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A SUPER POWER M.F BROADCAST TRANSMITTER

INTRODUCTION

AN OVER ALL MAIN H.T EFFICIENCY of 67·5% when delivering a modulated output in excess of 1·0 megawatt, distortion less than 1·0% over the greater part of the audio-frequency range and an indoor plan area less than 45 square metres are the major features of the Marconi 750-kW m.f broadcast transmitter. Additional salient features are non-critical circuit adjustments, long-life solid-state rectifiers, vapour cooling, unit construction and ease of installation.

The transmitter incorporates many of the features already proven in the 100-kW h.f broadcast transmitter described in a previous issue.[1]

Tetrode valves, for example, are used throughout, their excellent linearity yielding improved modulation performance in both r.f and modulator stages.

In the final modulator stage these vapour-cooled tetrodes lead to a compact low-power audio unit using comparatively small and inexpensive valves. Their use in the final r.f stage realizes the advantage of a single driver stage requiring an input of only 15 W from the solid-stage oscillator/drive unit. In addition, the already high efficiency obtainable from the tetrode valves is, in the final r.f stage, further enhanced by the patented Marconi 'High Efficiency amplifier System',[2] thus making possible the high overall efficiency previously referred to. Together these points add up to a design economic in the use of space.

The final r.f stage anode circuits are motor tuned so that, once preset on a particular frequency within the m.f range, fine tuning and coupling can be achieved from the front of the transmitter. To facilitate such adjustments, controls and associated meters are grouped on one central control panel.

All h.t rectification is by reliable long-life silicon diodes[3] engineered with their associated components to withstand full short-circuit faults across their output terminals. Main h.t fault clearance is by high-speed vacuum switches backed by a main h.t circuit breaker operating to 'lock-out' after a predetermined number of restorations.

The main h.t rectifiers are forced-air cooled, the cooling air then serving for general cabinet cooling. Cabinet-mounted components are thus ensured of maximum life and reliability by virtue of their lower operating temperatures.

A large saving of space within the transmitter hall is achieved by outdoor rated main h.t transformers, automatic voltage regulator and modulation transformer and reactor. When installed outside personnel protection may be provided by only a light roof and chain-link boundary fence. Overall running costs may still be decreased even with indoor installation of these components since they can be accommodated in a space not subject to the heating and ventilation requirements, which apply to areas occupied by operating staff. Installation of the outdoor rated components is simplified by the use of factory-fabricated tubular connectors to wall bushings, which are similarly connected internally to the rectifier assemblies and to the final stage valve units.

Modulation components are rated for continuous operation at a modulation depth of 50% increasing to 100% for 10 min in each hour.

In either new or existing buildings installation effort is minimized by the unit construction, by factory-installed inter-cabinet wiring, which need only be unrolled and reterminated to screw-type terminals, and by no requirement for plinths or underfloor ducting.

A preferred layout is shown in Fig. 1 but other arrangements are possible where special conditions exist.

RADIO-FREQUENCY STAGES

The radio-frequency section of the transmitter, consisting of a power-amplifying stage followed by a power-output stage, is contained in three cabinets which separate for ease of manufacture and transport. After installation the cabinets form an integral part of the transmitter module. Two of these three cabinets house the final stage and its associated anode and feeder output components. The remaining cabinet accommodates the driver stage, equipment associated with the vapour cooling of the final stage valves, the r.f control panel and, when fitted, the crystal-controlled drive unit. These r.f cabinets can be seen on the right-hand side of Fig. 2 which shows a front view of the transmitter.

Economy in valve stages is achieved by the use of three tetrode valves in the final r.f stage which delivers a carrier output power of 750 kW with an input power of less than 6 kW delivered from the single tetrode driving stage.

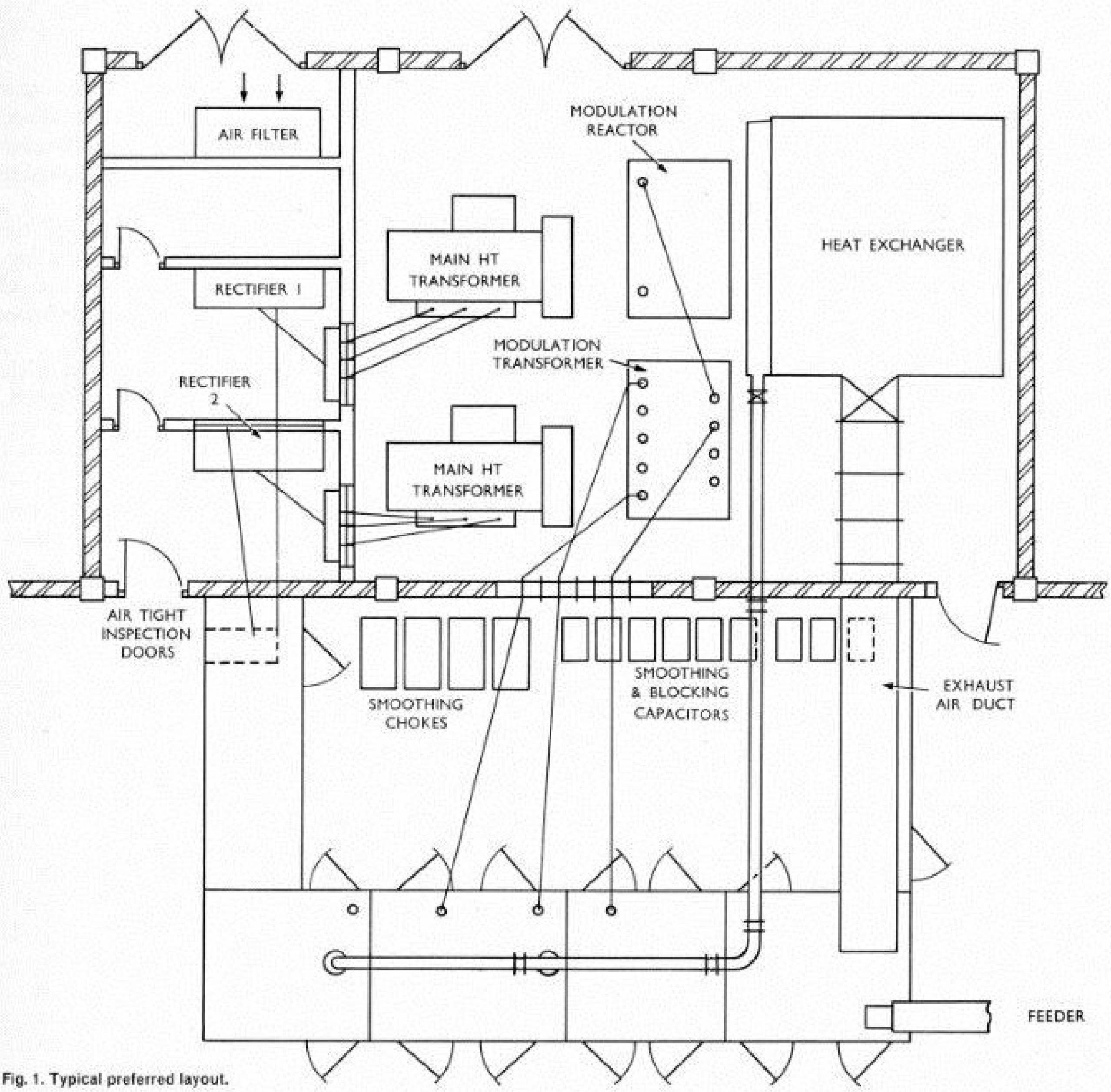

Fig. 1. Typical preferred layout.

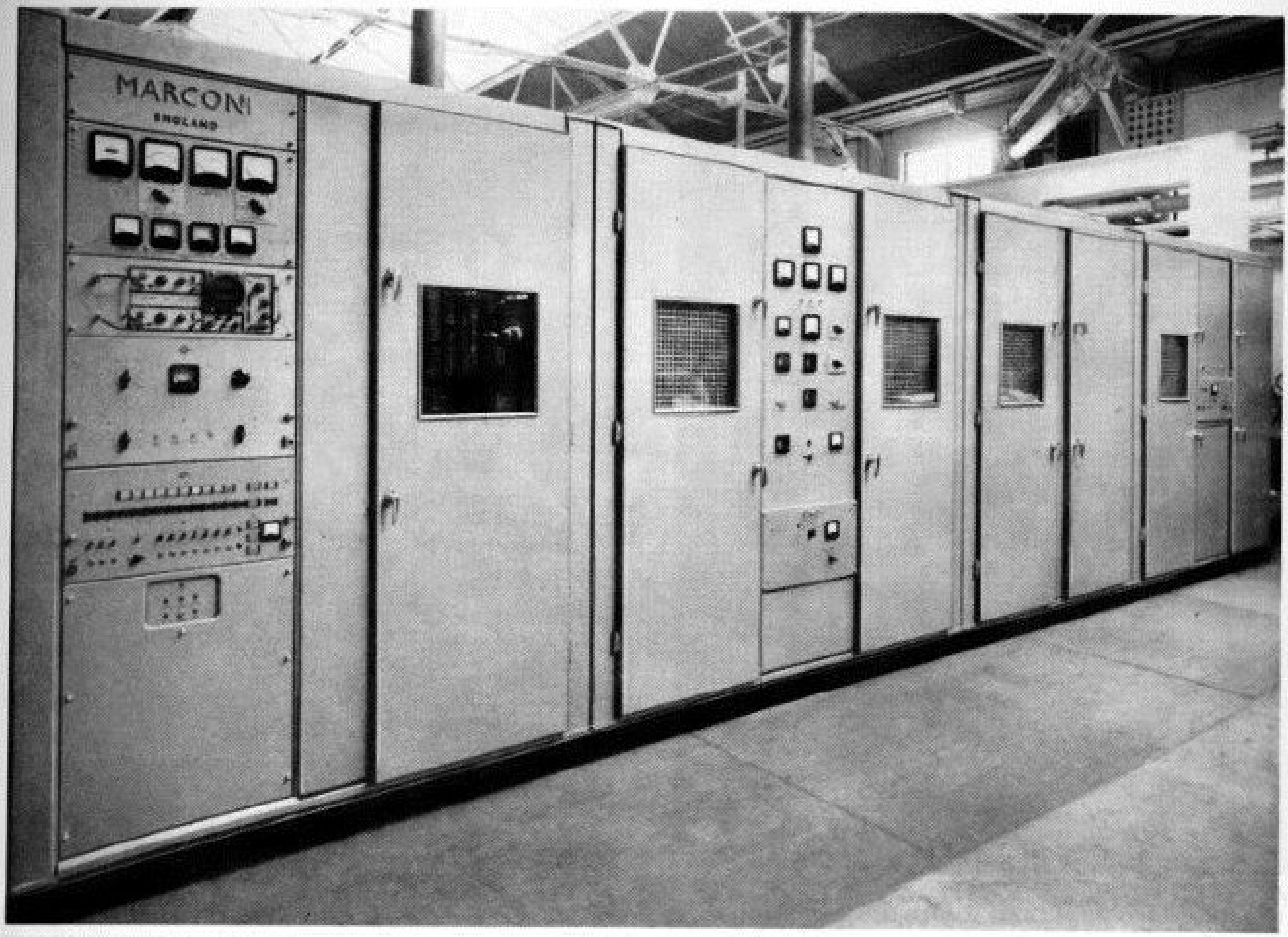

Fig. 2. Front view of 750 kW broadcast transmitter.

An associated solid-state crystal-controlled drive unit, mounted on a 'pull-out' chassis to facilitate servicing, may be incorporated as part of the transmitter or housed remotely in a central drive room. Two versions of this drive unit are available depending upon the frequency stability required, but any other suitable drive may also be used external to the transmitter.

The input required by the driver stage is 15 W which is fed to this grid through a 100-Ω balanced co-axial cable and impedance step-up transformer. The valve is a forced-air cooled tetrode (4CX5000A) in Class C grounded-cathode operation and the amplified output is applied to the final-stage grids by an impedance step-down π matching network. High-tension supply to this stage is derived by a resistance potential divider from the main h.t, d.c supply, the supply for the screen grid and bias for the control grid being derived in similar fashion from the corresponding supplies to the final stage.

The initial high efficiency obtained from the three parallel-connected grounded-cathode tetrodes in the final power-output stage is increased by the patented Marconi 'High Efficiency R.F Amplifying System'.

In essence this system employs anode-current pulses and anode to cathode voltage waveforms which have a high ratio of fundamental to d.c content and thus realizes a higher efficiency than obtainable with normal sinusoidal waveforms. The correct shape of current pulse and voltage waveform is obtained by circuits in grid and anode, tuned to the third harmonic of the working frequency. Operating levels and circuit adjustment are rendered non-critical by virtue of the self-correcting properties of this system with Class C operation.

The anodes of the final stage valves are matched to the 100-Ω co-axial feeder by a π-coupling network. A high degree of harmonic rejection is thereby obtained and this is increased by series-tuned trap circuits backed up by an additional low-pass π network before the external feeder.

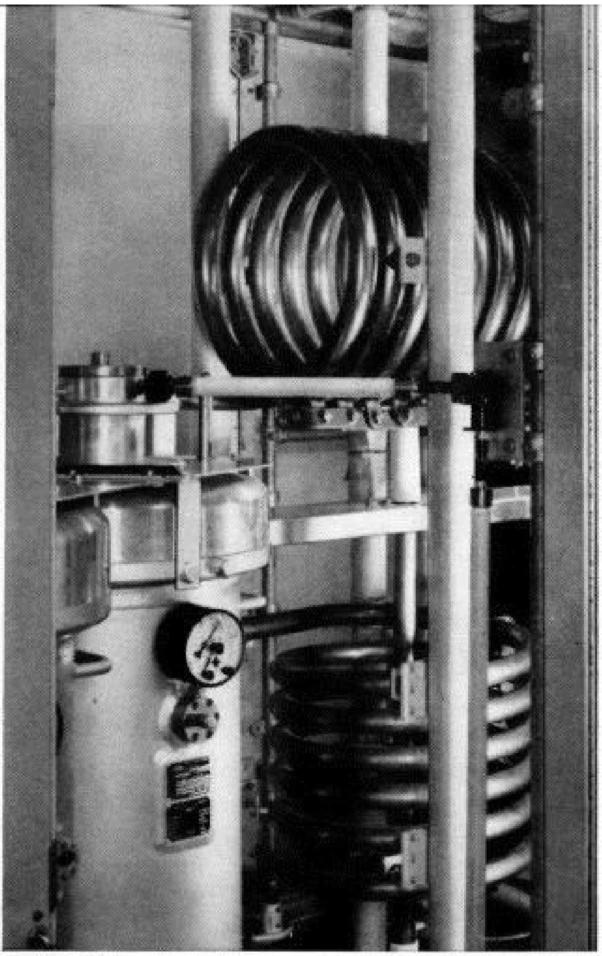

Fig. 3. View of anode tuning capacitors and π output and anode coil.

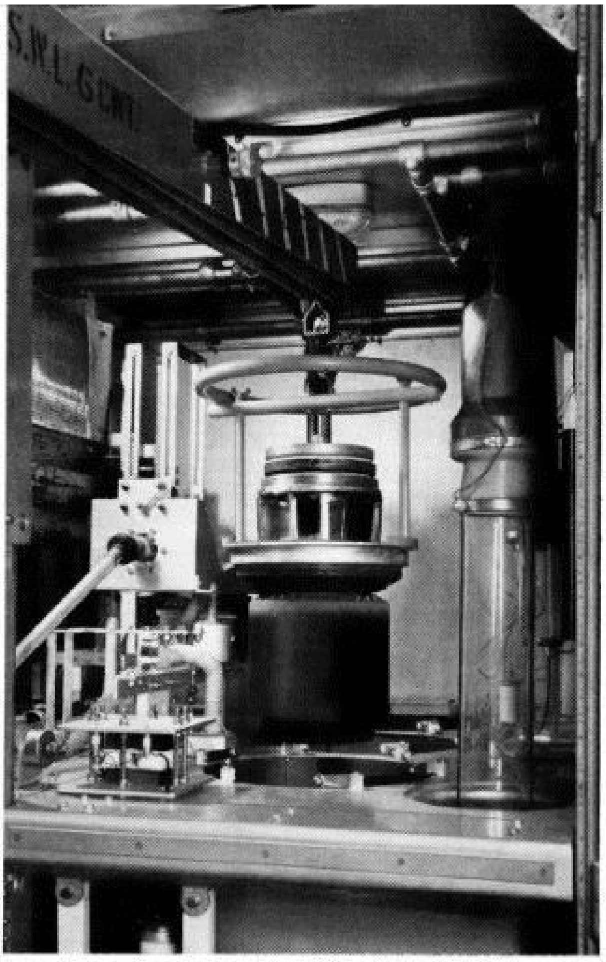

Fig. 4. Final stage valve removal.

Gas-filled variable capacitors are used in both anode and π output circuits and one of these is shown in Fig. 3 together with the associated π and anode coil. These capacitors are of robust design, field proven over a considerable period of years and with their small plan area materially assist in the economic use of transmitter floor space. With the exception of the fundamental grid circuit, which uses an oil-filled mica capacitor, all other circuits are tuned by ceramic vacuum capacitors.

Coarse adjustments of final-stage anode and output circuits is achieved by tapped coils and by presetting the continuously variable gas-filled capacitors, while fine tuning control from the r.f control panel is by motor-driven adjustment of one capacitor in each group. Tuning control of other r.f circuits is achieved in a similar fashion, manual adjustment replacing motor control in the lower-power circuits.

A very small proportion of the total input power required by the final stage is actually dissipated by the control grids. Screen-grid dissipation is limited to a safe value in all conditions by individual series resistors, which incidentally allow the use of the same d.c supply for these electrodes in both modulator and r.f stages. Through these resistors a proportion of the anode modulating voltage is applied from a tertiary winding on the modulation transformer, the resulting combination of self and driven modulation giving excellent linearity which is virtually independent of amplitude and phase variations of the tertiary voltage.

Monitoring facilities built into the transmitter include an audio output, obtained by detection from the r.f output, and two radio-frequency outputs, one of which is available for use with external measuring equipment, the other feeding the inbuilt envelope monitor oscilloscope. The output feeder conditions are monitored by a reflectometer which indicates v.s.w.r and by a feeder current indicator, both of these circuits also being used to protect against feeder faults.

MODULATOR

The vapour-cooled tetrode valves (VCP2002) used in the final r.f stage are also employed in the main modulator, the same d.c.h.t supply serving both stages. By this arrangement the number of valve types used and the number of power supplies required are minimized. In addition, as in the Marconi 100-kW h.f transmitter, the use of tetrodes in the final modulator stage allows the low-power amplifiers to be housed in a separate 'pull-out' chassis of small volume.

The low-power amplifier unit consists of three push-pull voltage amplifiers followed by a push-pull cathode-follower stage. The first two stages are high-gain linear pentodes type E810F and the third and cathode follower stage are tetrodes type 4CX1000A. These latter two stages have their screen to cathode potentials stabilized by means of zener diode chains. A limiter, preventing over-modulation, is connected to the cathode-follower control grid, the level at which limiting occurs being selected over a restricted range in stages of approximately 1 dB.

Front-panel gain control consists of both a preset control, allowing for standard inputs of 0 dBm and 10 dBm or levels intermediate to these, and a stepped attenuator allowing adjustment over a range of ± 5 dB in ½ dB steps. Also controlled from the front panel is the main modulator bias, a phase correction control, associated with clipped speech operation, and the limiting level.

Modulation is applied to the anodes of the final radio-frequency stage by a transformer and reactor, and to the screen grids of that stage via a tertiary winding on the transformer. Both clipped speech (trapezium modulation) and high-quality broadcast signals are accurately reproduced, negative feedback ensuring their excellent reproduction without critical adjustments. The degree of overall feedback in normal operation is 19 dB, but either 22 dB or 0 dB may be applied for routine testing.

FINAL-STAGE VALVES

In the final power stages of both r.f and modulator vapour-cooled tetrodes, type VCP2002, are used. Although each valve is capable of dissipating 180 kW, the anode dissipation in this application never, in any conditions, exceeds 55 kW per valve in the r.f stage and 120 kW in the modulator.

The envelope is of glass and the valve is designed for operation with the copper anode downwards. All other electrodes, which are arranged concentrically, are of rugged basket-type construction and employ a ceramic to metal technique.

Contact between the valve anode and boiler is achieved by a ring of spring fingers, the weight of the valve ensuring a low-resistance connection at this point. Connections to the external anode circuit are taken from the boiler and valve removal (Fig. 4), which can be accomplished rapidly and simply using the lifting tackle supplied, involves only removal of the low-power electrode connectors. In the r.f stage these connections are made to a one-piece header unit which has inbuilt screen decoupling and provision for mounting cathode decoupling immediately adjacent to

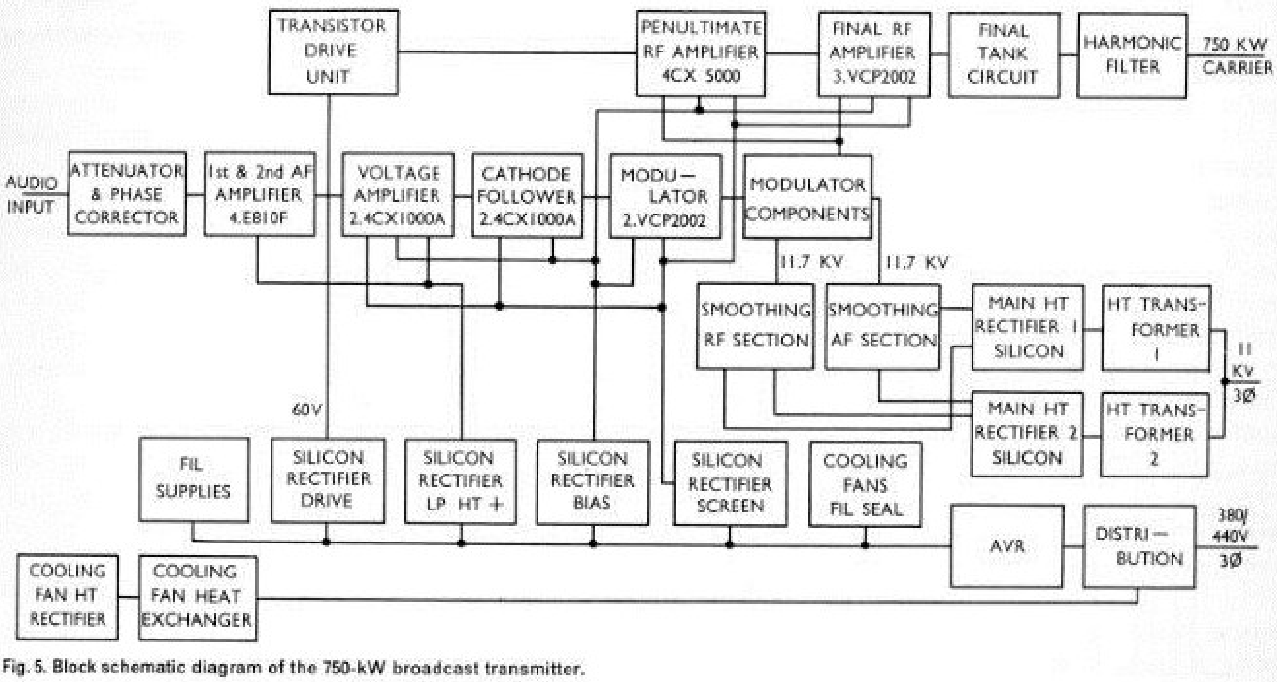

Fig. 5. Block schematic diagram of the 750-kW broadcast transmitter.

the filament terminals. Connections in the audio circuit are made to control and screen grid by individual spring-loaded rings and to both filament terminals by a concentric connector unit.

The steam outlet is from an offset section at the top of the boiler with the water inlet centrally located in the base. At this point an electrolytic target is fitted, the condition of which may be seen through the glass water inlet.

POWER SUPPLIES

For long life and high reliability all the d.c power supplies used in the transmitter are derived from three-phase full-wave rectifiers using silicon diodes. As in the case of the Marconi 100-kW high-frequency transmitter[1] the philosophy underlying the choice of diodes is that they must withstand full short circuits for the fault duty cycle required. The auxiliary rectifiers are protected against such conditions by manually reset miniature circuit breakers, normal overcurrent faults being cleared by the supply contactors. There are only four auxiliary supplies in the transmitter as shown in the block schematic diagram (Fig. 5).

The main high-voltage rectifier consists of two rectifiers in parallel, each having a continuous rating of 11·7 kV, 53 A d.c. They are connected in a manner similar to that first used on the Marconi 250-kW high-frequency transmitter.[4] The essential feature of this system is that the two supply transformers, having a 30° phase difference, give an effective 12-phase commutation. For a given rectifier load this 12-phase commutation system gives less harmonic current interference than a 6-phase system and allows a public supply system of a lower fault capacity to be used.[3] If two transmitters are installed on one site, then the two sets of transformers operate with a phase difference of 15°, equivalent to 24-phase commutation. This also allows the same system to be used as for a single transmitter, i.e. there need be no increase in the system fault capacity. The d.c outputs from

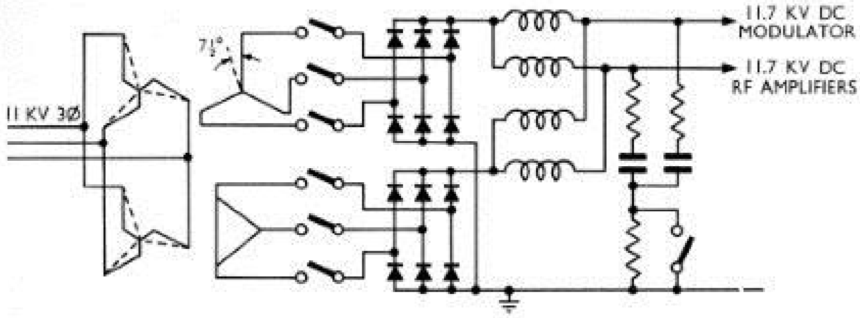

Fig. 6. Simplified circuit diagram of the main h.t supply.

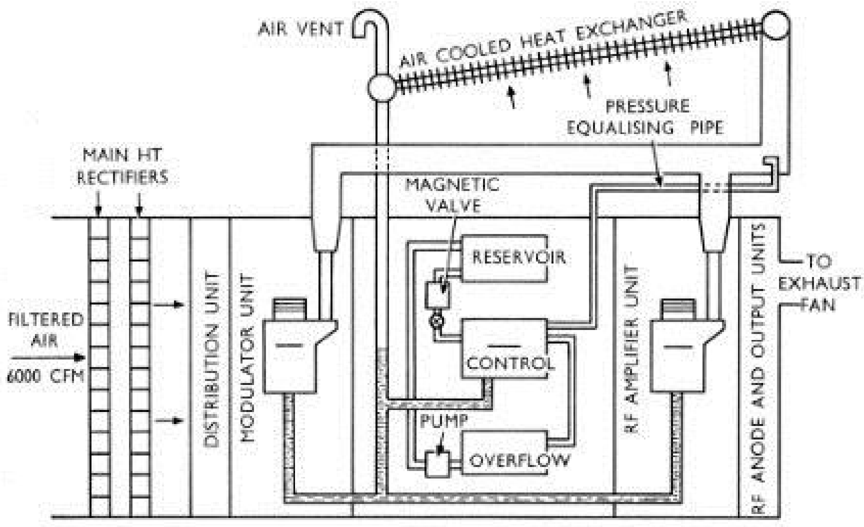

Fig. 7. Schematic diagram of transmitter cooling.

the rectifiers are paralleled via separate smoothing chokes as shown in Fig. 6, ensuring equal load sharing between the two rectifiers.

Each rectifier is protected against over-voltage by having surge diverters fitted on the a.c side, and surge-suppression circuits on both a.c and d.c sides. The diverters limit any peak transient voltage on the mains supply to a level well below that of the maximum peak reverse transient voltage rating of any arm of the rectifier. The diverter limits at 28 kV whilst the peak reverse volts of each rectifier arm is 42 kV.

The rectifiers are air cooled, the flow across any diode heat sink being at least 200 ft min, this being sufficient for the duty cycle at tropical temperatures with allowance for uneven air distribution. They are connected to the secondaries of the main positive h.t transformers via vacuum switches which, under fault conditions, remove the a.c supply to the rectifiers in less than one cycle of supply voltage. The duty cycle of the transmitter is three shots (two reclosures) to lock-out with approximately 1-sec intervals between shots and a 1-sec lockout time. In the event of failure of the vacuum switches, the diodes are capable of withstanding short circuits until the oil circuit breaker on the primary side opens, i.e. they are capable of withstanding the full short-circuit fault current for a period of seven cycles of the supply frequency. As well as clearing faults in the main h.t circuits the vacuum switches are used to clear over current faults in the final modulator and r.f amplifier.

In addition to the six vacuum switches feeding the two rectifiers, another similar switch is used to short-circuit a resistance in series with the main smoothing capacitors as shown in Fig. 6. One function of this resistor is to limit the charging current and hence voltage swing across the condensers at switch-on, after which it is switched out. Under fault conditions requiring the removal of the main h.t, it also initially limits fault current by being reinserted in the circuit by the opening of the vacuum switch.

Modulator and r.f stage filaments utilize Scott connection, all valve filaments being a.c heated and regulated.

TRANSMITTER COOLING

The transmitter uses cooling by evaporation for the final valves of the modulator and r.f amplifier, and air for the cooling of the silicon diodes in the main h.t rectifier. This air is economically used for cooling the transmitter cubicles, which form part of the air duct, and extracting heat radiated by the valve boilers and components. Some 6,000 c.f.m of filtered air is used, the volume being determined by the overload and restoration requirements of the silicon diodes. Separate blowers are used for cooling the low-power audio stages, the penultimate r.f amplifier, the final r.f amplifier filament seals and the final r.f tank coils (Fig. 7).

Vapour-cooling used in the transmitter is the 'classic' steam-up system, with the water level at the valve anodes determined by an external control tank. Water is replenished by gravity feed from the heat exchanger condensate return. Initially, at transmitter switch-on, there is considerable temporary 'water loss' in the main steam header and heat exchanger since the average amount of heat being transferred is some 208 kW, equivalent to a 328 cfm steamflow. This loss is made up with water from the control tank, which is automatically replenished from a reservoir tank of approximately similar volume mounted immediately above, by the opening of a magnetic valve controlled by a sensing device in the control tank. The rate of replenishment is preset by a hand-operated valve to prevent 'hunting' of the water level. Due to the relatively small volume of the control system, relative to the surface area of the main steam header, heat exchanger and condensate return pipe, the initial loss from the reservoir may reach 60% of its total volume. As the temperature of the steam headers, etc. rise and reach equilibrium the temporary loss is returned to the control tank and valve boilers from the condensate return. Because of the returned volume, the control tank overflows and the greater part of the returned 'loss' passes into the overflow tank. This contains a sensing device so that at a predetermined water level a pump is operated, transferring water from the overflow tank back to the reservoir, thus restoring the initial water conditions.

The pressure in the control tank is equalized to that obtaining in the valve boilers by means of a pressure-equalizing pipe connecting the control tank to the main steam header. This steam connection also allows the temperature of the water in the control tank to be approximately the same as that in the boilers. These two conditions ensure that the water levels in the boilers and control tank are in very close agreement. This is essential for, in addition to controlling replenishment from the reservoir, the control tank must also sense the condition when operation becomes unsafe due to low water level at the valve anode. At this level it operates a sensor to remove the power supplies.

As a further safety precaution, the vapour-cooled valves are fitted with thermal fuses attached to an external part of the anode structure. Any excessive rise in temperature of the anode causes a spring-loaded trip switch to operate and remove the main positive h.t supply, the trip switch being linked to a fusible element fitted to the anode.

The whole of the water system, reservoir, control, overflow tanks and accessories occupies only a very small volume in relation to the power of the transmitter. They are contained in a volume of 7-ft × 1-ft × 1-ft 8-in.

Warning lamps on the control panel of the transmitter indicate when the reservoir needs replenishing and when the purity of the water has degenerated below a preset value. Remedial action can then be planned and taken after normal shut-down. The condition of low water level which removes the valve h.t supplies is also indicated.

LAYOUT AND CONSTRUCTION

A typical preferred layout of the 750-kW m.f transmitter is shown in Fig. 1 and a front view of the complete transmitter in Fig. 2.

The main transmitter is contained in five cabinets, initially separate for ease of manufacture, transport and installation, which ultimately form a composite structure. Four of the five cabinets contain valves with their associated circuit components, the fifth cabinet housing supply distribution, protection components and auxiliary h.t supplies.

The r.f stages are housed in three cabinets all 8 ft high by 6 ft 3 in. deep, two of the cabinets having a width of 7 ft 11 in., the third, which houses the final stage anode circuits, being 6 ft 3 in. wide. All cabinets are fitted with 7 ft high by 2 ft 6 in. wide doors giving ready access to all components and all doors are fitted with two handles to ensure the good electrical contact essential for maintaining the high degree of screening afforded by the cabinet construction.

The two end cabinets of Fig. 2 house the final-stage anode and output components. The third cabinet contains the final-stage valves with associated grid components, the driving stage and, in addition, water-control equipment associated with the vapour-phase cooling of the final-stage valves.

Radio-frequency controls and associated meters are conveniently grouped on the front panel of the third cabinet, enabling fine adjustment and monitoring to be carried out from this one centrally located position.

The final modulator stage, the low-power audio stages and sequence control circuits are contained in the fourth cabinet, where the latter two units are runner mounted for ease of servicing. Monitoring facilities, operational controls and meters associated with the audio stages and auxiliary supplies are again compactly grouped on one front panel of this cabinet.

An enclosure, formed by the transmitter and one external wall of the building, accommodates the main h.t smoothing components and also allows access to the doors at the rear of the cabinets. The door giving access to this area is interlocked with the transmitter supplies in the same way as all other access points.

The modulation transformer and reactor, the a.v.r and the main h.t transformers all have outdoor ratings and are situated external to the transmitter hall, connections being made by bare tubular connectors through wall bushings to the internal equipment. The main h.t rectifier stacks are also situated externally in an airtight compartment which, together with the transmitter cabinets, forms an air duct through which filtered air is drawn for rectifier and cabinet cooling.

TYPICAL MEASURED TRANSMITTER PERFORMANCE

Power output

750-kW carrier: 525–1625 kHz

R.F output impedance

Unbalanced 100-Ω (max V.S.W.R = 1·3)

A.F frequency response

100 Hz to 15 kHz within ±0·5 dB
60 Hz −0·9 dB
40 Hz −3·0 dB

A.F harmonic distortion (95% modulation)

120 Hz to 7·5 kHz ≯ 0·75%
60 Hz to 10·0 kHz ≯ 2·5%

Power consumption

	Carrier	*50% mod.*	*100% mod.*
Power output (kW)	750	814	1050
Main h.t input (kW)	986	1260	1564
Auxiliary supplies (kW)	83	83	83
Main h.t efficiency (%)	76	64·5	67
Overall efficiency (%)	70	60·5	63·6
Carrier compression (%)	—	1·7	3·5
Altitude	6,000 ft max.		
Temperature, ambient	0°C to 45°C		
Humidity	95% max.		

REFERENCES

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4 D. F. Bowers and H. F. Bartlett: A New 250-kW Broadcasting Transmitter; *Sound and Vision broadcasting*, Vol. 4, No. 1, p. 6, Spring 1963.