW was ever run in service with the remaining transmitter carrying the European service on MF at 150 kW/200 kW.

The first Tee antenna was used on test on 200 kHz in January 1943 and was suspended between two of the 500-foot masts; the driving-point impedance (dpz) at 200 kHz was 6.4–j66 Ω. A revised arrangement was implemented in October 1944, rated to 600 kW/800 kW using a paralleled second Tee between the other pair of 500-foot masts, giving a dpz of 8.0–j40 Ω. Refer to an earlier article in *Signal* for further detail **[6]**.

For a period just after the end of the War, the site was in operation with two transmitter units on 250 kHz at 400 kW. Problems were caused to shipping with the second harmonic, 500 kHz, being the International Distress Frequency and the station changed to 271 kHz and later in 1946 to 167 kHz, but with a power restriction of 200 kW.

During this same time, there were MF overseas services on 977 kHz at 100 kW and later 1122 kHz. With the loss of the 167 kHz channel following the Copenhagen Plan implementation in March 1950, OSE 5 then became a relief site for maintenance at Aspidistra on 1295 kHz with LF transmissions ceasing completely. Having had just a ten-year-life, the entire site was closed in February 1953 and dismantled with much plant placed into storage.

Conclusion

Arriving at the start of the post-War period neatly concludes the three previous time-line headings.

On July 29th, 1945 with peace-time services restored, Droitwich was again back with 150 kW on 200 kHz, with the new "Light Programme" from the 5XX transmitter. 5GB at 50 kW was carrying the Midland Home Service on 1013 kHz and either T4A or T4B was on 583 kHz after September 29th, 1946 at 150 kW with the then new "Third Programme".

Next time will be presented the story of the author going from HF to LF and from "OP2" to "OP4"; Droitwich Longwave going from 150 kW to 400 kW and again to 400 kW then finally to 500 kW as well as being joined by two LF stations over the border.

References

1. D Porter G4OYX. Tricks of the Trade. *Signal* 2024, **45** (August), 45−49.
2. https://frank.pocnet.net/sheets/139/c/CAT14.pdf
3. D Porter G4OYX and Chris Pettit G0EYO. Tricks of the Trade. *Signal* 2018, **49** (November), 13−16.
4. D Porter G4OYX and Andy Matheson G3ZYP. Tricks of the Trade. *Signal* 2009, **12** (July), 15−17.
5. D Porter G4OYX. Tricks of the Trade. *Signal* 2019, **53** (November), 33−35.
6. D Porter G4OYX, T Brook G3WBQ, D Fisher G3SAK and A Preedy G3LNP. Tricks of the Trade. *Signal* 2022, **64** (August), 67−79.

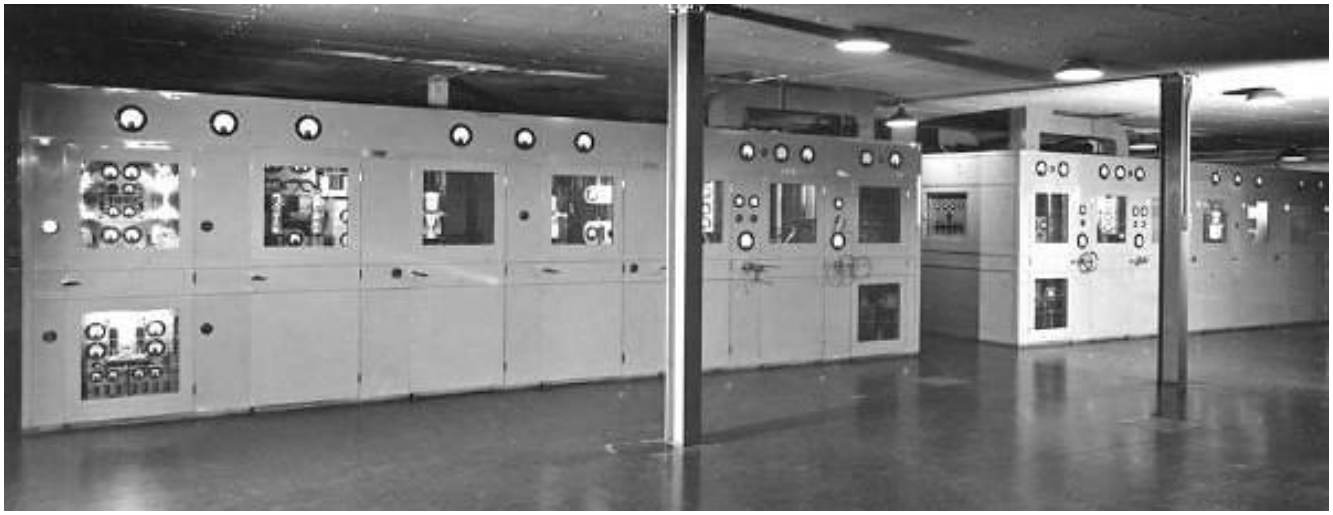


Figure 4. Droitwich 1941. HPMW (OSE6). Two 200 kW Marconi transmitters operating in parallel